2023 NRRA Call for Innovation

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

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Budget: $330,000 (NRRA+Partnership)

NRRA funds = $200,000

Partnership (donated) funds = $130,000

Submission Date: May 5, 2023

Type of Submission: (use one that applies from below on this line and delete the rest)

- X Call for Construction
- ☐ Research/Implementation Need
- X NRRA Project Proposal
- ☐ Other

Research/Implementation Impact:

Water is the source of virtually all problems with subgrades and pavement systems. This project is primarily about controlling water for increased performance. As such we will obtain insight on all aspects of performance including deformation and durability as a function traffic loading. 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. For example, seasonal frost heaving and freeze-thaw weakening have a significant effect on pavements, with estimated yearly costs of over 2 billion dollars (FHWA 1999). Pavements in northern plains are routinely subjected to seasonal freeze-thaw cycles, resulting in extensive damage from frost-related problems such as frost heave, frost boils, thaw weakening, rutting, and potholes. The damage increases maintenance costs and adversely affects public safety and mobility. The current findings from an article published by the Transportation Research Board`s 2019 State Partnership Visits Program observes that many states, especially in northern plains (e.g. Minnesota, Iowa, North Dakota), have been searching and developing new methods to overcome the negative impact of freeze-thaw cycles on roadways.

There have been many different approaches to minimize the negative impacts of soil freeze-thaw 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 use of nanoscale-organo-silane (OS) products as additives to mitigate the damage that occurs due to freeze-thaw 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, prevents ice formation and minimizes the freeze-thaw damage to pavement systems. Recent efforts of the PIs have shown that the integration of these materials in soils have improved their freeze-thaw 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 freeze-thaw resistance of the roadways. Such a study would help NRRA states by demonstrating the potential of this new method for general performance enhancement as well as freeze-thaw 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 sites with OS and conduct field tests and modeling analyses. Laboratory tests will evaluate soil index properties, strength, indicators of water repellency, and frost action. Field test results will be integrated with freeze-thaw 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. This project will help answering certain questions including (but not limited to); (a) what is the long-term performance OS in pavement foundation systems?; and (b) what are the best practices to use for installation of OS during construction of pavement foundation layers?

Objective and Scope:

The overarching research objective of this proposal is to evaluate the use of organo-silane (OS) to control water and increase subgrade and overall pavement system performance. It will also explore the extent to which OS can mitigate frost heave-thaw settlement and freeze-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 (as well as control) and evaluate their geomechanical (e.g., stiffness, strength, freeze-thaw 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).

Tasks:

Task 1 – Material Collection & Analyses

- **Description** – Subgrade soils from MnROAD will be collected. Based on the PI`s previous laboratory results, it is decided to focus on one commercially available 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 before OS treatment. Thus, all subgrade soil samples will be air-dried for both physical and chemical laboratory analyses. Samples will be analyzed by X-ray diffraction (XRD) using a Siemens D500 X-ray diffractometer equipped with a diffracted beam monochromator and a sample spinner 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 D422). The specific gravity (G_s) of all soils will be measured in accordance with ASTM C311. Liquid limit and plastic limit of all materials will be determined in accordance with ASTM D43187. Moreover, subgrade soil collected will be treated with different OS at different concentrations to determine the optimum design mixtures that will be implemented in the field demonstration test sections. Contact angle and water droplet penetration time tests will be conducted on 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^o) when mixed with subgrade soils.
- **Deliverable** - A full soils report to complement the growing database of information
- **Cost** - $70,000

Task 2 – Construction of Field Test Sections/Development of Field Testing Plan/Monitoring at MnROAD

- **Description** - Two identical roadway sections will be built (one with selected OS and concentration and one with no treatment) at MnROAD facility in summer 2024 (Figure 1). The research team will 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 will be provided by University of North Carolina-Charlotte, as well as their installation. OS treatment will be applied on subgrade layer. It is important to install the sensors mentioned above at least every 6 inches in depth from top of base layer to 8 ft depth into subgrade to observe the full temperature and moisture profile during monitoring. It is also recommended to place these sensors at the center and edge of the pavements.

