Calcium-Based Stabilizer Induced Heave in Oklahoma Sulfate-Bearing Soils

ANNUAL REPORT FOR FY 2009

ODOT SPR ITEM NUMBER 2210

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Problem Statement: ***To advance the understanding of, and ability to effectively design and construct roadway sub-bases on and with, sulfate bearing soil and shale deposits***

Lime and other calcium-based stabilizers are added to soils in order to reduce their plasticity, increase their shear strength, reduce their compressibility, and reduce their tendency to undergo volume change when subjected to variations in water content. In simple terms, additives like lime render highly plastic expansive soils non-plastic and non-expansive. However, when a calcium-based soil stabilizer is added to soil containing soluble sulfate the resulting reactions can have the opposite effect and actually make the volume change tendencies much more devastating. An example of such devastation was realized on a recently constructed Oklahoma State Highway, where due to what appears to be sulfate-induced heave in lime stabilized soil, miles of new pavement were destroyed resulting in the loss of millions of dollars.

Soils and shales containing gypsum are common in Oklahoma; gypsum is a primary source of soluble sulfate. Generally, when soils/shales containing soluble sulfates are mixed with calcium-based stabilizers and given access to water, there is the potential for significant increases in soil volume (swelling) due to the formation of calcium-aluminum-sulfate-hydrate minerals such as ettringite. When soluble sulfates are present and stabilization is required, measures must be taken to counter the adverse effects of adding a calcium-based stabilizer. Such measures typically aim at promoting and accelerating the adverse reactions in the soil prior to compaction. For example, this might include using a prolonged mellowing period (typically 3 to 7 days) after mixing and prior to final compaction, providing plenty of water to promote the reactions during mixing (typically 3 to 5 percentage points above optimum), and providing additional water during mellowing and curing. Another option that ODOT utilizes when working in sulfate-bearing soils is to put down a twelve-inch select topping overtop of the existing sub-grade, however, during grading process, the sulfate-bearing soils get mixed in with the select topping and the same problems can occur. Finally, stabilization with a calcium based stabilizer may be ruled out as a viable option should the potential for sulfate-induced heave be too great.

2.0 Objectives

The overriding goal of this research is to reveal the physical, mineralogical, electrical, and chemical characteristics of Oklahoma soils that are vulnerable to adverse sulfate reactions due to calcium-based stabilizers. In achieving this goal, a methodology for assessing this threat will be developed, we will critically evaluate ODOT's current method of soil-sulfate testing to determine the most accurate and repeatable soil sulfate test methodology possible, the database of Oklahoma sulfate-bearing soils will be enhanced and presented in the form of an interactive "sulfate hazard" map, and the likelihood of costly pavement failures in future soil stabilization projects will be greatly reduced. The research goal will be achieved through a detailed study of clay mineralogy/chemistry and physical characteristics of several natural sulfate-bearing clay soils from Oklahoma. In addition, the mechanical response of these soils to calcium-based stabilizer treatment and saturation with water will be examined using the oedometer. In this way, the link between chemical and/or physical indicators and heave

susceptibility can be identified. Specific research objectives and associated tasks for the proposed research are as follows.

Objective A: *Determine an accurate, repeatable and economical soil sulfate test methodology.*
Task A.1: With the experience gained in our previous year-long project, formulate and validate an improved soil sulfate test methodology to be used by ODOT.

Objective B: *Collect and characterize selected sulfate bearing soils in Oklahoma.*
Task B.1: Through consultation with ODOT personnel, identify soils containing sulfates and obtain sufficient samples to add to the testing program and soil database and collect available information on the geology and soil properties of test site locations.
Task B.2: Conduct basic index property and physical property tests on test soils.
Task B.3: Conduct laboratory tests to determine the electrical and chemical properties of test soils.
Task B.4: Conduct free swell tests on selected compacted test soils in an oedometer apparatus with and without calcium-based stabilizer additive.
Task B.5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences.

Objective C: *Create an interactive "sulfate hazard" map that can be used by ODOT when roadway stabilization projects are planned by the end of the second year.*
Task C.1: Compile basic information about each testing site such as aerial and ground pictures, boring logs, and soil index parameters and mechanical response results into a central database that will form the basis for the interactive, online soil-sulfate hazard map.
Task C.2: Create and continually update the interactive map and make available to all online.

Objective D: *Identify soil properties that are indicators of severity of sulfate induced heave caused by calcium-based stabilizers by the end of the second year.*
Task D.1: Use the centralized sulfate-soil database compiled for Objective C, for a multivariable parameter (ANOVA) analysis and statistically examine the relationship between *individual* soil properties and *combinations* of soil properties and volume change behavior measured in the laboratory in both the natural and manufactured soils.
Task D 2: Validate the statistically determined relationships with additional test soils.

