TTI: 0-6880

Expanding FDR Technologies in Maintenance Operations: Technical Report

Technical Report 0-6880-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
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16. Abstract

Full-depth reclamation (FDR) is the main approach used across Texas to rehabilitate thin roadways that are structurally damaged. With the Eagle Ford Shale boom, the Texas Department of Transportation (TxDOT) faced the need to rehabilitate many miles of pavement in energy-sector areas of the state while placing heavy traffic back on the roadway the same day as treatment. Based on promising results with same-day energy-sector traffic placed on an asphalt-treated FDR pilot project, this research project planned, designed, and constructed 12 test sections in coordination with TxDOT district staff using foamed asphalt or emulsion. The results showed that FDR with these treatments can offer a viable solution for rehabilitating pavements with rapid project delivery time and generally successful early opening to traffic. The results also showed the 200 ksi modulus assumption reasonable for pavement design with these FDR layers. Based on this project and input from stakeholders, multiple approaches exist for using these asphalt-based FDR tools within maintenance operations. Not all distressed pavements are candidates for asphalt-based FDR, so to assist stakeholders in developing successful applications of these technologies, this project provided technical guidance and workflow forms as separate deliverables to help define the best practices and processes for setting up an FDR project.

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EXPANDING FDR TECHNOLOGIES IN MAINTENANCE OPERATIONS: TECHNICAL REPORT

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DISCLAIMER

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- Bryan District: James Robbins, Carl Schroeder and Crew.
- Paris District: Tommy Henderson, Wade Blackmon, David Escobedo and Crew.
- Tyler District: Justin Smith, Sarah Hatley, Jeremy Reid and Crew.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1. INTRODUCTION

BACKGROUND

Full-depth reclamation (FDR) is the main approach used across Texas to rehabilitate thin roadways that are structurally damaged. In the FDR process, the existing surface and base materials are pulverized, mixed together, and treated with a stabilizer. The type and amount of stabilizer to add are determined in the laboratory to provide sufficient strength and moisture resistance. The compacted treated base then receives a thin surfacing.

The stabilizers historically used by the Texas Department of Transportation (TxDOT) include cement, lime, emulsified asphalt, and fly ash. While cement-treatment is still the most frequently used, combinations of stabilizers may be desirable. Additionally, laboratory studies have concluded that for the common stabilizers lime and cement, adding the treatment in slurry form generally provides a more uniform and more effectively treated material.

With the Eagle Ford Shale boom, TxDOT faced the need to rehabilitate many miles of pavement in energy-sector areas of the state. Figure 1 shows typical distressed pavements. In these operational environments, one major project requirement was that no matter the rehab treatment, the roadway must be opened to energy-sector traffic at the end of each working day.

Figure 1. Energy-Sector Pavements in Need of Rehab.

Based on the need to rapidly renew energy-sector damaged pavements and subject them to same-day energy-sector traffic, TxDOT's Corpus Christi District performed a pilot using foamed asphalt treatment on FM 99 in June 2014. Figure 2 shows that traffic was turned within 2 hours of working and treating a half section. The district reported good performance of the FDR mix under intense early energy-sector traffic loads. This success led to increased interest in emerging FDR approaches, especially asphalt-based stabilization, within TxDOT.

Figure 2. Energy-Sector Traffic within 2 Hours of Treatment on FM 99.

OBJECTIVES

Some concerns do exist with asphalt-based stabilization. Specifically, the foamed asphalt or emulsified asphalt treatments are more expensive than cement treatment, and the performance of asphalt-based stabilization with variable field materials is not well defined in Texas.

The objective of this project was to identify generally short sections of high-profile roadways with TxDOT and then design and construct experimental sections with a focus on using foamed asphalt or emulsion. After constructing and monitoring the performance of these sections, Texas A&M Transportation Institute (TTI) researchers developed guidelines for using the foamed asphalt and emulsion technologies in maintenance operations, with the end goal of expanding TxDOT's toolkit of potential methods to address distressed pavements in a maintenance setting.

METHODS

To accomplish the objectives, researchers gathered information on the current state of the practice and emerging FDR technologies. They secured resources suitable for placing test sections and worked with TxDOT districts to identify and place 12 test sections. They monitored the test sections, gathered stakeholder feedback, and used the results to develop guidelines and workflow forms suitable to assist stakeholders in successfully developing and delivering a project in the maintenance setting.

STATE OF THE PRACTICE

Recent work with FDR indicates that the following eight processes should be followed to maximize potential for project success:

1. Assemble background information—including historic plans, maintenance history, and soils maps.
2. Perform non-destructive testing (NDT)—including ground-penetrating radar, falling weight deflectometer (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 different potential stabilization strategies and stabilizer rates.
5. Perform pavement thickness design—including flexible pavement system (FPS) design and Texas 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—including pulverization level, moisture content, uniform application of proper amount of stabilizer, density attainment, and surface finish.
8. Conduct performance review—including feedback from stakeholders as well as assessment of structural condition through time.

TxDOT Experience with FDR

TTI researchers dialogued with TxDOT staff from multiple energy-sector impacted districts to obtain feedback on FDR approaches and issues associated with early traffic. TTI received feedback from the Bryan, Corpus, Odessa, and San Antonio Districts. Within these districts, the most common FDR approach used cement treatment. Concerns noted with this treatment were:

- Ability to uniformly distribute stabilizer.
- Loss of surface finish under early traffic.
- Treated layer cracking under super heavy loads.
- Performance problems with high truck traffic when final surface is a surface treatment.

One key observation in recent work is consistency with which FDR projects exhibit surface bonding problems. A need exists to determine best practices for stabilization of the entire pavement width and proper bonding of the surface.

Another issue is ride quality, particularly on roadways where a seal coat provides the final surface; many completed FDR projects exhibit poor ride. Discussion is needed on whether ride requirements should be included in FDR projects. If ride requirements are included, the specification approach and test timing will need to be developed.

Recommendations from Trade Groups

Both the Asphalt Recycling and Reclaiming Association (ARRA) and the Asphalt Academy publish excellent resources for pavement recycling. Guidelines available from ARRA and in its *Basic Asphalt Recycling Manual* provide valuable resources for project investigation, mixture design, construction guidelines, and quality control. Similarly, the Asphalt Academy's *Technical Guideline: Bitumen Stabilised Materials* provides a comprehensive approach to mixture design, structural design, construction processes, and quality control.

Common recommendations from these trade groups include:

- The FDR process must include material characterization and mixture design.
- The FDR process must include pavement design.
- The FDR process must include proper construction processes and quality control.

These recommendations align well with the eight processes noted previously for successful FDR.

Industry Equipment

The currently available pavement recyclers are from Bomag, Caterpillar, Roadtec and Wirtgen. The Bomag and Wirtgen products can perform asphalt (foam or emulsion) stabilization, along with more traditional lime, cement, or fly ash stabilization. Caterpillar and Roadtec recyclers do not appear to be available with foamed asphalt injection systems.

