TTI: 5-6271-05

Best Practices for Implementing FDR for Pavements in the Energy Sector

Implementation Report 5-6271-05-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

Full-depth reclamation (FDR) can offer an economical and rapid strategy for pavement renewal. With pavement damage coinciding with energy sector development, departments of transportation need rapid and economical methods to strengthen and renew these impacted pavements. This project focused on implementing FDR for pavements in the energy sector. A systematic approach for evaluating pavement sections was developed, and training workshops were conducted. Nominated pavement projects were analyzed to determine their candidacy for FDR, and mixture design options were developed for the available materials with particular focus on asphalt-based stabilization. A total of 10 pavement projects were constructed and monitored during this implementation effort, representing a spectrum of asphalt-based and calcium-based FDR along with two mill and inlay projects for comparison. Field performance of constructed sections shows FDR with asphalt-based stabilization is a viable structural option to other alternatives such as mill and inlay or cement treatment with base overlay. While not every distressed pavement is a candidate for FDR, successful FDR projects can renew the pavement at a cost typically at least 50 percent cheaper than other alternatives. FDR can also offer significant time benefits in terms of production rate and minimized disruption to traffic. With the substantial benefits of successful FDR demonstrated in this implementation effort, updated construction specifications were developed.

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BEST PRACTICES FOR IMPLEMENTING FDR FOR PAVEMENTS IN THE ENERGY SECTOR

by

Stephen Sebesta
Research Scientist
Texas A&M Transportation Institute

Ross Taylor
Research Associate
Texas A&M Transportation Institute

and

Tom Scullion, P.E.
Senior Research Engineer
Texas A&M Transportation Institute

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

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Tom Scullion, P.E. #62683 (TX).

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CHAPTER 1. IMPLEMENTATION METHODS

OVERVIEW

The general methods in this project for implementing full-depth reclamation (FDR) in the energy sector consisted of construction planning and monitoring, workshops, and specification development. The construction planning and monitoring activities served to identify candidate sections for FDR and monitor their construction and performance after construction. Using the best practices from construction planning and monitoring, the research team prepared and conducted three workshops to disseminate information for more widespread implementation.

Finally, using the results and findings from the construction planning and monitoring and workshop activities, the research team coordinated with the Texas Department of Transportation (TxDOT) to prepare updated construction specifications.

CONSTRUCTION PLANNING AND MONITORING

Figure 1 shows an example pavement in the energy sector in need of renewal. However, not all distressed pavements are candidates for FDR. Steps must be taken to make sure a property strategy is selected appropriate to the cause of the pavement distress.

Figure 1. Example Pavements in the Energy Sector Needing Renewal.

To systematically determine the cause of pavement distress, identify if a nominated pavement section is a candidate for FDR, develop FDR mixture and pavement design options, and then monitor construction and performance, the research team used the following eight-step approach for sections nominated by TxDOT:

1. Assemble background information that includes historic plans, maintenance history, and soils maps.
2. Perform non-destructive tests (NDT) that include ground-penetrating radar (GPR), falling weight deflectometer (FWD), dynamic cone penetrometer (DCP), and visual assessment.

3. Verify the structure and sampling, including auguring material into the subgrade and returning materials to the laboratory.
4. Perform lab mix designs, including varying proportions of materials in the FDR mixture and determining different potential stabilization strategies and stabilizer rates.
5. Perform pavement thickness design, including a flexible pavement system (FPS) and triaxial check.
6. Consider local conditions, including potential impacts of highly plastic subgrades, microcracking, and early trafficking on the stabilization strategy and pavement design.
7. Perform construction quality control that determines level of pulverization, moisture content, application of proper amount of stabilizer in a uniform manner, attainment of density, and surface finish.
8. Execute a performance review that gathers feedback from stakeholders and assesses structural condition through time.

In this implementation effort, a total of 20 pavement sections were nominated and investigated. A total of 10 pavement sections were constructed during the performance period of this implementation effort. Chapter 2 of this document details those efforts specific to pavement section construction planning and monitoring.

WORKSHOPS

Using the best practices from the construction planning and monitoring activities in this project, the research team performed three workshops focusing on the following key topics:

- Introduction to FDR.
- Using the Web Soil Survey.
- Condition Surveys and NDT.
- Sampling.
- Lab Procedures.
- Thickness Design.
- Construction.

The workshop content is available separately from this document in products 5-6271-05-P3 (presentation materials), 5-6271-05-P4 (instructor guide), and 5-6271-05-P5 (student handbook).

SPECIFICATION DEVELOPMENT

Based on the results from construction planning and monitoring activities and feedback from the project technical committee and workshop attendees, the research team worked with TxDOT to develop updated construction specifications. Efforts particularly focused on updated specifications for FDR and treatment (road mixed) using emulsion or foamed asphalt. Appendices A and B in this document present the recommended updated construction specifications for emulsion and foamed asphalt, respectively.

CHAPTER 2. RESULTS

OVERVIEW

This chapter presents a summary of the construction planning and monitoring activities for implementing FDR. In this implementation effort, a total of 20 pavement sections were nominated and evaluated as potential candidates for FDR. Not every nominated section was a candidate for FDR. Other sections, although determined to be candidates for FDR, were not constructed during the performance period of this implementation effort. The sections in this chapter present summaries of the construction planning and monitoring activities according to whether the pavement sections were constructed or not during the implementation performance period.

SUMMARY OF PAVEMENT SECTIONS NOT CONSTRUCTED

Table 1 presents a summary of the nominated pavement sections that were evaluated and not constructed during this implementation project.

Table 1. Pavement Sections Not Constructed.

Pavement	Limits	Construction Planning Outcome
OSR	Madison Co.— FM 39 to 7 mi E	FDR options developed with flex OL.
OSR	Brazos Co.— FM 46 to 7 mi W of FM 46	FDR options developed with special considerations for high plasticity index locations.
SH 7	Leon Co.— SH 75 to 6 mi W of Trinity R.	FDR options developed with hot-mix asphalt (HMA) final surface.
US 181	Karnes Co.— FM 1144 to CR 150	Not a candidate for FDR. HMA options provided to district for various design lives.
IH 35 E FR	LaSalle Co.— SH 44 to 7.038 mi S of FM 133	Partition project. FDR options developed to treat south half with cement and treat north half with foamed asphalt.
SH 97	LaSalle Co.— BI 35 to McMullen C/L	FDR options developed with both emulsion or foamed asphalt.
SH 44	Duval Co.— 2 mi W of SH 359 to FM 3196	Not a candidate for FDR with available materials.
FM 846	Martin Co.— TRM 290 to Howard C/L	Not a candidate for FDR with available materials.
SH 302	Loving Co.— Pecos R. to East FM 1933	FDR options developed using emulsion.
SH 72	McMullen Co.— SH 97 to SH 16	Not a candidate for FDR with available materials.

RESULTS FROM CONSTRUCTED PAVEMENT SECTIONS

A total of 10 pavement sections were constructed and monitored during this implementation effort. The participation of constructed projects represented the following rehabilitation strategies:

- Mill and inlay: 2 projects.
- FDR with cement treatment and then flex-base overlay: 2 projects.
- FDR with emulsion: 3 projects.
- FDR with foamed asphalt: 3 projects.

Table 2 summarizes the projects that were constructed and monitored according to the pavement renewal strategy. The remaining sections of this chapter detail the construction planning and monitoring results from each of these sections.

Table 2. Projects Constructed and Monitored.

Strategy	Pavement	Limits	Comments	CSJ
Mill and Inlay	SH 16	Duval Co.—US 59 to McMullen C/L	Changed from planned FDR to mill and inlay	0517-04-055
	US 59	Duval Co.— 5 mi N of SH 44 to McMullen C/L		0542-04-031
FDR with cement then flex overlay	SH 202	Bee Co.— CR 425 to Refugio C/L	FDR options for emulsion, foam, or cement provided. District proceeded with cement	0447-03-039
	FM 1996	Coryell Co.— US 84 to FM 107	Project included high reclaimed asphalt pavement (RAP) FDR mixture	0567-01-027
FDR with asphalt emulsion	IH 10	Reeves Co.— 0.6 mi W of FM 3078 to 5.5 mi E of FM 3078	*No comments*	0441-09-043 & 044
	SH 115	Winkler Co.— TRM 373.153 to 378.063 (SH 302 to CR 202)	Phase I constructed with 5.5% CSS-1H. Phase II constructed with 2.8% high yield emulsion	0354-01-044
	IH 10	Crockett Co.— TRM 373 to 377	Emergency FDR as part of existing mill/inlay project	
FDR with foamed asphalt	SH 7	Leon Co.— FM 39 to 1 mi W	*No comments*	0335-03-046
	SH 44	Duval Co.— Duval/Webb C/L to US 59	Original design of 1% cement plus 2.4% asphalt field changed to 2% cement plus 2.4% asphalt	0237-04-013
	FM 541	Atascosa Co.— IH 37 to 2.6 mi E	*No comments*	1011-02-017

Mill and Inlay Projects

SH 16

Soil Survey. Figure 2 shows the soils maps from the SH 16 section. The data show that the plasticity index (PI) values of the subgrade soil are expected to range from below 10 to just below 30, and the section is expected to not contain gypsum.

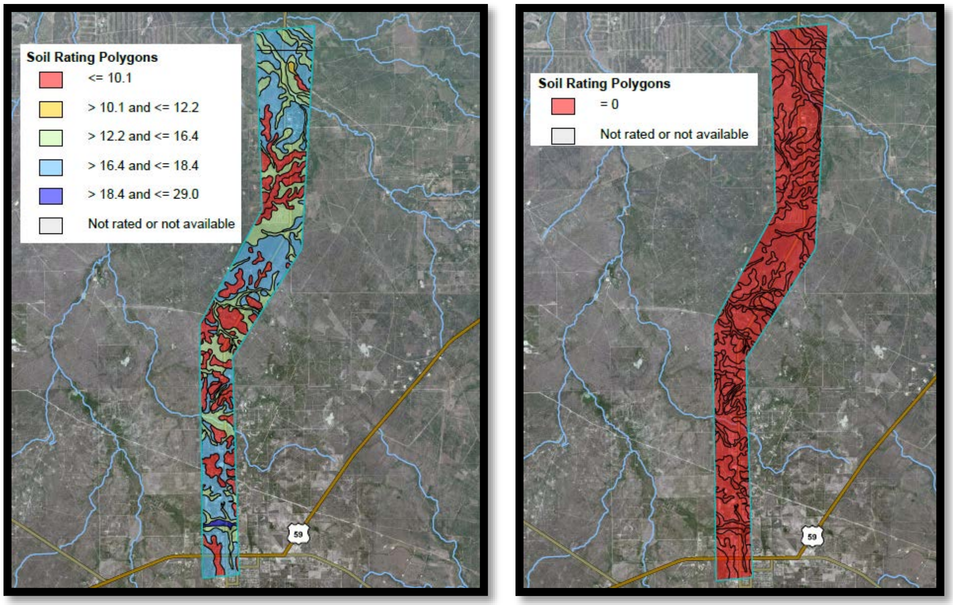


Figure 2. Plasticity Index (Left) and Gypsum (Right) Soils Maps for SH 16.

GPR and DCP Results. Figure 3 presents example GPR data from SH 16. The key observation from the GPR was varying surface thickness, which the research team considered in selected test locations for further investigation.

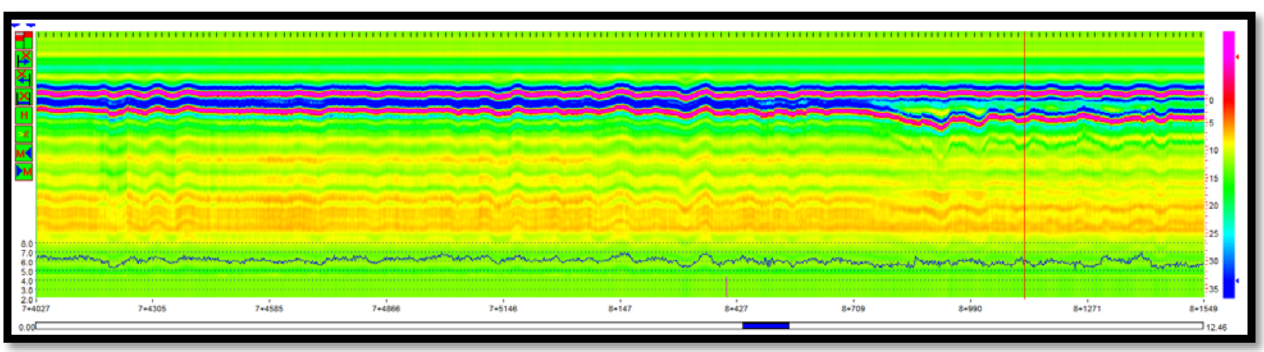


Figure 3. Example GPR Data from SH 16.

Figure 4 presents example DCP data from the section. The DCP data indicate that the pavement total structure was between 15 and 19 in. with a low to marginal quality base. From the DCP, the base modulus estimates ranged from 24 to 37 ksi, and the subgrade modulus ranged from 10 to 14 ksi.

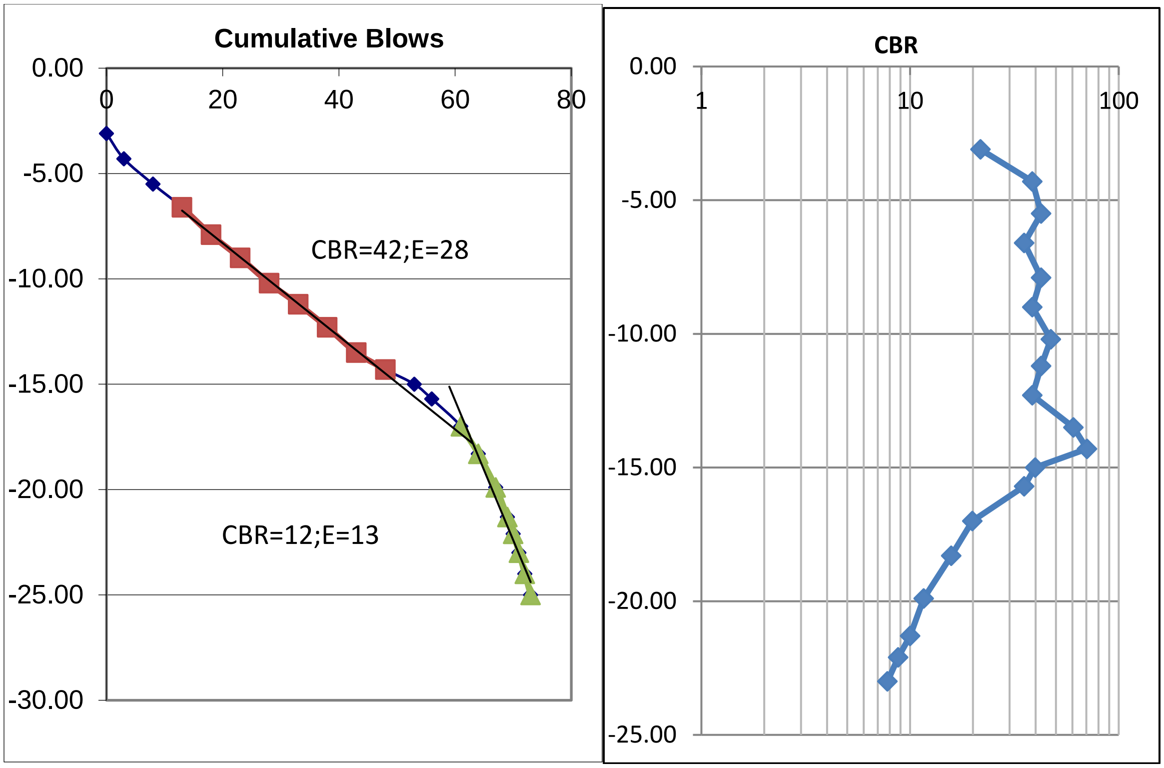


Figure 4. Example DCP Results from SH 16.

Auguring Results. Figure 5 summarizes the results from auguring. These results are consistent with the DCP results and show ample existing pavement exists that may be a candidate for FDR.

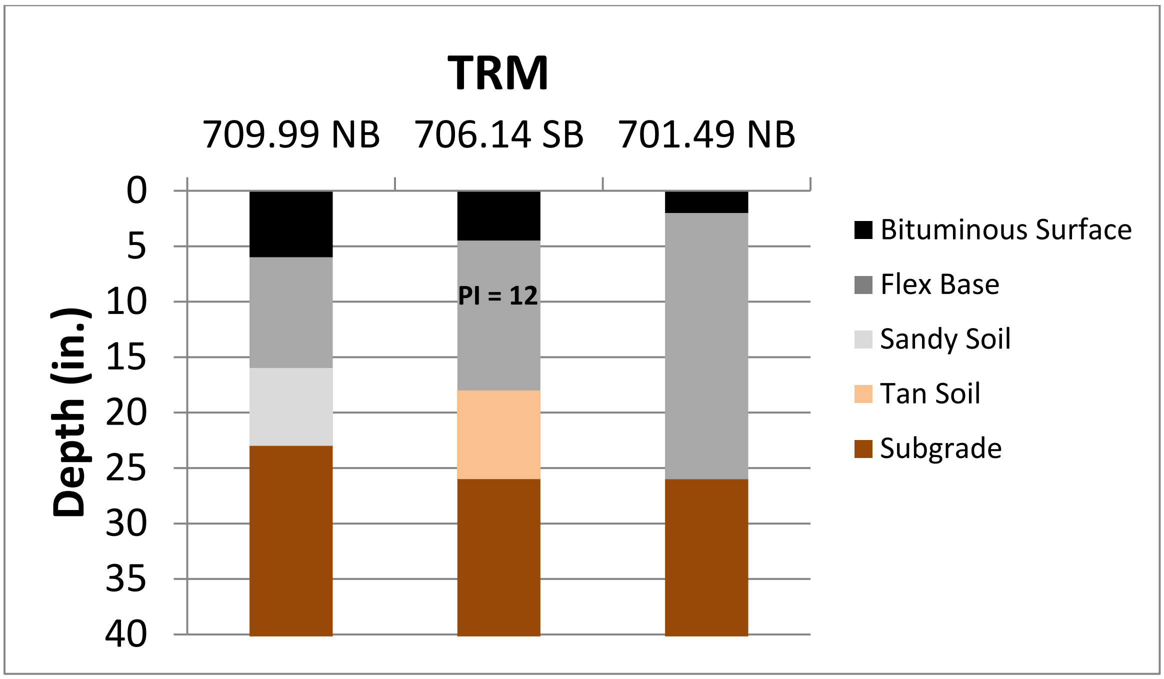


Figure 5. Augur Results from SH 16.

FWD Results. No FWD tests were performed on the section.

Laboratory Mixture Design. Based on the field test results and TxDOT's requests for FDR options with foamed asphalt, Figure 6 presents the laboratory mixture design results. The lab mix designs assumed a 10 in. treatment depth and consisted of two different proportions of RAP with salvage base to represent expected field conditions. To pass mix design criteria, a pretreatment with 3 percent lime and a minimum 2-hour mellowing time is required prior to treating with foamed asphalt. After the lime pretreatment, application of foam at a rate of 2.7 percent meets the mix design requirements for both expected proportions of RAP/base. The requirement for the lime pretreatment is reasonable since the existing base material had a PI of 12.

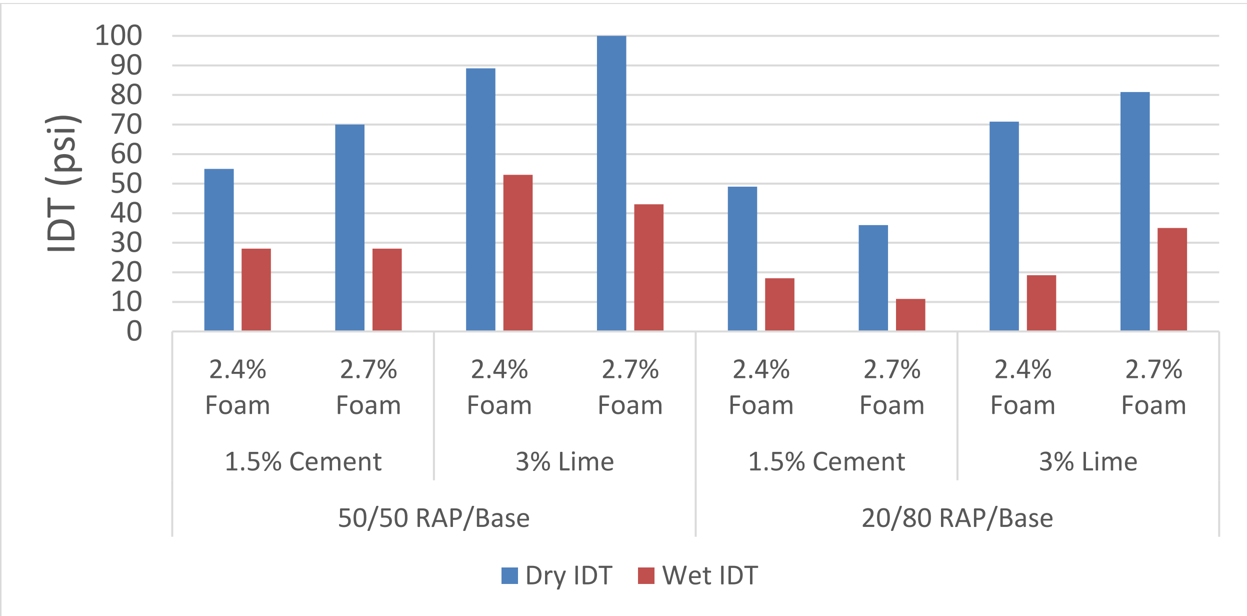


Figure 6. Mix Design Results for SH 16.

Pavement Design. All pavement design activities were performed by TxDOT.

Recommended Sequence. Based on the results, the section is a candidate for FDR with foamed asphalt treatment using the following general sequence:

- Pretreat 10 in. with 3 percent lime and mellow for 24 hours.
- Stabilize with 2.7 percent foamed asphalt:
  - Alternatively, the project could be partitioned according to the expected percentage RAP. The extents with higher RAP content could have the foamed asphalt treatment level reduced to 2.4 percent.
- Place surfacing.

Construction Results. The original FDR construction planning for this project developed a FDR mix design using foamed asphalt. The project was later changed to mill and inlay with a September 2016 completion date. Figure 7 illustrates typical processes used for the construction activities.

Figure 7. Mill and Inlay on SH 16.

FWD data were collected in December 2016 on a representative completed section from TRM 704 to 708 in the SB travel direction. The reported district goal was to have less than 30 mils deflection under the 12klb FWD load. Figure 8 illustrates that about 44 percent of the section evaluated did not meet that deflection goal. Table 3 presents the complete FWD results under a 12klb FWD load and illustrates that, on average, the maximum 30 mil deflection was not attained.

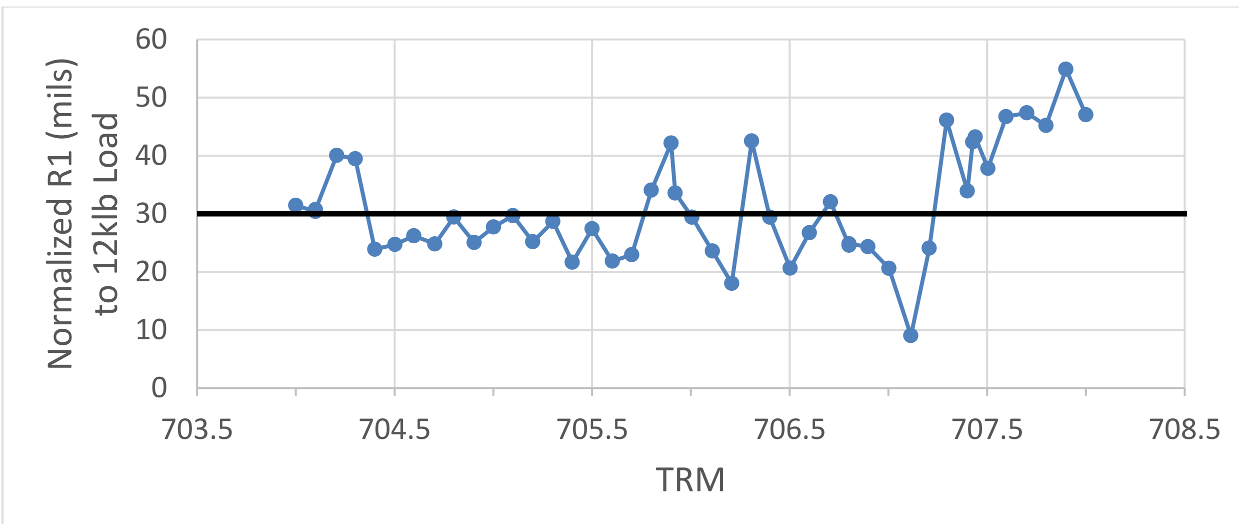


Figure 8. FWD Sensor 1 Deflection with Distance on SH 16.

