TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____IOWA DOT______________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(183)*	**Transportation Pooled Fund Program - Report Period:** Quarter 1 (January 1 – March 31) X Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) Quarter 4 (October 4 – December 31)

Project Title:
Improving the Foundation Layers for Concrete Pavement

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Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:**
RT 0314	Addendum 352	3/16/09
Original Project End Date: 3/15/14	**Current Project End Date:** 3/15/20**14**	**Number of Extensions:**

Project schedule status:

X On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$700,000	$297,940.70	70

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$1,064.04		10

Project Description:

The objective of this research is to improve the construction methods, economic analysis and selection of materials, in-situ testing and evaluation, and development of performance-related specifications for the pavement foundation layers. The outcome of this study will be conclusive findings that make pavement foundations more durable, uniform, constructible, and economical. Although the focus of this research will be PCC concrete pavement foundations, the results will likely have applicability to ACC pavement foundations and, potentially, unpaved roads. All aspects of the foundation layers will be investigated including thickness, material properties, permeability, modulus/stiffness, strength, volumetric stability and durability. Forensic and in-situ testing plans will be conceived to incorporate measurements using existing and emerging technologies (e.g. intelligent compaction) to evaluate performance related parameters as opposed to just index or indirectly related parameter values. Field investigations will be conducted in each participating state. The results of the study will be compatible with each state's pavement design methodology and capable for use with the Mechanistic-Empirical Pavement Design Guide (MEPDG). Evaluating pavement foundation design input parameters at each site will provide a link between what is actually constructed and what is assumed during design. There are many inputs to the pavement design related to foundation layers and this project will provide improved guidelines for each of these. The study will benefit greatly from maximizing the wide range of field conditions possible within the framework of a pooled fund study.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

A conference call with TAC was conducted on June 19th to discuss overview of field project reports, update TAC on the Manual, discuss recommendations for future specification changes, discuss potential continuation of the pooled fund study to allow working with AASHTO to update guide specifications, request typical pavement performance data and pavement cross sections from state DOTs, and provide an overview of freeze thaw laboratory test results.

The main research activities during this quarter involved the following [related research task number is in the parenthesis]:

- Conducting laboratory testing (frost-heave/thaw-weakening) on samples obtained from the field projects [Sub Task 1.5],
- Conducting laboratory horizontal permeability testing on three materials [Sub Task 1.5],
- Conducting in-situ test data analysis on three field projects (Pennsylvania SR422, Iowa I-35, Michigan I-96, and Pennsylvania SR-22) and developing field project reports [Sub Tasks 1.5, 1.7, 3.1, 3.2, 3.4,]
- Conducting seasonal evaluation testing in Iowa test sites [Sub Task 1.5]
- Conducting performance evaluation using M-EPDG and finite element methods [Sub Task 2.3]
- Obtaining temperature sensor array data on Iowa Hwy 30 project and conducting in-situ testing [Sub Task 3.1].

<u>Laboratory testing:</u>

As indicated in the last QPR, a new experimental plan with a list of materials for development of a comprehensive database of laboratory test parameters has been developed. The material list is provided below:

A. western Iowa loess,
B. chemically treated western Iowa loess (with fly ash and cement),
C. recycled asphalt pavement (RAP) base material (with varying fines content: 0%, 6%, 12%, natural fines content),
D. crushed limestone base material (with varying fines content: 0%, 6%, 12%, natural fines content),
E. recycled portland cement concrete (RPCC) base material (with varying fines content: 0%, 6%, 12%, natural fines content),
F. concrete sand

G. pea gravel
H. composite RPCC material + loess (with and without geosynthetic reinforcement)
I. composite RAP material + loess (with and without geosynthetic reinforcement)
J. composite crushed limestone material + loess (with and without geosynthetic reinforcement)

Update for each of the laboratory test is as follows:

