Improving Moisture Resistance/Control of Pavement Foundation Systems via Engineered Water Repellency

Revised Interim REPORT for Tasks 1: Initial Memorandum on Expected Research Benefits and Potential Implementation Steps

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CHAPTER 1: INTRODUCTION

1.1. RESEARCH PROJECT ABSTRACT AND OBJECTIVES

Water is the source of virtually all problems with subgrades and pavement systems. This project is primarily about controlling water in pavement foundation layers for increased pavement performance. As such we will obtain insight on all aspects of pavement performance including deformation and durability as a function of traffic loading and environmental effects. A highlight of the project is the focus on frost action which is a useful starting point from which to consider the full spectrum of geotechnical behavior. Pavements in northern plains are routinely subjected to seasonal freeze-thaw (F-T) cycles, resulting in extensive damage from frost-related problems such as frost heave, frost boils, thaw settlement, thaw weakening, rutting, and potholes. The damage increases maintenance costs and adversely affects public safety and mobility. Many states have been searching and developing new methods to overcome the negative impact of F-T cycles on roadways.

There have been many different approaches to minimize the negative impacts of soil F-T cycles. While some of these techniques have had success, their applicability and efficiency are limited, particularly within frost-susceptible (e.g., silt rich) subgrade soils. As an alternative, this study proposes to make subgrade soils water repellent via the use of nanoscale organo-silane (OS) products as additives to mitigate the damage that occurs due to F-T cycles. It is hypothesized that water repellent additives in pavement foundation layers (subgrade in particular) will prevent the migration of water from ground water or other sources during freezing conditions. This, in turn, reduces ice formation and minimizes the F-T damage to pavement systems.

The overarching research objective of this project is to evaluate the use of OS to control water and increase subgrade and overall pavement performance. It will also explore the extent to which OS can mitigate frost heave-thaw settlement and thaw weakening of frost susceptible pavement foundation layers. This will be achieved through the completion of four objectives: (1) collect both subgrade soils and OS materials, (2) develop a viable treatment design for field construction; (3) construct test sites with OS and without OS (control) and evaluate their geomechanical (e.g., stiffness, strength, F-T durability) and environmental (e.g., temperature, moisture, and matric suction) performances; and (4) collect data and calibrate numerical models. Advanced technologies provided as a match to the project will be used, including Light Detection and Ranging (LiDAR) and shape array sensors (SAS).

1.2. ORGANIZATION OF THE MEMO

This memorandum consists of three chapters: (1) introduction, (2) benefits of this research, and (3) the implementation process.

CHAPTER 2: EXPECTED RESEARCH BENEFITS

2.1. HOW DOES THIS RESEARCH BENEFIT TAXPAYERS OF NRRA DOT MEMBERS?

The benefits of the proposed research include an increased understanding of moisture sensitivity and F-T performance of pavement foundations systems that are treated with commercially available water repellent agents (OS) and the improvement in the service life of paved roads. Other benefits the NRRA states will receive from the results and conclusions of this research include: (1) longer pavement service life; (2) conservation of natural resources resulting in reduced environmental impacts; and (3) reduced operation/maintenance costs. The outcome of this research in the form of a pavement design specification can be immediately implemented by the departments of transportation (DOTs) of states participating in National Road Research Alliance (NRRA).

2.2. INITIAL PROJECTION OF EXPECTED BENEFITS

The following benefits are initially expected to be accomplished by end of this project:

- **Decrease Engineering/Administrative Costs:** Reduce the planning and subsequent design cost of transportation infrastructures
- **Lifecycle:** The water repellent treated subgrade soils will significantly improve the life-span of stabilized roadbeds when subjected to coupled environmental conditions
- **Operation and Maintenance Savings:** Limit the future distresses on transportation infrastructures by comprehensively studying the performance of the water repellent treated soils under coupled loads and subsequently reduce the need for future site maintenance and associated labor and equipment costs
- **Reduce Risk:** The coupled durability analyses would provide valuable inputs on the performance of treated geomaterials which will minimize the risk of failure of pavement foundation due to extreme environmental conditions
- **Safety:** Minimize the collision risk between maintenance equipment and public vehicles during maintenance
- **Technology:** This project will provide a clear basis on whether and how to scale the water repellent use technology for broader use in pavement applications

