# RESEARCH PROJECT WORK PLAN

INV. No.

TITLE OF PROJECT: Best Value Granular Material for Road Foundations

IS THIS A RESPONSE TO A PROBLEM STATEMENT? ☐ NO ☒ YES
IF YES, STATE NAME OF CONTACT PERSON. John Siekmeier

PRINCIPAL INVESTIGATOR (LAST, FIRST, MIDDLE). Tutumluer, Erol

POSITION TITLE/DEGREES Associate Professor / PhD


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TOTAL BUDGET:

| FUNDING SOURCE | AMOUNT |
|---|---|
| Mn/DOT | $150,000 |
| Local Road Research Board | |

TOTAL BUDGET PERIOD:
START DATE: August 1, 2008
END DATE: July 31, 2010
PROJECT LENGTH (MONTHS): 24

KEY PERSONNEL OTHER THAN PRINCIPAL INVESTIGATOR.

| | |
|---|---|
| NAME | NAME |
| POSITION TITLE | POSITION TITLE |
| ORGANIZATION | ORGANIZATION |
| DEGREE(S) | DEGREE(S) |
| ROLE ON THE PROJECT | ROLE ON THE PROJECT |

PROJECT LIAISONS

TECHNICAL LIAISON:
NAME John Siekmeier
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ORGANIZATION Mn/DOT

ADMINISTRATIVE LIAISON:
NAME Nelson Cruz, Information Technology Specialist
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ORGANIZATION Mn/DOT
ADDRESS Office of Investment Management
Research Services Section

TECHNICAL LIAISON: (Check one electronic approvals accepted)

Work Plan Approved ☐
Work Plan Approved with Changes Noted ☐
Work Plan Not Approved ☐

PRINT NAME:

DATE:

PRINCIPAL INVESTIGATOR:
I agree to accept responsibility for the scientific conduct of this project and to provide the required progress reports.

SIGNATURE OF
PRINCIPAL INVESTIGATOR: [signature]

DATE: 7/17/2008

MANAGER, ROAD RESEARCH SECTION :

I hereby certify sufficient staff time will be scheduled for the Principal Investigator to complete the research as outlined in the attached work plan.

SIGNATURE OF
MANAGER ROAD RESEARCH SECTION:

DATE:

DIRECTOR OF RESEARCH SERVICES:

**Charles F. Zukoski**
**Chair, Research Board**

SIGNATURE OF
DIRECTOR OF RESEARCH SERVICES: Charles F. Zukoski

DATE: 7-21-08

***RESEARCH PROJECT WORK PLAN***

KEY WORDS
Aggregate supply, pavement design, benefit/cost, best value, performance related

**ABSTRACT**

The type and quality of aggregate materials are directly linked to their engineering properties, which would determine the corresponding Mn/DOT aggregate class designation for designing conventional flexible pavements with aggregate base/subbase layers. Depending on the location of the project, Mn/DOT Districts may use various locally available aggregates or granular materials in pavement design. This research project aims to collect information on the types, sources, costs and properties of the locally available aggregate materials to link their engineering properties to mechanistic inputs of laboratory and field modulus and strength characteristics. Main advantages will be to enable (i) proper material selection and utilization, (ii) aggregate layer thickness optimizations during the design process based on cost and mechanistic material properties related to performance defined by MnPAVE program, and as a result, (iii) more economical use of the locally available aggregate materials in Minnesota.

**IMPLEMENTATION** *What methods, procedures, products, and/or standards should change as a result of this research project?*

Aggregate base materials are becoming increasingly expensive in many parts of Minnesota because gravel mines and rock quarries are being lost to other land uses. These aggregate materials are classified for use and placed in quantities based on design procedures and testing techniques that are several decades old. Though these traditional procedures have been adequate and have generally produced long lasting roads, there is likely significant opportunity for better value to be achieved. New mechanistic design procedures and testing techniques exist that need to be implemented so that road construction can better optimize material use and reduce waste.

Mn/DOT, County, and City Engineers would need to implement mechanistic pavement design and the field and laboratory tests required. A granular material best value software tool will be added to MnPAVE to further encourage implementation of mechanistic design.

*What are the specific benefits of this change(s), why would this change(s) be important, and how can these benefits be measured?*

Construction dollars would be better utilized because material types and layer thicknesses would be optimized during the design process based on mechanistic material properties related to performance and the cost of locally available materials.