The Wirtgen equipment offers the most comprehensive available feature set among the reviewed equipment. Of the field equipment manufacturers, they are the only manufacturer to also offer complimentary lab equipment for mixture designs and publish their own cold recycling manual.

Recommended Next-Generation Field and Supporting Lab Equipment

Based on the full feature set and tie-in between field equipment and supporting laboratory testing capabilities, Figure 3 shows the recommended field and supporting lab equipment for developing and placing test sections in this project.

Figure 3. Recommended Field and Supporting Lab Equipment.

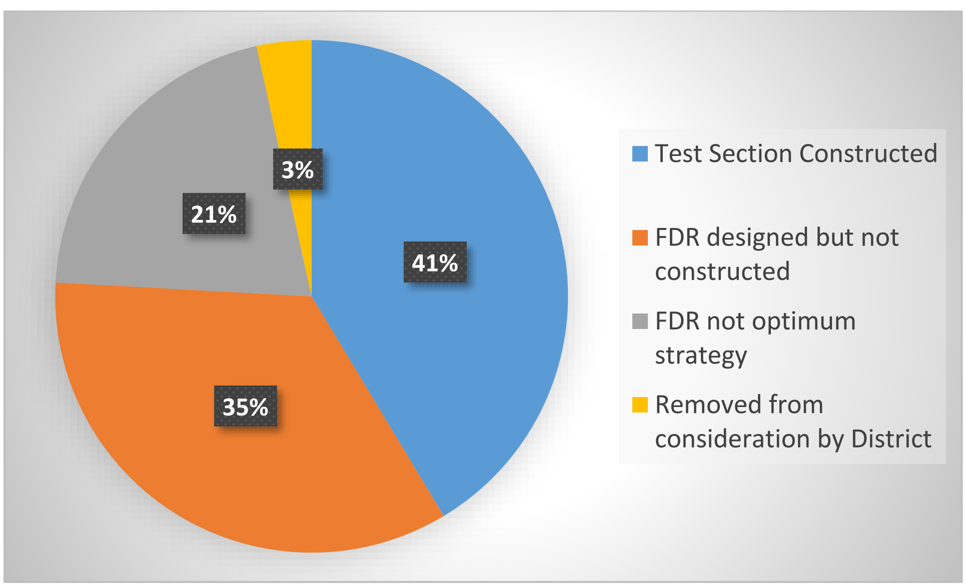
CHAPTER 2. PLACEMENT OF TEST SECTIONS

OVERVIEW

TTI researchers worked with 14 TxDOT districts, which nominated 29 pavement sections totaling almost 160 centerline miles, to evaluate, design, and construct test sections. Researchers performed non-destructive evaluation of the existing sections, selected representative locations, sampled materials, and worked with the participating districts to develop FDR mixture and pavement designs. If analysis showed the pavement section was not a good candidate for FDR, researchers provided other options for the district's consideration.

RESULTS

Figure 4 summarizes the outcomes of test section development. In total, 10 districts placed test sections across 12 different pavements. The remainder of the nominated sections were either good candidates for FDR but not constructed for various reasons or sections where FDR did not provide the optimum rehabilitation strategy; in on case a section was removed from consideration by the district after initial collection of NDT. Figure 4 illustrates that FDR with asphalt-based treatments could provide a viable pavement rehabilitation solution for about 75 percent of nominated candidates. Given the cost and effort to set up and deliver a project, it is critical to properly conduct the upfront testing to eliminate the projects that are not good candidates.



Note: Total number of sections = 29.

Figure 4. Key Outcomes from FDR Section Development.

Table 1 summarizes the test sections placed, which totaled about 39 lane-miles. While this research project focused primarily on asphalt-based treatments, in some cases, other treatments were also included for evaluation purposes.

Table 1. Constructed Test Sections.

District	Roadway	Placement Date	Treatment	Location
SAT	FM 99	April–August 2016	Lime pretreat (2.5%) + 2.5% foamed asphalt	McMullen/Live Oak CL to 4.15 mi south
		June 2016	Lime pretreat (2.5%) + 4% emulsion*	
LBB	IH 27 FR	August 2016	Lime pretreat (4%) + 2.4% foamed asphalt	Swisher Co. between 6th St and SH 86
	FM 2150	August 2016	1.5% cement + 2.4% foamed asphalt	Lubbock Co. TRM 311.19 to 308, WB only
			Added 25% RAP + 2.5% cement + 2.4% foamed asphalt	
AUS	Spur 619	March 2017	1.5% cement	Williamson Co. FM 619 to CR 304
			1.5% cement + 2.4% foamed asphalt	
BWD	SH 6	August 2017	1.5% cement	Eastland Co. TRM 370 – 0.23 to 370 – 0.64
			1.5% cement + 2.4% foamed asphalt	
BMT	SH 62	May 2018	1% cement + 2.5% foamed asphalt	Jasper Co. CR 812 to CR 813
SJT	US 83	March 2019	1% cement + 4.8% emulsion	Menard/Concho CL to 10.7 mi south—actual repair locations field located
			10% added LRA; 1% cement + 4.8% emulsion	
			4.8% emulsion	
ODA	SH 176	April 2019	1% cement + 3.2% foamed asphalt	Andrews Co. TRM 232 – 0.66 to 232 – 0.16 EBOL & SHLDR
BRY	FM 2159	July 2019	1% cement + 4.5% emulsion	Robertson Co. TRM 380 + 0.98 to Old Hwy
PAR	FM 1335	July 2019	1% cement + 4% emulsion	Delta Co. SH 24 to FM 198
AUS	US 281	August 2019	1% cement + 2.4% foamed asphalt	Blanco Co. TRM 482 + 0.98 to 486 + 0.26
TYL	FM 3080	October 2019	3% lime pretreatment + 4.5% emulsion	SH 198 to CR 2813

***Section treated with cement after lime and emulsion operations due to field curing concerns.**
Note: CL = county line; RAP = reclaimed asphalt pavement; LRA = limestone rock asphalt.

General Placement Process

Researchers coordinated with TxDOT to use the following general sequence:

- The additive, generally cement, was spread on top of the existing pavement.
- The pavement reclaimer pushed an asphalt transport and pulled a compaction water transport.
- The reclaimer pulverized the pavement material, injected the foamed asphalt or asphalt emulsion, and injected the required amount of compaction water in one pass to the required depth.
- A padfoot roller served as the primary compaction mechanism.
- Finishing took place with a blade, pneumatic and flat wheel roller, and sprinkling.
- A light fog was generally applied at the end of each day.
- Traffic was generally allowed on the roadway at the end of each day's construction.

During test section placement, researchers worked with TxDOT districts to provide equipment and process startup support including performing essential equipment operations (Figure 5[a]); setting a processing speed to attain proper pulverization (Figure 5[b]); and sequencing the FDR process including treatment, proper compaction, and finishing (Figure 6). For short test sections requiring only a few days of production, researchers stayed on site throughout the duration of treatment. For longer test sections, after training TxDOT staff, researchers provided remote support as needed.

