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16. Abstract

This implementation project was developed to provide technical support to the Texas Department of Transportation (TxDOT) in developing subgrade soil mixture designs in high sulfate soils and to monitor the performance of projects constructed following the guidelines established in Project 4240. Secondly, the researchers were to assess equipment needs of the TxDOT districts, train laboratory personnel in mix design procedures in high sulfate soils, and provide educational materials for TxDOT to train additional personnel.

Mix designs of high sulfate soils for two projects, in the Austin and Laredo Districts, are reported as technical support to districts. The construction and subsequent reevaluation of the project in Eagle Pass is reported to give TxDOT a record of the construction process used in the high sulfate soil on the Second Street project and shows how the project has performed since construction. Evaluation of the 3-D swell procedure shows the test to be repeatable if the density and water source are tightly controlled. A review of the equipment needed for adequate testing of the high sulfate subgrade soils showed that all required equipment can be obtained at minimal cost to TxDOT.

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EVALUATION OF STABILIZATION OF SULFATE SOILS IN TEXAS

by

Pat Harris
Associate Research Scientist
Texas Transportation Institute

Report 5-4240-01-1
Project Number 5-4240-01
Project Title: Implementation of Stabilization of High Sulfate Soils in the Field

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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The United States Government and the state of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

Dr. German Claros, P.E., and Ms. Claudia Izzo, from the Texas Department of Transportation are program coordinator and project director, respectively, of this important project and have been active in providing direction to the research team. Mr. Mike Arellano, P.E.; Mr. Rene Soto, P.E.; and Mr. Ramon Rodriguez, P.E., from TxDOT, have also been active in assisting the researchers. Both TxDOT and the FHWA provided funds for this project.

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CHAPTER 1

SUMMARY OF ENGINEERING PROPERTIES OF HIGH SULFATE SOILS

TASK 1 – TECHNICAL SUPPORT TO DISTRICTS *(Mix Designs for the Laredo and Austin Districts)*. The researchers received soils with moderate to high plasticity from projects that contained sulfate concentrations in excess of 3000 ppm to determine the optimum stabilizer design criteria. In the paragraphs that follow, the mixture designs that were selected will be reviewed.

EAGLE PASS, SECOND STREET PROJECT

The Laredo District started a new road construction project in Eagle Pass, Texas. The district personnel discovered sulfates on the site and asked the researchers to do a subgrade mixture design and make recommendations on which stabilizer to use. Figure 1.1 is a portion of the Geologic Atlas of Texas and shows the location of the Second Street project (red arrow). The project is constructed on the Escondido Formation, which is not listed as bearing any sulfur minerals.

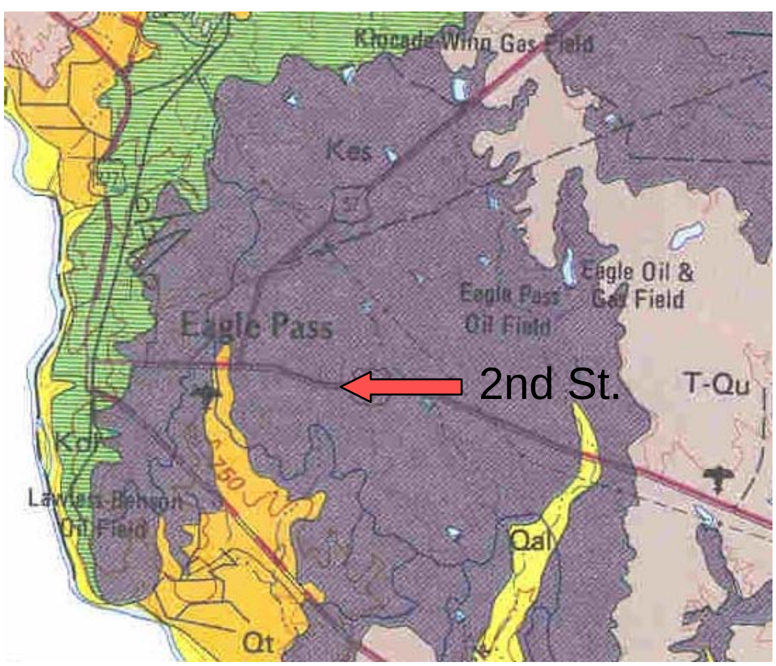

Figure 1.1. Geologic Map of Eagle Pass Area Shows Construction Is on Escondido Formation. ***From*****: Geologic Atlas of Texas: Crystal City-Eagle Pass Sheet, 1976.**

Soil samples from Second Street in Maverick County were shipped to the Texas Transportation Institute (TTI) from the Laredo District of the Texas Department of Transportation (TxDOT) to evaluate the suitability of ground granulated blast furnace slag (GGBFS) + lime for stabilizing these soils, which bear high concentrations of sulfate. Initially, one bag from each of the following eight stations were shipped to TTI: Station 15 + 28; Station 20 + 56; Station 29 + 77; Station 35 + 05; Station 40 + 33; Station 45 + 61; Station 50 + 89; and Station 56 + 00.

The plasticity index (PI) and conductivity of each of these soils were determined and are presented in Table 1.1.

Table 1.1. Engineering Properties of Initial Samples.

Station Number	LL	PL	PI	Conductivity (µS) *MS
15 + 28	44	16	28	163
20 + 56	51	17	35	732
29 + 77	31	13	18	57
35 + 05	26	12	13	76
40 + 33	35	14	21	69
45 + 61	34	15	20	66
50 + 89	31	15	16	68
56 + 00	47	18	28	1.66*

Conductivity ≥ 240 µS is above sulfate threshold
(LL) liquid limit, (PL) plastic limit, (MS) millisiemens

Following the initial testing, additional soil samples were sent to TTI for soil stabilization mixture design. Above approximately 8000 ppm of sulfate is generally too high for traditional soil stabilizers like hydrated/quick lime or cement, so the Laredo District wanted to evaluate what options were available for Eagle Pass soils.

The Laredo District shipped 150 to 200 lb of soil from the following six stations for stabilization design recommendations: Station 30 + 00; Station 35 + 00; Station 40 + 00; Station 45 + 00; Station 51 + 00; and Station 55 + 00.

Table 1.2 lists the plasticity index and sulfate concentration for each of these stations along with the optimum moisture content and maximum dry density for each station stabilized with lime. The liquid and plastic limits are for the unstabilized soil, while the moisture contents and densities are for 5 percent lime.

Table 1.2. Engineering Properties of New Stations.

Station Number	LL	PL	PI	Opt. M.C.	Max. ρ pcf	Sulfate Content 3 meas. Ave.
30 + 00	23	14	9	17%	107	160 ppm
*35 + 00	26	12	13	20%	104	120 ppm
40 + 00	27	15	12	18.5%	106	973 ppm
45 + 00	38	18	20	22%	101	133 ppm
*51 + 00	31	15	16	21%	100	133 ppm
55 + 00	43	22	21	21%	104	> 32,000 ppm

**Did not measure PIs because close to original stations.*
(M.C.) moisture content

The optimum lime content of the six stations using the Tex-121-E, part III procedure ranged from 4 to 5 percent by dry weight of soil.

Figure 1.2 shows the unconfined compressive strengths for duplicate, 4 by 6 inch, samples from Stations 40 + 00, 45 + 00, and 55 + 00 that were subjected to a seven day moist cure. The researchers prepared the samples at the moisture/density relations listed in Table 1.2 and then tested the samples in a Material Test Systems (MTS) machine at a speed of 0.135 inches per minute. Moisture/density curves for each stabilizer were not constructed due to limited soil and time constraints. We did not do strength or swell testing on Stations 30 + 00, 35 + 00, and 51 + 00 because these soils were similar to Stations 40 + 00 and 45 + 00. The 4 percent GGBFS mixed with 1 percent lime performed the best for all of the stations.

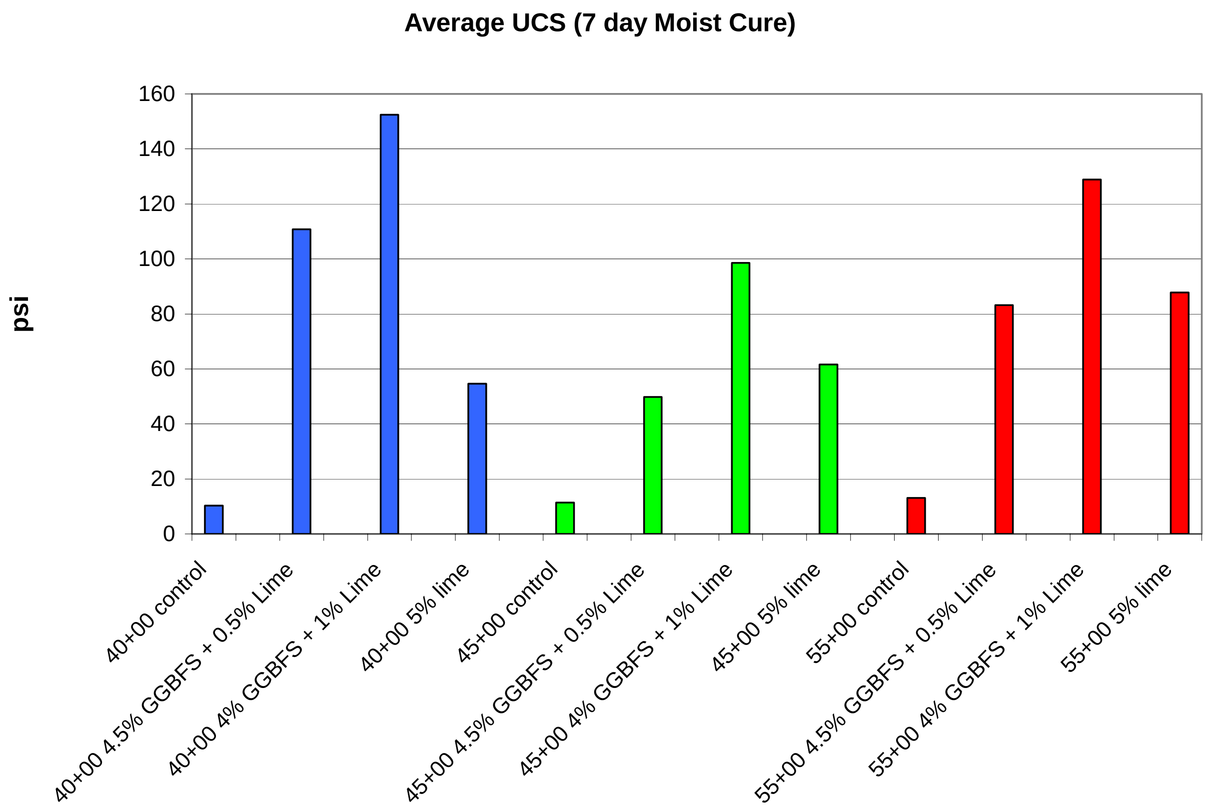

Figure 1.2. Unconfined Compressive Strength (UCS) Data for Eagle Pass Soils.

Figures 1.3, 1.4, and 1.5 are three-dimensional (3-D) swell curves for stations 40 + 00, 45 + 00, and 55 + 00. For stations 40 + 00 and 45 + 00, the lime-stabilized samples are performing as well as the GGBFS-treated samples. These results match the sulfate concentrations we measured for the soils sent to TTI; the sulfate contents were 973 ppm and 133 ppm, respectively. But, station 55 + 00 shows what typically happens with high sulfate soils; the GGBFS-treated samples exhibit less swell than the 5 percent lime-stabilized samples. The lime-stabilized samples continue to increase in swell, which indicates that the sulfates are coarser-grained particles.

