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16. Abstract
This report presents the results from the second year of research work investigating issues with flexible base acceptance testing within the Texas Department of Transportation. This second year of work focused on shadow testing non-density-based acceptance methods in parallel with the nuclear density gauge. The research team investigated methods of setting target values and then performed parallel testing of the new devices with the density gauge on three construction projects. In addition to using the nuclear density gauge as the default test device, the research team employed a portable falling weight deflectometer, dynamic cone penetrometer (DCP), and portable seismic pavement analyzer. The field testing showed the DCP to be the most preferred device to use in lieu of the nuclear density gauge. Based on the findings, this report presents a modified construction specification for flexible base and a draft test procedure for using the DCP for compaction acceptance.

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ALTERNATIVE METHODS OF FLEXIBLE BASE COMPACTION ACCEPTANCE

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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 United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Tom Scullion, P.E. (Texas, #62683).

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This project was conducted in cooperation with TxDOT and FHWA. Mike Arellano, P.E., served as the project director. Project advisors included Darlene Goehl, P.E.; Caroline Herrera, P.E.; Stevan Perez, P.E.; Daniel Taylor, P.E.; Andrew Wanees, P.E.; and Mike Wittie, P.E.

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EXECUTIVE SUMMARY

Adequate compaction of roadway materials plays a major role in their performance in the field. Most departments of transportation rely on field density measurements to verify adequate compaction; however, concerns with safety and regulatory requirements of using nuclear density gauges, along with the desire to explore compaction methods that more directly measure mechanical properties, led to this project investigating non-density-based test devices for flexible base acceptance. The devices evaluated included the portable falling weight deflectometer (PFWD), dynamic cone penetrometer (DCP), and portable seismic pavement analyzer (PSPA). In addition to these non-destructive test (NDT) devices, during the course of this project, the research team evaluated issues regarding lift thickness, test timing, and moisture content during compaction.

In an earlier phase of this project, results indicated most agencies restrict lift thickness to 6 in., and controlled experiments revealed restrictions on moisture content during compaction should be in place in order to maximize the compacted materials' mechanical properties. Specifically, current Texas Department of Transportation (TxDOT) specifications place a lower limit but do not place an upper limit on water content; such an upper limit should be added to the construction specification. These controlled experiments conducted in the first phase of this project also showed that of the NDT devices evaluated, the DCP could best distinguish among sites constructed with systematic variations in compaction effort.

This current report presents results from shadow testing each of the NDT devices in parallel with the nuclear density gauge on three field construction projects. While these results suggest both the DCP and PFWD may be acceptable for flexible base compaction acceptance, the DCP should be considered as the best non-density-based device for compaction acceptance because:

- In shadow testing, the DCP most closely matched the pass/fail results from the nuclear density gauge.
- Prior evaluation of these devices with Texas materials showed the DCP to be the preferred device.
- The DCP has already been implemented in another department of transportation (DOT) for compaction acceptance of granular materials.

The results from this project led to developing the draft flexible base construction specification in Appendix A and the draft test procedure in Appendix B. Combined, these documents provide both a framework for implementing the DCP for compaction acceptance and improvements in areas of the construction specification regarding lift thickness, moisture content during compaction, and timing of acceptance testing. TxDOT should consider shadow testing this draft specification and test procedure on upcoming projects of varying grades and rock types.

CHAPTER 1: BACKGROUND AND METHODS

Acceptance of flexible base compaction on TxDOT construction projects generally occurs by testing for density with a nuclear gauge. In this project, researchers field tested non-density devices in parallel with the nuclear gauge. The other devices employed include the portable falling weight deflectometer, dynamic cone penetrometer, and portable seismic pavement analyzer. Based on a literature review and controlled pilot tests described in technical report 0-6587-1, the research team performed field testing using these non-destructive test devices on three construction projects to evaluate the following approaches:

- Approach 1: Set NDT target with field test strip. In this approach, the contractor performs compaction until the NDT reaches a maximum modulus value, or minimum deflection; this maximum modulus (or minimum deflection) then becomes the NDT acceptance target for compaction.
- Approach 2: Use NDT as surrogate for density. In this approach, NDT tests conducted on a section meeting density control serve to set the target value. The NDT target is set as the least restrictive value where density requirements meet specifications.
- Approach 3: Use pre-set NDT criteria for acceptance. This approach essentially seeks to validate whether Minnesota Department of Transportation (MnDOT) criteria for the DCP penetration index are reasonable for Texas materials.

