

RESEARCH PROPOSAL

SUBMITTED TO: Michigan Department of Transportation
8885 Ricks Road
P.O. Box 30049
Lansing, Michigan 48909

SUBMITTED BY: Gilbert Baladi, PhD
Department of Civil & Environmental Engineering
Michigan State University
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PROJECT TITLE: Pavement Subgrade MR Design Values for Michigan's Seasonal Changes

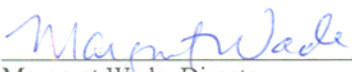
PROJECT DATES: August 1, 2006 – July 31, 2008

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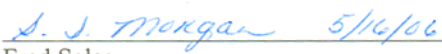

APPROVALS:



Ronald Harichandran, Chairperson
Department of Civil & Environmental Engineering



Margaret Wade, Director
Division of Engineering Research

 5/16/06 
or Fred Salas
Senior Contract & Grant Administrator
Contract and Grant Administration

95293
APP #

MICHIGAN STATE UNIVERSITY

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<u>Baladi, Gilbert</u>	<u>CEE / Engineering</u>	<u>16148 / 100%</u>	<u> / %</u>
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PROJECT LEADER(S)	Department(s)/College(s)	CUC & % for Overhead Credit	Depart. Credit if different

Departmental contact person: Cindy Sweeley Phone: 3-5473 CUC of unit responsible for bookkeeping: 16148

SPONSOR: Michigan Department of Transportation Prime Sponsor (if different) _____
If requesting more than \$20,000 from a private or corporate foundation, e-mail or faxed approval from University Development MUST be attached. AGENCY Deadline
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TITLE OF PROJECT: Pavement Subgrade MR Design Values for Michigan's Seasonal Changes
Other project keywords: _____

TYPE OF PROJECT: New Supplement Continuation/Renewal Revision of APP # _____

PRIMARY NATURE OF PROJECT: Research Education Public Service Other

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FIRST/CURRENT YEAR DATES & BUDGET (Sponsor's share only) TOTAL PROJECT DATES & BUDGET (Sponsor's share only)
From: 8/1/06 To: 9/30/06 \$ 13,758.00 From: 8/1/06 To: 7/31/08 \$ 165,908.00

Overhead Rate: 51% Amount to be subcontracted: \$ 0.00 Total cost sharing/matching/in-kind included: \$ 0.00

WILL THIS PROJECT REQUIRE OR INVOLVE:	Yes	No	Yes	No-N/A
Additional space on or off campus? (Requires approval of OPB/Facilities Planning & Space Mgt. & copy of space plan.)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Major alterations or renovations? (Requires cost estimate from Physical Plant and approval of OPB/FPSM.)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Significant outreach component?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
International activities? (Requires approval of ISP)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Is this associated with an MAES faculty appt. or project?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
For NSF & PHS/NIH proposals, is the required financial conflict of interest disclosure attached?.....	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Have patent or copyright commitments been promised to the Sponsor? Patent <input type="checkbox"/> Copyright <input type="checkbox"/> No <input checked="" type="checkbox"/>				
Human subjects?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Human blood/materials/fluids?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Vertebrate animals?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Recombinant DNA?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Pathogens/biohazards?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Hazardous/regulated chemicals?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Radioisotopes?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

If we will conduct all research and creative activity in a manner consistent with accepted scholarly standards and in conformity with legal, professional, and University codes, policies, and regulations governing research and creative endeavors. I understand the proposed use of human subjects, human materials, vertebrate animals, hazardous substances, or international activities require appropriate review and approval prior to initiating the project.

Gilbert Baladi Project Leader(s) 5/16/06 Date

ADMINISTRATIVE ENDORSEMENTS / APPROVALS

Endorsement by Department(s) and College(s) indicates: approval of the project; approval to approach listed grantor(s); cognizance of project's risks and of administrative obligations; confirmation that appropriate space and facilities are/will be available; and that arrangements for matching funds are in place if the proposal is funded.

[Signature] 5/16/06 Date
Chairperson or Director Date

[Signature] 5/16/06 Date
Dean Date

_____ Date
Chairperson or Director Date

_____ Date
Dean Date

MI Agricultural Experiment Station or Extension Service Director, Division Director, Date
or Research Unit Director (if applicable) MAES Project # _____

Int'l Studies & Programs (IPSI) FPSM (if applicable) Date

Approval of Budget for conformity with MSU policies:

REMARKS:

[Signature] [Signature]
Contract & Grant Administration Date

ROUTING: Department(s) => Dean(s) => Contract & Grant Administration
MSU IS AN AFFIRMATIVE ACTION/EQUAL OPPORTUNITY INSTITUTION

Pavement Subgrade MR Design Values for Michigan's Seasonal Changes

PROPOSAL SUBMITTED TO

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Construction & Technology Division
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Pavement Subgrade Resilient Modulus (MR) Design Values for Michigan's Seasonal Changes

PROJECT STATEMENT

Michigan consists of glacial soils with distinct seasonal (stiffness) changes in terms of soil temperature (possible frozen condition) and moisture levels. The Michigan Department of Transportation current pavement design process follows the procedure outlined in the 1993 AASHTO design guide. One of the inputs of said procedure is the effective value of the resilient modulus (MR) of the roadbed soil, which is a function of seasonal changes. The pending new AASHTO procedure is even more stringent for defining MR in terms of seasonal effects. Currently, the department's various Regions provide the "adjusted" MR value used for pavement design. The MR value is derived from either backcalculated deflection data or a correlation with known "soil support" values.

