Performance Monitoring of State Highway 289 in Grayson County, Texas

By

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INTRODUCTION

Over the past 20 years problems with sulfate induced heave in pavements have surfaced around the world. This problem 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. The State Highway (SH) 289 Extension project 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.

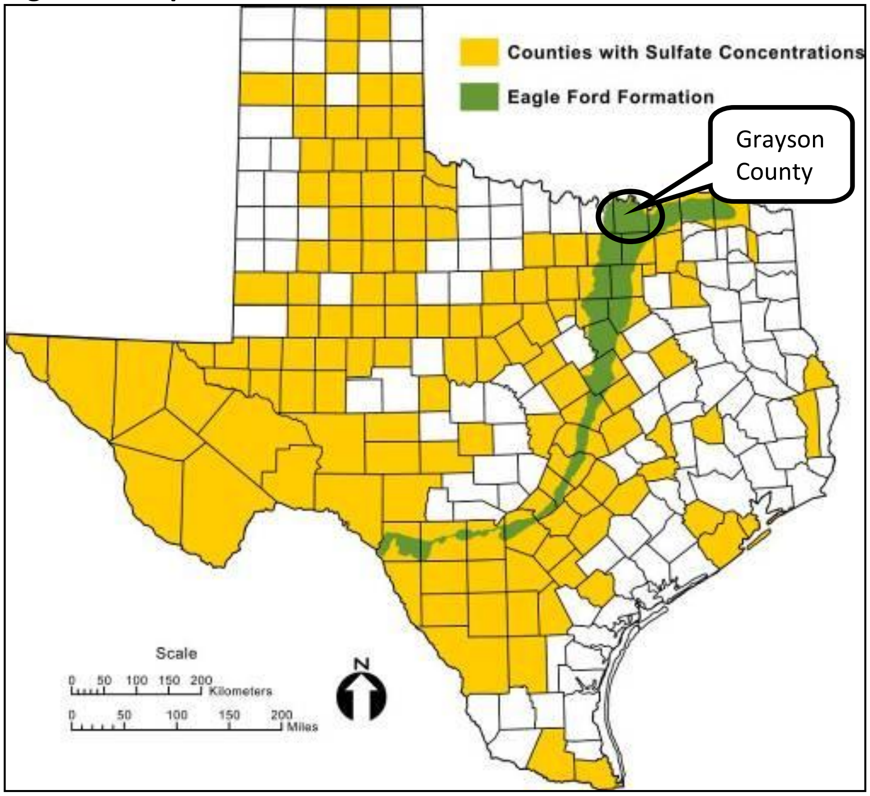
Subsequent to the project construction, H&L was contracted by the Lime Association of Texas to provide long-term performance monitoring on the SH 289 project and to provide a projected cost comparison of the methods that were utilized on this project versus the cost of removing and replacing the sulfate rich soil with suitable replacement fill. As part of the performance monitoring, H&L collected profile data on the project and also collected lime treated subgrade samples to perform additional sulfate testing approximately 1 year after stabilization. H&L had the assistance of TxDOT in providing some of these performance tests, such as falling weight deflectometer (FWD), dynamic cone penetrometer (DCP), and ground penetrating radar (GPR). All field tests were performed in mid-March 2010.

BACKGROUND

Sulfate heave problems typically occur during or shortly after construction after a heavy rain event. 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. If the highway construction is performed during a dry season, then the failure may be delayed several years. Future problems are usually associated with an unusual rainfall event.

In the past several 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. Grayson County is located entirely in the Eagle Ford shale formation. This is shown in Figure 1.

Figure 1. Map of Texas Counties Known to have Sulfate-Rich Soils (2)



Significant sulfates concentrations were encountered on the SH 289 extension project in October, 2008, during the construction of the 8-inches of lime stabilized subgrade. H&L performed field and laboratory testing in accordance with the following TxDOT tests methods: TEX-145-E, Determining Sulfate Contents in Soils-Colorimetric Method, and TEX-146-E, Conductivity Test for Field Detection of Sulfates. These methods were employed to test from approximately station number 240+00 to station number 550+00. Additionally, samples from the borrow pits were collected for further laboratory evaluation.

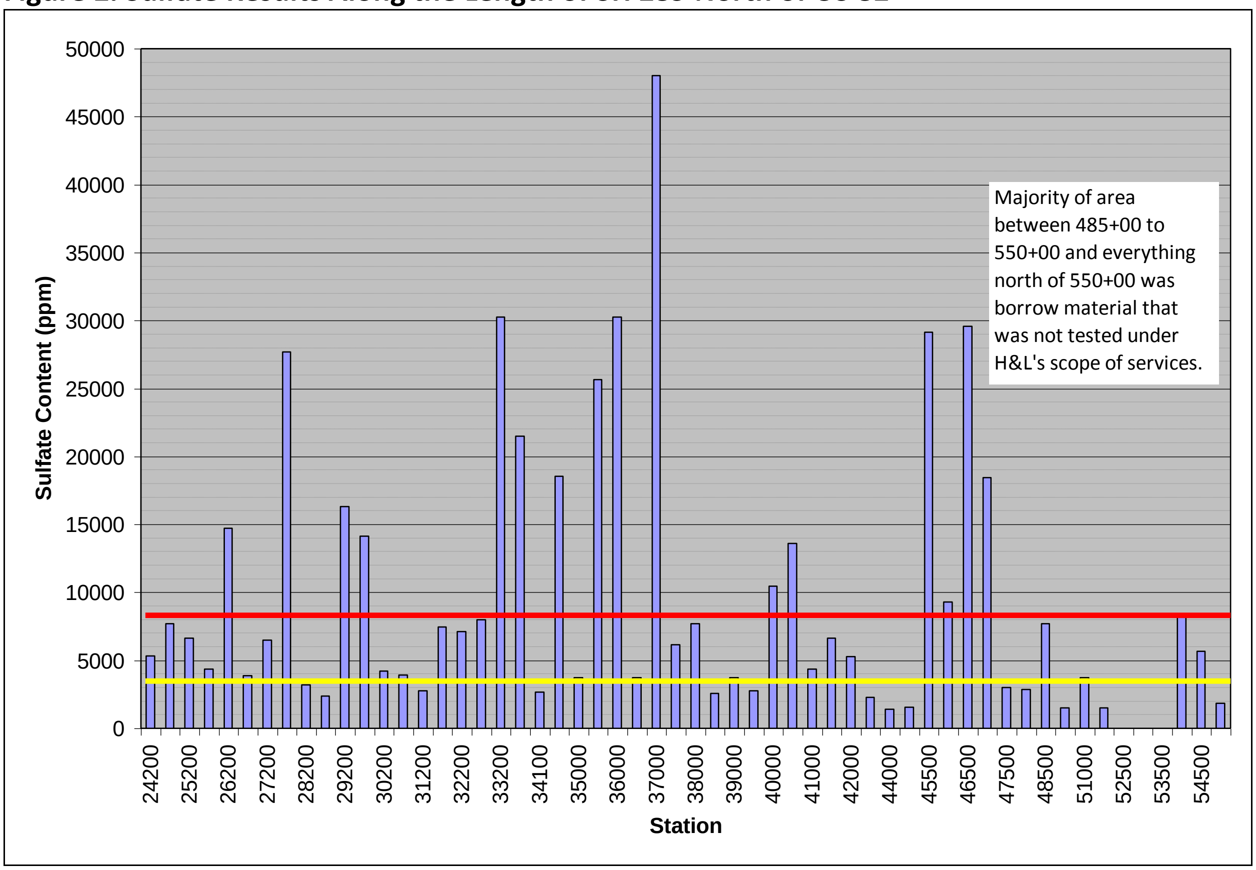
The results of the field conductivity measurements and the laboratory sulfate analysis aided in the selection of materials to include in the laboratory mix design testing developed under TTI project 4240, which includes unconfined compressive strength testing and volumetric swell measurements. Because of the high variability of sulfate concentrations and because the presence of sulfates was so extensive along this project, a design limit of 30,000 ppm sulfates was set to reduce the amount of material that would need to be removed and replaced. The ability of the material to be stabilized by both traditional and non-traditional stabilizers was evaluated in the mix design and would be determined by an increase in strength and a reduction in volumetric swell. (2)

In the meantime, in an effort to reduce additional construction delays and penalties, a pretreatment of the subgrade with a 3 percent lime slurry application followed by an extended mellowing period was suggested in the hopes of inducing some of these sulfate reactions prior to placement of the subsequent pavement layers. Early indications in the field & in the laboratory were that for the most part the sulfate-rich subgrade soils could be effectively lime stabilized with extended mellowing techniques.

Initial Field Investigation

Testing in the field was conducted in accordance with TxDOT test method TEX-146-E, in which the conductivity of the soils is measured in an effort to identify the extent of the sulfate concentration and to determine where materials were to be sampled for further laboratory testing. The actual sulfate concentrations of the sampled materials were then determined in the laboratory in accordance with TxDOT test method TEX-145-E. Based on the results of these two tests, materials collected from stations 277+00, 307+00, 370+00, and 465+00 were selected for inclusion in the laboratory mix design to be discussed later. Results of the sulfate testing along the length of the project north of US 82 are shown in Figure 2.

Figure 2. Sulfate Results Along the Length of SH 289 North of US 82



High concentrations of sulfate deposits were observed all along the project during the field investigation. 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 3.

Figure 3. Variety of Sulfate Concentrations and Crystal Sizes Observed at Various Locations

3a. Station 277+00

3b. Station 425+00

3c. Station 425+50

3d. Borrow Pit

3e. Station 345+00

3f. Station 372+00

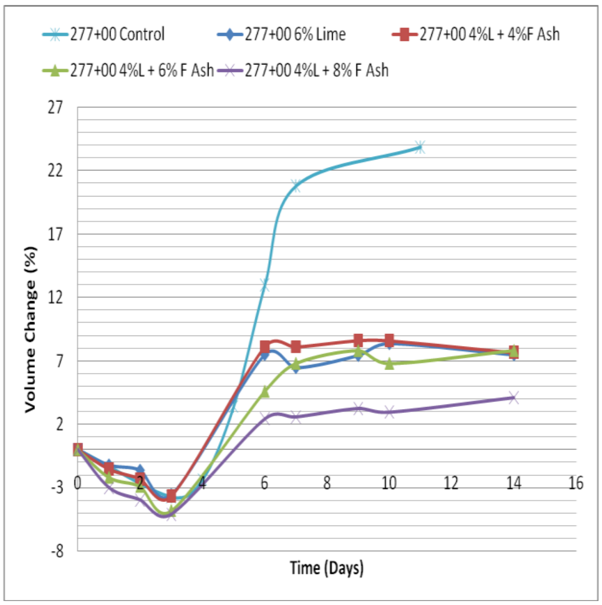
Laboratory Mix Design

The laboratory mix design testing developed under TTI project 4240, which includes unconfined compressive strength testing and volumetric swell measurements, was followed. As was previously mentioned, a design limit was set for materials containing 30,000 ppm or less. 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. (Even though sulfate concentrations exceeded the 30,000 ppm design limit, soils collected at station 370+00 were included in this portion of the testing because of the high variability of sulfate concentrations.)