Figure 1.1 illustrates the general field testing plan the research team tried to employ on projects. After setting NDT targets with the first two approaches, an evaluation section served to shadow test the NDT technologies.

Control Section (Approach 1)	**Control Section (Approach 2)**	**Evaluation Section**
Rolling controlled by NDT reaching asymptote NDT performed multiple times during rolling pattern Some contractor delay may occur	Rolling controlled by density control NDT performed after attainment of 100 percent density No contractor delay expected	NDT performed when contractor ready for density control testing NDT performed at each station with offsets randomly determined

Figure 1.1. Plan for Field Control and Evaluation Sections with NDT.

After field testing, the research team evaluated the data to determine which of these approaches were feasible in the field, which NDT device best met the needs of testing under these approaches, and how each approach should be modified.

CHAPTER 2: TEST RESULTS FROM US 183

OVERVIEW

On March 2, 2011, Texas A&M Transportation Institute (TTI) researchers performed an evaluation of Grade 4 flexible base compaction on US 183 in Travis County. This base had a Tex-113-E maximum density of 129.5 pcf at 9.7 percent moisture. Table 2.1 presents the Item 247 specification characterization tests for this base material. Researchers performed the testing to evaluate setting an NDT acceptance target with a field test strip, where the maximum modulus (or minimum deflection) became the NDT acceptance target for compaction. The testing also served to evaluate the applicability of the MnDOT DCP criteria to Texas materials.

Table 2.1. Item 247 Specification Test Results from Base Used on US 183.

Gradation		Compaction Test		Wet Ball Mill		Plasticity Index		Strength Test	
Sieve Size	Cumulative Percent Retained	Max Density (pcf)	129.5	Ball Mill Value	37	Liquid Limit	19	Lateral Pressure (psi)	Strength (psi)
1 3/4	0	Percent Water	9.7	Increase in - #40	14	Plastic Limit	16	0	34
7/8	20					Plasticity Index	3	3	95
3/8	48							15	194
#4	60	*This space intentionally left blank*							
#40	78								
#200	85								

In construction of the test strip, the contractor performed five rolling sequences. Between the fourth and fifth sequence, water was added to the base to slightly increase the moisture content.

TESTING SEQUENCE

The contractor placed two 4.5 in. lifts of flexible base from the Wood pit. TTI researchers tested the second lift and sought to perform the control strip evaluations shown in Figure 2.1 for setting NDT targets. On the day of testing, an evaluation section for shadow implementation of the NDT targets on a larger section of the project was not available. Later efforts to test an evaluation section did not materialize.

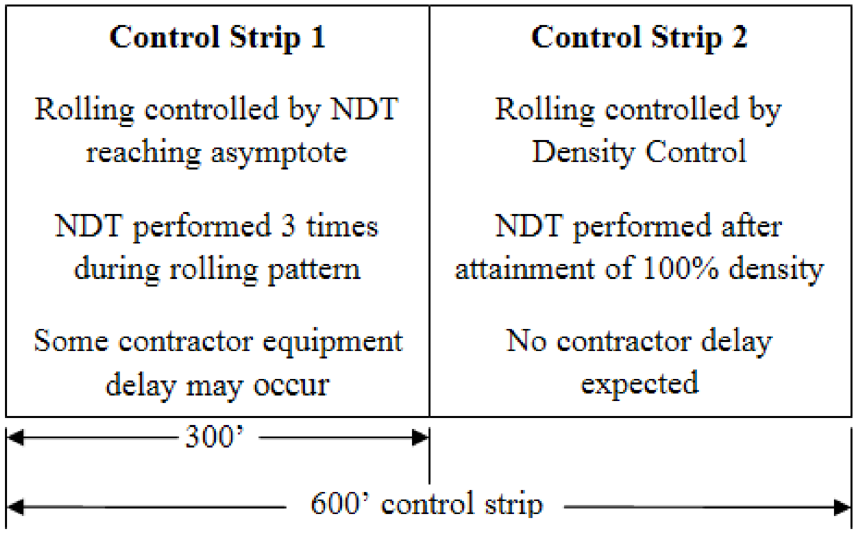

Figure 2.1. Test Sequence Planned for US 183.

