Stabilizing Sulfate-Rich Soils Using Traditional Stabilizers: A Continuing Case Study of State Highway 289 in Grayson County, Texas

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ABSTRACT
Because of the risk of sulfate induced heave, the Texas Department of Transportation (TxDOT) has limited the use of traditional, calcium-based stabilizers on construction projects where sulfate concentrations exceed 8,000 parts per million (ppm). Beyond that limit non-traditional additives must be evaluated for use, or the material must be removed and replaced with a select material with acceptable sulfate concentrations. Significant sulfate concentrations were encountered on the State Highway (SH) 289 extension project in October, 2008 during the construction of the 8-inches of lime stabilized subgrade. Due to the limited availability of both non-traditional stabilizers and select replacement material, and after extensive laboratory testing, these sulfate-rich subgrade soils were successfully stabilized with lime using alternative construction techniques. These alternative techniques included extended mellowing and additional pulverization of the stabilized subgrade. Performance monitoring was conducted on the SH 289 project in the Spring of 2010. Non-destructive test methods, such as inertial profiler, falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP) were utilized in order to evaluate the overall performance of the pavement. TxDOT assisted in the collection of the non-destructive test data. Additionally, lime treated subgrade samples were collected in order to perform follow-up sulfate testing approximately 14 months after stabilization was completed. With a satisfactory overall pavement performance, the results of this study indicate that the construction methods employed on this project provide a viable alternative to removal and replacement on projects with sulfate-rich soils.
INTRODUCTION

Over the past 20 years problems with sulfate induced heave in pavements have surfaced around the world. The first documented sulfate heave problem in Texas occurred at Joe Pool Lake just south of Dallas in the mid 1980’s. Since that failure, several additional failures have occurred during construction. In the past many years sulfate testing of soils has been performed state wide on TxDOT projects involving soil stabilization. By doing this, significant sulfates on at least one project have been reported in many Texas counties. The Eagle Ford shale formation, which passes through the State, is particularly well known for its problematic, sulfate-rich soils. This is shown in Figure 1.

Figure 1. Map of Texas Counties Known to have Sulfate-Rich Soils (1)

Sulfate heave, which typically occurs during or shortly after construction, occurs when traditional calcium-based stabilizers, like lime or cement, are used to stabilize subgrade soils that contain sulfate minerals. The cause of the heaving is due to the formation of a mineral called ettringite, which requires four components to form. These include: the calcium available in the lime or cement, the aluminates available in the soil, the sulfate that occurs in several Texas soils and that is normally present in the form of gypsum, and, finally, water. Ettringite contains a large amount of water in its structure, and the formation of this can lead to increases in volume of up to 200 percent.

Because of this, the Texas Department of Transportation (TxDOT) has limited the use of traditional, calcium-based stabilizers on construction projects where sulfate concentrations exceed 8,000 parts per million (ppm). Beyond that limit non-traditional additives must be evaluated for use, or the material must be removed and replaced with a select material with acceptable sulfate concentrations. (1)

The State Highway (SH) 289 Extension project, located in the Eagle Ford formation shown in Figure 1, was under construction in the fall of 2008 in Grayson County, Texas, when sulfate concentrations in the range of 30,000 to 50,000 ppm were encountered. Due to the limited availability of both non-traditional stabilizers and select replacement material, and after extensive laboratory testing, these sulfate-rich subgrade soils were successfully stabilized with lime using alternative construction techniques. (2)

Performance testing was performed on the SH 289 project during the Spring of 2010. As part of this testing, TxDOT assisted by providing some of the performance tests, such as inertial profiling, falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP). Additionally, lime-treated subgrade samples were collected to test sulfate levels 1 year after the completion of the lime stabilization.
BACKGROUND

Significant sulfate concentrations were encountered during the construction of the 8-inches of lime stabilized subgrade and were observed along the project. These pockets of sulfates included gypsum crystals in a broad range of concentrations and sizes. Some examples of the variety of sulfate concentrations and crystal sizes observed on the project are shown in Figure 2.

Figure 2. Variety of Sulfate Concentrations and Crystal Sizes Observed at Various Locations

2a. Station 277+00  2b. Station 425+00  2c. Station 425+50  2d. Borrow Pit  2e. Station 345+00  2f. Station 372+00

In 2002, TxDOT initiated a research study (4240) with the Texas Transportation Institute (TTI) to find new tools to assist engineers to minimize the risks associated with stabilization of sulfate rich soils. As a result of this research, the following guidelines were adopted by TxDOT: sulfate concentrations below 3000 ppm are considered low risk, concentration between 3000 to 8000 ppm are considered medium risk and require special construction techniques, and concentrations greater than 8000 ppm are considered high risk and lime or cement is not recommended for use. (1)

Test methods also developed under TTI’s research study were employed on the SH 289 project to conduct testing in both the field and the laboratory. These test methods are TxDOT tests methods: TEX-145-E, Determining Sulfate Contents in Soils-Colorimetric Method, and TEX-146-E, Conductivity Test for Field Detection of Sulfates. Testing was conducted at 500-foot intervals on almost 6 miles of the subgrade, which was all located north of US 82. Results of the sulfate testing are shown in Figure 3.

