Texas A&M Transportation Institute

Implementation of Small Samples for Developing Full-Depth Recycling Mix Designs

Technical Report 5-6271-03-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

Oftentimes renewal of deteriorated pavements relies on stabilization to strengthen pavement materials. Typically, this process takes place with full depth recycling, where in-situ materials receive treatment and mixing with a stabilizing agent to result in a renewed and strengthened base or subbase material. A properly designed and constructed stabilized base or subbase mixture can significantly reduce the required total pavement thickness to meet pavement design requirements. Traditionally, these stabilized mixtures are designed in the lab based on unconfined compressive strength. However, given typical field material variability, different potential stabilizers, and different treatment levels, the lab mix design historically requires significant amounts of material and significant time to return results. This project focused on initial implementation of a small sample mix design approach using reduced sample sizes and indirect tensile strength. The small sample approach allows practitioners to screen multiple factors of material proportions and stabilizers all while requiring less material than traditional compressive strength methods. Additionally, the small sample approach can return test results in as little as 5 days.

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IMPLEMENTATION OF SMALL SAMPLES FOR DEVELOPING FULL-DEPTH RECYCLING MIX DESIGNS

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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. (Texas, #62683).

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CHAPTER 1: IDENTIFICATION AND SAMPLING OF PROJECTS

UPCOMING FDR PROJECTS

Working with the Texas Department of Transportation (TxDOT) Bryan District lead, the following construction projects were initially nominated by TxDOT staff for applying small sample size mixture design:

- FM 542 (Bryan District).
- FM 416 (Bryan District).
- US 59 (Yoakum District).
- IH 10 (Odessa District).
- FM 1375 (Bryan District).
- FM 831 (Bryan District).
- SH 115 (Odessa District).
- FM 99 (San Antonio District).

SAMPLES ON TXDOT PROJECTS

Working with the TxDOT Bryan District lead and CST, samples were received for the nominated construction projects. The samples received from these projects constituted products 5-6271-03-P1 and 5-6271-03-P2. Table 1 summarizes the general scope of each project including proposed stabilizers, the agency that performed the sampling, the time frame of sampling, the approximate quantity of sample obtained, and the location of the samples for testing.

Table 1. Details of Proposed Projects for Small Sample Mixture Design.

Project	District	Proposed Stabilizer(s)	Sampled by Agency	Sampled Date	~ Quantity Sampled	Location of Samples for Testing
FM 542	Bryan	Cement, Foamed Asphalt	TxDOT-Bryan	Sept 2014	400 lb	BRY, TTI
FM 416	Bryan	Cement	TxDOT-Bryan	Oct 2014	400 lb	BRY, TTI
US 59	Yoakum	Cement	TxDOT-Yoakum	Oct 2014	300 lb	CST, TTI
IH 10	Odessa	Asphalt Emulsion	TxDOT-Odessa	Sept 2014	800 lb	CST, TTI
FM 1375	Bryan	Cement	TxDOT-Bryan	Sept 2014	400 lb	BRY, TTI
FM 831	Bryan	Cement	TxDOT - Bryan	Oct 2014	400 lb	CST, TTI
SH 115	Odessa	Asphalt Emulsion	Industry	Dec 2015	600 lb	TTI
FM 99	San Antonio	Foamed Asphalt; Asphalt Emulsion	TTI	Dec 2015	400 lb	TTI

CHAPTER 2: TESTING RESULTS

DEMONSTRATION OF NEW TEST PROCEDURES

Working with the TxDOT Bryan District lead, TxDOT's Construction Division, TTI's materials laboratory, and industry, the following construction projects were evaluated with both large sample and small sample mixture design tests:

- YKM District: US 59.
- ODA District: IH 10, SH115.
- SAT District: FM99.
- BRY District: FM 1375, FM 831, FM 542, and FM 416.

Table 2 presents the treatments evaluated along with the maximum density and optimum moisture content determined from Tex-113-E for each project.

The remainder of this chapter presents:

- The individual small sample test results for each project.
- The large sample test results.
- The recommended stabilizer content based on large and small samples.
- A preliminary evaluation of the small sample molded dry density as compared to the reported Tex-113-E maximum dry density.

Table 2. Treatments and Moisture-Density Data for Projects.

District	Material	Treatments	Moisture Density Data	
			Max Density (pcf)	OMC (%)
BRY	FM 542	2% cement 3% cement 4% cement	132.1	6.5
BRY	FM 416	2% cement 3% cement 4% cement	131.2	8.7
YKM	US 59	1% cement 3% cement 5% cement	132.4	6.6
ODA	IH 10	1% Cement with 2.4% Res. from Emulsion 1% Cement with 2.8% Res. from Emulsion 1% Cement with 3.2% Res. from Emulsion	121.4	8
BRY	FM 1375	2% cement 3% cement 4% cement	126.7	6.1
BRY	FM 831 TY A GR 2	2% cement 3% cement 4% cement	134.3	7.1
BRY	FM 831 75% Salvage	2% cement 3% cement 4% cement	120.5	9
BRY	FM 831 Redo 75% Salvage	2% cement 3% cement 4% cement	120.5	9
ODA	SH115	3.0% Res. from Emulsion 3.3% Res. from Emulsion 3.6% Res. from Emulsion	121.0	11.6
SAT	FM99	2% Lime with 2.5% Foamed Asphalt 2% Lime with 2.5% Res. from Emulsion	121.3	9.1

INDIVIDUAL SMALL SAMPLE TEST RESULTS

FM 542

Table 3 presents the small sample results from FM 542. This was the first material investigated by the Bryan District using the small samples, and sufficient sample only existed for testing the material at one lab. For this reason, no statistical analysis is available with these data. The samples were molded at the BRY District lab and then tested at TTI's lab.