(a) Equipment operations (b) Setting processing speed

Figure 5. Equipment Operation and Processing Startup Support.

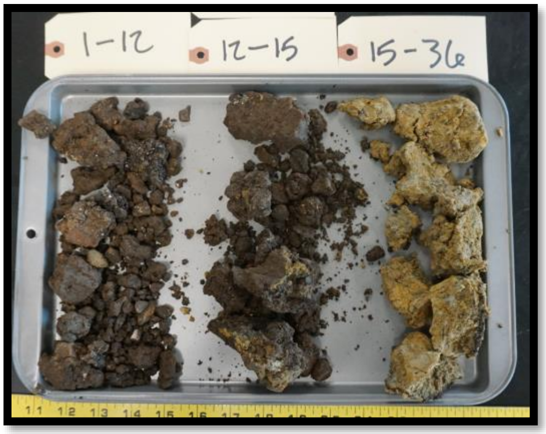
Figure 6. FDR Sequencing.

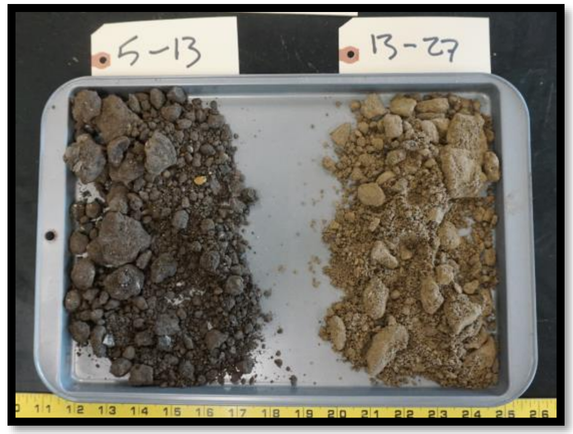
Special Considerations for Marginal Materials

During the evaluation of test sections, researchers encountered marginal materials on a few projects. Table 1 showed that the test sections in the San Antonio, Lubbock, and Tyler Districts used lime as an additive, rather than the more typically used cement. The reason for using lime was due to the poor quality of the salvage site materials. For example, Figure 7 shows the FM 3080 site, which had a variable structure and a salvage base plasticity index (PI) up to 20. Based on the existing marginal materials, researchers explored treatment options including lime, lime plus cement, lime plus emulsion, and lime plus foamed asphalt. In the case of FM 3080, the district chose to proceed with a lime pretreatment followed by emulsion treatment using the following sequence:

- Add 3 inches of RAP from stockpile.
- Pretreat 8 inches with 3 percent lime.
- Perform FDR of 8 inches with 4 percent emulsion.

Due to marginal quality of existing site materials, FM 99 in the San Antonio District and the IH 27 frontage road (FR) in the Lubbock District also used a lime pretreatment. Using the lime pretreatment provided a means of dropping the PI of the existing material, thus making the site material more compatible with asphalt treatments. Increasing the RAP percentage, such as occurred on FM 3080 and on a section of FM 2150, also generally makes materials more compatible with asphalt-based treatments.





Base PI = 20; clay subgrade   Base PI = 11; sandy subgrade

Figure 7. Example Materials That Used Lime Pretreatment.

CONSIDERATIONS FOR PLACEMENT PROCESS IMPROVEMENTS

Based on observations and experiences with planning, developing, and placing test sections, researchers noted the following items that may require special attention:

- Procurement of oil can prove difficult. Districts interested in the asphalt-based FDR tools need mechanisms in place to order and procure materials in a timely manner. Districts often reported 4 to 6 months lead time required to procure oil.
- The pintle hitch requirements of the oil transports need to be communicated clearly to the material suppliers in advance. Occasionally, suppliers do not have and do not want to equip their trucks with these hitches.
- For foamed asphalt, the binder must be sampled and tested in advance to make sure it meets the expansion ratio and half-life. This requirement, and the target delivery temperature requirement, need to be clearly communicated to the supplier in advance.
- Particular attention should be paid to the moisture content of the existing material prior to treatment, particularly when daily trafficking is required. The layer could become unstable if it is too wet after treatment. Generally, foamed asphalt should not be added if the material is greater than optimum, and emulsion should not be added if the material is greater than 70 percent of optimum.
- Treatment, compaction, and finishing need to all take place the same day.
- For processing, a cut plan should be developed, and cut lines should be used to ensure proper location of the treatment overlap. A minimum 6-inch overlap is recommended. Not using a cut plan and not having good cut lines to follow increases the risk of leaving longitudinal streaks of untreated material.
- Additive, if applicable, should be spread all the way to the cut lines or the full planned treatment width of the cut plan. Reclaimers mix linearly and provide very little cross blending.

- Multiple rollers may be used for compaction; however, care must still be exercised to apply the proper rolling pattern. The material should be compacted in one lift.
- The compacted material should not be overworked with the blade and will generally not have as smooth a surface as sometimes associated with flexible base.
- Fines cannot be used to fill pad dimples or irregularities. Particularly if the final surface will be a seal coat, blading and finishing operations need to remove the pad marks.
- The FDR layer is not intended to be an unsurfaced road. A light fog seal should be applied daily, particularly if daily trafficking is required. Figure 8 shows a treated, finished section after applying the fog seal. A seal coat or next course should be applied within 14 calendar days of compaction. Ideally, a seal should be placed at the end of each week of FDR treatment. The duration of acceptable time to run traffic without a seal coat in part depends on traffic counts.

Figure 8. Treated, Finished Section after Fog Seal.

CHAPTER 3. PERFORMANCE MONITORING OF TEST SECTIONS

OVERVIEW

The research team visited the test section sites and conducted performance evaluations on each site. Over time, researchers collected visual condition and FWD data to evaluate the performance of each of the 12 test sections constructed in this project. The primary goals of this performance monitoring included exploring these topics:

- Was the pavement design assumption met?
- Was stabilization effective?
- What types of distresses are present? What may have caused the distresses?
- How does the observed performance impact best practices for how future projects should be selected, designed, and constructed?

PERFORMANCE MONITORING METHODS

Researchers visited each test section over time, visually examining the pavement condition and documenting distresses. They also used NDT, primarily the FWD, to quantify the pavement's structural response. In some cases, researchers collected cores as a means of ground-truthing the condition of the treated layer. Figure 9 shows the typical FWD collection in progress and a core collected from one of the test sections.

Figure 9. FWD Collection and Core from FDR Layer.