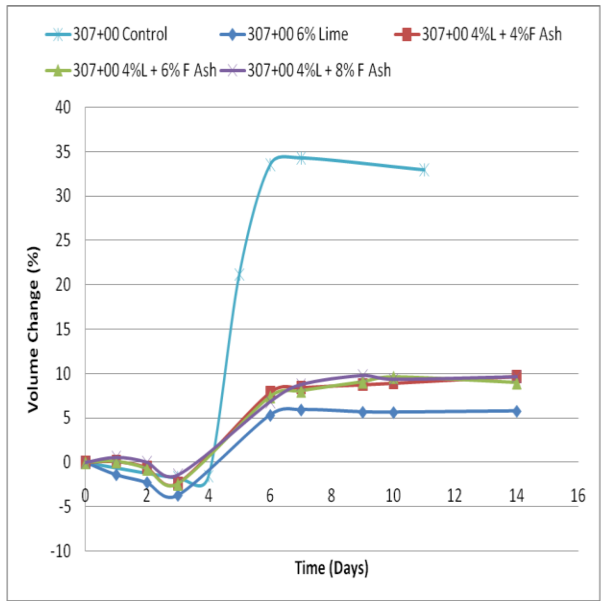
The ability of the material to be stabilized by both traditional and non-traditional stabilizers was evaluated in the mix design and would be determined by an increase in strength and a reduction in volumetric swell. As was previously discussed, a pretreatment of the subgrade with a 3 percent lime slurry application followed by an extended mellowing period was suggested to be performed while the laboratory mix design was being conducted in the hopes of inducing some of these sulfate reactions prior to placement of the subsequent pavement layers. Because of this recommendation, samples were also pre-treated with a 3 percent lime application in the lab and allowed to mellow for 3 days prior to molding the samples. 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.

Figure 4. Volumetric Swell Results

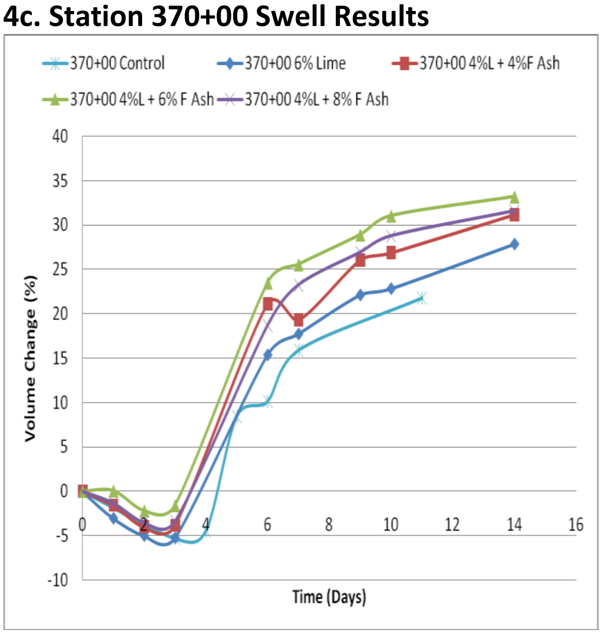
4a. Station 277+00 Swell Results



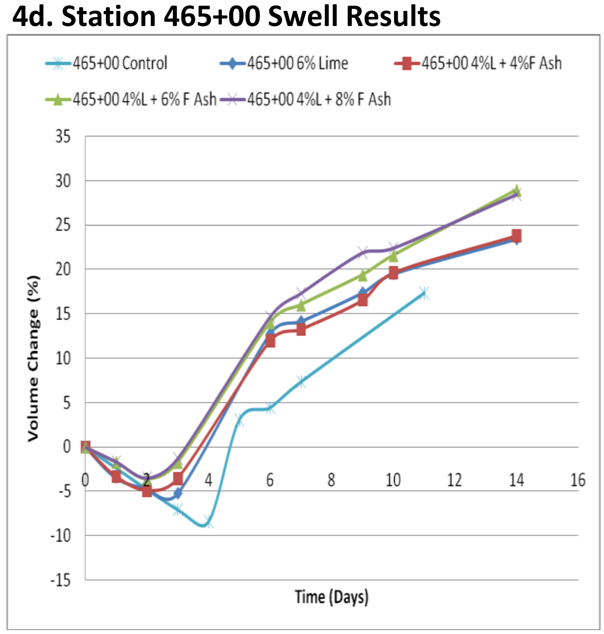
4b. Station 307+00 Swell Results



4c. Station 370+00 Swell Results



4d. Station 465+00 Swell Results



Final results for the laboratory mix design testing are shown in Table 1.

Table 1. Final Mix Design Test Results

Sample Station Location	Plasticity Index	Initial Sulfate Content (ppm)	Sample ID	Wet UCS after Swell Test (psi)	Final % Change in Volume
277+00	37	27,680	**Control**	3.66	23.87
			6% Lime	41.64	7.46
			4% Lime + 4% F Ash	41.56	7.65
			4% Lime + 6% F Ash	42.04	7.83
			4% Lime + 8% F Ash	71.29	4.12
307+00	32	3,900	**Control**	2.23	32.98
			6% Lime	19.19	5.78
			4% Lime + 4% F Ash	31.53	9.69
			4% Lime + 6% F Ash	55.18	8.97
			4% Lime + 8% F Ash	36.70	9.61
370+00	55	48,000	**Control**	1.91	21.82
			6% Lime	11.54	27.84
			4% Lime + 4% F Ash	4.46	31.14
			4% Lime + 6% F Ash	2.95	33.20
			4% Lime + 8% F Ash	4.22	31.58
465+00	48	29,564	**Control**	2.23	17.39
			6% Lime	4.14	23.41
			4% Lime + 4% F Ash	4.78	23.82
			4% Lime + 6% F Ash	5.49	28.95
			4% Lime + 8% F Ash	6.21	23.39

Subgrade Pre-Treatment Recommendations

While the laboratory mix design was being conducted, the client was provided with some construction recommendations. These included the removal of material that was found to contain greater than 30,000 ppm sulfate concentrations to a depth of 24-inches or greater from the top of the finished subgrade and that these materials be replaced with suitable fill material with a sulfate concentration less than 3000 ppm. Upon completion of this step, it was recommended that the subgrade be pulverized to a depth of 8 inches and pretreated with a 3 percent lime slurry application. It was further recommended that an additional 4 percent moisture above optimum be applied and mixed into the pre-treated material and allowed to mellow for a minimum of 7 days. Additionally, based on construction notes for another high-sulfate project in Texas provided by Mike Arellano, P.E. with TxDOT, it was recommended that the soil-lime mixture be sprinkled continuously during the mellowing period to prevent the loss of moisture. In addition, it was suggested that the soil-lime mixture be pulverized repeatedly during the mellowing period in an effort to break down gypsum crystals and to allow the water to penetrate throughout the lime treated layer. Again, these suggestions were made in the hopes of inducing some of the sulfate reactions while the mix design was being conducted and prior to placement of the subsequent pavement layers.

These recommendations were followed from approximately station 240+00 to 339+00, and a pre-treatment of 3 percent lime slurry was applied to the subgrade at optimum moisture plus 2 percent. This treated material was kept wet and reworked approximately 3 to 5 times for a period of 7 days. After no apparent signs of sulfate-induced heave were observed, it was decided to add the remaining 3 percent lime. This was followed by another mellowing period. The project also received several inches of rainfall during this time.

In late November, more field testing was conducted on the areas of subgrade that had received the full 6 percent lime treatment to evaluate the performance of the lime stabilized subgrade. More specifically, we were looking for any signs of sulfate-induced heave on this treated section. Additional samples were also collected in the field that had received the full 6 percent lime treatment to compare the sulfate concentrations obtained before and after lime treatment. These results are shown in Table 2.

Table 2. Sulfate Concentrations Before and After Lime Stabilization in the Field

Station No.	Sulfate Concentration Before Lime Stabilization (ppm)	Sulfate Concentration After Lime Stabilization (ppm)
242+00	5320	1920
272+00	6480	1440
277+00	27680	3300
292+00	16320	4720
307+00	3900	3420
317+00	7440	2300

Recommendations for Construction

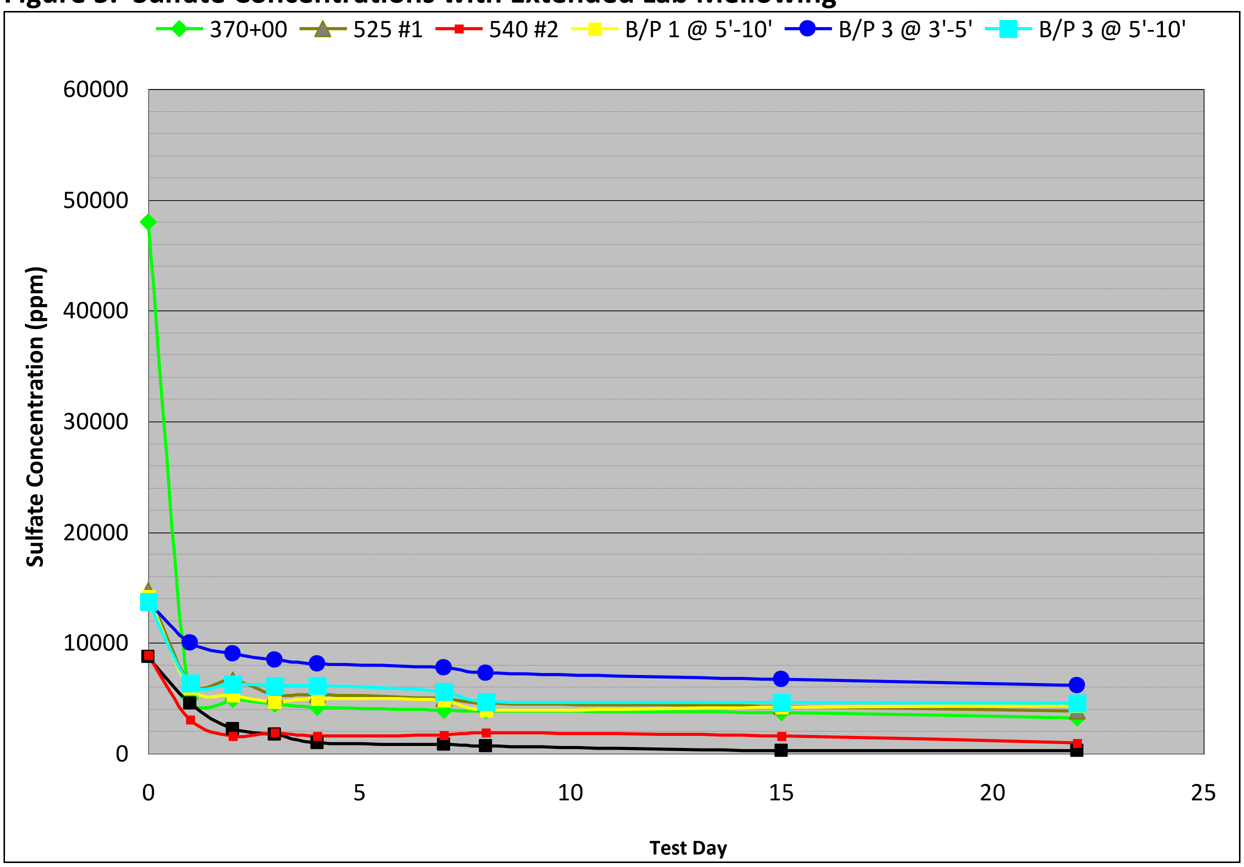
There were several causes for concern in regard to the sulfate concentrations on this project. The high range of variability in both field conductivities and actual measured sulfate concentrations demanded extreme caution during construction of the stabilized subgrade. Secondly, because of the wide range of performance of materials tested during the lab mix design, especially when comparing the vastly different results obtained from stations 277+00 and 465+00, which had comparable sulfate concentrations, it was apparent that no generalities could be applied. With that being said, there were also several favorable factors that lended themselves to an ultimately successful construction project.