Table 3. Individual Test Results for FM 542 Small Samples.

FM 542					
Percent Cement	Condition	Indirect Tensile (IDT) Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	Wet	55.8	40.2	47.3	47.8
	Dry	32.4	32.6	25.7	30.3
3%	Wet	55.7	40.4	47.4	47.9
	Dry	47.5	44.9	57.3	49.9
4%	Wet	69.6	58.8	70.6	66.4
	Dry	63.9	81.6	44.3	63.3

FM 416

Table 4 presents the small sample results, and Figure 1 illustrates the results for the small samples from FM 416. Both TTI and CST evaluated this material using the same small sample mix design procedure.

Table 4. Individual Test Results for FM 416 Small Samples.

FM 416

Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	CST Wet	17.6	21.5	21.2	20.09
	TTI Wet	40	34	43	39.00
	CST Dry	25.5	21.8	22.1	23.13
	TTI Dry	41	22	47.0	36.67
3%	CST Wet	40.9	49.0	40.9	43.60
	TTI Wet	62	62	34	52.67
	CST Dry	39.4	52.5	46.6	46.17
	TTI Dry	76	30	83	63.00
4%	CST Wet	42.6	43.4	42.3	42.77
	TTI Wet	83	73	57	71.00
	CST Dry	38.4	43.4	42.1	41.30
	TTI Dry	9	97	105	70.33

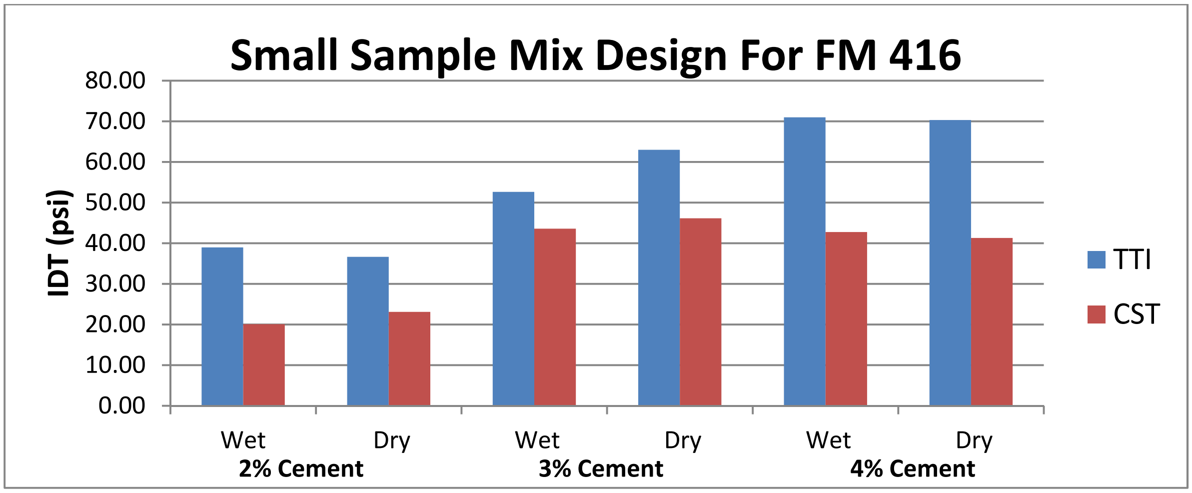


Figure 1. Summary of Small Sample Results for FM 416.

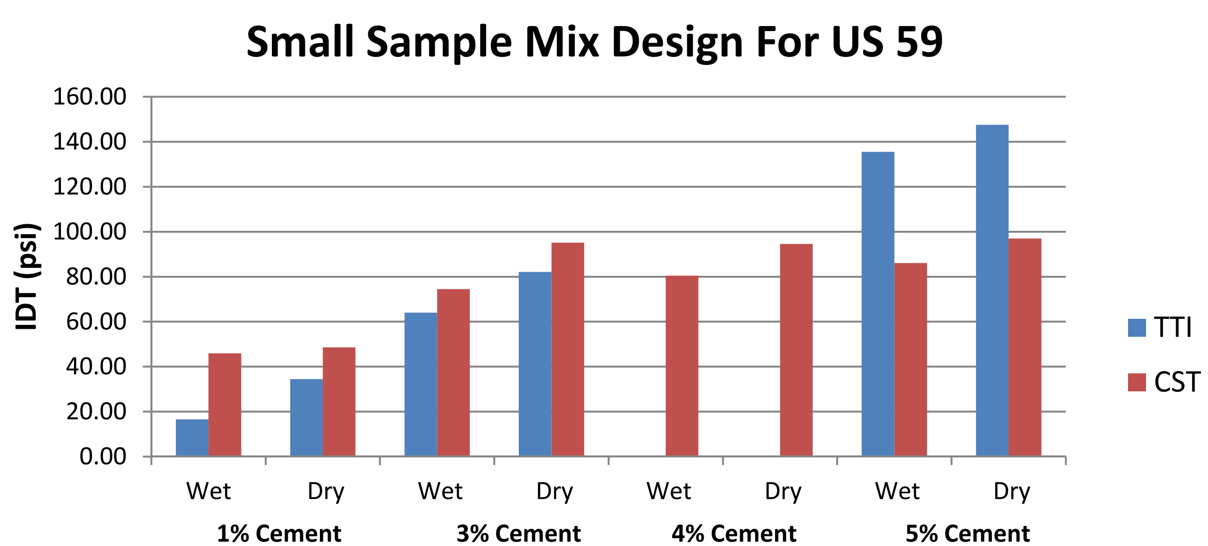
US 59

Table 5 presents the small sample results, and Figure 2 illustrates the results from small samples for US 59. Both TTI and CST evaluated US 59 using the same small sample mix design procedure.