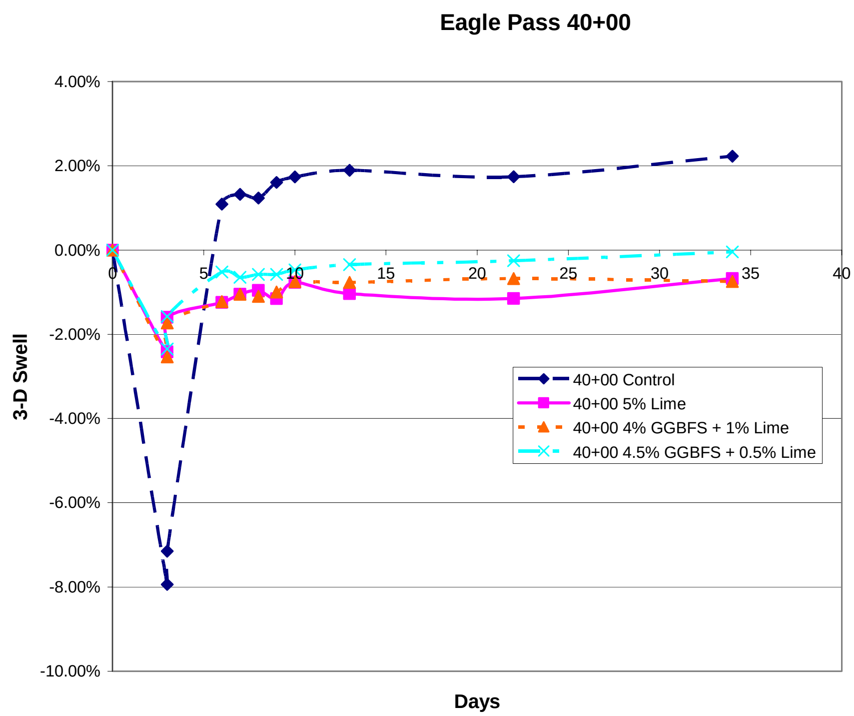

Figure 1.3. Three-Dimensional Swell for Station 40 + 00.

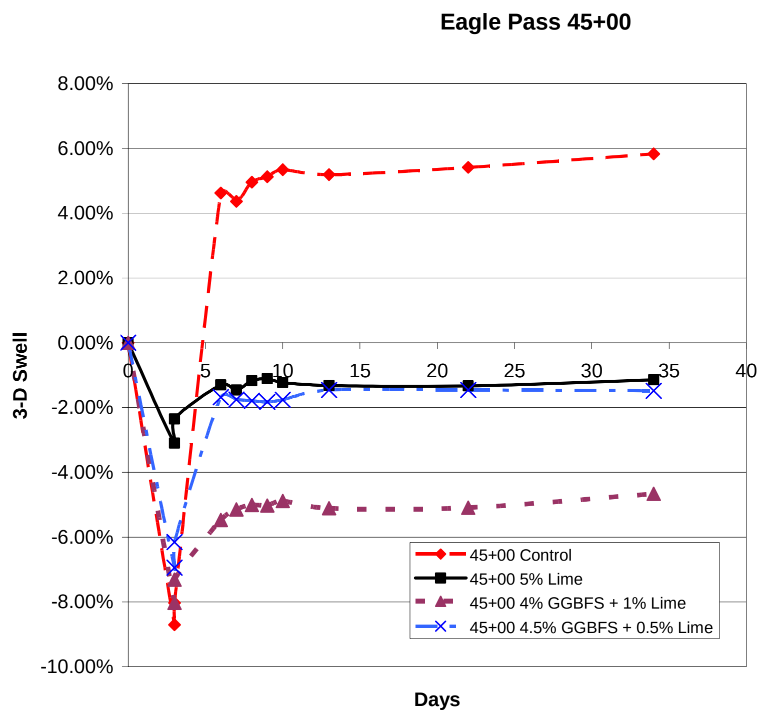

Figure 1.4. Three-Dimensional Swell for Station 45 + 00.

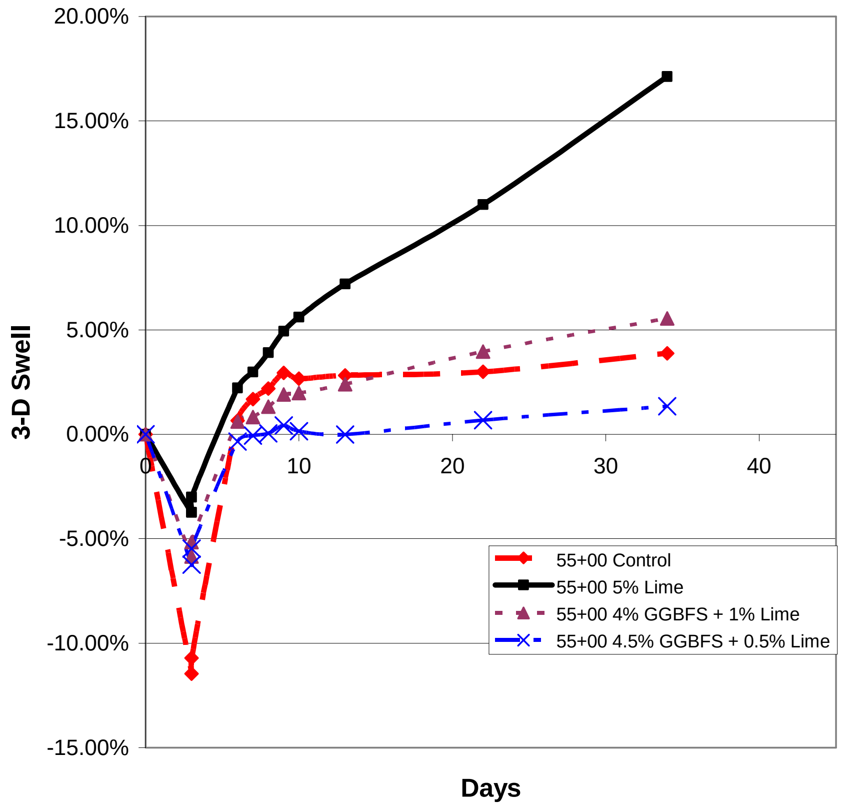

Figure 1.5. Three-Dimensional Swell for Station 55 + 00.

RECOMMENDATIONS FOR EAGLE PASS

Based on these results, we recommend using 4 percent GGBFS to 1 percent lime to stabilize the entire section where sulfates are suspected to occur. We didn't choose 4.5 percent GGBFS because TxDOT wanted the higher strengths obtained with 4 percent GGBFS, and the contractor was afraid that he couldn't control the 0.5 percent lime addition in the field. The GGBFS provided superior strength in addition to less swell in the high sulfate soil.

Austin, US 183

The Austin District started a new road construction project on US 183 in Austin, Texas. The district personnel discovered sulfates on the site and asked the researchers to do a subgrade mixture design and make recommendations on which stabilizer to use. Figure 1.6 is a portion of the Geologic Atlas of Texas and shows the location of the project (red arrow). The project is constructed on the Ozan Formation, which is listed as bearing pyrite, a sulfide mineral that converts to sulfate upon exposure to oxygen.

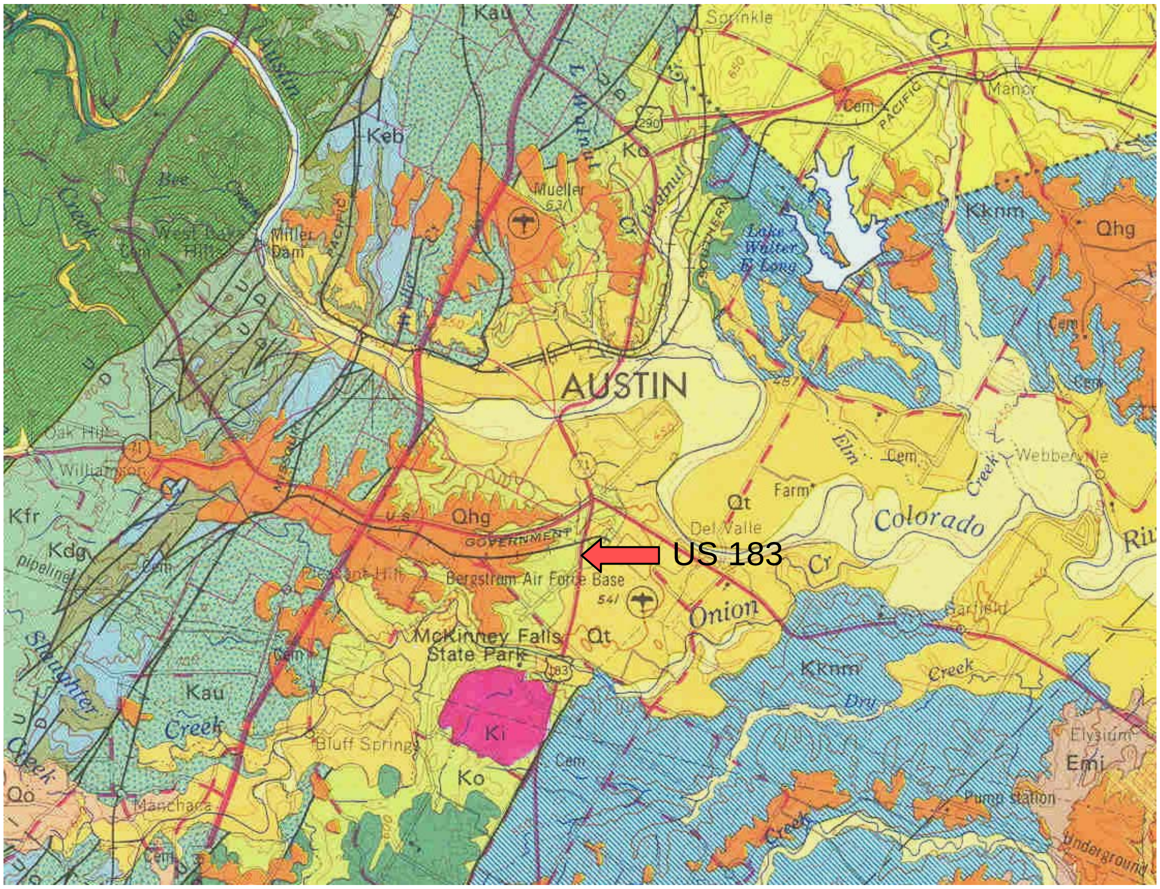

Figure 1.6. Geologic Map Shows Construction of US 183 Is in Ozan Formation. *From:* Geologic Atlas of Texas: Austin Sheet, 1974.

The first step was to measure the plasticity and sulfate content of the subgrade soil to be treated. The plasticity of the unstabilized soil was so great (PI = 47 to 48), TxDOT wanted to add lime as a pretreatment to reduce plasticity and the sulfate concentration. Table 1.3 shows the effect of adding 2 and 3 percent lime to the soil. Both plasticity and sulfate concentration are reduced substantially by adding 2 percent lime after mellowing for 24 hours. Higher percentages of lime and additional mellowing time do not produce significant benefits over the 2 percent at 24 hours of mellowing.

Table 1.3. PI and Sulfate Changes with Lime Addition.