The drastic difference in both swell and strength results obtained in the laboratory at stations 277+00 and 465+00 was surprising. In the visits to the project to evaluate the performance of the lime stabilized subgrade, several observations were made that could potentially explain this difference in performance. The most notable difference in material observed in the field was the size of the gypsum crystals. Refer back to Figure 3 for an example of this.

Initially, a pre-treatment of the subgrade was suggested with 2 to 3 percent lime slurry, keep it wet, and pulverize it several times during the mellowing period in the hopes of inducing some of the sulfate reactions, while the lab mix design was being conducted. This was done on a portion of the project located approximately between station 240+00 and station 339+00. This was 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 Table 2.)

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, H&L conducted sulfate testing 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. Then 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.

Figure 5. Sulfate Concentrations with Extended Lab Mellowing



If this section continues to perform well with time it could indicate that the testing sequence undertaken in this project would be a better test of lime's ability to treat soils with high sulfate content. If the soil does well in strength gain, volumetric swell and also shows a large drop in available sulfates then it should be a good candidate for lime stabilization.

Based on the field testing and observations as well as the lab testing and mix designs, it is hypothesized that the size of the gypsum crystals may have a greater impact on a subgrade's candidacy for lime stabilization than does the actual sulfate content. Additionally, the construction technique used between station 240+00 and station 339+00 indicated that pre-treating and mellowing subgrades with high sulfate concentrations of finer gypsum crystals in some instances provide a viable alternative for this project. However, based on the lab performance of the samples tested from 370+00 and 465+00 and the size of the gypsum crystals observed in these areas, it was suggested that materials in those locations be removed and placed at the bottom of the embankment fill for the railroad overpass located at the far north end of the project. The exact limits of materials that were recommended for removal were as follows:

- From Station 339+00 to 375+00
- From Station 420+00 to 427+00
- From Station 455+00 to 470+00

Fill material from borrow pits east of the project replaced these unsuitable materials.

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. 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.

PERFORMANCE MONITORING RESULTS (MARCH 2010)

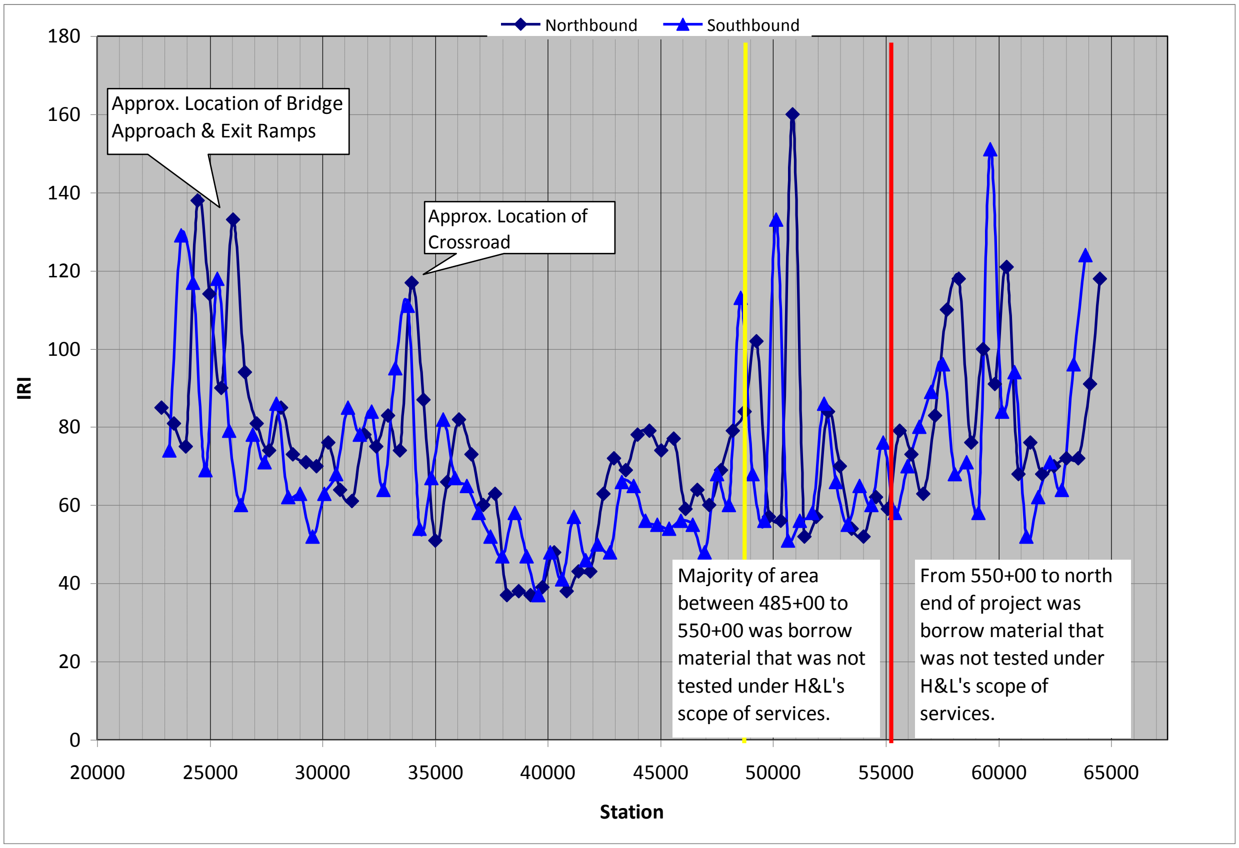
H&L visited the SH 289 project in March, 2010 in order to collect profile data as well as additional lime treated subgrade samples in order to perform sulfate testing approximately 1 year after stabilization. Also, H&L had the assistance of TxDOT in providing some other performance tests, such as falling weight deflectometer (FWD), and dynamic cone penetrometer (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) H&L collected profile data in accordance with TxDOT spec item 585, Ride

Quality for Pavement Surfaces and utilized the profile data to evaluate the possibility of the development of sulfate induced heave. Results from the profiling are shown in Figure 6.

Figure 6. Profile Data for SH 289 North of US 82



Pay adjustment schedules for Spec Item 585 are shown in the Appendix under Table A1.

Sulfate Testing

During its March site visit, H&L collected additional samples in order to monitor sulfate concentrations on the stabilized subgrade. H&L collected these samples at locations where sulfate concentrations had been previously determined. A comparison of concentrations before stabilization and approximately 14 months after stabilization is shown in Table 3. Sulfate concentrations determined 1-2 weeks after lime stabilization are also provided. (All sulfate testing was conducted in accordance with TEX 145-E.)

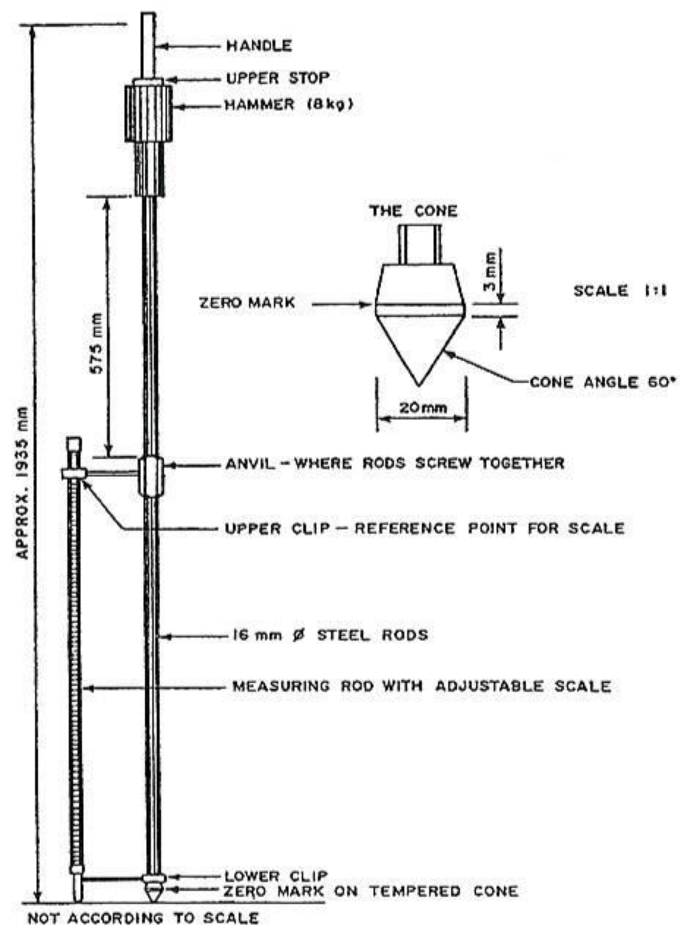
Table 3. Sulfate Concentrations Before and ~ 14 Months After Lime Stabilization in the Field

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

Dynamic Cone Penetrometer

The Dynamic Cone Penetrometer (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. A schematic of the DCP is shown in Figure 7.

Figure 7. Schematic of Dynamic Cone Penetrometer



The 8-kg (17.6-pound) weight is raised to a height of 575 mm (22.6 inches) and then dropped, driving the cone into the soil or other material being tested. 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. Back-Calculated Modulus results are shown in Figures 8 – 12 for various locations. (DCP data & results are shown in the Appendix in Tables A2-A6.)

