TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Oklahoma Department of Transportation

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(297)*	**Transportation Pooled Fund Program - Report Period:** O Quarter 1 (January 1 – March 31) X Quarter 2 (April 1 – June 30) O Quarter 3 (July 1 – September 30) O Quarter 4 (October 1 – December 31)
Project Title: **Improving Specifications to Resist Frost Damage in Modern Concrete Mixtures**	

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Lead Agency Project ID: **TPF-TPF5(297)RS / JOB PIECE 30802(04)**	**Other Project ID (i.e., contract #):** AA-5-52974	**Project Start Date:** March 10, 2014
Original Project End Date: February 28, 2017	**Current Project End Date:** **September 1, 2019**	**Number of Extensions:** 1

Project schedule status:

On schedule X 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
$590,000	$400,000	65%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
$20,500	$20,500	48%

Project Description:

Concrete can be damaged when it is 1) sufficiently wet (has reached a critical degree of saturation) and 2) is exposed to temperature cycles that enable freezing and thawing. The damage that occurs due to freezing and thawing can lead to premature deterioration, costly repairs, and premature replacement of concrete infrastructure elements. Current specifications for frost durability are largely based on work completed in the 1950s, and while this work included many landmark discoveries (Kleiger 1952, 1954). This work from the 1950s may not be representative of materials used in modern concrete mixtures. Results from recent studies suggest that there are several ways in which frost damage can be reduced through new tests and improve specifications that can lead to extended service life of concrete infrastructure.

This report focuses on the work completed in Phase II of the project.

The goal of the research is to produce improved test methods and specifications for freeze-thaw resistant concrete. In addition, the work will strive to improve the understanding of the underlying mechanisms of frost damage. Specifically, this work will seek to develop new test procedures that may be faster and/or more reliable than the existing methods.

The objectives of Phase II are:

- Continued Development of the SAM and Investigation of Field Construction Practices
- Validate and standardize the Bucket Test
- Measuring and Modeling different freeze thaw exposure conditions
- Confirm the freeze thaw results with X-ray and neutron imaging

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

Phase II

Task 1 – Continued Development of the SAM (Oklahoma State)

The SAM has been significantly improved with the research to date. A new o-ring has been developed, there have been improvements to the gauge, a new device was developed to help add water to the bottom chamber without creating bubbles. The top cap design has been changed to make it harder for an operator to inadvertently push the top lever during pumping. All of these new additions have been sent to the states for them to use in the field and provide feedback.

A precision and bias statement has been developed by using two different SAM testers. Work is underway to develop data for multiple users. To do this the research team is using four or five operators on the same concrete mixtures. This will be sent to the AASHTO TP 118 to finalize the test method. A new recommendation was made to AASHTO PP 84 for the use of the SAM.

It was recommended that in the mixture design stage that the air content be > 4% and the SAM Number < 0.20. However, in the field the recommended values are air content > 4% and the SAM Number < 0.30.

Task 2 – Investigate field construction practices and aid SAM adoption (Oklahoma State)

A paper was recently submitted to a peer reviewed journal that summarizes the field study on this project. The paper has been included with this submission for the sponsoring states to read. The results show a good agreement between the laboratory and field testing when you compare the SAM Number and spacing factor. This is a great accomplishment for this project.

The research team focused heavily on sampling field concrete before and after pumping. The research shows that it is common to see air volume lost during pumping. However, the air that is lost seems to return to the concrete before it hardens. This has been investigated in both laboratory and field testing. In all cases, if the air void system was satisfactory when it is added to the pump then it appears to be satisfactory after pumping. A MS thesis summarizing these findings has been included with this document.

Based on the 16 laboratory and 18 field mixtures investigated the following conclusions have been made:

- 67% of the mixtures showed a change in the air content of more than 0.5% and 92% showed an increase in SAM Number by 50% due to pumping.
- Mixtures that lost air and increase SAM Number from pumping showed an improvement in the SAM Number with measurements over time.
- For the Eighteen samples investigated with an air volume > 4% and SAM Number < 0.32 all showed satisfactory performance in ASTM C666 testing regardless of any change in fresh air content, SAM Number, number of cycles through the pump, pumping pressure, and pump configuration.
- Twenty-two samples were found to have a fresh air volume < 4% or a SAM Number > 0.32 when sampled after pumping and all showed satisfactory freeze-thaw performance regardless of the number of cycles through the pump, the change in air content, or the change in SAM number due to pumping.

- 83% of mixtures after one cycle through the pump and pipe network fell within the recommend spacing factor coefficient of variation limit per ASTM C457.
- There was an average increase in the air volume of 11% from the measured fresh air volume to the hardened air volume after pumping and no difference in the fresh and hardened air volume difference prior to pumping.

Several presentations were made about these results and a YouTube video was made and posted here:
https://youtu.be/38H6yXi_of8

This video has been watched over 1000 times in less than three months.

Task 3 – Standardizing a new rapid freeze thaw test (Oregon State and Oklahoma State)

As part of the previous research on the pooled fund project it was realized that critical degree of saturation has a significant impact on the freeze thaw resistance of concrete. This means that as the concrete becomes increasingly saturated that there will be a point when the concrete becomes critically saturated after which time a freezing cycle results in damage. The current model uses 4 variables: Critical Saturation (S_{CR}), Matrix Saturation (S_{Matrix}), the Secondary Rate of Absorption (dS_2/dt) and the drying parameter (ϕ).