INTRODUCTION

The state of Michigan is geographically located within the glaciated section of North America and most of its soil has developed from glacial deposits. The ice sheet advanced over the state in three lobes, one along Lake Michigan trough, one along Lake Huron and the third along Lake Erie. A branch from Lake Huron lobe advanced southwesterly and connected to the other three lobes. During the advance of ice a large amount of soil and bedrock along the path of each ice lobe were pulverized and incorporated into the ice sheet to be later redeposited. When the Wisconsin ice sheet retreated to the north, these materials (known as glacial drift) were superimposed on sedimentary rock of the Michigan Basin in the Lower Peninsula and the eastern part of the Upper Peninsula and on igneous and metamorphic rocks in the western part of the Upper Peninsula. The thickness and composition of the drift varies from one location to another. For example, the thickness of the drift in Alpena area is only few inches whereas it is more than 1200 ft thick in the Cadillac area. The glacial drift also varies from clay to gravel; the granular texture may be segregated or mixed heterogeneously with boulders and clays. Because of these complex arrangements, about one hundred and sixty-five different soil types were formed and are being used for engineering purposes by the Michigan Department of Transportation (MDOT 1970). The engineering and physical characteristics of these soils vary drastically from those of gravel and sand in the western side of the Lower Peninsula, to clay in the eastern side and to Varved clay in the western part of the Upper Peninsula. In general, the state of Michigan can be divided into five different zones based on the various soil types and properties as shown in Figure 1. In the western side of the Lower Peninsula, good quality granular soils are predominant, in the middle section of the Lower Peninsula, the soil changes from sand to silty sand, to sandy silt, to sandy clay and to clayey sand as one travel from the west to the east. Many pockets of organic soil can be found in this section. In the eastern side of the Lower Peninsula, the soils consist of soft clay, silty clay, organic materials and very limited pockets of sand. In the Upper Peninsula, Varved clay (layers of clay and sand) that was deposited when parts of the Upper Peninsula was under water (Lake Superior) is predominant in the western side of the peninsula whereas mix of sand, silt, and clay can be found in the eastern side.

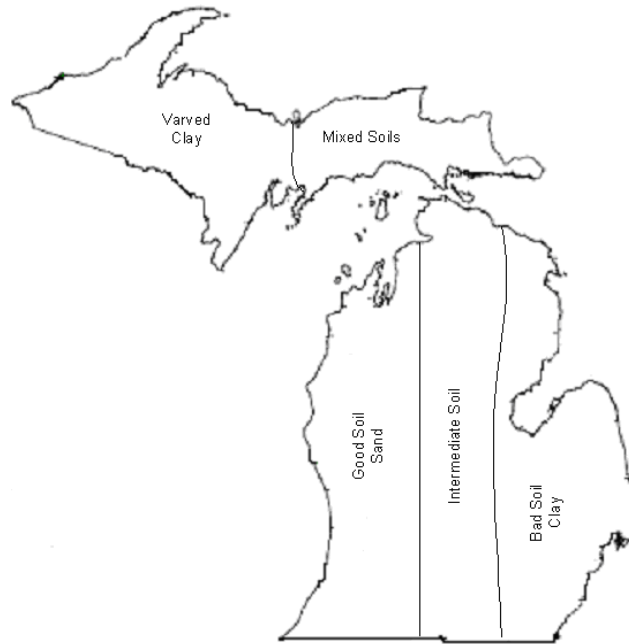


Figure 1 General Zoning of Michigan according to Soil Types

Due to the diversity and complexity of Michigan soils, any effort to characterize their engineering and physical properties requires a great deal of study and research to adopt it to highway design and construction. The next paragraph briefly details the history of these efforts that have been carried out by the Michigan Department of Transportation (MDOT).

The Michigan Department of State Highways efforts to characterize soils in the State of Michigan commenced with the development of Pedological Soil Classification System and Field Manual of Soil Engineering. Several revisions of the manual were published and used by highway engineers as a tool for the practical application of soil engineering principles to the design, construction, and maintenance of highways. With the advent of the AASHTO Pavement Design Guide in the early 1960's, which requires that for pavement design purposes the roadbed soil be characterized by its soil support value (SSV), the department directed efforts and a chart was developed relating soil types to their SSV as shown in the left hand side of Figure 2. It should be noted that the SSV can be thought of as an index which expresses the relative ability of the subgrade soils to support the traffic loadings. In later versions of the AASHTO Pavement Design Guide, the SSV was replaced by the effective resilient modulus of the roadbed soil. Once again, the department directed efforts to develop a chart relating the SSV to the resilient modulus of the roadbed soil. Said chart is shown in the right hand side of Figure 2. In order to verify the relationship between the SSV and the resilient modulus, in 1975, the department sponsored a two phase research study that was conducted under the direction of Dr. Baladi at Michigan State University. During the study, the research team in cooperation with personnel from the Michigan Department of Highways collected Shelby tube samples for clay and Varved clay soils and box samples for sand. The samples were tested in the laboratory using repeated load triaxial testing device on both re-compacted and undisturbed soil samples. The test results were analyzed and, for each soil type included in the study, the laboratory values of the resilient modulus were obtained as well as the permanent strain to assess the rut potential. The test results

were correlated to the SSV (Baladi and Boker 1978; Baladi and Goitom 1981; Boker 1978; Goitom 1981; Lentz 1979; Young and Baladi 1977). .