2.3. EXPECTED TECHNICAL OUTCOME

The following items below will be provided at the end of this study:

- A database including the index and engineering properties of materials that will be used in this study.
    - Index and compaction data
        - Material type
        - General gradation characteristics
        - Atterberg limits
        - Specific gravity
        - Maximum dry unit weight and optimum moisture content
    - Engineering properties (per laboratory testing)
        - Contact angle
    - Engineering properties (per field testing)
        - Sensitivity to moisture and temperature changes
        - Deformation
        - Elastic modulus
- Provide the optimum mix design for using water repellent agents (OS) in pavement foundation systems

- Develop a model to predict the extent to which OS inclusion: (1) impacts the maximum frozen soil depths; and (2) delays freezing of soils, frost heave, and strength loss, across a range of climate conditions and soils with specific characteristics
- Final Report

CHAPTER 3: POTENTIAL IMPLEMENTATION STEPS

3.1. SUMMARY OF RESEARCH METHODOLOGY (SCOPE)

The research plan of this study includes evaluation, material collection and analyses, field construction and monitoring, and numerical modelling. It mainly contains four phases: (1) collection of subgrade, base and OS materials; (2) building and monitoring field test cells (OS-treated and untreated pavement systems) to evaluate the effects of hydrophobicity on pavement performance; (3) conducting a thorough numerical modelling to quantify/predict the performance of the OS-treated and untreated pavement systems; and (4) providing a guideline to use similar stabilizers for such applications.

Recent efforts of the PIs have shown that the integration of OS products in soils have improved their F-T resistance. However, the efficiency and constructability of this approach requires study and development. To that end, a field study and modeling effort is proposed to better understand the use of OS in subgrade applications and its impact on the F-T resistance of roadways. Such a study would help NRRA states by demonstrating the potential of this new method for general performance enhancement as well as F-T damage mitigation to pavement systems.

The duration of this project is estimated to be 24 months, and it benefits from significant support from a complementary National Science Foundation (NSF) funded study led by the PIs. The purpose of this project is to construct test sites with and without OS and conduct field tests and modeling analyses. Laboratory tests will evaluate soil index properties, indicators of water repellency, and frost action. Field test results will be integrated with F-T models. These models will then be used to predict the effectiveness of using OS to improve pavement foundation system performance. The proposed research, in conjunction with ongoing research by the PIs, will provide a clear basis on whether and how to scale the technology for broader use in pavement applications. The PIs have already completed laboratory and field tests on this technology and are well-positioned to explore its performance in the MnROAD facility.

3.2. IMPLEMENTATION

Implementation of each task is shown below:

- Under Task 2, subgrade soils from MnROAD were collected. Based on the PI`s previous laboratory results, it has been decided to focus on one commercially available OS product. It should be noted that subgrade soils should have a high SiO_2 content to be able to bind well with OS materials. Therefore, it is important to determine the chemical characteristics of subgrade soils. Thus, the subgrade soil samples are air-dried for both physical and chemical laboratory analyses. Samples will be analyzed by X-ray fluorescence (XRF) using a Bruker S4 PIONEER – a 4 kW wavelength dispersive X-ray fluorescence spectrometer (WDXRF) to determine the SiO_2 and other oxide contents of the subgrade soil. In addition, particle size distribution of the subgrade soils will be determined via sieve analysis and hydrometer analyses (ASTM D6913). The specific gravity (G_s) of the subgrade soil will be measured in accordance with ASTM D854. Liquid limit and plastic limit of all the materials will be determined in accordance with ASTM D4318. Moreover, the subgrade soil collected will be treated with different OS products at different concentrations to determine the impact of OS concentrations on hydrophobicity levels of the selected subgrade soil. Contact angle and water droplet penetration time tests will be conducted on the OS-treated subgrade samples to select the minimum treatment level resulting in the maximum reliable water repellency. The research team will develop relationships that are not a function of the chemical (per se), but rather the resulting hydrophobicity. The chemicals will be prepared at varying dosages to achieve a range of contact angles in the hydrophobic range (e.g., > 90°) when mixed with subgrade soils.