Proposed Activities for FY10:

We are still working on determining a viable, accurate, soil sulfate test methodology and will hopefully be able to present our results of this extensive study by May 2010. We are currently working on Tasks A1 and B5, and will soon move onto Tasks B1-B4, Tasks C1-C2 and Tasks D1-D2.

September 2009

Work in Progress

The following tasks are a work in progress:

- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a CEES graduate student, is currently performing a new test method for the detection of sulfate using multiple washes of Na_2CO_3 to remove the sulfate from the soil sample. This test has been modified to acidify the wash mixture with a 1:1 ratio of HCl to Na_2CO_3, so that the Na_2CO_3 does not react with $BaCl_2$ to form $BaCO_3$, a white precipitate. After acidifying the Na_2CO_3, the sample is tested with $BaCl_2$ to detect the presence of sulfate. The new test will be compared with the colorimetry.
    - Preliminary tests show improved sulfate detection. Michaela is concentrating on repeatability.
- Task B5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences. Michaela Campbell is also working on free swell oedometer tests on Hickory clay soil with sulfate.

Problems Encountered

- Colorimeter readings of final wash solution are not very accurate, so we are working on a way to verify if the new test method is pulling more or all of the sulfate out of the soil.

August 2009

Work in Progress

The following tasks are a work in progress:

- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a CEES graduate student, is currently performing a new test method for the detection of sulfate using multiple washes of Na_2CO_3 to remove the sulfate from the soil sample. The sample is then tested with $BaCl_2$ to detect the presence of sulfate. This test will be modified to acidify the wash mixture. The new test will be compared with the colorimetry. Preliminary tests show improved sulfate detection. Michaela is concentrating on repeatability.
- Task B5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences.
- Michaela Campbell is also working on free swell oedometer tests on Hickory clay soil with sulfate.

July 2009

Work in Progress

The following tasks are a work in progress:

- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a CEES graduate student, is currently performing a new test method for the detection of sulfate using multiple washes of Na_2CO_3 to remove the sulfate from the soil sample. The sample is then tested with $BaCl_2$ to detect the presence of sulfate. This test will be modified to acidify the wash mixture. The new test will be compared with the colorimetry. Michaela is concentrating on repeatability.
- Task B5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences.
- Michaela Campbell is also working on free swell oedometer tests on manufactured soil with sulfate.

Problems Encountered

- Burn test is not accurate due to components other than sulfate being burned off. This test cannot be used.
- There is a problem with the new test using the wash method because the Na_2CO_3 combines with the $BaCl_2$ to form $BaCO_3$, which is a white precipitate, like $BaCl_2$ and sulfate.

June 2009

Work in Progress

The following tasks are a work in progress:

- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a CEES graduate student, is currently performing colorimetry and burn tests on a manufactured soil with known concentrations of sulfate, to determine if the tests are reporting accurate concentrations of sulfate. The burn tests will be compared to the ODOT standard colorimetry test. Also, the ODOT standard colorimetry test is being modified to determine if sulfate dissolution is time dependent and concentration dependent. She is concentrating on repeatability.
- Task B5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences.
- Michaela Campbell is also working on free swell oedometer tests on blank manufactured soil and manufactured soil with sulfate.

May 2009

Work in Progress

The following tasks are a work in progress:

- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a CEES graduate student, is currently performing colorimetry and burn tests on a manufactured soil with known concentrations of sulfate, to determine if the tests are reporting accurate concentrations of sulfate. The burn tests will be compared to the ODOT standard colorimetry test. Also, the ODOT standard colorimetry test is being modified to determine if sulfate dissolution is time dependent. She is concentrating on repeatability.
- Task B5: Conduct free swell tests on carefully prepared and controlled manufactured single mineral and mixed mineral compacted soils in an oedometer

apparatus, with and without sulfate and with and without lime to try and isolate ettringite formation from other soil parameter heave influences.
- Michaela Campbell is also working on free swell oedometer tests on blank manufactured soil and manufactured soil with sulfate.

April 2009

Work in Progress

The following tasks are a work in progress:
- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology.
- Michaela Campbell, a senior CEES student, continues to work on burn tests and acid tests and comparing them to the ODOT standard colorimetry test. She is concentrating on repeatability.

Additional Comments

- Site visit from Chris Westlund, ODOT Planning and Research Division, on Wed., April 1, 2009.
- He met with the students working on various ODOT-sponsored projects, toured the lab, and learned general progress updates.

March 2009

Work in Progress

The following tasks are a work in progress:
- Task A1: Determine an accurate, repeatable and economical soil sulfate test methodology by the end of the first year
- Michaela Campbell, a senior CEES student was hired to start work on this project in late February 2009. She has been working on burn tests and acid tests and has been hired as a graduate student and will start her M.S.C.E. degree in June. Her thesis topic is the same as this ODOT project.

Additional Comments

- Site visit from Chris Westlund, ODOT Planning and Research Division, on Wed., March 4, 2009.
- He met with the students working on various ODOT-sponsored projects, toured the lab, and learned general progress updates.