Figure 2.2 shows the test location, which was approximately 60 ft wide and 420 ft long, at the intersection of CR 263. The contractor first spread and compacted base on the western half of the pavement width; researchers used this section for control strip 1. Next, the contractor spread and compacted base on the eastern half of the pavement width; researchers desired to use this section for control strip 2. However, the section did not meet 100 percent density, and so control strip 2 was not completed. The comments from the field were that the density tests for acceptance were generally not performed until one to two days after completion of compaction, and when tested in that time frame, the contractor had routinely met density requirements.

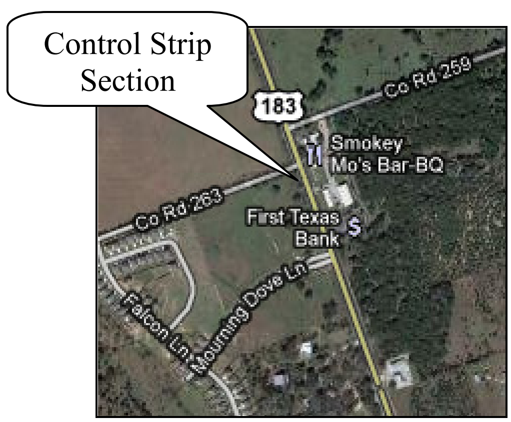

Figure 2.2. Location of Control Strips on US 183.

Results from Control Strip 1 on US 183

Figure 2.3 shows the contractor spreading and compacting the section used for control strip 1. For compaction, the contractor used a Dynapac CP271 and IR SD-100D rollers. Table 2.2 summarizes the rolling patterns after which NDTs were conducted. To conduct the NDTs, after the first rolling pattern, researchers marked seven test locations at 60 ft intervals. Researchers tested in the following order: PSPA, PFWD, DCP, and then nuclear gauge.

Figure 2.3. Spreading and Compacting Control Strip 1.

Table 2.2. Rolling Patterns Performed on US 183.

Rolling Sequence	Rolling Performed
1	2 passes pneumatic, 1 pass steel wheel
2	1 pass steel wheel
3	1 pass steel wheel
4	1 pass steel wheel
5	Add water to surface and let soak, 5 passes pneumatic

Results from PSPA

The PSPA was set for a measurement depth of 4.5 in.; researchers collected and averaged three data points at each of the test locations. Figure 2.4 shows PSPA testing in progress.

Figure 2.4. PSPA Testing on US 183 Flex Base.

Table 2.3 presents, and Figure 2.5 illustrates, the average seismic modulus values measured after each of the rolling patterns. Figure 2.5 also presents the average water content. Due to the time required to obtain quality readings with the PSPA, data at all test points were not obtainable between all rolling passes. Unfortunately, nuclear gauge readings for water content were also not obtainable between all rolling passes. The PSPA data show:

- A peak average modulus value occurred after the fourth rolling pattern.
- The modulus after the fifth rolling sequence was significantly lower than the modulus after rolling sequence 4. However, interpretation of the modulus after the fifth rolling pattern was complicated by the addition of water to the base after rolling sequence 4. The large drop in measured modulus from rolling sequence 4 to 5 likely indicates a strong sensitivity of the PSPA to moisture content. Unfortunately, time constraints

precluded collection of moisture content data after rolling sequence 4, so numerical data does not exist to prove or disprove this hypothesis.

- The typical coefficient of variation was around 50 percent.

Table 2.3. PSPA Modulus (ksi) on US 183 after Rolling Sequences.

Test Location	Rolling Sequence				
	1	2	3	4	5
1	17			34	35
2	19		39	148	56
3	30		97		74
4	15			62	46
5	49			124	35
6	29	29		76	42
7	27			52	26
AVG	**26.57**	**29**	**68**	**82.67**	**44.86**
St Dev	**11.57**		**41.01**	**44.18**	**15.98**
C.V. %	**43.56**		**60.31**	**53.44**	**35.63**