Figure 8. Modulus Results from DCP Testing at Sta 242+00

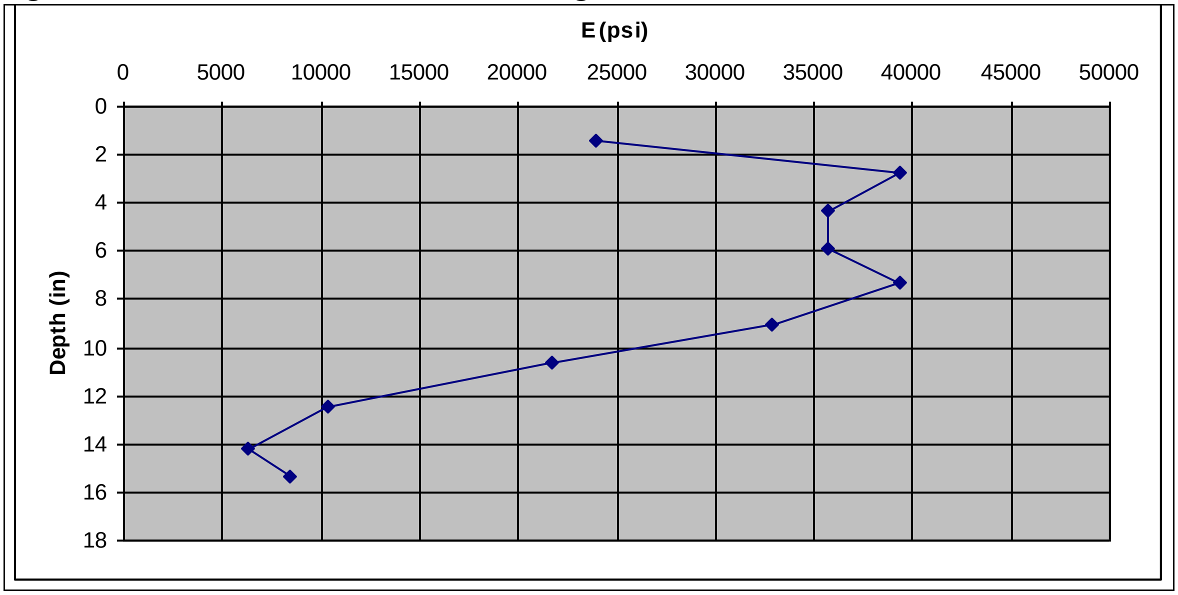


Figure 9. Modulus Results from DCP Testing at Sta 277+00

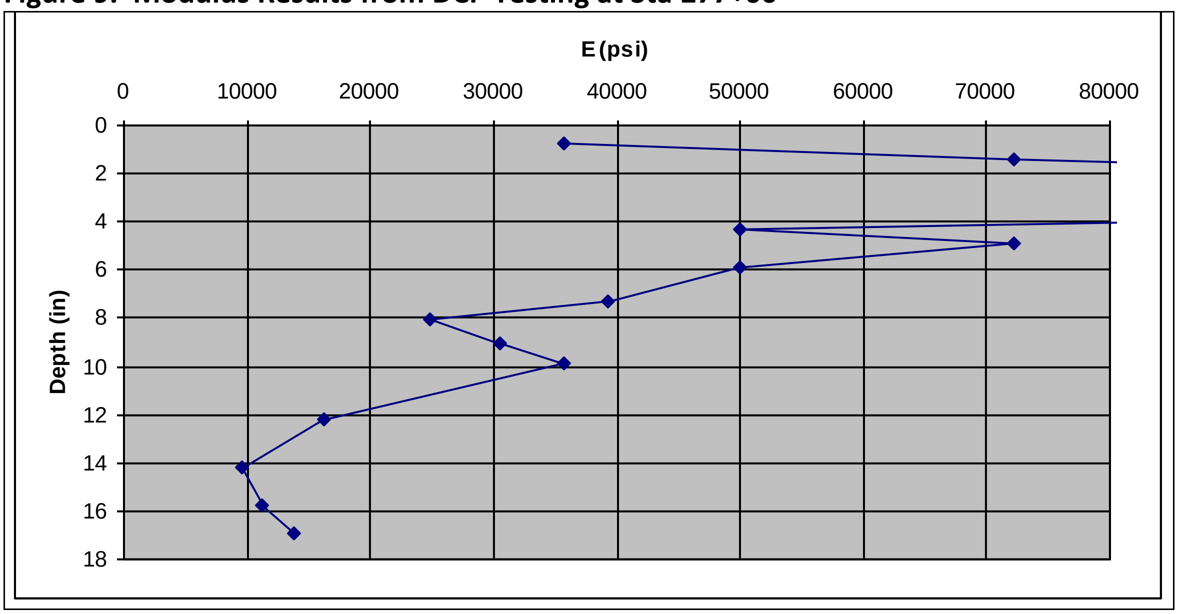


Figure 10. Modulus Results from DCP Testing at Sta 345+00

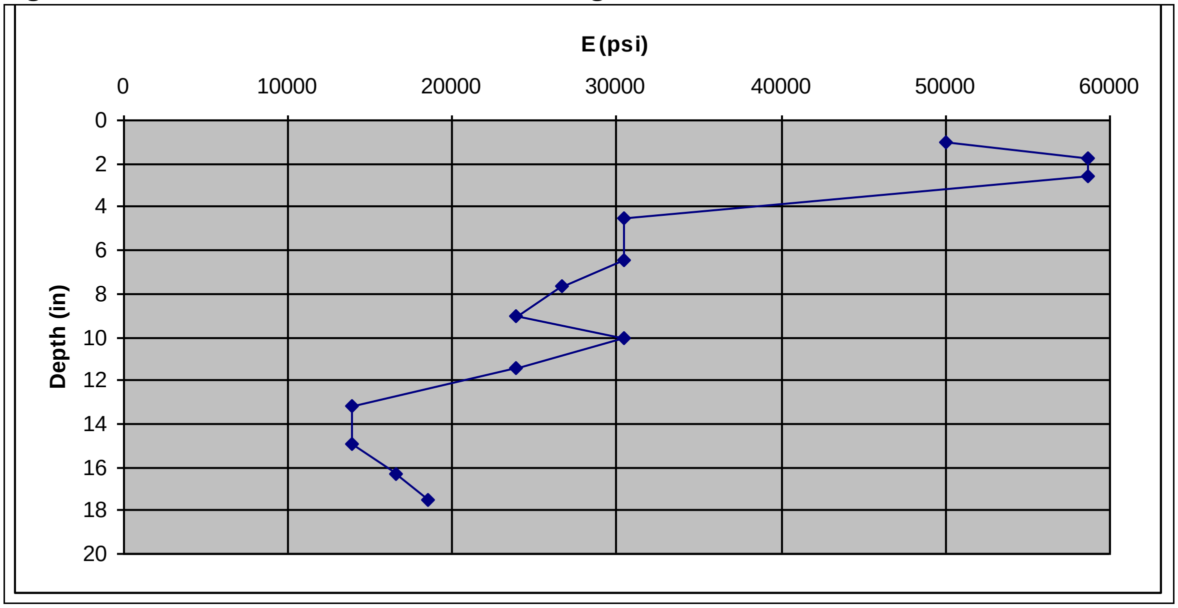


Figure 11. Modulus Results from DCP Testing at Sta 377+00

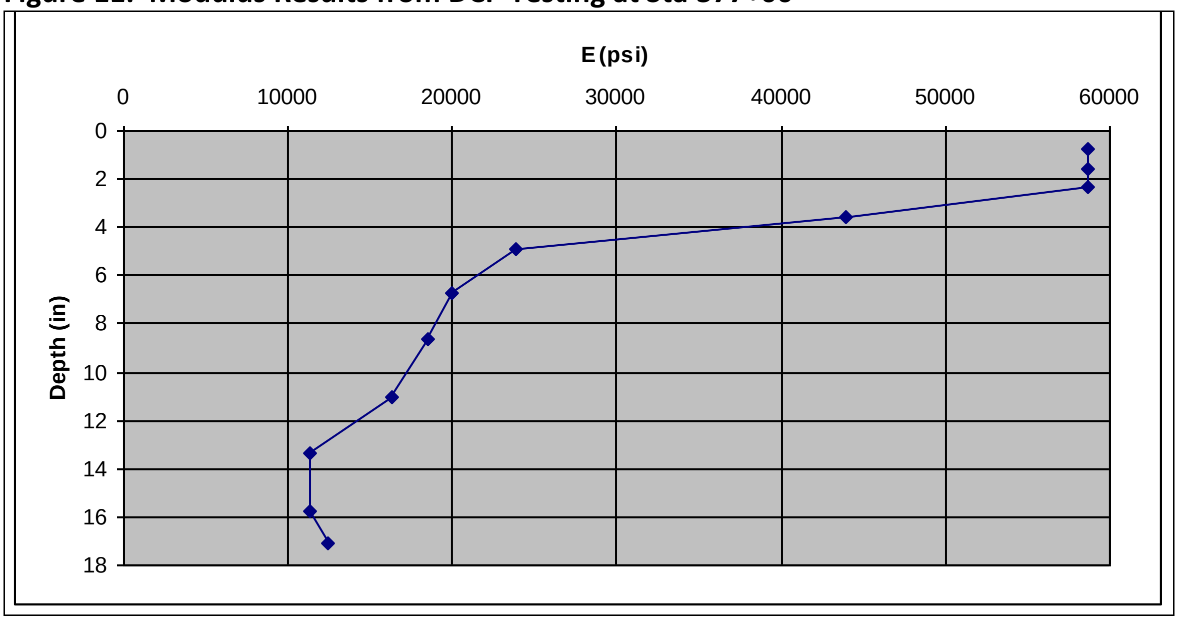
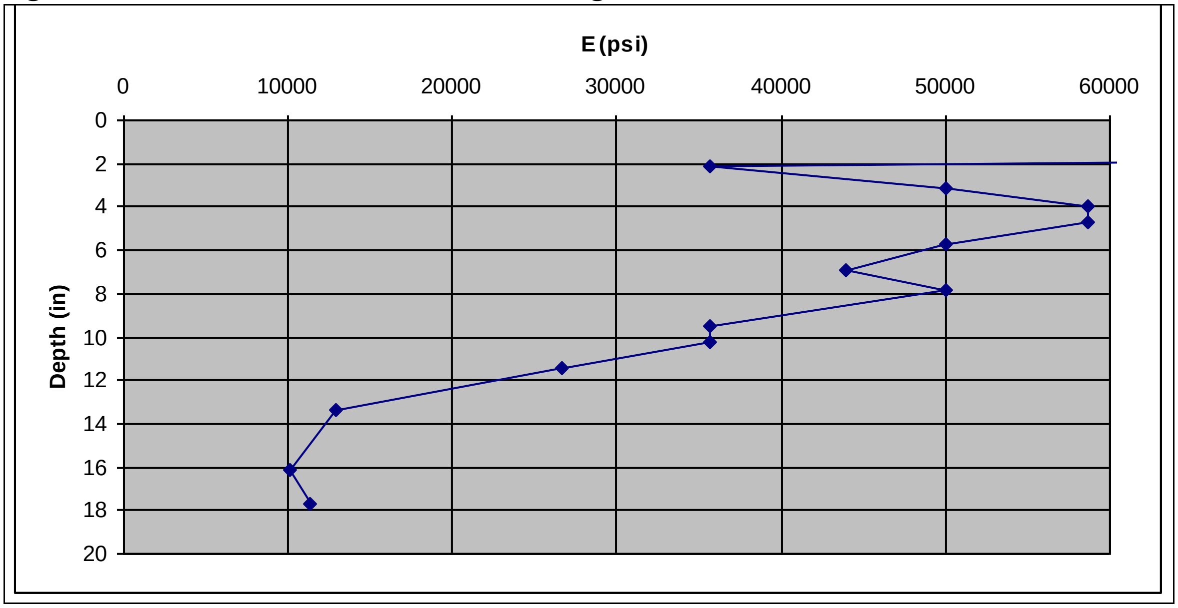


Figure 12. Modulus Results from DCP Testing at Sta 465+00

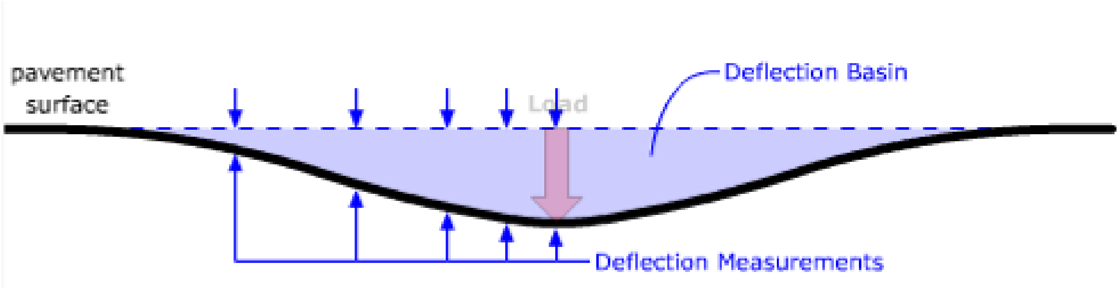


Falling Weight Deflectometer Testing

The Falling Weight Deflectometer (FWD) is a non-destructive test that is used to evaluate a flexible pavement structure by 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.