Table 5. Individual Test Results for US 59 Small Samples.

US 59

Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
1%	CST Wet	55.8	42.7	39.3	45.93
	TTI Wet	15.03	14.95	19.77	16.58
	CST Dry	50.9	48.9	45.8	48.53
	TTI Dry	-	40.44	28.57	34.50
3%	CST Wet	70.9	66.8	85.7	74.47
	TTI Wet	27.82	92.18	71.98	63.99
	CST Dry	85.4	91.9	108	95.10
	TTI Dry	106.1	75.26	64.91	82.09
4%	CST Wet	94.1	86	61.4	80.50
	TTI Wet	-	-	-	-
	CST Dry	97.2	92.5	94.1	94.60
	TTI Dry	-	-	-	-
5%	CST Wet	85.1	95.9	77.2	86.07
	TTI Wet	111.27	150.98	144.22	135.49
	CST Dry	95.6	96.8	98.6	97.00
	TTI Dry	149.75	172.75	120.21	147.57



* TTI lab did not have sufficient material to test with 4% cement

Figure 2. Summary of Small Sample Results for US 59.

IH 10

Table 6 presents the small sample results, and Figure 3 illustrates the small sample results from IH 10. The TTI lab used the draft small sample test procedures using 4 in. × 2 in. samples, while CST used the methods from TxDOT SS 3003 requiring 6 in. × 2 in. samples. Due to these variations, comparison of results among the two labs is probably not representative.

Table 6. Individual Test Results for IH 10 Small Samples.

IH 10 Percent Asphalt from Emulsion*	Lab	IDT Strength (psi) Sample 1	2	3	Average IDT Strength (psi) Xbar
2.4	CST Dry	100.4	136.9	134.3	123.87
	TTI Dry	84.1	66.56	89.9	80.19
	CST Wet	-	-	-	-
	TTI Wet	34.12	30.72	30.56	31.80
2.8	CST Dry	125.9	120.3	133.7	126.63
	TTI Dry	59.13	75.64	57.76	64.18
	CST Wet	-	-	-	-
	TTI Wet	26.47	32.77	28.81	29.35
3.2	CST Dry	127.9	131.9	128.5	129.43
	TTI Dry	73.89	93.89	80.51	82.76
	CST Wet	-	-	-	-
	TTI Wet	44.11	39.78	47.05	43.65

*All treatments also include 1% cement.

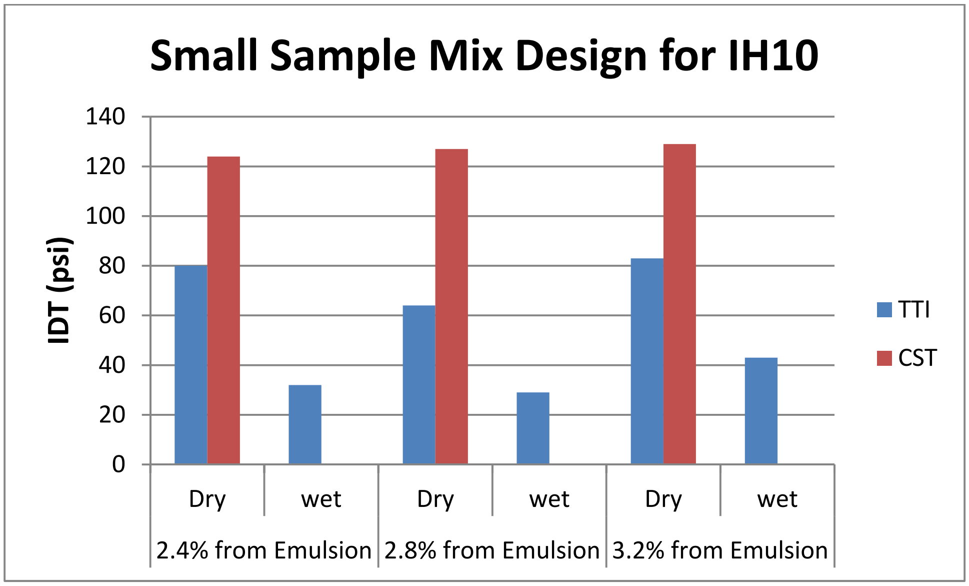


Figure 3. Summary of Small Sample Results for IH 10.
Note: all treatments included 1% cement.

FM 1375

Table 7 presents the small sample results, and Figure 4 illustrates the small sample results from FM 1375. Both TTI and CST evaluated FM 1375 using the same small sample mix design procedure.

Table 7. Individual Test Results for FM 1375 Small Samples.

FM 1375					
Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	CST Wet	35.6	43.6	43.1	40.77
	TTI Wet	18.98	22.51	26.27	22.59
	CST Dry	36.4	38.1	46.4	40.30
	TTI Dry	41.93	45.08	38.5	41.84
3%	CST Wet	51.4	42.6	51.2	48.40
	TTI Wet	51.74	48.66	35.06	45.15
	CST Dry	54.5	60.7	59	58.07
	TTI Dry	53.87	74.1	54.94	60.97
4%	CST Wet	43.9	55.5	53.2	50.87
	TTI Wet	77.7	41.12	70.92	63.25
	CST Dry	64.7	62.1	64.1	63.63
	TTI Dry	116.86	46.49	61.36	74.90