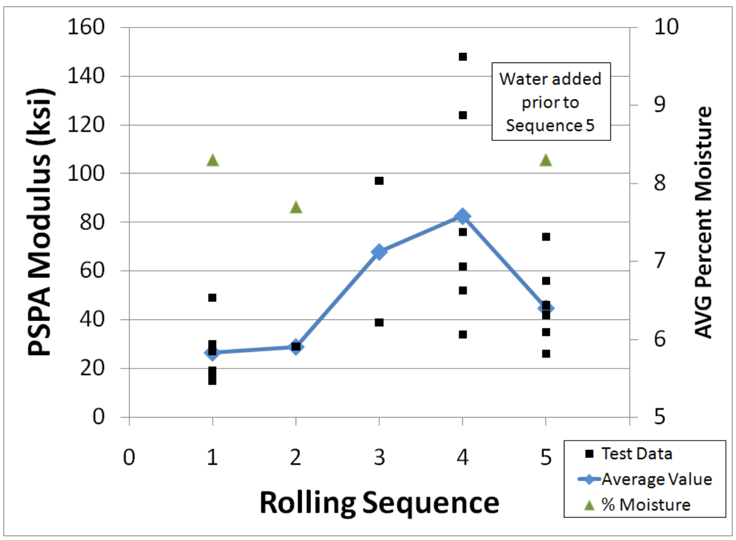

Figure 2.5. PSPA Modulus with Rolling Passes on US 183.

Due to the addition of water prior to rolling sequence 5, the research team investigated if the increase in mean seismic modulus observed after sequence 4 may be attributable simply to drying. In Figure 2.5, from rolling sequence 1 to 2, the average percent moisture decreases approximately 0.6 percentage points, whereas the modulus exhibits minimal change. Comparing sequence 2 to 5, the average percent moisture increases approximately 0.6 percentage points, while the modulus actually increases approximately 50 percent. These observations do not provide conclusive evidence of the moisture content impact within the range of measurements represented by the data set.

Figure 2.6 presents the individual test location data points of the PSPA modulus versus the measured water content for the two rolling data sequences with sufficient PSPA and corresponding moisture content data. These data do not show a significant relationship between the seismic modulus and measured water content. Sufficient data do not exist to determine a significant role of the measured water content in the PSPA data collected during construction of the test strip.