During construction stage, the research team will conduct the following tests on each test section DCP, LWD, and FWD results. FWD tests will be conducted before and after the surface layer (either rigid or asphalt) is built. Field tests proposed to be collected every 50 ft in all test cells. In addition, both base and subgrade samples will be collected to determine index properties of the materials.

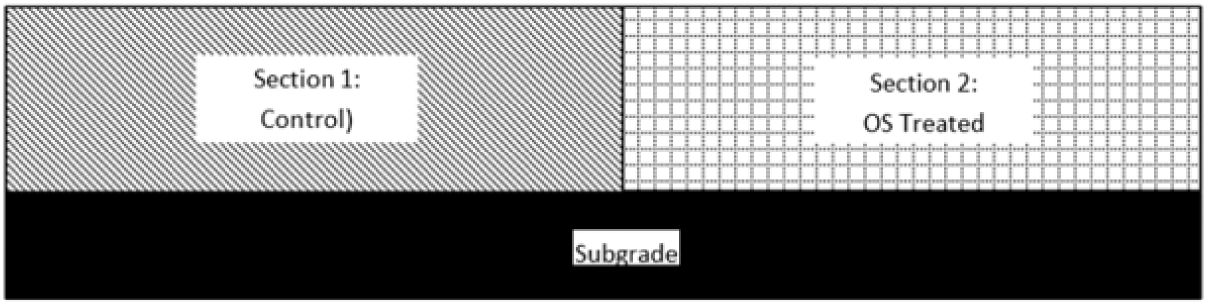

Figure 1. Schematic diagram of proposed test sections

Under this task, the research team will analyze the FWD, pavement surface conditions (e.g., IRI, rutting) and frost heave-thaw settlement measurements (e.g., LiDAR and SAS). In addition, using the field-collected temperature and moisture data, the number of freeze–thaw (F-T) cycles and the frost depth of each test section with depth will be determined. From the analyses of this data, the research team plans to determine the number of F-T cycles of base and subgrade layer 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 the F-T cycles. After completion of previous tasks, the research team will summarize the findings from the field and conduct analyses on the results. Based on the data analyses, a detailed review will be done of pavement performance data and recommendations on the best construction practices will be provided.

- **Deliverable** - Construction monitoring and testing report, long -term field test results report & presentation
- **Cost** – $120,000

Task 3 – Modelling

- Description - Modeling will evaluate the extent to which 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 soil will be conducted in response to climatic inputs. The PIs intend to calibrate field test results with the COMSOL Multiphysics platform 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, COMSOL. 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).
- **Deliverable** - The results will be a calibrated model that can make informed predictions
- **Cost** – $120,000

Task 4 – Final Report

- Description - Three months prior to the end date, the research team will submit the draft final report documenting all tasks completed, conclusions, and recommendations along with the curated data in Excel files for future use, analysis, and interpretation. The final report will be submitted to the project TAP members. Their feedback will be incorporated into the final report.
- Deliverable – Final report & presentation
- **Cost** - $20,000

Schedule:

The proposed schedule for this proposal is 24 months

Task	Month, Beginning 7/1/2023																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	■	■	■	■	■	■	■	■																
2									■	■	■	■	■	■	■	■	■	■						
3																	■	■	■	■				
4																					■	■	■	■

Budget/Partnerships:

Expected from NRRA – $200,000
Expected from (MSU & UNCC) - $65k from MSU (this is a 12 months full funding for a PhD student from MSU) and $65k from UNCC (this includes entire instrumentation cost such as thermocouples, shape array sensors, moisture and matric suction sensors, and data acquisition system, travel, part time student cost) (total cost share from the research team is $130,000).

Implementation of Results:

The proposed innovation is a new process for mitigating frost damage in pavement systems. Because OS is primarily a technology that controls infiltration and suction, it has relevance to all pavement systems, with potential benefits in terms of increased strength, decreased volume change, and longer-term performance. For example, OS has been shown to reduce swelling which could be applied to pavement systems where subgrade soils have high swelling-shrinking potential (e.g., Texas).