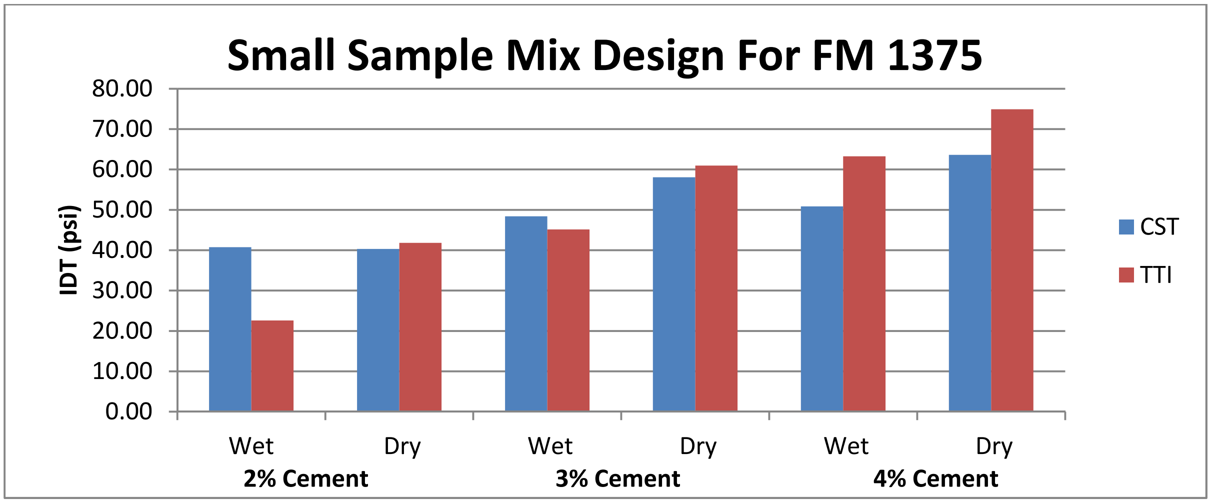


Figure 4. Summary of Small Sample Results for FM 1375.

FM 831TY A GR 2

Table 8 presents the small sample results, and Figure 5 illustrates the small sample results from FM 831 with TY A GR 2 base. Both TTI and CST evaluated this material using the same small sample mix design procedure.

Table 8. Individual Test Results for FM 831TY A GR 2 Small Samples.

FM 831 Ty A GR 2

Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	CST Wet	33.3	32.7	27.9	31.30
	TTI Wet	60.97	63.46	64.91	63.11
	CST Dry	35.6	36.9	31.0	34.52
	TTI Dry	76.00	80.59	67.99	74.86
3%	CST Wet	33.5	33.5	39.6	35.53
	TTI Wet	57.82	70.86	73.18	67.29
	CST Dry	31.3	35.7	39.5	35.50
	TTI Dry	88.36	79.31	82.11	83.26
4%	CST Wet	57.1	51.0	49.6	52.57
	TTI Wet	98.21	75.32	105.92	93.15
	CST Dry	49.1	47.4	45.3	47.27
	TTI Dry	71.21	82.51	89.09	80.94

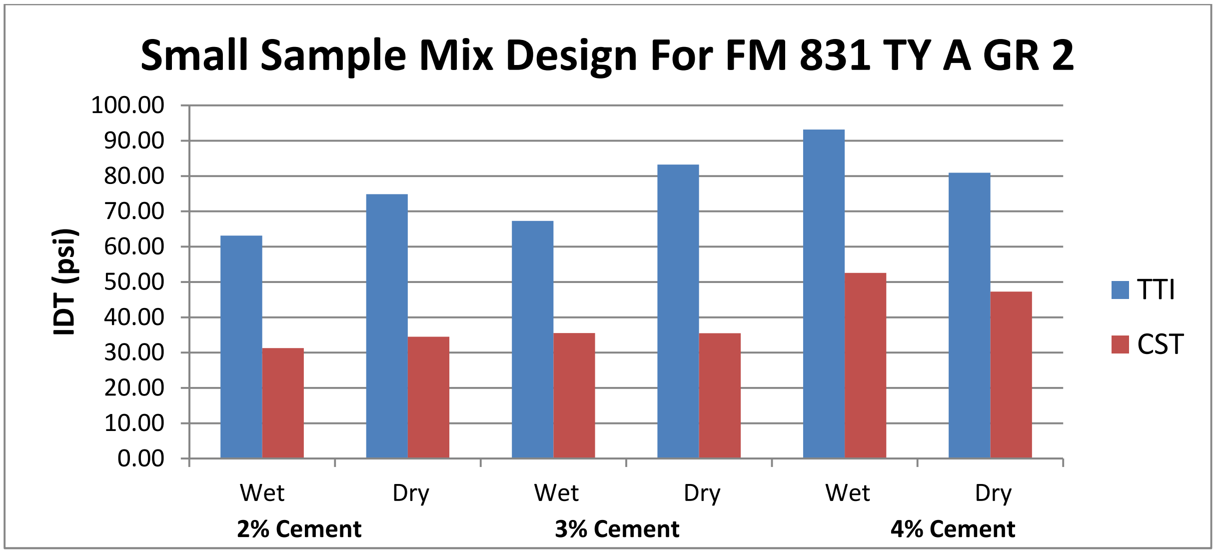


Figure 5. Summary of Small Sample Results for FM 831 TY A GR 2.

FM 831 – 75 Percent Salvage

Table 9 presents the small sample results, and Figure 6 illustrates the small sample results from FM 831 with salvage base. This material consisted of 75 percent salvage with 25 percent new base. Both TTI and CST evaluated this material using the same small sample mix design procedure.

Table 9. Individual Test Results for FM 831 -75 Percent Salvage Small Samples.