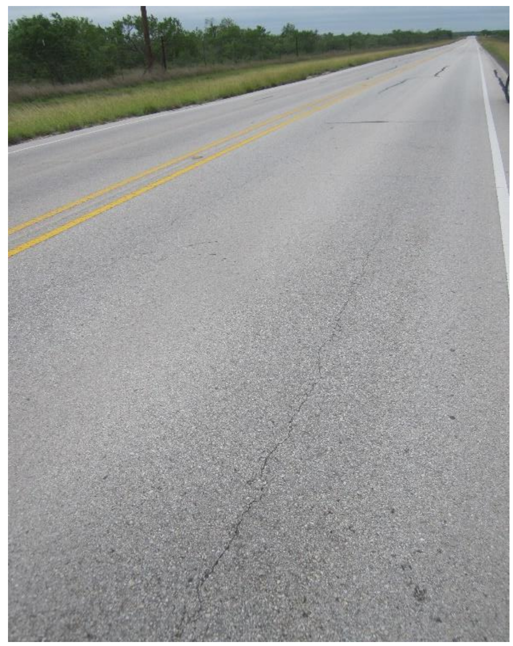
To evaluate whether the pavement design assumptions were met, researchers used Modulus 7.0 to analyze the FWD data and determine if the design modulus and deflection criteria were met. To quantify whether stabilization was effective, researchers used a threshold of 125 ksi, where any FWD backcalculation of the FDR layer modulus below 125 ksi was classified as not effectively stabilized. Finally, researchers analyzed overall pavement performance in the context of site conditions and design assumptions to develop conclusions and lessons learned from the field performance.

RESULTS FROM TEST SECTIONS

Figure 10 through Figure 23 present a summary of the results from each test section.

Section	**FM 99 (SAT)**
Constructed	April–May 2016
Pavement Structure	1.5" HMA + 10" foamed asphalt
Treatment	2.5% lime pretreat (slurry) + 2.5% foamed asphalt

Dec. 2015 before FDR



May 2021 after FDR

Summary of Structural Analysis	**Aug. 2016**	**Dec. 2016**	**May 2018**	**May 2021**
AVG normalized deflection (mils)	9.6	7.1	9.8	9.7
AVG FDR layer modulus (ksi)	520	938	626	547
Percent of section with effective stabilization	96	100	98	91
AVG subgrade modulus (ksi)	19.9	20.8	17.4	16.6

Note: 1.5" HMA overlay placed between Aug. and Dec. 2016

Comments

This section shows some shrinkage cracking, some longitudinal cracking, and some localized fatigue cracking. Transverse and block cracking is likely due to shrinkage from the lime reaction over time. Some longitudinal cracking is not in the wheel path and thus likely not load associated. Some longitudinal cracking is in the wheel path and thus likely load related. At some locations, wheel path cracking also has 1/8 to 1/2" rut depth. Especially near the county line, localized significant distress has recurred.

Lessons Learned

The lime pretreatment allowed attainment of a mix design with poor site materials.

Figure 10. FM 99 (Foamed Asphalt) Summary.

Section	FM 99 (SAT)
Constructed	April–May 2016
Pavement Structure	1.5" HMA + 10" emulsion
Treatment	2.5% lime pretreat (slurry) + 4% emulsion + cement

May 2021 after FDR

Summary of Structural Analysis	Aug. 2016	Dec. 2016	May 2018
AVG normalized deflection (mils)	28.1	13.9	23
AVG FDR layer modulus (ksi)	103	325	163
Percent of section with effective stabilization	23	71	43
AVG subgrade modulus (ksi)	10.8	16	11.8

Note: 1.5" HMA overlay placed between Aug. and Dec. 2016

Comments

The emulsion section is only in the southbound direction from 1.17 to 2.2 mi south of the county line. During construction, TxDOT elected to mix in cement a few days after mixing emulsion. This section shows some localized longitudunal and fatigue cracking. Some longitudinal cracking is not in the wheel path and likely not load related. Some cracking is in the wheel path, which is likely load related; some wheel path cracking also exhibits rutting. The FDR layer modulus does not appear stable over time. This section also seems to have poorer subgrade compared to the entire project extents.

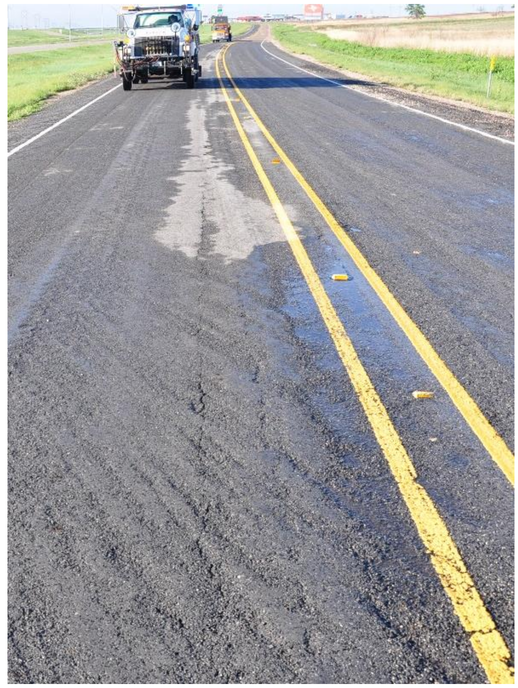
Lessons Learned

The emulsion treatment was mixed with site material already exceeding optimum moisture content. This urgency for productivity conflicted with best practices and likely contributed to the high deflections and slow rate of gain in modulus of the FDR layer.

Figure 11. FM 99 (Emulsion) Summary.

Section	**IH 27 FR (LBB)**
Constructed	August 2016
Pavement Structure	Sealcoat + 8" foamed asphalt
Treatment	4% lime pretreat (slurry) + 3% foamed asphalt

May 2016 before FDR



June 2021 after FDR

Summary of Structural Analysis	**Aug. 2016**	**Jan. 2017**	**March 2018**	**June 2021**
AVG normalized deflection (mils)	18.9	11.4	9.2	9.8
AVG FDR layer modulus (ksi)	127	397	699	846
Percent of section with effective stabilization	44	97	94	97
AVG subgrade modulus (ksi)	18.4	20.9	21.3	19.5

Comments

The seal coat peeled and extensive raveling occurred in the first year, particularly in the southbound direction. A forensice investigation revealed the treated material was solid but raveled severely with the loss of the surface treatment protection. Blade on material was used to address the raveling. Transverse, relatively evenly spaced cracking exists, along with block cracking. Combined with increasing base modulus over time, this observation suggests long-term pozzolanic reactions are dominant in this section. Longitudinal cracking is also present in some locations.

Lessons Learned

The lime rate was too high, overshadowing the influence of the asphalt and producing distress mechanisms of a cemetitious treated material. Mix designs need to make sure the additive does not become the primary stabilizing agent. If the seal coat peels, action needs to be taken to protect the surface.

Figure 12. IH 27 FR Summary.

Section	**FM 2150 (LBB)—0.85 to 2.4 mi W of RM 312**
Constructed	August 2016
Pavement Structure	Sealcoat + 8" foamed asphalt
Treatment	1.5% cement + 2.4% foamed asphalt

December 2015 before FDR

June 2021 after FDR

Summary of Structural Analysis	**Aug. 2016**	**Jan. 2017**	**March 2018**	**June 2021**
AVG normalized deflection (mils)	17.0	18.0	20.7	24.2
AVG FDR layer modulus (ksi)	116	254	259	161.8
Percent of section with effective stabilization	19	58	50	41
AVG subgrade modulus (ksi)	10.2	12.5	11.0	13.5

Comments

This project was segmented due to different materials and lab results obtained during the planning stage. This section treated 100% in-situ materials. Some edge failures exist, along with some locations of fatigue and block cracking in the inside wheel path. The structural analysis data suggest that effective stabilization throughout the section was never fully achieved. The structural data also suggest that somewhere between about 2 and 5 years in service, the structural capacity of the base layer may have started to decline. This observation and the most recent (June 2021) results may in part be influenced by potential impacts of the 2021 winter storm on the pavement.