- Under Task 3, two identical roadway sections were built (one with selected OS and concentration and one with no treatment) at MnROAD facility in Fall 2023. The research team would summarize as-built details of both sections (e.g., thickness of each pavement layer, width, material types used along with the locations of temperature, moisture, shape array, and matric suction sensors). All sensors were provided by University of North Carolina-Charlotte, as well as their installation. OS treatment were applied on the subgrade layer. It is important to install the sensors mentioned above at least every 6 inches in depth from the top of the base layer to 4 ft depth into subgrade to observe the full temperature and moisture profile during monitoring. The sensors were placed at the center of the pavements.

  During field testing, frost penetration depth, number of F-T cycles, and heaving/settlement caused by F-T actions will be monitored. The instrumentation plan will involve a redundant array of sensors to measure total suction, moisture content, temperature, and SAS to measure frost heave and thaw settlement. Data will be collected and uploaded for continuous monitoring from both sections simultaneously.

  During construction stage, the research team conducted light weight deflectometer (LWD), and falling weight deflectometer (FWD) (if available at MnROAD) tests on each test section. Both base and subgrade samples were collected to determine the index properties of the materials.

  Under this task, the research team will analyze the FWD test results, evaluate the pavement surface conditions [e.g., international roughness index (IRI), rutting] and measure the frost heave and thaw settlement (e.g., LiDAR and SAS). In addition, using the field-collected temperature and moisture data, the number of F-T cycles and the frost depth of each test section will be determined. From the analyses of the data, the research team plans to determine the number of F-T cycles of the base and subgrade layers for each year as well as in total. Such data will be used to evaluate the impact of the utilization of OS on the following parameters: (1) F-T cycles and frost depth; (2) moisture variation; and (3) variation of elastic modulus with F-T cycles. After completion of the previous tasks, the research team will summarize the findings from the field and conduct analyses of the results. Based on the data analyses, a detailed review will be done and recommendations on the best construction practices will be provided.

- Under Task 4, we will model the efficiency of the use of OS varies under a broader range of spatial and temporal conditions, especially in terms of the rate and duration of freezing and thawing, as well as scale effects not observed in the laboratory. Modeling of the complex thermo-hydro-mechanics of the freezing and thawing will be conducted in response to climatic inputs. The PIs intend to calibrate field test results with one of the preferred (COMSOL, Plaxis etc.) platform [(which will be discussed with the Technical Advisory Panel (TAP)] and then use these models to predict future behavior of these designs. The field results obtained in this work will be used to inform models. These models will help predict the extent to which OS inclusion: (1) impacts the maximum frozen soil depths; and (2) delays freezing of soils, frost heave, and strength loss, across a range of climate conditions and soils with specific characteristics. In this task, the measured soil and climate data will be utilized as input into the multi-physics modeling software that will be selected/decided. This model will be calibrated and then used to evaluate efficacy under other conditions, including design (OS treatment, subgrade thickness), loading (weight/frequency), and weather/site conditions (temperature, access to moisture.

- Tasks 5, 6, 7 will provide all results and recommendations of the durability test method that most effectively considers all seasonal environmental conditions, mimics field durability conditions, and provides soil condition parameters that may lead to early pavement failures following extreme weather events. They will also include key steps that agencies could take to implement the research.