Pavement deflection is measured by applying a force to the pavement and measuring the vertical deflected distance of the pavement surface. An example of this is shown in Figure 13.

Figure 13. FWD Deflection Measurements (3)



FWD data was collected in the outside wheel-path of the north and southbound outside lanes. For the analysis, the cement stabilized base and the lime stabilized subgrade were combined into one layer, as the subgrade in this pavement structure will experience a very low stress because the loads are well distributed in the cement-stabilized base layers. Overall, the modulus values for the flexible base are very high with normal values being in the range of 50 to 70 ksi. This can be contributed to the fact that the base is confined from below by the cement-stabilized layer, and the base was dry at the time of testing. From the results of the

FWD testing, it can be deemed that this pavement is structurally sound. As with any pavement, it is essential to keep moisture out of the flexible base. The results of the FWD analysis are shown in Tables 4 and 5.

Table 4. FWD Analysis (NB Lanes)

		Measured Deflections (mils):							Calculated Moduli values (ksi):				Absolute	Dpth to
Station	Load (lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
5.501	9,668	4.63	2.71	2.06	1.61	1.22	1.17	0.89	822.10	250.00	419.10	34.20	4.26	300.00 *
5.6	9,561	5.49	3.48	2.92	2.45	1.96	1.91	1.66	822.10	228.30	588.40	18.40	3.14	300.00
5.701	9,644	6.60	3.09	1.93	1.41	0.98	0.89	0.63	822.10	163.90	141.10	43.70	4.26	256.30
5.801	9,382	13.53	8.65	5.12	3.46	2.41	2.21	1.56	822.10	108.90	50.00	15.60	6.52	287.40 *
5.9	9,271	14.23	7.11	3.54	2.32	1.61	1.53	1.19	822.10	56.50	50.00	23.80	7.34	267.90 *
6	9,422	12.35	7.35	4.13	2.71	1.80	1.56	1.20	822.10	109.70	50.00	21.30	5.80	189.50 *
6.107	9,334	14.38	8.41	4.26	2.50	1.62	1.43	1.06	822.10	57.50	50.00	21.40	11.83	164.50 *
6.209	9,537	8.91	4.77	2.89	2.10	1.49	1.36	1.00	822.10	155.50	82.20	28.40	4.45	300.00
6.303	9,628	7.17	4.30	2.67	1.82	1.31	1.21	0.95	822.10	250.00	93.00	31.90	5.69	300.00 *
6.429	9,370	15.28	8.14	3.58	2.19	1.52	1.35	1.00	822.10	44.30	50.00	24.50	8.72	140.30 *
6.505	9,581	11.29	6.56	3.69	2.40	1.61	1.44	1.15	822.10	138.20	50.00	25.00	5.69	201.90 *
6.601	9,549	7.66	4.70	3.19	2.51	1.96	1.95	1.57	822.10	190.30	161.90	20.80	5.99	300.00
6.701	9,513	7.83	4.78	2.69	1.87	1.40	1.39	1.13	822.10	250.00	74.50	30.70	7.94	300.00 *
6.801	9,406	10.72	8.02	5.28	3.69	2.58	2.29	1.70	822.10	250.00	50.00	15.30	5.53	296.20 *
6.901	9,545	7.22	4.66	3.32	2.40	1.70	1.54	1.16	822.10	250.00	113.70	23.90	4.56	300.00 *
7.011	9,390	10.81	6.88	4.39	2.93	2.08	1.91	1.46	822.10	216.20	50.00	19.10	5.16	300.00 *
7.106	9,231	17.80	11.77	7.17	4.52	3.10	2.93	2.19	822.10	53.20	50.00	11.10	9.79	269.80 *
7.204	9,569	5.64	3.71	3.06	2.52	1.99	1.93	1.54	822.10	250.00	454.10	18.40	3.38	300.00 *
7.301	9,581	6.12	3.89	2.81	2.18	1.69	1.63	1.28	822.10	250.00	230.50	23.60	4.90	300.00 *
7.402	9,581	6.09	3.41	2.34	1.85	1.42	1.39	1.13	822.10	190.60	244.40	29.80	5.52	300.00
7.501	9,577	5.90	3.27	2.17	1.63	1.22	1.15	0.93	822.10	235.60	178.10	35.60	4.85	300.00
7.601	9,589	5.46	3.13	2.42	1.93	1.32	1.30	1.01	822.10	243.80	278.60	29.60	4.05	223.40
7.701	9,680	4.80	2.89	2.47	2.12	1.74	1.77	1.44	822.10	204.10	1237.40	19.70	4.14	300.00
7.801	9,581	5.70	3.77	3.03	2.47	1.96	1.93	1.54	822.10	250.00	427.20	18.80	4.10	300.00 *
7.901	9,406	10.04	6.06	3.84	2.92	2.13	2.05	1.55	822.10	162.20	79.60	19.00	5.37	300.00
8.001	9,414	12.24	7.64	4.82	3.47	2.44	2.15	1.60	822.10	161.80	50.00	16.40	3.58	300.00 *
8.101	9,581	6.32	3.75	2.67	2.09	1.61	1.56	1.30	822.10	214.70	223.90	25.50	4.85	300.00
8.204	9,581	3.67	2.51	2.19	1.84	1.49	1.46	1.17	822.10	250.00	1124.30	25.90	6.13	300.00 *
8.304	9,501	7.18	4.31	3.01	2.30	1.75	1.69	1.35	822.10	209.90	158.80	23.40	4.78	300.00
8.445	9,569	8.04	4.40	2.83	2.21	1.68	1.63	1.29	822.10	140.60	148.60	25.50	5.78	300.00
8.501	9,418	6.44	4.19	2.99	2.26	1.73	1.69	1.34	822.10	250.00	187.90	22.50	5.36	300.00 *
8.6	9,533	6.30	3.41	2.24	1.75	1.36	1.39	1.04	822.10	169.20	229.10	31.30	7.00	230.00
8.604	9,346	4.72	2.85	2.12	1.63	1.27	1.25	1.01	822.10	250.00	329.90	32.40	5.11	300.00 *
8.701	9,529	7.42	4.09	2.74	2.06	1.57	1.57	1.16	822.10	158.10	162.90	26.70	5.99	300.00
8.806	9,509	7.63	4.16	2.72	1.92	1.38	1.35	1.01	822.10	182.80	111.40	30.00	5.28	300.00
8.903	9,477	8.98	5.13	3.34	2.40	1.71	1.60	1.24	822.10	176.10	84.90	24.00	4.30	300.00
9.01	9,477	9.27	5.81	4.06	2.90	2.17	2.05	1.53	822.10	221.90	84.80	18.60	4.33	300.00
9.102	9,541	6.89	3.60	2.62	2.04	1.56	1.48	1.14	822.10	138.20	254.50	26.70	3.98	300.00
9.201	9,525	8.18	4.15	2.61	1.97	1.52	1.46	1.21	822.10	119.40	144.00	28.60	5.88	300.00
9.334	9,374	12.31	7.77	4.93	3.33	2.31	2.08	1.65	822.10	149.90	50.00	16.60	5.28	275.10 *
9.402	9,517	7.44	4.74	3.54	2.81	2.23	2.23	1.82	822.10	202.10	214.00	17.30	5.00	300.00
9.501	9,378	11.94	7.48	5.17	3.75	2.79	2.66	2.13	822.10	159.20	64.50	14.20	4.20	300.00
9.603	9,378	13.44	9.88	6.78	4.76	3.37	3.06	2.23	822.10	196.40	50.00	11.00	5.38	300.00 *
9.701	9,521	7.50	4.67	3.26	2.39	1.70	1.55	1.20	822.10	250.00	112.20	23.90	3.80	300.00 *
9.801	9,553	6.62	3.79	2.65	1.95	1.38	1.20	0.86	822.10	250.00	132.60	30.60	2.50	300.00 *
9.9	9,513	8.48	5.22	3.64	2.67	1.93	1.76	1.36	822.10	238.40	93.30	21.10	3.27	300.00
10.006	9,501	9.21	5.66	3.69	2.78	2.13	2.08	1.65	822.10	179.30	98.40	19.40	5.84	300.00
10.102	9,497	10.00	6.17	4.32	3.23	2.41	2.27	1.80	822.10	175.90	90.80	16.70	3.85	300.00
10.201	9,529	7.58	4.87	3.86	3.13	2.39	2.35	1.86	822.10	203.60	231.20	15.60	3.43	300.00
10.301	9,466	9.59	5.48	4.00	3.16	2.42	2.31	1.83	822.10	115.40	157.60	16.30	3.79	300.00
10.4	9,549	6.72	3.22	2.56	2.05	1.57	1.51	1.20	822.10	107.10	476.00	25.80	3.29	300.00
10.498	9,477	10.20	5.03	3.07	2.42	1.82	1.74	1.46	822.10	83.90	118.20	23.30	5.59	300.00
10.551	9,402	12.02	6.56	4.22	3.03	2.15	1.97	1.51	822.10	108.70	63.70	18.80	3.59	300.00
	Mean:	8.72	5.21	3.43	2.51	1.84	1.74	1.36	822.10	181.50	198.10	23.20	5.17	300.00
	Std. Dev:	3.10	2.01	1.11	0.70	0.49	0.45	0.35	0.00	61.20	233.10	6.50	1.68	58.30
	Var Coeff(%):	35.57	38.55	32.53	28.05	26.43	25.81	25.58	0.00	33.70	117.70	28.20	32.44	20.10

Table 5. FWD Analysis (SB Lanes)