US 183 Atterburg Limits and SO4 Consumption for Mellowing with Lime				
Sample Name	PL	LL	PI	SO4 Concentration (ppm)
No Stabilizer	25	72	47	42,560
No Stabilizer	21	69	48	55,360
2% Lime 24 hrs.	33	52	19	20,320
2% Lime 48 hrs.	33	51	18	16,640
3% Lime 24 hrs.	33	48	15	21,280
3% Lime 48 hrs.	38	53	15	18,080

The optimum lime content was determined by measuring the pH using the Tex-121-E, part III procedure. The optimum lime content was determined to be 5 percent. The researchers constructed optimum moisture/density curves using Tex-114-E for the raw soil, for ground granulated blast furnace slag, and Class F fly ash. The slag and fly ash samples were pretreated with 2 percent lime and mellowed for two days prior to the addition of the slag plus lime and fly ash plus lime mixtures. Figure 1.7 is a graph of the three soils. The raw soil has a maximum dry density of 93 pcf and an optimum moisture content of 27 percent; the slag/lime mixture lowers the maximum density to 90 pcf and increases the optimum moisture to 29 percent. The addition of the fly ash/lime mixture further reduces the maximum density to 89.5 pcf and maintains the optimum moisture content at 29 percent.

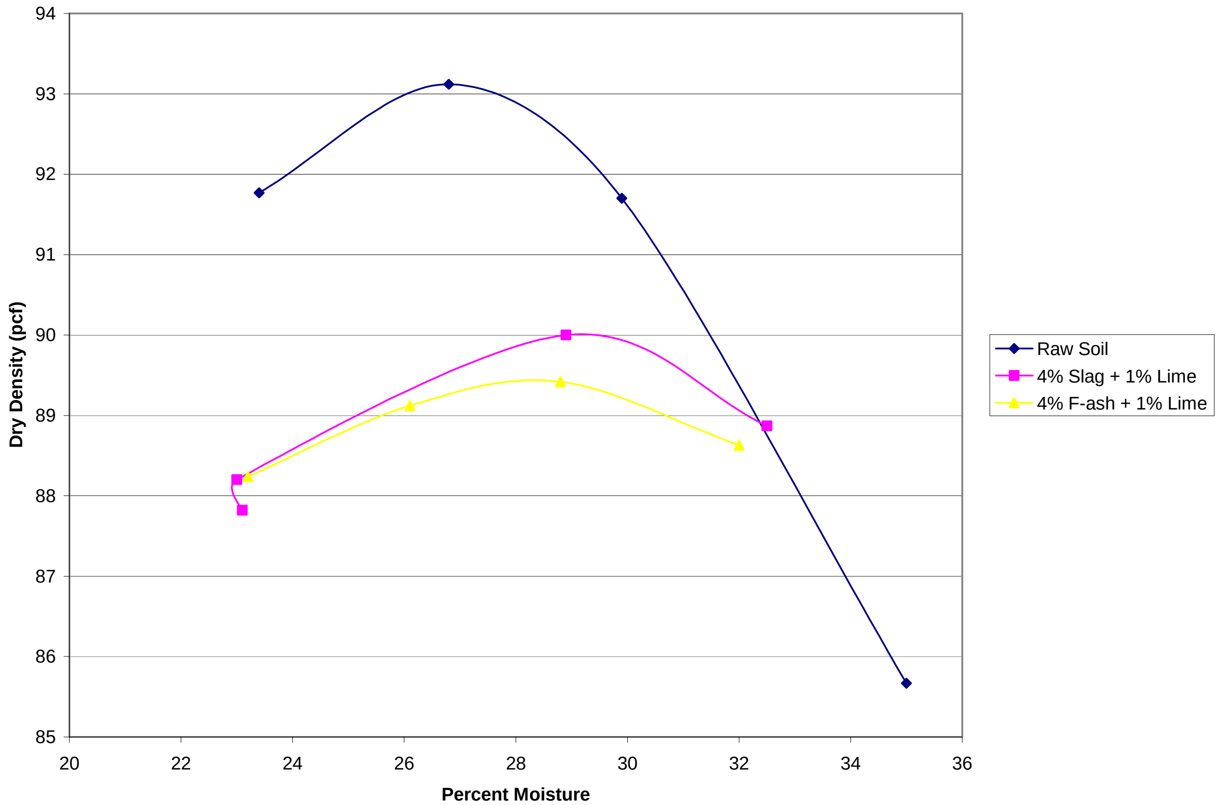

Figure 1.7. Moisture/Density Curves for US 183 Soil with Fly Ash and Slag Stabilizers.

Researchers prepared samples for three-dimensional swell testing in a Superpave gyratory compactor at the densities shown in Figure 1.7. The samples were pretreated with 2 percent lime and mellowed for 48 hours prior to stabilizer addition and compaction for swell and strength testing: results of the swell testing are shown in Figure 1.8. As one can see, after 85 days, the samples are still swelling, which indicates that the sulfates are relatively coarse grained. The soil treated with 5 percent lime swelled over 35 percent. The Class F fly ash samples didn't do much better: the 4 percent F ash plus 1 percent lime (4% F-ash:1% Lime) treatment swelled about 34 percent, and the 6 percent F ash plus 2 percent lime (6% F-ash:2% Lime) swelled about 31 percent. The unstabilized (Raw) soil appears to have decreased in swell over time, but the apparent reduction is due to loss of sample in the water bath and a subsequent decrease in sample volume. The 4 percent slag plus 1 percent lime (4% GGBFS:1% Lime) treatment reduced swell only about 5 percent over the unstabilized soil.

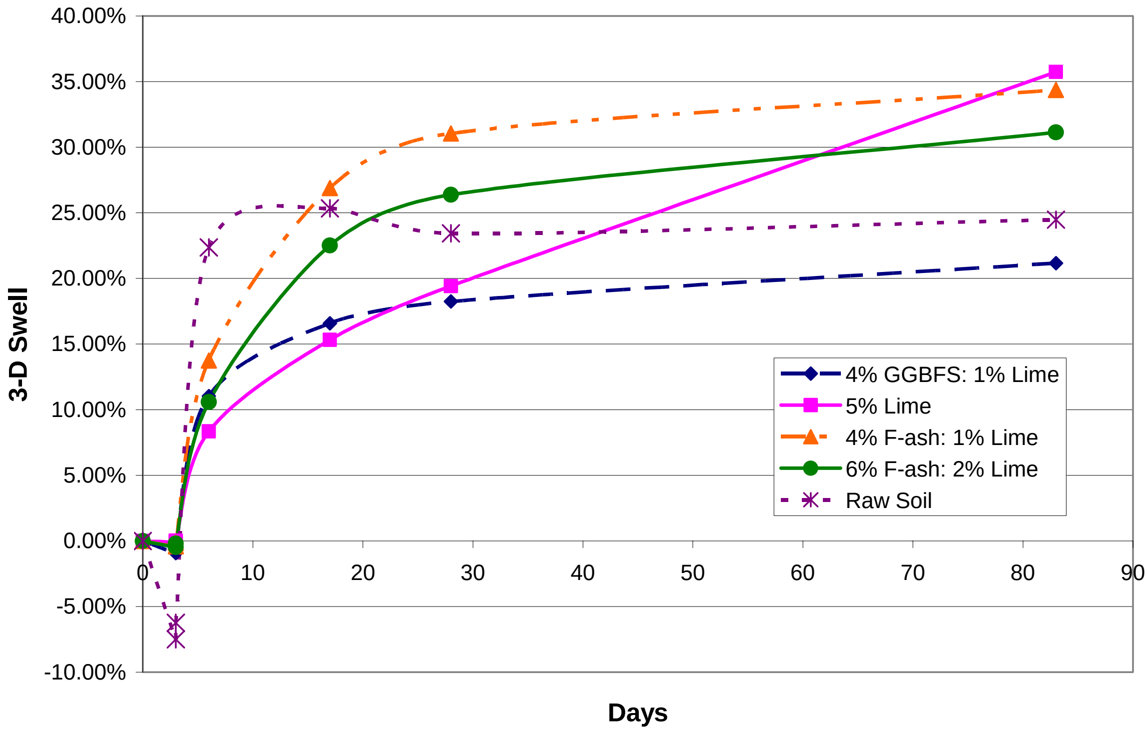

Figure 1.8. Three-Dimensional Swell of High Sulfate Subgrade Soil Samples Treated with Various Stabilizers from US 183.

Researchers measured the unconfined compressive strength on duplicate samples after a seven day moist cure (Table 1.4). The samples that were subjected to swell testing were also tested for retained strength after 88 days in the swell test to get an idea of the permanency of the stabilization. These results are posted adjacent to the strengths obtained after the seven day moist cure. All of the strengths after swell testing (88 day) are lower than the strengths obtained after the seven day moist cure. The samples stabilized with 1 percent lime plus 4 percent F-ash, and the samples with no stabilizer had significantly lower strengths following the 88 day 3-D swell test. These data suggest that the positive effects of the stabilizer have largely been removed following exposure to moisture in the 3-D swell testing.

Table 1.4. Unconfined Compressive Strength Data for US 183.

US 183 Sample Name	7-day Moist Cure UCS Stabilizer	UCS (psi)	88 day 3-D Swell UCS UCS (psi)
1A	1% L/4% F-Ash	67.54	16.60
1B	1% L/4% F-Ash	69.07	19.50
1C	2% L/6% F-ash	73.91	41.10
1D	2% L/6% F-ash	80.83	47.70
2A	5% Lime	54.03	43.00
2B	5% Lime	55.86	broken
3A	Raw Soil	30.61	2.60
3B	Raw Soil	30.26	2.70
4A	1% L/4% GGBFS	97.00	61.70
4B	1% L/4% GGBFS	104.24	64.60

RECOMMENDATIONS FOR US 183

Based on the results of the laboratory testing, the researchers suggest that 2 percent lime pretreatment with at least 24 hours mellowing should be followed by the addition of 4 percent GGBFS plus 1 percent lime. However, the GGBFS is not readily available in Austin, so TxDOT decided to use 2 percent lime pretreatment and 24 hours mellowing followed by adding 6 percent F-ash plus 2 percent lime.

CHAPTER 2

CONSTRUCTION OF SECOND STREET PROJECT IN EAGLE PASS

Based on the results of the laboratory 3-D swell and UCS testing made by TTI, TxDOT decided to stabilize the subgrade of the eastern portion of the Second Street Project (station 29 to station 55) with a combination of 4 percent GGBFS and 1 percent hydrated lime.

Figure 2.1 presents a typical cross section of the road construction. The subbase was stabilized to 8 inches with GGBFS/lime in a ratio of 4:1 percent dry weight; then, 12 inches of flexible base was added, which was then topped by 4 inches of asphalt. The section presented is from station 52 + 80.00 to station 55 + 83.00, which is in the middle of the high sulfate region.