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Prior to the start of the laboratory testing, the subgrade was pretreated with a 3 percent lime slurry application, which was followed by an extended mellowing period. This was done in an effort to reduce construction delays, while the laboratory mix design was being conducted, and in an effort to induce sulfate reactions prior to the placement of subsequent pavement layers.

The ability of the material to be stabilized by was evaluated in the laboratory. Testing was conducted in accordance with the mix design testing developed under TTI project 4240 and was based on an increase in strength and a reduction in volumetric swell. Based on the results of the conductivity testing and sulfate measurements, materials were selected from Stations, 277+00, 307+00, 370+00, and 465+00 to be included in the mix design testing. Samples were treated with a 3 percent lime application in the laboratory and allowed to mellow for 3 days prior to molding to mimic the lime application in the field. The stabilizer contents that were evaluated in the mix design were as follows: 6 percent lime, 4 percent lime + 4 percent class F fly ash, 4 percent lime + 6 percent class F fly ash, and 4 percent lime + 8 percent class F fly ash. A control sample with no additive was also fabricated for comparison. Results of the volumetric swell tests are shown in Figure 4. (2)
While the mix design testing was being performed, additional samples were obtained from the field that had been pre-treated with lime. Sulfate testing was conducted on these samples, and the results were encouraging in that the initial lime treatment and mellowing reduced the sulfate content in the soils to the levels that TxDOT considers low risk. This seemed to collaborate with laboratory findings, where sulfate testing was conducted with time to verify the reduction in sulfate concentrations. For this testing, 3 percent lime was added to the soil samples at optimum plus 2 percent moisture with an additional 1 percent moisture added daily until no further drop in sulfates was realized. Another 3 percent lime was added along with additional moisture after 7 days of testing, and sulfates were monitored for another 15 days. These results are shown in Figure 5.
All of the lime has been placed in the subgrade tested under H&L’s scope of services since late January or early February, 2009. Long-term performance monitoring on the SH 289 project was conducted in March, 2010. As part of the performance monitoring, profile data was collected as well as lime treated subgrade samples in order to perform additional sulfate testing approximately 14 months after stabilization. TxDOT assisted in the testing by providing some of the performance tests, such as FWD and DCP.

PERFORMANCE MONITORING RESULTS (MARCH 2010)

In March, 2010 profile data was collected as well as additional lime treated subgrade samples. These samples were collected in order to perform sulfate testing approximately 1 year after stabilization. Also, TxDOT assisted by providing some other performance tests, such as FWD and DCP.

Profile Data

Pavement roughness is generally defined as irregularities in the pavement surface that adversely affect the ride quality. Roughness is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. The international roughness index (IRI) constitutes a standardized roughness measurement. (3) Profile data was collected in accordance with TxDOT spec item 585, Ride Quality for Pavement Surfaces and the profile data was utilized to evaluate the possibility of the development of sulfate induced heave. Results from the profiling are shown in Figure 6.
Sulfate Testing

Additional samples were also collected in order to monitor sulfate concentrations on the stabilized subgrade. H&L collected these samples at locations where sulfate concentrations had been determined in a previous study. A comparison of concentrations before stabilization and approximately 14 months after stabilization is shown in Table 1. Sulfate concentrations determined 1-2 weeks after lime stabilization are also provided. (All sulfate testing was conducted in accordance with TEX 145-E.)

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Sulfate Concentration Before Lime Stabilization (ppm)</th>
<th>Sulfate Concentration 1-2 Weeks After Lime Stabilization (ppm)</th>
<th>Sulfate Concentration ~ 14 months After Lime Stabilization (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>242+00</td>
<td>5320</td>
<td>1920</td>
<td>1560</td>
</tr>
<tr>
<td>277+00</td>
<td>27680</td>
<td>3300</td>
<td>3120</td>
</tr>
<tr>
<td>345+00</td>
<td>18560</td>
<td>N/A</td>
<td>2980</td>
</tr>
<tr>
<td>465+00</td>
<td>29564</td>
<td>N/A</td>
<td>3970</td>
</tr>
</tbody>
</table>

Dynamic Cone Penetrometer

The DCP is an instrument designed to provide a measure of the in-situ strength of fine-grained and granular subgrades, granular base and subbase materials, and weakly cemented materials. It is used to measure the rate of penetration rate (mm/blow) through the various pavement layers. The California Bearing Ratio (CBR) is then calculated as a function of the penetration rate, which also provides a correlation for the modulus of the in-situ material. Average back-calculated modulus results are shown in Table 2 for various locations.
Table 2. Average Modulus Results from DCP Testing