		Measured Deflections (mils):							Calculated Moduli values (ksi):				Absolute	Dpth to
Station	Load (lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0	9,803	8.59	5.24	3.35	2.52	1.85	1.73	1.29	822.10	228.80	89.20	25.40	4.52	300.00
0.123	9,680	12.25	3.52	2.59	2.13	1.78	1.72	1.38	822.10	26.60	1001.40	24.90	3.78	300.00
0.2	9,613	7.16	4.87	3.72	2.85	2.23	2.20	1.69	822.10	250.00	192.80	19.30	4.77	300.00 *
0.301	9,787	6.83	4.51	3.45	2.81	2.29	2.28	1.81	822.10	249.80	261.00	19.50	4.27	300.00 *
0.401	9,807	7.28	4.82	3.41	2.54	1.96	1.64	1.52	822.10	250.00	119.90	25.20	2.76	300.00 *
0.505	9,760	5.87	4.08	3.39	2.54	2.03	1.72	1.54	822.10	250.00	273.10	23.20	3.79	300.00 *
0.507	9,763	6.33	4.23	3.31	2.69	2.16	2.13	1.63	822.10	250.00	296.70	20.70	3.87	300.00 *
0.6	9,724	8.37	5.53	3.51	2.44	1.71	1.52	1.15	822.10	250.00	77.20	26.20	5.29	288.30 *
0.701	9,779	5.50	3.10	2.37	1.87	1.42	1.26	0.86	822.10	247.80	273.30	33.90	1.31	300.00
0.804	9,704	7.85	5.08	3.53	2.65	1.92	1.76	1.26	822.10	250.00	111.50	23.80	3.60	300.00 *
0.912	9,485	13.14	8.63	5.56	3.94	2.87	2.64	1.94	822.10	153.20	50.00	15.20	4.71	300.00 *
1.001	9,525	11.54	7.09	4.56	3.31	2.41	2.12	1.56	822.10	189.40	51.50	19.00	2.92	300.00
1.102	9,589	6.90	4.68	3.48	2.77	2.21	2.20	1.76	822.10	250.00	215.20	19.70	4.72	300.00 *
1.292	9,593	9.60	5.13	2.92	2.11	1.55	1.47	1.13	822.10	144.50	70.10	30.60	5.69	300.00
1.401	9,561	8.24	4.90	3.24	2.30	1.60	1.51	1.18	822.10	250.00	78.00	27.90	4.32	267.00 *
1.501	9,477	12.27	7.74	5.44	3.83	2.75	2.50	1.84	822.10	197.00	50.00	16.00	3.42	300.00 *
1.603	9,632	5.37	3.29	2.52	1.99	1.57	1.52	1.17	822.10	250.00	335.90	28.90	3.62	300.00 *
1.704	9,473	9.60	5.19	2.81	1.97	1.50	1.43	1.12	822.10	151.60	62.00	32.10	6.55	300.00
1.802	9,537	7.16	4.69	3.35	2.49	1.84	1.69	1.22	822.10	250.00	130.40	24.60	4.06	300.00 *
1.903	9,589	6.28	3.38	2.31	1.74	1.34	1.28	1.00	822.10	197.40	189.00	35.60	4.37	300.00
2.003	9,505	7.14	4.75	3.29	2.41	1.82	1.70	1.35	822.10	250.00	118.40	24.90	4.91	300.00 *
2.055	9,688	3.67	2.58	2.17	1.81	1.49	1.31	1.24	822.10	250.00	461.40	39.60	14.58	300.00 *
2.104	9,549	6.94	4.07	2.73	1.99	1.53	1.52	1.19	822.10	227.40	137.30	30.20	5.46	300.00
2.206	9,521	7.06	4.20	2.90	2.03	1.51	1.45	1.12	822.10	250.00	117.60	30.00	4.98	300.00 *
2.306	9,517	6.90	4.08	3.03	2.33	1.77	1.66	1.24	822.10	218.20	175.30	25.70	2.67	300.00
2.402	9,501	5.83	3.97	2.92	2.28	1.79	1.50	1.17	822.10	250.00	208.30	26.70	3.14	300.00 *
2.505	9,549	5.43	3.48	2.39	1.84	1.46	1.39	1.06	822.10	250.00	263.40	31.40	5.33	300.00 *
2.602	9,481	7.35	4.49	3.13	2.54	1.96	1.85	1.42	822.10	207.10	163.80	23.40	3.70	300.00
2.701	9,509	6.85	4.67	3.51	2.70	2.12	2.08	1.61	822.10	250.00	192.10	20.30	4.78	300.00 *
2.804	9,589	6.21	4.22	3.22	2.48	1.92	1.86	1.44	822.10	250.00	260.00	22.40	4.78	300.00 *
2.901	9,501	5.40	3.13	2.28	1.79	1.37	1.31	1.00	822.10	250.00	261.50	33.60	3.49	300.00 *
3	9,454	5.29	3.43	2.27	1.57	1.12	0.94	0.74	822.10	250.00	187.80	39.50	7.56	300.00 *
3.105	9,485	5.80	3.67	2.67	1.97	1.38	1.24	1.06	822.10	250.00	162.20	33.00	5.20	278.90 *
3.208	9,529	4.72	2.83	2.33	1.93	1.55	1.55	1.24	822.10	238.60	678.50	28.00	3.44	300.00
3.303	9,497	6.90	4.58	3.42	2.77	2.18	2.09	1.64	822.10	250.00	204.00	20.10	3.59	300.00 *
3.402	9,557	5.85	3.70	2.83	2.34	1.87	1.79	1.39	822.10	250.00	318.10	24.00	3.26	300.00 *
3.504	9,394	8.26	5.43	3.56	2.53	1.88	1.74	1.37	822.10	250.00	81.40	23.70	4.97	300.00 *
3.606	9,410	9.36	5.55	3.39	2.35	1.69	1.54	1.15	822.10	223.20	57.40	27.00	4.36	300.00
3.708	9,148	16.11	9.35	4.76	3.19	2.24	1.99	1.50	822.10	46.30	50.00	17.70	7.82	300.00 *
3.803	9,454	6.20	4.05	2.76	2.07	1.58	1.49	1.15	822.10	250.00	178.30	28.40	4.84	300.00 *
3.9	9,434	6.37	5.03	3.87	2.98	2.26	2.19	1.70	822.10	250.00	217.80	18.70	6.98	300.00 *
3.999	9,386	11.59	7.28	4.29	2.81	1.89	1.64	1.13	822.10	142.30	50.00	22.10	6.02	208.80 *
4.066	9,374	11.57	7.75	4.77	3.16	2.05	1.60	1.13	822.10	158.90	50.00	20.10	8.57	164.30 *
4.101	9,315	11.33	7.07	4.19	2.58	1.45	1.22	0.88	822.10	128.30	50.00	25.50	12.84	96.10 *
4.201	9,394	9.86	5.84	3.34	2.00	1.44	1.40	1.10	822.10	184.00	50.00	30.40	7.96	190.30 *
4.306	9,394	10.65	6.35	3.70	2.54	1.74	1.48	1.05	822.10	169.40	50.00	25.60	3.57	237.40 *
4.401	9,414	9.89	7.31	4.81	3.22	2.08	1.63	1.08	822.10	250.00	50.00	20.40	8.60	160.00 *
4.499	9,362	8.87	5.46	3.16	2.20	1.56	1.48	1.13	822.10	250.00	55.60	29.00	5.92	300.00 *
4.605	9,243	12.33	7.18	3.98	2.56	1.73	1.65	1.28	822.10	100.10	50.00	23.40	7.63	216.20 *
4.703	9,267	10.13	6.96	4.74	3.37	2.31	1.91	1.33	822.10	250.00	50.00	19.00	3.90	242.60 *
4.802	9,382	5.44	2.74	1.82	1.33	0.88	0.69	0.52	822.10	250.00	141.20	52.10	3.60	175.40 *
4.91	9,477	6.16	3.65	2.64	2.08	1.59	1.49	0.97	822.10	238.70	204.70	28.90	3.01	300.00
5.001	9,458	6.72	3.81	2.72	2.02	1.51	1.42	1.04	822.10	215.50	156.20	30.30	3.31	300.00
5.048	9,418	9.11	5.42	3.25	2.12	1.50	1.43	1.20	822.10	250.00	50.00	30.50	5.19	300.00 *
5.107	9,485	8.49	4.99	3.07	2.12	1.56	1.43	1.19	822.10	241.10	67.60	29.80	4.58	300.00
5.207	9,414	7.23	4.31	2.73	1.97	1.48	1.36	1.09	822.10	250.00	100.10	31.00	4.70	300.00 *
5.304	9,338	7.74	4.15	2.38	1.68	1.30	1.27	1.04	822.10	178.90	89.50	36.10	6.83	300.00
5.402	9,398	7.68	5.57	3.83	2.67	1.93	1.72	1.30	822.10	250.00	93.40	22.90	6.14	300.00 *
5.508	9,398	7.23	3.65	2.22	1.73	1.31	1.26	1.00	822.10	146.30	141.90	36.00	5.71	300.00
5.607	9,327	8.15	4.41	2.63	1.77	1.23	1.06	0.84	822.10	225.10	62.50	37.50	2.74	263.30
5.703	9,398	6.36	2.98	1.89	1.50	1.19	1.17	0.92	822.10	134.80	226.30	40.10	6.46	300.00
5.8	9,434	6.63	3.75	2.60	1.86	1.43	1.38	1.07	822.10	219.50	148.40	32.20	4.51	300.00
5.905	9,406	6.26	3.53	2.59	2.09	1.63	1.54	1.44	822.10	182.60	261.40	28.00	3.18	300.00
5.908	9,350	9.21	6.37	4.90	3.77	2.82	2.53	2.09	822.10	250.00	92.60	15.70	3.45	300.00 *
6	9,374	6.44	3.44	2.53	2.08	1.63	1.55	1.24	822.10	149.30	301.00	28.10	3.40	300.00
Mean:		7.92	4.85	3.25	2.38	1.76	1.63	1.26	822.10	215.60	169.50	27.00	4.98	300.00
Std. Dev:		2.36	1.49	0.84	0.56	0.40	0.37	0.29	0.00	52.00	154.20	6.80	2.20	82.40
Var Coeff(%):		29.83	30.79	25.92	23.47	22.60	22.88	23.25	0.00	24.10	91.00	25.40	44.06	28.80

COST COMPARISON OF IN-PLACE LIME STABILIZATION VERSUS REMOVE & REPLACE

A significant portion of H&L's scope of services included providing a projected cost-benefit analysis of the in-place lime stabilization of sulfate-rich subgrades using extended mellowing techniques as opposed to the removal and replacement with suitable material. In order to accomplish this, several assumptions had to be made.

First, unsuitable material was defined as that with sulfate concentrations in excess of 30,000 ppm and that this unsuitable material could be placed in an embankment within the limits of the roadway. Also, replacement material could be obtained from either a local source that would require extended mellowing or a source that met the specified 3000 ppm sulfate limit. Secondly, it was assumed that embankment material obtained from on-site or from a local borrow source contained sulfates with levels ranging from 3000 to 30,000 ppm and that the extended mellowing technique would require 2 more additional manipulations than typical stabilization. Costs for the 2 additional manipulations were obtained from TxDOT's 12-month average bid prices for lime stabilization. Also, no royalties were added for the borrow material, which could have a significant impact on the overall cost comparison.