A. Laboratory classification tests (i.e., specific gravity, Atterberg limits, grain size distribution, soil classification, and natural moisture content – Completed for all materials listed above.
B. Moisture-density relationship (i.e., using Proctor tests for non-granular materials and vibratory compaction tests for granular materials) – Completed for all materials listed above.
C. Cyclic triaxial tests according to NCHRP598 loading sequences – During this quarter, calibration work has been done on the the new higher load capacity actuator that was acquired. This new actuator allows conducting tests at higher deviator stresses (10 to 180 psi) per recommendations by NCHRP Report 598. There was nearly a three month delay in installing this equipment in the laboratory by the manufacturer. Calibration on the equipment has not been finished. The equipment manufacturer has agreed to visit ISU to perform onsite calibration early next quarter. Testing materials with this new actuator is expected to begin early next quarter.
D. Horizontal permeability test (HPT on a 113 cm L x 54 cm W x 30 cm H sample) – HPTs have been completed on materials C, D, E, F, and G.
E. Gas permeability test (GPT) (on HPT samples) – GPTs have been completed on materials C, D, E, F, and G.
F. Core hole permeability (CHP) test (on HPT samples) – CHP tests have been completed on materials C, D, E, F, and G.
G. Light weight deflectometer test (on HPT samples) – LWD tests have been completed on materials, C, D, E, F, and G.
H. Dynamic cone penetrometer test (on HPT samples) – LWD tests have been completed on materials, C, D, E, F, and G.
I. Freeze-thaw durability tests and California bearing ratio tests – Freeze thaw durability tests was conducted in accordance with ASTM D560. Twelve tests were performed during this quarter on material A, C, D, E, and F. The western Iowa loess (material A) was stabilized with Portland cement and fly ash. The targeted Portland cement, fly ash, and water contents were determined from the 2in X 2in compressive strength study that was performed over the previous two quarters. An additional 90 2in X 2in stabilized samples were made this quarter with varied moisture and stabilizer contents. The additional samples expanded the range of Portland cement contents that have been tested. Vacuum saturation was performed on 45 of the samples, to represent the strength after several freeze-thaw cycles had occurred. Compressive strength tests were performed on the samples and the results were used to determine which moisture contents and stabilizer contents would be targeted for frost-heave and thaw-weakening testing and freeze-thaw durability testing.

As indicated in the last QPR, these materials have been selected due to the availability of large quantities of these materials from local Iowa quarries and sites. Materials obtained from field project sites are available only in limited quantities. Laboratory test methods were selected to characterize each material's classification, strength, stiffness, and permeability properties, which are primary inputs for pavement foundation layer properties in MEPDG.

Pavement performance testing:
The six sites across Iowa were tested once during this quarter using the FWD and DCP.

Instrumentation on US Highway 30, Iowa:
A summary of instrumentation installed on the US30 project is provided in the last QPRs. In brief, a temperature array with fourteen sensors to continuously record temperature changes both across the pavement width and in the foundation layers with depth was installed at the project site. A Campbell Scientific CR5000 data logger was installed on site to continuous record the temperature in the foundation layers at one hour intervals. Data is being periodically downloaded from the project.

Field data to conduct performance evaluation using M-EPDG and finite element analysis:
A meeting between the UI and ISU research group was held on June 5, 2012 at UI to discuss updates to the M-EPDG sensitivity and finite element analysis results. The M-EPDG report has been finalized. The finite element analysis report is 90% complete.

Anticipated work next quarter:

- Continue frost-heave and thaw-weakening testing (emphasis on stabilized materials)
- Continue frost-heave (with emphasis on stabilized materials), CBR, cyclic triaxial, and aggregate degradation testing on samples collected from all field project sites.
- Conduct periodic performance monitoring testing in Iowa (to capture summer seasons).
- Complete data analysis for the field projects and develop project reports

Significant Results:

Laboratory testing:
A new experimental plan has been developed to develop a comprehensive database of laboratory test parameters for selected materials. The test methods included in this experimental plan includes:

- laboratory classification tests (i.e., specific gravity, Atterberg limits, grain size distribution, soil classification, and natural moisture content,
- moisture-density relationship (i.e., using Proctor tests for non-granular materials and vibratory compaction tests for granular materials),
- cyclic triaxial tests according to NCHRP598 loading sequences,
- resilient modulus tests according to AASHTO T-307,
- horizontal permeability test (HPT on a 113 cm L x 54 cm W x 30 cm H sample),
- gas permeability test (GPT) (on HPT samples),
- core hole permeability (CH) test (on HPT samples),
- light weight deflectometer test (on HPT samples),
- dynamic cone penetrometer test (on HPT samples).
- freeze-thaw durability tests,
- California bearing ratio tests,

The tests described above are being planned on the following selected materials:

- western Iowa loess,
- chemically treated western Iowa loess (with fly ash and cement),
- recycled asphalt pavement (RAP) base material (with varying fines content: 0%, 6%, 12%, natural fines content),
- crushed limestone base material (with varying fines content: 0%, 6%, 12%, natural fines content),
- recycled portland cement concrete (RPCC) base material (with varying fines content: 0%, 6%, 12%, natural fines content),
- concrete sand
- pea gravel
- composite RPCC material + loess (with and without geosynthetic reinforcement)
- composite RAP material + loess (with and without geosynthetic reinforcement)

- composite crushed limestone material + loess (with and without geosynthetic reinforcement)

These materials have been selected due to the availability of large quantities of these materials from local Iowa quarries and sites. Materials obtained from field project sites are available only in limited quantities. Laboratory test methods were selected to characterize each materials' classification, strength, stiffness, and permeability properties, which are primary inputs for pavement foundation layer properties in MEPDG. Strength (e.g., DCP test) and stiffness (LWD test) tests were planned on HPT samples to be able to correlate between these properties with permeability properties. GPT used for permeability testing on field test sites and a newly developed CHP testing for testing permeability of base materials under existing pavements are used on HPT samples to get comparisons between these different test methods.

Laboratory Frost-Heave and Thaw-Weakening Testing: Equipment malfunctions prevented any tests from being performed in the previous quarter. The equipment was originally returned in February, but did not operate correctly. The equipment was just returned at the end of the quarter and appears to be operating correctly. Testing should resume early in the next quarter. A stabilization study was performed on a western Iowa loess material. The study consisted of making 180 specimens of 2in X 2in size and varying the moisture content and stabilizer content. Portland cement and fly ash were used as stabilizers. Vacuum saturation was performed on 90 of samples, to represent the strength after several freeze-thaw cycles had occurred. The results will be used to determine which moisture contents and stabilizer contents should be targeted for frost-heave and thaw-weakening testing and freeze-thaw durability testing. Sixteen freeze-thaw durability samples were made last quarter and are currently being tested in accordance with ASTM D560.

Cyclic Triaxial and Aggregate Degradation Testing: As described in the last QPR, cyclic triaxial tests were conducted on recycled portland cement concrete (RPCC) subbase material obtained from the Iowa US30 project. Tests with 100,000 loading cycles were conducted on samples compacted to different target densities, confining pressures, and deviator stresses. Results indicated permanent strains < 0.15% at the end of 100,000 loading cycles. During this quarter, a new higher load capacity actuator has been installed to upgrade our cyclic triaxial testing system. This new actuator allows conducting tests at higher deviator stresses (10 to 180 psi) per recommendations by NCHRP Report 598 on RPCC materials. There was nearly a three month delay in installing this equipment in the laboratory by the manufacturer, due to equipment calibration issues. This caused a delay in conducting laboratory tests. The new actuator is currently being calibrated by the ISU team and testing with this new actuator is expected to begin early next quarter.