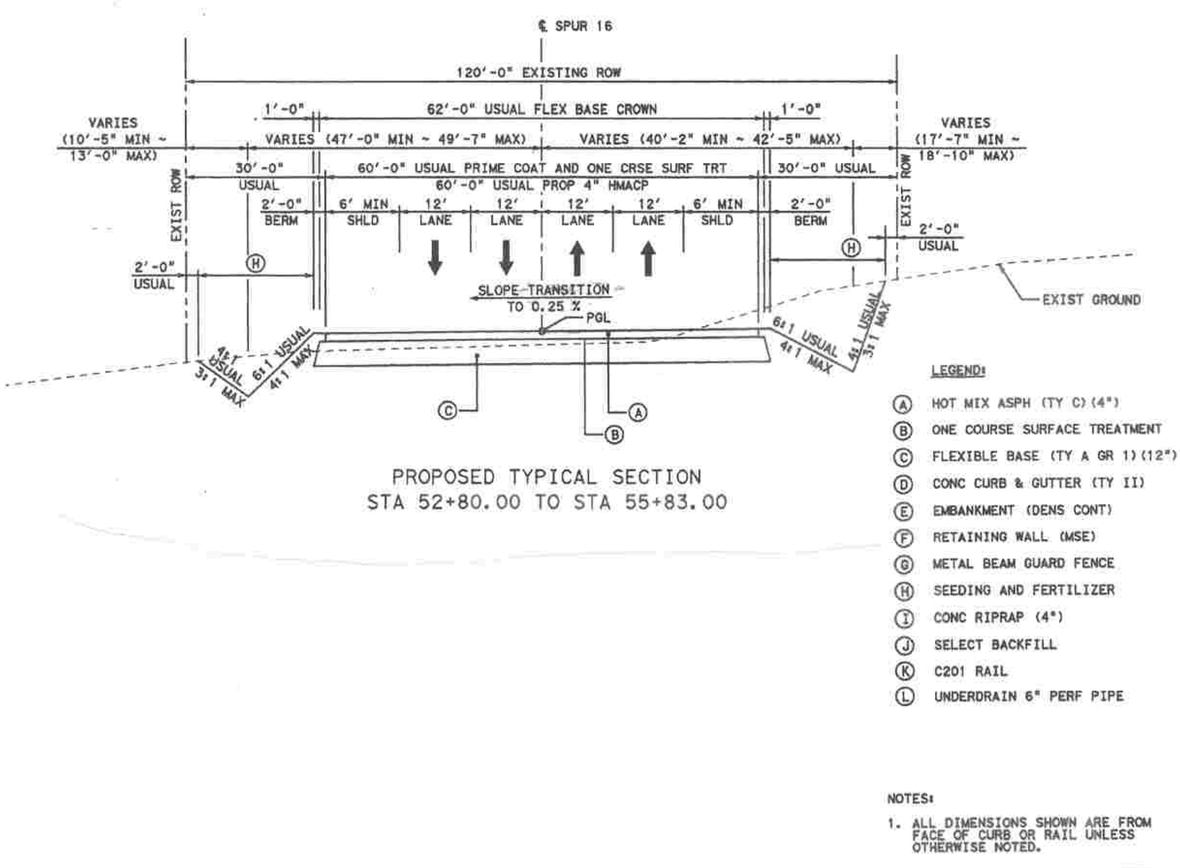

Figure 2.1. Cross Sectional View of Plans for the Second Street Project.

After the section to be stabilized was cut to grade, the contractor identified four different soil types. TxDOT collected samples from Stations 30 + 00, 36 + 00, 42 + 00, and 52 + 00, which were determined to be where the soil changes on the east side of the project. Table 2.1 lists the results of moisture/density measurements (TEX 114-E) for the unstabilized soil and sulfate determination (TEX 145-E) at the four stations.

Table 2.1. Engineering Properties of Untreated Soil Types from Second Street.

Station Number	Max. Density TEX 114-E	Sulfate Content (ppm) TEX 145-E
30 + 00	117.3 PCF @ 13.9% moisture	114
36 + 00	111.3 PCF @ 13.6% moisture	126
42 + 00	109.8 PCF @ 16.5% moisture	13,100
52 + 00	105.7 PCF @ 19.9% moisture	15,520

The contractor estimated the amount of GGBFS (4 percent) and lime (1 percent) needed for the project based upon a density of 104 PCF with a length of 2600 feet, a width of 62 feet, and a depth of 8 inches. The density of 104 PCF and moisture content of ~18.5 percent were determined by averaging the densities and moisture contents obtained from the laboratory mix design reported in Table 1.2 of Chapter 1 of this project.

The contractor was concerned that the soils used in the laboratory mix design were not representative of the soils at grade, so TxDOT decided to send samples to Raba Kistner in San Antonio to determine moisture/density relationships with the additives mixed in the field. Table 2.2 lists the moisture/density relationships for field stabilized soil samples from Eagle Pass. There was 4 percent GGBFS and 1 percent lime in these samples that were molded by Raba Kistner; there was a four to five hour delay between mixing and molding of the samples. They molded the samples using the TEX 120-E compactive effort, which is for cement, in addition to TEX 114-E, which is for raw subgrade and embankment soils (Table 2.2).

Table 2.2. Compaction Properties of Stabilized Soil Types from Second Street.

	TEX 114-E		TEX 120-E	
Station	Density (PCF)	Moisture (%)	Density (PCF)	Moisture (%)
30 + 00	N/A	N/A	122.01	10.8
36 + 00	N/A	N/A	119.7	10.4
42 + 00	104.7	20.6	111.7	17.9
52 + 00	104.5	16	113.4	15.4
53 + 00	105.1	20.4	110.2	18.8
55 + 00	105.1	20.4	110.2	18.8

These are field collected samples that were treated with 4% GGBFS and 1% Lime.

CONSTRUCTION OF THE EXPERIMENTAL SECTION AT EAGLE PASS

Initially, the researchers collected Dynamic Cone Penetrometer (DCP) data (Figure 2.2) prior to stabilization in the eastbound direction starting at station 29 + 00 and collecting data every 300 feet until the end of the project. Data were then collected at station 54 + 50 to ensure that data were not collected on the edge of the stabilized section.

Figure 2.2. Ramon Rodriguez Collecting DCP Data on the Second Street Project.

Four trucks of GGBFS were delivered with 25 tons each. The GGBFS was spread along the project with a spreader bar in a dry powdery form (Figure 2.3).

Figure 2.3. GGBFS Being Spread along the Project in Eagle Pass.

Two CMIs were used to mix the GGBFS into the subgrade in a dry form to a depth of 8 inches (Figure 2.4). The in situ moisture content of the subgrade was in the range of 3 percent, which allowed efficient mixing of the GGBFS (Figure 2.5).

Figure 2.4. CMIs Used to Mix the GGBFS into the Subgrade.

Figure 2.5. The CMIs Efficiently Mixed the GGBFS into the Subgrade.

Following the mixing of the GGBFS with the CMIs, a pneumatic roller was used to compact the surface (Figure 2.6) so that the lime truck had a smooth surface to drive over while placing the 1 percent lime.

Figure 2.6. Pneumatic Roller Used to Prepare the Surface for Lime Placement.

Following placement of GGBFS and compaction with the pneumatic roller, the hydrated lime $\{Ca(OH)_2\}$ was placed in a dry, powder form using a spreader bar (Figure 2.7). The contractor commented that it would be difficult to get the lime mixed into the subgrade at a concentration of 1 percent.

Figure 2.7. Application of the Lime to the Subgrade Following GGBFS Placement.

After placement of the hydrated lime, water trucks were attached to the CMIs, and the lime was mixed into the subgrade while the water was simultaneously added (Figure 2.8).

Figure 2.8. Addition of Water and Mixing of Lime into Subgrade in Eagle Pass.

The contractor walked behind the CMI to monitor water placement into the subgrade. The contractor had the water valves opened all the way to get water mixed into the subgrade, and they still had to reduce the speed of the CMI to get enough water. The contractor stated that the most difficult part of this project was getting enough water mixed into the subgrade to reach the optimum moisture content. There was a lot of downtime associated with the CMIs waiting for the water trucks to refill their tanks (Figure 2.9).

Figure 2.9. Progress Halted by CMI Waiting on a Water Truck.

Immediately after the lime/water was mixed with the CMI, a padfoot roller compacted the GGBFS/lime subgrade to density (Figures 2.9 and 2.10).

Figure 2.10. Padfoot Roller Used to Achieve Compaction Following the Mixing of Lime and Water.

A road grader followed directly behind the roller (Figures 2.9, 2.10, and 2.11) and made a smooth surface on the compacted subgrade so the surveyors could set blue tops.

Figure 2.11. A Road Grader Was Used to Blade Off the Subgrade Following Compaction.

Questions or Concerns Developed as a Result of Construction

1. Compaction procedures. Do we use TEX 114-E or TEX 120-E/TEX 121-E? All of the laboratory testing performed in Project 4240 used TEX 114-E because it is a lower compactive effort, which results in lower densities that are desirable for reducing swell in the high sulfate soils. This is documented in Research Report 0-4240-2.
2. Does the nuclear density gauge need correction for use of GGBFS and lime mixtures?
3. The microwave drying procedure (TEX 103-E Part II) does not work with the GGBFS and lime mixtures. There is a note at the end of the procedure that reads "This method does not give true representative results for materials containing significant amounts of halloysite, montmorillonite, or gypsum minerals, highly organic soils, or materials in which the pore water contains dissolved solids."
4. There was a big problem with not having moisture/density curves before the construction project began.
5. The lack of in situ moisture (3 percent or less) initially caused lots of problems with mixing the GGBFS and lime mixtures. The contractor had to place a lot more water than anticipated, which required more water trucks than the contractor originally planned to use.

Questions Raised Due to Equipment Failure

1. How much stabilizer do you lose due to dusting with long construction delays?
2. Does it matter if GGBFS is mixed in 16-18 hours before adding the lime?
3. What is the window (4, 8, 12, 24 hours, etc.) for compacting the GGBFS/lime mixtures?
4. Do we need moist curing of the subgrade after compaction?

CHAPTER 3
COMPARISON OF 3-D SWELL RESULTS

TASK 2 – FINALIZING LAB TEST PROCEDURES

The objective of this task was to determine the consistency of the three-dimensional swell test developed in Project 4240. The researchers collected a moderate PI soil from SH 6 that didn't contain sulfates and added $CaSO_4$ to the soil at a concentration of about 12,000 parts per million. Enough soil was mixed up for TTI and the Austin District and Cedar Park laboratories to construct six samples each and place in the three-dimensional swell test developed in project 4240.

The researchers supplied TxDOT with the following materials: 8 ice chests, 8 plastic coated metal wire racks, 32 porous stones (¼ inch thick by 4 inch diameter), 16 latex membranes, 20,000 grams of soil, 300 grams of hydrated lime, 400 grams of GGBFS (slag), 6 pie tapes (to measure sample circumference), and spreadsheets to record and plot swell data.

Mike Arellano with the Austin District laboratory mixed, molded, and monitored 3-D swell to compare with swell data obtained by the implementation director (Claudia Izzo) and data gathered by the researchers (TTI). Mike's swell data is plotted in Figure 3.1. After 20 days in the test, the raw soil swelled to 19.7 percent, the 1 percent lime plus 4 percent slag soil swelled 12.5 percent, and the 5 percent lime soil had a final swell of 4.7 percent.

Figure 3.2 shows data generated by the Materials and Pavements lab in Cedar Park. After 20 days in the test, Claudia's data using tap water correlates very well with data obtained from the Austin District lab. The raw soil had the same exact swell of 19.7 percent; the 1 percent lime plus 4 percent slag swelled to 11.7 percent, and the 5 percent lime soil swelled to 4.77 percent. Samples molded with distilled water (Figure 3.3) swelled 1 to 2 percent more.

Samples molded at TTI with distilled water (Figure 3.4) exhibited the highest swells. The raw soil had 21.9 percent swell after 20 days; the 1 percent lime plus 4 percent slag had 17.9 percent swell, and the 5 percent lime swelled to 7.9 percent. The higher swells for the TTI samples can be explained by a higher compactive effort, which yielded more dense samples.