With successful completion of all the research tasks, best value in granular material use will be realized in Mn/DOT construction projects through

(i) proper material selection and utilization according to aggregate properties;
(ii) aggregate layer thickness optimizations during the design process based on cost and mechanistic material properties related to performance, and as a result;
(iii) more economical use of the locally available aggregate materials in Minnesota.

| DETAILED BUDGET FOR ENTIRE PROJECT | | | |
|---|---|---|---|
| **SALARY:** | DOLLAR AMOUNT (OMIT CENTS) | | |
| NAME/ROLE | YEAR 1 | YEAR 2 | TOTALS |
| Erol Tutumluer, Principal Investigator | 11,222 | 11,671 | 22,893 |
| Graduate Research Assistant (RA) | 20,241 | 20,848 | 41,089 |
| Fringe Benefits | 5,035 | 5,226 | 10,260 |
| | | | |
| **TOTAL SALARIES** | **36,498** | **37,745** | **74.243** |
| **DIRECT COSTS:** | | | |
| CONSULTANT/CONTRACTOR COSTS (See Note[1]) | | | |
| EQUIPMENT (ITEMIZE) | | | |
| SUPPLIES | | | |
| TRAVEL (In-state only) | 1,011 | 1,051 | 2,063 |
| OTHER EXPENSES (i.e., testing)<br>ATREL Lab Fee + Tuition (56% of RA Salary) | 13,210 | 13,615 | 26,825 |
| **TOTAL DIRECT COSTS** | **50,719** | **52,411** | **103,130** |
| **TOTAL PROJECT COSTS** (Direct Costs + 58.5% UIUC TDC Less tuition and equipment) fy09 rate | **73,759** | **76,242** | **150,000** |

Note[1]: Contracts for consultants/contractors will be processed by P.I. through Consultant Services and encumbered directly from LRRB accounts. Requisition for contract is sent through Research Services for coding of accounting information

IF PROJECT EXTENDS BEYOND TWO YEARS, DUPLICATE BUDGET PAGE AND PROVIDE PROJECT TOTAL AT THE END OF ADDITIONAL YEARS.

BUDGET BY TASK:

(List Task number and dollar value for each task in work plan. Equipment and subcontractors should not constitute over 50% of total work plan. List equipment and subcontractors as separate task. If project includes consultant/contractor, provide breakdown of task budget for Materials and consultant/contractor)

| Task No. | Description | Mn/DOT | Contractor |
|---|---|---|---|
| 1 | Establish Aggregate Index Properties | $21,500 | $ |
| 2 | Collect Aggregate Strength and Modulus Data | $21,500 | $ |
| 3 | Establish Linkages Aggregate Properties and Design Inputs | $21,500 | $ |
| 4 | Sensitivity Analyses | $21,500 | $ |
| 5 | Development of Best Value Material Selection Tool Components | $21,500 | $ |
| 6 | Draft Final Report | $21,500 | $ |
| 7 | Final Report | $21,000 | $ |
| | Total | $150,000 | $ |

COMMENTS/JUSTIFICATION

## BACKGROUND:

Davich et al. (2004) performed thirty-six resilient modulus ($M_R$) tests on samples of six granular materials commonly used within pavement structures in Minnesota. The materials tested included A-1-a, A-1-b, A-2, and A-3 type soils according to AASHTO classification. Three of them also had grain size distributions falling within the Mn/DOT Class 3 maximum and minimum gradation band. Kim and Labuz (2007) recently conducted $M_R$ tests following the NCHRP 1-28A test protocol on virgin, recycled, and blended Mn/DOT Class 5 aggregate materials. In general, $M_R$ increased with increase of confining pressure, but $M_R$ showed little change with deviator stress. It was concluded that the base material produced with various %RAP content would perform at a similar level to 100% aggregate in terms of $M_R$ and strength when properly compacted. A recent Mn/DOT study by Gupta et al. (2007) focused on pavement design by using unsaturated soil technology. Different $M_R$ soil suction models were developed for compacted subgrade soils and a framework was provided to incorporate these models in the development of resistance factors of the MnPAVE mechanistic based pavement design program.

The Mn/DOT LRRB investigation report 828 focuses on "Local Road Material Properties and Calibration for MnPAVE" (Chadbourn, 2007). Base and subbase gradation specifications are given for Class 3, 4, 5, and 6 unbound aggregate materials. For these aggregate classes, the report lists average $M_R$ values backcalculated from Falling Weight Deflectometer (FWD) data collected from MnROAD pavement test cells and presents the season multipliers for the fall, winter, spring thaw, spring recovery, and summer periods. In addition, seasonal pore suction resistance factors, determined by Roberson et al. (2005) using the Van Genuchten (1980) equation for predicting matric suction from field moisture contents for three base materials at MnROAD, are listed relative to the equilibrium moisture states for spring, summer and winter seasons.

