TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Date: 7/31/2014

Lead Agency (FHWA or State DOT): FHWA

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 # *(i.e, SPR-2(XXX), SPR-3(XXX) or TPF-5(XXX)* SPR-2(208)	**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☑Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)

Project Title: Pavement Subgrade Performance Study		
Name of Project Manager(s): Nadarajah Sivaneswaran	**Phone Number:** 202-493-3147	**E-Mail** n.sivaneswaran@dot.gov
Lead Agency Project ID: DTFH61-11-D-00009-T11004	**Other Project ID (i.e., contract #):**	**Project Start Date:** 1999
Original Project End Date: 09/30/2014	**Current Project End Date:** 11/30/2014	**Number of Extensions:**

Project schedule status:

☐ On schedule ☑ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
$2,923,784.74	$2,813,941.90	98%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
$32,631.01 (1%)	$32,631.01	

Project Description:

The objective of SPR-2(208) was to develop prediction models for permanent deformation in the subgrade soil that incorporate the effect of soil type and moisture content. The full-scale experimental phase of the study was conducted at the Cold Region Research Laboratory (CRREL) of the U.S. Army Corps of Engineers in Hanover, New Hampshire, between 1999 and 2007. Four flexible pavements with the same granular base layer and asphalt concrete surface layer were built inside the Frost Effects Research Facility and were subjected to accelerated pavement testing (APT). The pavements were built with a combination of four soil types and three moisture levels, which resulted in a total of 12 sets of pavement sections, named cells. Each of the four soil types were placed in the pits of the facility at three moisture contents. For each cell, between four and six pavement sections, named windows, were subjected to accelerated pavement testing. The MARK HVS IV was used as the loading device. Up to four wheel load magnitudes were used for the windows in the same cell. The test sections were instrumented with stress, strain, moisture and temperature sensors. Surface rutting was monitored with a Laser Profilometer. Falling Weight Deflectometer (FWD) tests were performed on each pavement section before the application of accelerated traffic. The testing phase of the project was completed and the final deliverables were received in February 2007 (Cortez et al., 2007).

The final deliverables from the testing phase included a comprehensive database containing APT testing data of the four different subgrade soils under various moistures and loading conditions, along with a series of reports. Preliminary data analysis showed that the database provides a wealthy amount of information for pavement engineers and researchers in the development of advanced subgrade performance models. However, because of its complexity due to the number of variables involved, its sheer size, and some incomplete/missing data, the potential use of the database couldn't be realized without a detail assessment of the database. The Technical Advisory Committee (TAC) of the TPF thus requested the FHWA to conduct an independent assessment of the database and to develop a work plan for future data analysis. The objectives of the database assessment were to 1) review the data variables, its completeness and to document them; 2) to obtain/assemble/input additional available laboratory test results and missing data and 3) with the assessment complete, to develop a detailed work plan for future data analysis and modeling. The data assessment task was completed in October 2010 and this resulted in a comprehensive report documenting the entire study effort to date, including detail documentation of APT and laboratory test data, and a Microsoft Access database with data for further analysis (Romanoschi, 2010).

The TAC met during the January 2011 Transportation Research Board Annual Meeting and recommended the final phase of this TPF to develop empirical models for permanent deformation in subgrade soils consistent and for use with the NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (MEPDG) and more fundamentally based mechanistic models for advancing the science of pavement design.

A Task Order under an existing IDIQ contract was awarded in January 2012 to Engineering & Software Consultants, Inc. to conduct the final phase of this study to:

1. Develop empirical models for permanent deformation in subgrade soils consistent and for use with the NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (MEPDG) and the associated model parameters for the subgrade soils tested in SPR-2(208) and validate them using the performance data collected.
2. Develop fundamentally based mechanistic models for the determination of permanent deformation in subgrade soils under repeated traffic loading and validate them through finite element modeling and the performance data collected for advancing the science of pavement design.

The TAC met during the January 2012 Transportation Research Board Annual Meeting where the research team conducting work under new TO presented their work plan and received feedback

The new TO consisted of the following five tasks:
Task 1: Comprehensive review of SPR-2(208) products
Task 2: Development of empirical and mechanistic models for permanent deformation in subgrade soils
Task 3: Advanced laboratory testing of subgrade soils for the determination of model parameters
Task 4: Finite element modeling (FEM) of permanent deformation accumulation for calibration and validation of model and model parameters
Task 5: Develop and submit a final report to document the entire research effort

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

Task 1: Comprehensive review of SPR-2(208) products
None this Quarter.

Task 2: Development of empirical and mechanistic models for permanent deformation in subgrade soils
None this Quarter.

Subtask 2.1 – Development of new empirical models
The outcome of the meeting with the Technical Advisory Panel was reviewed. Work on the paper to be submitted to the 2015 TRB meeting has started.

Subtask 2.2 – Development of fundamentally based mechanistic models

Model Development:
Triaxial tests on compacted specimens from soil samples from CRREL site have continued. Some of the compacted specimens did not perform well under triaxial tests. They are continuing to make changes to the test protocol to ensure the results are consistent. They have also started to perform some resilient modulus tests to compare parameters.

The optimum moisture content and maximum density (OMC-MDD) test, indirect tensile strength (IDT) tests, unconfined compressive strength (UCS) tests and uniaxial compressive strength tests were performed on all three kinds of CREEL soil samples. Consolidated-Undrained (CU) triaxial tests has been performed on A-6 CREEL soils.

The suction tests of CREEL soils and Pullman silt has been performed. Soil Water Characteristic Curve (SWCC) and suction stress characteristic curve (SSCC) of all these soils have been obtained. They will be applied to better predict the friction angles under different water contents. For each soil, 5 different IDT samples with different moisture content were prepared and tested to plot the internal friction angle and shear failure surface by using SWCC and SSCC. Resilient Modulus with GCTS has been started. CU-Triaxial test of soil type A-7-5 has been performed.

Model Implementation:

Task 4: Finite element modeling of permanent deformation accumulation
Implementation of the Cap-Model in ABAQUS software has been started. The model will be verified by simulating the triaxial test results.

The Drucker-Prager Cap-Model has been built into ABAQUS software and used to simulate the USC tests and triaxial tests performed to verify performance. Different types of loadings and boundary conditions were simulated with 3-D finite element models. Since the use of triaxial testing to obtain model parameters is cumbersome, they have also looked at some other simpler tests to obtain Cap-Model parameters.

The FE simulation of CRREL pavements using ABAQUS with Linear Drucker-Prager Cap-Model continued. Different types loadings and boundary conditions were simulated using 2-D and 3-D asymmetric finite element models.

Anticipated work next quarter:

1. The tests including UCS, IDT and UU triaxial will be finished in next period on the rest of the soil samples. The test methods will be improved and modified continually as needed.
2. Collection of parameters of Drucker-Prager Cap model will be completed, the verification of the model by using finite element analysis will be performed.
3. Numerical simulations will be continued.

Significant Results:

Circumstance affecting project or budget. (Please 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).

Potential Implementation:

1. Empirical models for permanent deformation in subgrade soils consistent and for use with the NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (MEPDG) and the associated model parameters for the subgrade soils tested in SPR-2(208).

2. Fundamentally based mechanistic models for the determination of permanent deformation in subgrade soils under repeated traffic loading for advancing the science of pavement design.

3. Fully documented APT performance and laboratory test data in a Microsoft Access database for future model validation and calibration.