A test method has been developed to measure critical saturation. This consists of placing samples that are saturated to varying degrees of saturation on a cold plate and performing a freeze-thaw cycle as observed in Phase I of the project.

Currently the ASTM C1585 model has been modified and used to develop the matrix saturation and the secondary rate of absorption. The research team has been focused on developing a revised version of the sorption test for use in this model as well as a numerical model. The simplified test may either be similar to ASTM C1585 or may be based on the extension to a very economical and simple test in which a concrete cylinder is placed in a bucket of pore solution water and the mass is measured after demolding and then over time.

Work at Oregon State has shown that it may be possible to extend this approach to an even faster test method that could be used as an input into the service life prediction model. If successful this would imply that data from the SAM test and bucket test could be used to provide an indication for the service life of a concrete element exposed to freezing and thawing.

Task 4 – Measuring different FT exposure conditions (Oklahoma State and Oregon State)

It is widely realized that different freeze thaw environments are different across the US. However, all of the freeze thaw specifications treat each environment the same. The research team aims to better describe these different regions by quantifying how the different environments impacts the moisture content and temperature of concrete. Because these are the two primary inputs to freeze thaw durability, this will be very valuable data.

At the writing of this quarterly report the circuit board design is being finalized and they are being printed. The research team would like to start creating samples and sending the samples to different states for testing. Two samples will be sent to each state for comparison. This will allow the weather conditions of the states to be compared for moisture and freeze thaw cycles.

Task 5 – Modeling different FT exposure conditions (Oregon State)

The data from the field monitoring (Task 4) will be essential in establishing models to simulate how different exposure conditions impact FT prediction. These models will aim to incorporate drying, wetting, salts, temperature ranges, etc. in making the ultimate prediction of FT field performance of concrete. The previous work on this pooled fund has used well known exposure conditions to better understand the freeze thaw performance of concrete. This has allowed us to build a new level of understanding of FT performance. In this task we aim to extend this knowledge to much more variable exposure conditions of the concrete. This may require some additional laboratory testing to look at how wetting and drying cycles impact the moisture penetration. It also may require completing some previous testing under the influence of salt solution. The ultimate goal of this work is to build a numerical model that will help DOTs design their concrete based on their local conditions and exposure levels. This tool could also be used to forecast the life of concrete of different qualities into the future. This would aid in the design, repair, and service life prediction of existing structures to predict differences in designed and provided life expectancy of structures.

Work will be completed on this as the field data is generated. Once the field system is deployed then a lot of data will be generated simultaneously. This will help this task tremendously.

Task 6 - Confirmation of FT results with X-ray and neutron imaging (Oregon State and Oklahoma State)

Both research groups on this project have been studying the movement of water with both X-ray and neutron tomography and radiography. These techniques lend themselves well to the study of freeze thaw damage within concrete as they can be used to evaluate structure, fluid movement, and damage. These methods will be a useful tool to validate the findings from this work and provide deeper insights to critical questions. These tools will not be extensively used in the research; however, they will be able to provide measurements that are not possible with any other method. It is anticipated that a freezing stage will be constructed for usage for neutron and X-ray imaging. This will allow in-situ imaging to be complete of materials as they are freezing.

Preliminary work is being completed at both Universities on this task. A paper on using neutron radiography to examine fluid absorption in mortar samples with different w/c and preconditioning has been completed. This study relates water absorption to the formation factor and suggests that the formation factor may be able to replace the water absorption test thereby saving substantial time in sample preparation and testing. In addition, the samples from a number of concrete mixtures (≈30 mixtures) with different w/cm and air contents and qualities were cut and preconditioned in order to conduct an absorption test on them by using neutron radiography. The goal of this experiment is to investigate the impact of different variables (e.g., w/cm and air content) on secondary rate of absorption, which is an important input for the service life modeling. The preliminary results of this experiment will be presented in the future. Furthermore, a preliminary work is in progress to study the freezing-thawing cycle in concrete using neutron radiography.

Anticipated work next quarter:

The team is continuing to evaluate methods to improve the SAM.

Using the SAM to investigate field concrete through pumping, vibration, and drop height.

The Bucket Test is being evaluated and improved.

Continued measurement of the samples with variation in w/c and air for porosity, formation factor, critical saturation, matrix saturation, rate of secondary absorption, the bucket test and neutron radiographic measures of absorption.

Significant Results:

Over 20 different presentations and webinars have been given over the research. Over 10 papers have been authored based on the work from this research. The SAM is now being used in 39 states, and five foreign countries. Specification language is being investigated in Idaho, Michigan, Wisconsin, Kansas, Oklahoma, and New York.

The publication and revision of the AASHTO TP118 test method is also an important result.

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, with recommended solutions to those problems).

Potential Implementation:

The Provisional AASHTO test method for the Super Air Meter has been published. Work will continue on the project to develop the precision and bias statement.

The results from this study have been included in the AASHTO PP84 durability specification for concrete pavements. This is an outstanding implementation of this work.