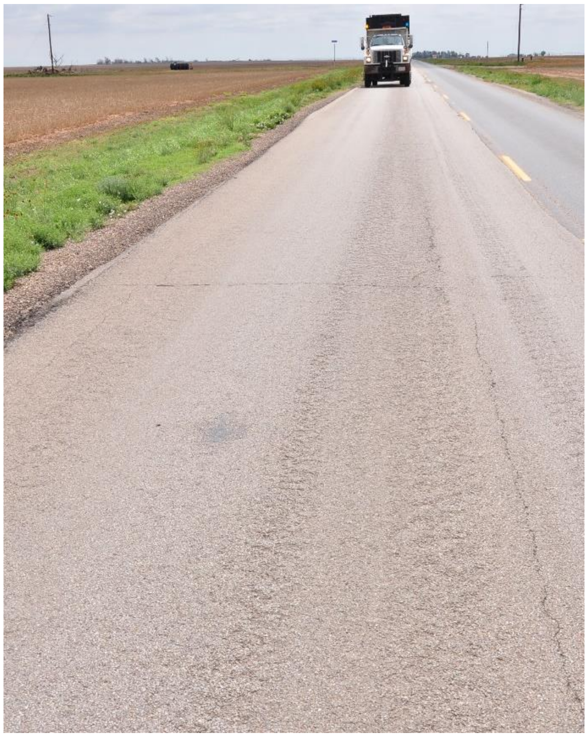
Lessons Learned

This material exhibited a very high dry strength in the lab, but only 28% retained strength. Treating only a half section of the road may partially have contributed to the distresses observed in the inside wheel path. This pavement serves the outbound loads from an aggregate pit; if at all possible, establishing more pavement width could help reduce the risk of edge failures.

Figure 13. FM 2150 Section 1 Summary.

Section	FM 2150 (LBB)—2.4 mi W of RM 312 to RM 308
Constructed	August 2016
Pavement Structure	Sealcoat + 8" foamed asphalt
Treatment	Add 2" RAP + 2.5% cement + 2.4% foamed asphalt

August 2016 before FDR



June 2021 after FDR

Summary of Structural Analysis	Aug. 2016	Jan. 2017	March 2018	June 2021
AVG normalized deflection (mils)	22.2	12.7	16.1	18.8
AVG FDR layer modulus (ksi)	94	512	440	420
Percent of section with effective stabilization	12	94	90	68
AVG subgrade modulus (ksi)	15.8	13.8	11.2	10.8

Comments

This section added 2" RAP prior to treatment and used a higher cement content due to low moisture-conditioned strengths observed in the lab when only treating existing site materials. This section clearly shows failure mechanisms of a cement-treated base, indicating the higher cement content largely overshadowed the asphalt treatment, with block cracking, some raveling of material in locations at the intersection of the transverse and longitudinal cracks, and localized areas of tightly spaced block cracks in the wheel path.

Lessons Learned

With dual stabilizer applications, when increasing the cement rates, evaluation should be made as to whether the asphalt treatment is worth the time, effort, and additional cost. While it is unknown what would be the condition of this section if only treated with cement, the site condition indicates essentially that a cement-treated base was constructed.

Figure 14. FM 2150 Section 2 Summary.

Section	Spur 619 (AUS)
Constructed	March 2017
Pavement Structure	Sealcoat + 8.5" foamed asphalt
Treatment	1.5% cement + 2.4% foamed asphalt

November 2016 before FDR

December 2020 after FDR

Summary of Structural Analysis	May 2017	May 2018	Dec. 2020
AVG normalized deflection (mils)	18.4	21.3	17.4
AVG FDR layer modulus (ksi)	324	288	294
Percent of section with effective stabilization	92	79	68
AVG subgrade modulus (ksi)	11.5	11.2	14.2

Comments

This section was constructed largely for the district to gain experience with new technologies in a low-risk environment. The existing pavement had significant edge and longitudinal cracking in localized areas, which has recurred over time. The photos show some of the poorest condition locations from the project extents. Some of the cracks have faulted. Localized rutting also exists, generally 1/4–3/4". This pavement does not meet Texas triaxial thickness requirements, which at least partially contributes to the observed rutting. While the average FDR layer modulus is relatively stable, the variability is increasing, as evidenced from the decline over time in percent of section with effective stabilization.

Lessons Learned

In the context of gaining experience in a low-risk setting, this project was a success. In the context of addressing the pavement distress, this project demonstrated that for pavements with edge or longitudinal cracking due to poor subgrades as the primary distress, FDR can improve conditions temporarily but is not addressing the real root cause, and caution and clear expections up front should be set during future project selections.

Figure 15. Spur 619 Summary.

Section	SH 6 (BWD)
Constructed	August 2017
Pavement Structure	Sealcoat + 12" foamed asphalt
Treatment	1.5% cement + 2.4% foamed asphalt

May 2017 before FDR

Nov. 2020 after FDR

Summary of Structural Analysis	Oct. 2017	March 2018	Nov. 2020
AVG normalized deflection (mils)	5.0	4.7	5.5
AVG FDR layer modulus (ksi)	1199	1103	1355
Percent of section with effective stabilization	100	100	100
AVG subgrade modulus (ksi)	25.3	25.8	24.4

Comments

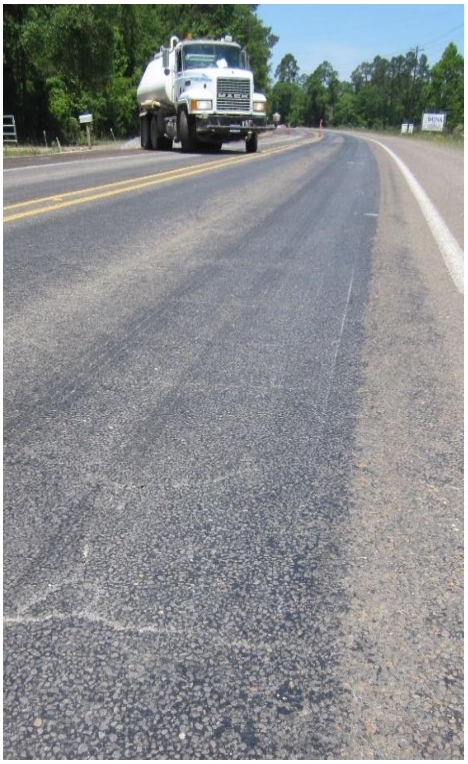
Prior to FDR, this section showed areas of severe rutting and significant fatigue cracking. After FDR, some shrinkage occurred, likely due to the cement rate. Some edge and longitudinal cracking also developed over time. A forensic analyis revealed these longitudinal cracks generally were not in the wheel paths and coincided with localized areas of low (~ 7–10 ksi) subgrade modulus, meaning the cracks are likely subgrade induced. A short 300' section at the north end was mixed with only cement, and shrinkage cracking was more prevalent in that section. Two short locations of failures (fatigue cracking and rutting) exist, one of which may coincide with transition from foam to cement treatment.