Approximately 5500 feet of material 60 feet wide and 24-inches deep (24,444 cubic yards) was recommended for removal. (For simplicity, the cost comparison will focus on the removal and replacement of this amount of material, and unit prices will be derived based on that.) It was also recommended that this material be buried in the large embankment fill at the far north end of the project. Estimates for the cost to remove the 5500 feet of material that was recommended for removal and to be placed in the embankment fill at the north end of the project were based on the following:

- 1 foreman with a pickup
- 1 Cat D-10 dozer
- 1 Cat D-10 dozer operator
- 5 Cat 631 scrapers
- 5 Cat 631 scraper operators
- 1 Cat 140 motorgrader
- 1 Cat 140 motorgrader operator

It was further assumed that approximately 5400 cubic yards of material could be removed in a day for a total of 5 days to remove the 24,444 cubic yards recommended for removal on this project. This was based on an estimated 30 pushes per hour, 10-hours a day, and 18 cubic yards per load.

As was previously discussed, this project is located in Grayson County, which is located entirely within the Eagle Ford Shale formation. This formation is well known for its sulfate-rich soils. Therefore, the exact location of suitable replacement material is unknown, and it was decided to estimate the costs to haul suitable material from a range of distances. Estimates for suitable imported borrow are based on the following:

- 1 foreman with a pickup
- 1 Cat 345 excavator
- 1 Cat 345 excavator operator
- 1 Cat D-6 dozer
- 1 Cat D-6 dozer operator

Haul costs will vary dependant upon the distance from the source to the project site. These costs were tabulated based on the information provided in Table 6.

Table 6. Variable Haul Costs with Distance

Haul Distance (miles)	No. trucks Required	Hourly Rate
5-10	12	$80.00
10-15	14	$80.00
15-20	17	$80.00
20-25	20	$80.00
25-30	24	$80.00

Lastly, the cost to place the suitable replacement material was also considered and was based on the following:

- 1 foreman with a pickup
- 1 Cat D-6 dozer
- 1 Cat D-6 dozer operator
- 1 Cat 815 roller
- 1 Cat 815 roller operator
- 1 Cat 140 motorgrader
- 1 Cat 140 motorgrader operator
- 1 water truck
- 1 water truck driver
- 1 Survey crew with related equipment and supplies

Based on all of the information listed above, a unit rate was developed per cubic yard of material for removal, and suitable replacement material was estimated based on varying haul distances from the project. These calculations are shown in Table 7.

Table 7. Determination of Unit Rates for Cost Comparison

ITEM DESCRIPTION	QTY	UNITS	EST. TIME TO COMPLETE (HRS)	RATE	LABOR COST	EQUIPMENT COST	SUBS	SUB-TOTALS	TOTAL & UNIT PRICE
COST OF REMOVING 24,444 CY OF MATERIAL AND PLACING IN SLOPES AT AN ESTIMATED 50 HOURS OF PRODUCTION									
FOREMAN WITH PICKUP	1.00	MH	50.00	$ 46.88	$2,343.75			$ 2,343.75	
PICKUP	1.00	HR	50.00	$ 10.00		$ 500.00		$ 500.00	
CAT D-10 DOZER	1.00	HR	50.00	$175.00		$ 8,750.00		$ 8,750.00	
CAT D-10 DOZER OPERATOR	1.00	MH	50.00	$ 30.00	$1,500.00			$ 1,500.00	
CAT 631 SCRAPER	5.00	HR	50.00	$110.00		$27,500.00		$ 27,500.00	
CAT 631 SCRAPER OPERATORS	5.00	MH	50.00	$ 16.50	$4,125.00			$ 4,125.00	
CAT 140 MOTORGRADER	1.00	HR	50.00	$ 80.00		$ 4,000.00		$ 4,000.00	
CAT 140 MOTORGRADER	1.00	MH	50.00	$ 33.00	$1,650.00			$ 1,650.00	
							TOTAL PRICE		$ 50,368.75
							UNIT RATE		$ 2.06
COST OF IMPORTING 27,160 CY OF MATERIAL THAT MEETS SPECS AT AN ESTIMATED 70 HOURS OF PRODUCTION									
FOREMAN WITH PICKUP	1.00	MH	70.00	$ 46.88	$3,281.25			$ 3,281.25	
PICKUP	1.00	HR	70.00	$ 10.00		$ 700.00		$ 700.00	
CAT 345 EXCAVATOR	1.00	HR	70.00	$135.00		$ 9,450.00		$ 9,450.00	
CAT 345 EXCAVATOR	1.00	MH	70.00	$ 30.00	$2,100.00			$ 2,100.00	
CAT D-6 DOZER	1.00	HR	70.00	$ 85.00		$ 5,950.00		$ 5,950.00	
CAT D-6 DOZER OPERATOR	1.00	MH	70.00	$ 21.00	$1,470.00			$ 1,470.00	
							TOTAL PRICE		$ 22,951.25
							UNIT RATE		$ 0.85
COST OF COMPACTING SELECT MATERIAL AT AN ESTIMATED 100 HOURS OF PRODUCTION									
	27,160.00	CY							
FOREMAN WITH PICKUP	1.00	MH	80.00	$ 46.88	$3,750.00			$ 3,750.00	
PICKUP	1.00	HR	80.00	$ 10.00		$ 800.00		$ 800.00	
CAT D-6 DOZER	1.00	HR	80.00	$ 85.00		$ 6,800.00		$ 6,800.00	
CAT D-6 DOZER OPERATOR	1.00	MH	80.00	$ 21.00	$1,680.00			$ 1,680.00	
CAT 815 ROLLER	1.00	HR	80.00	$ 93.00		$ 7,440.00		$ 7,440.00	
ROLLER OPERATOR	1.00	MH	80.00	$ 17.40	$1,392.00			$ 1,392.00	
CAT 140	0.50	HR	40.00	$ 80.00		$ 1,600.00		$ 1,600.00	
CAT 140 MOTORGRADER	0.50	MH	40.00	$ 33.00	$ 660.00			$ 660.00	
WATER TRUCK	1.00	HR	80.00	$ 60.00		$ 4,800.00		$ 4,800.00	
WATER TRUCK DRIVER	1.00	MH	80.00	$ 17.40	$1,392.00			$ 1,392.00	
SURVEY CREW	2.00	MH	20.00	$150.00	$6,000.00			$ 6,000.00	
SURVEY	1.00	HR	20.00	$ 35.00		$ 700.00		$ 700.00	
SURVEY SUPPLIES	1.00	LS	0.00	$100.00		$ 100.00		$ 100.00	
							TOTAL PRICE		$ 37,114.00
							UNIT RATE		$ 1.37
VARYING HAUL COSTS (TRUCKS)									
									UNIT RATE
5 TO 10 MILES	12.00	HR	70.00	$ 80.00			$ 67,200.00	$ 67,200.00	$ 3.32
10 TO 15 MILES	14.00	HR	70.00	$ 80.00			$ 78,400.00	$ 78,400.00	$ 3.74
15 TO 20 MILES	17.00	HR	70.00	$ 80.00			$ 95,200.00	$ 95,200.00	$ 4.36
20 TO 25 MILES	20.00	HR	70.00	$ 80.00			$112,000.00	$112,000.00	$ 4.97
25 TO 30 MILES	24.00	HR	70.00	$ 80.00			$134,400.00	$134,400.00	$ 5.80

As a baseline, costs included in the original bid are considered not to include any additional stabilization methods. The presence of sulfates in excess of 3000 ppm would then require additional manipulation to achieve a stable subgrade. Stabilization of these sulfates would add additional costs to this baseline budget. In our analysis, there are two options to address the presence of sulfates. The first option is the cost associated with using the on-site, or local, material that contained between 3000 to 30,000 ppm sulfates and the extended mellowing process. The second option is the cost associated with the removal of the material that had sulfate concentrations in excess of 30,000 ppm or that which performed poorly in the laboratory and replacing it with suitable material that contained less than 3000 ppm sulfates that must be hauled from an unknown distance. The comparison of these 2 options is shown in Table 8.

Table 8. Cost Comparison for Mellowing versus Removal and Replacement

Item Description	Quantity	Unit	Cost/Unit	Extended Cost
Mellowing cost:				
Mellowing cost	36,667	SY	$ 2.62	$ 96,068.00
Lime (Assumes 38.35 lb/sy & $135/ton)	703	TONS	$ 135.00	$ 94,917.00
Cost for 8" lime stabilization (based on recent TxDOT's 12-month average bid price for 8-inches of lime stabilization)	36667	SY	$ 1.65	$ 60,501.00
				$ 251,486.00
Borrow source located between 5 and 10 miles:				
Removal Cost (5 scrapers, push dozer, & associated support equipment for 7 days - See Table 7)	1	EA	$ 50,370.00	$ 50,370.00
Replacement Select Fill (Assumes 120 lb/ft3)	43,999	TONS	$ 2.50	$ 109,998.00
Replacement Haul cost (Assumed 5 to 10 miles to source - See Table 7)	27,160	CY	$ 3.32	$ 90,171.00
Cost to Compact Select Material (See Table 7)	27,160	CY	$ 1.37	$ 37,209.00
				$ 287,748.00
Borrow source located between 10 and 15 miles:				
Removal Cost (5 scrapers, push dozer, & associated support equipment for 7 days - See Table 7)	1	EA	$ 50,370.00	$ 50,370.00
Replacement Select Fill (Assumes 120 lb/ft3)	43,999	TONS	$ 2.50	$ 109,998.00
Replacement Haul cost (Assumed 10 to 15 miles to source - See Table 7)	27,160	CY	$ 3.74	$ 101,578.00
Cost to Compact Select Material (See Table 7)	27,160	CY	$ 1.37	$ 37,209.00
				$ 299,155.00
Borrow source located between 15 and 20 miles:				
Removal Cost (5 scrapers, push dozer, & associated support equipment for 7 days - See Table 7)	1	EA	$ 50,370.00	$ 50,370.00
Replacement Select Fill (Assumes 120 lb/ft3)	43,999	TONS	$ 2.50	$ 109,998.00
Replacement Haul cost (Assumed 15 to 20 miles to source - See Table 7)	27,160	CY	$ 4.36	$ 118,418.00
Cost to Compact Select Material (See Table 7)	27,160	CY	$ 1.37	$ 37,209.00
				$ 315,995.00
Borrow source located between 20 and 25 miles:				
Removal Cost (5 scrapers, push dozer, & associated support equipment for 7 days - See Table 7)	1	EA	$ 50,370.00	$ 50,370.00
Replacement Select Fill (Assumes 120 lb/ft3)	43,999	TONS	$ 2.50	$ 109,998.00
Replacement Haul cost (Assumed 20 to 25 miles to source - See Table 7)	27,160	CY	$ 4.97	$ 134,985.00
Cost to Compact Select Material (See Table 7)	27,160	CY	$ 1.37	$ 37,209.00
				$ 332,562.00
Borrow source located between 25 and 30 miles:				
Removal Cost (5 scrapers, push dozer, & associated support equipment for 7 days - See Table 7)	1	EA	$ 50,370.00	$ 50,370.00
Replacement Select Fill (Assumes 120 lb/ft3)	43,999	TONS	$ 2.50	$ 109,998.00
Replacement Haul cost (Assumed 25 to 30 miles to source - See Table 7)	27,160	CY	$ 5.80	$ 157,528.00
Cost to Compact Select Material (See Table 7)	27,160	CY	$ 1.37	$ 37,209.00
				$ 355,105.00

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.

