TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 0-4240-S
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Project 0-4240: Develop Guidelines and Procedures
for Stabilization of Sulfate Soils

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Identification, Quantification, and Stabilization of Sulfate-Bearing Soils in Texas

PROJECT SUMMARY REPORT

Over the last 15 years, the Texas Department of Transportation (TxDOT) has seen an increase in pavement failures during and immediately after construction on roads designed to last 20 years or more (see Figure 1). The cause of many of these failures is sulfate-induced heave where an expansive mineral called ettringite (see Figure 2) is formed from a calcium-based stabilizer (lime or cement) reacting with clay and sulfate minerals (usually gypsum) in the soil (see Figure 3).

Traditionally, TxDOT has removed and replaced soils with more than 2000 ppm sulfates, which can be quite expensive. This project focused on four main objectives:

1. identifying sulfates prior to construction;
2. determining the highest sulfate concentration that can be treated with lime using normal construction techniques;
3. evaluating the effectiveness of alternative construction practices for calcium-based stabilizers

Figure 1. Vertical Heaves Generated during Construction of US 67 near Midlothian.

aimed at reducing swell in high sulfate soils (these practices include extended mellowing, double lime application, and increased field moisture contents); and

4. identifying the maximum sulfate concentration that can safely be treated with calcium-based stabilizers and what alternative stabilizers can be used in subgrade soils with very high sulfate levels.

What We Did...

Texas Transportation Institute (TTI) researchers began this project by evaluating two laboratory procedures for measuring sulfates, namely test method Tex-620-J, a gravimetric approach, and ion chromatography. Soil samples were fabricated in the laboratory with known sulfate contents and submitted to TxDOT and several private labs for analysis.

Additionally, efforts were made to identify potential sulfate problems prior to construction. The Geologic Atlas of Texas (GAT) provides a mineralogical description of rocks at any site where a construction project may be
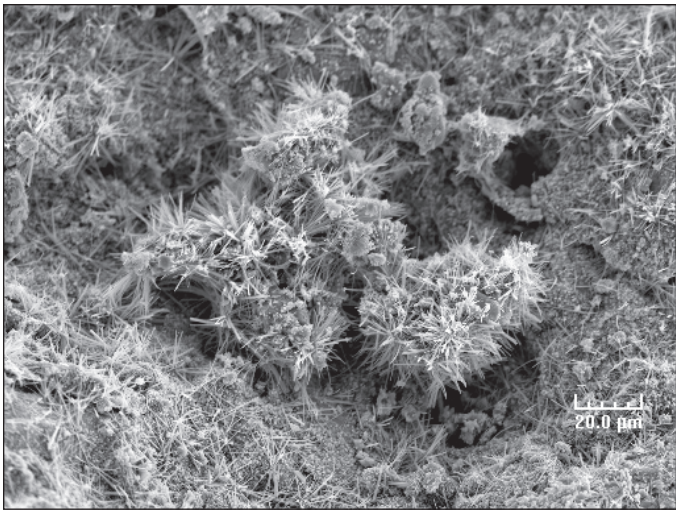
Figure 2. Scanning Electron Microscope Image of Ettringite.

Figure 3. Scanning Electron Microscope Image of Very Small Gypsum Crystals.

placed (see Figure 4). Consulting the geologic atlas can reveal areas where sulfate minerals are located prior to any testing. Sulfate swell problems are frequently localized, so four rapid field tests for identifying sulfates in soils were evaluated.

To determine what concentrations of sulfate are too high for stabilization with lime in Texas, a soil from the Vertisol order that contained no detectable sulfates was selected for three-dimensional (3-D) swell measurements. Two different sulfate compounds were added to the soil: sodium sulfate (Na_2SO_4) and gypsum ($CaSO_4 \cdot 2H_2O$). Samples containing sulfate concentrations of 0, 1000, 2000, 3000, 5000, 7000, and 12,000 parts per million (ppm) were then subjected to a 3-D swell test for a minimum of 45 days.

Using TxDOT construction constraints, researchers identified lime as a plausible stabilizer in soils bearing up to 7000 ppm sulfates. To determine if anything can be used to stabilize soils (reduce swell and increase strength) with sulfate concentrations above 7000 ppm, 3-D swell was measured on laboratory-prepared specimens

with sulfate concentrations of 0, 10,000, and 20,000 ppm. Twelve nonstandard stabilizers were selected for the 3-D swell testing based upon positive results obtained by other researchers. Stabilizers that significantly reduced swell in the high-sulfate soils were then subjected to unconfined compressive strength (UCS) testing.

In the last phase of this research project, a database was developed of pavement failures due to sulfate-induced heave. Eight case studies located across Texas are discussed in research documentation.

What We Found…

In terms of both accuracy and repeatability, the researchers found that the ion chromatography approach is superior to TxDOT Test Method Tex-620-J. Many steps were identified in the TxDOT procedure where error could be introduced.

Two of the four rapid field tests provided excellent results in measuring sulfate concentrations in the soil. The conductivity test was identified as a rapid test (can get results in 3 minutes) that can be used to identify potential problem

areas (see Figure 5). In soils with high conductivities, the researchers discovered that the colorimeter does an exceptional job of measuring actual sulfate content in ppm. This test, however, requires about 30 to 45 minutes to run and would be better suited to the field office.