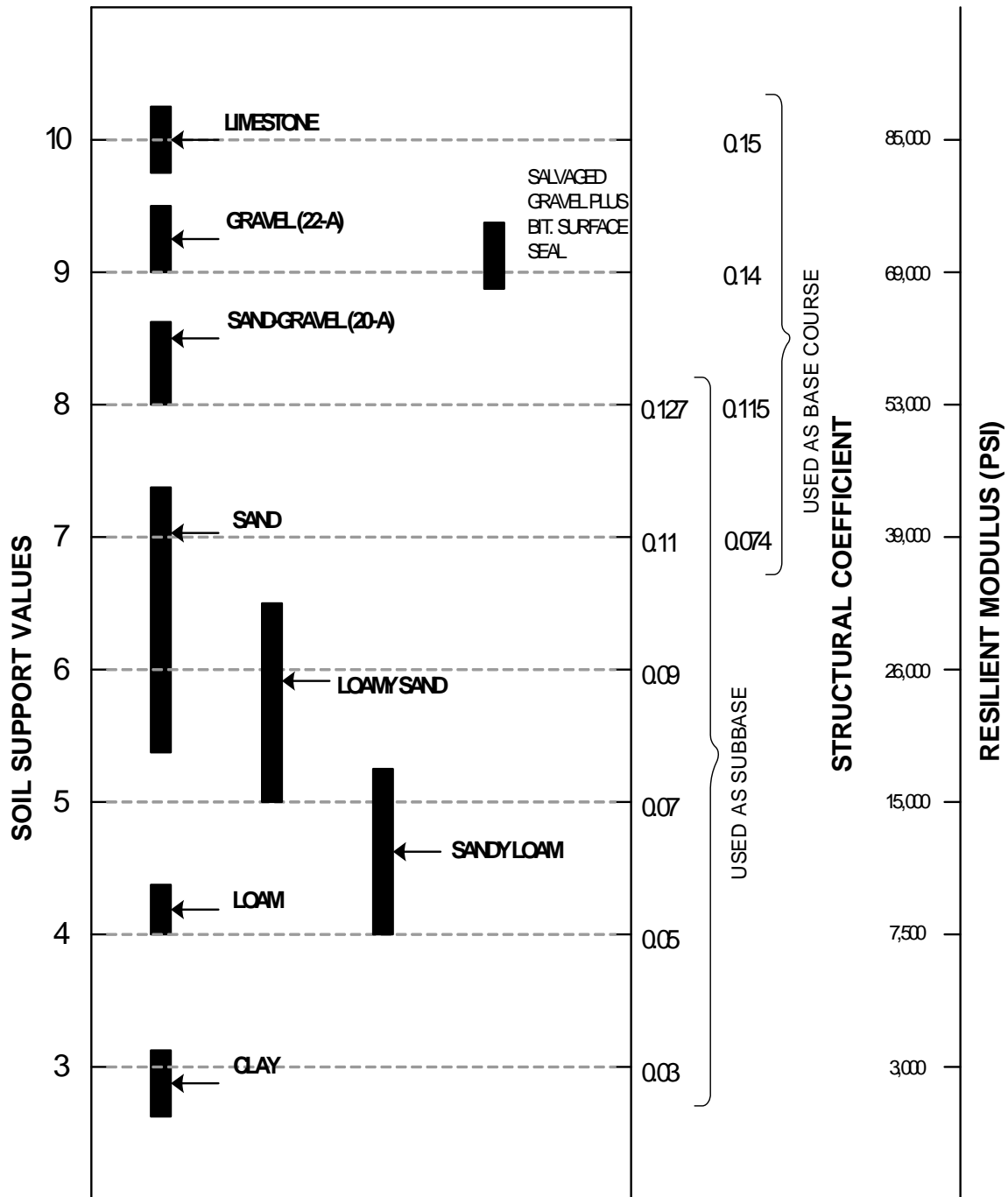


Figure 2 Range of Soil Support Values, Structural Coefficients and Resilient Moduli for Various Materials

BACKGROUND

The characteristics and behavior of roadbed soils have a major influence on the design and performance of pavement systems. Several methods/procedures have been used to characterize the properties and behavior of subgrade soils. These procedures and the resulting soil characteristics were based on the empirical procedure used for flexible pavement design. For example, the California Bearing Ratio (CBR) test has been used to determine the minimum pavement thickness based on the probable strength of the subgrade. Similarly, the soil support value concept was developed for the empirical AASHTO Design Procedure. Such practices raised two types of concern among highway engineers, the empiricism of the pavement design method and the tests used to characterize the roadbed soil. The latter are based on static load, which does not simulate moving traffic load or the insitu stress boundary conditions. Hence, new test methods based on dynamic loading were developed and the pavement design procedure has been or is being reformulated to incorporate the results of mechanistic analyses.