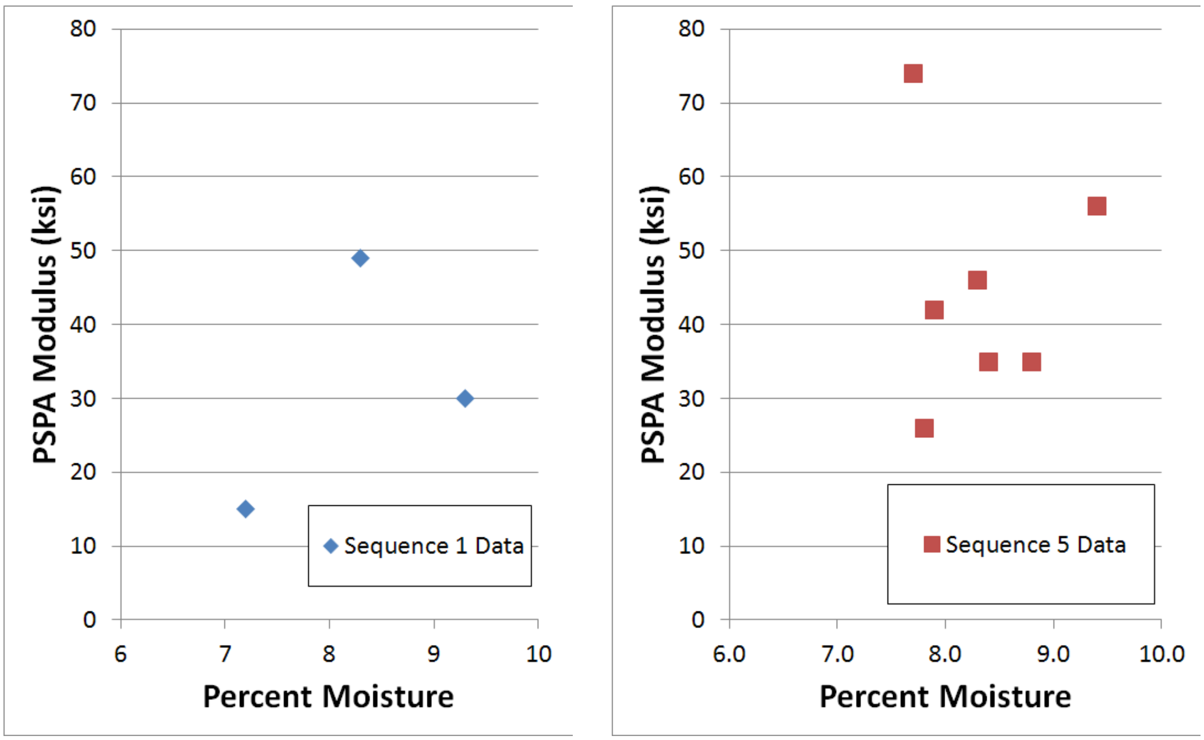

Figure 2.6. PSPA Modulus versus Percent Moisture for Individual Test Points on US 183.

Results from PFWD

The PFWD was dropped from approximately 24 in. and used the 4 in. radius loading plate, resulting in an average force of 1954 lb, an average stress state of 40 psi, and an average pulse time of 14 ms. Researchers conducted PFWD drops in triplicate at each time of data collection. To minimize contractor delay between roller passes, only three locations were tested during the intermediate stages of the rolling sequence. Figure 2.7 shows the PFWD testing in progress.

Figure 2.7. PFWD Data Collection on US 183.

Table 2.4 presents, and Figures 2.8 and 2.9 illustrate, the PFWD results. The PFWD data show:

- The typical coefficient of variation was around 20 percent.
- No significant change in average deflection or E1 modulus occurred between rolling sequences 1 through 4. Based on the average data, the initial rolling pattern was optimized after rolling sequence 2, as Figures 2.8 and 2.9 illustrate.
- From rolling sequence 4 to 5, the average deflection significantly decreased (Figure 2.8), and the average modulus increased (Figure 2.9). This contrasts with the PSPA results, which showed a significant decrease in modulus from rolling sequence 4 to 5.

Table 2.4. PFWD Data from US 183.

	Rolling Sequence									
	1		2		3		4		5	
Test Location	**D1 (mils)**	**E1 (ksi)**	**D1 (mils)**	**E1 (ksi)**	**D1 (mils)**	**E1 (ksi)**	**D1 (mils)**	**E1 (ksi)**	**D1 (mils)**	**E1 (ksi)**
1	11.3	27							5.6	47
2	10.2	27							6.7	40
3	6.4	42	7.9	33	7.3	36	5.5	48	7.3	36
4	8.6	32	7.0	38	7.4	36	9.0	29	6.5	41
5	10.4	26	9.4	28	9.1	28	11.8	22	7.7	34
6	8.6	32							7.1	38
7	10.3	26							5.3	51
AVG	**9.4**	**30**	**8.1**	**33**	**7.9**	**33**	**8.8**	**33**	**6.6**	**41**
St Dev	**1.6**	**6**	**1.2**	**5**	**1.0**	**5**	**3.2**	**13**	**0.9**	**6**
C.V. (%)	**17.5**	**20**	**15.1**	**15**	**12.5**	**14**	**36.0**	**40**	**13.4**	**14**

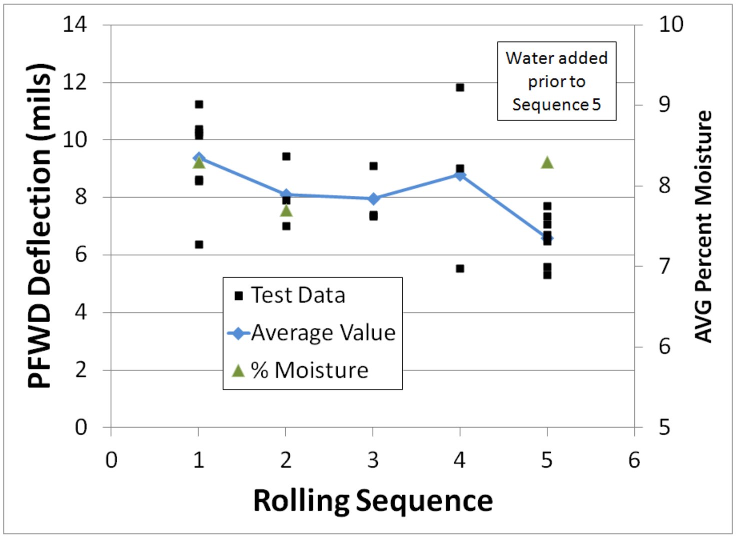

Figure 2.8. PFWD Deflection with Rolling Passes on US 183.