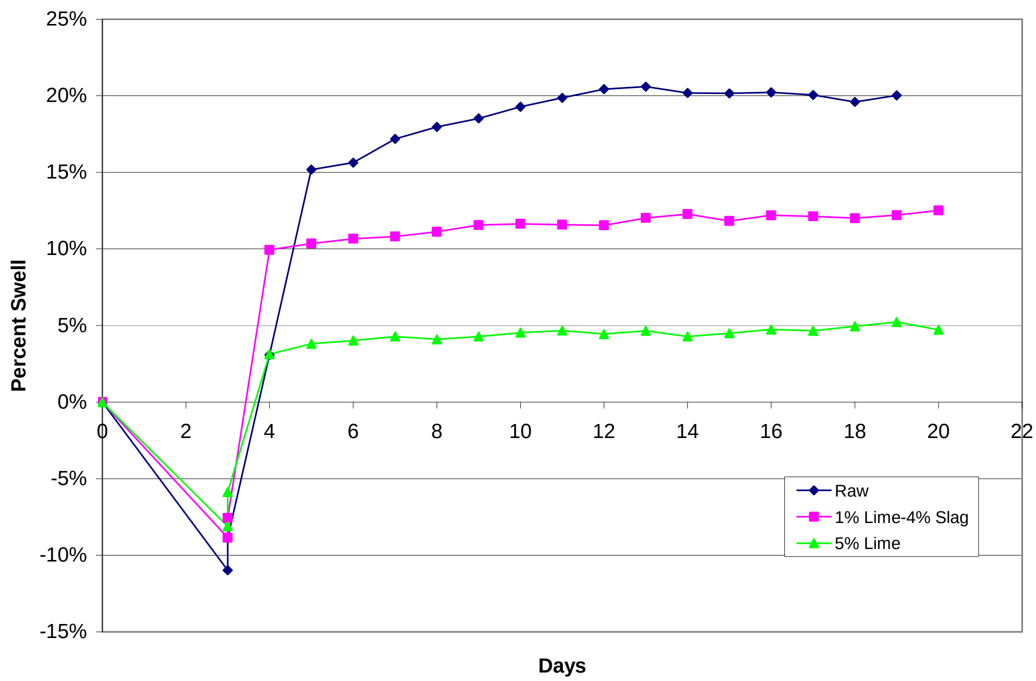

Figure 3.1. Swell Data from Austin District Lab.

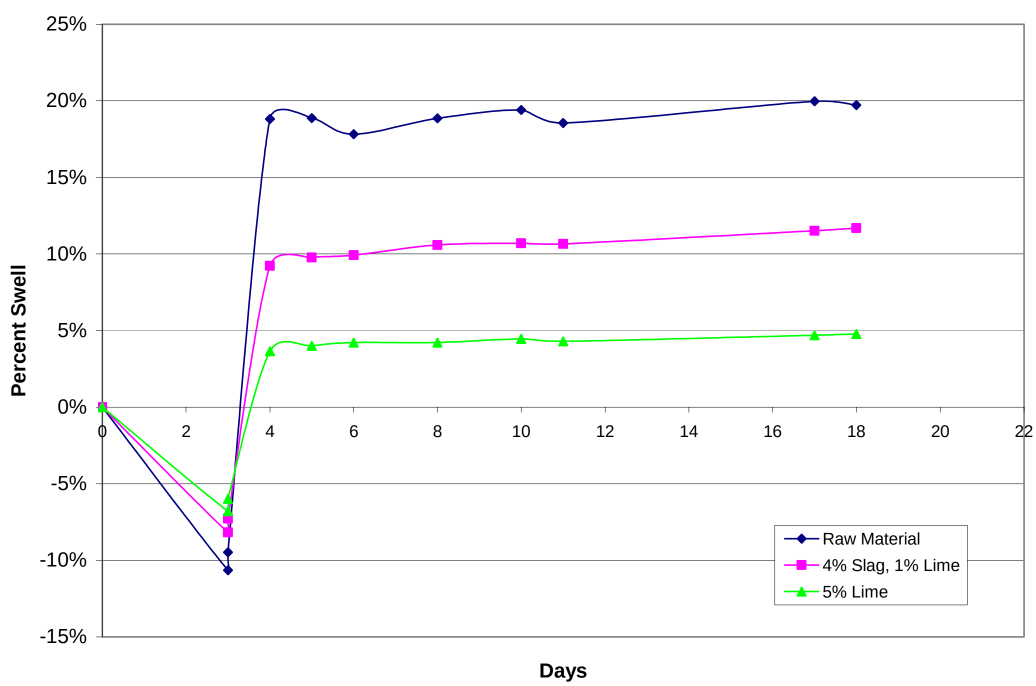

Figure 3.2. Swell Data from Cedar Park Lab Using Tap Water.

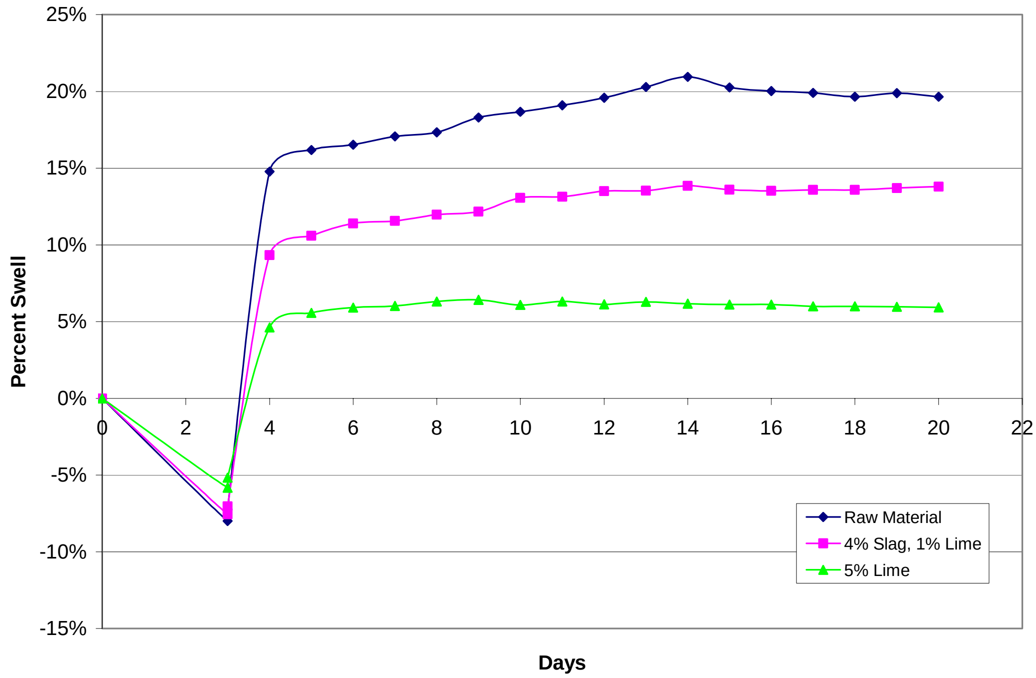

Figure 3.3. Swell Data from Cedar Park Lab Using Distilled Water.

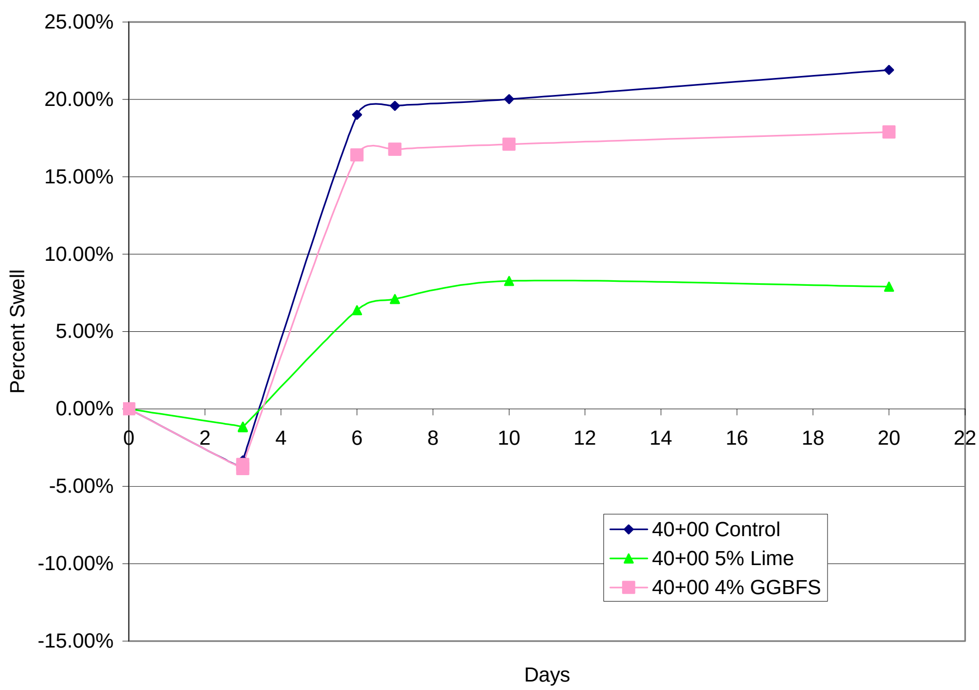

Figure 3.4. Swell Data from TTI Lab Using Distilled Water.

Table 3.1 shows the height and circumference measurements of the samples immediately after molding. One can see that the samples molded by the Austin District and Cedar Park labs are very close to the target height of 4.5 inches, but the TTI samples are about 0.3 inches shorter. The weights of the molded samples are very close (within 20 to 30 g or ~1.8 percent difference), which would make the TTI samples have a higher density after molding. The densities of the Cedar Park and TTI samples are listed in Table 3.1 as well. The TTI samples have an average density of 0.13 g/cm^3 higher that the Cedar Park samples. The more dense samples have less void space to accommodate reaction products and/or water and result in a higher percentage of swell.

Table 3.1. Size of Samples Molded for 3-D Swell Test.

	Original Sample Size for 3-D Swell Test							
	Austin District		Cedar Park Lab			Texas Trans. Inst.		
Sample Name	Height (in.)	Circ. (mm)	Den. (g/cm3)	Height (in.)	Circ. (mm)	Den. (g/cm3)	Height (in.)	Circ. (mm)
Raw	4.44	315.4	1.93	4.44	315.4	2.08	4.08	315.5
1% Lime 4% slag	4.49	315.7	1.92	4.48	315.8	2.04	4.19	315.5
5% Lime	4.505	315.6	1.89	4.49	315.4	2.00	4.17	315

The data illustrate three important points:

- The data from all laboratories show the same trend with lime producing the lowest swell and the raw material producing the highest swell.
- The water source is critical; for consistency in swell results, distilled water was supposed to be used to remove swell attributed to different ions in the water. In a perfect world, one would use the same water to be used on the project.
- One needs to make sure that samples are molded to the density obtained by proctor compaction because, as seen by the TTI data, a higher density will result in higher percentages of swell.

This three-dimensional swell procedure consistently yields data that correlate with field observations. If there is control on the molding water used, the sample height (±0.05 inches), and the sample weight (~2 percent), then reproducible swell results can be obtained. The researchers want to point out that the swell test was only verified for one level of sulfate using a manufactured sample.

A laboratory testing procedure consisting of two parts has been developed as part of this implementation project and is included as appendices to this report. Appendix A is the procedure for evaluating additives to alter the engineering properties of high sulfate soils. Appendix B is the 3-D swell procedure used to help discern the usefulness of additives in high sulfate soils.