Table 3. FWD Output from SH 16 Mill and Inlay.

```
TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                                  (Version 6.1)

District:                                                  MODULI RANGE(psi)
County  :                             Thickness(in)      Minimum      Maximum     Poisson Ratio Values
Highway/Road:             Pavement:        0.50           421,600      421,600      H1: v = 0.35
                          Base:            6.00            50,000    1,000,000      H2: v = 0.35
                          Subbase:         0.00                                     H3: v = 0.00
                          Subgrade:      167.21(by DB)            10,000            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	12,071	31.62	24.30	14.65	9.01	5.71	4.24	3.35	421.6	399.6	0.0	8.2	3.28	164.6	
0.100	12,323	31.16	26.32	18.16	11.56	7.47	5.08	3.70	421.6	663.8	0.0	6.6	2.27	192.5	*
0.100	12,136	31.05	26.16	18.03	11.49	7.43	5.07	3.70	421.6	657.0	0.0	6.6	2.26	193.8	*
0.207	12,235	40.76	32.13	22.26	14.67	9.47	6.28	4.32	421.6	481.0	0.0	5.3	0.43	189.6	
0.301	12,071	39.68	30.69	19.66	13.13	8.65	5.96	4.29	421.6	420.5	0.0	5.7	2.35	223.1	
0.400	12,071	24.04	19.94	13.57	9.04	5.93	4.15	3.09	421.6	848.3	0.0	8.5	2.56	196.0	*
0.502	12,465	25.69	20.83	14.31	9.91	6.76	4.81	3.68	421.6	810.9	0.0	8.1	5.50	244.8	*
0.598	12,356	27.00	19.97	12.65	8.17	5.57	4.17	3.28	421.6	602.2	0.0	9.3	4.92	269.7	
0.704	12,180	25.17	21.11	14.69	9.77	6.19	3.92	2.60	421.6	811.9	0.0	8.1	2.14	143.7	*
0.800	12,060	29.57	24.45	16.93	11.19	7.26	4.83	3.41	421.6	688.0	0.0	6.9	1.52	178.5	*
0.903	12,410	25.87	21.41	15.02	10.04	6.53	4.34	2.98	421.6	803.5	0.0	8.0	2.72	171.2	*
1.001	12,191	28.11	19.93	10.69	5.57	3.12	2.04	1.48	421.6	223.6	0.0	12.9	10.47	94.6	
1.099	11,939	29.54	22.47	13.72	8.21	5.21	3.61	2.71	421.6	404.3	0.0	8.9	1.85	165.4	
1.200	12,027	25.24	21.16	15.17	10.76	7.56	5.60	4.31	421.6	762.9	0.0	7.6	9.80	300.0	*
1.302	12,005	28.69	22.04	13.81	8.79	5.80	4.15	3.16	421.6	527.3	0.0	8.4	2.73	210.0	
1.400	11,786	21.26	16.44	10.33	6.28	3.73	2.19	1.33	421.6	583.0	0.0	12.2	5.87	116.9	
1.500	11,852	27.11	19.40	10.77	6.49	4.52	3.71	3.06	421.6	359.8	0.0	10.9	6.61	230.4	
1.603	12,290	22.40	17.40	11.43	7.49	5.11	3.80	3.01	421.6	903.3	0.0	10.1	4.18	263.1	
1.701	12,213	23.37	18.94	13.10	8.90	6.05	4.36	3.39	421.6	884.9	0.0	8.9	4.99	258.6	*
1.800	12,169	34.50	25.15	13.78	7.90	4.78	3.50	2.91	421.6	235.5	0.0	9.2	3.30	132.7	
1.900	12,049	42.32	31.63	18.71	11.30	7.01	4.66	3.33	421.6	240.7	0.0	6.5	1.44	156.8	
1.921	12,060	33.72	25.74	15.57	9.47	6.22	4.67	3.80	421.6	375.5	0.0	7.7	3.64	213.5	
2.006	12,071	29.58	23.07	14.92	9.30	6.20	4.46	3.38	421.6	552.3	0.0	7.9	2.59	235.6	
2.109	12,213	23.99	19.31	12.81	8.39	5.70	4.15	3.18	421.6	888.7	0.0	8.9	3.37	260.6	*
2.207	12,377	18.50	15.73	9.46	6.05	4.28	3.31	2.63	421.6	1000.0	0.0	12.2	6.95	300.0	*
2.308	12,542	44.17	31.60	16.93	9.80	6.49	4.93	4.05	421.6	185.3	0.0	7.4	4.96	176.9	
2.400	12,312	30.15	23.69	15.70	10.25	6.81	4.82	3.70	421.6	643.9	0.0	7.4	2.31	225.4	
2.503	12,520	21.46	16.29	9.55	5.55	3.37	2.39	1.91	421.6	511.7	0.0	14.1	3.47	126.7	
2.600	12,180	27.12	20.03	11.56	6.77	4.14	2.76	2.13	421.6	355.9	0.0	11.2	2.99	134.0	
2.707	12,323	32.80	22.67	11.58	6.37	3.87	2.82	2.24	421.6	191.1	0.0	11.2	4.17	119.1	
2.801	12,169	24.91	18.58	12.31	8.22	5.45	3.81	2.79	421.6	748.8	0.0	9.4	3.34	207.6	
2.801	11,928	24.67	18.46	12.22	8.15	5.44	3.81	2.80	421.6	746.8	0.0	9.2	3.50	218.2	
2.897	12,180	24.70	19.55	12.77	8.26	5.51	3.94	3.03	421.6	769.5	0.0	9.1	2.66	222.6	
3.003	12,224	21.00	15.54	9.15	5.51	3.56	2.51	1.89	421.6	544.2	0.0	13.9	1.69	170.2	
3.114	12,169	9.17	7.78	6.02	4.59	3.47	2.70	2.12	421.6	1000.0	0.0	25.0	29.74	300.0	*
3.207	12,608	24.95	15.60	7.08	3.40	1.96	1.38	1.05	421.6	159.1	0.0	19.2	13.36	74.1	
3.295	12,531	47.75	30.91	15.10	8.89	6.53	5.37	4.38	421.6	125.7	0.0	7.9	9.41	197.9	
3.400	12,564	35.34	23.58	11.43	6.32	4.12	3.11	2.54	421.6	160.6	0.0	11.2	4.55	121.7	
3.427	14,021	46.97	26.08	9.74	5.02	3.55	2.84	2.33	421.6	66.3	0.0	13.3	9.27	65.5	
3.440	12,991	45.69	30.73	15.29	8.00	5.00	3.75	3.07	421.6	123.0	0.0	8.8	4.94	99.9	
3.504	12,443	38.96	26.75	14.20	8.01	5.00	3.57	2.81	421.6	176.2	0.0	9.1	2.74	141.6	
3.596	12,553	48.43	34.90	19.04	10.57	6.41	4.35	3.19	421.6	152.2	0.0	6.9	3.95	137.4	
3.701	12,498	48.96	34.28	18.53	10.47	6.63	4.82	3.74	421.6	149.0	0.0	6.9	3.58	152.3	
3.798	12,334	46.21	33.68	19.23	11.07	6.73	4.73	3.75	421.6	185.8	0.0	6.6	2.54	145.2	
3.899	12,892	57.41	40.11	21.03	11.51	7.49	5.49	4.41	421.6	118.2	0.0	6.2	4.61	129.6	
4.000	12,279	47.93	35.34	21.30	13.29	8.26	5.38	3.87	421.6	226.0	0.0	5.7	0.86	161.1	
Mean:		31.93	23.74	14.22	8.76	5.70	4.05	3.08	421.6	488.4	0.0	9.4	4.70	173.7	
Std. Dev:		10.13	6.56	3.73	2.42	1.58	1.08	0.81	0.0	283.6	0.0	3.6	4.62	69.0	
Var Coeff(%):		31.74	27.66	26.21	27.66	27.76	26.63	26.35	0.0	58.1	0.0	37.8	98.32	40.0	

US 59

Soil Survey. Soils data from the Web Soil Survey, illustrated in Figure 9, show the subgrade plasticity index generally as less than 20 throughout most of the project, with a few localized areas of higher plasticity index. Figure 10 shows that the project subgrade should largely be sulfate free, with a single localized area containing sulfate concentration of up to 30,000 ppm.

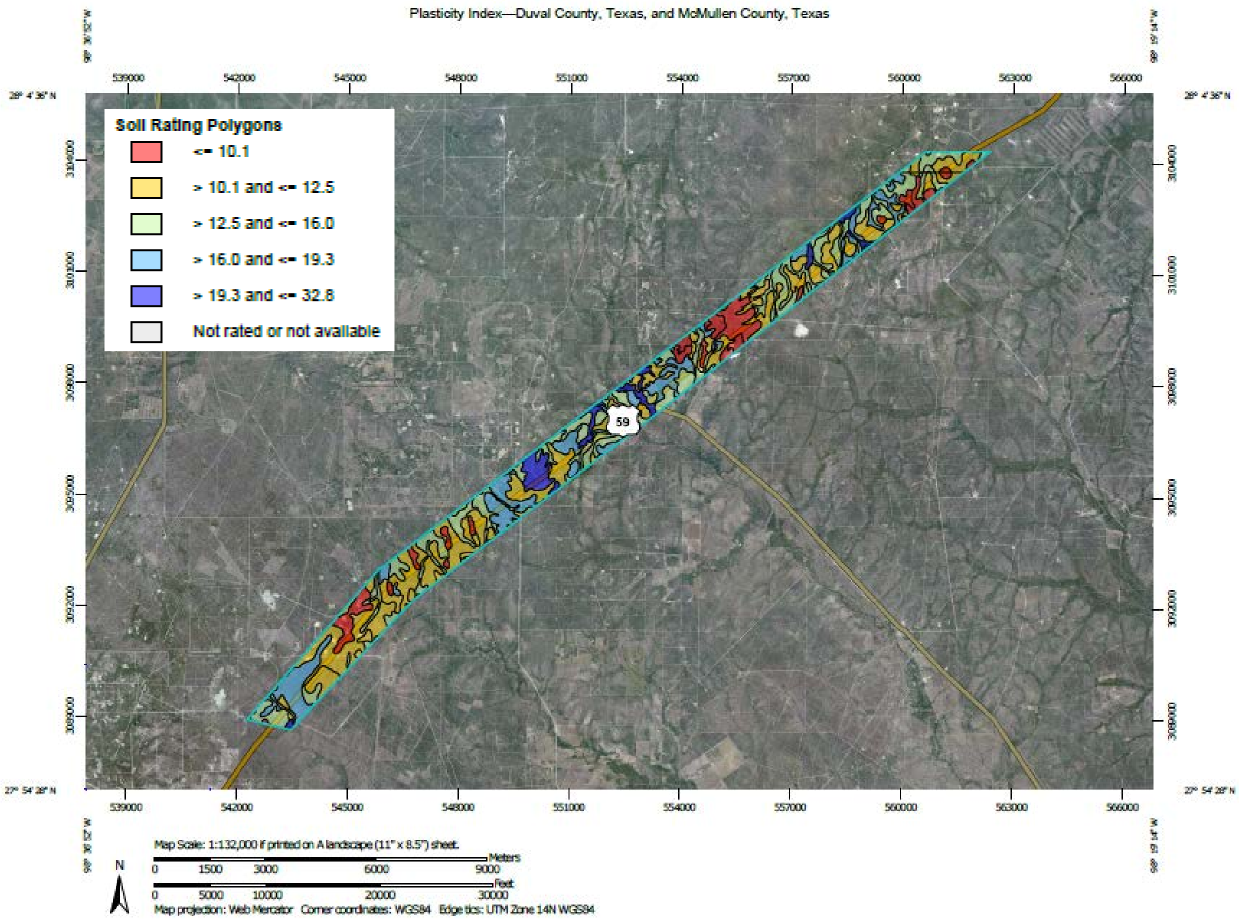


Figure 9. Web Soil Survey for Plasticity Index for US 59.

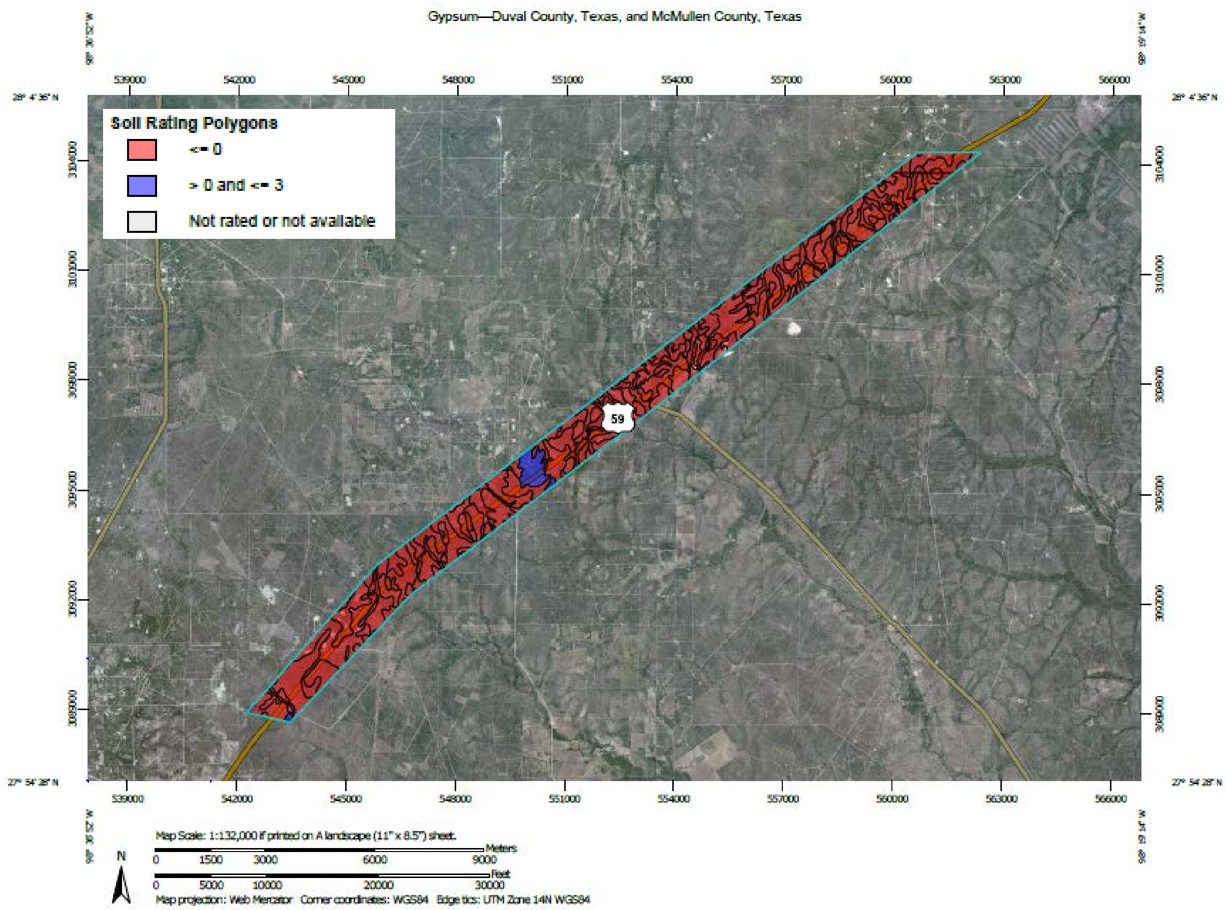


Figure 10. Web Soil Survey for Gypsum from US 59.

GPR and DCP Results. Figure 11 illustrates the typical GPR reflections observed throughout the section. The GPR data show the section should be a uniform structure, although the depth of the base layer was not readily detectable in the GPR.

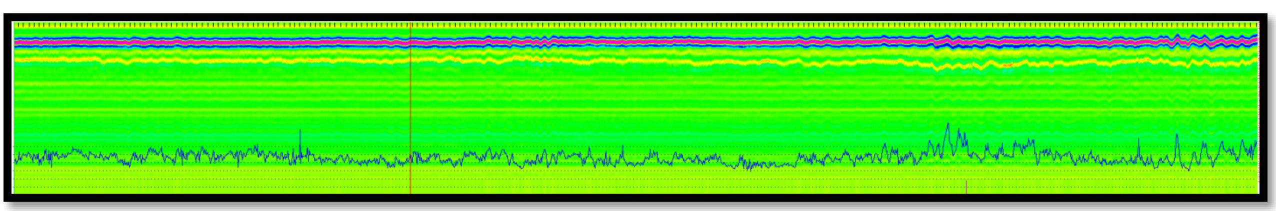


Figure 11. Example GPR from US 59.

Figure 12 presents example DCP results, and Table 4 presents a summary from the DCP testing.

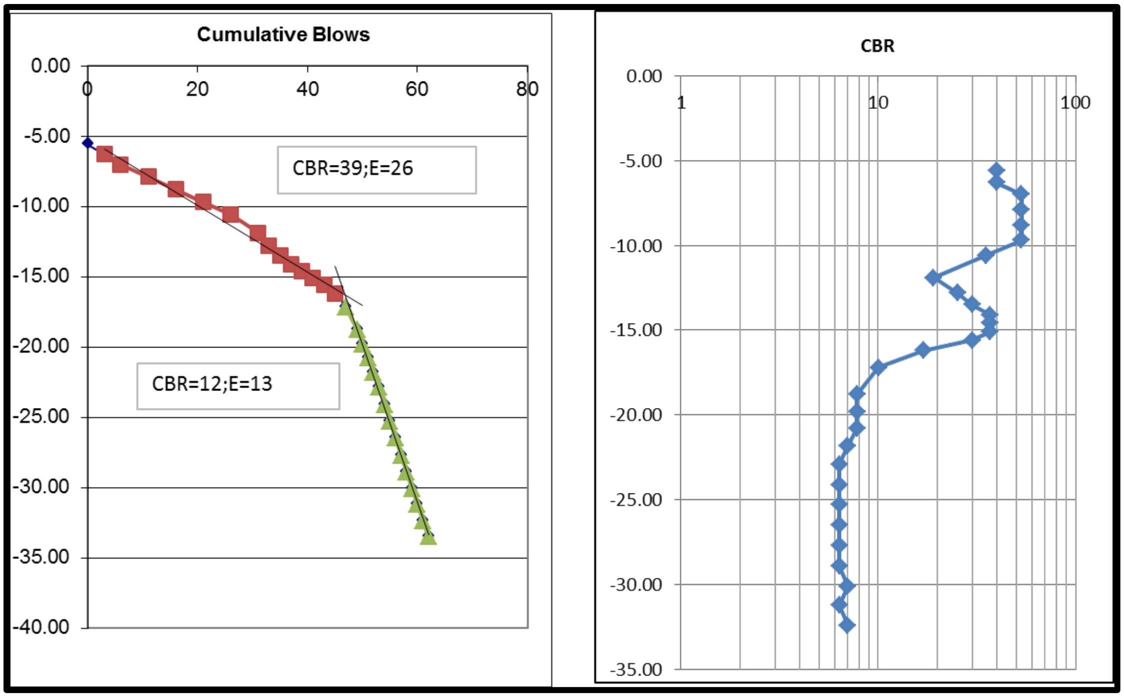


Figure 12. Example DCP Results from US 59.

Table 4. Summary of DCP Results for US 59.

Location (TRM)	Base Modulus (ksi)	Estimated Total Pavement Thickness (in.)	Subgrade Modulus (ksi)
749.3	26	17	13
754	92	10	21
756.8	35	14	17
759.6	45	13.5	23

Auguring Results. At each spot test location, the research team used a drilling rig to map the pavement structure and collect material for use in lab tests. Figure 13 presents the structures observed. The auguring results show:

- The typical pavement section is 12 to 16 in. of total structure, which includes a 5 in. HMA surface layer.
- The base plasticity index was 11.
- The plasticity index of the subgrade soil ranged from 4 to 25.

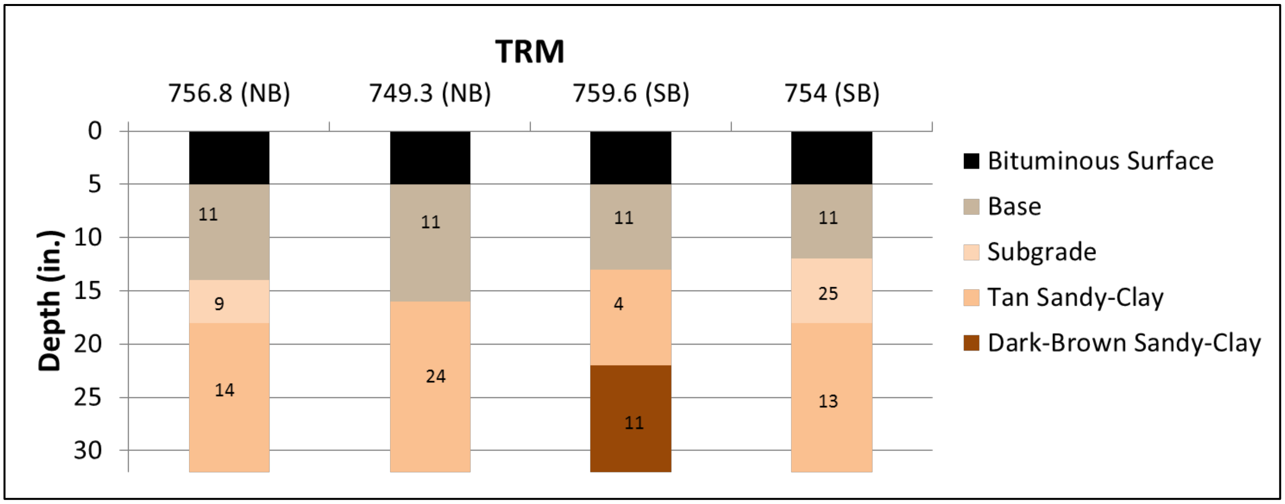


Figure 13. Augur Results from US 59.

Note: Plasticity index of depth zones indicated by numeric values.

FWD Results. No FWD data were collected on this section.

Laboratory Mixture Design. To cover envisioned field scenarios and asphalt-based stabilizer options requested by TxDOT, the lab mixture design included foamed asphalt and asphalt emulsion treatment options.

Figure 14 presents the laboratory mixture design results. All results used 50 percent RAP with 50 percent salvage base assuming a 10 in. treatment depth.

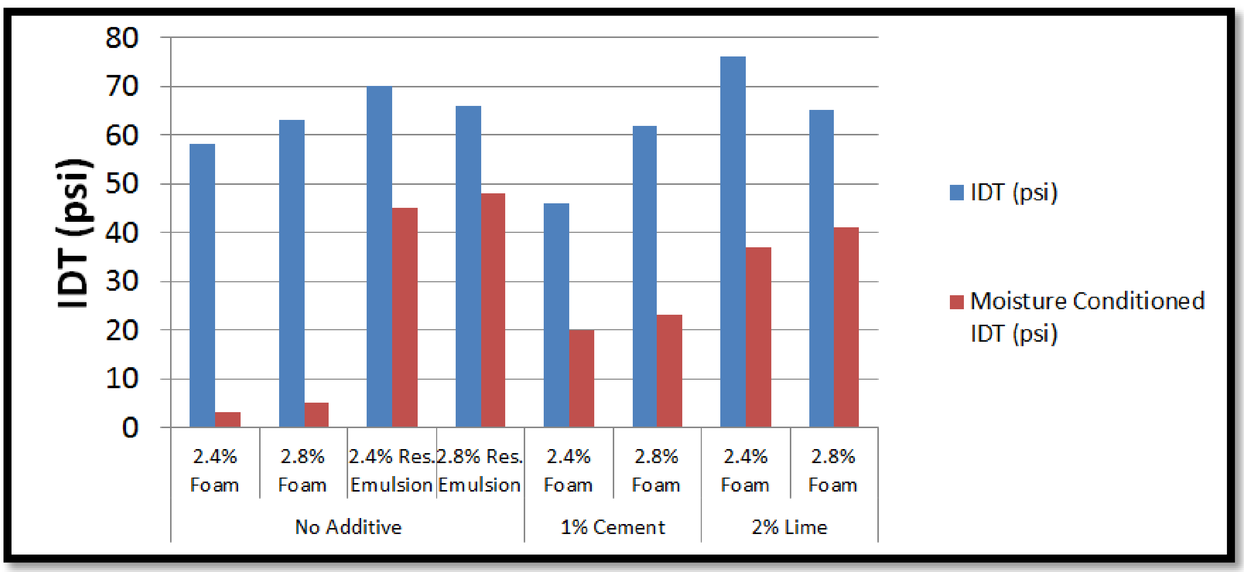


Figure 14. Lab Mix Design Results for US 59.

Based on the lab results, Figure 14 shows:

- To use foamed asphalt, a 2 percent lime pretreatment followed by a minimum 2-hour mellowing period followed by an application of 2.4 percent foamed asphalt meets the mixture requirements.
- Alternatively, the District may consider using asphalt emulsion with a treatment level of 2.4 percent residual asphalt. This treatment would only require one step in field construction.

Pavement Design. TxDOT performed a pavement design resulting in 10 in. stabilized base with a 3 in. HMA surface.

Recommended Sequence. To perform rehabilitation with foamed asphalt, the following general sequence is required:

- Pretreat 10 in. with 2 percent lime. Mellow for at least 2 hours.
- Treat 10 in. with 2.4 percent foamed asphalt.
- Place HMA surface.

To perform rehabilitation with asphalt emulsion, the following general sequence is required:

- Treat 10 in. with 2.4 percent residual asphalt emulsion.
- Place HMA surface.

Construction Results. Similar to SH 16, the US 59 project was changed from the planned FDR to mill and inlay. The same contractor that performed construction on SH 16 also constructed US 59 using similar methods, as shown in Figure 7. FWD data were collected on a representative completed section from TRM 758 to 754 in the NB travel direction in December 2016, as illustrated in Figure 15. Figure 16 illustrates that over 90 percent of the project is expected to meet the target goal of less than 30 mils deflection. Table 5 presents the complete FWD results, showing that on average this project met the district goal of less than 30 mils deflection under the 12klb FWD load.

Figure 15. FWD Collection on Completed US 59 Mill and Inlay.

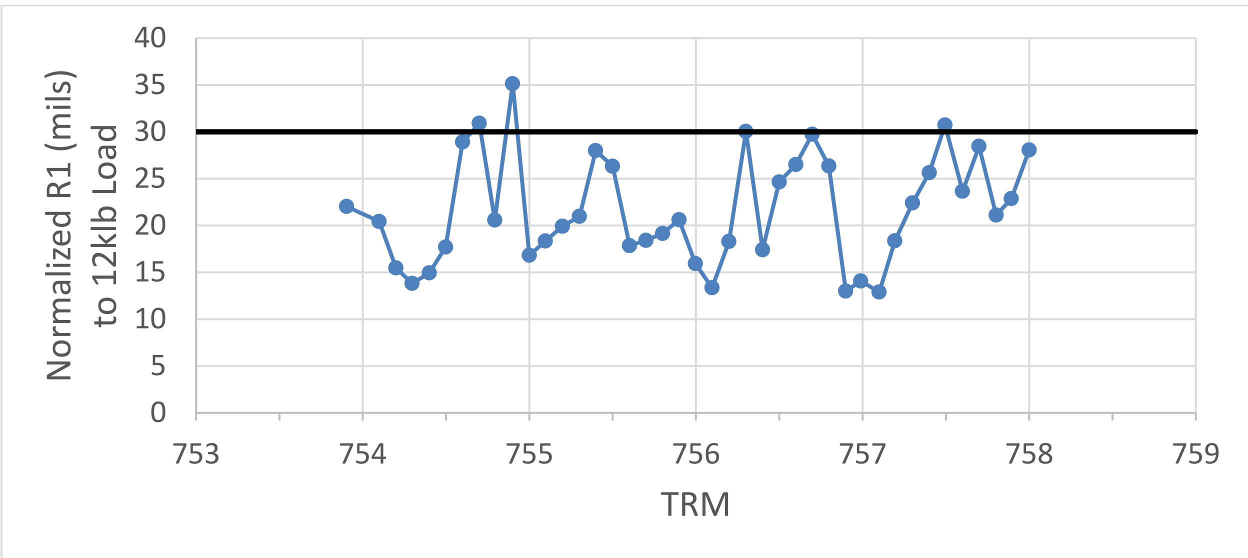


Figure 16. FWD Sensor 1 Deflection with Distance on US 59.

Table 5. FWD Output from US 59 Mill and Inlay.

```
TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                                    (Version 6.1)

District:                                                        MODULI RANGE(psi)
County  :                              Thickness(in)          Minimum      Maximum     Poisson Ratio Values
Highway/Road:             Pavement:        2.00               247,400      247,400       H1: v = 0.35
                          Base:            6.00                50,000    1,000,000       H2: v = 0.35
                          Subbase:         0.00                                          H3: v = 0.00
                          Subgrade:      194.18(by DB)                10,000             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	13,210	30.68	24.10	16.10	10.81	7.19	4.96	3.53	247.4	454.1	0.0	7.9	1.18	206.3
0.107	13,199	24.91	20.37	13.96	9.28	6.13	4.17	2.93	247.4	675.5	0.0	9.2	1.08	186.4
0.198	13,221	23.07	18.29	12.13	8.20	5.64	4.05	3.03	247.4	752.1	0.0	10.2	2.86	251.9
0.301	13,122	30.85	24.35	15.85	10.34	6.72	4.54	3.28	247.4	380.4	0.0	8.1	1.15	186.5
0.400	13,243	25.85	20.22	13.21	8.67	5.99	4.44	3.44	247.4	571.8	0.0	9.5	3.51	300.0
0.505	13,221	33.40	27.01	18.34	12.58	8.63	6.08	4.47	247.4	489.8	0.0	6.7	1.84	241.4
0.599	13,309	28.08	22.80	15.75	10.71	7.26	5.05	3.65	247.4	644.2	0.0	8.0	1.29	214.0
0.700	13,199	24.31	19.11	12.70	8.51	5.77	4.21	3.26	247.4	667.0	0.0	9.8	2.63	247.7
0.806	13,352	20.21	15.11	9.22	5.67	3.65	2.55	1.89	247.4	506.9	0.0	14.7	2.19	164.0
0.900	13,484	14.39	11.22	7.65	5.17	3.49	2.44	1.71	247.4	1000.0	0.0	17.7	6.36	183.6 *
1.011	13,506	15.72	12.70	9.05	6.25	4.22	2.94	2.15	247.4	1000.0	0.0	14.8	6.70	195.5 *
1.101	13,506	14.39	10.97	7.26	4.99	3.57	2.69	2.02	247.4	1000.0	0.0	18.0	8.84	254.6 *
1.202	13,188	28.52	21.57	13.24	8.28	5.38	3.76	2.85	247.4	324.7	0.0	10.0	2.30	183.5
1.302	13,090	32.00	24.31	14.49	9.02	5.85	4.12	3.17	247.4	253.2	0.0	9.0	2.89	185.3
1.400	13,221	28.87	22.22	14.49	9.54	6.24	4.22	2.96	247.4	420.1	0.0	8.9	0.91	183.0
1.500	13,188	26.93	20.92	13.22	8.29	5.21	3.48	2.50	247.4	375.7	0.0	10.2	2.00	150.9
1.600	13,352	19.33	16.09	11.52	7.93	5.33	3.69	2.63	247.4	1000.0	0.0	11.2	2.83	195.3 *
1.700	13,144	32.57	24.37	15.36	9.70	6.17	4.12	3.00	247.4	271.2	0.0	8.7	0.96	165.2
1.802	13,341	20.17	16.13	10.85	7.25	4.82	3.31	2.37	247.4	881.4	0.0	11.8	1.38	187.1
1.903	13,528	14.92	12.27	8.94	6.49	4.81	3.63	2.74	247.4	1000.0	0.0	14.9	13.77	265.7 *
2.003	13,331	17.58	13.09	8.38	5.48	3.59	2.45	1.72	247.4	786.6	0.0	15.6	1.64	176.5
2.101	13,221	22.54	17.30	11.00	7.15	4.76	3.39	2.57	247.4	575.7	0.0	11.7	2.55	208.7
2.200	13,341	21.14	17.13	11.59	7.68	5.04	3.40	2.39	247.4	815.2	0.0	11.2	1.01	173.6
2.300	13,363	20.30	16.63	11.68	8.31	6.00	4.48	3.39	247.4	1000.0	0.0	10.6	5.99	285.6 *
2.398	13,331	19.57	16.11	11.19	7.80	5.44	3.94	2.93	247.4	1000.0	0.0	11.2	4.01	255.2 *
2.500	13,199	28.70	23.02	15.40	10.22	6.73	4.52	3.22	247.4	491.6	0.0	8.3	0.87	178.7
2.602	13,122	30.31	25.20	17.30	11.52	7.60	5.13	3.58	247.4	514.4	0.0	7.3	1.62	187.7
2.699	13,341	23.17	19.59	14.63	10.58	7.39	5.11	3.61	247.4	874.0	0.0	8.7	5.94	197.8 *
2.801	13,298	21.89	17.76	12.77	9.32	6.98	5.37	4.20	247.4	1000.0	0.0	10.0	8.53	300.0 *
2.904	13,320	20.15	16.28	10.91	7.32	4.92	3.38	2.34	247.4	908.4	0.0	11.7	1.61	183.6
3.000	13,440	18.78	15.89	11.91	8.69	6.11	4.28	2.97	247.4	1000.0	0.0	10.9	8.68	182.3 *
3.100	13,079	37.82	28.19	17.43	11.09	7.25	5.11	3.87	247.4	219.1	0.0	7.4	2.18	203.4
3.207	13,341	22.68	17.98	11.68	7.67	5.15	3.59	2.60	247.4	657.8	0.0	11.0	2.20	206.9
3.300	13,133	33.64	27.26	18.48	12.49	8.43	5.80	4.09	247.4	444.1	0.0	6.7	1.25	209.9
3.400	13,166	31.49	24.73	16.30	10.80	7.25	5.10	3.74	247.4	417.1	0.0	7.7	1.86	236.0
3.502	13,429	19.61	15.37	10.24	6.84	4.56	3.15	2.25	247.4	881.0	0.0	12.6	1.54	191.3
3.600	13,506	16.78	14.02	10.30	7.55	5.41	3.89	2.85	247.4	1000.0	0.0	12.9	11.37	226.5 *
3.703	13,473	15.48	12.94	9.39	6.61	4.53	3.13	2.22	247.4	1000.0	0.0	14.3	9.03	186.8 *
3.800	13,440	17.24	14.24	10.28	7.32	5.14	3.67	2.74	247.4	1000.0	0.0	12.8	8.41	229.4 *
3.901	13,287	22.43	17.55	11.42	7.41	4.89	3.35	2.41	247.4	618.9	0.0	11.4	1.53	187.9
4.096	13,309	24.19	18.84	11.81	7.41	4.75	3.30	2.49	247.4	456.9	0.0	11.3	2.14	164.9
Mean:		23.77	18.86	12.62	8.46	5.71	4.00	2.92	247.4	690.9	0.0	10.9	3.67	202.2
Std. Dev:		6.13	4.67	2.92	1.91	1.28	0.90	0.67	0.0	262.2	0.0	2.8	3.27	31.8
Var Coeff(%):		25.80	24.74	23.14	22.61	22.51	22.45	22.93	0.0	38.0	0.0	26.0	88.98	15.9

FDR with Cement and Flex-Base Overlay

SH 202

Soil Survey. Figure 17 shows the plasticity map, and Figure 18 shows the gypsum map. The subgrade is expected to have a PI in the low 20s or less, and the section has low likelihood of sulfates.

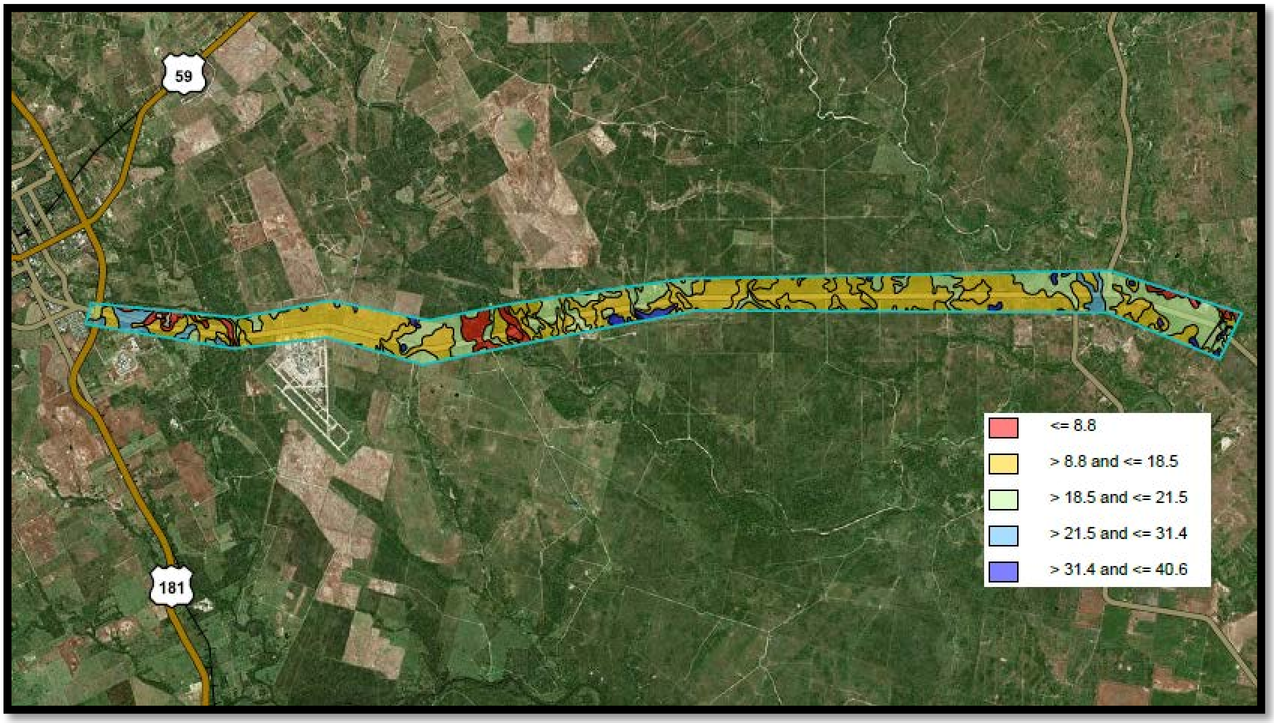


Figure 17. PI Map from SH 202.

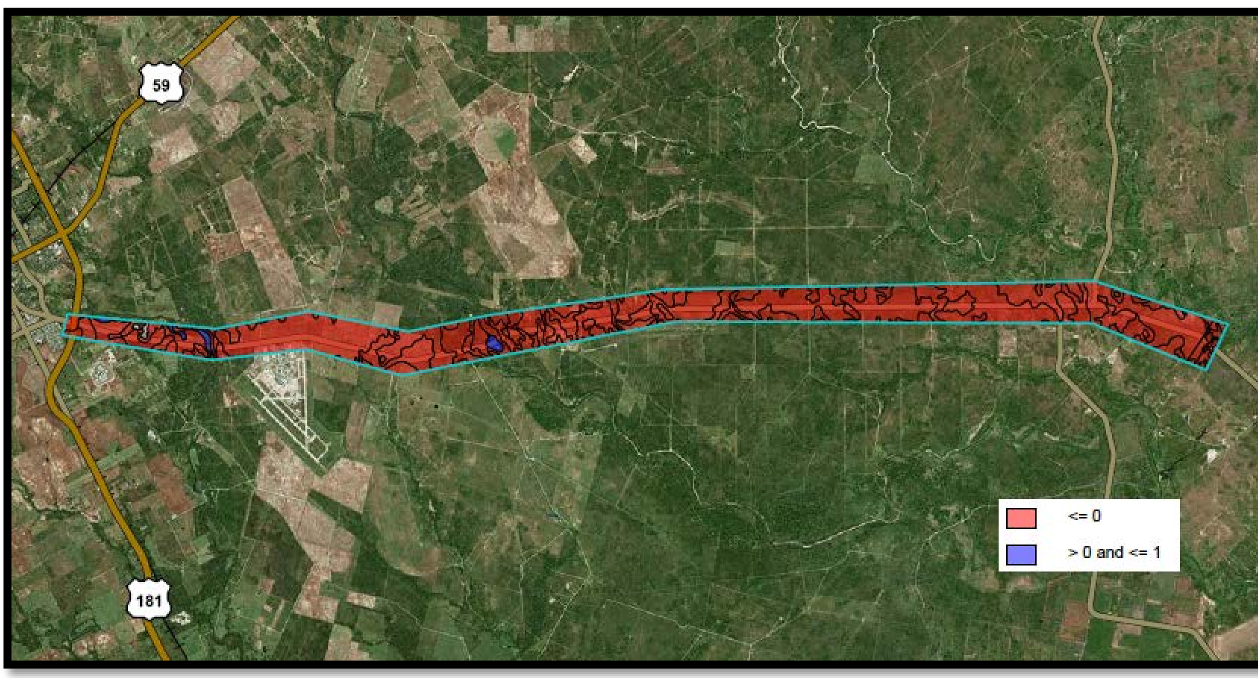


Figure 18. Gypsum Map from SH 202.

GPR and DCP Results. Figure 19 shows example GPR data, where the biggest observations were variations in surface thickness due to maintenance activities.

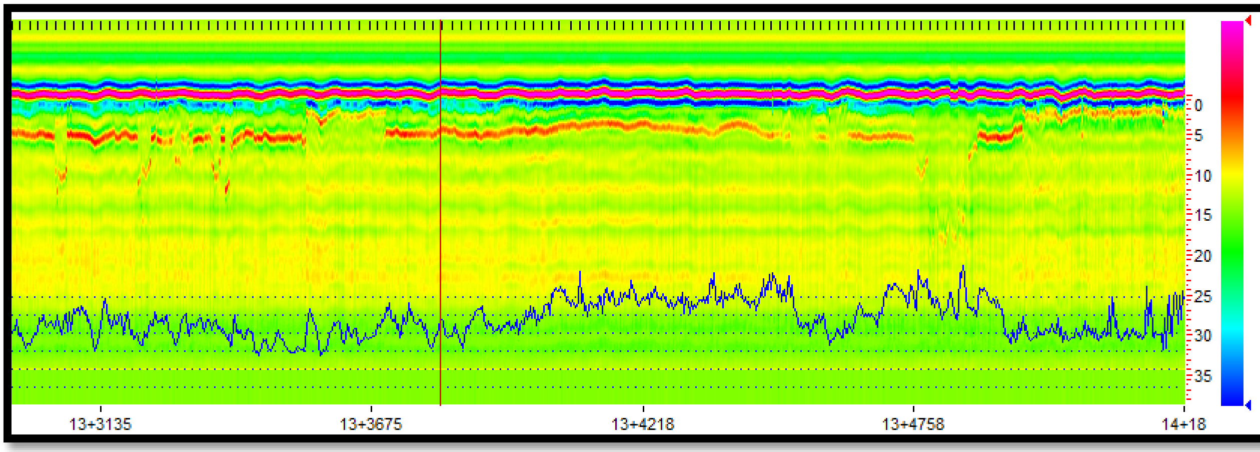


Figure 19. Example GPR from SH 202.

Figure 20 presents example DCP and companion coring results; the data indicate the stabilized base layers have deteriorated under the traffic loadings over time.

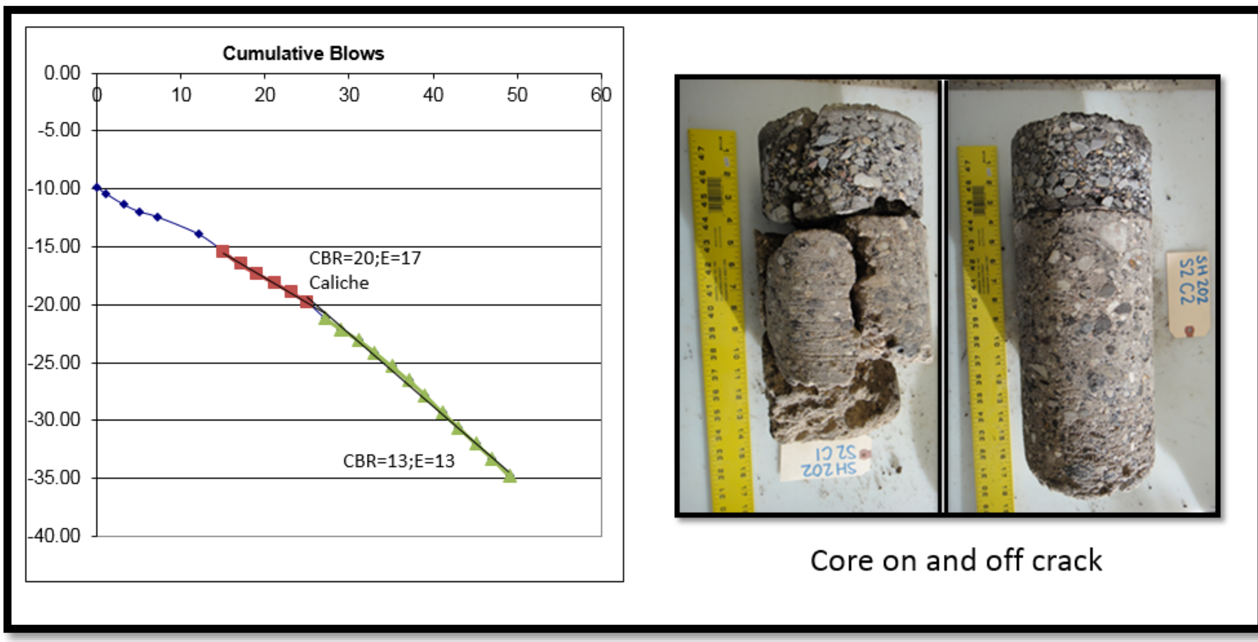


Figure 20. DCP and Companion Coring Results.

Auguring Results. Figure 21 presents a summary of the auguring results. The augur results support the general partitioning of the project, as illustrated in Figure 22.