## OBJECTIVE:

The main objective of this research is to demonstrate that locally available materials can be economically efficient in the implementation of the available mechanistic based design procedures in Minnesota through MnPAVE Mechanistic-Empirical Flexible Pavement Design Method. The goal is to develop the components of a new granular material best value software module, which will be added to the MnPAVE program. The deliverables from this project will be a final report and the best value engineering software module components intended to provide pavement designers with index aggregate properties linked to modulus and strength characteristics and include example pavement designs. These designs will demonstrate the benefits and costs of implementing new mechanistic design procedures and material testing techniques.

## SCOPE:

The Minnesota Office of Materials Aggregate Source Information System (ASIS) is a database used to store and retrieve information on gravel pits, rock quarries and commercial aggregate sources. The ASIS database and other aggregate index property databases will be utilized to obtain typical costs and to categorize locally available aggregate base and granular subbase materials from quarries and borrow pits around the State. Existing laboratory and in situ test data from the LRBB Investigation 828 report and other research studies will be used to define reasonable mechanistic target value design inputs for aggregate base and subbase layers from the established database aggregate index properties. Average strength and $M_R$ values will be assigned to different Mn/DOT aggregate classes with corresponding seasonal pore suction resistance factors and sensitivity analyses will be conducted using the MnPAVE program for generated pavement life expectancies. As a result, guidelines will be established to choose a range of design moduli for different Mn/DOT aggregate classes and target values for strength, modulus, and thickness will be recommended for different design scenarios involving various types and qualities of locally available aggregate materials.

## TASKS:

### (1) *Establish Aggregate Index Properties*

The Aggregate Source Information System (ASIS) is a database developed by the Mn/DOT Office of Materials to store and retrieve information on gravel pits, rock quarries and commercial aggregate sources. It is used primarily by the Aggregate Unit at the Maplewood Lab and District Materials personnel as a data resource for recommending aggregate sources for construction projects. In addition, there is another aggregate index property database which presents individual aggregate test results in electronic data tables to be linked to quarry/pit locations. This task will categorize the types, sources, and properties of locally available aggregates in Minnesota and obtain typical costs. The material property databases, if not readily available to download from the Internet, and the cost information will be compiled and provided to the research team on CDs/DVDs and/or other electronic media.

*Deliverable:* Upon successful completion of this task, aggregate location, property and cost database spreadsheets will be produced as deliverables.

*Duration:* Approximately 4 months will be needed to complete this task.

### (2) *Collect Aggregate Strength and Modulus Data*

This task is intended to collect mechanistic pavement analysis and design inputs as the strength and resilient modulus ($M_R$) data for unbound aggregate pavement base and subbase applications. Existing laboratory and in situ test data will be obtained for Minnesota aggregates from the LRBB Investigation 828 report, Davich et al. (2004) study, Kim and Labuz (2007) report and other related research studies performed for/by Mn/DOT. In addition, as part of a comprehensive literature search, strength and $M_R$ data will be collected from other relevant research efforts, such as a large database of laboratory $M_R$ test results compiled by the PI for over a decade and the current Illinois DOT research project laboratory data on three different types and qualities of aggregate materials. With any such strength and modulus data, aggregate index properties will also need to be collected and archived.

*Deliverable:* Upon successful completion of this task, aggregate strength and modulus database spreadsheets will be produced as deliverables.

*Duration:* Approximately 6 months will be needed to complete this task.

### (3) *Establish Linkages between Aggregate Properties and Design Inputs*

In this task, the aggregate index properties will be linked to the collected field and laboratory aggregate strength and $M_R$ data and the aggregate properties, such as gradation, shape, texture and angularity, fines content, PI, and moisture state in relation to optimum moisture for identifying mechanistic design moduli ranges.

*Deliverable:* Upon successful completion of this task, correlations will be established as deliverables between the strength and modulus data and the various aggregate properties. These correlations will be added to the deliverables from Tasks 1 and 2 and the modified spreadsheets, also containing the correlations, will be produced as deliverables.

*Duration:* Approximately 4 months will be needed to complete this task.

**(4) *Sensitivity Analyses***

For the various aggregate types and properties identified/used throughout Minnesota for different Mn/DOT aggregate classes, a comprehensive matrix of mechanistic design moduli and seasonal pore suction resistance factor inputs will be established in this task. Using these inputs, MnPAVE analyses will be conducted to identify the sensitivity of the design inputs to pavement life expectancies.

*Deliverable:* Upon successful completion of this task, the sensitivity analysis results will be provided as deliverables.

*Duration:* Approximately 4 months will be needed to complete this task.