FM 831 – 75% Salvage

Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	CST Wet	27.8	24.9	26	26.23
	TTI Wet	60.97	63.46	64.91	63.11
	CST Dry	41	38.3	34	37.77
	TTI Dry	76.00	80.59	67.99	74.86
3%	CST Wet	50.8	44.9	48.3	48.00
	TTI Wet	57.82	70.86	73.18	67.28
	CST Dry	33.9	32.9	35.5	34.10
	TTI Dry	88.36	79.31	82.11	83.26
4%	CST Wet	70.8	65.6	73.7	70.03
	TTI Wet	71.21	82.51	89.09	80.94
	CST Dry	65.8	65.2	65.4	65.47
	TTI Dry	98.21	75.32	105.92	93.15

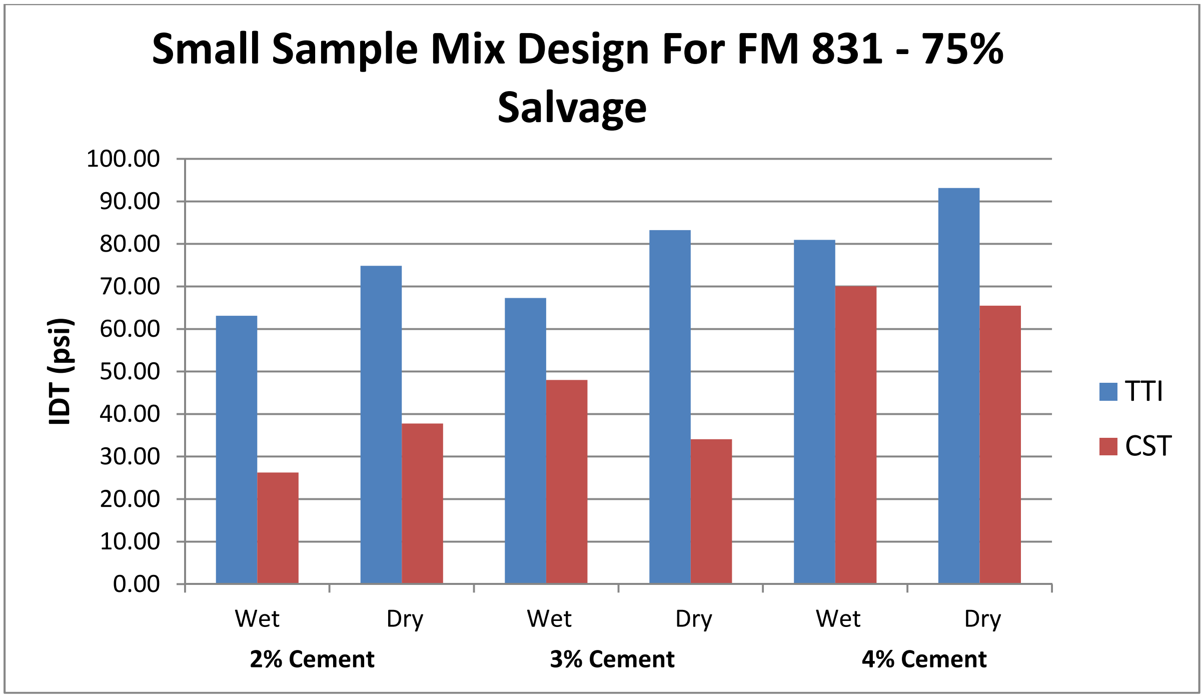


Figure 6. Summary of Small Sample Results for FM 831 – 75% Salvage.

FM 831 Redo

Based on the poor agreement between labs observed with the initial small sample tests using FM 831 – 75 percent salvage, TTI and CST investigated their processes and discovered some deviations occurred that may have contributed to the poor observed precision. Thus, the labs performed a redo of this mix design sequence. In the redo, to maximize material uniformity, all material was recombined by CST, and then each lab only added the appropriate amount of water and stabilizer prior to compaction of the material and performance of the mixture design tests. Table 10 presents the small sample results, and Figure 7 illustrates the results from the FM 831 redo. This material again consisted of 75 percent salvage with 25 percent new base.

Table 10. Individual Test Results for FM 831Redo Small Samples.

FM 831 Redo

Percent Cement	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2%	CST Wet	30.2	29.8	28	29.34
	TTI Wet	26.05	34.00	28.96	29.67
	CST Dry	30.8	35	29	31.60
	TTI Dry	48.07	40.53	27.67	38.75
3%	CST Wet	35.8	36.1	37	36.30
	TTI Wet	41.82	35.33	36.78	37.98
	CST Dry	47.9	46	43.9	45.93
	TTI Dry	38.21	45.52	43.88	42.54
4%	CST Wet	42.2	35.6	39.5	39.10
	TTI Wet	56.56	42.60	50.64	49.93
	CST Dry	40.9	46.6	45.2	44.23
	TTI Dry	48.49	47.06	52.58	49.38