CHAPTER 4

REEVALUATION OF SECOND STREET PROJECT

TASK 3 - MONITOR PERFORMANCE OF TEST SECTIONS

The researchers went back to the Second Street Project in Eagle Pass, Texas, on January 9, 2007, to evaluate the effectiveness of the GGBFS plus lime stabilization in the high sulfate soil on the east side of the project. Figure 4.1 shows how the road looks today with the high sulfate section in the foreground and the lower sulfate area in the background. The bridge in the background marks the transition from stabilized to unstabilized subgrade (west of the bridge).

Figure 4.1. Second Street View to the West. The High Sulfate Section Is in the Foreground.

A few days prior to the return visit to Eagle Pass, there was a lot of rain. The drainage ditch adjacent to the street has abundant mudcracks and moist soil, which provides evidence of the recent rains (Figure 4.2). The rain also washed the soil away from the gypsum crystals (Figure 4.3), making it easier to identify the sulfate-rich areas on the east side of the project.

Figure 4.2. Drainage Ditch Adjacent to Second Street Shows Signs of Recent Rains.

Figure 4.3. Gypsum Crystals Visible in Drainage Ditch Following Rains.

Following visual inspection, the researchers selected sites to take DCP measurements. Holes were drilled through the asphalt and base to the top of the subgrade layer. Figure 4.4 is a composite of DCP measurements taken before the GGBFS plus lime stabilizer was added (dashed line with diamonds). The subgrade was extremely hard because the region had been in a drought for several months. Immediately after stabilization and compaction, the DCP data (solid line with squares) show a high penetration rate, which is due to adding almost 18 percent water to the soil to aid in the chemical reactions responsible for stabilization. The third curve (triangles) represents DCP data obtained 280 days after stabilization. The lower penetration rate indicates that the subgrade is stronger than before treatment. The most recent measurements were made when the surrounding soil was weakened by recent rains (Figure 4.2).

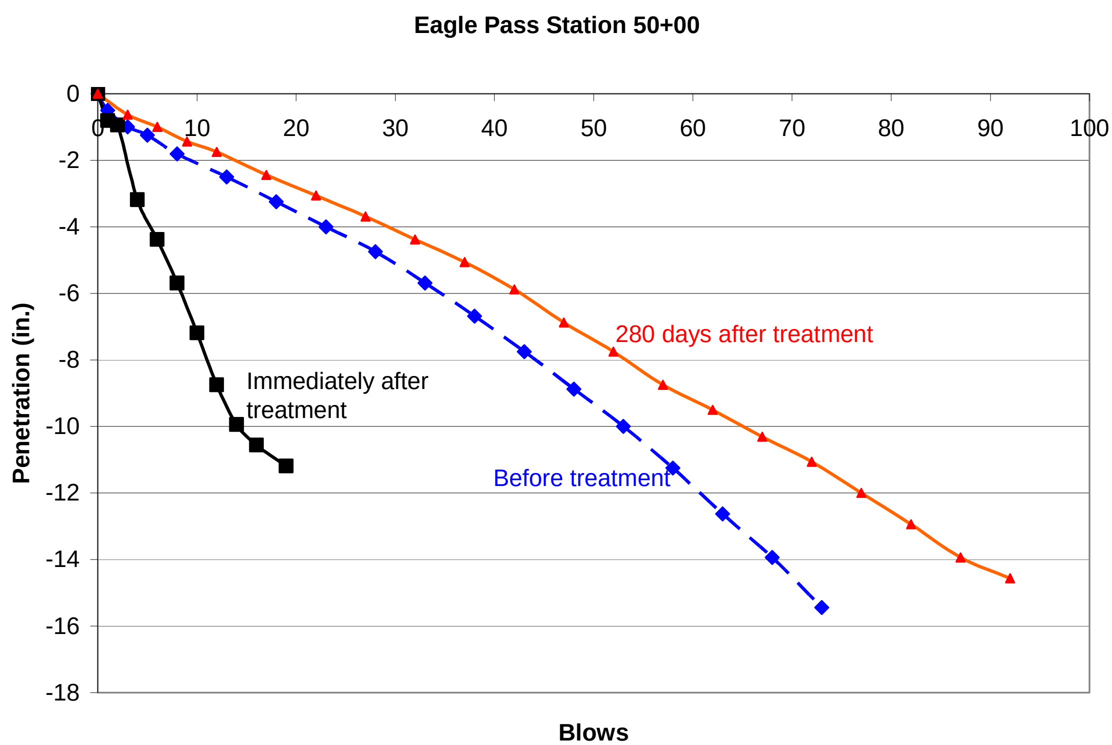

Figure 4.4. Dynamic Cone Penetrometer Data for Station 50 + 00 Shows the Strength Attained by Treatment.

The researchers also obtained falling weight deflectometer (FWD) data over the entire project spaced every 150 feet to compare the stiffness of the untreated subgrade (west of the canal) to the stabilized subgrade east of the canal. Table 4.1 shows the summary report of the FWD data. The air temperature at the time of FWD testing was cool at around 60 degrees F. The data shown in Table 4.1 contains three different sections. From 0 to 900 feet is the high sulfate area treated with slag cement; from 900 to 3301 feet is the low sulfate area, which was also treated with slag cement. From 3449 feet to the end of the testing, the subbase was untreated. The average backcalculated moduli values for the three sections are 228 ksi, 260 ksi, and 108 ksi, respectively. There is a significant increase in average maximum deflection and a corresponding decrease in backcalculated stiffness between the treated and untreated sections. The data show that the stabilizer is providing a stiff subgrade layer without causing the heaves that are inherent in lime-stabilized sulfate soils.

The data also show that the subgrade on the total project is very good. Even in the untreated area, the subgrade modulus is over 20 ksi. If high sulfate contents are encountered on future projects, one clear alternative is not to chemically treat the subgrade layer.

Ride quality analysis was performed on each lane of the Eagle Pass project on October 10, 2006, and again on January 9, 2007, to observe changes in ride quality. Dynatest collected the profiles in October, and Pavetex did the testing in January. Both companies use the same profiler with the same filters, so the researchers are assuming the data are comparable. There is no guarantee that the data from these two companies are comparable, but the profiler used by Pavetex was calibrated shortly before the testing in January; therefore, the researchers are reasonably confident that the data collected in January are accurate. Pavement smoothness for each wheelpath of the eastbound lanes is plotted in Figure 4.5. The profile for October 2006 has lower amplitude elevation changes than the profile for January 2007. This large change suggests that the subgrade swelled between October and January (Fernando, personal communication). The high amplitude data from approximately 800 feet to about 1700 feet is a bridge approach and concrete bridge deck.

Figure 4.6 is a plot of pavement smoothness for the westbound lanes of the Eagle Pass project. The same exact trends in the data are observed for these lanes, again suggesting that the subgrade has expanded causing the ride to be less smooth. The high amplitude data from approximately 2500 feet to 3400 feet is a bridge approach and concrete bridge deck.

Table 4.1. FWD Data for Eagle Pass Second Street Project.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

District:22 (Laredo)
County :159 (MAVERICK)
Highway/Road: SS0016

MODULI RANGE(psi)

	Thickness(in)	Minimum	Maximum	Poisson Ratio Values
Pavement:	4.00	340,000	2,000,000	H1: v = 0.35
Base:	12.00	10,000	350,000	H2: v = 0.35
Subbase:	8.00	30,000	350,000	H3: v = 0.35
Subgrade:	276.00(by DB)		5,000	H4: v = 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock	
0.000	9,231	5.04	3.19	2.09	1.68	1.31	1.03	0.86	1536.5	137.4	298.5	29.9	0.97	300.0 *	High Sulfates with Slag
151.000	9,307	5.23	3.19	2.17	1.69	1.30	1.00	0.79	1005.6	174.4	179.0	31.3	0.62	300.0	
300.000	9,243	3.97	2.58	1.89	1.48	1.19	0.96	0.81	1524.3	247.2	313.3	32.6	0.32	300.0	
450.000	9,319	4.59	2.83	1.95	1.50	1.15	0.91	0.75	1200.0	201.6	194.9	35.0	0.36	300.0	
600.000	9,219	5.94	3.52	2.02	1.45	1.09	0.88	0.73	1632.6	71.6	350.0	35.9	1.08	300.0 *	
752.000	9,108	6.04	3.88	2.31	1.59	1.09	0.80	0.64	1691.4	113.4	37.0	38.3	0.81	298.6	
900.000	9,100	4.38	2.75	1.80	1.33	0.96	0.73	0.59	1333.6	225.4	72.4	43.2	0.67	300.0	
1051.000	9,116	7.48	4.19	1.92	1.18	0.86	0.70	0.61	1430.7	36.3	350.0	44.9	1.81	253.8 *	Low Sulfates with Slag
1201.000	9,100	9.00	4.83	2.26	1.42	1.04	0.79	0.69	961.1	38.0	134.8	38.0	0.54	300.0	
1350.000	9,279	6.03	3.99	2.52	1.76	1.24	0.92	0.74	1690.1	138.8	32.5	34.9	0.42	300.0	
1501.000	9,100	4.63	2.93	1.83	1.37	1.04	0.80	0.65	2000.0	123.0	236.1	37.8	0.66	300.0 *	
1651.000	9,017	6.57	3.47	1.48	0.88	0.65	0.52	0.46	1390.9	42.1	350.0	59.2	1.62	127.1 *	
1800.000	9,084	2.97	1.57	1.07	0.85	0.69	0.56	0.48	902.3	350.0	350.0	61.6	3.79	300.0 *	
1950.000	9,108	4.56	2.61	1.59	1.17	0.89	0.69	0.56	1527.2	120.6	338.0	44.3	0.17	300.0	
2100.000	9,211	3.41	1.87	1.28	1.03	0.81	0.61	0.50	751.1	315.4	350.0	52.3	1.32	300.0 *	
2252.000	9,168	3.38	1.88	1.28	1.00	0.76	0.60	0.50	962.4	279.7	350.0	53.0	0.66	300.0 *	
2401.000	9,092	3.09	1.69	1.05	0.81	0.62	0.48	0.42	1328.2	248.0	350.0	66.0	1.19	300.0 *	
2550.000	9,072	3.89	2.40	1.56	1.20	0.92	0.70	0.58	1843.8	179.7	259.0	43.0	0.83	300.0	
2701.000	9,235	4.08	2.80	2.16	1.73	1.34	1.09	0.90	1748.5	286.3	228.6	28.6	1.07	300.0 *	
2852.000	9,219	5.39	3.19	1.81	1.24	0.95	0.76	0.66	1888.4	74.7	350.0	41.8	1.14	300.0 *	
3151.000	8,989	14.42	8.96	4.31	2.36	1.61	1.29	1.13	1081.8	15.2	66.2	23.6	2.01	121.3	
3301.000	9,164	5.14	3.22	2.04	1.48	1.10	0.86	0.71	1725.9	125.6	135.3	36.3	0.44	300.0	
3449.000	9,112	10.07	6.69	3.79	2.41	1.59	1.09	0.84	1809.8	35.0	30.0	25.8	1.61	202.5 *	Unstabilized
3600.000	9,076	7.92	5.52	3.57	2.43	1.68	1.22	0.95	2000.0	49.4	68.0	24.5	3.56	300.0 *	
3750.000	9,108	12.17	8.53	5.11	3.13	1.96	1.37	1.07	2000.0	16.3	71.6	20.0	3.42	155.1 *	
3900.000	9,088	9.57	6.61	4.02	2.49	1.62	1.15	0.89	2000.0	34.8	41.3	24.2	3.19	191.8 *	
4050.000	9,040	8.32	5.19	2.97	1.92	1.32	0.97	0.77	1307.0	65.9	31.9	30.8	0.22	300.0	
4200.000	9,124	6.64	4.24	2.72	2.01	1.45	1.10	0.88	1141.1	128.1	52.9	28.5	0.71	300.0	
4350.000	9,152	6.00	3.67	2.09	1.45	1.09	0.84	0.70	1895.0	65.7	246.9	36.4	0.45	300.0	
4441.000	9,176	5.75	3.71	2.28	1.55	1.08	0.83	0.68	2000.0	72.4	165.2	36.2	2.64	300.0 *	
Mean:		6.19	3.86	2.30	1.59	1.15	0.88	0.72	1510.3	133.7	201.1	37.9	1.27	300.0	
Std. Dev:		2.71	1.84	0.98	0.55	0.33	0.23	0.17	381.5	96.5	126.8	11.5	1.05	93.9	
Var Coeff(%):		43.78	47.82	42.53	34.45	28.55	25.93	24.33	25.3	72.1	63.0	30.3	82.38	33.7	