Results of the systematic swell experiments revealed the following about the effectiveness of alternative construction practices for calcium-based stabilizers:

- sulfate contents up to 3000 ppm can safely be treated with traditional lime stabilization,
- coarse-grained sulfates take longer to swell and form deleterious reaction products,
- mellowing effectively treats sulfate concentrations up to at least 7000 ppm (mellowing is where the stabilizer is added to the subgrade and allowed to cure for a specified amount of time prior to compaction),
- higher molding moisture contents (2 percent above optimum) reduce swell better than optimum moisture, and
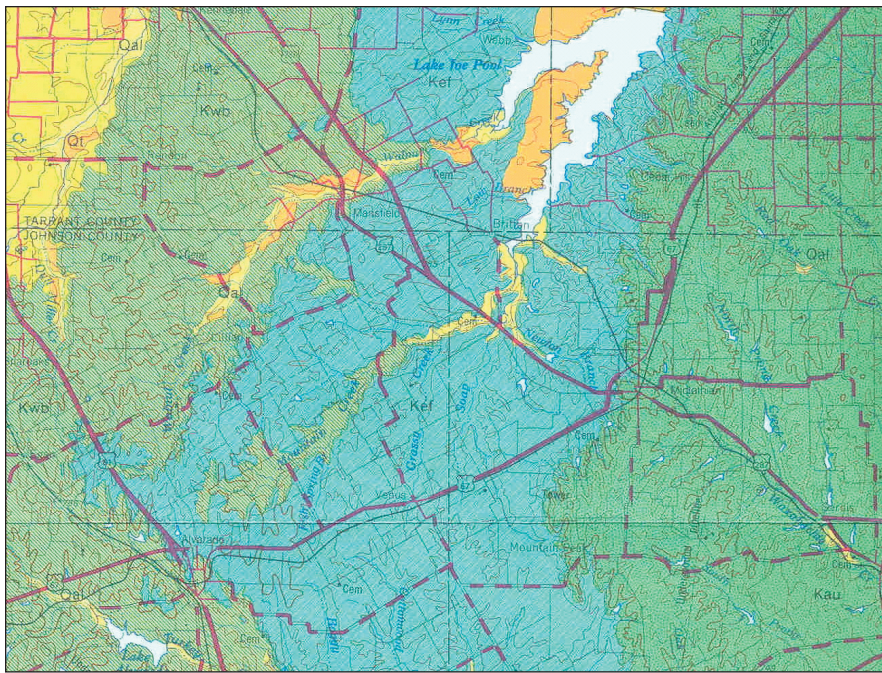
Figure 4. Portion of Geologic Atlas of Texas Showing US 67 West of Midlothian Passing through the Eagle Ford Formation (in Blue).

Figure 5. Conductivity Meter Used for Quick Field Test of Sulfates, Tex-146-E.

• single application of lime reduces swell better than double application.

In soils with sulfate concentrations too high to be treated with traditional calcium-based stabilizers (> 7000 ppm), three nonstandard stabilizers (Claystar7, ground granulated blast furnace slag [GGBFS] + lime, and class F fly ash + lime) were evaluated at sulfate concentrations in excess of 20,000 ppm sulfates. Each of these stabilizers provided significant swell reduction (10 to 12 percent) over the untreated soil; two of the stabilizers were selected for strength testing. The fly ash swell test results were obtained too late to include in strength testing. The Claystar7 showed an improvement of 41 lb/in^2 over the untreated sample for retained strength in the unconfined compressive strength after 10 days capillary rise test. The ground granulated blast furnace slag showed a 79 lb/in^2 retained strength.

In field testing, the Claystar7 and the ground granulated blast furnace slag + lime mixtures were evaluated on three soils containing sulfates in excess of 20,000 ppm. The Claystar7 showed improvement in strength but did not reduce swell over the long term. A mixture of ground granulated blast furnace slag and lime increased strength and reduced swell in all high-sulfate soils tested.

The Researchers Recommend...

Based on findings over the last four years from this research project, a general protocol for evaluating sulfate soils has been established. During the planning stages of a highway project, the engineers need to look at geologic maps of areas where a project is slated to be placed. The GAT has identified 75 percent of the sulfate-prone areas. If the GAT does not show problems on your project, the researchers recommend doing a field evaluation that includes visual observation and running the rapid field tests for sulfates (Tex-145-E and Tex-146-E).
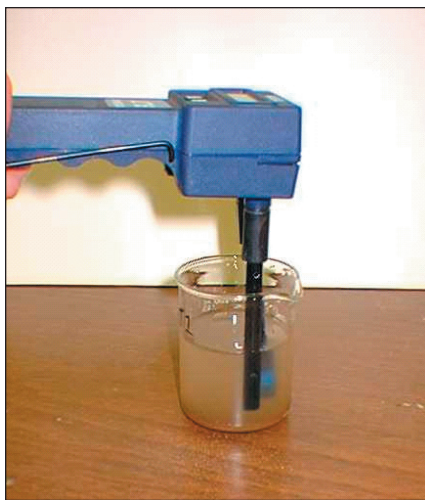
Once sulfates have been identified in a project, it is critical to determine the source and concentration of the sulfate. For sulfate concentrations below 3000 ppm, normal construction with calcium-based stabilizers can be used. If the sulfate concentration ranges between 3000 and 7000 ppm, then revised construction techniques like mellowing, single lime application, and adding water 2 percent above optimum should be evaluated. At sulfate concentrations above 7000 ppm, alternative stabilizers like GGBFS + lime and fly ash + lime need to be investigated.

An economic analysis should be done to compare the expense of stabilizing with alternative stabilizers to removing the subgrade and replacing it with a select material. If the plasticity index is 30 or higher, the removal and replacement cost starts to exceed most stabilization treatments.

For More Details...

Research is documented in the following reports:

Report 0-4240-1: *Laboratory and Field Procedures for Measuring the Sulfate Content of Texas Soils*
Report 0-4240-2: *Hydrated Lime Stabilization of Sulfate-Bearing Soils in Texas*
Report 0-4240-3: *Recommendations for Stabilization of High-Sulfate Soils in Texas*
Report 0-4240-4: *Database of Sulfate Stabilization Projects in Texas*

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