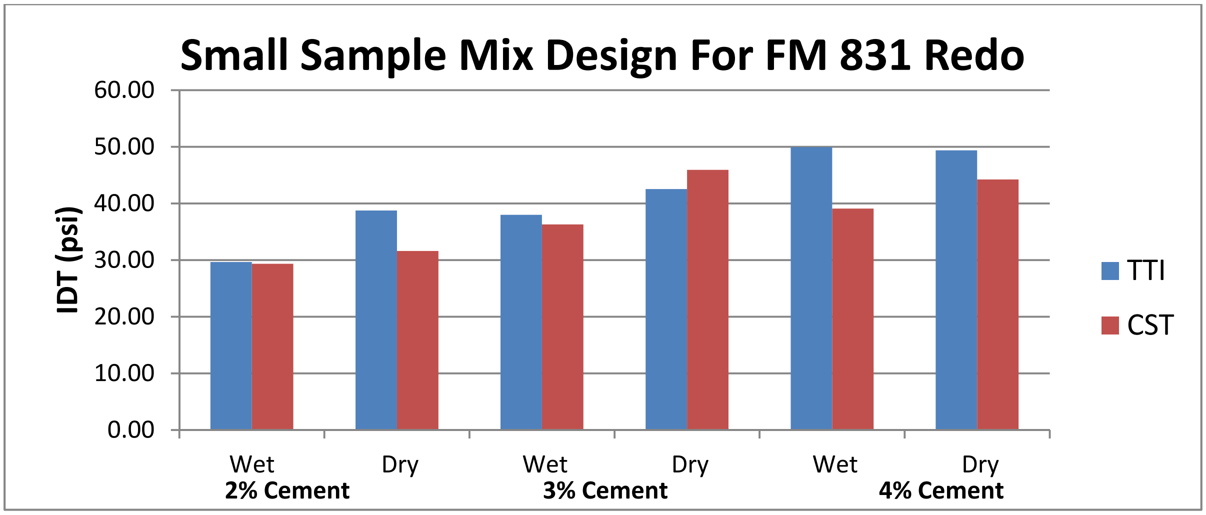


Figure 7. Summary of Small Sample Results for FM 831 Redo.

SH 115

Working with CST and industry, both small and large sample designs were performed on material from SH115 consisting of 80 percent reclaimed base and 20 percent existing sand. Table 11 presents, and Figure 8 illustrates, the small sample results, which were only performed at TTI.

Table 11. Individual Test Results for SH115.

SH 115 Percent Asphalt from Emulsion	Lab	IDT Strength (psi) Sample 1	2	3	Average IDT Strength (psi) Xbar
3.0	TTI Dry	66.58	57.94	71.63	65.39
	TTI Wet	41.50	41.82	32.10	38.47
3.3	TTI Dry	74.34	66.32	73.55	71.40
	TTI Wet	43.03	49.30	56.60	49.64
3.6	TTI Dry	69.71	72.22	95.86	75.93
	TTI Wet	52.10	41.79	62.56	52.15

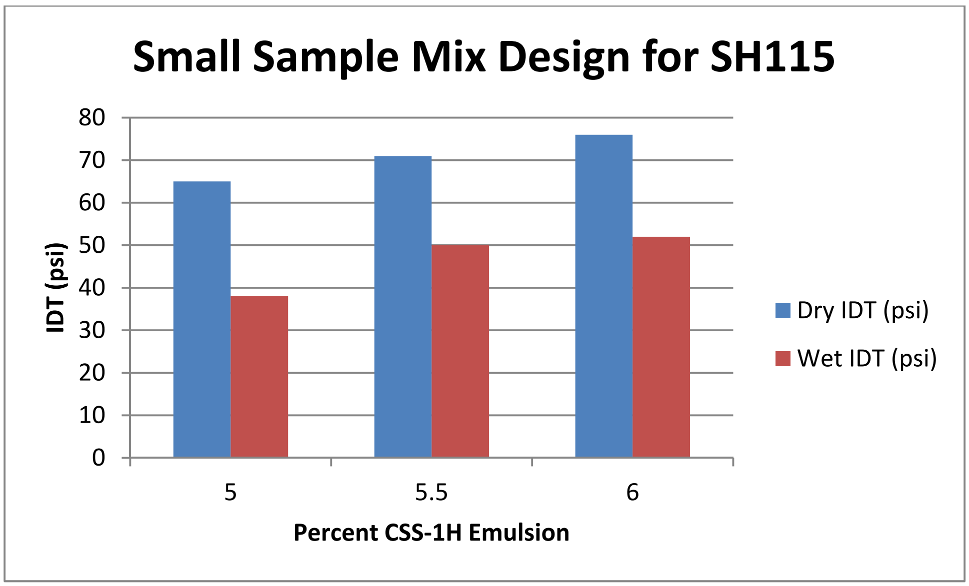


Figure 8. Summary of Small Sample Results for SH115.

FM 99

Table 12 presents, and Figure 9 illustrates, the small sample design results from FM 99. The materials consisted of 70 percent salvage base and 30 percent salvage subbase. Based on prior screening of the material, a pretreatment with 2 percent lime was required to make stabilization with asphalt a potential solution. All tests were performed only at TTI labs.

Table 12. Individual Test Results for FM 99.

FM 99

Percent Asphalt*	Lab	IDT Strength (psi) Sample			Average IDT Strength (psi)
		1	2	3	Xbar
2.5% Foam	TTI Dry	88.07	96.85	74.51	86.48
	TTI Wet	47.32	25.62	42.10	38.34
2.5% from emulsion	TTI Dry	78.30	53.39	58.70	63.46
	TTI Wet	43.11	33.24	40.24	38.86

*All treatments include 2% lime pretreatment.