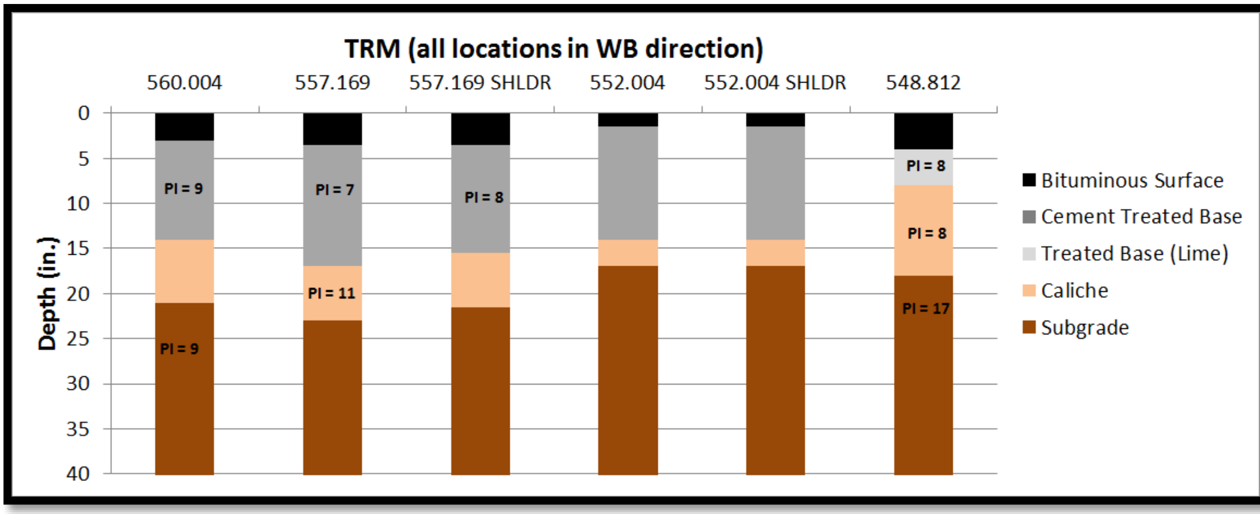


Figure 21. Augur Results from SH 202.

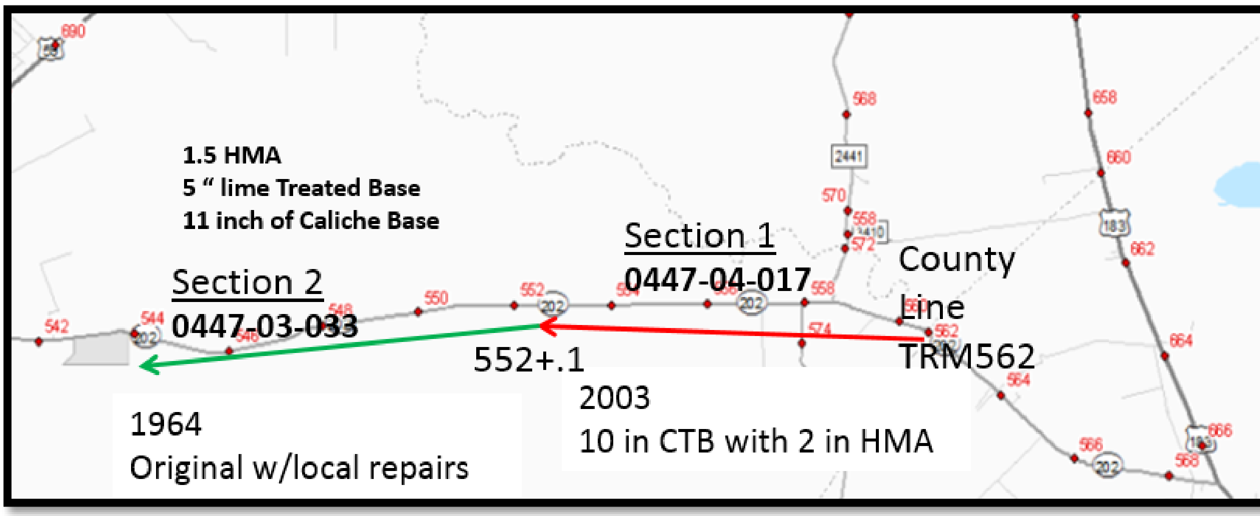


Figure 22. Partitioning of SH 202.

FWD Results. Table 6 presents example FWD results on the existing pavement, and the results support the conclusion that the stabilized base layer has deteriorated. The FWD results also provide data for a subgrade modulus for later use in the pavement design.

Table 6. Example FWD Results from Existing Section on SH 202.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	1.50	1,500,000	1,500,000	H1: v = 0.35
Base:	12.50	20,000	2,000,000	H2: v = 0.25
Subbase:	0.00			H3: v = 0.00
Subgrade:	121.30 (by DB)	10,000		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	9,858	7.04	5.69	4.41	3.35	2.44	1.83	1.30	1500.0	557.2	0.0	13.3	1.54	185.9
157.000	9,201	35.14	25.38	15.03	9.06	5.56	4.38	3.67	1500.0	33.2	0.0	4.8	7.59	150.9
329.000	10,351	26.73	16.14	13.15	7.72	5.82	3.88	2.35	1500.0	69.7	0.0	6.1	4.27	195.8
450.000	9,902	34.31	15.02	5.54	3.33	2.32	1.80	1.33	1500.0	20.0	0.0	13.9	9.38	62.4 *
600.000	9,475	11.75	8.14	5.30	3.38	2.08	1.55	1.19	1500.0	139.5	0.0	13.7	5.54	128.1
901.000	9,573	16.44	10.30	5.88	3.38	1.99	1.47	1.14	1500.0	72.6	0.0	13.8	7.31	111.6
1052.000	10,099	26.35	12.22	5.80	3.45	1.92	1.50	1.08	1500.0	32.6	0.0	14.7	4.50	95.6
Mean:		22.54	13.27	7.87	4.81	3.16	2.34	1.72	1500.0	132.1	0.0	11.5	5.73	135.3
Std. Dev:		10.98	6.48	4.31	2.48	1.74	1.24	0.96	0.0	191.7	0.0	4.1	2.60	55.0
Var Coeff(%):		48.72	48.80	54.73	51.48	54.99	52.74	55.85	0.0	145.1	0.0	36.1	45.31	40.6

Laboratory Mixture Design. Based on the project partitioning, Figure 23 and Figure 24 show the lab mix design results for Sections 1 and 2, respectively. For Section 1, any of the FDR designs are options except for the 1.5 percent cement with 2.4 percent foam. For Section 2, treatment with 3 percent cement was the only strategy that produced a passing design.

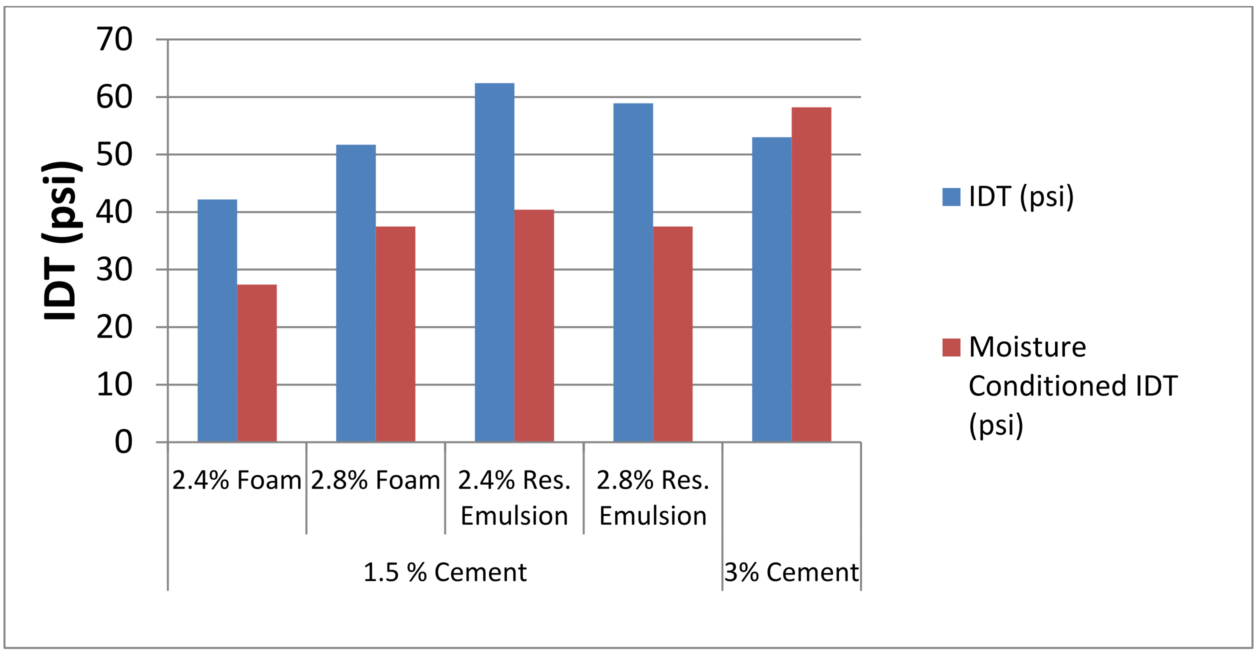


Figure 23. Lab Mix Designs from SH 202 Section 1.
Note: All mixtures included 30 percent new TY A GR 1 Flex Base.

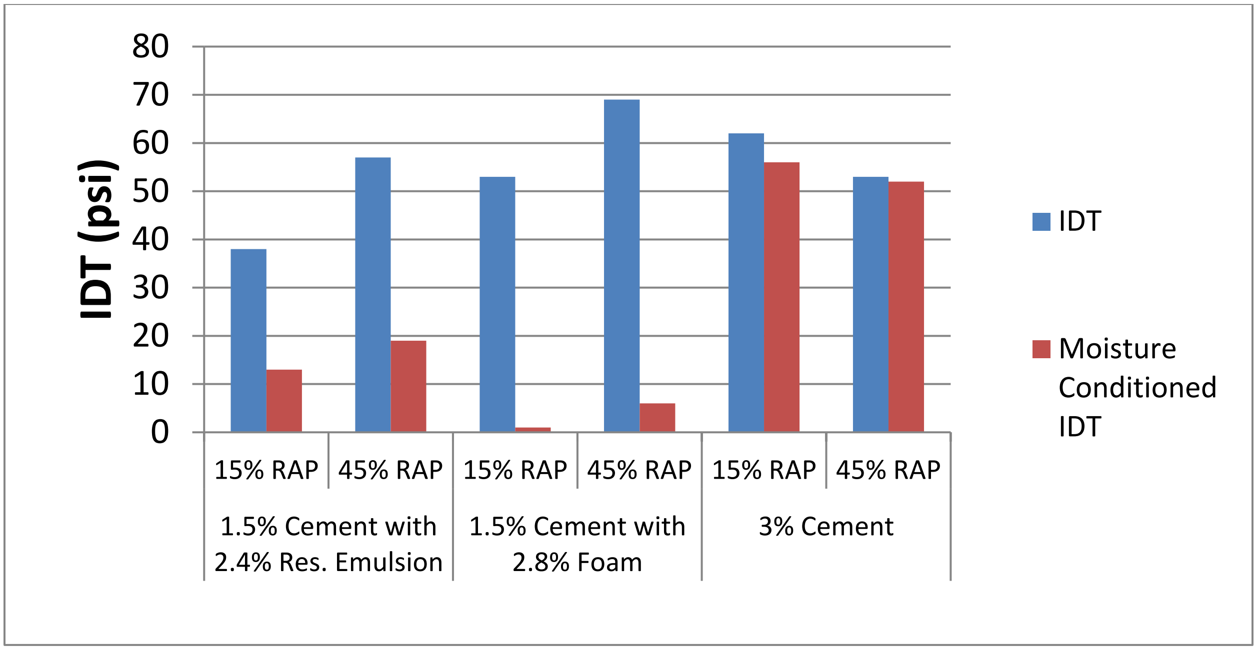


Figure 24. Lab Mix Designs from SH 202 Section 2.

Note: All mixtures included 30 percent new TY A GR 1 Flex Base.

Pavement Design. TxDOT requested pavement designs assuming 5M equivalent single axle loads (ESALS) to compare the performance periods for the following potential pavement renewal strategies:

- FDR with HMA.
- FDR with surface treatment.
- Untreated flex base for comparison.

Figure 25 summarizes the designs for those criteria, where the assumed subgrade modulus was 8 ksi, the assumed stabilized FDR layer modulus was 150 ksi, the assumed flexible base modulus was 40 ksi, the assumed modulus of surface treatment was 200 ksi, and the assumed modulus of HMA was 500 ksi.

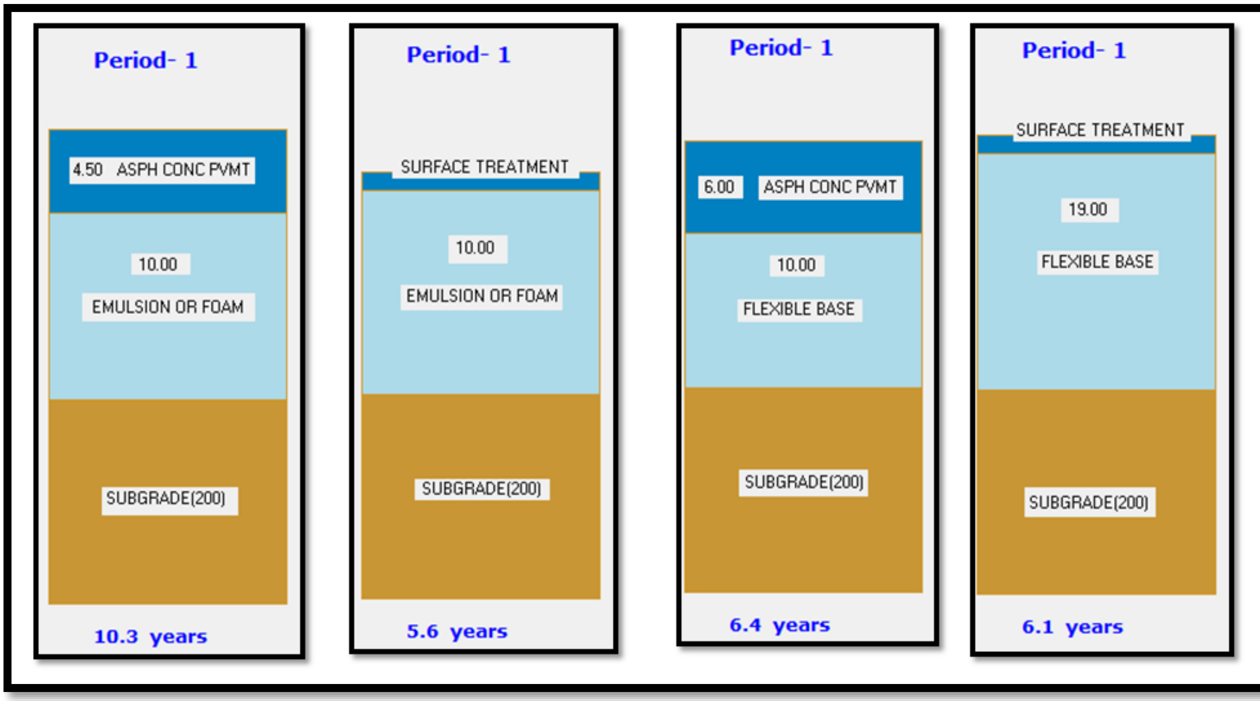


Figure 25. First Performance Periods for SH 202 with Different Renewal Strategies.

Recommended Sequence. For Section 1, FDR options include:

- Place 2 in. new base, FDR 10 in. total, with either:
  - 1.5 percent cement + 2.7 percent foamed asphalt.
  - 1.5 percent cement + 2.4 percent residual asphalt from emulsion.
  - 3 percent cement.

For Section 2, the only FDR strategy meeting mix design requirements is to treat with 3 percent cement. A treatment depth of 10 in. was used in this option.

Construction Results. This project was designed with potential alternates of foamed asphalt, asphalt emulsion, or cement-only treatment. TxDOT chose to implement FDR treatment of 10 in. with 3 percent cement and then overlay with 6 in. of new flexible base with a three-course surface treatment.

Construction took place from spring 2016 through fall 2016. Figure 26 shows the basic FDR operation of the project through placement of the flexible base overlay.

Figure 26. Typical Construction Sequence on SH 202.

The research team visited the project at different stages and used the FWD to monitor the strength gain with time of the stabilized layer. Figure 27 shows the increase in modulus of the FDR layer over time, from the day of compaction to 8 months after compaction, as measured with the FWD. Testing during construction took place at TRM 549 to TRM 549.189. Data were collected in the EB travel direction.

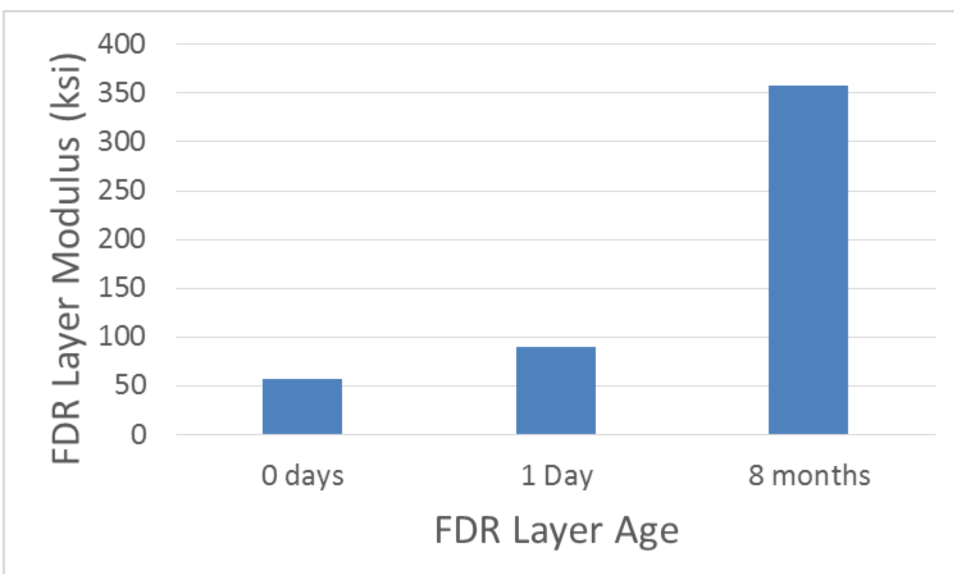


Figure 27. Growth of FDR Layer Modulus on SH 202.

FWD data representing an excerpt of the completed project were collected in May 2017 from TRM 548 to 550 in the eastbound travel direction. The data in Table 7 show very reasonable values for the cement-treated subbase modulus and for the flexible base overlay modulus. The data also give additional justification to assuming a higher flexible base layer modulus when a base overlay is placed on a well-stabilized subbase foundation.

Table 7. FWD Output from SH 202 Cement Treatment with Flex-Base Overlay.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	216,700	216,700	H1: v = 0.35
Base:	6.00	10,000	150,000	H2: v = 0.35
Subbase:	10.00	100,000	2,000,000	H3: v = 0.25
Subgrade:	221.33(by DB)	8,000		H4: v = 0.35

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	8,993	8.28	5.86	4.22	2.95	1.99	1.35	0.96	216.7	150.0	410.7	15.5	7.12	165.5 *
264.000	9,014	8.82	5.48	3.24	2.18	1.53	1.15	0.89	216.7	150.0	197.2	20.2	9.93	294.0 *
527.000	9,124	8.92	5.42	3.57	2.47	1.74	1.33	1.06	216.7	150.0	242.0	18.6	7.89	300.0 *
792.000	8,982	8.27	5.28	3.60	2.60	1.89	1.44	1.08	216.7	150.0	435.6	16.5	9.95	242.8 *
1055.000	9,004	10.22	5.13	3.20	2.37	1.74	1.46	1.05	216.7	150.0	112.3	21.2	10.52	300.0 *
1321.000	9,113	10.71	5.27	2.68	1.90	1.44	1.17	0.98	216.7	150.0	100.0	23.9	12.76	300.0 *
1585.000	9,036	15.50	8.61	4.81	2.93	1.85	1.25	0.83	216.7	70.6	100.0	16.5	9.76	144.1 *
1846.000	9,201	9.35	5.08	3.32	2.04	1.32	0.90	0.66	216.7	150.0	156.8	22.5	7.99	159.4 *
2111.000	9,321	13.40	7.34	3.55	2.15	1.44	1.04	0.79	216.7	62.6	274.7	19.9	17.29	201.3
2378.000	9,113	10.33	5.32	2.87	1.84	1.17	0.86	0.61	216.7	87.1	289.5	23.3	15.87	143.5
2638.000	9,004	17.02	10.53	6.40	4.37	3.10	2.27	1.79	216.7	80.8	100.0	11.3	4.76	278.4 *
2903.000	9,080	7.55	4.16	3.02	2.22	1.57	1.17	0.85	216.7	150.0	525.0	18.5	11.45	202.5 *
3168.000	9,102	10.46	5.52	3.24	2.21	1.46	1.07	0.80	216.7	150.0	101.4	22.1	7.38	179.1 *
3431.000	9,234	11.38	5.74	3.72	2.60	1.89	1.39	1.03	216.7	137.2	123.4	19.0	6.65	228.2
3694.000	9,047	18.98	12.13	8.33	5.82	4.13	3.07	2.31	216.7	92.7	100.0	9.3	2.69	280.3 *
3959.000	9,266	11.30	7.40	5.65	4.24	3.14	2.39	1.81	216.7	109.6	608.2	11.0	5.55	265.6 *
4225.000	9,004	9.50	5.29	3.47	2.46	1.81	1.32	1.00	216.7	150.0	188.5	18.8	6.91	247.9 *
4488.000	9,201	13.42	6.61	3.33	2.05	1.27	0.86	0.63	216.7	55.8	308.1	22.3	16.04	128.7
4752.000	9,234	9.96	5.56	3.02	1.99	1.45	1.05	0.80	216.7	150.0	122.3	22.9	10.37	235.5 *
5017.000	9,102	4.64	3.24	2.46	1.86	1.44	1.11	0.87	216.7	150.0	1261.9	17.8	28.23	300.0 *
5281.000	8,861	11.60	6.37	4.24	2.94	2.15	1.62	1.22	216.7	136.1	129.3	16.3	4.90	255.2
5543.000	9,464	10.84	5.82	3.24	2.12	1.43	1.00	0.70	216.7	150.0	100.3	23.0	8.43	176.8 *
5809.000	9,288	13.98	6.67	3.59	2.40	1.65	1.21	0.87	216.7	61.2	242.1	19.3	13.93	245.7
6071.000	8,993	6.73	4.37	3.26	2.33	1.73	1.31	0.94	216.7	150.0	390.6	19.1	14.11	193.3 *
6337.000	9,047	6.50	4.14	3.03	2.30	1.71	1.31	1.01	216.7	150.0	408.0	19.5	17.06	282.9 *
6599.000	9,562	6.81	4.80	3.65	2.88	2.20	1.70	1.30	216.7	128.9	1355.6	12.9	16.85	267.9 *
6864.000	9,047	8.67	5.79	4.29	3.32	2.55	2.02	1.61	216.7	150.0	305.3	15.6	13.17	300.0 *
7390.000	9,036	8.17	6.23	4.97	4.01	3.23	2.64	2.13	216.7	113.8	831.4	11.4	15.35	300.0 *
7656.000	8,993	6.91	5.42	4.45	3.69	3.02	2.58	2.13	216.7	119.4	1020.0	11.9	20.98	300.0 *
7921.000	8,938	10.35	7.09	5.52	4.39	3.48	2.81	2.18	216.7	100.3	763.5	10.0	9.04	300.0 *
8185.000	8,905	15.89	9.14	6.43	4.95	3.93	3.15	2.50	216.7	66.3	276.1	9.4	5.95	300.0
8498.000	9,091	8.41	4.22	2.70	1.97	1.44	1.13	0.83	216.7	150.0	240.6	22.8	10.37	300.0 *
8711.000	8,905	11.04	7.64	6.12	4.96	3.99	3.25	2.59	216.7	87.2	828.7	8.7	8.56	300.0 *
8975.000	9,091	12.47	9.41	7.03	5.36	4.02	3.06	2.38	216.7	94.9	451.3	9.5	5.65	300.0 *
9242.000	9,014	10.27	6.03	3.49	2.22	1.51	1.04	0.71	216.7	150.0	108.6	21.0	7.40	164.5 *
9509.000	9,014	9.04	5.06	3.15	2.30	1.81	1.43	1.01	216.7	150.0	222.2	19.4	10.80	180.5 *
9769.000	8,916	11.51	6.19	3.28	1.97	1.26	0.90	0.65	216.7	114.9	100.0	22.4	13.27	150.0 *
10032.000	9,190	18.33	8.07	3.26	2.06	1.46	1.11	0.81	216.7	34.9	274.3	21.5	21.60	81.5
10296.000	8,971	10.75	6.77	4.45	3.30	2.58	2.06	1.63	216.7	150.0	144.3	15.6	9.30	300.0 *
10561.000	8,938	13.46	9.34	6.76	5.06	3.90	3.09	2.43	216.7	100.7	254.6	10.1	6.61	300.0 *
10608.000	8,949	12.61	9.15	6.74	5.12	3.92	3.03	2.35	216.7	95.6	460.2	9.6	5.85	300.0 *
Mean:		10.79	6.41	4.18	3.00	2.20	1.69	1.29	216.7	120.7	357.7	17.1	10.93	237.8
Std. Dev:		3.20	1.88	1.43	1.16	0.95	0.78	0.63	0.0	34.9	315.2	4.9	5.28	87.9
Var Coeff(%):		29.66	29.41	34.29	38.67	42.90	46.01	49.16	0.0	28.9	88.1	28.7	48.25	38.4

FM 1996

Soil Survey. TxDOT nominated this section for inclusion in this implementation effort after construction was already underway, so no soils maps were collected.

GPR and DCP Results. At the start of construction, locations were discovered with RAP contents significantly exceeding the 30 percent RAP used in the initial mixture design. In January 2017, the research team collected GPR from the project and estimated the existing asphalt thickness, as Figure 28 illustrates. For the planned FDR thickness of 7 in., the GPR data suggested over 70 percent of the project would have RAP content exceeding 50 percent of the FDR mixture, and about 30 percent of the project would be 100 percent RAP in the FDR mixture.

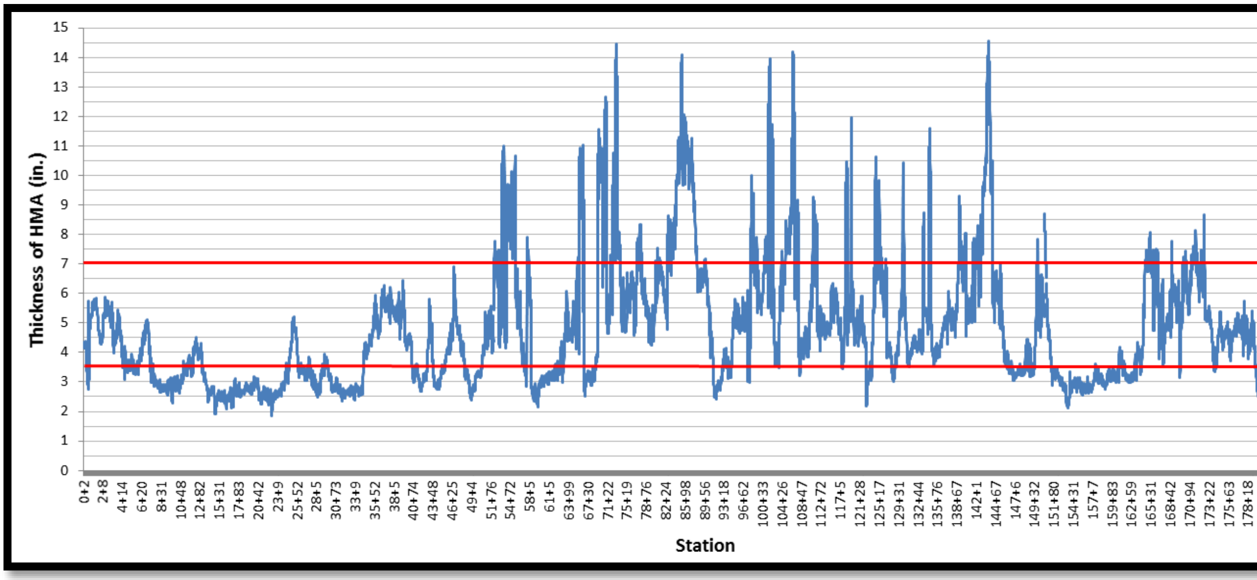


Figure 28. Estimation of RAP Thickness on FM 1996 Using GPR.

Since the project was already under construction when its participation in this implementation effort began, no DCP were collected.

Auguring Results. No auguring was performed as part of this implementation effort.

FWD Results. No FWD results prior to construction were collected as part of this implementation project.

Laboratory Mixture Design. Prior to this section's participation in this implementation effort, TxDOT established a mix design using 3 percent cement. Due to observed potential RAP contents exceeding 50 percent once construction began, the research team was asked to evaluate if the higher RAP content would impede effective stabilization with cement.

Figure 29 presents the lab mix designs. Figure 29 shows that at the planned treatment level, the high RAP content did not adversely impact the effectiveness of stabilization. However, at the planned treatment level of 3 percent cement, the materials from STA 30 did not pass proposed indirect tensile (IDT) strength mix design requirements. Based on these results, TxDOT decided to increase the cement content to 3.5 percent and proceed with the planned typical sections.

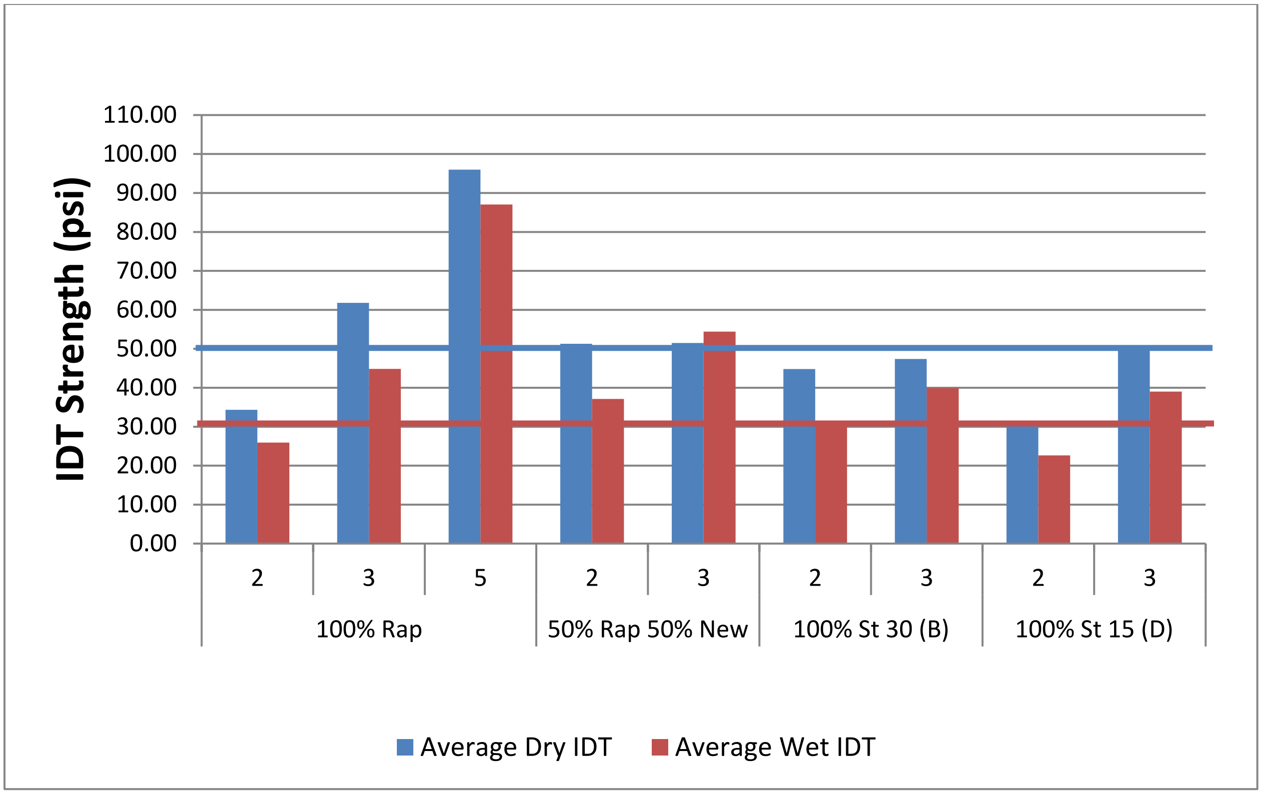


Figure 29. Lab Mix Designs for FM 1996.

Pavement Design. TxDOT performed a pavement design consisting of 7 in. of FDR, 4 in. of flexible base overlay, and 2 in. of HMA.

Recommended Sequence. This implementation project was not part of the construction section planning process for this section.

Construction Results. In June 2017, FWD results were collected on the completed section minus the final hot mix surface. Based on the design assumptions, at this stage of completion, the Sensor 1 deflection should not exceed 19.2 mils under the 9klb FWD load. Figure 30 illustrates that only approximately 12 percent of the data points exceeded this deflection. Figure 30 also illustrates, as evaluated in context with Figure 28, that RAP contents exceeding 50 percent of the mixture did not adversely impact field performance with this material and treatment level.

The average normalized deflection in locations where the RAP content is expected to exceed 50 percent was 12.3 mils; in locations where the RAP content is expected to be less than 50 percent, the average normalized deflection was 11.7 mils.

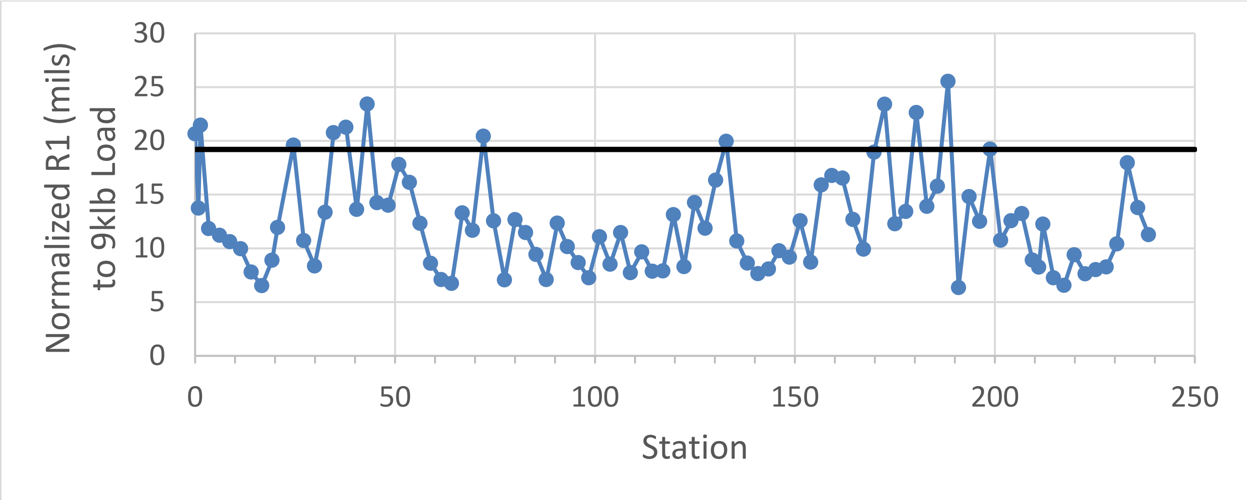


Figure 30. FWD Sensor 1 Deflection with Distance for FM 1996.

FDR with Asphalt Emulsion

IH 10 (Reeves County)

Soil Survey. Soil survey data were not collected on this section as part of this implementation effort.

GPR and DCP Results. GPR and DCP data were not collected on this section as part of this implementation effort.

Auguring Results. Material samples from this section were obtained and provided by TxDOT.