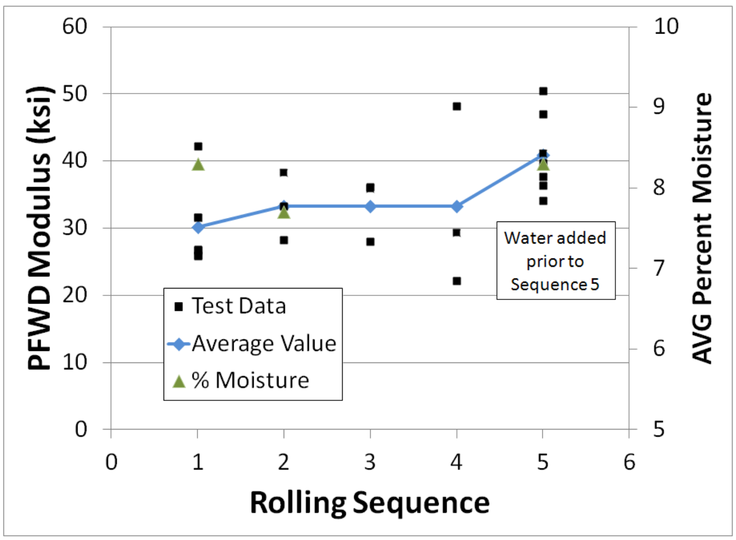

Figure 2.9. PFWD Modulus with Rolling Passes on US 183.

Researchers also investigated the potential influence of water content on the measurements with the PFWD data set. Figures 2.8 and 2.9 do not suggest a relationship between the average water content and the modulus measured with the PFWD. From rolling sequence 1 to 2, the average water content decreased by approximately 0.6 percentage points, and the PFWD showed a small increase in modulus. However, comparing rolling sequences 2 and 5, the average percent moisture increased approximately 0.6 percent, yet the modulus also increased. The range of moisture contents observed did not seem to affect the PFWD modulus.

To further investigate a potential influence of moisture on the PFWD readings, Figure 2.10 plots the PFWD modulus versus the measured percent moisture (using a nuclear gauge) for the individual test locations. Analysis of the data represented in the scatter plot shows no significant trend between the point-specific water content measurements and the point-specific PFWD modulus. Sufficient data do not exist to determine a significant role of the measured water content in the PFWD data collected during construction of the test strip.

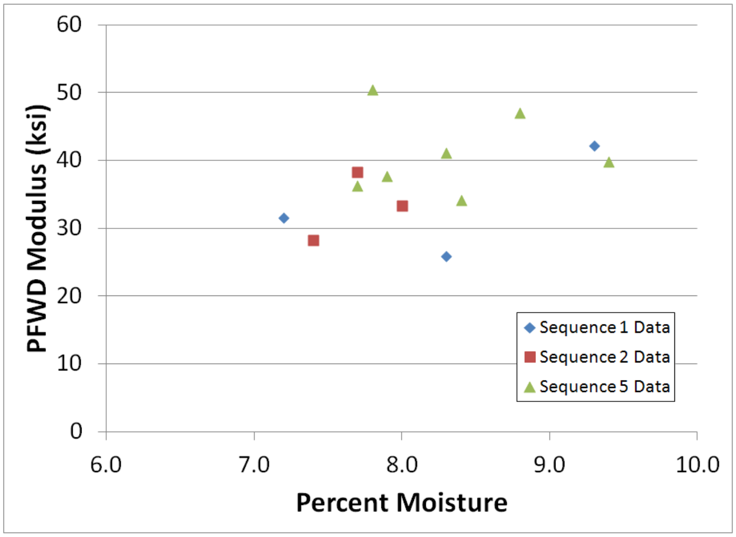

Figure 2.10. PFWD Modulus versus Percent Moisture for Individual Test Points on US 183.

Results from DCP

The research team conducted DCP tests after rolling sequences 1 and 5. Time constraints between rolling passes precluded collection of DCP data during the intermediate rolling sequences. Figure 2.11 shows the DCP testing in progress.

Figure 2.11. DCP Testing on US 183 Flex Base.