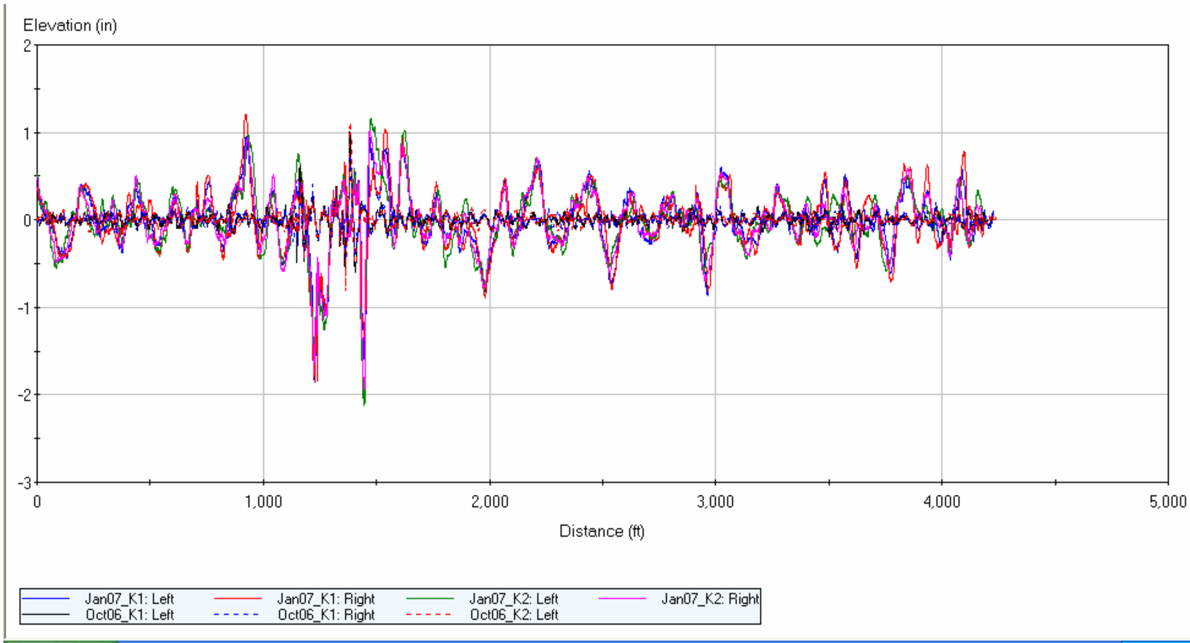

Figure 4.5. Plot of Pavement Smoothness from October 2006 to January 2007 for the Eastbound Lanes.

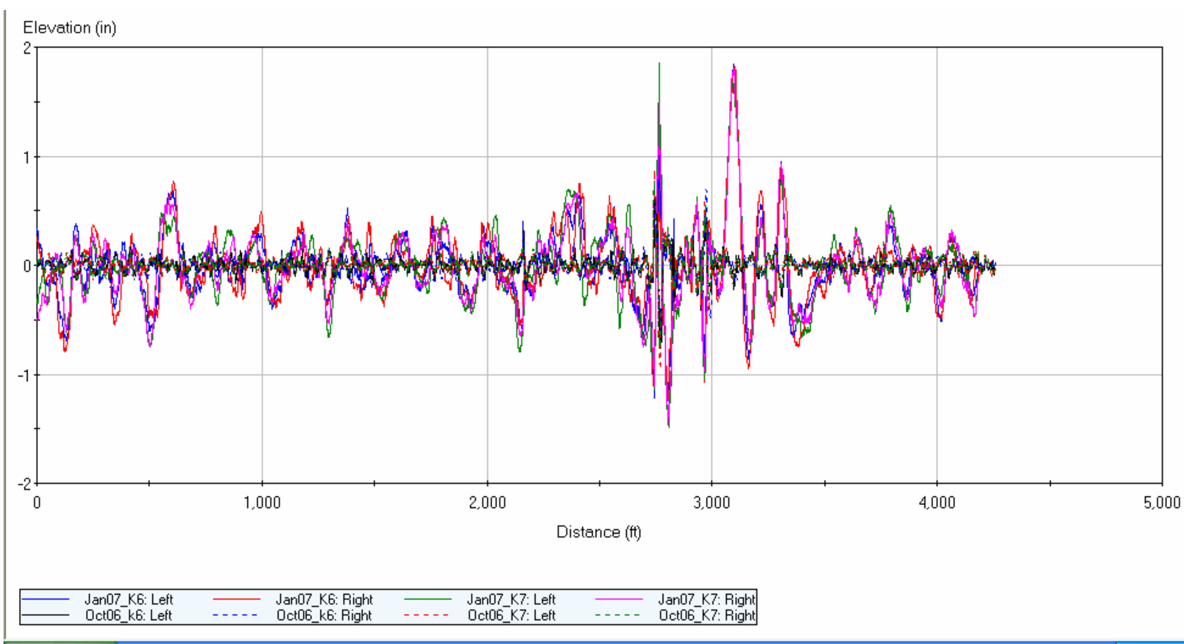

Figure 4.6. Plot of Pavement Smoothness from October 2006 to January 2007 for the Westbound Lanes.

The ride data were also entered into the Ride Quality Analysis software used for the TxDOT Smoothness Specification 585. Each wheelpath was analyzed separately to prevent averaging out any bumps or dips in the pavement, which may be the case if an average of the two (left and right) wheelpaths is used.

An analysis of the data reveal minor changes in bumps and dips from October to January. In January, Lane K1 (left wheelpath) had one dip in the high sulfate region that was not present in the data collected in October. The right wheelpath had one bump in the unstabilized section, one dip at the bridge approach, two bumps in the low sulfate stabilized section, and two bumps and two dips in the high sulfate stabilized section.

The data from Lane K2 (left wheelpath) reveal one dip in the low sulfate stabilized section that was not present in October. The data from the right wheelpath showed one dip at the bridge approach.

The data collected in January for Lane K6 (left wheelpath) indicate two new bumps in the unstabilized section. The data from the right wheelpath show two new bumps in the unstabilized section and one bump and one dip in the high sulfate stabilized section.

Lane K7 left wheelpath data reveal no bumps for October or January. There were only two bumps in the unstabilized section of the right wheelpath present in the data gathered in January. The size of the dips ranged from 0.5 to 8.5 feet wide by 0.151 to 0.240 inches deep. The size of the bumps ranged from a width of 0.5 to 7 feet and a height of 0.159 to 0.365 inches.

CONCLUSIONS

The FWD and DCP data show that the subgrade benefited from the addition of the GGBFS plus lime stabilizer on the form of higher strengths. However, the ride data suggest that there was some expansion of the subgrade, which resulted in decreased ride quality.

CHAPTER 5
EQUIPMENT ISSUES AND TRAINING MATERIALS

TASK 4 - EQUIPMENT ISSUES FOR DISTRICTS

TxDOT has concerns that it does not have the proper equipment to construct samples for the 3-D swell test. TxDOT's primary concern is access to a Superpave Gyratory compactor, which is capable of molding soil specimens to the densities obtained by proctor compaction. The compactor is, by far, the most expensive piece of equipment needed for the test. All districts that have been impacted by sulfate heave were contacted about the type of Superpave compactor that they use. All districts contacted use the Troxler Superpave compactor.

The researchers put together a training class held on April 24, 2007, for the Austin District and Claudia Izzo from the Materials and Pavements Section. They were instructed in the proper technique to use for mixing and molding specimens. They were also taught how to measure 3-D swell and given Excel spreadsheet templates in which to record and plot the data.

Both the Materials and Pavements Section (Cedar Park) and the Austin District lab use the Troxler compactor and successfully mold samples (data reported in Task 2) with a 4 inch diameter and 4.5 inches tall using the following settings: **400 KPa** pressure and **129 mm** sample height. The Troxler Superpave compactor is readily available in all districts affected by sulfates and will easily mold samples for the 3-D swell test.

Training Materials

The researchers put a 76-slide Powerpoint® presentation together for Caroline Herrera to use in a formal TxDOT training class dealing with stabilization of sulfate soils. We also submitted a 45-page document to include with the Powerpoint presentation as a training module for TxDOT to use in its "in house" training of employees.

APPENDIX A

Soil Sample Preparation with a Gyratory Compactor for Subgrade Soils with High Sulfates (>3000 ppm) (Laboratory Mixed)

Tex – XXX – E, Parts I and II

Soil Sample Preparation with a Gyratory Compactor for Subgrade Soils with High Sulfates (>3000 ppm) (Laboratory Mixed)

Prepare samples to measure the three-dimensional swell and/or unconfined compressive strength of subgrade soils containing sulfates in excess of 3000 ppm to gage the effectiveness of soil treatments in improving the engineering properties of the soil.

Apparatus

- Apparatus outlined in Test Methods Tex-101-E, Tex-113-E, Tex-117-E, and Tex-XXX-E, Part II (3-D swell)
- Compression Testing Machine, with capacity of 267 kN (60,000 lb), meeting the requirements of ASTM D 1633
- Triaxial Screw Jack Press, if anticipated strengths do not exceed 2758 kPa (400 psi)

Materials

- Hydrated lime
- Distilled water
- Approximately 200 lb of soil ****More soil will be needed if more than three different stabilizer combinations will be evaluated.*

Sample Preparation

Select approximately 91 kg (200 lb) of material and prepare in accordance with Test Method Tex-101-E, Part II.

Sampling

	Sample Preparation
Step	**Action**
1	Sample soil within the depth of proposed stabilization and maintain a gradation of 100% passing the ¾ inch sieve and 60% ±5% passing the #4 sieve.
2	Obtain enough soil to construct moisture density curves for both treated and untreated curves. In addition, there should be enough soil to construct two (4 in. x 4.5 in.), and three (4 in. x 6 in.) samples of each treatment combination selected for testing: five samples of the treated material and five samples of the untreated material at the moisture content of the treated material. Depending upon the maximum density of the soil, the amount of soil required to construct the samples may be vastly different.
3	Seal the soil in containers to maintain field moisture contents.