FWD Results. Testing on the section with the FWD prior to construction was not performed as part of this implementation effort.

Laboratory Mixture Design. The contractor provided a mixture design using 4.5 percent emulsion with 1 percent cement.

Pavement Design. TxDOT created a pavement design consisting of 7 in. flex base to remain in place, 9 in. of emulsion-treated base, and 4 in. of HMA with modulus values of 35, 250, and 500 ksi, respectively. The design assumed a subgrade modulus of 22 ksi.

Recommended Sequence. Sequence recommendations were not performed as part of this implementation project.

Construction Results. This project was designed with 4.5 percent asphalt emulsion and 1 percent cement for an FDR treatment depth of 9 in. Construction was performed in the fall and winter 2015. Figure 31 shows the typical construction sequence of the FDR layer.

Figure 31. Typical Construction Sequence on IH 10 (Reeves County).

Figure 32 shows the increase in the FDR layer modulus over time, from the day of compaction through 8 months after completion. FWD testing took place at westbound TRM 202 to 201 on the inside lane to generate these data. The data show that after only 2 days curing, the emulsion-treated layer was very near its eventual in-service modulus value.

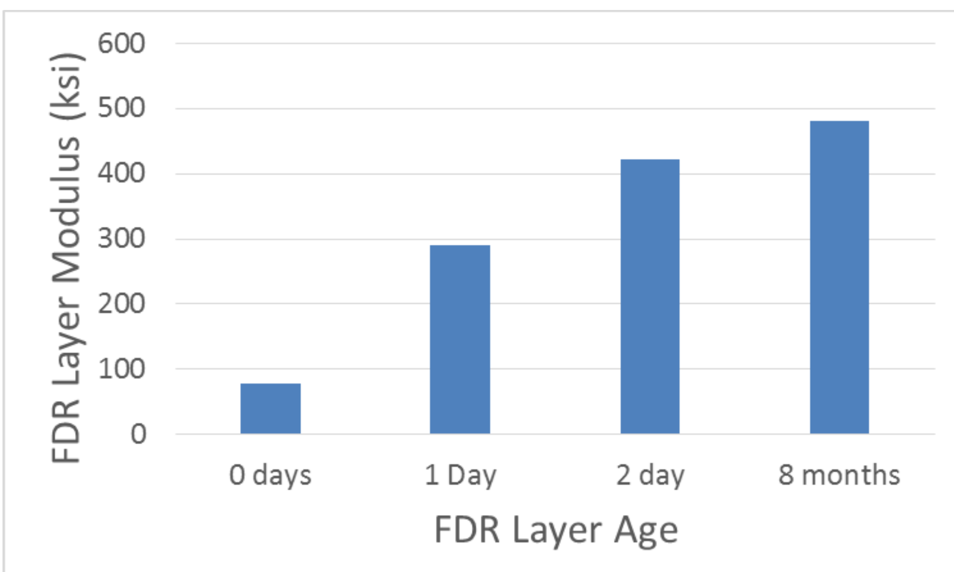


Figure 32. Growth of FDR Layer Modulus on IH 10 (Reeves County).

Table 8 presents an example of the FWD output from the completed section that was tested in June 2016. Under the design assumptions, the deflection under a 9klb FWD load should not exceed 7.69 mils. The data show the pavement structure easily met the design assumptions.

Table 8. FWD Output from IH 10 (Reeves County) Completed Section.

```
                          TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                    (Version 6.1)
District:                                                    MODULI RANGE(psi)
County   :                            Thickness(in)        Minimum      Maximum     Poisson Ratio Values
Highway/Road:              Pavement:      4.00              50,000      300,000       H1: v = 0.35
                           Base:          9.00              50,000    1,000,000       H2: v = 0.35
                           Subbase:       7.00              10,000      150,000       H3: v = 0.35
                           Subgrade:    202.00(by DB)             20,000              H4: v = 0.35
```

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	9,545	5.24	2.69	1.63	1.09	0.70	0.51	0.37	300.0	342.0	64.4	59.7	1.15	179.0 *
0.100	9,624	5.45	2.91	1.70	1.15	0.72	0.53	0.41	300.0	362.6	44.5	59.2	2.12	156.7 *
0.200	9,632	9.02	3.70	1.69	1.06	0.77	0.61	0.41	300.0	75.7	76.6	54.7	3.53	244.0 *
0.300	9,521	5.00	3.13	2.11	1.42	0.95	0.70	0.56	300.0	452.8	71.8	44.3	2.74	237.8 *
0.400	9,640	3.67	2.04	1.17	0.71	0.47	0.39	0.43	300.0	486.3	110.3	87.7	5.75	218.8 *
0.500	9,613	3.83	1.96	1.11	0.75	0.46	0.37	0.30	300.0	573.9	78.2	88.5	3.76	143.5 *
0.600	9,601	4.30	2.04	1.14	0.70	0.51	0.43	0.35	300.0	373.9	100.4	84.3	4.79	300.0 *
0.699	9,597	3.38	1.49	0.78	0.49	0.33	0.27	0.31	300.0	515.7	119.9	126.8	4.15	252.5 *
0.800	9,601	3.99	1.76	1.06	0.72	0.57	0.51	0.54	185.0	815.1	150.0	81.5	7.76	300.0 *
0.900	9,601	3.48	1.85	1.22	0.89	0.69	0.48	0.46	300.0	1000.0	123.5	70.8	4.62	223.0 *
0.995	9,537	5.19	2.66	1.67	1.17	0.85	0.63	0.56	300.0	304.2	150.0	51.6	1.84	300.0 *
Mean:		4.78	2.38	1.39	0.92	0.64	0.49	0.43	289.5	482.0	99.1	73.6	3.84	222.0
Std. Dev:		1.60	0.68	0.39	0.28	0.19	0.13	0.09	34.7	251.4	34.9	23.5	1.90	59.8
Var Coeff(%):		33.42	28.52	28.25	29.90	29.26	25.37	22.06	12.0	52.2	35.3	32.0	49.54	25.9

SH 115

Soil Survey. Soil survey data were not collected on this section as part of this implementation effort.

GPR and DCP Results. GPR and DCP data were not collected on this section as part of this implementation effort.

Auguring Results. Material samples from this section were obtained and provided by TxDOT.

FWD Results. Testing on the section with the FWD prior to construction was not performed as part of this implementation effort.

Laboratory Mixture Design. The contractor provided a mixture design using 5.5 percent emulsion. The second phase of the project was constructed with a contractor-provided mix design of 2.8 percent high-yield emulsion.

Pavement Design. TxDOT performed a pavement design consisting of an 8 in. emulsion-treated subbase, 10 in. flex-base overlay, and a three-course surface treatment with assumed modulus values of 250, 100, and 200 ksi, respectively. The design assumed a subgrade modulus of 27.8 ksi.

Recommended Sequence. Sequence recommendations were not performed as part of this implementation project.

Construction Results. Construction was completed in two phases on this project, using different asphalt emulsions. Phase 1 used CSS-1H at a treatment rate of 5.5 percent. Phase 2 used a high-yield asphalt emulsion at a treatment rate of 2.8 percent. Figure 33 shows the approximate limits of the project and each phase. Figure 34 shows the typical construction sequence of the FDR layer.

Figure 33. Project and Phase Limits for SH 115.

Figure 34. Typical Construction Sequence on SH 115.

Construction was performed from summer to fall 2016. Figure 35 presents the modulus values of the emulsion-treated layer with time from Phase 2 of the project as measured with the FWD. Monitoring during the construction of Phase 2 was conducted at approximately TRM 376 to TRM 376.4. The data in Figure 35 suggest that, even after almost a year in service, the stabilized layer modulus assumption of 250 ksi was not attained.

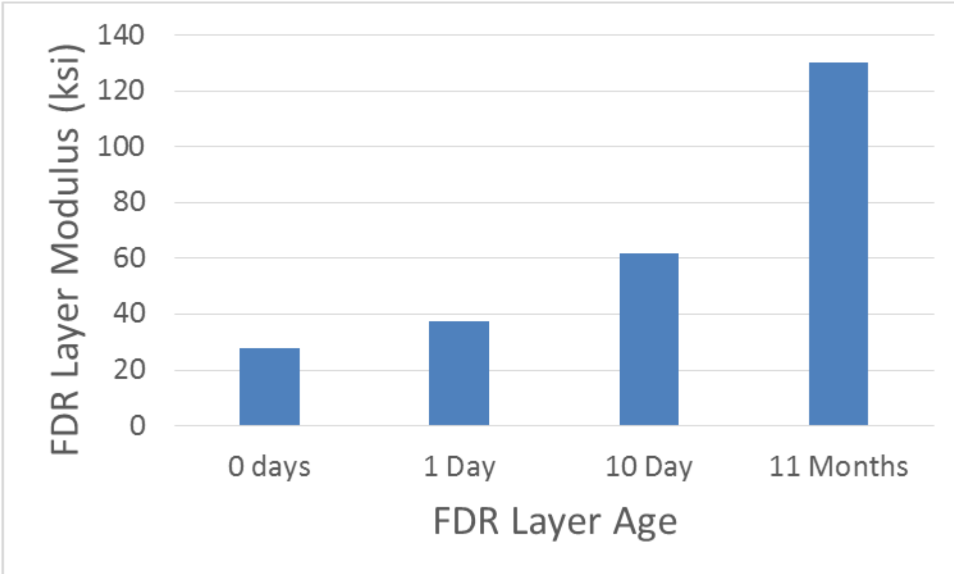


Figure 35. Growth of FDR Layer Modulus on SH 115.

Table 9 and Table 10 present the FWD output collected on the completed Phase 1 and 2 sections, respectively, after approximately 11 to 14 months in service. For reference, under a 9klb FWD load, the expected Sensor 1 deflection would be 9.98 mils. The FWD data suggest:

- The design assumptions were not met in either phase.
- The subgrade is very good.
- The design assumptions were probably not met in the stabilized layer, the flexible base overly, or both.
- Significant variability exists in the expected modulus of the stabilized subbase.

Table 9. FWD Output from SH 115 Completed Phase 1 Section.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	663,400	663,400	H1: v = 0.35
Base:	10.00	10,000	150,000	H2: v = 0.35
Subbase:	8.00	50,000	1,000,000	H3: v = 0.35
Subgrade:	190.76 (by DB)	20,000		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	9,661	13.81	5.68	2.76	1.80	1.30	0.98	0.78	663.4	84.7	50.0	32.4	4.48	300.0 *
260.000	9,595	14.33	5.48	2.63	1.76	1.24	0.96	0.73	663.4	78.0	50.1	33.9	4.51	300.0 *
528.000	9,551	13.30	5.13	2.12	1.34	0.96	0.72	0.52	663.4	80.4	50.0	41.4	6.43	89.9 *
793.000	9,562	15.10	5.84	2.63	1.79	1.29	1.00	0.80	663.4	71.8	50.0	32.8	5.98	170.7 *
1067.000	9,573	13.93	5.62	2.90	1.95	1.36	0.98	0.75	663.4	83.5	51.2	30.9	2.32	225.8
1320.000	9,507	15.44	4.71	2.10	1.35	1.00	0.82	0.66	663.4	61.1	56.8	41.6	7.22	154.2
1580.000	9,825	8.06	3.00	1.54	1.12	0.88	0.73	0.58	663.4	125.9	289.3	48.0	11.93	300.0
1847.000	9,540	10.21	4.09	2.22	1.44	1.03	0.76	0.63	663.4	114.3	76.9	39.4	3.19	264.7
2112.000	9,540	14.04	5.20	2.48	1.66	1.23	1.00	0.89	663.4	76.5	58.2	34.8	6.63	300.0
2379.000	9,595	13.79	5.72	3.05	2.07	1.41	1.11	0.85	663.4	85.5	55.3	29.0	2.34	223.2
2639.000	9,420	21.12	7.41	3.07	1.89	1.34	1.02	0.68	663.4	42.8	50.0	28.7	6.70	92.1 *
2908.000	9,343	16.23	5.73	2.79	1.91	1.29	0.90	0.65	663.4	62.6	50.0	31.9	2.80	300.0 *
3200.000	9,836	9.56	4.26	2.37	1.62	1.14	0.84	0.65	663.4	135.1	82.8	36.0	2.59	260.8
3443.000	9,617	11.13	3.54	1.36	0.84	0.58	0.42	0.32	663.4	85.6	67.5	62.4	6.83	66.9
3694.000	9,650	15.31	5.63	2.82	1.78	1.18	0.84	0.59	663.4	70.6	50.0	34.0	1.61	182.8 *
3961.000	9,672	11.65	4.54	2.23	1.37	0.92	0.63	0.44	663.4	99.6	54.0	42.6	3.26	168.4
4225.000	9,716	12.27	5.45	2.44	1.50	1.02	0.75	0.56	663.4	96.8	50.0	37.8	4.78	161.7 *
4492.000	9,420	17.53	8.09	3.82	2.49	1.66	1.22	0.95	663.4	61.3	50.0	23.1	7.09	300.0 *
4754.000	9,507	12.88	4.12	1.82	1.14	0.76	0.55	0.33	663.4	75.7	59.6	49.4	3.13	141.4
5018.000	9,759	13.81	5.13	2.54	1.66	1.15	0.84	0.64	663.4	81.0	54.9	36.6	2.83	246.9
5286.000	9,420	16.11	5.46	2.71	1.86	1.33	1.04	0.85	663.4	60.5	67.0	31.9	4.27	300.0
5561.000	9,332	18.66	5.79	2.81	1.88	1.33	1.00	0.72	663.4	48.9	57.8	31.3	3.22	300.0
5706.000	9,529	13.68	5.15	2.51	1.73	1.24	0.92	0.67	663.4	78.8	61.9	34.4	4.44	300.0
Mean:		14.00	5.25	2.51	1.65	1.16	0.87	0.66	663.4	80.9	67.1	36.7	4.72	209.3
Std. Dev:		2.92	1.10	0.53	0.36	0.24	0.19	0.16	0.0	22.4	49.3	8.3	2.36	111.0
Var Coeff(%):		20.86	21.04	21.01	21.63	20.57	21.26	24.41	0.0	27.6	73.4	22.6	50.07	55.3

Table 10. FWD Output from SH 115 Completed Phase 2 Section.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	663,400	663,400	H1: v = 0.35
Base:	10.00	10,000	150,000	H2: v = 0.35
Subbase:	8.00	50,000	1,000,000	H3: v = 0.35
Subgrade:	127.54 (by DB)	20,000		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
5807.000	9,529	17.07	6.32	3.05	2.06	1.45	1.07	0.79	663.4	61.1	54.9	26.1	4.37	300.0
6071.000	9,573	16.41	6.58	3.28	2.29	1.59	1.26	0.96	663.4	66.4	59.4	23.4	4.54	300.0
6334.000	9,442	11.31	4.54	2.72	1.83	1.32	1.00	0.76	663.4	92.9	134.2	28.2	2.21	260.2
6604.000	9,748	14.39	5.62	3.01	1.98	1.28	0.87	0.60	663.4	80.3	55.1	28.8	1.96	156.2
6864.000	9,727	9.81	3.92	2.26	1.46	0.98	0.70	0.49	663.4	118.8	97.9	37.1	2.44	196.9
7126.000	9,748	10.86	4.50	2.72	1.84	1.26	0.92	0.65	663.4	104.5	118.9	29.5	0.64	231.5
7393.000	9,606	11.90	4.24	2.66	1.84	1.35	0.98	0.74	663.4	79.0	264.5	29.5	1.51	235.4
7651.000	9,748	14.55	4.51	1.96	1.04	0.57	0.40	0.28	663.4	65.5	50.0	49.8	8.78	89.3 *
7927.000	9,496	9.30	4.03	2.31	1.54	1.05	0.78	0.57	663.4	128.6	96.3	33.6	2.52	222.0
8186.000	9,989	7.49	3.09	1.76	1.20	0.81	0.58	0.45	663.4	150.0	147.4	48.6	6.99	202.2 *
8455.000	9,683	12.88	4.50	2.25	1.63	1.17	0.83	0.67	663.4	76.0	125.1	34.6	4.77	300.0
8712.000	9,957	9.55	4.56	2.67	1.76	1.24	0.93	0.72	663.4	143.5	85.9	29.8	2.11	298.0
8975.000	9,869	12.09	4.82	2.80	1.98	1.43	1.09	0.85	663.4	88.4	150.2	27.7	3.05	300.0
9244.000	9,431	14.45	4.58	2.28	1.63	1.27	1.06	0.82	663.4	60.1	181.4	32.2	8.48	300.0
9503.000	9,705	13.49	4.70	2.39	1.69	1.22	0.90	0.68	663.4	72.7	121.4	32.9	4.75	300.0
9773.000	9,836	7.72	2.43	1.38	1.02	0.76	0.63	0.51	663.4	114.0	1000.0	49.7	11.17	300.0 *
10033.000	9,606	12.18	3.83	1.85	1.18	0.81	0.61	0.45	663.4	81.4	77.0	46.4	5.27	233.0
10298.000	9,639	10.39	3.38	1.46	0.95	0.62	0.44	0.33	663.4	97.3	75.6	58.1	4.71	117.3
10583.000	9,551	18.65	8.01	3.46	1.98	1.38	1.05	0.88	663.4	54.8	50.0	24.1	7.81	121.5 *
10826.000	9,442	26.96	9.17	4.55	3.02	2.19	1.68	1.35	663.4	34.8	50.0	17.1	4.50	300.0 *
11090.000	9,475	18.10	5.23	2.26	1.44	0.97	0.68	0.53	663.4	49.8	50.0	36.7	3.69	119.0 *
11370.000	9,398	22.24	6.61	2.13	1.28	0.88	0.67	0.50	663.4	35.6	50.0	34.2	10.20	52.7 *
11630.000	9,332	17.09	4.35	1.72	1.07	0.75	0.56	0.44	663.4	48.2	50.0	45.8	6.04	73.8 *
11879.000	9,529	18.58	4.83	2.00	1.33	0.97	0.74	0.60	663.4	44.7	64.1	38.7	7.80	90.6
12144.000	9,475	20.97	7.46	3.37	2.12	1.45	1.05	0.76	663.4	45.7	50.0	24.3	3.92	180.2 *
12422.000	9,255	16.58	4.15	1.89	1.29	0.98	0.81	0.68	663.4	45.9	130.9	38.6	9.22	189.6
12677.000	9,321	18.76	7.01	3.52	2.57	1.96	1.60	1.29	663.4	51.2	85.1	20.1	7.34	300.0
12942.000	9,628	10.99	2.46	1.26	1.01	0.84	0.71	0.61	663.4	66.6	1000.0	52.6	13.07	300.0 *
13203.000	9,387	13.44	3.47	1.17	0.85	0.61	0.48	0.39	663.4	61.7	60.6	60.4	11.88	53.5
13462.000	9,409	12.46	3.81	1.57	1.22	0.95	0.75	0.61	663.4	72.0	105.2	44.9	12.56	87.6
13725.000	9,562	17.88	5.23	2.10	1.23	0.79	0.62	0.45	663.4	49.5	50.0	40.1	4.81	78.7 *
13993.000	9,288	18.75	5.07	2.08	1.37	0.98	0.79	0.61	663.4	44.7	54.1	36.7	7.99	86.5
14258.000	9,529	14.58	4.35	2.21	1.47	1.12	0.90	0.73	663.4	59.4	155.9	35.6	6.89	300.0
14521.000	9,299	16.43	6.41	3.25	2.28	1.63	1.27	1.02	663.4	62.2	68.1	22.7	4.70	300.0
14775.000	9,420	18.27	5.54	1.57	0.98	0.67	0.54	0.42	663.4	43.6	50.0	45.5	11.87	54.3 *
15050.000	9,496	30.55	13.49	5.94	3.50	2.39	1.89	1.44	663.4	30.6	50.0	13.2	10.62	148.2 *
15316.000	9,387	20.95	6.12	2.85	1.90	1.39	1.11	0.93	663.4	41.1	70.3	27.1	6.59	249.9
15577.000	9,343	18.78	5.14	2.12	1.31	0.90	0.71	0.55	663.4	45.2	50.0	37.7	5.95	89.1 *
15840.000	9,518	20.67	6.75	2.03	1.11	0.75	0.59	0.48	663.4	39.5	50.0	37.2	14.18	52.8 *
16110.000	9,606	34.26	17.76	5.48	2.49	1.52	1.12	0.85	663.4	24.3	50.0	16.3	29.25	54.3 *
16360.000	9,398	22.68	9.30	2.46	1.26	0.91	0.74	0.67	663.4	36.2	50.0	30.0	19.78	58.7 *
Mean:		16.21	5.66	2.53	1.63	1.15	0.88	0.69	663.4	67.5	130.2	34.8	7.34	146.0
Std. Dev:		5.77	2.81	1.01	0.58	0.41	0.32	0.26	0.0	30.6	204.7	11.1	5.35	97.9
Var Coeff(%):		35.61	49.73	39.87	35.62	35.83	36.88	37.70	0.0	45.4	157.2	31.9	72.84	68.1

Figure 36 presents the Sensor 1 deflection with distance for SH 115. The data suggest that approximately 87 percent of Phase I and 86 percent of Phase II did not meet the design assumption that Sensor 1 deflection should not exceed 9.98 mils.

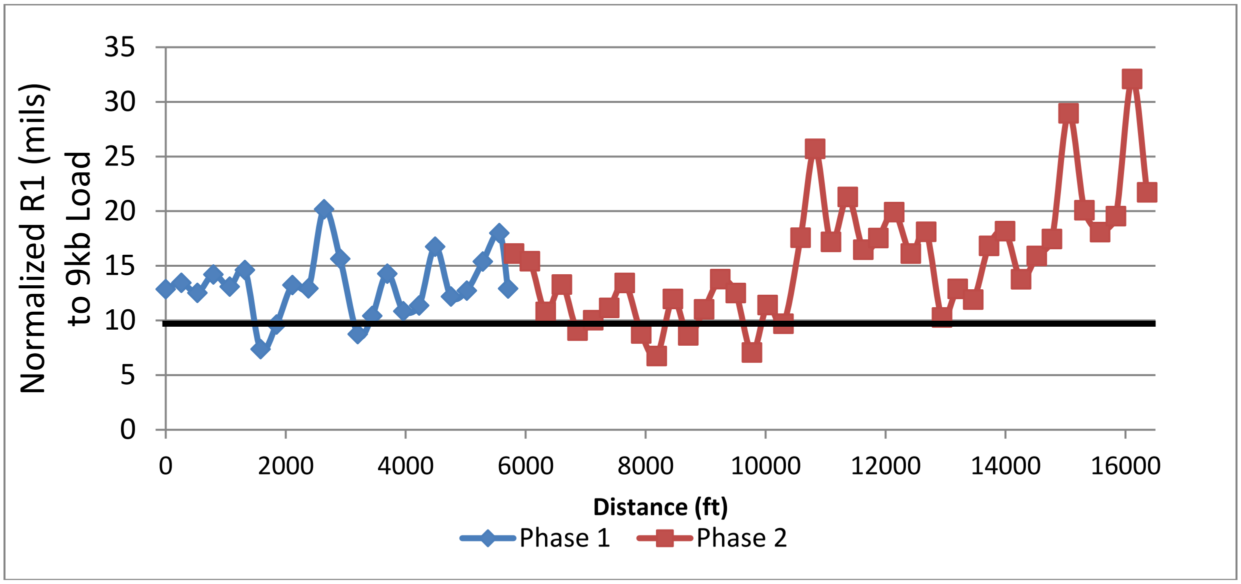


Figure 36. FWD Sensor 1 Deflection with Distance for SH 115.

Based on the FWD results, limited DCP tests were conducted to evaluate the flex base and treated layers. Figure 37 presents example DCP results collected during the course of construction. The results in Figure 37 align with the FWD observations, suggesting the subgrade is very good, and the stabilized and flex-base layers may not have met their design assumptions.

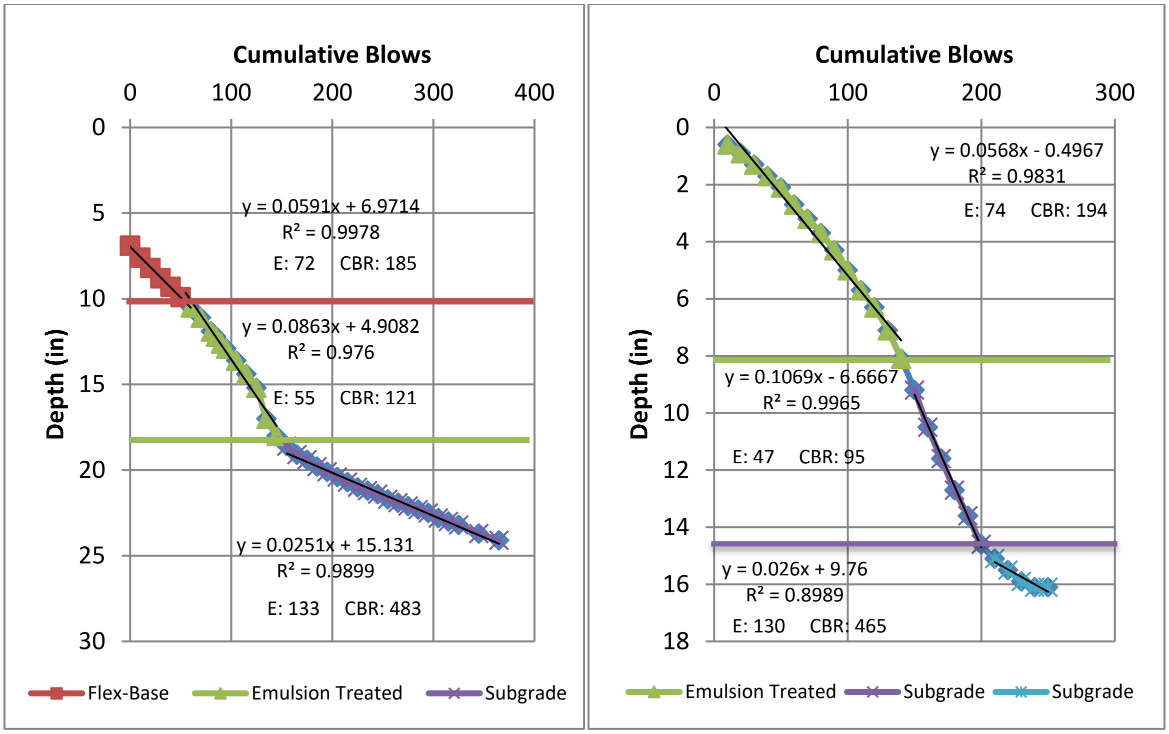


Figure 37. Example DCP Data from SH 115 Phase 1 (Left) and Phase II (Right) after FDR.

IH 10 (Crockett County)

Soil Survey. This project was a mill and inlay project in a playa lake region that experienced instability while under construction. Its participation in this implementation effort was requested while the mill and inlay operations were already underway.

GPR and DCP Results. GPR and DCP data were not collected on this section as part of this implementation effort.

Auguring Results. Material samples from this section were obtained and provided by TxDOT.

FWD Results. Testing on the section with the FWD prior to construction was not performed as part of this implementation effort.

Laboratory Mixture Design. The contractor provided a mixture design using 1 percent cement plus 4 percent emulsion.

Pavement Design. Pavement design work was not performed as part of this implementation effort.

Recommended Sequence. Sequence recommendations were not performed as part of this implementation project.

Construction Results. Due to the instability encountered in the playa lake region while under construction with mill and inlay, TxDOT implemented an FDR option using 10 in.

treatment with 1 percent cement plus 4 percent emulsion to strengthen the pavement within the limits of concern.

Construction was performed in fall 2016. Table 11 presents FWD output from TRM 375 to 374 (WB travel direction) tested in September 2016 directly on top of the completed FDR layer but prior to placement of the hot mix.

Table 11. FWD Output from IH 10 (Crockett County) Emulsion Treatment prior to Hot Mix.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	663,400	663,400	H1: v = 0.35
Base:	10.00	50,000	1,000,000	H2: v = 0.35
Subbase:	0.00			H3: v = 0.00
Subgrade:	181.60 (by DB)	10,000		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	9,223	6.34	3.91	2.78	2.14	1.74	1.40	1.17	663.4	856.1	0.0	27.8	11.57	300.0
216.000	9,069	13.89	12.19	7.92	5.67	4.13	3.19	2.49	663.4	357.6	0.0	9.7	4.69	300.0
402.000	9,398	10.00	7.14	5.23	3.96	3.07	2.37	1.86	663.4	617.3	0.0	14.8	5.77	300.0
608.000	9,365	8.18	6.69	5.00	3.78	2.92	2.23	1.61	663.4	924.7	0.0	14.9	2.21	201.6
805.000	8,828	18.14	8.30	4.87	3.29	2.19	1.52	1.09	663.4	82.8	0.0	18.7	5.36	188.5
844.000	9,058	9.68	5.52	3.33	2.28	1.58	1.18	0.86	663.4	236.5	0.0	26.6	5.18	261.3
1000.000	9,683	3.23	3.87	2.99	2.71	1.80	1.40	1.06	663.4	1000.0	0.0	36.2	29.14	300.0 *
1202.000	9,365	10.12	6.49	4.37	3.04	2.00	1.34	0.90	663.4	308.7	0.0	21.6	1.51	157.0
1409.000	8,773	61.22	22.80	9.81	4.74	2.28	1.25	0.83	663.4	50.0	0.0	8.7	55.33	79.9 *
1612.000	9,201	10.46	6.75	4.15	2.67	1.78	1.24	0.87	663.4	238.9	0.0	22.6	1.81	182.2
1802.000	9,365	7.48	3.69	1.92	1.31	0.90	0.74	0.59	663.4	236.3	0.0	45.5	8.15	233.9
2004.000	9,475	8.04	3.72	1.60	0.78	0.42	0.28	0.23	663.4	144.1	0.0	62.1	17.89	73.2
2202.000	9,639	9.75	4.63	2.04	1.00	0.58	0.40	0.29	663.4	124.5	0.0	49.7	15.65	74.3
2408.000	9,464	7.33	3.51	1.73	1.02	0.70	0.53	0.41	663.4	209.1	0.0	52.4	4.29	161.8
2604.000	9,420	17.42	10.77	6.56	4.49	3.22	2.39	1.81	663.4	145.6	0.0	13.7	4.43	279.8
2799.000	9,376	6.36	3.16	1.60	1.02	0.68	0.54	0.43	663.4	267.3	0.0	55.0	4.78	185.5
3003.000	9,496	7.29	3.76	2.22	1.52	1.16	0.91	0.71	663.4	314.1	0.0	40.2	10.28	300.0
3202.000	9,365	6.89	4.80	2.44	1.26	0.59	0.34	0.20	663.4	248.7	0.0	45.8	24.49	72.9
3413.000	9,387	5.31	2.42	1.10	0.57	0.35	0.25	0.12	663.4	254.3	0.0	79.8	7.93	84.7
3610.000	9,354	4.71	2.49	1.07	0.54	0.28	0.20	0.17	663.4	290.6	0.0	84.9	11.44	78.7
3806.000	9,672	4.81	2.96	1.83	1.20	0.81	0.60	0.43	663.4	601.3	0.0	51.5	3.18	203.3
4000.000	9,486	11.11	8.80	5.81	3.75	2.11	1.20	0.63	663.4	272.4	0.0	18.2	13.30	97.5
4404.000	9,310	13.77	8.80	5.96	4.15	2.82	1.91	1.20	663.4	224.9	0.0	15.5	2.31	137.9
4609.000	9,584	9.85	5.93	3.80	2.65	1.94	1.41	1.07	663.4	303.2	0.0	24.3	6.08	243.1
4803.000	9,442	8.60	5.84	3.71	2.79	2.31	1.85	1.46	663.4	542.8	0.0	21.4	10.30	300.0
5012.000	9,453	13.02	5.74	3.37	2.34	1.78	1.56	1.28	663.4	132.0	0.0	27.4	13.37	300.0
5206.000	9,288	8.25	4.32	2.64	1.94	1.54	1.35	1.10	663.4	316.0	0.0	31.6	13.87	300.0
5267.000	9,212	9.97	5.92	3.64	2.47	1.89	1.63	1.33	663.4	269.3	0.0	23.9	9.29	300.0
5407.000	9,234	9.96	4.71	2.62	1.78	1.38	1.17	1.02	663.4	177.6	0.0	33.6	11.59	300.0
5612.000	9,540	7.86	3.94	2.30	1.74	1.50	1.23	1.06	663.4	319.9	0.0	36.2	16.61	300.0
5804.000	9,179	9.19	3.72	2.09	1.58	1.33	1.15	0.93	663.4	174.2	0.0	40.0	19.59	300.0
6015.000	9,124	8.70	4.80	2.97	2.16	1.73	1.47	1.14	663.4	307.7	0.0	28.0	12.58	296.4
Mean:		10.84	6.00	3.55	2.39	1.67	1.26	0.95	663.4	329.6	0.0	33.8	11.37	192.1
Std. Dev:		9.77	3.85	2.02	1.31	0.92	0.69	0.54	0.0	234.0	0.0	19.0	10.41	115.3
Var Coeff(%):		90.15	64.10	57.02	54.86	54.96	55.26	57.09	0.0	71.0	0.0	56.1	91.57	60.6

Table 12 presents FWD output collected on the completed pavement in January 2017. These data in Table 12 were also collected from TRM 375 to 374 (WB travel direction).

The data show very good moduli values, exceeding 300 ksi, in the emulsion-treated layer during the construction phase. After completion of the section with the hot mix, the emulsion-treated layer modulus value exceeded 1,000 ksi. This value is very high and may indicate that less stabilizer could have been used with the material.