In 1982, the American Association of State Highway and Transportation Officials (AASHTO) established a laboratory standard test method to characterize the resilient modulus of subgrade soils (AASHTO Designation T 274-82, AASHTO Specifications 1986). Since then, several workshops and studies have been conducted to further revise the test method as to improve its repeatability and to make the loading sequence more representative of the actual loading conditions experienced by subgrade soils. The current AASHTO adopted resilient modulus test procedure was developed by the Strategic Highway Research Program (SHRP), Details of this and other related tests will be included in an interim report to be submitted to MDOT six months after the start of the project. Finally, to effectively utilize the new M-E Pavement Design procedure, the effective resilient modulus of the subgrade soils must be evaluated under simulated construction and seasonal conditions. It should be noted that the use of resilient modulus in the Mechanistic-Empirical Pavement Design Guide (M-E PDG) procedure offers many advantages over the earlier empirical design methods. These advantages include:

- The effects of tire load on the behavior of each pavement layer (HMA, base, and subbase) and on the roadbed soil can be analyzed. The results can be used to determine whether or not a given pavement layer is subjected to relatively high stresses that may lead to high rutting potential.
- The effects of high moisture contents due to low permeability or the lack of adequate drainage on the load induced stresses and strains in each pavement layer can be assessed. The 1993 AASHTO empirical design procedure suggests that the thickness of any pavement layer having low drainage coefficient be increased as to produce the required structural number.
- The relative damage delivered to a pavement structure in various seasons can be analyzed by using the seasonal resilient modulus of the roadbed soil.
- The impact of new or modified HMA mixes on pavement performance can be analyzed.
- The response of a given pavement structure due to increases in the axle load or the tire pressure can be analyzed.

Further, as compared to earlier empirical design methods, the M-E PDG considers several factors influencing the resilient modulus including:

- Stress state.
- Moisture/density variations.
- Freeze/thaw effects.

Detailed review of the role of the resilient modulus of the roadbed soil in design levels 1, 2, and 3 of the M-E PDG will be included in an interim report to be submitted to MDOT six months after the start of the project.

TYPICAL RESILIENT MODULUS VALUES USED IN PAVEMENT DESIGN

The new M-E PDG recommends different approaches to be used for obtaining the resilient modulus (MR) of the roadbed soil. For design level 3, typical values that are included in the M-E PDG are recommended. For design levels 1 and 2 tests are recommended especially nondestructive deflection testing using the falling weight deflectometer and backcalculation of layer moduli. Detail of the M-E PDG recommendations for design levels 1, 2, and 3 will be included in the literature review section of the final report.

RESEARCH OBJECTIVE

The main objective of this study is to evaluate the exiting process used by all Regions of MDOT for determining the resilient modulus (MR) of the roadbed soil for flexible pavement design and the modulus of subgrade reaction (k) for rigid pavement design as to:

- Determine the similarities and differences (is any) between the Regions
- The needed modifications to make the process compatible with the new M-E PDG.

To accomplish the objective, a research plan consisting of six tasks was developed and is presented in the next section.

RESEARCH PLAN

Task 1— Review and Information Gathering

In this task, the research team will become familiar with MDOT's current and historical processes/procedures for selecting MR and k values for the design of flexible and rigid pavements. The information could be obtained by calling the various regions and talking to the soil engineers. The research team will also obtain information from MDOT that is needed for the other tasks in this study. These include:

1. The locations of FWD tests that were conducted in the past and the availability of the measured deflection data and the pavement cross-section data that existed at the time of testing.
2. The depth of frost penetration especially in the northern part of the Lower Peninsula and in the Upper Peninsula.

3. The repeated load triaxial test data that were obtained as part of research projects that were sponsored by MDOT from 1975 to 1979. The data will be digitized and tabulated along with the roadbed soil type and will be used in later tasks.
4. Traffic data in terms of average daily traffic (ADT) and percent commercial.

The deliverables of this task will include:

1. Tabulation of the procedures used by the various Regions for selecting MR and k values and the basis of such selection. Based on the information, differences and similarity in these procedures will also be tabulated.
2. Tabulation of the range and typical MR and k values used by the regional soil engineers for the various soil types.
3. A brief summary of the background and the development of the SSV-resilient modulus chart provided in Figure 2.
4. Assessment of the adequacy and sufficiency of the existing process for estimating MR and k values to be used in the new M-E PDG.
5. For all available deflection data, tabulation of the locations of all FWD tests that were conducted in the past and the pavement cross-section that existed at the time of testing.
6. A map or a chart showing the depth of frost penetration where data are available.
7. Tabulation of the cyclic stress, confining pressure, vertical and horizontal deformations and strains, and the resilient modulus of the various roadbed soils included in the MDOT sponsored research projects during the period of 1975 to 1979.