While the idea was to place two 4.5 in. lifts, the example DCP profiles in Figure 2.12 illustrate that the actual test layer thickness (indicated by the change in slope in the DCP profiles) was between 3 and 4 in., so for purposes of this evaluation, the test layer thickness was assumed as 3.5 in.

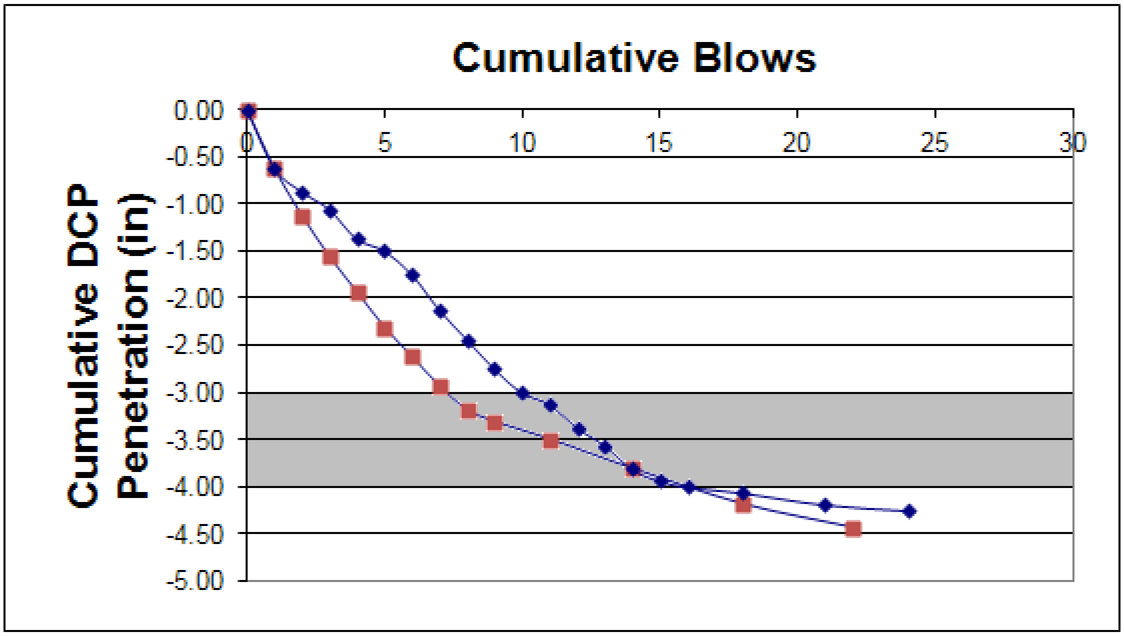

Figure 2.12. Example DCP Profiles from US 183.

Table 2.5 presents the DCP penetration rate (PR) for the test layer. The Seat, DCP penetration index (DPI), and adequate layer parameters presented are those adopted by MnDOT and were examined for comparative purposes.

Table 2.5. DCP Results from US 183.

	Rolling Sequence							
	1				5			
Location	PR (in/blow)	Seat (in)*	DPI (in/blow)**	Adequate Layer***	PR (in/blow)	Seat (in)*	DPI (in/blow)**	Adequate Layer***
1				Yes	-0.22	-0.63	-0.25	Yes
2				Yes	-0.15	-0.69	-0.23	Yes
3	-0.39	-1.13	-0.40	Yes	-0.26	-0.88	-0.21	Yes
4	-0.35	-0.94	-0.33	Yes	-0.21	-0.81	-0.21	Yes
5	-0.44	-1.19	-0.44	Yes	-0.23	-0.75	-0.17	Yes
6				Yes	-0.33	-1.06	-0.31	Yes
7	-0.54	-1.25	-0.52	Yes	-0.34	-0.81	-0.35	Yes
AVG	-0.43	-1.13	-0.42		-0.25	-0.80	-0.25	
St Dev	0.08	0.14	0.08		0.07	0.14	0.07	
C.V. (%)	19.08	12.00	18.18		27.23	17.64	26.41	

*The total penetration in the first 2 blows; MnDOT spec = 1.6 in. max

** The penetration rate in blows 3 through 5; MnDOT spec = 0.6 in. max

***Yes if total penetration after 5 blows < test layer thickness; otherwise no

Analysis of the DCP results shows:

- The DCP PR significantly decreased between the first and fifth rolling sequence, so the test layer was mechanically better after the fifth rolling sequence as compared to after the first rolling sequence.