Table 12. FWD Output from IH 10 (Crockett County) Emulsion Treatment after Placement of Hot Mix.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	4.50	100,000	800,000	H1: v = 0.35
Base:	10.00	50,000	1,500,000	H2: v = 0.35
Subbase:	0.00			H3: v = 0.00
Subgrade:	67.48(by DB)	10,000		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	10,329	5.43	3.50	2.50	1.96	1.55	1.26	1.00	387.9	1500.0	0.0	15.3	10.40	110.7 *
155.000	10,121	8.66	6.52	4.81	3.78	3.00	2.39	1.86	714.9	562.9	0.0	7.1	6.35	119.0 *
300.000	10,088	7.32	4.68	3.27	2.61	2.15	1.83	1.53	192.9	1500.0	0.0	10.7	10.55	300.0 *
461.000	10,252	5.93	3.94	2.87	2.32	1.90	1.60	1.31	382.0	1500.0	0.0	12.2	10.75	140.0 *
601.000	10,219	6.54	4.13	2.75	2.15	1.77	1.42	1.14	207.6	1500.0	0.0	13.8	11.07	121.6 *
754.000	10,241	6.25	5.03	3.83	3.03	2.39	1.89	1.47	481.9	1500.0	0.0	8.2	4.11	110.9 *
901.000	10,241	4.95	3.12	2.03	1.55	1.19	0.91	0.68	289.7	1500.0	0.0	21.2	10.47	84.4 *
1051.000	10,187	4.12	2.86	2.07	1.52	1.08	0.76	0.54	527.6	1500.0	0.0	21.2	4.22	78.4 *
1202.000	10,143	6.33	4.39	3.01	2.14	1.53	1.06	0.70	246.6	1111.4	0.0	15.0	5.22	76.5
1351.000	10,132	6.36	4.90	3.70	2.84	2.13	1.56	1.13	328.0	1452.8	0.0	9.8	2.89	89.5
1501.000	10,132	5.04	3.95	2.83	2.00	1.42	0.93	0.61	800.0	755.0	0.0	15.8	2.40	74.5 *
1651.000	10,132	5.02	3.93	2.81	2.00	1.39	0.91	0.57	800.0	740.1	0.0	16.0	2.08	71.6 *
1845.000	10,143	6.31	4.65	3.21	2.29	1.60	1.12	0.76	800.0	481.9	0.0	14.0	4.11	80.0 *
1953.000	10,055	4.64	2.82	1.61	0.96	0.56	0.34	0.21	800.0	323.0	0.0	37.4	5.07	61.0 *
2105.000	10,088	6.20	4.11	2.47	1.57	1.01	0.65	0.46	800.0	278.3	0.0	22.3	6.03	72.9 *
2261.000	10,154	3.54	2.16	1.20	0.66	0.35	0.20	0.12	800.0	418.3	0.0	55.0	5.02	53.4 *
2401.000	10,143	4.00	2.73	1.85	1.26	0.89	0.60	0.41	471.5	1280.6	0.0	26.4	5.67	73.8
2553.000	10,099	3.81	2.28	1.28	0.75	0.43	0.26	0.17	800.0	415.6	0.0	48.1	5.22	57.8 *
2701.000	10,044	5.83	4.30	3.23	2.55	2.15	1.79	1.48	575.0	1500.0	0.0	9.3	7.91	171.7 *
2853.000	10,000	7.56	5.92	4.63	3.69	2.96	2.34	1.83	673.2	859.0	0.0	6.7	4.50	121.0 *
3020.000	10,077	4.00	2.81	1.98	1.37	1.00	0.71	0.50	486.3	1500.0	0.0	23.0	5.52	79.0 *
3160.000	10,066	4.60	2.89	1.75	1.19	0.80	0.53	0.36	347.5	879.0	0.0	29.3	8.19	70.4
3302.000	10,077	5.20	3.41	2.26	1.61	1.13	0.83	0.59	234.4	1500.0	0.0	19.9	6.97	80.9 *
3455.000	10,132	4.42	2.89	1.89	1.31	0.91	0.64	0.45	295.0	1494.9	0.0	25.3	6.67	77.5
3929.000	10,099	3.65	2.24	1.38	0.87	0.55	0.35	0.22	674.7	677.9	0.0	41.4	6.18	65.6
4105.000	10,055	4.21	2.71	1.70	1.13	0.72	0.47	0.29	655.3	633.2	0.0	31.6	5.61	66.6
4267.000	10,088	5.69	4.31	3.27	2.44	1.84	1.33	0.92	367.9	1500.0	0.0	11.5	3.04	81.6 *
4402.000	10,055	5.30	3.96	2.98	2.30	1.74	1.31	0.98	468.2	1500.0	0.0	12.1	4.04	92.8 *
4550.000	10,154	6.17	4.77	3.63	2.84	2.19	1.68	1.27	400.9	1500.0	0.0	9.3	3.70	99.0 *
4708.000	10,099	5.52	3.94	2.85	2.14	1.56	1.16	0.83	324.4	1500.0	0.0	14.0	4.72	83.7 *
4858.000	10,055	5.89	4.04	2.82	2.15	1.68	1.33	1.02	277.9	1500.0	0.0	13.6	8.11	100.0 *
5008.000	10,187	4.78	3.38	2.51	2.00	1.61	1.32	1.07	734.6	1500.0	0.0	13.5	8.59	125.7 *
5151.000	10,143	3.83	2.64	1.93	1.54	1.25	1.05	0.87	800.0	1500.0	0.0	19.7	11.21	140.5 *
5281.000	10,121	3.90	2.86	2.11	1.71	1.37	1.17	1.00	800.0	1500.0	0.0	15.9	10.92	300.0 *
Mean:		5.32	3.73	2.62	1.95	1.46	1.11	0.83	527.8	1157.8	0.0	19.6	6.40	82.0
Std. Dev:		1.22	1.04	0.88	0.76	0.66	0.56	0.47	217.8	451.0	0.0	11.6	2.75	27.5
Var Coeff(%):		22.96	27.80	33.68	39.21	45.08	50.76	56.23	41.3	39.0	0.0	59.4	42.94	31.7

FDR with Foamed Asphalt

SH 7

The 1 mi section eventually constructed with FDR on SH 7 began as a larger nominated section from 1.1 mi east of Marquez to FM 39. According to records, the section could be partitioned as follows:

- From 1.1 mi east of Marquez to TRM 630.618 (Section 1—approximately 5.1 mi). Bryan District records show this section should consist of 2.5 in. HMA with 12 in. cement-treated base.
- TRM 630.618 to FM 39 (Section 2—approximately 2.1 mi). District records show this section should consist of an HMA surfacing with base on top of a lower layer of HMA with base.

Figure 38 shows the general location of these sections.

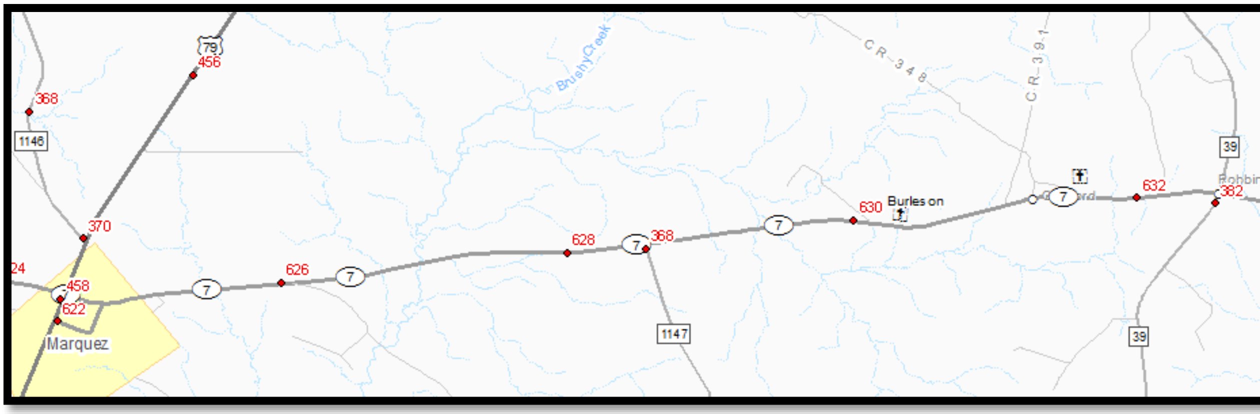


Figure 38. Location of SH 7 Sections Investigated for Construction Planning.

Soil Survey. Figure 39 shows the soils map for the PI, where the PI generally should not exceed 24.

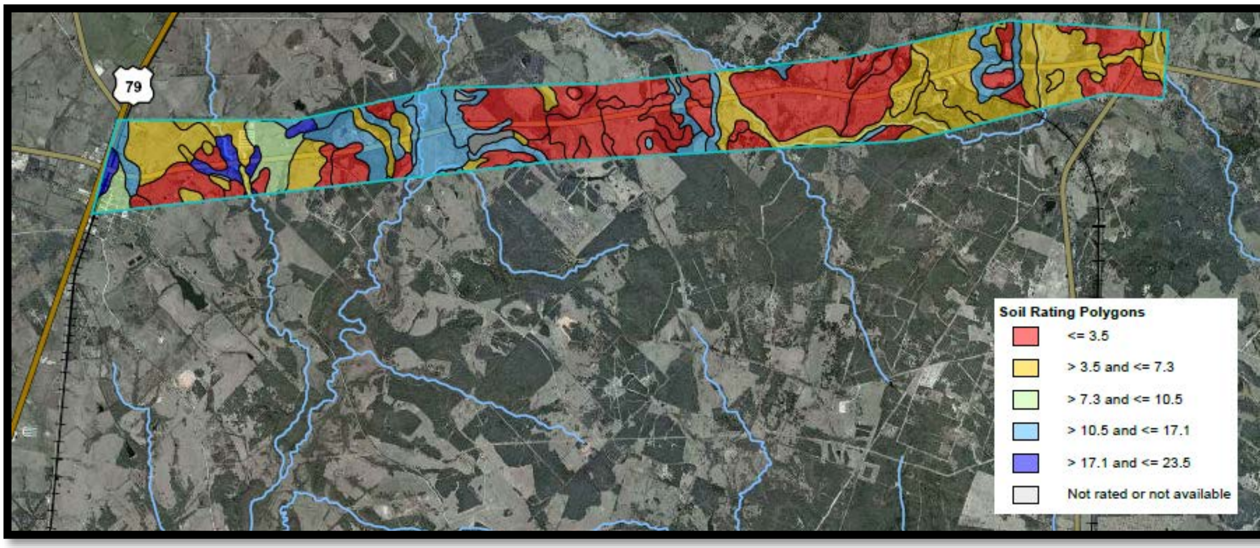
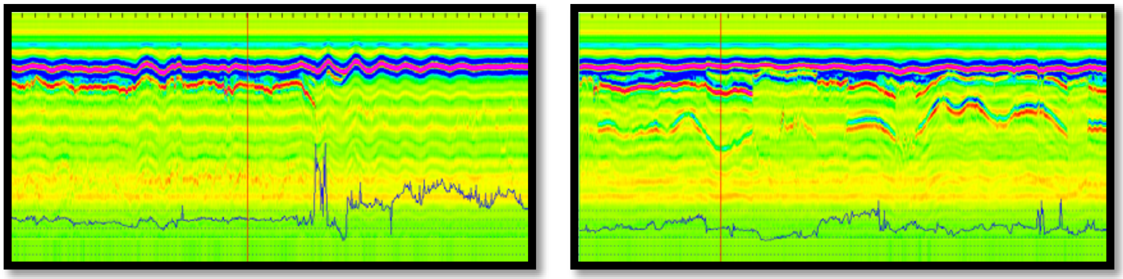


Figure 39. Soil Map of PI for SH 7.

GPR and DCP Results. Figure 40 shows example GPR data. The key findings from the GPR are that the surface could vary from a seal coat up to approximately 4 in. of asphalt material.



Section 1 (left); Section 2 (right)

Figure 40. Example GPR Data from SH 7.

Auguring Results. Figure 41 illustrates the results from pavement sampling, which showed the typical existing structures generally having around 14 in. of pavement with subgrade soils of plasticity index less than 19.

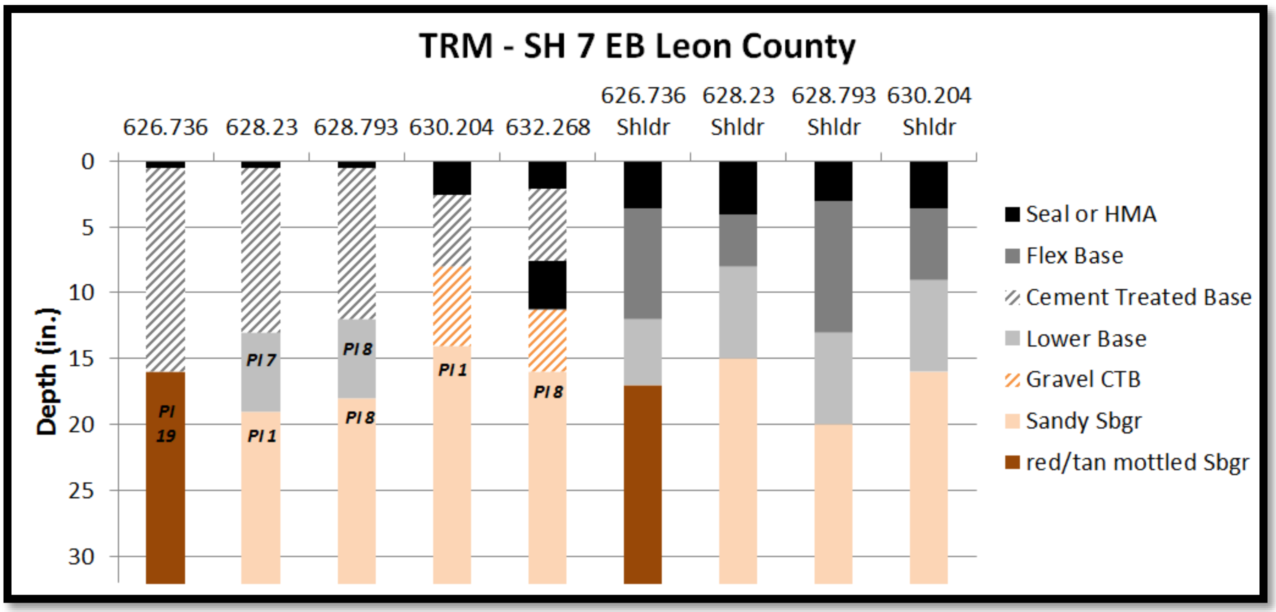


Figure 41. Observed Existing Structures with Measured Plasticity Index for SH 7.

FWD Results. TxDOT collected FWD over the section and provided researchers the data. Table 13 presents the summary results. A total of 51 drops were collected in Section 1 and a total of 14 drops in Section 2.

Table 13. Summary of FWD Results from SH 7 Existing Pavement.

	Surface Modulus (ksi)	Base Modulus (ksi)	Subbase Modulus (ksi)	Subgrade Modulus (ksi)	Error/Sensor
Section 1	247	736	Not applicable	19.8	9.1
Section 2	247	91*	81	20.4	7.8

**Excludes clearly high backcalculated modulus values from tabulation of the average.*

Laboratory Mixture Design. Based upon the existing typical sections and preferences of TxDOT, laboratory mixture designs were performed using foamed asphalt. Figure 42 presents the designs, which illustrate strong sensitivity to the percentage RAP in the mixture and little sensitivity to the cement additive.

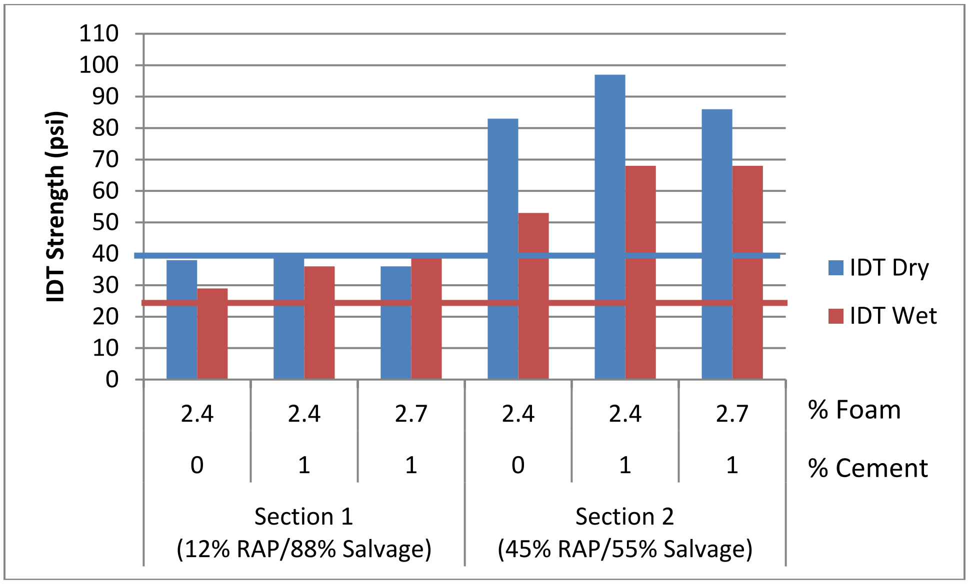


Figure 42. Laboratory Mixture Design Results for SH 7.

Pavement Design. TxDOT chose to proceed with a 1-mi section of foamed asphalt treatment from 1 mi west of FM 39 to FM 39 (within the limits of Section 2) using a treatment level of 2.4 percent foamed asphalt and no cement. Table 14 shows the FPS design assumptions. The remaining pavement below the proposed foamed asphalt-treated FDR layer was considered a subbase with a modulus value assigned based on the average subbase FWD results from Table 13. Figure 43 shows the design; the FPS design thickness of 14.5 in. meets the minimum modified triaxial thickness required of 12.29 in.

Table 14. FPS Design Assumptions for SH 7.

Length of Analysis (yr)	20
Beginning ADT	3400
Ending ADT	5830
20 yr 18 kip ESAL (M)	5.832
Percentage Trucks	20.1
Surface Treatment Modulus (ksi)	200
Foamed Asphalt Stabilized Base Modulus (ksi)	300
Gravel Subbase Modulus (ksi)	150
Subgrade Modulus (ksi)	10*

**Represents lower spectrum of FWD observations.*

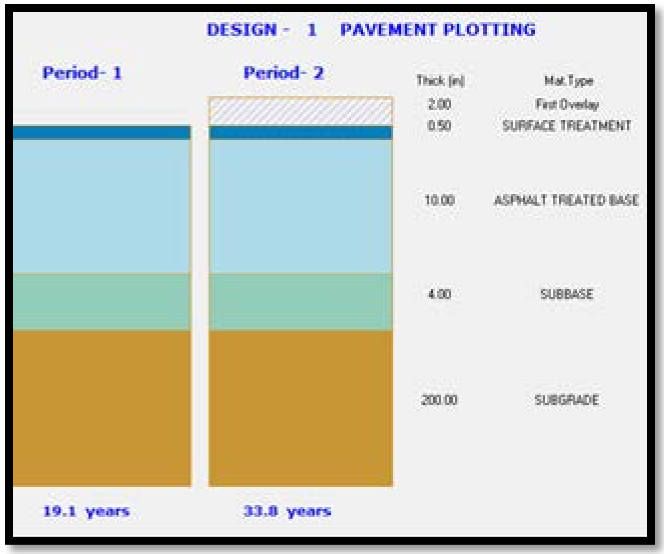


Figure 43. FPS Design for SH 7.

Recommended Sequence. Based on the mix design, the recommended sequence was to achieve the required pulverization, apply the proper amount of stabilizer, and attain the needed compaction moisture content all in one pass.

Construction Results. This project treated 10 in. of existing materials in place with 2.4 percent foamed asphalt. Construction took place in August 2016, as illustrated in Figure 44.

Figure 44. Typical Construction Sequence on SH 7.

Table 15 presents the data for verification of attaining proper pulverization, and Figure 45 illustrates verifying proper expansion ratio and half-life of the foamed asphalt.

Table 15. Pulverization Check at Start of Construction on SH 7.

Sieve Size	Percent Passing
1¾	100
¾	3
Passing ¾	97

Note: Cutter speed was 153 rpm and machine travel speed was 17 fpm.

Figure 45. Checking Expansion Ratio and Half-Life of Foamed Asphalt on SH 7.

During the course of construction, the following problems were noted:

- Locations of excessive moisture were not aerated prior to treatment, and instability under early trafficking occurred, as Figure 46 illustrates. In some locations, the moisture content after compaction was 4 to 8 percentage points above optimum. The construction specification should better address moisture content prior to adding the treatment.
- Disconnect points for the FDR train resulted in localized excessive wet zones that failed overnight, as shown in Figure 47. This problem could have been avoided by moving the FDR train off the pavement prior to disconnecting the water truck.
- Significant material variability existed both longitudinally and transversely, as illustrated by Figure 48. The result was that, in general, the actual materials treated did not match what was used in design.

Figure 46. Instability in Location Constructed at Excessive Moisture.

Figure 47. Localized Failure Due to Excessive Water at Location of Disconnecting FDR Train.

Figure 48. Material Variability on SH 7.

To address the problem locations, aerating was performed, and cement was locally applied. Figure 49 illustrates the general final layout of the treatments on SH 7.

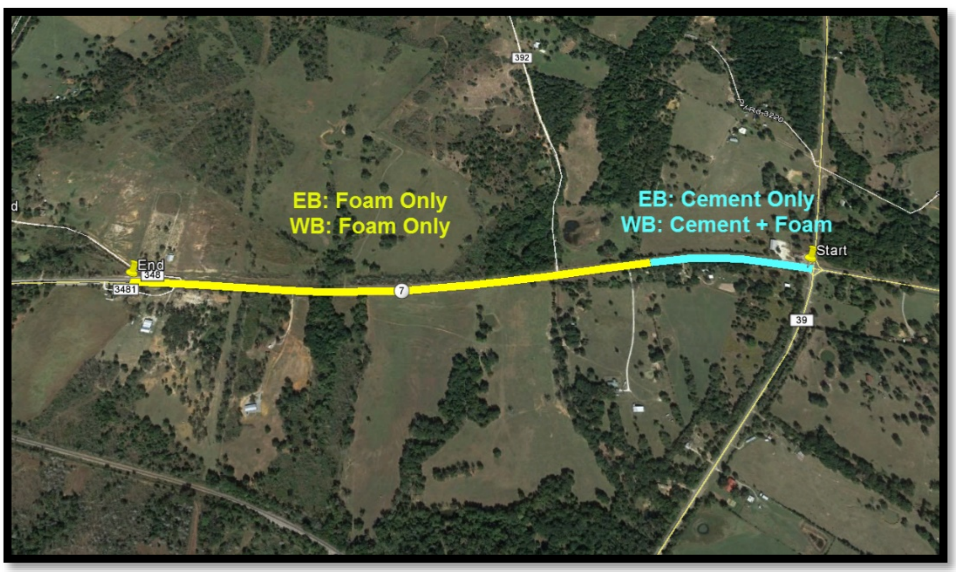


Figure 49. Layout of Treatments on SH 7.

FWD tests on the completed sections were conducted in September 2016. Table 16 and Figure 50 summarize these data. The FWD results show:

- Sections treated only with foamed asphalt did not attain the assumed design modulus of 300 ksi.
- The small amount of cement added in combination with the foamed asphalt significantly increased the modulus of the FDR layer, well exceeding the modulus value of the same amount of cement applied without the dual application of foamed asphalt.

Table 16. FWD Summary on Completed SH 7 Pavement.

Section	AVG Modulus (ksi)			Error/Sensor	Number of Test Points
	Surface	Base	Subgrade		
WB—Foam + Cement	290	413	26.1	3.59	13
WB—Foam	282	159	24.6	4.33	34
EB—Foam	284	126	24.9	3.98	29
EB—Cement	296	154	22.1	3.83	14

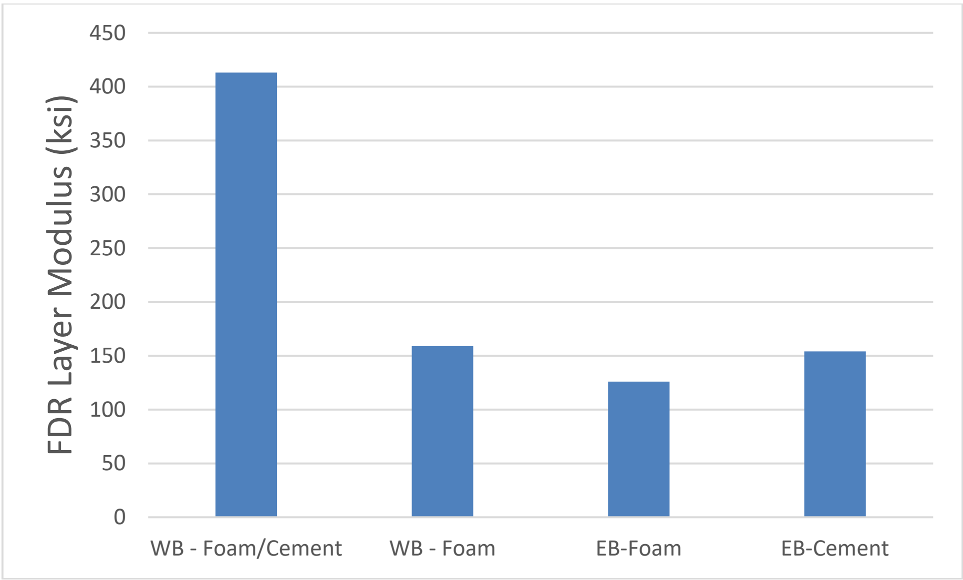


Figure 50. Base Layer Moduli on SH 7 FDR Sections.

SH 44

Soil Survey. Soils data illustrated in Figure 51 show the subgrade PI to be < 20 throughout most of the project, with potentially localized areas of high plasticity. Figure 52 shows that localized areas of the project also could have high sulfates, with concentrations up to 80,000 ppm.

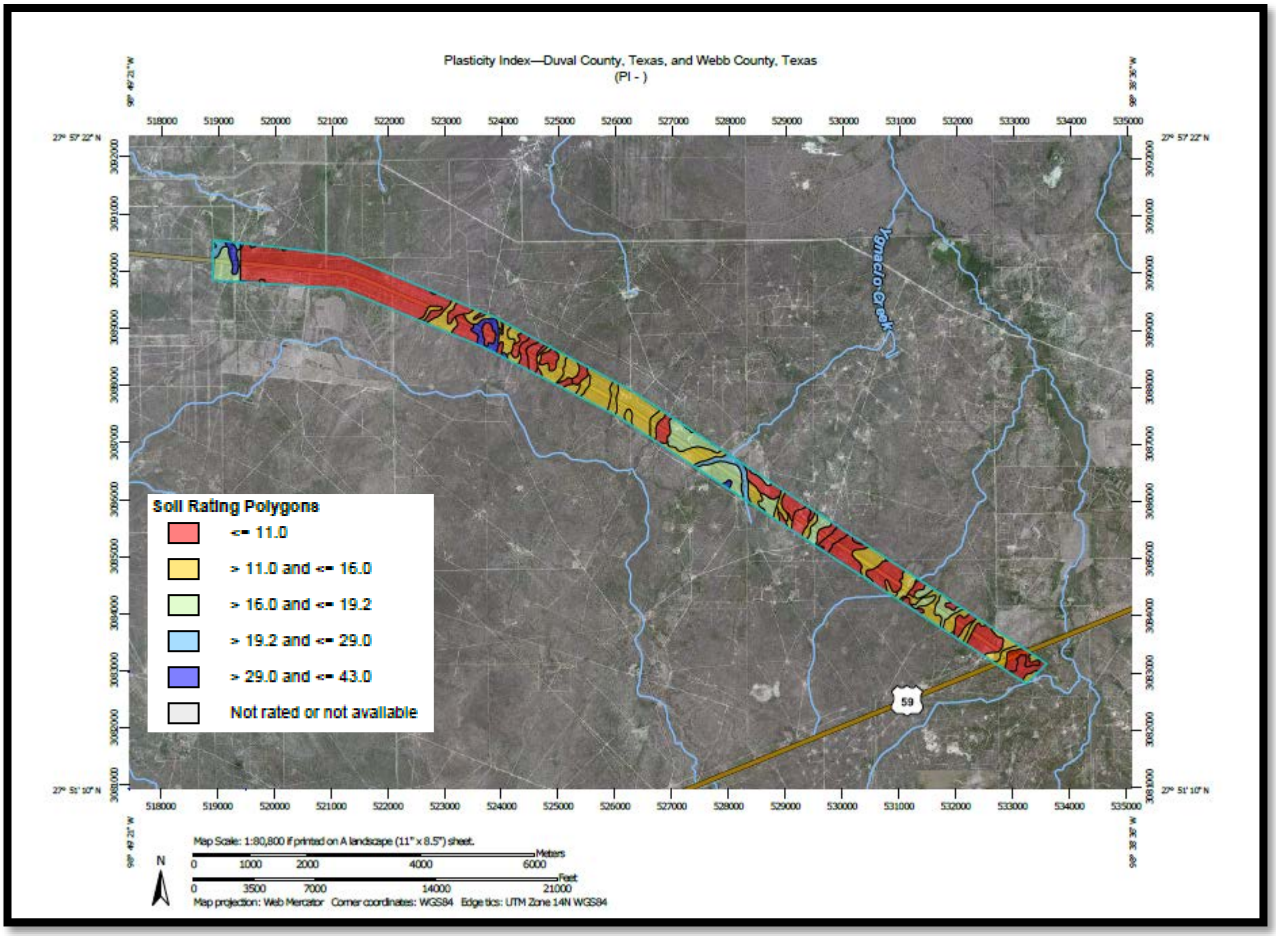


Figure 51. Soil Map of PI for SH 44.

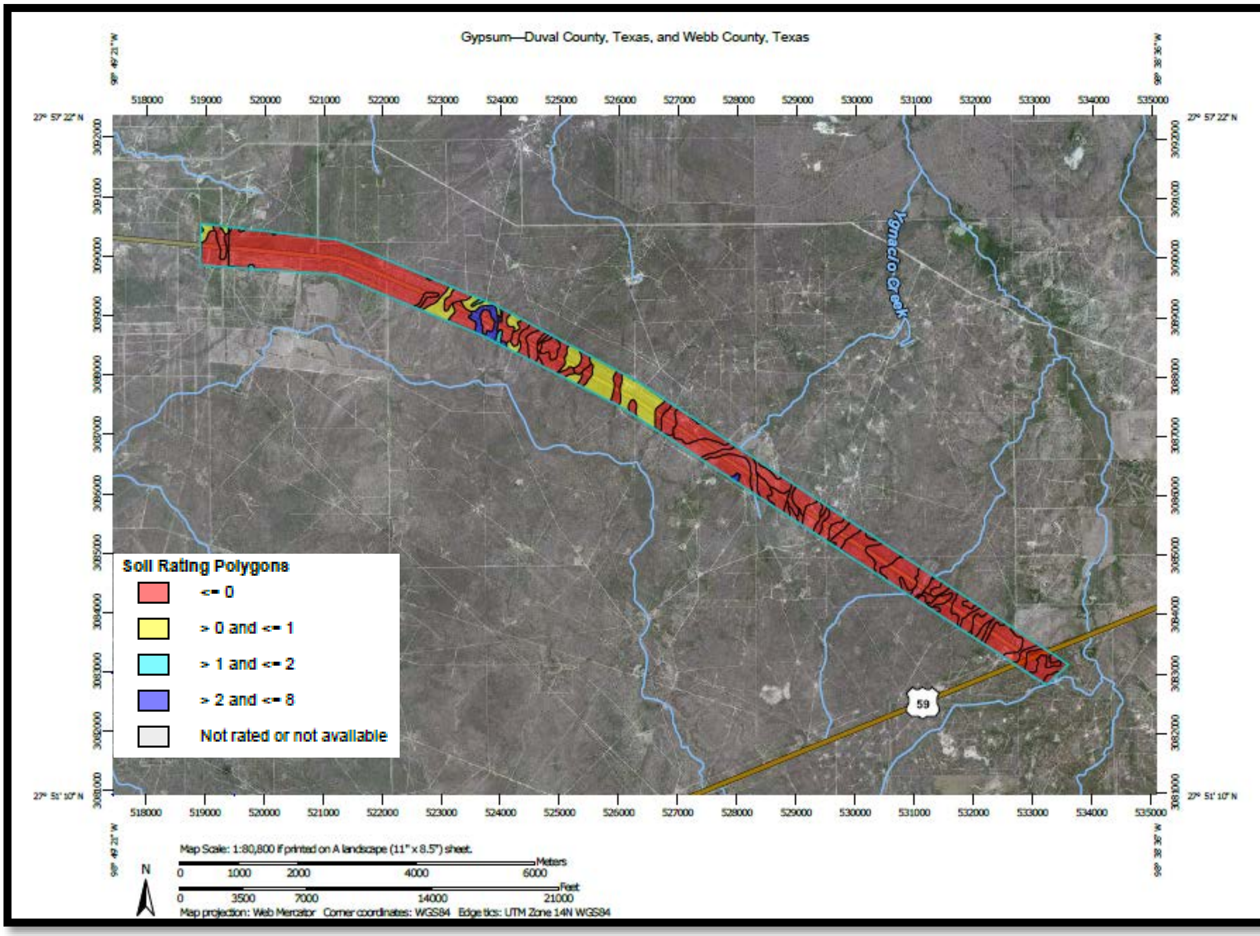


Figure 52. Soil Map of Gypsum for SH 44.

GPR and DCP Results. The example GPR data in Figure 53 illustrate the typical consistent radar view of the roadway, where subsurface reflections were difficult to regularly observe.

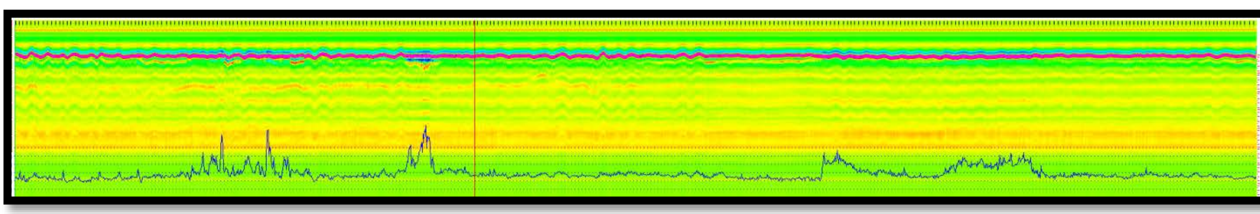


Figure 53. Example GPR from SH 44.

Figure 54 presents example DCP results, and Table 17 presents a summary of the output from the DCP testing.

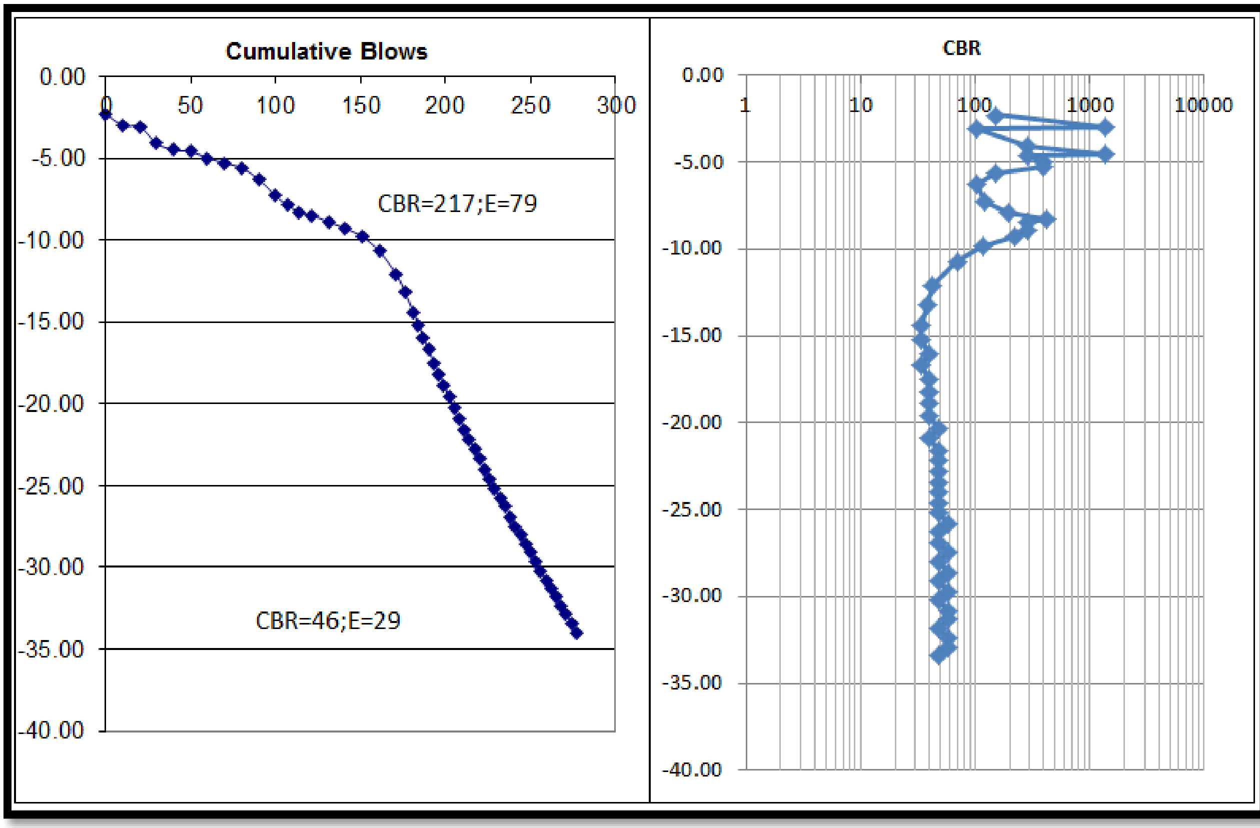


Figure 54. Example DCP Results from SH 44.