**(5) *Development of Best Value Granular Material Selection Tool Components***

This task deals with the development of the best value granular material tool components to incorporate into the MnPAVE program and to implement mechanistic pavement design concepts in aggregate selection/utilization. With the proposed developments, the current version of the MnPAVE program is targeted for a major improvement for aggregate design property selection. The final coding and packaging of MnPAVE software with the developed components, however, is not an intended goal but rather that task is left to software developers who work for Mn/DOT.

*Deliverable:* Upon successful completion of this task, the best value granular material selection tool components/algorithms will be packaged and provided as deliverables for incorporation into MnPAVE program.

*Duration:* Approximately 6 months will be needed to complete this task.

**(6) *Draft Final Report***

A draft final report will be prepared and submitted to the project Technical Advisory Panel (TAP). The draft final report will include all of the project research findings and the best value tool components will described by giving detailed examples on how to use the developed correlations and mechanistic design moduli inputs and therefore accomplish more economical use of the locally available aggregate materials in Minnesota.

*Deliverable:* Upon successful completion of this task, a draft final report will be submitted as the deliverable. The final report format will be such that it will be easily folded into Mn/DOT's Pavement Design Manual. The final report will also include catalogue of typical pavements designs for ease in use and implementation of the research findings.

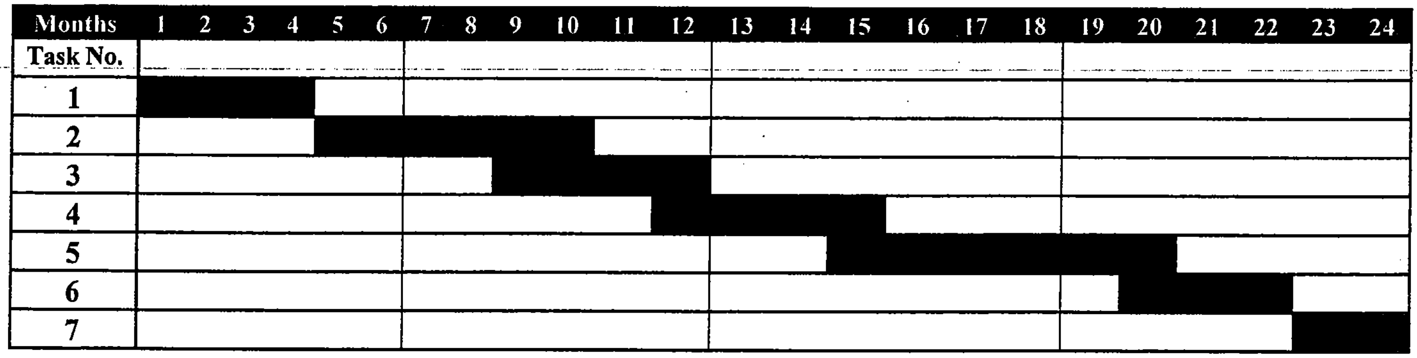
*Duration:* Approximately 3 months will be needed to complete this task.

**(7) *Final Report***

The draft final report will be revised based on the review comments by the project TAP. The final revised version will be submitted as the main project deliverable.

*Duration:* Approximately 2 months will be needed to complete this task.

**PROJECT SCHEDULE:**




**LITERATURE SEARCH:**

Davich et al. (2004) performed thirty-six resilient modulus ($M_R$) tests on samples of six granular materials commonly used within pavement structures in Minnesota. The materials tested included A-1-a, A-1-b, A-2, and A-3 type soils according to AASHTO classification. Three of them also had grain size distributions falling within the Mn/DOT Class 3 maximum and minimum gradation band. The $M_R$ tests were performed at three different values of moisture content for each material; one repetition of each test was carried out to investigate the repeatability of the data. The $M_R$ test results indicated that larger stiffnesses were typically obtained at low moisture contents.

Kim and Labuz (2007) recently conducted $M_R$ tests following the National Cooperative Highway Research Program (NCHRP) 1-28A test protocol on virgin, recycled, and blended aggregate materials. Virgin aggregate materials were collected from County Road (CR) 3 in Wright County, Minnesota and various blended mixtures with different ratios of recycled asphalt pavement (RAP) and virgin aggregate were produced (% RAP/aggregate): 0/100, 25/75, 50/50, 75/25. All gradation curves of virgin and blended aggregate specimens were within the minimum and maximum gradation bands of the Mn/DOT Class 5 specification. In general, $M_R$ increased with increase of confining pressure, but $M_R$ showed little change with deviator stress. It was concluded that the base material produced with various %RAP content would perform at a similar level to 100% aggregate in terms of $M_R$ and strength when properly compacted.