Lessons Learned

The foamed asphalt treatment provided a high modulus base with less shrinkage cracking compared to only mixing cement. The very high modulus of the base on this project means future efforts should analyze mixture design methods and develop techniques to optimize the mixture design for materials and site conditions. This mix, if anything, is probably overstabilized.

Figure 16. SH 6 Summary.

Section	**SH 62 (BMT)**
Constructed	May 2018
Pavement Structure	2.5" surface (underseal + HMA) + 7.5" foamed asphalt
Treatment	Add 2" RAP + 1% cement + 2.5% foamed asphalt



May 2018 before FDR

March 2021 after FDR

Summary of Structural Analysis	**Jan. 2019**	**March 2021**
AVG normalized deflection (mils)	8.4	11.3
AVG FDR layer modulus (ksi)	768	532
Percent of section with effective stabilization	100	96
AVG subgrade modulus (ksi)	14.4	15.6

Comments

This sectioned addressed localized distresses prior to placement of a seal and new overlay. Cement and RAP mixed in advance were placed on the roadway prior to FDR to provide more thickness of better material. Following FDR, some transverse cracks and longitudinal cracks were observed in the hot mix. The longitudinal cracks do potentially appear load related based on proximity to wheel path. Given the FWD results, properties of the hot mix may be a more likely contributor rather than potential lack of support from the base.

Lessons Learned

This project demonstrated a great leveraging of state capabilities to address a short trouble section prior to placing a new pavement course.

Figure 17. SH 62 Summary.

Section	**US 83 (SJT)**
Constructed	March 2019
Pavement Structure	A-R seal + seal coat + 10" emulsion treatment
Treatment	1% cement + 4.8% emulsion

Before FDR (photo courtesy TxDOT)

May 2021 after FDR

Summary of Structural Analysis	**April 2019**		**May 2021**	
	P5_SB	**P6_NB**	**P5_SB**	**P6_NB**
AVG normalized deflection (mils)	23.2	15.4	17.5	13.5
AVG FDR layer modulus (ksi)	101	230	148	234
Percent of section with effective stabilization	29	68	45	70
AVG subgrade modulus (ksi)	12.2	13.6	15.0	16.4

Comments

This section consisted of multiple locations in passing lanes to restore failures in a Super 2 widening prior to placement of a full-width asphalt rubber seal. Results show for passing lane 5 (P5), which was poorer material, less desireable structural results compared to passing lane 6 (P6), which had better material. P5 materials did not meet lab requirements during testing, and the structural results show the field also did not meet general design assumptions. Thus far, the sections are holding up well to intense traffic, with some locations of depressions visible at the inside ~ 6" of the FDR cut. Given the very poor prior condition, and the fact that the materials treated had already been treated with cement at least once and rapidly failed, results thus far are positive from this section.

Lessons Learned

This section represented another excellent leveraging of state resources to prep specific sections of a larger corridor for future contract work. The nature of the original failures suggests future projects should try to avoid non-uniform widening. The viability of treating materials that have already been reworked multiple times also potentially expands the scope of the asphalt-based FDR toolkit.

Figure 18. US 83 Summary.

Section	**SH 176 (ODA)**
Constructed	April 2019
Pavement Structure	2CST + 10" foamed asphalt + 8" granular subbase
Treatment	1% cement + 3.2% foamed asphalt

April 2019 before FDR

May 2021 after FDR

Summary of Structural Analysis	**May 2019**	**May 2021**
AVG normalized deflection (mils)	6.8	5.6
AVG FDR layer modulus (ksi)	341	449
Percent of section with effective stabilization	96	100
AVG subgrade modulus (ksi)	39	48

Comments

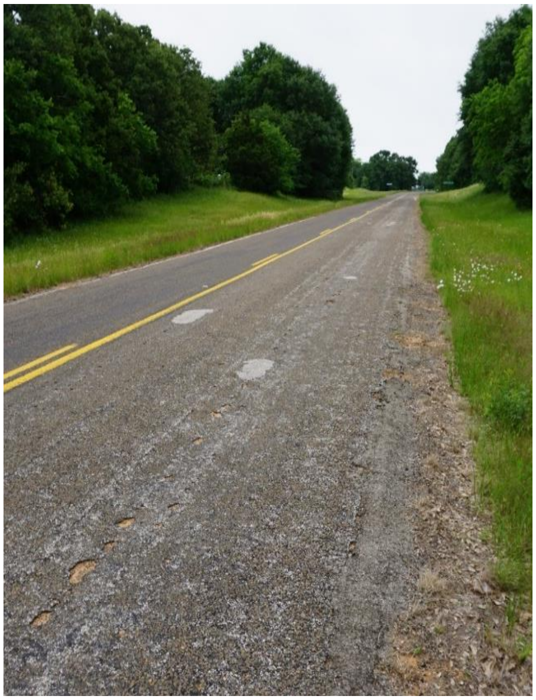
This pavement failed prematurely after a construction project due to a low-strength, moisture-susceptible flex base. The short foamed asphalt test section served as a demonstration of one potential strategy to rapidly strengthen the pavement and place energy-sector traffic on the road the same day. There is some localized rutting, ~ 1/4", and at the time of the May 2021 survey, focused FWD drops where this distress was observed did not reveal any unusual or concerning base, subbase, or subgrade modulus values.

Lessons Learned

Construction projects should use extreme caution when using Item 247 Grade 4 with no strength requirements. Foamed asphalt provides a viable option for a long-term solution to strengthen this pavement. The material from this project did not exeed the 120 psi unconfined compressive strength, yet thus far, field performance has raised no concerns. Review of requirements for FDR mix design may be a topic to consider in the future. For in-house operations, the district reported this 1/2 mi long, 20' wide section cost $168,000, which puts a strain on the district's ability to fund these type of activities.

Figure 19. SH 176 Summary.

Section	FM 2159 (BRY)
Constructed	July 2019
Pavement Structure	Seal coat + 8" emulsion treatment
Treatment	Add 4" RAP + 1% cement + 4.5% emulsion



Before FDR (photo courtesy TxDOT-BRY)

Dec. 2020 after FDR

Summary of Structural Analysis	Sept. 2019	May 2021
AVG normalized deflection (mils)	10.6	7.4
AVG FDR layer modulus (ksi)	606	936
Percent of section with effective stabilization	97	100
AVG subgrade modulus (ksi)	21.4	26.0

Comments

Adding the RAP prior to treating allowed for working with marginal site materials from a thin existing pavement. Some loclized transverse and longitudinal cracks were noted; however, the overall results thus far are very good, and the structural data suggest the FDR layer is very stiff, well exceeding the typical design assumption value.