Table 17. Summary of DCP Results for SH 44.

Location (TRM)	Base Modulus (ksi)	Estimated Total Pavement Thickness (in.)	Subgrade Modulus (ksi)	Comment
474.7	79	10	29	
477.6	114	9.5	62	
478.0	125	11	54	
482.0	97	9	*	*DCP could not test beyond 9 in.

Auguring Results. Figure 55 illustrates the structures observed and the measured plasticity index of subgrade materials up to a depth of 32 in. The auguring results show:

- The typical pavement section is 9 to 11 in. of total structure, with the surface layer being 1 to 2 in.
- The plasticity index of the subgrade soil ranged from 7 to 51. The PI of the top 2 ft of subgrade was generally below 30, with higher plasticity index values at deeper depth.

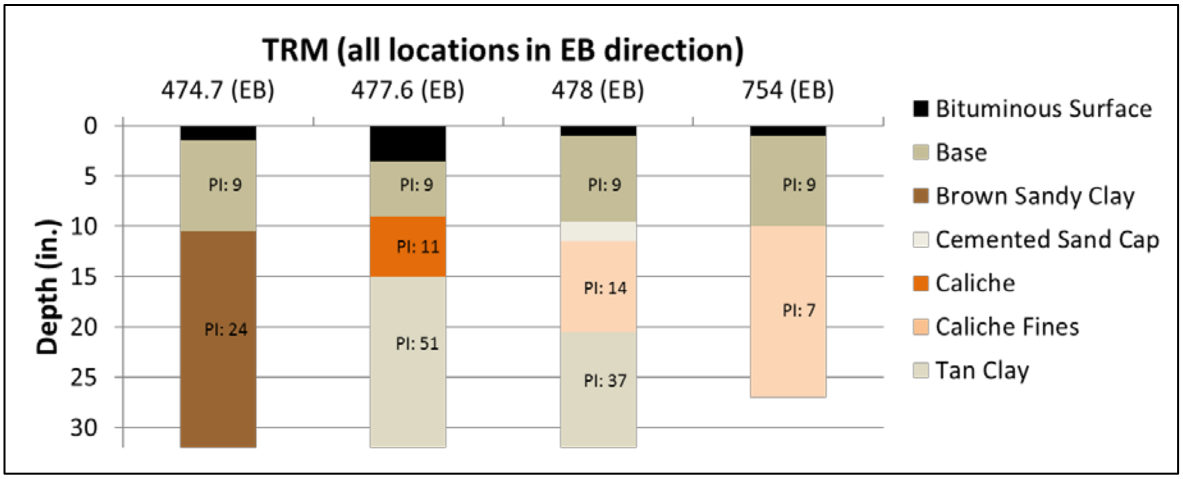


Figure 55. Observed Existing Structures on SH 44—Duval County.
Note: Plasticity index of depth zones indicated by numeric values.

Table 18 illustrates that sulfates were observed in the subgrade. Although elevated sulfate concentrations existed in some locations, the depths are beyond any anticipated treatment range and should not pose a concern for pavement rehab strategies.

Table 18. Sulfate Contents for SH 44.

TRM	Depth (in.)	Sulfate Content (ppm)	Material
474.7	12 – 21	220	Brown clay
	21 – 32	230	Brown Clay
477.6	20 – 27	8400	Tan Clay
	27 – 32	7300	Tan Clay
478	17 – 21	150	Caliche Fines
	21 – 32	5800	Tan Clay

FWD Results. TxDOT collected FWD data over the section at 0.1 mi intervals. Table 19 presents the summary results, which tend to show a much weaker pavement structure than indicated by the DCP.

Table 19. Summary of FWD Results from SH 44.

Average Flexible Base Modulus (ksi)	Average Subgrade Modulus (ksi)	Average Error per Sensor
41.1	**7.3**	**7.3**

Laboratory Mixture Design. Table 20 presents the results from the laboratory mixture design. Treatment with 1 percent cement plus 2.4 percent foamed asphalt meets the mixture design requirements.

Table 20. Laboratory Mixture Design for SH 44.

% RAP	% Salvage Base	Additive	% Foamed Asphalt	Dry Strength	Wet Strength
15	**85**	**1% Cement**	**2.4**	**72**	**36**
			2.8	**52**	**21**

Pavement Design. Table 21 presents the FPS design assumptions, which result in a 10-in. FDR layer and an estimated first performance period of 10 years.

Table 21. FPS Design Assumptions for SH 44.

Length of Analysis (yr)	20
Beginning ADT	3128
Ending ADT	5317
20 yr 18 kip ESAL (M)	3.843
Percentage Trucks	22
Surface Treatment Modulus (ksi)	200
Foamed Asphalt Stabilized Base Modulus (ksi)	300
Subgrade Modulus (ksi)	7.3

Recommended Sequence. Based on the mix design, the cement additive should be spread on top and then FDR should be performed in a one-pass operation to achieve the required pulverization, foamed asphalt content, and compaction moisture content.

Construction Results. This project was designed as FDR using 1 percent cement plus 2.4 percent foamed asphalt and a 10-in. treatment depth. Construction took place in fall 2016. At the early stages of construction, TxDOT collected field mix and performed IDT tests on the field mix. These IDT results did not meet the minimum specifications, so the mix design was modified to 2 percent cement plus 2.4 percent foamed asphalt. Subsequent IDT tests on the field mix did meet the minimum specifications, so the district proceeded with the remainder of the project using the higher cement treatment level. Figure 56 shows the basic FDR operation on the project.

Figure 56. Typical Construction Sequence on SH 44.

Figure 57 presents the FWD Sensor 1 deflection with distance. These data show about 32 percent of the test points did not attain the district's stated goal of less than 30 mils deflection under the 12klb FWD load. Table 22 presents the FWD output collected on the completed project in December 2016, which does show that on average the Sensor 1 deflection was less than 30 mils. For reference, prior to FDR, the average deflection was 58 mils under the 12klb FWD load.

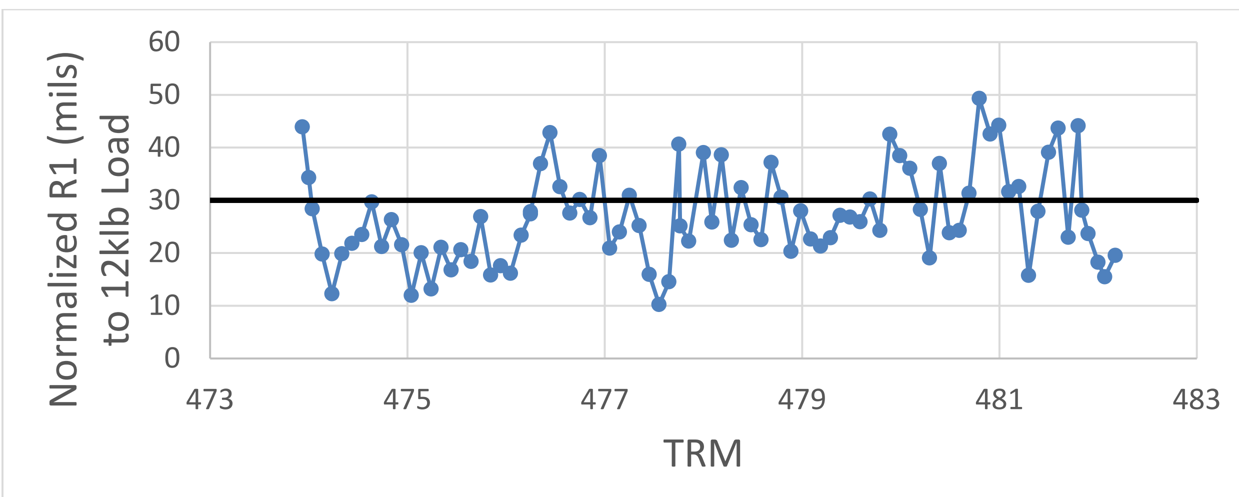


Figure 57. FWD Sensor 1 Deflection with Distance for SH 44.

Table 22. FWD Output from Completed SH 44.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:
County :
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.75	421,600	421,600	H1: v = 0.35
Base:	10.00	50,000	1,000,000	H2: v = 0.35
Subbase:	0.00			H3: v = 0.00
Subgrade:	219.60(by DB)	10,000		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	13,079	47.46	28.36	14.36	9.40	6.82	5.28	4.16	421.6	50.9	0.0	8.7	7.02	300.0
0.064	13,265	37.59	24.56	14.70	9.96	6.95	5.05	3.74	421.6	88.5	0.0	8.6	3.10	268.5
0.100	13,298	31.18	19.49	11.18	7.57	5.42	4.02	3.02	421.6	99.4	0.0	11.5	4.23	276.0
0.200	13,495	22.01	16.96	12.84	9.88	7.62	5.89	4.53	421.6	443.2	0.0	8.5	3.40	300.0
0.298	13,758	13.93	11.04	8.80	7.07	5.61	4.39	3.41	421.6	1000.0	0.0	11.7	3.61	300.0 *
0.399	13,473	22.18	17.70	12.90	9.50	6.91	5.05	3.65	421.6	345.0	0.0	9.3	0.81	217.9
0.500	13,473	24.33	18.91	13.88	10.31	7.58	5.58	4.11	421.6	315.2	0.0	8.5	1.12	242.9
0.600	13,451	26.22	19.36	13.70	10.01	7.24	5.27	3.85	421.6	237.8	0.0	9.0	1.55	233.6
0.700	13,341	32.95	21.89	13.74	9.49	6.75	4.96	3.71	421.6	117.1	0.0	9.3	3.06	278.2
0.800	13,429	23.61	19.15	14.41	10.80	8.00	5.91	4.44	421.6	371.7	0.0	7.9	0.62	275.5
0.900	13,451	29.31	22.54	15.92	11.23	8.02	5.87	4.44	421.6	206.0	0.0	7.9	1.36	300.0
1.002	13,506	24.12	18.99	13.84	10.22	7.42	5.38	3.89	421.6	309.1	0.0	8.7	0.64	220.5
1.100	13,648	13.57	10.39	7.63	5.59	4.06	2.97	2.17	421.6	579.5	0.0	16.6	0.75	215.8
1.200	13,539	22.43	17.34	13.03	9.78	7.24	5.32	3.91	421.6	372.3	0.0	9.0	1.31	235.9
1.300	13,681	14.94	12.04	9.58	7.50	5.76	4.36	3.21	421.6	849.0	0.0	11.2	1.60	224.8
1.400	13,418	23.47	17.42	12.43	9.17	6.78	5.02	3.80	421.6	289.0	0.0	9.7	2.44	284.2
1.501	13,539	18.79	16.99	14.03	11.00	8.28	6.07	4.38	421.6	744.1	0.0	7.4	2.54	212.4 *
1.600	13,396	22.94	15.86	10.40	6.97	4.64	3.09	2.11	421.6	176.9	0.0	13.4	2.92	161.2
1.703	13,528	20.67	17.46	13.65	10.45	7.79	5.72	4.15	421.6	522.2	0.0	8.0	0.78	219.9
1.800	13,276	29.59	21.02	14.63	10.39	7.48	5.57	4.22	421.6	181.0	0.0	8.5	2.22	300.0
1.901	13,550	17.74	13.43	10.06	7.76	5.94	4.55	3.45	421.6	534.9	0.0	11.2	3.64	271.3
2.001	13,484	19.81	14.76	10.57	7.74	5.61	4.06	2.97	421.6	339.9	0.0	11.8	1.28	225.5
2.100	13,582	18.24	13.08	9.38	6.94	5.19	3.89	2.90	421.6	383.4	0.0	13.3	3.64	245.7
2.209	13,407	26.09	19.86	13.86	9.72	6.70	4.65	3.28	421.6	211.1	0.0	9.4	1.82	201.7
2.303	13,341	30.34	20.15	12.28	8.09	5.48	3.87	2.84	421.6	111.3	0.0	10.9	1.96	226.4
2.303	13,144	30.33	20.22	12.28	8.11	5.51	3.90	2.87	421.6	110.1	0.0	10.7	1.97	230.3
2.404	13,166	40.21	26.80	15.99	10.56	7.06	4.85	3.47	421.6	78.3	0.0	8.1	2.75	202.8
2.500	13,133	46.62	31.63	17.66	10.49	6.47	4.31	3.18	421.6	55.9	0.0	7.9	9.10	147.9
2.600	13,166	35.67	24.98	16.14	11.19	7.89	5.65	4.07	421.6	117.6	0.0	7.8	2.10	231.9
2.700	13,331	30.37	21.67	15.28	11.28	8.36	6.28	4.78	421.6	200.1	0.0	7.8	3.60	300.0
2.800	13,276	33.17	24.81	17.52	12.61	8.92	6.26	4.41	421.6	170.0	0.0	7.0	0.61	207.9
2.903	13,298	29.41	24.28	17.54	12.22	8.32	5.62	3.87	421.6	205.4	0.0	7.3	4.58	184.4
2.999	13,013	41.63	30.92	21.17	14.77	10.30	7.26	5.19	421.6	114.1	0.0	5.8	1.24	240.8
3.102	13,462	23.33	19.40	14.73	11.10	8.28	6.10	4.52	421.6	404.6	0.0	7.6	0.58	252.5
3.201	13,418	26.74	19.13	13.16	9.30	6.51	4.52	3.12	421.6	190.3	0.0	9.9	0.74	183.4
3.301	13,155	33.59	20.70	14.59	11.28	8.87	6.99	5.49	421.6	166.2	0.0	7.8	9.56	300.0
3.399	13,331	27.83	16.39	8.76	5.28	3.46	2.49	1.93	421.6	86.5	0.0	16.2	4.90	183.0
3.501	13,528	17.80	14.62	11.34	8.87	6.88	5.30	4.02	421.6	684.5	0.0	9.2	1.86	274.6
3.600	13,736	11.63	8.88	6.87	5.46	4.33	3.46	2.67	421.6	1000.0	0.0	15.8	5.20	289.7 *
3.700	13,528	16.39	13.14	9.79	7.19	5.20	3.75	2.70	421.6	504.3	0.0	12.5	0.62	206.4
3.800	12,969	43.48	27.68	16.31	10.89	7.64	5.54	4.17	421.6	69.5	0.0	7.6	3.50	299.8
3.812	13,210	27.57	20.37	14.18	10.38	7.64	5.64	4.17	421.6	219.7	0.0	8.4	2.44	252.4
3.900	13,407	24.81	17.49	12.06	8.57	6.15	4.46	3.29	421.6	213.6	0.0	10.7	1.84	244.3
4.018	13,254	42.43	22.88	11.78	7.50	4.86	3.17	2.10	421.6	50.0	0.0	11.5	5.14	153.3 *
4.104	13,276	28.53	20.81	14.09	9.60	6.54	4.61	3.37	421.6	163.2	0.0	9.4	1.70	227.1
4.200	13,013	41.52	23.44	11.86	7.01	4.53	3.13	2.23	421.6	50.0	0.0	11.5	7.39	176.8 *
4.302	13,046	24.30	15.44	8.97	5.31	3.14	2.00	1.42	421.6	105.7	0.0	16.6	9.90	113.8
4.399	13,002	34.83	20.56	13.09	8.92	6.11	4.26	3.02	421.6	89.4	0.0	9.9	2.37	207.5
4.500	13,320	28.08	19.91	13.51	9.55	6.78	4.87	3.58	421.6	177.1	0.0	9.5	1.45	245.6
4.600	13,407	25.15	16.30	10.07	6.59	4.46	3.14	2.34	421.6	135.0	0.0	13.6	1.75	214.5
4.701	13,090	40.28	27.31	16.70	10.35	6.37	4.11	2.85	421.6	72.9	0.0	8.3	7.31	142.8
4.802	13,166	33.34	20.32	11.85	7.39	4.72	3.10	2.11	421.6	79.3	0.0	11.9	4.87	158.4
4.902	13,331	22.54	15.31	9.63	6.34	4.20	2.88	2.02	421.6	162.1	0.0	14.4	2.80	183.5
5.000	13,177	30.58	19.89	12.19	8.04	5.35	3.61	2.46	421.6	105.5	0.0	10.9	2.30	175.6
5.100	13,374	25.23	16.41	10.14	6.54	4.22	2.87	2.09	421.6	128.8	0.0	13.9	3.78	166.6
5.200	13,352	23.71	17.97	12.67	8.93	6.13	4.18	2.93	421.6	236.1	0.0	10.3	2.14	181.5
5.300	13,309	25.33	18.16	12.38	8.48	5.70	3.87	2.63	421.6	181.7	0.0	10.9	2.24	174.5
5.398	13,243	29.87	20.12	13.66	9.54	6.71	4.72	3.40	421.6	148.5	0.0	9.5	1.37	220.2
5.497	13,298	29.63	20.30	12.89	8.30	5.33	3.55	2.48	421.6	116.7	0.0	10.8	4.54	167.8
5.599	13,254	28.56	19.28	12.66	8.58	5.82	4.05	2.94	421.6	138.6	0.0	10.6	0.84	205.6
5.700	13,166	33.04	23.84	16.45	11.59	8.19	6.09	4.65	421.6	154.2	0.0	7.5	1.63	300.0
5.799	13,298	26.92	18.83	12.00	7.94	5.50	4.03	3.14	421.6	148.2	0.0	11.1	2.09	298.8
5.900	12,903	45.41	28.83	18.47	12.88	9.16	6.69	5.09	421.6	78.0	0.0	6.6	3.41	300.0
6.000	13,079	41.53	25.88	16.49	11.50	8.27	6.10	4.63	421.6	85.4	0.0	7.5	4.20	300.0
6.101	13,068	38.97	26.07	16.37	11.46	8.44	6.43	5.00	421.6	101.5	0.0	7.4	4.80	300.0
6.208	13,221	30.88	21.94	15.37	11.48	8.69	6.71	5.26	421.6	202.2	0.0	7.5	4.89	300.0
6.301	13,418	21.25	16.00	11.46	8.54	6.48	5.00	3.87	421.6	358.3	0.0	10.2	3.59	300.0
6.401	13,111	40.14	22.44	13.20	9.09	6.59	4.92	3.70	421.6	69.2	0.0	9.6	5.39	287.5
6.500	13,276	26.25	18.10	12.06	8.62	6.28	4.64	3.43	421.6	186.1	0.0	10.4	3.19	247.1
6.601	13,276	26.74	17.69	11.15	7.61	5.48	4.18	3.34	421.6	147.0	0.0	11.6	3.55	300.0
6.700	13,210	34.09	21.45	13.75	9.70	6.97	5.14	3.85	421.6	110.9	0.0	9.1	4.11	278.1
6.802	12,980	52.75	28.84	14.54	9.09	6.37	4.85	3.90	421.6	50.0	0.0	8.4	8.20	300.0 *
6.912	12,991	45.77	30.33	18.53	12.37	8.55	6.12	4.54	421.6	71.2	0.0	6.7	2.66	280.7
7.000	12,892	47.07	28.99	17.47	11.70	7.94	5.59	4.14	421.6	61.6	0.0	7.2	1.91	242.2
7.100	13,243	34.65	22.30	13.60	8.97	6.09	4.34	3.24	421.6	93.0	0.0	9.7	1.60	247.1
7.201	13,243	35.58	23.46	14.01	9.02	6.06	4.29	3.18	421.6	87.9	0.0	9.5	2.65	237.6
7.300	13,539	17.80	11.74	7.09	4.45	2.82	1.85	1.26	421.6	181.9	0.0	20.6	5.27	145.9
7.396	13,133	30.42	18.91	11.22	7.21	4.88	3.45	2.59	421.6	96.3	0.0	12.0	1.89	226.7
7.501	13,155	42.60	26.52	15.58	9.92	6.50	4.43	3.22	421.6	64.8	0.0	8.6	3.07	196.2
7.599	12,958	46.84	28.26	16.69	10.67	7.12	5.01	3.73	421.6	57.1	0.0	7.9	1.94	237.4
7.700	13,309	25.48	18.84	12.64	8.68	5.99	4.31	3.20	421.6	191.4	0.0	10.4	1.42	255.8
7.801	13,024	47.36	25.30	12.32	7.19	4.65	3.30	2.55	421.6	50.0	0.0	10.5	12.18	173.6 *
7.837	13,341	31.15	22.04	13.33	8.05	4.83	2.97	2.06	421.6	97.0	0.0	11.0	10.67	124.4
7.901	13,341	26.32	18.78	12.04	7.60	4.78	3.13	2.17	421.6	136.2	0.0	11.9	6.72	148.8
8.031	13,363	20.13	14.07	9.37	6.60	4.73	3.47	2.57	421.6	246.1	0.0	14.0	2.02	241.0
8.098	13,363	17.02	11.79	7.43	4.98	3.47	2.52	1.89	421.6	245.6	0.0	18.3	1.61	252.7
8.204	13,341	21.46	14.30	9.29	6.54	4.76	3.53	2.55	421.6	208.1	0.0	14.1	3.30	211.3
Mean:		29.60	20.14	13.07	9.04	6.36	4.59	3.39	421.6	220.6	0.0	10.2	3.27	230.4
Std. Dev:		9.24	5.01	2.81	2.00	1.52	1.18	0.93	0.0	200.9	0.0	2.8	2.44	58.1
Var Coeff(%):		31.23	24.87	21.47	22.11	23.90	25.79	27.37	0.0	91.1	0.0	27.0	74.60	25.4

FM 541

This section of FM 541 was let as a rehab project that included reworking the existing base, excavating the subgrade and preparing the subgrade, placing salvaged base and lime-treating the salvage based, adding 12 in. of new flex base, and then performing a two-course surface treatment. Due to the significant time requirements of the scope of the work, this project was nominated for inclusion in this implementation project to determine if FDR would provide a renewal option with significantly faster project delivery.

Soil Survey. Figure 58 shows the soil map for PI from the entire project limits, and Figure 59 shows the map for gypsum. The soil map suggests that the PI increases from west to east along the project. The data also suggest that a good portion of the project is in the vicinity of soils with gypsum contents from 20 to 60,000 ppm, indicating that concerns could exist with lime treatment.

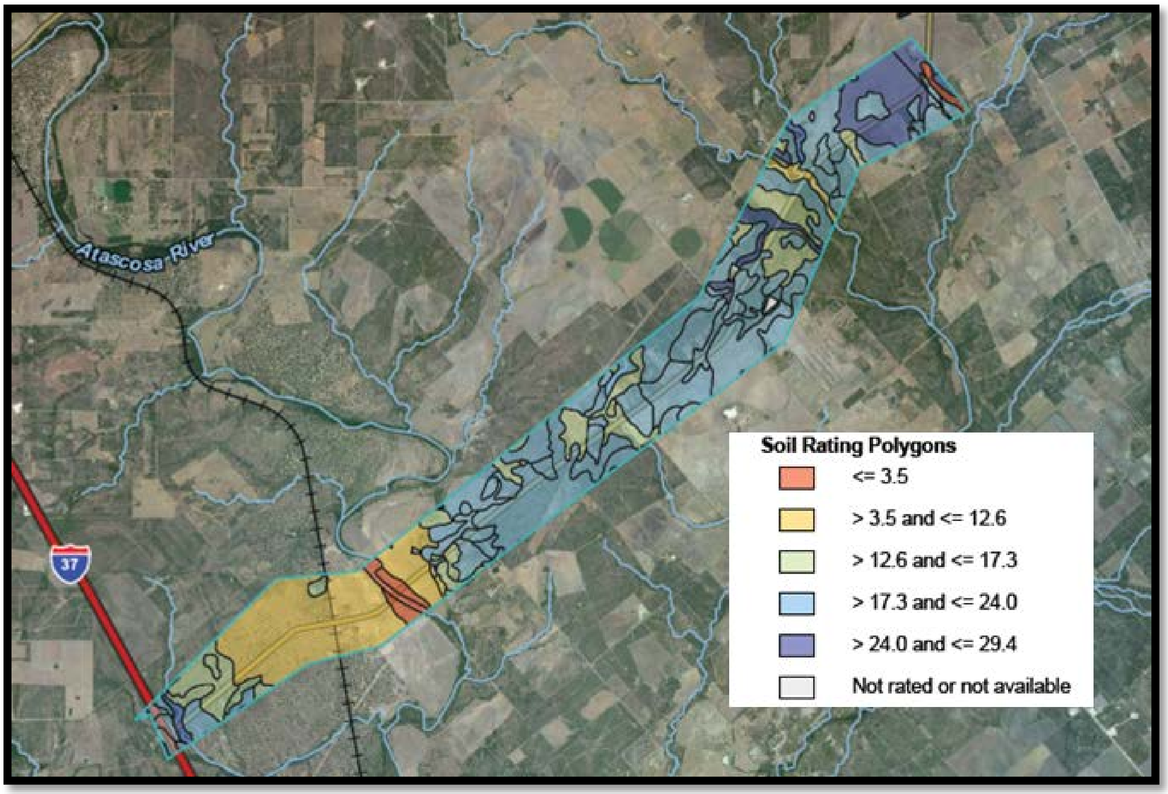


Figure 58. Soil Map for PI from FM 541.

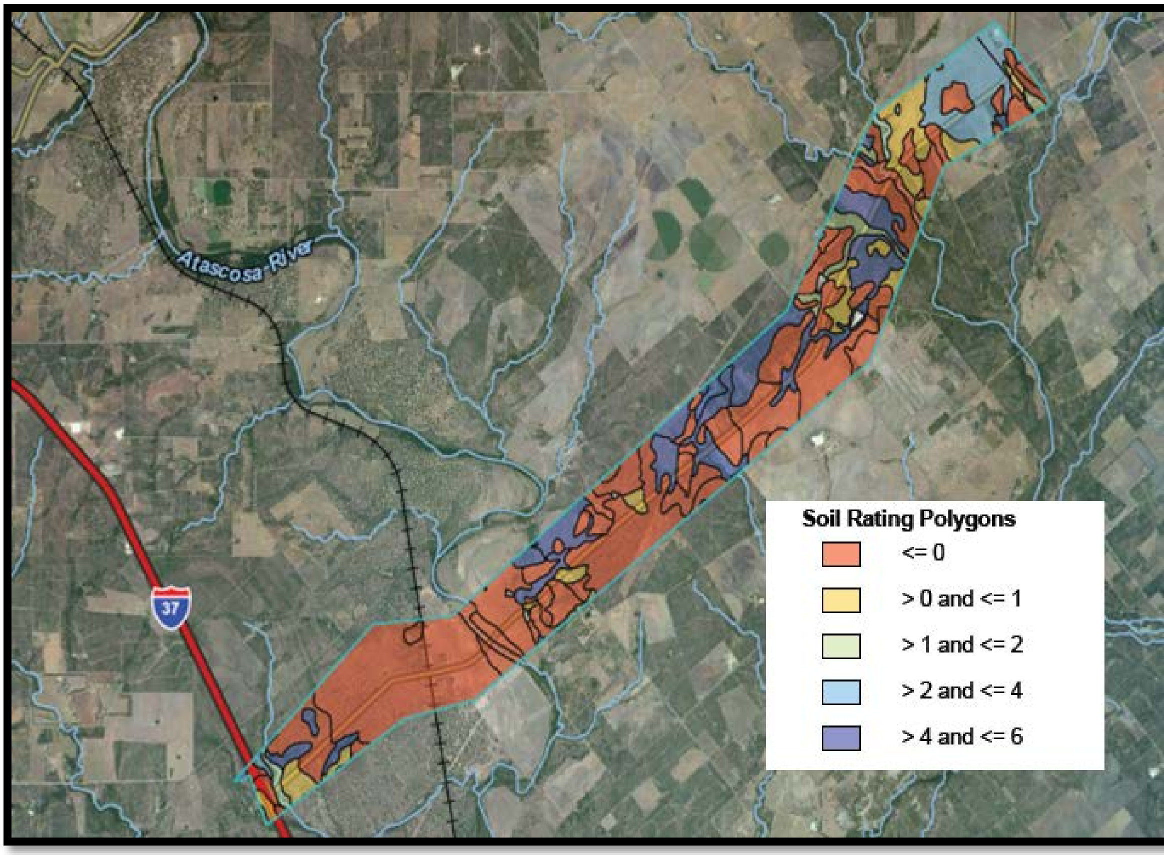


Figure 59. Soil Map for Gypsum from FM 541.

GPR and DCP Results. Figure 60 illustrates example GPR data, and Figure 61 shows example DCP data from the section. The key finding from these data is that the existing pavement is probably widely variable in terms of both thickness and subgrade support. The DCP data suggest better subgrade support exists toward the western extents of the project, which is consistent with expectations from the soil PI map.

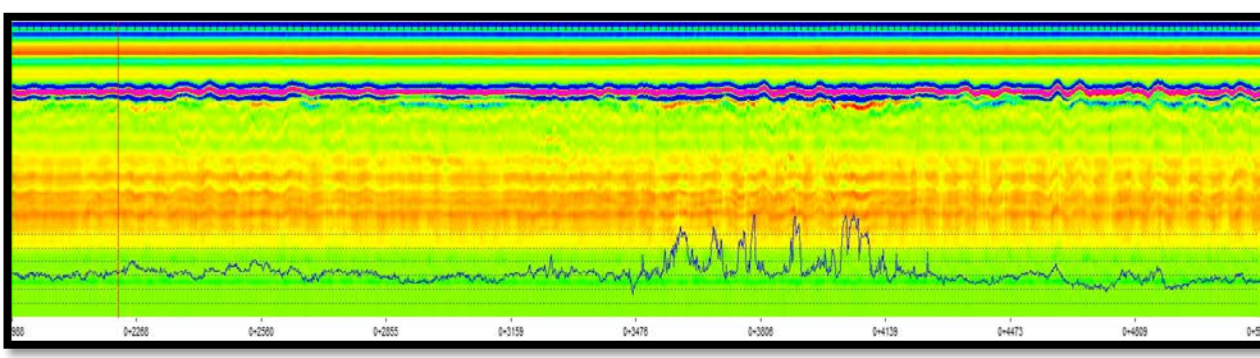


Figure 60. Example GPR from FM 541.

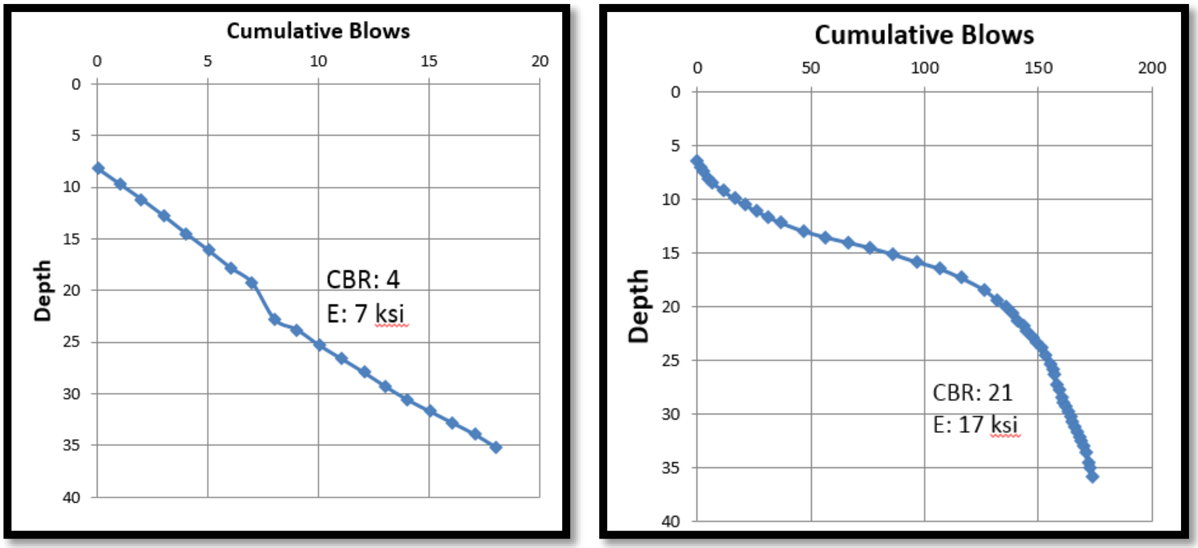


Figure 61. Example DCP Results from FM 541.
Note: Left—TRM 532.55 at eastern part of project; Right—TRM 522.749 at western part of project.

Auguring Results. Figure 62 illustrates example augur results from the section. The results show that the existing pavement structure has significant variability, with existing pavement thickness ranging from 4 to 10 in.

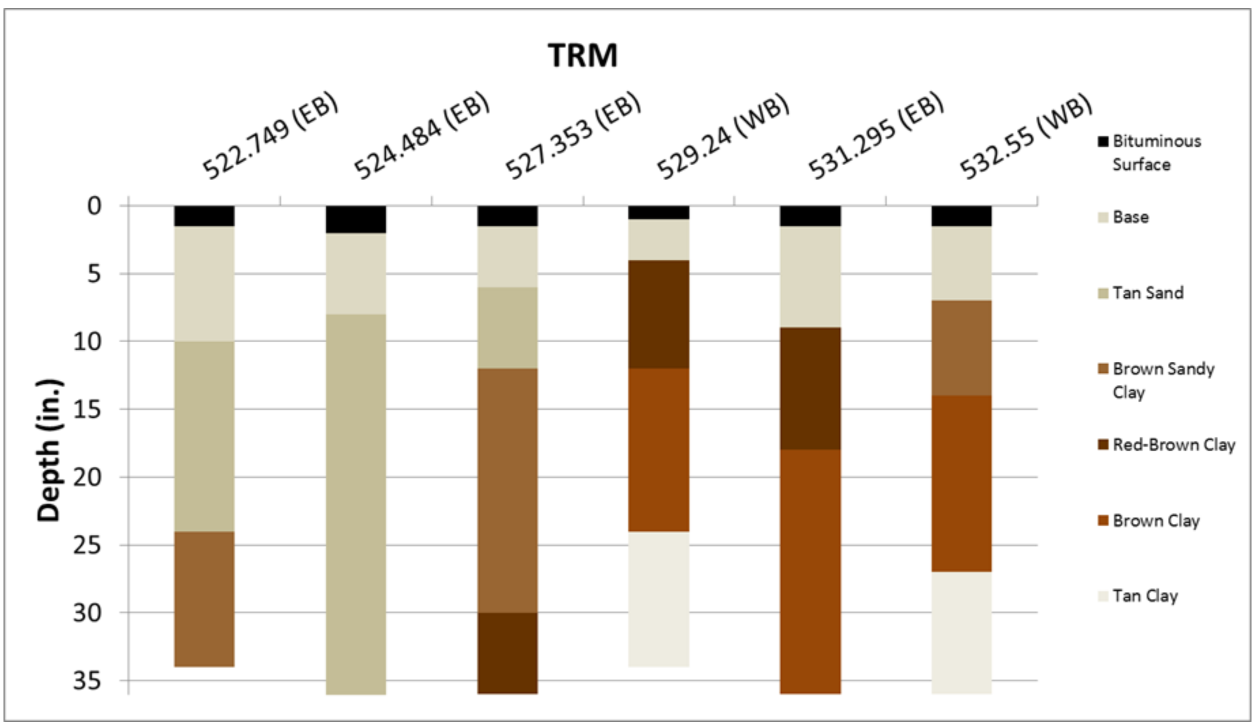


Figure 62. Augur Results from FM 541.

FWD Results. Figure 63 illustrates the FWD output from the project. Based on the FWD, the western portion of the project had significantly improved subgrade conditions, which is consistent with prior observations from the soil map and DCP data. With the better existing subgrade, the western extents of the project were identified as possible limits for FDR with asphalt-based stabilization.