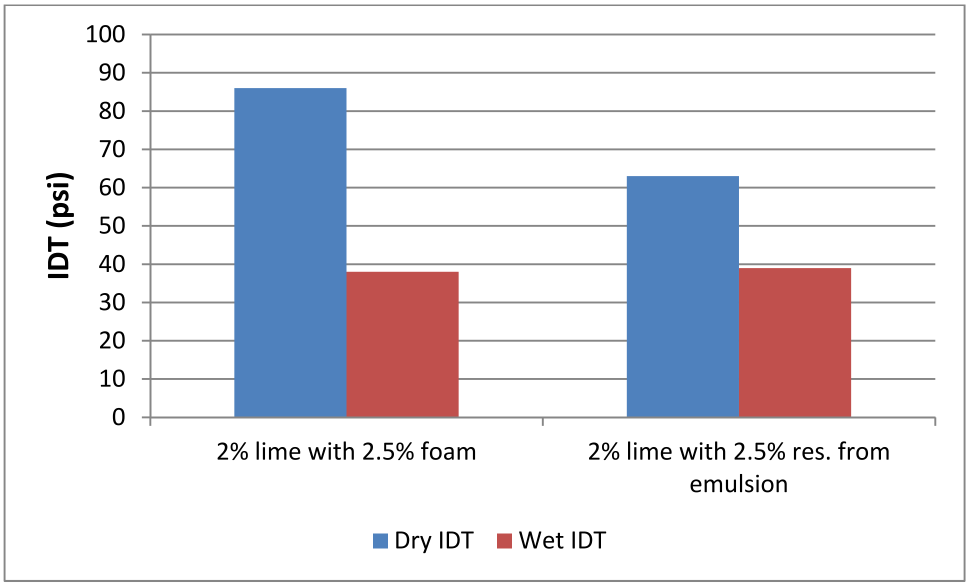


Figure 9. Summary of Small Sample Results for FM 99.

LARGE SAMPLE TEST RESULTS

Table 13 presents the large sample test results for each material. The soaked tests consist of placing the large sample in a 10-day capillary rise condition prior to testing. Due to material availability and specific district preferences, soaked tests were not performed for all materials.

Table 13. Large Sample Test Results.

District	Material	Treatments	Unconfined Compressive Strength (psi) Soaked	Unsoaked
BRY	FM 542	2% cement	No soaked tests performed	247
		3% cement		321
		4% cement		341
BRY	FM 416	2% cement	No soaked tests performed	147
		3% cement		142
		4% cement		181
YKM	US 59	1% cement	No soaked tests performed	153
		3% cement		411
		5% cement		432
ODA	IH 10	1% Cement with 2.4% Res. Emulsion	349	454
		1% Cement with 2.8% Res. Emulsion	362	426
		1% Cement with 3.2% Res. Emulsion	336	337
BRY	FM 1375	2% cement	163	165
		3% cement	177	172
		4% cement	148	151
BRY	FM 831 TY A GR 2	2% cement	No soaked tests performed	560
		3% cement		684
		4% cement		1015
BRY	FM 831 75% Salvage	2% cement	No soaked tests performed	205
		3% cement		232
		4% cement		264
ODA	SH 115	3.3% Res. Emulsion	302	311
SAT	FM 99	2% Lime with 2.5% Foam	136	290
		2% Lime with 2.5% Res. Emulsion	186	322

RECOMMENDED STABILIZER CONTENT FROM LARGE AND SMALL SAMPLES

Based on the large and small sample results, Table 14 presents the recommended stabilizer content for the materials form both large and small samples.

Table 14. Recommended Stabilizer Content from Large and Small Samples.

District	Material	Recommended Stabilizer Content	
		Large Samples	Small Samples
BRY	FM 542	2% cement	3% cement
BRY	FM 416	4% cement	3% cement
YKM	US 59	3% cement	3% cement
ODA	IH 10	1% cement with 2.8% residual from emulsion	1% cement with 2.4% residual from emulsion
BRY	FM 1375	3% cement	3% cement
BRY	FM 831 TY A GR 2	2% cement	2% cement
BRY	FM 831 75% Salvage	2% cement	2% cement
BRY	FM 831 Redo 75% Salvage	4% cement	2% cement
ODA	SH 115	3.3% Res. Emulsion	3.0% Res. Emulsion
SAT	FM 99	2% Lime with 2.5% Asphalt from Foam or Emulsion	2% Lime with 2.5% Asphalt from Foam or Emulsion

EVALUATION OF SMALL SAMPLE COMPACTED DRY DENSITY

Since the small sample mix design uses an entirely different compaction mechanism than Tex-113-E, Figure 10 illustrates the observed deviation from the Tex-113-E maximum density with the small samples. These results show:

- On average, the small sample densities were 1.8 pcf below the Tex-113-E maximum.
- With the observed variability, this difference was not significantly different from zero.

These data, although relatively small in sample size, do indicate that on average the small sample design procedure can replicate Tex-113-E maximum density. However, as evidenced by the variability of results in Figure 10, some materials may be undercompacted and some materials may be overcompacted with the current small sample procedure.