Lessons Learned

Adding the RAP prior to treating significantly increased the workload and time required to deliver the project. Regardless, the results thus far are promising, and the strategy demonstrated that road-mixed FDR treatments with asphalt can be viable even in situations with poor materials and thin pavements. It is imperative that upfront analysis and design work take place to first develop a viable strategy.

Figure 20. FM 2159 Summary.

Section	FM 1335 (PAR)
Constructed	July 2019
Pavement Structure	Seal coat + 10" emulsion treatment
Treatment	Add 2" new base + 1% cement + 4% emulsion

June 2018 before FDR

June 2021 after FDR

Summary of Structural Analysis	Sept. 2019	May 2021
AVG normalized deflection (mils)	19.0	18.8
AVG FDR layer modulus (ksi)	324	307
Percent of section with effective stabilization	79	74
AVG subgrade modulus (ksi)	11.1	12.2

Comments

This section serves a cotton gin and, prior to FDR, showed significant cracking and rutting. The FDR strategy did thicken the total pavement structure, although due to constraints, it still did not meet Texas triaxial required thickness for the poor subgrade. While some rutting, typically 1/4–1/2" has occurred, edge cracking thus far has not recurred, and in the context of the industry traffic and design decisions made, this section has shown good performance to date.

Lessons Learned

The existing material moisture content was such that either aeration may have been required or construction delayed. It was decided to monitor moisture and delay construction. Particularly in wetter and more humid portions of the state, special care must be taken to not mix emulsion if materials are too wet, especially if same-day industry traffic is required.

Figure 21. FM 1335 Summary.

Section	US 281 (AUS)
Constructed	July–August 2019
Pavement Structure	4" HMA + 8" foamed asphalt
Treatment	1% cement + 2.4% foamed asphalt

May 2019 before FDR

February 2021 after FDR

Summary of Structural Analysis	Feb. 2021
AVG normalized deflection (mils)	7.1
AVG FDR layer modulus (ksi)	319
Percent of section with effective stabilization	44
AVG subgrade modulus (ksi)	41

Comments

This section showed significant cracking and rutting prior to FDR; localized partial-depth patches had been tried with limited success. After treatment, while the average FDR layer modulus was good, the variability was extremely high, with a coefficient of variation of over 100%. The low percentage measured with effective stabilization reflects this variability but also reflects complications processing the FWD data due to shallow depth to bedrock. In this situation, the normalized deflection is likely a better indicator of overall effectivenss of the pavement rehabilation. The FWD data show that 87% of the project extents do not exceed the 10.4 mil anticipated deflection from design assumptions.

Lessons Learned

Especially with high ADT, the daily fog needs application prior to opening to traffic. Trying to work the treated material in lifts was not very successful, and mostly resulted in additional time and effort on the roadway. In this high traffic environment, production was capped at one oil transport per day.

Figure 22. US 281 Summary.

Section	FM 3080 (TYL)
Constructed	July 2019
Pavement Structure	1.5-2" HMA + 8" emulsion
Treatment	Add 3" RAP, pretreat 8" with 3% lime, mix 4% emulsion

April 2019 before FDR

June 2021 after FDR

Summary of Structural Analysis	Dec. 2019	June 2021
AVG normalized deflection (mils)	19.0	17.1
AVG FDR layer modulus (ksi)	273	403
Percent of section with effective stabilization	87	80
AVG subgrade modulus (ksi)	13.2	13.7

Comments

Compared to the 56 mil average deflection prior to construction, FDR offered dramatic improvement on this section. Following FDR, the seal coat did not bond well, and most of the section received an overlay. At the most recent site visit, some localized edge cracking was noted in low-lying areas, and there is evidence of some shrinkage cracking, likely due to ongoing reactions from the lime. The average FDR layer modulus is good, although the increase in the average modulus value over time coinciding with a decrease in the percent of effective stabilization suggests increasing variability of field conditions.

Lessons Learned

This project demonstrated how combining better materials, along with a lime pretreatment, made asphalt-based FDR viable with extremely marginal existing materials. The peformance of this section should continue to be monitored over time.

Figure 23. FM 3080 Summary.

EXAMPLE IMPACT OF TEST SECTIONS ON PAVEMENT SCORE

The test section on FM 99 in the San Antonio District represents the oldest and one of the longest test sections in this project. Figure 24 shows the overall condition score of the extents represented by the FM 99 test section, from several years prior to FDR to the present. The results clearly show poor condition prior to FDR, and to date, the results show the pavement condition remaining excellent over the 5 years since FDR. Evaluation of the underlying data in these scores shows that prior to FDR, low ride scores and rutting were the main drivers of the deteriorating condition scores. After FDR, the data show longitudinal cracking has occurred, but to date, rutting is minimal and ride scores are good.

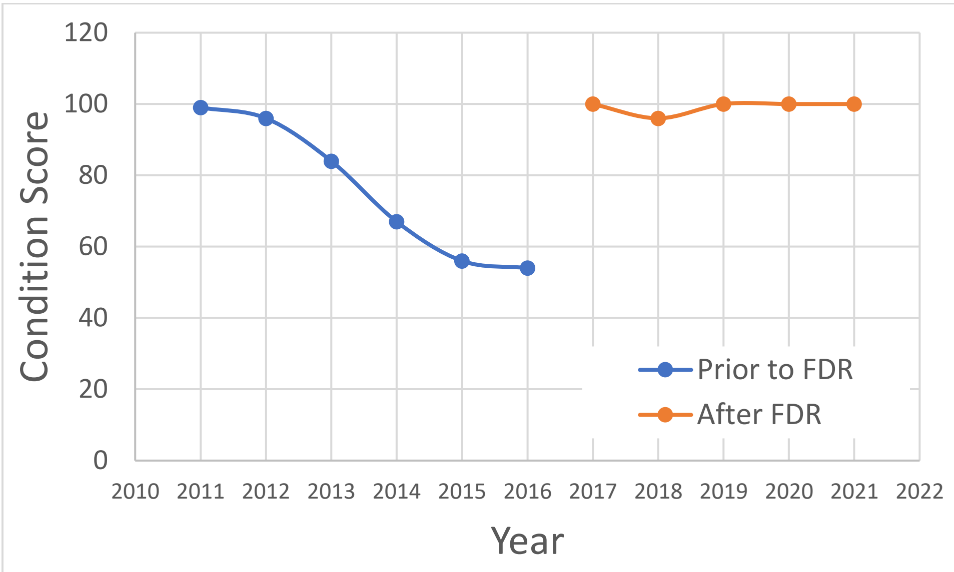


Figure 24. Pavement Condition over Time on FM 99 Test Section.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

OVERVIEW

FDR can provide a rapid way to rehabilitate a pavement in a cost-effective manner. This project involved the planning, design, and construction of 12 test sections using foamed asphalt or emulsion and evaluation of their performance over time. The results showed these treatments can offer a viable solution for rehabilitating pavements with significant cost savings and rapid project delivery time. The successes revealed in this project have several districts interested in placing additional sections, and during the performance of this research, TxDOT lettings using foamed asphalt and emulsion grew significantly. Oftentimes, after districts placed a test section and observed the performance, they began exploring constructing additional projects through lettings.