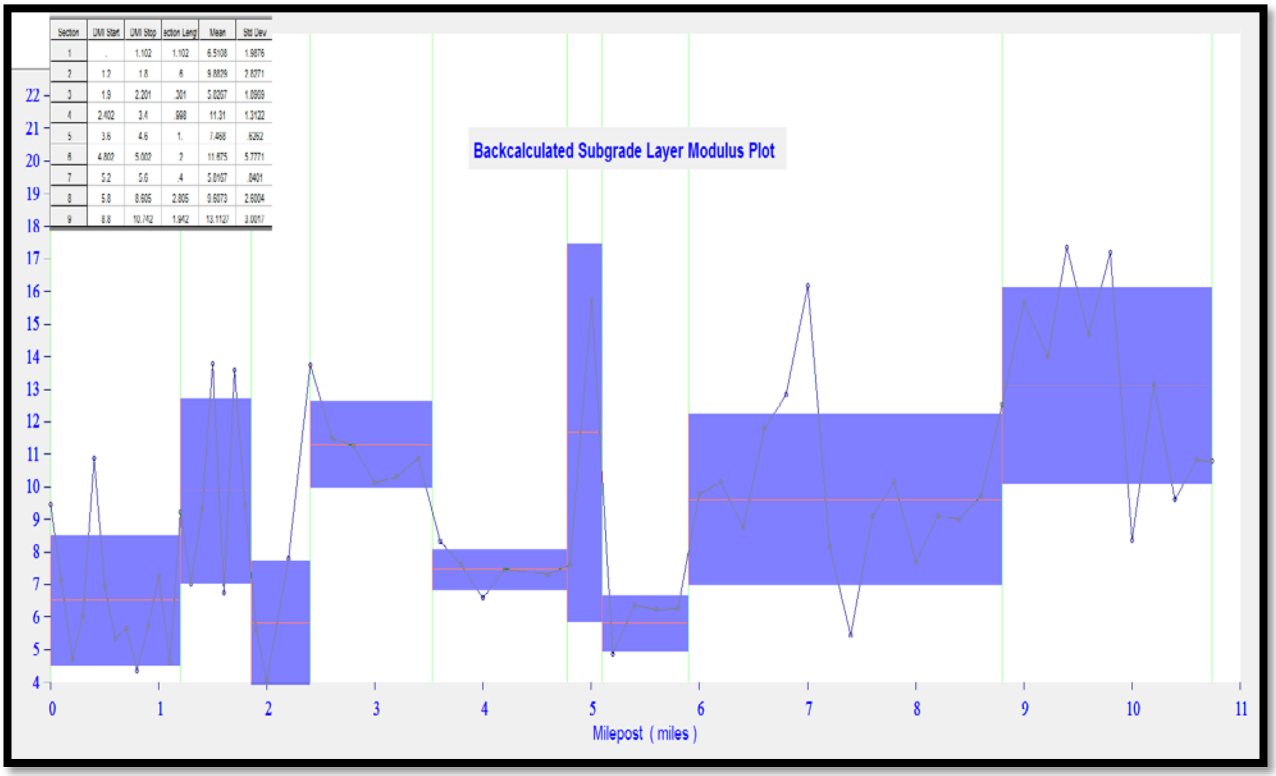


Figure 63. FWD Output from FM 541 Existing Pavement.

Note: Milepost zero is at eastern limits of project extents at the Atascosa/Wilson C/L.

Laboratory Mixture Design. Based on the available information, the research team performed lab mixture designs with materials sampled from TRM 532.55 and from TRM 522.749. All the mixture designs used 60 percent salvage material with 40 percent new base. Figure 64 shows the results. The designs from TRM 532.55 used cement only due to the poorer quality of the in-place materials and subgrade. The designs from TRM 522.749 used foamed asphalt based on the better subgrade support and input from TxDOT.

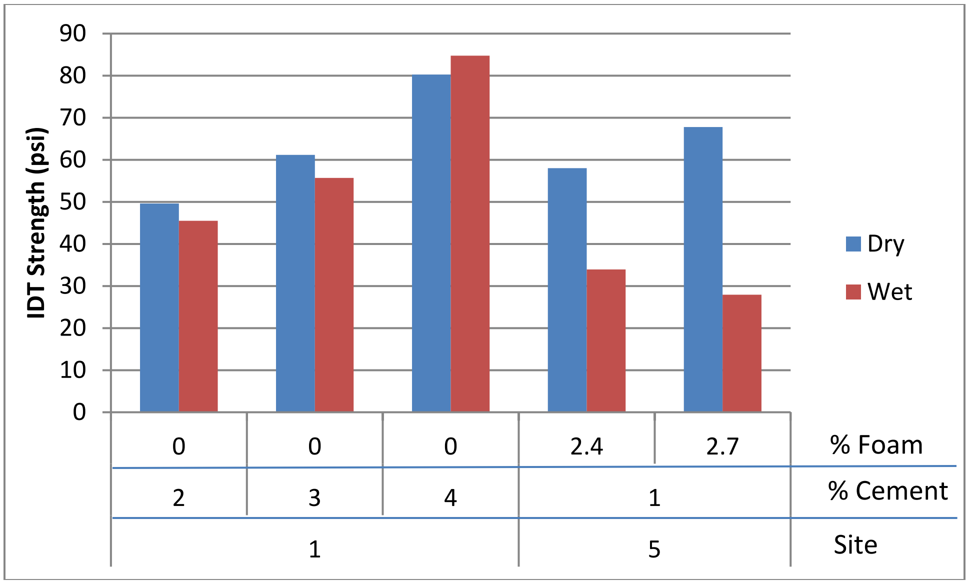


Figure 64. Mixture Designs from FM 541.

Note: Site 1 is from TRM 532.55; Site 2 is from TRM 522.749.

Pavement Design. After review of the mixture designs and discussion with the contractor, TxDOT changed a portion of the project to use FDR with foamed asphalt. Table 23 shows the design assumptions, and Figure 65 shows the pavement design.

Table 23. FPS Design Assumptions for FM 541.

Length of Analysis (yr)	20
Beginning ADT	1033
Ending ADT	1440
20 yr 18 kip ESAL (M)	2.4
Percentage Trucks	30.9
Surface Treatment Modulus (ksi)	200
Foamed Asphalt Stabilized Base Modulus (ksi)	300
Subgrade Modulus (ksi)	7

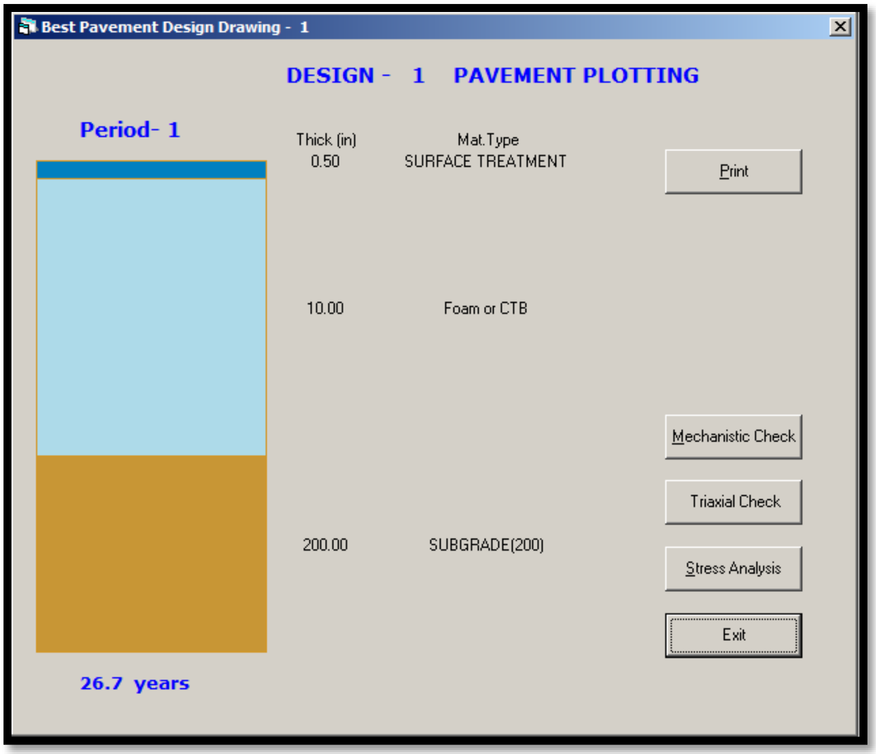


Figure 65. Pavement Design for FM 541.

Recommended Sequence. To proceed with FDR, the proposed sequence included:

- Widen the subgrade.
- Scarify the existing pavement and spread full width.
- Add 4 in. new flex base.
- Perform FDR 10 in. and treat with 1 percent cement plus 2.4 percent foamed asphalt.
- Place surface treatment.

Construction Results. This project was originally planned for undercutting subgrade, placing and treating salvage base, and adding a 12 in. flex-base overlay with a 2 CST. For time reasons, an FDR option was explored and developed for part of the project. Approximately 2.6 mi at the west end of the project limits were determined suitable for FDR and were constructed using 1 percent cement plus 2.4 percent asphalt and a 10 in. treatment depth consisting of 40/60 new/salvage material. A control section was placed in September 2015, and the remainder of the FDR limits was completed at a rate of approximately 1.5 days per lane-mile. Figure 66 presents the typical construction sequence.

Figure 66. Typical Construction Sequence on FM 541.

Figure 67 illustrates the growth in stiffness of the FDR layer over time measured with the FWD. The data show that after approximately 1 month, the FDR layer treated with cement plus foamed asphalt reached a representative in-service value.

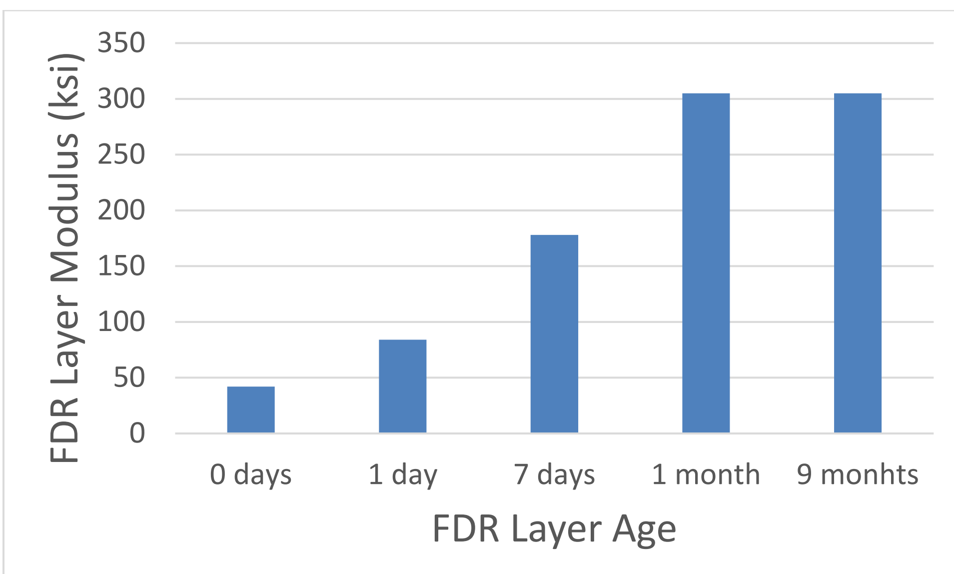


Figure 67. Growth in FDR Layer Modulus with Time on FM 541.

Table 24 presents the FWD data output from June 2016 that was collected in the EB travel direction starting at TRM 522 and represents an excerpt of the completed project. The data show that on average the assumed 300 ksi value for the stabilized layer was achieved.

Table 24. FWD Output from FM 541.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

District:		Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
County :	Pavement:	0.50	200,000	200,000	H1: v = 0.35
Highway/Road:	Base:	10.00	50,000	1,000,000	H2: v = 0.35
	Subbase:	0.00			H3: v = 0.00
	Subgrade:	207.04(by DB)	10,000		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	8,993	11.32	8.93	6.13	4.23	2.96	2.19	1.69	200.0	425.7	0.0	14.0	2.45	300.0
528.000	8,467	13.75	11.12	8.14	5.71	3.94	2.81	2.02	200.0	360.3	0.0	10.0	2.09	216.8
1056.000	8,511	16.36	13.92	10.23	7.30	5.15	3.66	2.63	200.0	331.7	0.0	7.7	2.83	224.3
1584.000	8,511	13.64	10.44	6.88	4.65	3.04	2.18	1.54	200.0	267.7	0.0	12.4	2.13	180.3
2112.000	8,445	24.36	15.03	7.98	4.91	3.30	2.38	1.85	200.0	75.3	0.0	10.7	3.82	236.3
2651.000	8,423	13.48	9.20	5.54	3.59	2.47	1.83	1.37	200.0	203.5	0.0	14.9	3.68	266.7
3168.000	8,883	13.45	10.38	6.61	4.38	3.01	2.24	1.70	200.0	281.6	0.0	13.2	3.86	267.6
3701.000	8,434	20.05	11.97	6.64	4.22	2.87	2.14	1.60	200.0	98.7	0.0	12.5	3.16	249.2
4261.000	8,664	10.87	9.33	6.77	4.82	3.34	2.36	1.72	200.0	506.4	0.0	12.0	3.23	214.9
4752.000	8,587	18.67	13.91	8.62	5.28	3.28	2.30	1.78	200.0	145.5	0.0	10.7	6.15	143.4
5280.000	8,511	17.93	13.91	8.78	5.50	3.43	2.28	1.59	200.0	162.7	0.0	10.4	6.70	145.9
5824.000	8,653	11.13	9.02	6.62	4.61	3.20	2.44	1.72	200.0	483.3	0.0	12.3	2.25	290.8
6336.000	8,719	17.48	15.30	11.43	8.20	5.63	3.81	2.63	200.0	317.2	0.0	7.2	5.13	183.2
6864.000	8,839	9.77	8.47	6.12	4.21	2.84	1.94	1.32	200.0	530.8	0.0	14.2	4.76	168.7
7392.000	8,817	14.72	11.30	7.12	4.53	3.03	2.15	1.72	200.0	226.3	0.0	12.6	3.45	216.9
7925.000	8,653	12.30	10.01	7.38	5.28	3.77	2.76	2.02	200.0	460.0	0.0	10.8	1.08	231.0
Mean:		14.96	11.39	7.56	5.09	3.45	2.47	1.81	200.0	304.8	0.0	11.6	3.55	217.5
Std. Dev:		3.93	2.33	1.58	1.18	0.84	0.55	0.37	0.0	147.3	0.0	2.2	1.52	49.7
Var Coeff(%):		26.27	20.42	20.87	23.28	24.29	22.48	20.64	0.0	48.3	0.0	18.6	42.89	22.8

CHAPTER 3. CONCLUSIONS AND RECOMMENDATIONS

OVERVIEW

Full-depth reclamation can offer a cost-effective and rapid renewal strategy for pavements. While not every distressed pavement is a candidate for FDR, successful FDR projects can renew the pavement at a cost typically at least 50 percent cheaper than other alternatives. To select a good candidate for FDR and maximize project success, the following steps were used in this implementation project and should be followed for future FDR projects:

1. Assemble background information that includes historic plans, maintenance history, and soils maps.
2. Perform NDT that include GPR, FWD, and visual assessment.
3. Verify the structure and sampling, including auguring material into the subgrade and returning materials to the laboratory.
4. Perform lab mix designs, including varying proportions of materials in the FDR mixture and determining different potential stabilization strategies and stabilizer rates.
5. Perform pavement thickness design, including an FPS and triaxial check.
6. Consider local conditions, including potential impacts of highly plastic subgrades, microcracking, and early trafficking on the stabilization strategy and pavement design.
7. Perform construction quality control that determines level of pulverization, moisture content, application of proper amount of stabilizer in a uniform manner, attainment of density, and surface finish.
8. Execute a performance review that gathers feedback from stakeholders and assesses structural condition through time.

In this implementation project, 20 pavement sections were nominated as candidates and investigated for possible implementation of FDR. In this project, 10 sections were constructed and evaluated. Of those 10 constructed projects, two utilized mill and inlay with hot mix, which is generally considered the next most comparable option (although generally more expensive in upfront cost) than FDR, two utilized cement treatment with flexible base overlay, three utilized emulsion treatment, and three utilized foamed asphalt treatment.

Time Savings from FDR

FDR can offer significant time savings compared to other strategies. Figure 68 illustrates that FDR can meet production rates of one lane-mile per 1.5 working days compared to other pavement renewal strategies. In Figure 68, the original design included undercutting followed by treatment of salvage material, which was then followed by placing flexible base. The improved project delivery time from FDR not only minimizes disruption to traffic but also reduces user costs.

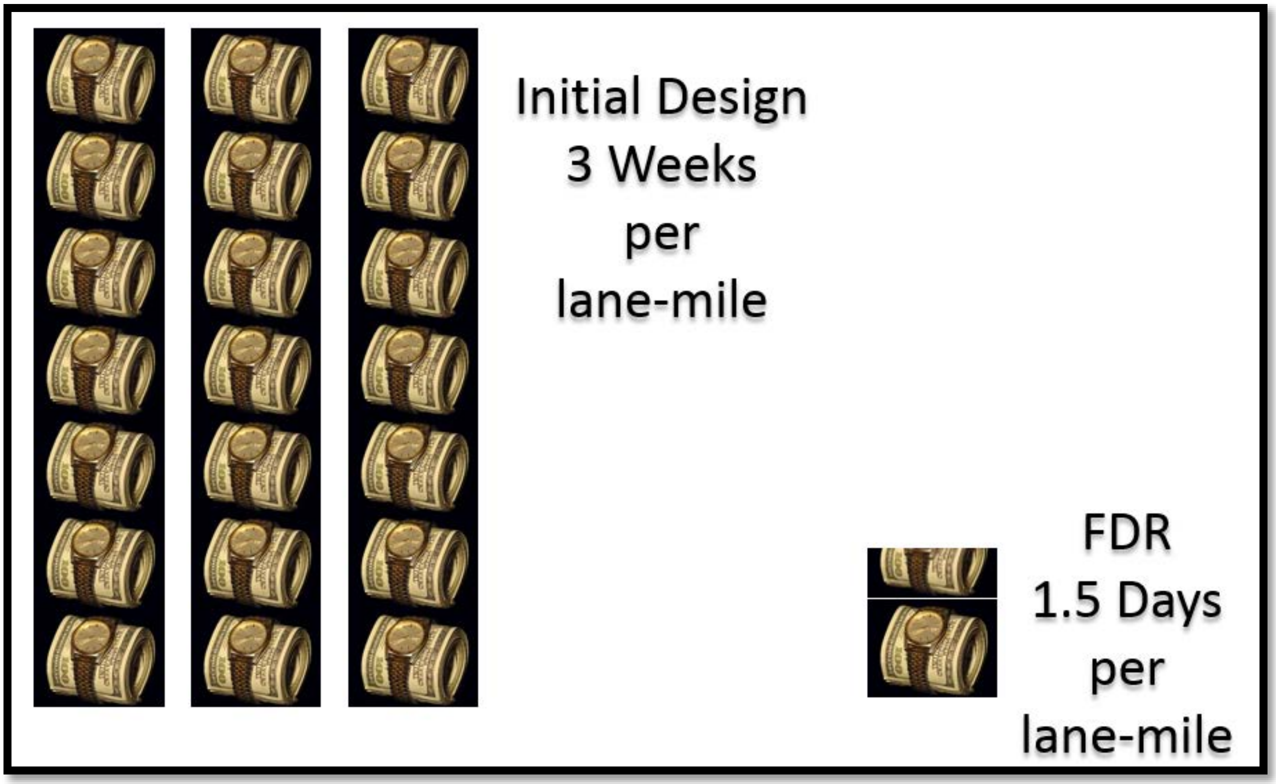


Figure 68. Time Savings from FDR.

Cost Savings from FDR

Figure 69 illustrates typical upfront costs for common pavement renewal options. The data suggest:

- Compared to the most comparable option (mill and inlay), FDR offers the potential of at least 50 percent savings in initial cost.
- Within FDR options, although recent initiatives (including this implementation project) have shown generally positive performance of asphalt-based stabilization with FDR, significant financial incentive exists to identify and explore techniques to address performance concerns with cement-only treatment in FDR.

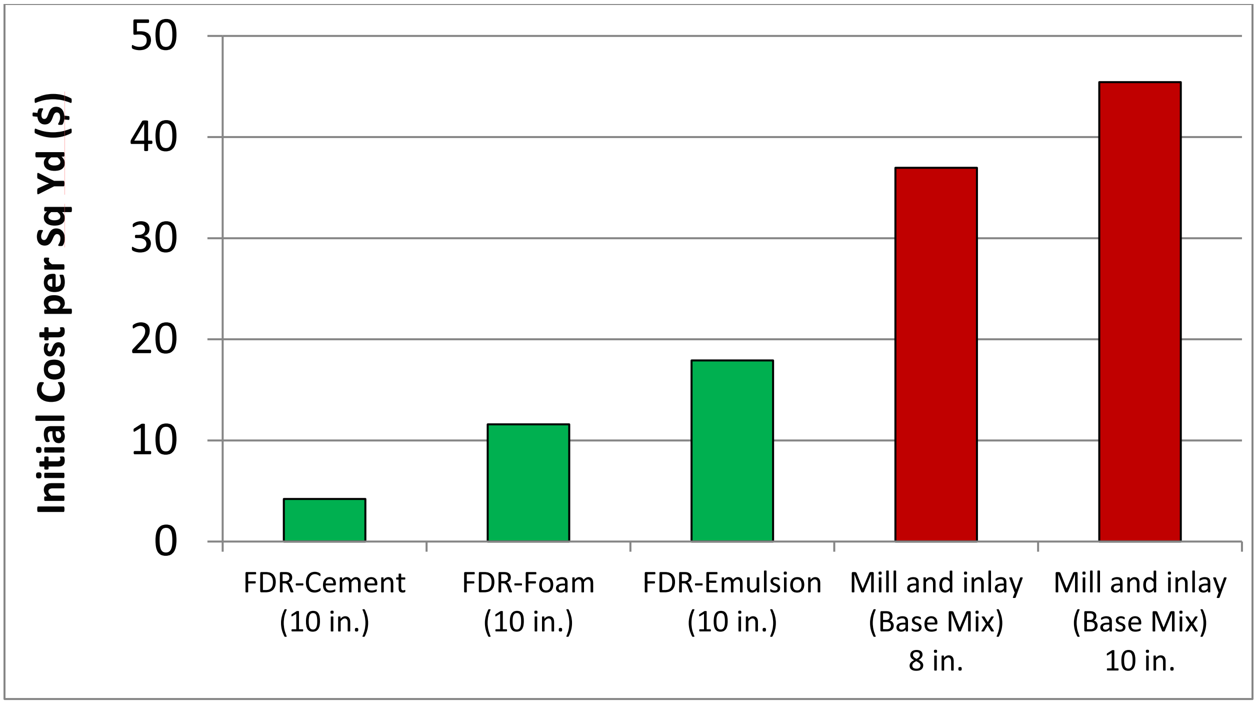


Figure 69. Typical Upfront Costs of FDR and Mill and Inlay.

PERFORMANCE OF FDR PROJECTS

In terms of performance, Table 25 presents the normalized deflection under the FWD of completed projects. Although not directly comparable across projects due to varying design requirements, support conditions, and type of surfacing, Table 25 supports the following generalized conclusions:

- FDR is a viable structural option for other alternatives such as mill and inlay or cement treatment with base overlay.
- Emulsion and foamed asphalt approaches, assuming suitable lab mixture designs, in theory should be relatively interchangeable. However, local conditions such as product availability, climate, and contractor or agency preferences may factor into selection of the stabilizer type.
- The data, although only from one project, suggest the high-yield emulsion treatment performed similarly to the commodity emulsion.
- A low percentage of additive (such as cement) when combined with the foamed asphalt treatment significantly increased field performance in comparison to asphalt-only or cement-only treatment.

Table 25. Normalized Deflections for FDR Projects with Mill and Inlay Reference.

		Normalized R1 (mils) to 9klb FWD Load
Mill/Inlay	SH 16	24.25
	US 59	16.8
CTB with Flex-Base Overlay	SH 202	11.04
	FM 1996	12.4
Emulsion	IH 10 (Reeves Co) prior to hot mix	10.2
	IH 10 (Reeves Co) after hot mix	4.48
	SH 115 Phase 1 (CSS-1H)	13.2
	SH 115 Phase 2 (high-yield)	15.3
	IH 10 (Crockett Co)—prior to hot mix	10.45
	IH 10 (Crockett Co)—after hot mix	4.73
Foam	SH 7 (foam prior to hot mix)	16.08
	SH 7 (after hot mix—foam only)	10.5
	SH 7 (after hot mix—foam with cement)	6.9
	SH 7 (after hot mix—cement only)	9.7
	SH 44	20.7
	FM 541	15.6

DESIGN ASSUMPTIONS FOR FDR LAYERS WITH EMERGING TECHNOLOGIES

This implementation project significantly increased the level of field experience with emerging asphalt-based FDR. For these treatments, the data show a representative in-service modulus may be attained in the field in as little as a few days or may take a month or longer. The data suggest the cure time to reach this representative modulus value is not specific to the treatment type.

This implementation project also provided an opportunity to develop better guidance for design assumptions of the asphalt-based FDR layer modulus. Table 26 summarizes the layer modulus according to stabilization type and project. The data suggest that, in general, the 200–300 ksi range should be reasonable design assumptions for materials meeting the mix design requirements. This field modulus range is consistent with current findings in other literature but should be further validated through the ongoing monitoring of additional projects as they are let and constructed.

Table 26. FDR Field Modulus from Asphalt-Based Stabilization.

Stabilization Type	Project	Field Layer Modulus (ksi)
Emulsion	IH10 (Reeves Co.)	482
	SH 115 Phase I (CSS-1H)	68
	SH 115 Phase II (high-yield)	130
	IH 10 (Crockett Co.)	1240
Foam	SH 7 (foam only)	142
	SH 7 (foam plus cement)	413
	SH 44	221
	FM 541	305

RECOMMENDATIONS FOR UPDATED SPECIFICATIONS

Throughout the duration of this implementation project, the research team also coordinated with TxDOT to document and develop needs for updated specifications. Key needs for specification updates were identified for asphalt-based FDR as follows:

- Formatting: the specs need to reflect 2014 formatting style.
- Mixture design: the existing specifications do not include approved test procedures. Approved test procedures need adoption and referencing in the specification. The mix design requirements should be harmonized between emulsion and foamed asphalt.
- Equipment: the minimum requirements for the equipment should be harmonized and foster adoption of improved technology in the field for improved attainment of the required level of pulverization, improved mixing, and improved production rate.
- Staffing: on-site staff meeting minimum prior relevant experience should be on site for some minimum duration at project startup.
- Mix design verification: the engineer should have the option to verify the mix design with the actual materials to be used on the project.
- Control section: the engineer should be able to require a control section.
- Construction: requirements should be modified to foster a one-pass operation. Controls and minimum level of testing for moisture content should be strengthened. Quality control and assurance minimum requirements should be reviewed and the minimum testing frequency possibly increased.
- Measurement and payment: emulsion should be allowed to be paid by weight or volume.

Based on addressing these specification needs, Appendices A and B present proposed updated construction specifications for emulsion and foamed asphalt-based FDR, respectively. These proposed specifications were developed in cooperation with input from TxDOT and should be considered for implementation on future FDR projects.

APPENDIX A. RECOMMENDED UPDATED CONSTRUCTION SPECIFICATION FOR FDR WITH ASPHALT EMULSION

Special Specification XXXX

Full-Depth Reclamation Using Asphalt Emulsion (Road Mixed)

1. DESCRIPTION

Full-Depth Reclamation (FDR) using an in-place mixing process to obtain a homogenous mixture of the existing surface and the underlying base material (with or without new material and additive added) using an emulsified asphalt.

2. MATERIALS

Furnish uncontaminated materials of uniform quality in accordance with the plans and specifications. Notify the Engineer of the proposed material sources and, when necessary, changes to material sources. The Engineer will verify the specification requirements are met before the sources are approved for use. The Engineer may sample and test project materials at any time during the project to verify specification compliance in accordance with Item 6, "Control of Materials."

2.1. **Emulsion.** Provide emulsified asphalt that is homogeneous, does not separate after thorough mixing, and meets the requirements listed in Table 1.

2.2. **Additional Material.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish base material meeting the requirements of Item 247 "Flexible Base" for the type and grade required.

2.3. **Additive.** When shown on the plans, required by the mixture design, or directed by the Engineer, use the type and amount of additive required.

2.3.1 **Lime.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish lime in accordance with DMS-6350, "Lime and Lime Slurry," and DMS-6330, "Pre-Qualification of Lime Sources." Use hydrated lime or commercial lime slurry as required.

2.3.2 **Cement.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish hydraulic cement in accordance with DMS-4600, "Hydraulic Cement," and the Department's Hydraulic Cement Quality Monitoring Program (HCQMP). Sources not on the HCQMP will require testing and approval before use.

2.3.3 **Fly Ash.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish fly ash in accordance with DMS-4615, "Fly Ash for Soil Treatment." Use Class CS or FS as shown on the plans.

2.4. **Mixture Design.** The Engineer will provide an approved mixture design using the Department-approved mixture design procedure provided by the Construction Division/Materials & Pavements Section before the start of any work pertinent to this item. The mixture design must meet the requirements listed in Tables 1 and 2 and report the optimum moisture content, maximum dry density, percent additive when applicable, percent of additional material when applicable, percent of existing material, type of emulsion, percent residue by distillation, and the optimum percent emulsion content.

2.5. **Mixture Design Verification.** When directed by the Engineer, provide the Engineer with representative samples of all materials that will be included in the treatment process prior to production. The Engineer will verify the target emulsion content and, when applicable, the target additive content that produces a mixture to meet the requirements listed in Tables 1 and 2. When the mixture fails to meet the material requirements listed in Tables 1 or 2, the Engineer may provide a new mixture design.

2.6. **Water.** Furnish water free of industrial waste and other objectionable material.

Table 1
Emulsified Asphalt Properties

Material Property	Test Method	Requirement	
		Minimum	Maximum
Distillation test: Residue by distillation, % by wt.	AASHTO T 59	60	–
Oil distillate, % by volume of emulsion		–	0.5
Sieve Test, %	AASHTO T 59	–	0.1
Test on residue from distillation: Penetration, 77°F, 100g, 5 sec	AASHTO T 49	55	95

Table 2
Laboratory Mixture Design Properties

Mixture Property[1]	Test Method	Minimum Requirement
Indirect Tensile Strength (IDT) psi	Provided by Engineer	50
Moisture Conditioned[2] IDT, psi		30
Moisture Conditioned[2] Unconfined Compressive Strength (UCS)[3], psi		120

1. Oven dry test specimens after compaction in an oven at 104 ± 5°F for a minimum of 72 hours.
2. Procedure for moisture conditioning test specimens will be provided by the Engineer. Moisture conditioning will be performed by submerging test specimens in water for 24 ± 1 hour before IDT and UCS strength testing.
3. Average of a minimum of two test specimens.

3. EQUIPMENT

Provide machinery, tools, and equipment necessary for proper execution of the work.

3.1. **Storage Facility.** Store cement, quicklime, dry hydrated lime, and fly ash in closed, weatherproof containers.

3.2. **Slurry Equipment.** Use slurry tanks equipped with agitation devices to slurry cement, hydrated lime, or quicklime at the project or at another location approved by the Engineer. The Engineer may approve other slurrying methods. Provide a pump for agitating the slurry when the distributor truck is not equipped with an agitator. Equip the distributor truck with a sampling device in accordance with Tex-600-J, Part I.

3.3. **Dry Distribution Equipment.** Provide equipment to spread the cement or lime or fly ash evenly across the area to be treated. Provide equipment with a rotary vane feeder to spread the cement or lime, when shown on the plans.

3.4. **Rollers.** Provide rollers in accordance with Item 210, “Rolling.”

3.5. **Proof Rollers.** Provide proof rollers in accordance with Item 216, “Proof Rolling,” when required.

3.6. **Reclaimer for Emulsion Treatment.** Use a reclaimer with the following equipment and capabilities:

3.6.1 Self-propelled mixer capable of fully mixing the existing road to the depth shown on the plans with emulsion, water, and when applicable, additives and additional material to produce a homogeneous material.

3.6.2 Minimum power capability of 400 horsepower.

3.6.3 Ability to mix the roadway with the additive and additional materials when applicable in a single pass for the width and depth specified by the plans.

3.6.4 Add emulsion with a full width spray bar consisting of a positive displacement pump interlocked to the machine speed such that the amount of emulsion added is automatically adjusted with changes of machine speed.

3.6.5 Equipped with an emulsion injection system capable of adding 7 gallons per square yard of emulsified asphalt.

3.6.6 Emulsion injection system spray bar equipped with individual valves that can be turned off to minimize emulsion overlap on subsequent passes.

4. STAFFING REQUIREMENTS

4.1. **Certification.** Provide Soils & Base 102 (SB102) Field Specialists certified by the Department-approved soils and base certification program to conduct all sampling and testing. Supply the Engineer with a list of certified personnel and copies of their current certifications before beginning production and anytime personnel changes are made.

4.2. The emulsion supplier is required to provide a representative on site at the start of treatment to determine adequate mixing and curing properties. This person will provide recommendations as deemed necessary to the Engineer.

5. CONTROL SECTION

When directed by the Engineer, construct a control section at a location approved by the Engineer using the equipment specified in Section 3. Process material in the control section for a lane width, minimum 300 ft. in length, and to the depth shown on the plans. Meet the quality control requirements in Section 7 and provide test results and any pertinent information to the Engineer upon completion of the control section.

When directed by the Engineer, proof roll the control section in accordance with Item 216. Proceed to full construction when approved by the Engineer.

6. CONSTRUCTION

Construct each layer uniformly, free of loose or segregated areas, with the materials, density, and moisture content as required by the mixture design from Section 2.4. Provide a smooth surface that conforms to the typical sections, lines, and grades shown on the plans or as directed.

6.1. **Reporting and Responsibilities.** Use Department-provided templates to record and calculate all test data and pertinent information for the mixture design and quality control testing. Obtain the current version of the templates at http://www.txdot.gov/inside-txdot/forms-publications/consultants-contractors/forms/site-manager.html or from the Engineer. The Engineer and the Contractor will provide any available test results to the other party when requested. Record and electronically submit all test results and pertinent information on Department-provided templates.

6.2. **Preshaping.** Where required to pre-shape the pavement, pulverize existing bituminous surface and all existing pavement layers to the required depth. Incorporate water and additional flexible base or other approved materials during this operation, if needed. Shape roadway material in accordance with applicable bid items to conform to typical sections shown on the plans and as directed before the addition of the emulsion. Compact the material to support equipment and/or traffic and to provide depth control during mixing.

6.3. **Application of Additive.** When required, start application only when the air temperature is at least 35°F and rising or is at least 40°F. The temperature will be taken in the shade and away from artificial heat. Suspend application when the Engineer determines that weather conditions are unsuitable. Apply the required additive uniformly across the roadway in advance of the mixer, when required. Minimize dust and scattering of additives by wind. Do not apply additives when, in the opinion of the Engineer, wind conditions cause blowing additive to become dangerous to traffic or objectionable to adjacent property owners.

6.3.1 **Lime.** Uniformly apply lime using dry or slurry placement as shown on the plans or as directed by the Engineer. Add lime at the percentage determined in the mix design. Apply lime only to the area to be reclaimed during the same working day.

6.3.1.1 **Dry Placement.** When necessary, sprinkle in accordance with Item 204, "Sprinkling." Distribute the required quantity of hydrated lime with approved equipment. Do not use a motor grader to spread hydrated lime.