<u>Laboratory horizontal permeability testing (HPT):</u>

During this quarter, calibration and repeatability evaluation of the HPT has been completed. The equipment showed good repeatability. The equipment design has been modified to be able to conduct CHP tests over HPT samples. HPTs along with CHP tests, GPT, DCP, and LWD tests were conducted on three materials during this quarter: (a) pea gravel, (b) concrete sand, and (c) crushed limestone base material. Laboratory classification and compaction tests of these materials have also been completed. Testing on RPCC and RAP base materials is being planned for next quarter. Nearly 50 5-gallon buckets of each material has been recently acquired from a local Iowa quarry.

<u>Pavement performance testing</u>:

During this quarter, the sites across Iowa were planned to be tested periodically to capture the change in strength during the freeze-thaw period. Due to the high temperatures, there was not a sustained freezing period during this winter. Therefore, the sites were not tested. A thawing period test is being planned for early next quarter. The six sites will be tested with FWD and DCP.

Instrumentation on US Highway 30, Iowa:

A summary of instrumentation installed on the US30 project is provided in the last QPRs. In brief, a temperature array with fourteen sensors to continuously record temperature changes both across the pavement width and in the foundation layers with depth was installed at the project site. A Campbell Scientific CR5000 data logger was installed on site to continuous record the temperature in the foundation layers at one hour intervals. Data is being periodically downloaded from the project.

Field data to conduct performance evaluation using M-EPDG and finite element analysis:

ISLAB2000, a 2-D finite element program, was used to determine whether measured non-uniformity in the subgrade strength, in terms of variations in k-value, played a significant role in the tensile stress response of concrete slabs. A mesh size of 2 inches by 2 inches was used in the analysis in order to maximum the accuracy of the solution. In order to define k-values, plate load test data collected by Iowa State was correlated to corresponding CBR of the subgrade along a longitudinal section of I-94 in Michigan. The correlation developed for this data set, which was used to define the k-values for the 7m by 7m spatial grid, is the following: $k=23.532CBR^{0.7787}$. The correlated k-values for this $49m^2$ area ranged from 31-202 psi/in.

Three cases with a different size of discretized k-value areas were analyzed to quantify the effects of non-uniformity. The 7m by 7m soil test grid was divided into four slabs of 3.5 m by 3.5 m to simulate the approximate size of concrete slabs on roadways. Three different axle configurations in the form of single, tandem, and steer-drive axles were traversed longitudinally across slabs to quantify the interactions between the support uniformity and the position of the different axle loadings. Three temperature differentials, +20°F, 0°F, -20°F, were also simulated to account for the extreme night and day time curling conditions and no curling conditions. The five loading paths for the 3 axle types that were analyzed included the right lane free edge, right lane wheel path, centerline of the roadway, left lane wheel path and left lane free edge.

The following conclusions were made based on the measured spatial k-value data and the assumptions for the loading configuration, loading path, temperature conditions, and discretization of the k-values in the finite element program:

- Single axles produced the greatest tensile stresses at the right and left lane free edges in conjunction with a positive temperature differential.
- Maximum stresses for tandem and steer-drive axles were lower by 2 % and 10% respectively, relative to the single axles.
- Tensile stresses developed for centerline loading were greatest for the steer-drive axle.
- The largest tensile stresses were produced by the non-uniform support case that used all 121 measured k-values. Each individual k-value represented an area of approximately 0.6m by 0.6m. As the area of nonuniformity grew, by averaging adjacent grid points, the tensile stresses decreased slightly.
- For the measured k-value distribution, only 2% difference existed between the tensile stresses developed by non-uniform and uniform cases. Hence, non-uniformity should not play a significant role in terms of stress development in the MI I-94 field data set for the assumed slab configuration, loading, axle configurations, and temperature differential conditions.
- A larger nonuniform area and greater range of non-uniform stiffness is required to increase tensile stresses in the slab as was found in literature.

Analysis will be continuing in the next quarter for other field data sites, e.g., PA US422 and WI US-10. Furthermore, a random assignment of k-values based on existing field data will be carried out and analyzed through finite element analysis in order to investigate if the randomly assigned k-values for a certain grid area will give different conclusions than the ones presented above for the MI I-94 test data.

Circumstance affecting project or budget (Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).