<table>
<thead>
<tr>
<th>Station</th>
<th>Average Modulus for Stabilized Subgrade (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>242+00</td>
<td>32.6</td>
</tr>
<tr>
<td>277+00</td>
<td>63.4</td>
</tr>
<tr>
<td>345+00</td>
<td>39.8</td>
</tr>
<tr>
<td>465+00</td>
<td>53.2</td>
</tr>
</tbody>
</table>

Falling Weight Deflectometer Testing

The FWD is a non-destructive test that is used to evaluate a flexible pavement structure by applying a force and measuring the surface deflections, which is a function of traffic (type and volume), pavement section, temperature, and moisture. These measurements can then be used to back-calculate layer stiffness (resilient modulus) values.

FWD data was collected in the outside wheel-path of the north and southbound outside lanes. Overall, the modulus values indicate that this pavement is structurally sound. Average back-calculated modulus values are shown in Table 3.

Table 3. Average Back-Calculated Modulus Values

<table>
<thead>
<tr>
<th>Lane</th>
<th>Average Back-calculated Modulus - Subgrade (ksi)</th>
<th>Range of Back-Calculated Modulus Values (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>23.0</td>
<td>11.0 - 43.7</td>
</tr>
<tr>
<td>Southbound</td>
<td>26.7</td>
<td>15.2 - 52.1</td>
</tr>
</tbody>
</table>

DISCUSSION OF RESULTS

There were several causes for concern in regard to the sulfate concentrations on this project. The high range of variability in both field conductivities and actual measured sulfate concentrations demanded extreme caution during construction of the lime stabilized subgrade. Initially, a pre-treatment of the subgrade was suggested with 2 to 3 percent lime slurry, additional moisture, and additional pulverization during the mellowing period. This was done in an effort to induce some of the sulfate reactions, while the lab mix design was being conducted. This was done on a portion of the project followed by an additional application of 3 percent lime slurry. Sampling materials from stations located within this pre-treated section and at stations for which sulfate concentrations had been previously determined provided a promising comparison. (Refer to Figure 5 and Table 1.)

These results were encouraging in that the initial lime treatment and mellowing reduced the sulfate content in the soils to the levels that TxDOT considers low risk. This seemed to collaborate with the other findings; namely that lime appears to have been effective in the field (no apparent swells) and in the lab (strength gain with no major swells). Additionally, the construction technique used indicated that pre-treating and mellowing subgrades with high sulfate concentrations in some instances provided a viable alternative.

All of the lime had been placed in the subgrade since late January or early February, 2009. The SH 289 Extension project experienced very high rainfall throughout the spring months with some extreme single rain events dropping over 6 inches of rain at a time. The profile data approximately 14 months after testing indicate that there are no significant signs of sulfate induced heave. Although the original profile data was unavailable, the contractor did qualify for bonuses based on the ride quality. The DCP and FWD results also indicate that the pavement is structurally sound.

CONCLUSIONS AND RECOMMENDATIONS

TxDOT has established guidelines that limit the use of calcium-based stabilizers, like lime or cement, in sulfate-rich soils in Texas. The guidelines are as follows: sulfate concentrations below 3000 ppm are considered low risk, concentration between 3000 to 8000 ppm are considered medium risk and require special construction techniques, and concentrations greater than 8000 ppm are considered high risk and lime or cement is not recommended for use.

However, due to limitations in material availability as well as the time constraints from the project being under
construction at the time of the testing and design of the subgrade, it was decided to proceed with the original project stabilization design of 6 percent lime treatment using the extended mellowing methods described in this report. This was decided only after substantial field and laboratory testing of the materials with lime. Good performance in the field and lab testing indicated that lime stabilization with extended mellowing was feasible, even with the very high sulfates encountered on this project.

Over 1 year after the lime stabilization was completed, the pavement was still performing very well. The results of the profiling indicate that there are some bumps in areas of the project, but upon further review it was determined that these bumps were located in areas where there are either crossroads or exit/entrance ramps. The original profile data was unavailable for comparison, but data collected in March, 2010 indicate that the pavement is not experiencing any significant signs of sulfate induced heave. Further sulfate testing show that sulfate levels in the stabilized layer are still within acceptable levels. DCP and FWD results show that this pavement is structurally sound.

With sulfates being encountered more frequently on construction projects throughout the State and suitable replacement material being in scarce supply, alternatives will have to be considered. The results of this project indicate that alternative construction techniques, such as extended mellowing, with traditional stabilizers could be considered as part of the stabilization design of sulfate rich soils. Laboratory testing should include: volumetric swell, strength gain, and sulfate loss tests. Good performance in these laboratory tests and field performance described above further substantiate the use of the extended mellowing techniques described in this report.

ACKNOWLEDGEMENT

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REFERENCES