6.3.1.2 **Slurry Placement.** Provide slurry free of objectionable materials at or above the approved minimum dry solids content and with a uniform consistency that will allow ease of handling and uniform application. Inject slurry directly into mixing chamber via independent metered spray system. Alternatively, distribute slurry uniformly by making successive passes over a measured section of roadway until the specified lime content is reached.

Deliver commercial lime slurry to the jobsite or prepare lime slurry at the jobsite or other approved location by using hydrated lime as specified.

6.3.2 **Cement.** Uniformly apply cement using dry or slurry placement as shown on the plans or as directed by the Engineer. Add cement at the percentage determined in the mix design. Apply cement only on an area where mixing, compacting, and finishing can be completed during the same working day.

6.3.2.1 **Dry Placement.** Distribute the required quantity of dry cement with approved equipment. Minimize dust and scattering of cement by wind. Do not apply cement when wind conditions, in the opinion of the Engineer, cause blowing cement to become dangerous to traffic or objectionable to adjacent property owners.

6.3.2.2 **Slurry Placement.** Mix the required quantity of cement with water, as approved. Provide slurry free of objectionable materials and with a uniform consistency that can be easily applied. Agitate the slurry continuously. Apply slurry within 2 hours of adding water and when the roadway is at a moisture content drier than optimum. Distribute slurry uniformly by making successive passes over a measured section of the roadway until the specified cement content is reached.

6.3.3 **Fly Ash.** Uniformly apply fly ash using dry or slurry placement as shown on the plans or as directed by the Engineer. Add fly ash at the percentage determined in the mix design. Apply fly ash only on an area where mixing, compacting, and finishing can be completed during the same working day. Distribute the required quantity of fly ash with approved equipment.

6.4. **Weather Restrictions.** Suspend emulsion application if the weather forecast calls for freezing temperatures within 3 days after incorporation of the emulsion. Suspend application when the Engineer determines the weather conditions are unsuitable.

6.5. **Mixing.** Thoroughly mix the material using approved equipment. Mix until a homogenous mixture is obtained.

6.5.1 **Lime.** When applicable, begin mixing within 6 hours of application of lime. Hydrated lime exposed to the open air for 6 hours or more between application and mixing or that experiences excessive loss due to washing or blowing will not be accepted for payment. Thoroughly mix the material and lime using approved equipment. Allow the mixture to mellow for a minimum of 24 hours or as directed by the Engineer before mixing with emulsion.

6.5.2 **Emulsion.** Achieve the required moisture content before mixing; aerate if too wet and add water if too dry. Apply the emulsion to obtain the optimum emulsion content determined in Section 2.4. Apply emulsion only for areas where mixing and compaction can be completed during the same working day. Do not dilute the emulsion at the jobsite. Monitor the required depth of mixing and meet the gradation requirements listed in Table 3.

Complete the entire operation of mixing the existing road and incorporating additional flexible base, cement, lime, or fly ash when applicable, water, and emulsion in one pass, with exception to preshaping as described in Section 6.2. Overlap each adjacent pass of the mixer with the previous pass by a minimum of 6 in. Use multiple passes if the quality control requirements specified in Section 7 are not met.

Table 3
Gradation Requirements

Sieve Size	Minimum Percent Passing
1-3/4 in.	100
3/4 in.	85

6.6. **Compaction.** Compact the mixture in one lift using density control unless otherwise shown on the plans.

Begin rolling longitudinally at the sides and proceed toward the center, overlapping on successive trips by at least one-half the width of the roller unit. On super-elevated curves, begin rolling at the low side and progress toward the high side. Offset alternate trips of the roller. Operate rollers at a speed between 2 and 6 mph, as directed.

Perform initial compaction using a heavy tamping roller applying high amplitude and low frequency. Continue rolling until the heavy tamping roller walks out of the material. Walking out for the heavy tamping roller is defined as light being evident between all of the pads at the material-heavy tamping roller drum interface.

After the completion of tamping rolling, remove remaining tamping marks. Cut slightly below the depth of the tamping marks and ensure material being cut is kept moist at all times. Achieve desired slope and shape to the lines and grades as shown in the plans. Perform final surface shaping on the same day as emulsion is incorporated. Clip, skin, or tight-blade the surface to remove and waste accumulated fines. Do not use fines to fill surface irregularities.

Use a vibratory roller and pneumatic roller to compact the bladed material. Do not finish-roll in vibratory mode. If necessary, use a light spray of water to aid in final compaction density and appearance.

Rework material that fails to meet or loses the required density, stability, or finish within 24 hours of completion of compaction. Add additional emulsified asphalt and additives as directed by the Engineer. Reworking includes loosening, adding material or removing unacceptable material if necessary; mixing; compacting; and finishing as directed. Continue work until specification requirements are met. Perform the work at no additional expense to the Department.

When an area fails to meet or loses required density, stability, or finish more than 24 hours after completion of compaction and before the next course is placed or the project is accepted, remove the unacceptable material and replace with treated flexible base that meets the mix design requirements in accordance with Item 247 or as directed by the Engineer. Compact and finish until specification requirements are met. Perform the work at no additional expense to the Department.

Suspend field operations when significant changes of materials being treated occur. Provide the Engineer with recommendations to modify operations based on the changes of materials. This may include changes in additives or percentages of emulsion. Provide the Engineer with an emulsion treatment proposal for all areas requiring full-depth repair.

Notify the Engineer when significant changes of materials being treated occur. The Engineer may suspend field operations and investigate the areas of concern.

6.6.1 **Ordinary Compaction.** Roll with approved compaction equipment, as directed by the Engineer. Correct irregularities, depressions, and weak spots immediately by scarifying the areas affected, adding or removing treated material as required, reshaping, and recompacting.

6.6.2 **Density Control.** The Engineer will determine the roadway density of completed sections in accordance with Tex-115-E for each day of production at a minimum of 1 per 3,000 CY or 1 per lift. The full depth of the layer shall be compacted to an average of 97.0%, and the bottom half of the layer shall not be less than 95.0% of the maximum density determined from the mixture design in Section 2.4 unless otherwise shown on the plans. The Engineer may accept the section if no more than one of the five most recent density tests is below the specified density and the failing test is no more than 3 pcf below the specified density.

6.7. **Curing.** Cure the finished section until the moisture content is a minimum of 2 percent below the optimum moisture content, or as directed by the Engineer, before applying the next successive course or prime coat. The Engineer may allow traffic on the finished section during curing when proof rolling indicates adequate stability.

6.8. Proof-roll the roadbed in accordance with Item 216, "Proof Rolling." If deformation occurs, do not allow traffic to return to the finished section until the mixed material is firm enough to accommodate traffic without deformation. Apply primes and seals or additional courses within 14 calendar days of final compaction.

When no specific detour is required, provide one-way traffic control until proof rolling permits the return of normal traffic to the compacted material.

7. QUALITY CONTROL

Perform quality control (QC) testing during the treatment process and for the completed base in accordance with Table 4 unless otherwise directed by the Engineer.

7.1. **Depth of Pulverization.** Determine the depth of pulverization in accordance with Tex-140-E.

7.2. **Gradation.** Sample the roadway mixture after mixing with the moisture and measure the gradation in accordance with Tex-101-E, Part III.

7.3. **Emulsion Content.** Verify the percentage of emulsion added to the pulverized material using meter readings or truck weight tickets as approved by the Engineer; the quantity of material treated (depth, width, and length); and estimated in-place density measured in accordance with Tex-115-E. Change of the emulsion content, type, or supplier must be approved by the Engineer before the start of production. Notify the Engineer when adjustments to the emulsion content are made during any day's production.

7.4. **Moisture Content.** Measure the moisture content in accordance with Tex-103-E or Tex-115-E before adding the emulsion. Verify the moisture content when precipitation occurs after testing and before the emulsion is added.

Table 4
Minimum Testing Frequency

Description	Test Method	Minimum Frequency
Depth of Pulverization	Tex-140-E	1 per day of production
Gradation	Tex-101-E, Part III	1 per day of production
Emulsion Content	Meter Readings or Truck Weight Tickets	1 per day of production
Moisture Content	Tex-103-E or Tex-115-E	3 per day of production

8. MEASUREMENT

8.1. **Emulsion.** Emulsified asphalt material will be measured by one of the following methods:

8.1.1 **Weight.** Asphalt material will be measured in tons using certified scales meeting the requirements of Item 520, "Weighing and Measuring Equipment" unless otherwise approved. The transporting truck must have a seal attached to the draining device and other openings. Random checking on public scales at the Contractor's expense may be required to verify weight accuracy.

Upon work completion or temporary suspension, any remaining asphalt material will be weighed by a certified public weigher. The quantity to be measured will be the number of tons received minus the number of tons remaining after all directed work is complete.

8.1.2 **Volume.** Asphalt material, including all components, will be measured at the applied temperature by strapping the tank before and after road application. The distributor-calibrated strap stick will be used for measuring the asphalt level in the distributor asphalt tank. The certified tank chart will be used to determine the beginning gallons and the final gallons in the distributor tank. The quantity to be measured for payment will be the difference between the beginning gallons and the final gallons.

8.2. **Additive.**

8.2.1 **Lime.** When lime is furnished in trucks, the weight of lime will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, "Weighing and Measuring Equipment."

8.2.1.1 **Hydrated Lime.**

8.2.1.1.1 **Dry.** Lime will be measured by the ton (dry weight).

8.2.1.1.2 **Slurry.** Lime will be measured by the ton (dry weight) of the hydrated lime used to prepare the lime slurry at the jobsite.

8.2.1.1.3 **Commercial Lime Slurry.** Lime slurry will be measured by the ton (dry weight) as calculated from the minimum percent dry solids content of the slurry multiplied by the weight of the slurry in tons delivered.

8.2.2 **Cement.** Cement will be measured by the ton (dry weight). When cement is furnished in trucks, the weight of cement will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, "Weighing and Measuring Equipment."

Cement slurry will be measured by the ton (dry weight) of the cement used to prepare the slurry at the jobsite or from the minimum percent dry solids content of the slurry, multiplied by the weight of the slurry in tons delivered.

8.2.3 **Fly Ash.** Fly ash will be measured by the ton (dry weight). When fly ash is furnished in trucks, the weight of fly ash will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, "Weighing and Measuring Equipment."

Fly ash slurry will be measured by the ton (dry weight) of the fly ash used to prepare the slurry at the jobsite or from the minimum percent dry solids content of the slurry multiplied by the weight of the slurry in tons delivered.

8.3. **Emulsion Treatment.** Emulsion treatment will be measured by the square yard of surface area. The dimensions for determining the surface area is established by the widths shown on the plans and lengths measured at placement.

9. PAYMENT

The work performed and materials furnished in accordance with this item and measured as provided under "Measurement" will be paid in accordance with Section 8—"Emulsion," Section 8.1—"Lime," Section 8.2.1—"Cement," Section 8.2.2—"Fly Ash," Section 8.2.3—"Fly Ash," and Section 8.3—"Emulsion Treatment."

Furnishing and delivering new base will be paid for in accordance with Item 247 unless otherwise shown on the plans.

Removal and disposal of existing asphalt concrete pavement will be paid for in accordance with pertinent items or Item 4, Section 4.2, "Changes in the Work."

Additives and emulsion used for reworking a section will not be paid for directly but will be subsidiary to this item.

Sprinkling and rolling, including proof rolling, will not be paid for directly but will be subsidiary to this item unless otherwise shown on the plans.

Where subgrade is constructed under this Contract, correction of soft spots in the subgrade or existing base will be at the Contractor's expense. Where subgrade is not constructed under this Contract, correction of soft spots in the subgrade or existing base will be in accordance with pertinent items or Item 4, Section 4.4, "Changes in the Work."

When an additional additive is required by the mixture design or required by the Engineer and not shown on the plans, it will be paid for in accordance with Article 4.4, "Changes in the Work."

9.1. **Emulsion.** Emulsion will be paid for at the unit price bid for "Emulsion." This price is full compensation for materials, delivery, equipment, labor, tools, and incidentals.

9.2. **Lime.** Lime will be paid for at the unit price bid for "Lime" of one of the following types: Hydrated (Dry), Hydrated (Slurry), or Commercial Lime Slurry. This price is full compensation for furnishing lime.

9.3. **Cement.** Cement will be paid for at the unit price bid for "Cement." This price is full compensation for furnishing cement.

9.4. **Fly Ash.** Fly Ash will be paid for at the unit price bid for "Fly Ash" of the type specified. This price is full compensation for furnishing fly ash.

9.5. **Emulsion Treatment.** Emulsion treatment will be paid for at the unit price bid for "Full-Depth Recycling and Treatment Using Emulsion (Road Mixed)" for the depth specified. No payment will be made for thickness or width exceeding that shown on the plans.

This price is full compensation for shaping existing material, loosening, mixing, pulverizing, spreading, applying additives and emulsified asphalt, compacting, finishing, curing, curing materials, blading, shaping and maintaining shape, replacing mixture, disposing of loosened materials, processing, hauling, preparing secondary subgrade, water, equipment, labor, tools, and incidentals.

APPENDIX B. RECOMMENDED UPDATED CONSTRUCTION SPECIFICATION FOR FDR WITH FOAMED ASPHALT

Special Specification XXXX

Full-Depth Reclamation Using Foamed Asphalt (Road Mixed)

1. DESCRIPTION

Full-Depth Reclamation (FDR) using an in-place mixing process to obtain a homogenous mixture of the existing surface and the underlying base material (with or without new material and additive added) using a foamed asphalt.

2. MATERIALS

Furnish uncontaminated materials of uniform quality in accordance with the plans and specifications. Notify the Engineer of the proposed material sources and, when necessary, changes to material sources. The Engineer will verify the specification requirements are met before the sources are approved for use. The Engineer may sample and test project materials at any time during the project to verify specification compliance in accordance with Item 6, "Control of Materials."

2.1. **Asphalt.** Furnish the type and grade of performance-graded (PG) binder or asphalt cement (AC) in accordance with Item 300, "Asphalts, Oils, and Emulsions," specified on the plans.

2.2. **Additional Material.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish base material meeting the requirements of Item 247, "Flexible Base," for the type and grade required.

2.3. **Additive.** When shown on the plans, provide the amount and type of additive required.

2.3.1 **Lime.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish lime in accordance with DMS-6350, "Lime and Lime Slurry," and DMS-6330, "Pre-Qualification of Lime Sources." Use hydrated lime or commercial lime slurry as required.

2.3.2 **Cement.** When shown on the plans, required by the mixture design, or directed by the Engineer, furnish hydraulic cement in accordance with DMS-4600, "Hydraulic Cement," and the Department's Hydraulic Cement Quality Monitoring Program (HCQMP). Sources not on the HCQMP will require testing and approval before use.

2.3.3 **Fly Ash.** When shown on the plans, furnish fly ash in accordance with DMS-4615, "Fly Ash for Soil Treatment." Use Class CS or FS as shown on the plans.

2.4. **Mixture Design.** The Engineer will provide an approved a mixture design using the Department-approved mixture design procedure provided by the Construction Division/Materials & Pavements Section before the start of any work pertinent to this item. The mixture design must meet the requirements listed in Tables 1 and 2 and report the optimum moisture content, maximum dry density, percent additive when applicable, percent of additional material when applicable, percent of existing material, type of asphalt, and the optimum foamed asphalt content.

2.5. **Mixture Design Verification.** When directed by the Engineer, provide the Engineer with representative samples of all materials that will be included in the treatment process prior to production. The Engineer will verify the target foamed asphalt content and, when applicable, the target additive content that produces a mixture to meet the requirements listed in Tables 1 and 2. When the mixture fails to meet the material requirements listed in Tables 1 or 2, the Engineer may provide a new mixture design.

2.6. **Water.** Furnish water free of industrial waste and other objectionable material.

Table 1
Foamed Asphalt Properties

Material Property	Test Method	Minimum Requirement
Asphalt Binder Expansion ratio[1]	Provided by Engineer	8 times
Asphalt Binder Half-Life, seconds[1]		6

1. The recycler shall have a test nozzle attached to one side of the spray bar from which a quantity of foamed asphalt is injected into a straight-sided container during recycling. The half-life is a measure of time for the foamed asphalt to reach half the height of the maximum expansion noted in the container. The container is set aside for a minimum of 1 hour or until the foamed asphalt has subsided completely and the unexpanded volume of the quantity of asphalt injected into the container is noted. The expansion ratio is the ratio of the maximum expansion volume to the unexpanded volume.

Table 2
Laboratory Mixture Design Properties

Mixture Property	Test Method	Minimum Requirement
Indirect Tensile Strength (IDT), psi	Provided by Engineer	50
Moisture Conditioned IDT, psi		30
Moisture Conditioned Unconfined Compressive Strength,[1] psi		120

1. Average of two test specimens. Oven dry test specimens after compaction in an oven at 104 ± 5°F for a minimum of 72 hours. After drying, allow the specimens to return to room temperature. Condition the test specimens with moisture by submerging them in water for 24 ± 1 hours before strength testing.

3. EQUIPMENT

Provide machinery, tools, and equipment necessary for proper execution of the work.

3.1. **Storage Facility.** Store cement, quicklime, and dry hydrated lime in closed, weatherproof containers.

3.2. **Slurry Equipment.** Use slurry tanks equipped with agitation devices to slurry cement, hydrated lime, or quicklime at the project or at another location approved by the Engineer. The Engineer may approve other slurrying methods. Provide a pump for agitating the slurry when the distributor truck is not equipped with an agitator. Equip the distributor truck with a sampling device in accordance with Tex-600-J, Part I.

3.3. **Dry Distribution Equipment**. Provide equipment to spread the cement or lime or fly ash evenly across the area to be treated. Provide equipment with a rotary vane feeder to spread the cement or lime, when shown on the plans.

3.4. **Rollers.** Provide rollers in accordance with Item 210, “Rolling.”

3.5. **Proof Rollers.** Provide proof rollers in accordance with Item 216, “Proof Rolling,” when required.

3.6. **Reclaimer for Foamed Asphalt Treatment.** Use a reclaimer with the following equipment and capabilities:

3.6.1 Self-propelled mixer capable of fully mixing the existing road to the depth shown on the plans with foam asphalt, water, and, when applicable, additives and additional material to produce a homogeneous mixture.

3.6.2 Minimum power capability of 600 horsepower.

3.6.3 Increase the effective volume of the mixing chamber in relation to depth of cut.

3.6.4 Two microprocessor controlled systems, complete with two independent pumping systems and spray bars, to regulate the application of foamed asphalt cement, separate from water that is used to increase the moisture content of the mixed material. Both systems shall perform in relation to the forward speed of the reclaimer and the mass of the material being processed.

3.6.5 Two spray bars, one for foamed asphalt cement and one for compaction moisture, each fitted with self-cleaning nozzles at a maximum spacing of one nozzle for each 6 in. in width of the mixing chamber. Monitor the flow rate of each nozzle to verify that all nozzles are producing foamed asphalt at the same rate.

3.6.6 The foamed asphalt cement shall be produced at the spray bar in individual expansion chambers into which hot asphalt cement, water, and air are injected under pressure through individual and small orifices that promote atomization. The rate of addition of water into the hot asphalt cement shall be kept at a constant percentage by mass of asphalt cement by the same microprocessor.

3.6.7 A system within the operator cabin to verify the foamed asphalt is being evenly distributed across the full width of the spray bar at the rate specified. The system shall be demonstrated to the Engineer to verify even spraying.

3.6.8 An electrical heating system capable of maintaining the temperature of asphalt cement flow components above 300°F.

3.6.9 A single asphalt cement feed pipe installed between the recycler and the supply tanker. Do not use circulating systems that incorporate a return pipe to the supply tanker.

3.6.10 An inspection or test nozzle shall be fitted at one end of the spray bar that produces a representative sample of the foamed asphalt cement.

4. STAFFING REQUIREMENTS

4.1. **Certification.** Provide Soils and Base 102 (SB102) Field Specialists certified by the Department-approved soils & base certification program to conduct all sampling and testing. Supply the Engineer with a list of certified personnel and copies of their current certifications before beginning production and when personnel changes are made.

5. CONTROL SECTION

When directed by the Engineer, construct a control section at a location approved by the Engineer using the equipment specified in Section 3. Process material in the control strip for a lane width, minimum 300 ft. in length, and to the depth shown on the plans. Meet the quality control requirements in Section 7 and provide results and any pertinent information to the Engineer upon completion of the control section.

When directed by the Engineer, proof roll the control section in accordance with Item 216. Proceed to full construction when approved by the Engineer.

6. CONSTRUCTION

Construct each layer uniformly, free of loose or segregated areas, and with the materials, density, and moisture content as required by the mixture design from Section 2.4. Provide a smooth surface that conforms to the typical sections, lines, and grades shown on the plans or as directed.

6.1. **Reporting and Responsibilities.** Use Department-provided templates to record and calculate all test data and pertinent information for the mixture design and quality control testing. Obtain the current version of the templates at http://www.txdot.gov/inside-txdot/forms-publications/consultants-contractors/forms/site-manager.html or from the Engineer. The Engineer and the Contractor will provide any available test results to the other party when requested. Record and electronically submit all test results and pertinent information on Department-provided templates.

6.2. **Preshaping.** Where required to pre-shape the pavement, pulverize existing bituminous surface and all existing pavement layers to the required depth less 1 in. Incorporate water and additional flexible base or other approved materials during this operation, if needed. Shape roadway material in accordance with applicable bid items to conform to typical sections shown on the plans and as directed before the addition of the foamed asphalt. Compact the material to support equipment and/or traffic and to provide depth control during mixing.

6.3. **Application of Additive.** When required, start application only when the air temperature is at least 35°F and rising or is at least 40°F. The temperature will be taken in the shade and away from artificial heat. Suspend application when the Engineer determines that weather conditions are unsuitable. Apply the required additive uniformly across the roadway in advance of the mixer, when required. Minimize dust and scattering of additives by wind. Do not apply additives when, in the opinion of the Engineer, wind conditions cause blowing additive to become dangerous to traffic or objectionable to adjacent property owners.

6.3.1 **Lime.** Uniformly apply lime using dry or slurry placement as shown on the plans, or as directed by the Engineer. Add lime at the percentage determined in the mix design. Apply lime only to the area to be reclaimed during the same working day.

6.3.1.1 **Dry Placement.** When necessary, sprinkle in accordance with Item 204, “Sprinkling.” Distribute the required quantity of hydrated lime with approved equipment. Do not use a motor grader to spread hydrated lime.

6.3.1.2 **Slurry Placement.** Provide slurry free of objectionable materials, at or above the approved minimum dry solids content, and with a uniform consistency that will allow ease of handling and uniform application. Inject slurry directly into mixing chamber via independent metered spray system. Alternatively, distribute slurry uniformly by making successive passes over a measured section of roadway until the specified lime content is reached.

Deliver commercial lime slurry to the jobsite or prepare lime slurry at the jobsite or other approved location by using hydrated lime as specified.

6.3.2 **Cement.** Uniformly apply cement using dry or slurry placement as shown on the plans, or as directed by the Engineer. Add cement at the percentage determined in the mix design. Apply cement only on an area where mixing, compacting, and finishing can be completed during the same working day.

6.3.2.1 **Dry Placement.** Distribute the required quantity of dry cement with approved equipment. Minimize dust and scattering of cement by wind. Do not apply cement when wind conditions, in the opinion of the Engineer, cause blowing cement to become dangerous to traffic or objectionable to adjacent property owners.

6.3.2.2 **Slurry Placement.** Mix the required quantity of cement with water, as approved. Provide slurry free of objectionable materials and with a uniform consistency that can be easily applied. Agitate the slurry continuously. Apply slurry within 2 hours of adding water and when the roadway is at a moisture content drier than optimum. Distribute slurry uniformly by making successive passes over a measured section of the roadway until the specified cement content is reached.

6.3.3 **Fly Ash.** Uniformly apply fly ash using dry or slurry placement as shown on the plans or as directed by the Engineer. Add fly ash at the percentage determined in the mix design. Apply fly ash only on an area where mixing, compacting, and finishing can be completed during the same working day. Distribute the required quantity of fly ash with approved equipment.

6.4. **Weather Restrictions.** Suspend foaming application when the surface temperature is below 50°F. Suspend foaming application when the weather forecast predicts freezing temperatures within 7 days after incorporation of the foamed asphalt. Suspend foamed asphalt application when the Engineer determines weather conditions are unsuitable.

6.5. **Mixing.** Thoroughly mix the material using approved equipment. Mix until a homogenous mixture is obtained.

6.5.1 **Lime.** When applicable, begin mixing within 6 hours of application of lime. Hydrated lime exposed to the open air for 6 hours or more between application and mixing or that experiences excessive loss due to washing or blowing will not be accepted for payment. Thoroughly mix the material and lime using approved equipment. Allow the mixture to mellow for a minimum of 24 hours or as directed by the Engineer before mixing with foamed asphalt.

6.5.2 **Foamed Asphalt**. Achieve the required moisture content before mixing; aerate if too wet and add water if too dry. Add foamed asphalt at the percentage determined in Section 2.4. Apply foamed asphalt only for areas where mixing and compaction can be completed during the same working day. Monitor the required depth of mixing and meet the gradation requirements listed in Table 3.

Complete the entire operation of mixing the existing road and incorporating additional flexible base, cement or fly ash when applicable, water, and foamed asphalt in one pass, with exception to preshaping as described in Section 6.2. Overlap each adjacent pass of the mixer with the previous pass by a minimum of 6 in. Use multiple passes if the quality control requirements specified in Section 7 are not met.

Table 3
Gradation Requirements

Sieve Size	Percent Passing
1-3/4 in.	100
3/4 in.	85

6.6. **Compaction.** Compact the mixture using density control unless otherwise shown on the plans.

Begin rolling longitudinally at the sides and proceed toward the center, overlapping on successive trips by at least one-half the width of the roller unit. On super-elevated curves, begin rolling at the low side and progress toward the high side. Offset alternate trips of the roller. Operate rollers at a speed between 2 and 6 mph, as directed.

Perform initial compaction using a heavy tamping roller applying high amplitude and low frequency. Continue rolling until the heavy tamping roller "walks out" of the material. Walking out for the heavy tamping roller is defined as light being evident between all of the pads at the material-heavy tamping roller drum interface.

After the completion of tamping rolling, remove remaining tamping marks. Cut slightly below the depth of the tamping marks and ensure material being cut is kept moist at all times. Achieve desired slope and shape to the lines and grades as shown in the plans. Perform final surface shaping on the same day as the foamed asphalt is incorporated. Clip, skin, or tight-blade the surface to remove and waste accumulated fines. Do not use fines to fill surface irregularities.

Use a vibratory roller and pneumatic roller to compact the bladed material. Do not finish-roll in vibratory mode. If necessary, use a light spray of water to aid in final compaction density and appearance.

Rework material that fails to meet or loses the required density, stability, or finish within 24 hours of completion of compaction. Add additional foamed asphalt and additives at the percentage directed by the Engineer. Reworking includes loosening, adding material, or removing unacceptable material if necessary; mixing; compacting; and finishing as directed. Continue work until specification requirements are met. Perform the work at no additional expense to the Department.

When an area fails to meet or loses required density, stability, or finish more than 24 hours after completion of compaction and before the next course is placed or the project is accepted, remove the unacceptable material and replace with treated flexible base that meets the mix design requirements in accordance with Item 247 or as directed by the Engineer. Compact and finish until specification requirements are met. Perform the work at no additional expense to the Department.

Suspend field operations when significant changes of materials being treated occur. Provide the Engineer with recommendations to modify operations based on the changes of materials. This may include changes in additives, or percentages of foamed asphalt. Provide the Engineer with a foamed asphalt treatment proposal for all areas requiring full-depth repair.

Notify the Engineer when significant changes of materials being treated occur. The Engineer may suspend field operations and investigate the areas of concern.

6.6.1 **Ordinary Compaction.** Roll with approved compaction equipment as directed by the Engineer. Correct irregularities, depressions, and weak spots immediately by scarifying the areas affected, adding or removing treated material as required, reshaping, and recompacting.

6.6.2 **Density Control.** The Engineer will determine roadway density of completed sections in accordance with Tex-115-E for each day of production at a minimum of 1 per 3,000 CY or 1 per lift.The full depth of the layer shall be compacted to an average of 97%, and the bottom half of the layer shall not be less than 95% of the maximum density determined from the mixture design in Section 2.4 unless otherwise shown on the plans. The Engineer may accept the section if no more than one of the five most recent density tests is below the specified density and the failing test is no more than 3 pcf below the specified density.

6.7. **Curing.** Cure the finished section for a minimum of 2 hours or as directed by the Engineer before opening to traffic. The Engineer may allow traffic on the finished section during curing when proof rolling indicates adequate stability. Proof roll the roadbed in accordance with Item 216, “Proof Rolling,” when shown on the plans or directed.

Proof roll the roadbed in accordance with Item 216, “Proof Rolling.” If deformation occurs, do not allow traffic to return to the finished section until the mixed material is firm enough to accommodate traffic without deformation. Apply primes and seals or additional courses within 14 calendar days of final compaction.

When no specific detour is required, provide one-way traffic control until proof rolling permits the return of normal traffic to the compacted material.

7. QUALITY CONTROL

Perform quality control (QC) testing during the treatment process and for the completed base in accordance with Table 4 unless otherwise directed by the Engineer.

7.1. **Depth of Pulverization.** Determine the depth of pulverization in accordance with Tex-140-E.

7.2. **Gradation.** Sample the roadway mixture after mixing with the moisture and measure the gradation in accordance with Tex-101-E, Part III.

7.3. **Foamed Asphalt Content.** Verify the percentage of asphalt added to the pulverized material using asphalt meter readings or truck weight tickets as approved by the Engineer; the quantity of material reclaimed (depth, width, and length); and estimated in-place density in accordance with Tex-115-E. Change of the asphalt content, type, or supplier must be approved by the Engineer before the start of production. Notify the Engineer when adjustments to the asphalt content are made during any day’s production.

7.4. **Foamed Asphalt Treatment Water Content.** Apply the water content determined from the mix design to produce the foamed asphalt. Measure the water content added using a water monitoring device from the reclaimer. When necessary, adjust the water content and notify the Engineer within 1 hour after material is reclaimed and treated.

7.5. **Expansion Ratio and Half-Life.** Measure the expansion ratio and half-life of the foamed asphalt before the start of daily production. Meet the requirements listed in Table 1.

7.6. **Moisture Content.** Measure the moisture content in accordance with Tex-103-E before adding the foamed asphalt. Verify the moisture content when precipitation occurs after testing and before the foamed asphalt is added.

Table 4
Testing Frequency

Test	Test Method	Frequency
Depth of Pulverization	Tex-140-E	1 per day of production
Gradation	Tex-101-E, Part III	1 per day of production
Foamed Asphalt Content	Meter Readings or Truck Weight Tickets	1 per day of production
Foamed Asphalt Treatment Water Content	Meter Readings	1 per day of production
Expansion Ratio and Half-Life	Provided by Engineer	1 per day of production
Moisture Content	Tex-103-E or Tex-115-E	3 per day of production

8. MEASUREMENT

8.1. **Asphalt.** Unless otherwise shown on the plans, asphalt material will be measured by the following method.

8.1.1 **Weight.** Asphalt material will be measured in tons using certified scales meeting the requirements of Item 520, “Weighing and Measuring Equipment,” unless otherwise approved. The transporting truck must have a seal attached to the draining device and other openings. Random checking on public scales at the Contractor’s expense may be required to verify weight accuracy.

Upon work completion or temporary suspension, any remaining asphalt material will be weighed by a certified public weigher. The quantity to be measured will be the number of tons received minus the number of tons remaining after all directed work is complete.

8.1.2 **Volume.** Asphalt material, including all components, will be measured at the applied temperature by strapping the tank before and after road application. The distributor-calibrated strap stick will be used for measuring the asphalt level in the distributor asphalt tank. The certified tank chart will be used to determine the beginning gallons and the final gallons in the distributor tank. The quantity to be measured for payment will be the difference between the beginning gallons and the final gallons.

8.2. **Additive.**

8.2.1 **Lime.** When lime is furnished in trucks, the weight of lime will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, “Weighing and Measuring Equipment.”

8.2.1.1 **Hydrated Lime.**

8.2.1.1.1 **Dry.** Lime will be measured by the ton (dry weight).

8.2.1.1.2 **Slurry.** Lime will be measured by the ton (dry weight) of the hydrated lime used to prepare the lime slurry at the jobsite.

8.2.1.1.3 **Commercial Lime Slurry.** Lime slurry will be measured by the ton (dry weight) as calculated from the minimum percent dry solids content of the slurry multiplied by the weight of the slurry in tons delivered.

8.2.2 **Cement.** Cement will be measured by the ton (dry weight). When cement is furnished in trucks, the weight of cement will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, "Weighing and Measuring Equipment."

Cement slurry will be measured by the ton (dry weight) of the cement used to prepare the slurry at the jobsite or from the minimum percent dry solids content of the slurry multiplied by the weight of the slurry in tons delivered.

8.2.3 **Fly Ash.** Fly ash will be measured by the ton (dry weight). When fly ash is furnished in trucks, the weight of fly ash will be determined on certified scales, or the Contractor must provide a set of standard platform truck scales at a location approved by the Engineer. Scales must conform to the requirements of Item 520, "Weighing and Measuring Equipment."

8.3. **Foamed Asphalt Treatment.** Foamed asphalt treatment will be measured by the square yard of surface area. The dimensions for determining the surface area is established by the widths shown on the plans and lengths measured at placement.

9. PAYMENT

The work performed and materials furnished in accordance with this item and measured as provided under "Measurement" will be paid in accordance with Section 8; "Asphalt," Section 8.1; "Lime," Section 8.2.1; "Cement," Section 8.2.2; "Fly Ash," Section 8.2.3; and "Foamed Asphalt Treatment," Section 8.3.

Furnishing and delivering new base will be paid for in accordance with Item 247, unless otherwise shown on the plans.

Mixing, spreading, blading, shaping, compacting, and finishing new or existing base material will be paid for under Section 8.3, "Foamed Asphalt Treatment."

Removal and disposal of existing asphalt concrete pavement will be paid for in accordance with pertinent items or Item 4, Section 4.2, "Changes in the Work."

Additives and foamed asphalt used for reworking a section will not be paid for directly but will be subsidiary to this item.

Sprinkling and rolling, including except proof rolling, will not be paid for directly but will be subsidiary to this item unless otherwise shown on the plans.

Where subgrade is constructed under this Contract, correction of soft spots in the subgrade or existing base will be at the Contractor's expense. Where subgrade is not constructed under this Contract, correction of soft spots in the subgrade or existing base will be in accordance with pertinent items or Item 4, Section 4.2, "Changes in the Work."

9.1. **Asphalt.** Asphalt will be paid for at the unit price bid for "Asphalt." This price is full compensation for materials, delivery, equipment, labor, tools, and incidentals.

9.2. **Lime.** Lime will be paid for at the unit price bid for "Lime" of one of the following types: Hydrated (Dry), Hydrated (Slurry), or Commercial Lime Slurry. This price is full compensation for furnishing lime.

9.3. **Cement.** Cement will be paid for at the unit price bid for "Cement." This price is full compensation for furnishing cement.

9.4. **Fly Ash.** Fly Ash will be paid for at the unit price bid for "Fly Ash" of the type specified. This price is full compensation for furnishing fly ash.

9.5. **Foamed Asphalt Treatment.** Foamed asphalt treatment will be paid for at the unit price bid for "Full-Depth Recycling and Treatment Using Foamed Asphalt (Road Mixed)" for the depth specified. No payment will be made for thickness or width exceeding that shown on the plans.

This price is full compensation for shaping existing material, loosening, mixing, pulverizing, spreading, applying additives and foamed asphalt, compacting, finishing, curing, curing materials, blading, shaping and maintaining shape, replacing mixture, disposing of loosened materials, processing, hauling, preparing secondary subgrade, water, equipment, labor, tools, and incidentals.