Task 2— Partitioned State Map

Based on the MDOT Field Manual of Soil Engineering (subgrade soil type), the information obtained from the various Regions in Task 1, and trunkline locations, partition the State into various geological zones for the purpose of field testing and soil sampling. It should be noted that another source of information will be consulted in this task, the soil maps of the US Soil Conservation Services. The deliverables of this task will include:

1. A partitioned State map based on trunkline locations and soil types. The partitioned map will include coarse and fine clusters as follows:
 - a) Coarse Cluster - Although more than 160 soil types can be found throughout the state, the goal herein is to partition the state into 15 zones where the soil within any given zone would have similar range of engineering and physical characteristics. This will be accomplished by conducting analyses using clustering techniques. It should be noted that the boundary of any one zone does not need to be contiguous.
 - b) Fine Cluster - After establishing the boundaries of the 15 zones, on average, each zone will then be further divided into seven areas as to narrow the range of the soil characteristics and to include similar depth of frost penetration. For some zones, division to one or two areas may be sufficient whereas for others, the zone may need to be divided into more than seven areas. The final fine cluster will consist of 105 areas.

2. The final partitioned state map would include 15 zones (coarse clusters) divided into one hundred and five different areas (fine clusters). It is very important to note that the information may dictate higher level divisions (more than 15 zones and 105 areas), in such a scenario, the research team will make the proper recommendations to members of the Research Advisory Panel (RAP). The division of 15 zones and 105 areas proposed herein is based mainly on the estimated cost of the study.
3. For each of the one-hundred and five areas, all available information that were obtained in task 1 and from the following sources will be tabulated:
 - a) The MDOT Field Manual of Soil Engineering
 - b) The maps of the US Soil Conservation Services.
 - c) The FWD data files
 - d) Data from previous studies of the resilient modulus of roadbed soils that were sponsored by MDOT
 - e) The typical and range of MR and k values that are used by the various Regions
 - f) Available resilient modulus data

The partitioned state map and the tabulated information will be presented to the RAP members for their input and approval. The research team will then modify the map based on the comments made by the RAP members. The approved map and the information will be used to determine the exact locations of field testing and soil sampling.

Task 3— Field and Laboratory Testing and Soil Sampling

In this task, the research team will finalize the field and laboratory testing and sampling plan based on the information obtained in tasks 1 and 2 and on the partitioned state map. Although it is not possible at this time to determine the exact number of field and lab tests for any one of the one-hundred and five areas on the partitioned map, it is possible to propose the total number of tests based purely on cost. Such information (the number of field and laboratory tests) are presented in the three subtasks listed below.

Subtask 3.1 - Field Tests and Soil Sampling – For each of the 15 zones (the coarse clusters) on the partitioned map, five locations will be identified. At each location, the MDOT ground penetrating radar (GPR) will be used (if available) to determine the thickness of the asphalt layer. After the GPR, FWD tests will be conducted followed by pavement coring, which will be followed by standard cone penetration testing, when available, of the roadbed soil and finally, for clay soils, disturbed subgrade samples will be obtained from each location and one Shelby tube from one location. For the cases of sand subgrade soils, no Shelby tube samples will be collected rather disturbed bag samples will be collected from within the drainage ditch area, if available, or from the soil adjacent to the road in question. Thus, a total of 75 FWD, possible 75 cone penetration tests will be conducted, 75 disturbed subgrade samples and at least 10 undisturbed (Shelby tube) samples will be collected. The main objective of this task is to establish cross-correlations between the laboratory test results, the cone penetration test results, and the roadbed modulus values obtained from backcalculation using the FWD

data. Said correlations will be used in task 3.3 below as to obtain the values of MR and k for all areas within the 15 zones using the FWD deflection data. It should be noted that, in case the cone penetration apparatus is not available, or the cone penetration tests cannot be conducted, the correlation between the standard cone penetration pressure and the resilient modulus will not be obtained.

Subtask 3.2 – Laboratory Testing – The laboratory investigation, in this study, consists of the following tests:

1. Soil classification – For each of the 75 disturbed samples (bag samples), the soil will be subjected to sieve analyses as to determine the breakdown fractions between sand and clay/silt particles. For any sample where the fine fraction (passing sieve number 200) is more than 7 percent, plastic and liquid limit tests will also be conducted. Results of the sieve analyses and Atterberg limits will be used to classify the soil according to the AASHTO soil classification and to the Unified Soil Classification System (USCS). The data (Atterberg limits and grain sizes and fractions) will be used to develop correlations to the resilient modulus of the material.
2. Repeated load triaxial tests - For each location where Shelby tube was collected, three repeated load triaxial tests will be conducted at three moisture contents (dry of optimum, optimum and wet of optimum) simulating seasonal changes and the resilient modulus of the soil will be determined. Note that, the water content of the samples will be changed to the desired level by either drying or by using back pressure technique in the triaxial cell. For each location where sand subgrade is encountered, three test specimens will be compacted at three water contents (dry of optimum, optimum and wet of optimum) and each test specimen will be subjected to repeated load triaxial test in accordance with the proper AASHTO standard test procedure. Results of the tests will be analyzed to determine the resilient modulus of the soil. It should be noted that the resilient modulus of sand soils is heavily dependent on the deviatoric stress (the difference between the vertical and the horizontal stresses). Therefore, the laboratory tests will be conducted at different stress states which will be estimated through mechanistic analyses as to simulate the probable in-situ field conditions.

It should be noted that all standard test procedures used in this study and the factors affecting the test results will be summarized and included in an interim report to be submitted to MDOT six months after the start of the study.