4	Determine the engineering properties (Tex-103-E, Tex-106-E, Tex-145-E, Tex-114-E) of the untreated soil, and establish the desired improvement (i.e., swell reduction, strength gain, etc.).
5	Select the treatments that are supposed to provide the desired improvement**.**

Procedure

	High Sulfate Soil Mix Design Procedure
Step	**Action**
1	Use only distilled water to dilute the chemicals or increase the water content of the soil.
2	Have the vendor supply the recommended application rate, mixing procedures, and curing procedure. The procedure should be the same for laboratory-molded samples and field application. **Note:** The engineer may decide to modify the recommended procedure if he or she deems it impractical to perform in the field.
3	Air dry or oven dry the soil (≤140°F) to facilitate pulverization so that 60% passes the #4 sieve. *Some vendors do not want the soil to be dried prior to addition of their product; the engineer may elect to use a more coarse gradation for specific cases.*
4	Use standard or modified proctor compactive effort to determine the optimum moisture content (OMC) and maximum density of the untreated soil using Tex-114-E and compact the treated soil using the procedure most fitting for the stabilizer (engineer's choice) to generate an OMD curve for the treated soil.
5	For soil to be treated, use distilled water to raise the soil moisture to a water content equal to the OMC of the treated soil minus the moisture content to be added with the chemical stabilizer. Allow the mixture to sit in a sealed container for approximately 16 hours.
6	For untreated control specimens, use distilled water to raise the soil moisture content to the OMC of the treated soil, and allow it to sit in a sealed container for approximately 16 hours. *It is imperative to construct samples treated with water only at the same level as the chemical treatment to determine the benefits of the chemical treatment.*
7	For the soil to be treated, mix in the vendor's recommended amount of chemical stabilizer using the recommended dilution ratio to bring the soil to the OMC of the treated soil. Mix the samples exactly how they are to be mixed in the field (i.e., dry, slurry, both, etc.).
8	Allow the treated mixture to sit in sealed stainless steel or plastic containers. For lime soil mixtures, allow the mixture to mellow for a minimum of 24 hours and a maximumof 72 hours. For any other stabilizers, allow the mixture to mellow according to vendor's recommendations.
9	Compact duplicate samples in a single lift, to a height of 4.5 inches and a diameter of 4 inches with a Superpave gyratory compactor at the moisture content and density determined in Step 4. Using an IPC Superpave gyratory compactor, the researchers set the height to terminate at 114.3 mm; using a maximum vertical stress of 250 to 300 kPa and an angle of gyration equal to 1.25 degrees usually achieved the correct compactive

	effort. Using a Troxler Superpave gyratory compactor, the Austin District determined that 400 kPa and 129 mm height yielded specimens 4.51 inches tall. **Note:** All samples should be no more than ±0.05 inches from 4.5 inches to maintain proper density.
10	Allow specimens to cure as outlined by the vendor unless the procedure cannot be replicated in the field. If no curing procedure is specified, then allow the specimens to cure for seven days at room temperature in a sealed plastic bag or container.
11	There should be two treated and two untreated specimens of each stabilizer combination. These specimens should be placed into a 3-D swell test (Tex-XXX-E, Part II).
12	Compact three treated and three untreated specimens (4 in. x 6 in.) for unconfined compressive strength using the drop hammer (Tex-113-E).
13	Allow samples to moist cure for a period of seven days before measuring UCS.
14	Follow UCS testing with Atterburg limits (Tex-106-E) and soil pH (Tex-128-E).

Interpretation of Data

Upon completion of these tests, there should be data of UCS measurements after seven day moist cure and 3-D swell data with UCS data following the 3-D swell test. The chemical stabilizers should meet the following criteria to be considered for treatment of subgrade soils:

- The treatment must reduce 3-D swell to 7% or less. (If the 3-D swell for the untreated soil is less than 5%, then the treated soil must not swell any more than the untreated soil.)
- The UCS of the treated soil should be at least 50 psi after curing and at least 25 psi greater than the strength of the untreated soil. (Both treated and untreated samples are to be cured exactly the same.)
- The UCS of the treated soil following the 3-D swell test should be at least 25 psi greater than the strength of the untreated soil.

APPENDIX B

Three-Dimensional Swell Measurements for Subgrade Soils with High Sulfates (>3000 ppm) (Laboratory Mixed)

Tex – XXX – E, Part II

Three-Dimensional Swell Measurement for Subgrade Soils with High Sulfates (>3000 ppm) (Laboratory Mixed)

This procedure monitors the three-dimensional swell of subgrade soils containing sulfates in excess of 3000 ppm to gage the effectiveness of soil treatments in improving the engineering properties of the soil.

Apparatus

- Apparatus outlined in Test Methods Tex-101-E, Tex-113-E, Tex-117-E, and Tex-XXX-E (3-D swell)
- Superpave Gyratory Compactor (IPC Servopac or Troxler Model 4140)

Materials

- Hydrated lime
- Ground granulated blast furnace slag, fly ash
- Distilled water
- Pie tape (0.5 mm divisions), scale (measure up to 10,000 g), 4 in. x 0. 5 in. porous stones (two for each sample), metal ruler (marked in 10ths and 100ths scale inches), calipers (digital to ten thousandths of an inch), paper towels (brown roll), latex membranes (4 in. by 0.012 in., Humboldt part# HM-4180.40), permanent marker, coated wire racks (enough for each set of samples tested), 20 gallon ice chests (one for each set of samples tested), Whatman No. 42 filter paper (4 in. diameter).
- Approximately 200 lb of soil. **More soil will be needed if more than three different stabilizer combinations will be evaluated.*

Sample Preparation:

Select approximately 91 kg (200 lb) of material and prepare in accordance with Test Method Tex-101-E, Part II.

Procedure

	3-D Swell Measurement
Step	**Action**
1	Using Tex-XXX-E, Part I, mold duplicate samples for each stabilizer combination in one lift with a Superpave gyratory compactor.
2	Weigh each sample immediately after it has been molded; place it on a 4 in. x 0.5 in. high

	porous stone with a Whatman #42 filter paper between the sample and porous stone label of the sample name, and record the weight and date on worksheet 1.
3	Measure the circumference of each sample in three places (near the bottom, top, and middle) using the pie tape, and record on worksheet 1.
4	Measure the height of each sample at approximately 120° intervals, and record on worksheet 1.
5	Let the samples air dry for three days**.**
6	Repeat steps 2, 3, and 4 for each sample immediately after molding.
7	Wet a brown paper towel in distilled water, and place it around the circumference of the sample.
8	Place another 4 in. diameter x 0.5 in. high porous stone on top of the sample.
9	Place a rubber membrane around the sample, and label the membrane with the sample name using a permanent marker.
10	Mark the membrane at approximately 120° intervals for height measurements around the circumference of the sample.
11	With the porous stones and membrane in place, measure the circumference and height as in steps 3 and 4.
12	Place the duplicate samples on a rubber-coated metal rack or a strong plastic rack, and set it in a 20-gallon ice chest. The ice chest should be air tight to control humidity (95 ±5%) and temperature (77° ±3.6°F or 25° ±2°C).
13	Add enough distilled water to the ice chest so the water level is near the top of the porous stones placed on the bottom of the samples but not high enough to be in direct contact with the soil in the samples.
14	Monitor swell as in steps 3 and 4 for at least the next 45 days or until swell plot has reached an asymptote (Figure B1).
15	Plot the percent swell (on y-axis) over time (in days on x-axis) using a spreadsheet like Excel (Figure B1).
16	Perform an unconfined compressive strength test on the samples following the swell test to compare with the UCS measurements made after moist curing for seven days (Tex-XXX-E, Part I). This test will give an indication of strength retention and permanence of stabilization.

WORKSHEET 1

Specimen:	
Description:	
Molded Date:	
Date Started in Swell Testing:	

Swell Test Measurements:

Date	Ht 1 (in)	Ht 2 (in)	Ht 3 (in)	Circ 1 (mm)	Circ 2 (mm)	Circ 3 (mm)	H2O Conductivity	H20 pH	H20 SO4 Content (ppm)

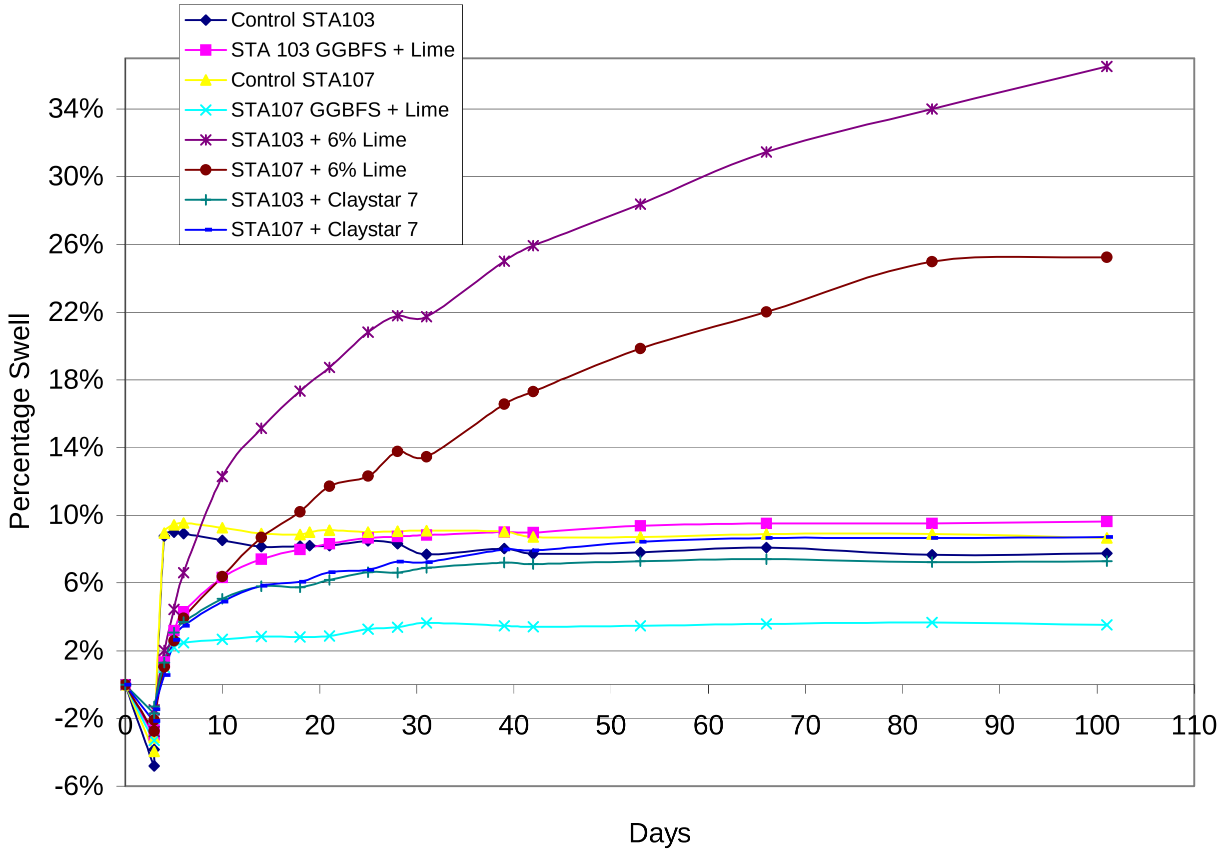

Figure B1. Graph of 3-D Swell Showing That Curves Reach Asymptote at Different Times.

Interpretation of Data

Upon completion of these tests, there should be data of UCS measurements after a seven day moist cure and 3-D swell data with UCS data following the 3-D swell test. The chemical stabilizers should meet the following criteria to be considered for treatment of subgrade soils:

- The treatment must reduce 3-D swell to 7 percent or less. (If the 3-D swell for the untreated soil is less than 5 percent, then the treated soil must not swell any more than the untreated soil.)
- The UCS of the treated soil should be at least 50 psi after curing and at least 25 psi greater than the strength of the untreated soil. (Both treated and untreated samples are to be cured exactly the same.)
- The UCS of the treated soil following the 3-D swell test should be at least 25 psi greater than the strength of the untreated soil.