CONCLUSIONS AND RECOMMENDATIONS FOR DESIGN MODULUS

Figure 25 shows the results of the field FDR layer modulus for each section at the most recent performance monitoring time. The results show that, with two exceptions, the average FDR layer in service exceeded the 200 ksi design modulus. In fact, in some cases, the data suggest that materials may be over-stabilized. This topic of potential overstabilization and how to optimize the mixture design may be an area for future research.

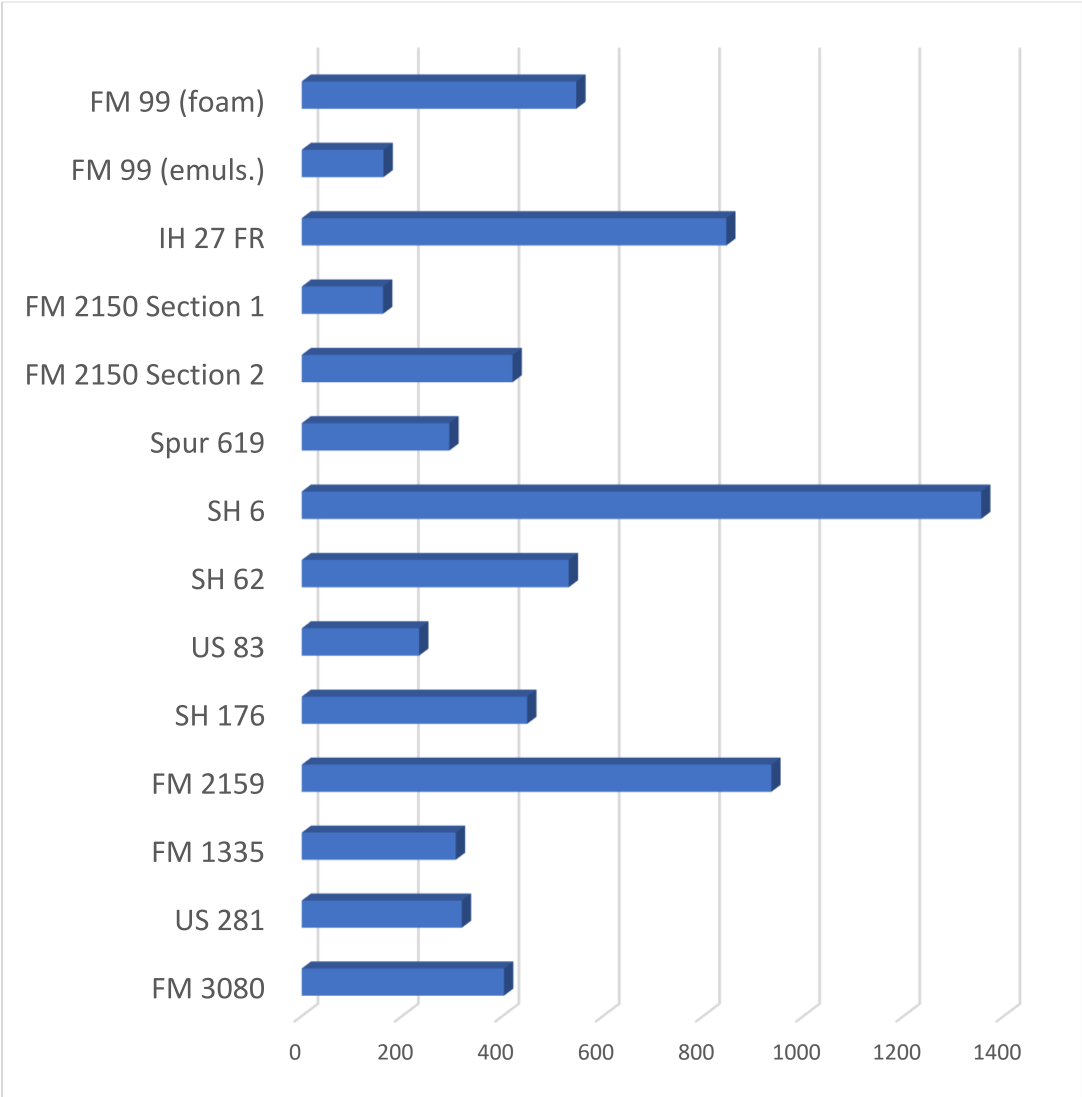


Figure 25. Summary Modulus of FDR Sections.

CONCLUSIONS AND RECOMMENDATIONS FOR PROCESS IMPROVEMENTS

To help move the proper use of these FDR tools forward, researchers gathered feedback from stakeholders on how to improve the FDR workflow. Figure 26 illustrates the main feedback from the TxDOT user groups. In general, participants provided positive feedback on the FDR process and speed of construction in placing test sections; several districts have since proceeded to let construction projects, and four districts specifically expressed interest in placing additional sections using TxDOT forces.

For areas of improvement, materials' cost and staff turnover/loss of expertise remain top concerns. Additionally, some districts expressed desire for a defined process to set up projects, or for turnkey assistance to analyze and help plan and develop a candidate section.

Figure 26. Summary of Stakeholder Feedback.

RECOMMENDED GUIDELINES FOR FUTURE PROJECTS

Based on the results from this project, FDR with foamed asphalt or emulsion can offer a viable solution to rehabilitate distressed pavements, and the 200 ksi FDR layer design assumption is reasonable based on the data. Particular care should be taken to properly develop and design sections, making sure the technology is compatible with actual site materials prior to proceeding to construction. Based on this project and input from stakeholders, approaches for using these asphalt-based FDR tools with maintenance resources may include the following:

- Place short evaluation sections for districts with limited experience with the technologies.
- Fix problematic excerpts of larger corridors that are otherwise in acceptable condition. This approach could particularly be valuable in seal coat prep or prep for other planned upcoming pavement preservation or preventive maintenance activities.

- Rehabilitate loops, spurs, or farm-to-market roads that are in poor condition and have low probability of warranting construction projects.

To help define the process and provide guidance to stakeholders, researchers recommend the following resources:

- Product 0-6880-P11, *Developing FDR Sections with In-House Resources*, available from TxDOT's Research and Technology Implementation (RTI), describes the steps necessary for properly developing an FDR candidate project.
- Product 0-6880-P13, *FDR Workflow Forms*, also available from TxDOT-RTI, provides a resource for a project lead to systematically implement and document the workflow for upfront testing, pavement and lab design, and construction planning.

Additionally, TxDOT's Maintenance Division has resources in place to assist interested districts in selecting, planning, and delivering projects using the foamed asphalt and emulsion-based FDR tools.