Subtask 3.3 – Additional Field Tests – For each of the one-hundred and five areas on the partitioned map, 20 FWD tests will be conducted (10 tests in the spring season and 10 tests in the late summer – early fall season). For those areas where FWD tests were conducted in the past and the deflection and the pavement cross-section data are available at MDOT, the data will be used and the number of FWD tests (to be conducted in this study) will be reduced according to the availability of spring and fall deflection data. For these areas, the minimum number of FWD tests that required in this study for verification purposes is six, three in the spring season and three in the late summer early fall season. It should be noted that the exact location of each field test cannot be determined at this

time. After obtaining all the information in task 1 and generating the partitioned state map, the locations of field testing will be marked on the map and will be presented to the RAP members for their approval.

It should be noted that analyses of various damage models including the AASHTO indicate that the two pint FWD testing (spring and fall seasons) is adequate to assess the relative pavement damage caused by the roadbed soil.

Task 4 – Data Analyses

The data analyses, in this study, will be accomplished according to the four subtasks presented below. First, it should be noted that for all soil types, the relationship between the resilient modulus (MR) and the modulus of subgrade reaction (k) found in the M-E PDG will be used. Since the relationship applies to all MR and k values, the analyses stated in the subtasks below will be conducted on the MR values and the results will be converted to the k values.

Subtask 4.1 – Backcalculation of Layer Moduli – All deflection data whether collected during this study or obtained from MDOT will be used to backcalculate the layer moduli using the MICHBACK program. Although the moduli of all pavement layers will be backcalculated, only the resilient modulus of the roadbed soils will be subjected to further analyses. The moduli of the other layers will be included in the final report. At the end of the backcalculation, for each test area on the partition map, two sets of moduli will be available; one set is based on the deflection data conducted in the spring season and the other in the late summer-early fall season. The two sets will be further analyzed to compare the amount of damage due to spring and fall conditions as presented in task 5 below.

The activities in this subtask will also include the analyses and backcalculation of layer moduli of the pavement sections using the deflection data measured at five locations in each of the 15 zones on the partition map (see subtask 3.1). The main objective of this analysis is to compare the values of the backcalculated moduli of the roadbed soils to those obtained in the laboratory and to those obtained from the cone penetration tests (when available). Based on said comparison, relationships between the three sets of modulus values will be developed. Such relationships would eliminate the needs for destructive testing.

It should be noted that a summary of existing relationships between the values of the backcalculated moduli and the laboratory obtained moduli will be included in the interim report to be submitted to MDOT six months after the start of the study.

Subtask 4.2 – Cone Penetration Data – In this subtask, the cone penetration data (when available) will be used to calculate the modulus values of the roadbed soils. The MR values will then be compared to those obtained from the laboratory and from backcalculation. Once again, the objective is to develop relationships between the three modulus values.

Subtask 4.3 – Laboratory Test Data – Results of the cyclic load tests conducted on Shelby tube and reconstituted bag samples at three moisture contents will be analyzed to determine the laboratory values of the resilient modulus of the roadbed soil. Results of the analyses will be used to assess the impact of moisture (season) on pavement damage and to compare the values to those obtained from backcalculation and from the cone penetration data.

In addition, the digitized cyclic stress-strain data of those research studies that were sponsored by MDOT from 1975 to 1979 will be analyzed. This pool of information will be used as supplement to verify the relationships or to increase the pool of data to develop more accurate relationships. It should be noted that in all tests that were conducted between 1975 and 1979, two linear variable differential transducers (LVDT) were mounted on the actuator of the MTS system, which was in violation of the 1974 AASHTO test procedure. However, it confirms with the current AASHTO procedure.

Finally, statistical correlation will be developed between the grain size, size fraction, and Atterberg limits data to the laboratory obtained resilient modulus and the backcalculate subgrade modulus. If such relationships can be obtained at good confidence level, the need for destructive sampling and expensive and laborious testing scheme would be eliminated.

Task 5— Damage Assessment Analyses

The damage assessment analyses (noted in subtask 4.1) will be conducted based on the seasonal MR and k-values obtained from the backcalculation of the FWD deflection data. The purpose of the analyses is to determine the effective MR and k values to be used in the design and rehabilitation of flexible and rigid pavements. The effective roadbed soil resilient modulus is an equivalent modulus that would result in the same damage as if the various seasonal resilient modulus values were used to assess the damage (Huang 2004). In the analyses, three methods will be used as follows:

1. The existing AASHTO 1993 damage model shown below.

$$u_f = 1.18 \times 10^8 \times (MR)^{-2.32} \quad (1)$$

where u_f = relative seasonal damage

2. The existing damage model in the M-E Design Guide, which is based on Minor's hypothesis of cumulative damage represented by the following equation.

$$D_r = \sum \frac{n_{ijklmn}}{N_{ijklmn}} \quad (2)$$

where: D_r = damage ratio, n_{ijklmn} = actual number of load repetitions, N_{ijklmn} = allowable number of load repetitions, in i th ages, j th seasons, k th axle combinations, l th load levels, m th temperature and n th traffic path.

3. Mechanistic analyses of stresses and strains induced in the roadbed soil due to traffic load. The magnitudes of the induced stresses and strains for various roadbed moduli will be compared as to arrive at a damage model or to verify the above models.