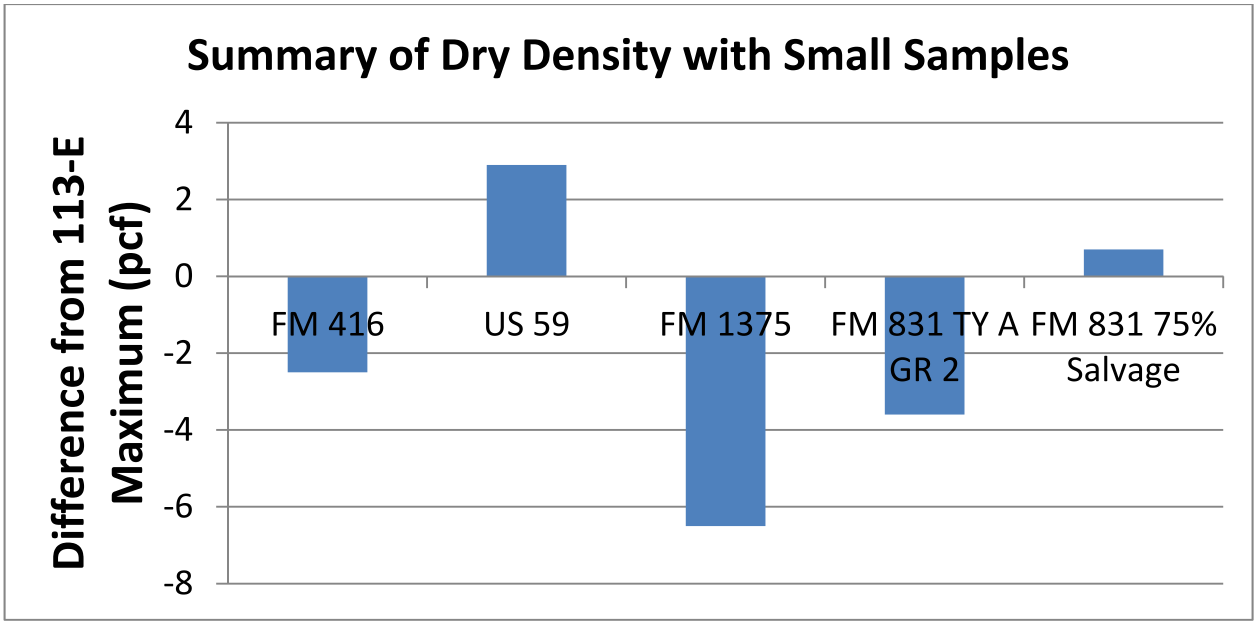


Figure 10. Difference in Average Small Sample Dry Density from Tex-113-E Maximum.

CHAPTER 3: CONCLUSIONS

Full depth recycling (FDR) will remain a valuable tool for practitioners for the foreseeable future. As agencies continue to face ever-increasing responsibilities to establish and maintain a safe system with finite materials resources, the option to recycle pavement materials in place to rapidly renew a deteriorated pavement section offers many potential advantages in cost, project delivery time, and sustainability.

To fully realize the advantages of FDR, a proper mixture and pavement design must take place. Rather than using large (typically about 18 lb each) specimens in unconfined compressive strength(UCS) for mixture design, this project performed initial implementation work using small (typically about 2 lb each) samples in IDT to perform mixture designs. Figure 11 illustrates how, with the amount of material required for one UCS specimen, the small sample procedure can perform an entire mix design. This reduction in material quantity requirements offer a major advantage, since many times four to eight different mixture designs may be under consideration. The small sample design procedure offers a quick method to screen stabilization options; if desired, the most promising treatments can then be verified with UCS.

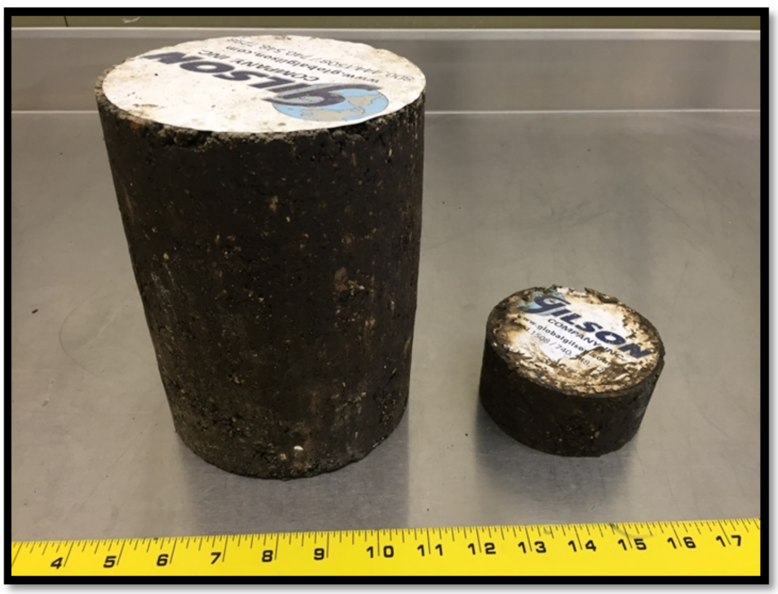


Figure 11. Contrast of Traditional (Left) and Small (Right) Samples.
Note: Small sample procedure uses 6 small samples in IDT.

The lab experiences and operator feedback using small samples illustrate promise for speeding up mixture design processes while using less material. The results from the initial implementation efforts in this project support the following:

- With cement, reasonable agreement exists between the recommended stabilizer content from both large and small samples.
- With other stabilizers, such as emerging asphalt treatments, initial data suggest reasonable agreement also exists between large and small sample design approaches.

- The precision of the small sample procedure needs improvement. Preliminary estimates place the repeatability limit between 20 and 30 psi, and the reproducibility limit between 35 and 45 psi. The entire procedure needs thorough review and updating to identify and minimize potential sources of variability.
- Data suggest the small sample procedure can on average replicate Tex-113-E density. However, procedural modifications should be explored to reduce the deviations from Tex-113-E maximum across materials when using the small sample procedure. Ideally, the procedure should aim to achieve a dry density within 1 pcf of the maximum dry density determined with Tex-113-E. Use of the Superpave Gyrator Compactor may facilitate a tighter density tolerance.

While the initial work in this project focused on cement-based stabilization, during the project, a portion of the attention turned to asphalt-based stabilization. A significant amount of discussion seems to remain within TxDOT and industry on where the developed small sample design procedures will apply in the construction specs, how best should the procedures be partitioned and implemented according to stabilizer type, and how the small sample procedure could be implemented into lime-based stabilization.

Additional implementation work should focus on providing more access to the required equipment for small sample FDR mix design in additional districts, improving the precision of the method, and conducting coordinated efforts with TxDOT, CST, and industry to refine and update the small sample test procedure and impacted construction specifications. Controlled and documented development of field projects designed with small sample approaches needs to take place, and field monitoring then performed to ensure design assumptions are met in construction and good pavement performance achieved over time.