A recent Mn/DOT study by Gupta et al. (2007) focused on pavement design by using unsaturated soil technology. The study characterized the effects of soil suction on shear strength and resilient modulus of four soils representing different regions of Minnesota. Different $M_R$ soil suction models were developed for compacted subgrade soils and a framework was provided to incorporate these models in the development of resistance factors of the MnPAVE mechanistic based pavement design program.

The Mn/DOT LRRB investigation report 828 focuses on "Local Road Material Properties and Calibration for MnPAVE" (Chadbourn, 2007). As part of the summary findings presented in the report, base and subbase gradation specifications are given for Class 3, 4, 5, and 6 unbound aggregate materials. For these aggregate classes, the report also lists average $M_R$ values backcalculated from Falling Weight Deflectometer (FWD) data collected from MnROAD pavement test cells and presents the season multipliers for the fall, winter, spring thaw, spring recovery, and summer periods. In addition, seasonal pore suction resistance factors, determined by Roberson et al. (2005) using the Van Genuchten (1980) equation for predicting matric suction from field moisture contents for three base materials at MnROAD, are listed relative to the equilibrium moisture states for spring, summer and winter seasons.

As part of the research activities undertaken for the NCHRP 4-23 project, entitled, "Performance Related Tests of Aggregates for Use in Unbound Pavement Layers," Seyhan and Tutumluer (2002) successfully applied a directional modulus testing approach to study thirteen aggregates with varying material properties obtained from eight different States in the U.S. The directional modulus testing approach used an advanced triaxial testing equipment, referred to as the UI-FastCell, and applied to specimens vertical and horizontal dynamic loads, vertical pulsing only to give vertical $M_R$ and horizontal pulsing only to give horizontal $M_R$ values. The horizontal to vertical modulus ratios were established as aggregate performance indicators relating these ratios to the quality and strength properties. Detailed analyses of the test data indicated that a consistent trend of increasing directional modulus ratios of "Good Quality" materials existed with increasing applied shear stresses that linked directional MR results to strength and permanent deformation performance characteristics. Using the approach, Tutumluer and Seyhan (2000) also determined an optimum fines content of 7% for a crushed limestone aggregate base material having an Illinois DOT CA-6 dense gradation.

An ongoing Illinois DOT research project directed by the principal investigator currently focuses on characterizing strength, stiffness, and deformation behavior of three different types and qualities of aggregate materials, i.e., crushed gravel, limestone and dolomite, commonly used in Illinois for subgrade replacement and subbase. Based on comprehensive laboratory testing and field rutting performances of constructed pavement aggregate subbase layers from full-scale accelerated testing, aggregate properties such as gradation, shape, texture and angularity, fines content, Plasticity Index (PI), and moisture state in relation to optimum moisture will be linked to $M_R$ and strength properties. This will identify, e.g., why dense-graded aggregates with high fines (minus No. 200 sieve size) contents and/or excessive PI values may exhibit increased or high moisture sensitivity. This project also utilizes the databases of imaging based indices of aggregate shape, texture, and angularity established through past research studies involving the University of Illinois Aggregate Image Analyzer (Tutumluer et al., 2000). Essential mechanistic based guidelines will be established for economizing the use of different types and qualities of aggregate by either reducing cover thickness on soft subgrades or avoiding poor quality aggregate failures. The outcome of this closely related project on aggregate properties affecting $M_R$ will be of major use to the proposed Mn/DOT research.

**REFERENCES:**

Chadbourn, B. (2007), "Local Road Material Properties and Calibration for MnPAVE," Task 2 Report on Model Selection, Local Road Research Board Investigation 828, Minnesota Department of Transportation, March, 25 pages.

Davich, P., Labuz, J.F., Guzina, B., and Drescher, A. (2004), "Small Strain and Resilient Modulus Testing of Granular Soils," University of Minnesota Final Report published by Minnesota Department of Transportation, August, 117 pages.

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Van Genuchten, M. (1980), "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Science Society of America Journal, Vol. 44, pp. 892-898.

Seyhan, U. and Tutumluer, E. (2002), "Anisotropic Modular Ratios As Unbound Aggregate Performance Indicators," Journal of Materials in Civil Engineering, ASCE, Volume 14, Number 5, September/October, pp. 409-416.

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Tutumluer, E., Rao, C., and Stefanski, J.A. (2000), "Video Image Analysis of Aggregates," Final Project Report, FHWA-IL-UI-278, Civil Engineering Studies UILU-ENG-2000-2015, University of Illinois Urbana-Champaign, Urbana, IL.