Results of the three analyses will be compared relative to the observed pavement performance in Michigan in terms of alligator cracking and rutting. Such observation will be made by the research team at each test site. Based on the results of the analyses, recommendation will be made relative to the model to be employed by MDOT.

Task 6 – Reports

Three types of report will be submitted, quarterly reports, an interim report and a final report.

Quarterly Reports - At the end of each quarter, a quarterly report will be submitted summarizing the findings, the results, and the expenditures of that quarter, and will address the scheduled activities for the next quarter.

Interim Report – An interim report will be submitted to MDOT six months after the start of the contract. The interim report will include

- All standard test procedures used in this study and the factors affecting the test results.
- A summary of the existing correlations between the backcalculated roadbed modulus and the laboratory obtained modulus.
- A summary of the role of roadbed soil modulus in the M-E PDG in design levels 1, 2 and 3.

The final report, which will be submitted toward the end of the project, will include:

- All test results, data, and procedures used throughout the study.
- Tables and charts for the selection of MR and k values for different roadbed soils.
- A map of the state trunkline showing the 15 zones and 105 test areas and, for each area, the map will display:
 - The test locations
 - The soil classification
 - The recommended MR and k values to be used in the design and rehabilitation of flexible and rigid pavements
- Procedures for evaluating the MR and k values using nondestructive deflection tests.
- Correlations between the backcalculated roadbed modulus and the laboratory obtained modulus.
- Statistical correlations between the grain size, size fraction and Atterberg limits and the resilient modulus of the roadbed soil.

- The range and expected changes in the MR and k values due to seasonal changes.
- Frost depth (where data is available)
- Recommendations concerning the selection of the effective values of the resilient modulus for flexible pavement design and the effective modulus of subgrade reaction for rigid pavement design for the current AASHTO design procedure and for the new M-E PDG.

RESPONSIBILITIES

To accomplish the objectives of this study, cooperation between the research team and MDOT personnel must be in full gear. To this end, the responsibilities can be divided into those expected from MDOT and those from the research team.

MDOT RESPONSIBILITY

Throughout this research, MDOT responsibility includes:

- Conducting all FWD and cone penetration tests (if available), pavement coring and Shelby tube sampling.
- When desired and available, conducting GPR tests to determine the thickness of the asphalt layer.
- Managing traffic control during field testing

MSU RESPONSIBILITY

The responsibility of the research team includes:

- Marking all field test locations
- Collecting all bag samples
- Labeling all field samples properly and transporting the samples to the MSU laboratories
- Conducting all laboratory tests
- Conducting all analyses
- Submitting timely quarterly reports and attending RAP meetings
- Submitting final report for MDOT review

ANTICIPATED RESEARCH OUTCOMES

The anticipated outcomes of this research study are stated in the bullets under the contents of the final report.

TIME SCHEDULE

It is expected that the proposed study will be accomplished in 24 months. The proposed time schedule is shown in Table 1.

BUDGET

It is estimated that the total cost of the study is \$165,908.00. The estimated cost breakdown for the different physical years is included in Table 2. The estimated total cost of \$165,908 includes \$50,997 indirect cost, \$113,811 labor cost, \$850 supplies and services, \$1050 for travel to the test sites within the State of Michigan.

THE RESEARCH TEAM

It is proposed that this study be directed by Dr. Gilbert Baladi who will be the principal investigator. Dr. Baladi will be assisted by two post doc research associates (Dr. Syed Waqar Haider and Dr. Hassan Salama) and by one graduate and several undergraduate students.

EQUIPMENT AND FACILITIES

The activities of the research team in this study require the use of desktop or laptop computers and libraries as resources of literature related to this study. The main and the Engineering Libraries at Michigan State University (MSU) provide access to major scientific literature databases such as the National Academy of Sciences, and internet databases such as ALTAVISTA. The two libraries at MSU also subscribe and provide access to several national and international journals and conference proceedings related to pavements and access to other academic libraries such as the University of Michigan's and Purdue's. Related information generated by other highway agencies and related to this study can be downloaded using the internet, which is available in all offices at MSU. Finally, the pavement laboratory in the Civil Engineering Department at Michigan State University houses several MTS systems. One system will be used for the laboratory testing in this study.

Table 1 Proposed time schedule

Task	Elapsed time from the start in the contract (month)																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24						
Task 1 - Review	████████████████																													
Task 2 - Map				██████████████																										
Task 3 – Tests																														
Subtask 3.1							██																							
Subtask 3.2										██																				
Subtask 3.3												██																		
Task 4- Analyses															██															
Task 5 - Damage																					██									
Task 6 - Reports			Q			Q			Q			Q			Q			Q			Q			F						

Q = Quarterly report

I = Interim report

FR = Final report FGF

Note: The starting point would depend on the RAP approval and paper processing.