After over 1 year since the lime stabilization was completed, this pavement is still performing very well. The results of the profiling indicate that there are some bumps in the area of the project that was included in H&L's scope of services, but upon further review it was determined that these bumps are located in areas where there are either crossroads or exit/entrance ramps. The original profile data is unavailable at this time for comparison, but data collected in March indicate that the pavement is not experiencing any signs of sulfate induced heave. Further sulfate testing show that sulfate levels in the stabilized layer are still within acceptable levels and FWD results show that this pavement is very 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 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. Additionally, a comparison of the costs of mellowing a stabilized subgrade versus the costs associated with hauling material from different distances away from the project show the feasibility of using locally available material, even if sulfate concentrations are deemed outside of TxDOT's acceptable limits. Good performance in these laboratory tests and field performance described above and a comparison of the alternative costs substantiate the use of the extended mellowing techniques described in this report.

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APPENDIX

Table A-1. Table 1, Pay Adjustment Schedules for Ride Quality

Table 1
Pay Adjustment Schedules for Ride Quality

Average IRI for each 0.10 mi. of Traffic Lane (in. / mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
< 30	600	600	300
30	600	600	300
31	580	580	290
32	560	560	280
33	540	540	270
34	520	520	260
35	500	500	250
36	480	480	240
37	460	460	230
38	440	440	220
39	420	420	210
40	400	400	200
41	380	380	190
42	360	360	180
43	340	340	170
44	320	320	160
45	300	300	150
46	280	280	140
47	260	260	130
48	240	240	120
49	220	220	110
50	200	200	100
51	180	180	90
52	160	160	80
53	140	140	70
54	120	120	60
55	100	100	50
56	80	80	40
57	60	60	30
58	40	40	20
59	20	20	10
60	0	0	0
61	0	0	0

Table A-1. Table 1, Pay Adjustment Schedules for Ride Quality (Continued)

Table 1 (continued)
Pay Adjustment Schedules for Ride Quality

Average IRI for each 0.10 mi. of Traffic Lane (in./mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
62	0	0	0
63	0	0	0
64	0	0	0
65	0	0	0
66	–20	0	0
67	–40	0	0
68	–60	0	0
69	–80	0	0
70	–100	0	0
71	–120	0	0
72	–140	0	0
73	–160	0	0
74	–180	0	0
75	–200	0	0
76	–220	–20	0
77	–240	–40	0
78	–260	–60	0
79	–280	–80	0
80	–300	–100	0
81	–320	–120	0
82	–340	–140	0
83	–360	–160	0
84	–380	–180	0
85	–400	–200	0
86	–420	–220	0
87	–440	–240	0
88	–460	–260	0
89	–480	–280	0
90	–500	–300	0
91	–520	–320	0
92	–540	–340	0
93	–560	–360	0
94	-580	-380	0

Average IRI for each 0.10 mi. of Traffic Lane (in./mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
95	–600	–400	0
> 95	Corrective Action	Corrective Action	Not Applicable

Table A-2. DCP Data for Sta 242+00

Project:	SH 289 Extension	**Date:**	3/18/2010
Location:	Sta 242+00	**Personnel:**	SLH
Zero Point (mm):	420	**Hammer Weight (lb):**	17.6
Material Classification:		**Hammer Blow Factor:**	1
Pavement Condition:	LSS	**Weather:**	Clear

Number of Blows	Cumulative Penetration (mm)	Cumulative Penetration (in)	Penetration between Readings (mm)	Penetration/ Blow (mm)	DCP Index (mm/blow)	CBR (%)	E (psi)
5	455	1.4	35	7.0	7.0	33.0	23912.2
10	490	2.8	35	3.5	3.5	71.8	39300.4
10	530	4.3	40	4.0	4.0	61.8	35713.2
10	570	5.9	40	4.0	4.0	61.8	35713.2
10	605	7.3	35	3.5	3.5	71.8	39300.4
10	650	9.1	45	4.5	4.5	54.2	32821.8
5	690	10.6	40	8.0	8.0	28.4	21729.5
2	735	12.4	45	22.5	22.5	8.9	10354.8
1	780	14.2	45	45.0	45.0	4.1	6300.3
1	810	15.4	30	30.0	30.0	6.5	8425.3

Table A-3. DCP Data for Sta 277+00

Project:		SH 289 Extension		**Date:**		3/18/2010	
Location:		Sta 277+00		**Personnel:**		SLH	
Zero Point (mm):		360		**Hammer Weight (lb):**		17.6	
Material Classification:				**Hammer Blow Factor:**		1	
Pavement Condition:		LSS		**Weather:**		Clear	
Number of Blows	**Cumulative Penetration (mm)**	**Cumulative Penetration (in)**	**Penetration between Readings (mm)**	**Penetration /Blow (mm)**	**DCP Index (mm/blow)**	**CBR (%)**	**E (psi)**
5	380	0.8	20	4.0	4.0	61.8	35713.2
10	395	1.4	15	1.5	1.5	185.4	72137.8
10	405	1.8	10	1.0	1.0	292.0	96468.4
10	415	2.2	10	1.0	1.0	292.0	96468.4
10	420	2.4	5	0.5	0.5	634.7	158549.0
10	430	2.8	10	1.0	1.0	292.0	96468.4
10	440	3.1	10	1.0	1.0	292.0	96468.4
10	445	3.3	5	0.5	0.5	634.7	158549.0
10	470	4.3	25	2.5	2.5	104.6	50019.8
10	485	4.9	15	1.5	1.5	185.4	72137.8
10	510	5.9	25	2.5	2.5	104.6	50019.8
10	545	7.3	35	3.5	3.5	71.8	39300.4
3	565	8.1	20	6.7	6.7	34.9	24763.2
5	590	9.1	25	5.0	5.0	48.1	30434.3
5	610	9.8	20	4.0	4.0	61.8	35713.2
5	670	12.2	60	12.0	12.0	18.1	16249.1
2	720	14.2	50	25.0	25.0	7.9	9601.6
2	760	15.7	40	20.0	20.0	10.2	11267.0
2	790	16.9	30	15.0	15.0	14.1	13847.2

Table A-4. DCP Data for Sta 345+00

Project:	SH 289 Extension	**Date:**	3/18/2010
Location:	Sta 345+00	**Personnel:**	SLH
Zero Point (mm):	365	**Hammer Weight (lb):**	17.6
Material Classification:		**Hammer Blow Factor:**	1
Pavement Condition:	LSS	**Weather:**	Clear

Number of Blows	Cumulative Penetration (mm)	Cumulative Penetration (in)	Penetration between Readings (mm)	Penetration/ Blow (mm)	DCP Index (mm/blow)	CBR (%)	E (psi)
10	390	1.0	25	2.5	2.5	104.6	50019.8
10	410	1.8	20	2.0	2.0	134.3	58695.8
10	430	2.6	20	2.0	2.0	134.3	58695.8
10	480	4.5	50	5.0	5.0	48.1	30434.3
10	530	6.5	50	5.0	5.0	48.1	30434.3
5	560	7.7	30	6.0	6.0	39.3	26705.8
5	595	9.1	35	7.0	7.0	33.0	23912.2
5	620	10.0	25	5.0	5.0	48.1	30434.3
5	655	11.4	35	7.0	7.0	33.0	23912.2
3	700	13.2	45	15.0	15.0	14.1	13847.2
3	745	15.0	45	15.0	15.0	14.1	13847.2
3	780	16.3	35	11.7	11.7	18.6	16580.5
3	810	17.5	30	10.0	10.0	22.2	18517.6

Table A-5. DCP Data for Sta 377+00

Project:	SH 289 Extension	**Date:**	3/18/2010
Location:	Sta 377+00	**Personnel:**	SLH
Zero Point (mm):	370	**Hammer Weight (lb):**	17.6
Material Classification:		**Hammer Blow Factor:**	1
Pavement Condition:	LSS	**Weather:**	Clear

Number of Blows	Cumulative Penetration (mm)	Cumulative Penetration (in)	Penetration between Readings (mm)	Penetration/ Blow (mm)	DCP Index (mm/blow)	CBR (%)	E (psi)
10	390	0.8	20	2.0	2.0	134.3	58695.8
10	410	1.6	20	2.0	2.0	134.3	58695.8
10	430	2.4	20	2.0	2.0	134.3	58695.8
10	460	3.5	30	3.0	3.0	85.3	43891.9
5	495	4.9	35	7.0	7.0	33.0	23912.2
5	540	6.7	45	9.0	9.0	24.9	19970.3
5	590	8.7	50	10.0	10.0	22.2	18517.6
5	650	11.0	60	12.0	12.0	18.1	16249.1
3	710	13.4	60	20.0	20.0	10.2	11267.0
3	770	15.7	60	20.0	20.0	10.2	11267.0
2	805	17.1	35	17.5	17.5	11.8	12398.7

Table A-6. DCP Data for Sta 465+00

Project:	SH 289 Extension	**Date:**	3/18/2010
Location:	Sta 465+00	**Personnel:**	SLH
Zero Point (mm):	350	**Hammer Weight (lb):**	17.6
Material Classification:		**Hammer Blow Factor:**	1
Pavement Condition:	LSS	**Weather:**	Clear

Number of Blows	Cumulative Penetration (mm)	Cumulative Penetration (in)	Penetration between Readings (mm)	Penetration/ Blow (mm)	DCP Index (mm/blow)	CBR (%)	E (psi)
5	355	0.2	5	1.0	1.0	292.0	96468.4
10	360	0.4	5	0.5	0.5	634.7	158549.0
20	365	0.6	5	0.3	0.3	1379.4	260580.4
10	405	2.2	40	4.0	4.0	61.8	35713.2
10	430	3.1	25	2.5	2.5	104.6	50019.8
10	450	3.9	20	2.0	2.0	134.3	58695.8
10	470	4.7	20	2.0	2.0	134.3	58695.8
10	495	5.7	25	2.5	2.5	104.6	50019.8
10	525	6.9	30	3.0	3.0	85.3	43891.9
10	550	7.9	25	2.5	2.5	104.6	50019.8
10	590	9.4	40	4.0	4.0	61.8	35713.2
5	610	10.2	20	4.0	4.0	61.8	35713.2
5	640	11.4	30	6.0	6.0	39.3	26705.8
3	690	13.4	50	16.7	16.7	12.5	12840.0
3	760	16.1	70	23.3	23.3	8.6	10088.3
2	800	17.7	40	20.0	20.0	10.2	11267.0