Table 2: Detailed Budget

Research Proposal Budget Form Worksheet
Michigan Department of Transportation

Project Title _____
 Research Organization Michigan State University
 Project Duration 24 months

					FY1	FY2	FY3	TOTAL
SALARIES & WAGES								
Specify number of hours to be worked and hourly rate for each individual below: Examples of role of individual are PI, Technician, Grad Student, etc.								
(role of individual)	Principal Investigator				8/01/06 - 9/30/2006	10/01/06 - 9/30/2007	10/01/07 - 7/31/2008	
Name of individual	Gilbert Baladi							
Enter rate/hr & FY hours >>>	Rate /hr*	FY1 hrs	FY2 hrs	FY3 hrs				
Fiscal Year 1 -	AY - \$77.87	13			\$976	\$0	\$0	\$976
	SU - \$77.87	84			\$6,506	\$0	\$0	\$6,506
Fiscal Year 2 -	AY - \$80.20		75			\$6,031	\$0	\$6,031
	SU - \$80.20		300		\$0	\$24,122	\$0	\$24,122
Fiscal Year 3 -	AY - \$82.61			62		\$0	\$5,177	\$5,177
	SU - \$82.61			251	\$0	\$0	\$20,705	\$20,705
(role of individual)	Research Assistant							
Name of individual	may vary by semester							
Enter rate/hr & FY hours >>>	Rate /hr	FY1 hrs	FY2 hrs	FY3 hrs				
	\$21.12	0	441	0	\$0	\$9,312	\$0	\$9,312
	\$21.75	0	63	420	\$0	\$1,370	\$9,135	\$10,506
(role of individual)	Student Hourly							
Enter rate/hr & FY hours >>>	Rate /hr	FY1 hrs	FY2 hrs	FY3 hrs				
Student 1	\$9.00	50	200	200	\$450	\$1,800	\$1,800	\$4,050
Sub-Total Salary & Wages					\$7,932	\$42,635	\$36,817	\$87,384
*The hourly rates reflected above are being provided for comparison purposes only. MSU does not maintain documentation of hours worked for its faculty and staff, with the exception of undergraduate students, but rather maintains documentation to support time expended on federal projects based on percentages of effort worked. This documentation is maintained in accordance with OMB Circular								
FRINGE BENEFITS								
Indicate Employee, appropriate negotiated rate for each and description of who the rate applies to. (e.g. - Sam Smith, 25% Summer Faculty. The rate is negotiated between the university and it's cognizant agency)								
Name	Gilbert Baladi							
(Rate Description)	As assigned by the University							
(% rate)	AY ----->	28.80%	29.70%	30.50%	\$281	\$1,791	\$1,579	\$3,651
(% rate)	SU ----->	7.65%	7.65%	7.65%	\$498	\$1,848	\$1,584	\$3,927
(Rate Description)	Graduate Assistant -							
(% rate)					\$0	\$1,660	\$1,475	\$3,135
(Rate Description)								
(% rate)					\$0	\$0	\$0	\$0
Sub-Total Fringe Benefits					\$779	\$5,298	\$4,638	\$10,712
SUBCONTRACTOR								
A copy of the subcontractor's budget must be attached. An MDOT approved subcontract is required for subcontractor costs in excess of \$25,000 prior to payment of invoices that contain subcontractor work. List all subcontractors on a separate line.								
Subcontractor Name & Amt.					\$0.00	\$0.00	\$0.00	\$0.00
Subcontractor Name & Amt.								\$0.00
Sub-Total Subcontractor					\$0.00	\$0.00	\$0.00	\$0.00
TRAVEL								
Must be in accordance with IDS contract requirements.								
In-State Travel (Destinations within Michigan)								
					\$300	\$500	\$250	\$1,050
Out-of-State Travel (Prior approval required)								
Provide destination, purpose, total mileage, total # of days, total # of meals, total # trips, names of individual(s) traveling								
								\$0
Sub-Total Travel					\$300	\$500	\$250	\$1,050
SUPPLIES								
Provide details if cost exceeds \$2,000. Individual line items in excess of \$1,000 require a detailed explanation regardless of total cost								
(Description)					\$100	\$250	\$500	\$850
Sub-Total Supplies					\$100	\$250	\$500	\$850
CAPITAL EQUIPMENT - Required for this research								
List items with a value in excess of \$500. Equipment in excess of \$5,000 requires prior approval.								
(Description)								\$0
(Description)								\$0
Sub-Total Equipment					\$0	\$0	\$0	\$0
OTHER EXPENSES								
Any project expense which does not fall into another category. Provide detailed explanation of the expense and applicable breakdown of costs (e.g. graduate student tuition).								
(Description)	Tuition & Fees				\$0	\$7,887	\$7,025	\$14,912
(Description)								\$0
Sub-Total Other Expenses					\$0	\$7,887	\$7,025	\$14,912
Total Sub-Totals					\$9,111	\$56,567	\$49,230	\$114,909
INDIRECT COSTS								
Indirect cost rates are negotiated between the university and it's cognizant agency. Indicate the type of negotiated indirect rate used and the percentage (e.g. On Campus Research, 52%)								
(Type)	MTDC (TD<T&F)		(%)	51%				
		FY1	FY2	FY3				
Enter \$ Amt per FY	MTDC =	\$9,111	\$48,681	\$42,205	\$4,647	\$24,827	\$21,625	\$50,997
Sub-Total Indirect Costs					\$4,647	\$24,827	\$21,625	\$50,997
TOTAL PROJECT COST					\$13,758	\$81,395	\$70,755	\$165,908