- The DCP data met the MnDOT specs after both the first and the fifth rolling passes.
- The data suggest the standard deviation for penetration rate was stationary at about 0.08 in./blow, resulting in coefficients of variation between 20 and 30 percent.
- Since the material met MnDOT criteria after the first rolling pass, but statistically significant mechanical improvement was observed after further rolling, the results suggest the MnDOT criteria may be too permissive, or at least may not optimize compaction, for common flexible bases used in Texas.

Results from Nuclear Gauge

The research team collected nuclear density readings after rolling sequences 1, 4, and 5. Figure 2.13 shows testing in progress; the measurement depth used was 4 in.

Figure 2.13. Collecting Nuclear Density Readings on US 183.

Table 2.6 presents, and Figure 2.14 illustrates, the nuclear density data. The nuclear data show no significant difference in means existed among the measured densities after each rolling sequence. Additionally, evaluations using the paired t-test showed no impact from the rolling sequences on the density. The data also show no differences in water content, even though it is known that water was added to the material after rolling sequence 4 and prior to rolling sequence 5.

Table 2.6. Nuclear Density Data from US 183.

	Rolling Sequence								
	1			4			5		
Location	DD	%M	% PR	DD	%M	% PR	DD	%M	% PR
1							125.7	8.8	97.5
2							126.0	9.4	97.7
3	123.8	9.3	96.0	121.8	8.0	94.3	123.4	7.7	95.7
4	118.5	7.2	91.9	124.6	7.7	96.6	123.5	8.3	95.8
5	120.3	8.3	93.2	118.1	7.4	91.5	120.8	8.4	93.6
6							120.5	7.9	93.4
7	121.7	7.4	94.3				120.5	7.8	93.5
AVG	121.1	8.1	93.9	121.5	7.7	94.1	122.9	8.3	95.3
St Dev	2.2	1.0	1.7	3.3	0.3	2.6	2.4	0.6	1.9
C.V. (%)	1.8	11.9	1.9	2.7	3.9	2.7	1.9	7.3	2.0

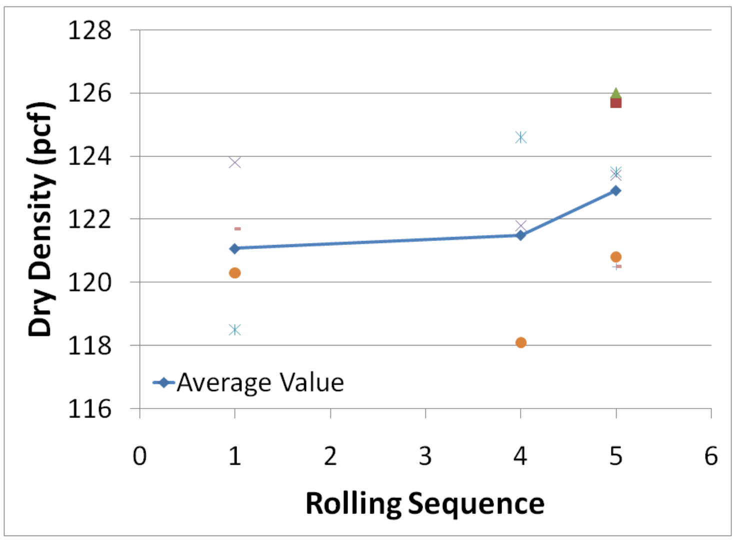

Figure 2.14. Nuclear Density on US 183.

CONCLUSIONS

Analysis of the data collected showed:

- The PSPA modulus peaked after rolling sequence 4. However, the water added prior to the fifth rolling sequence made that PSPA data incompatible for comparison with the prior seismic modulus results.
- The PFWD showed no significant change in deflection or layer 1 modulus between rolling sequences 1 through 4. However, the PFWD showed statistically significant improved mechanical properties (in terms of deflection and layer 1 modulus) after the fifth rolling sequence.
- The DCP showed statistically significant improved mechanical properties after the fifth rolling sequence as compared to after the first. Due to time constraints, DCP testing was not feasible after each rolling sequence.

- The base met MnDOT's modified penetration index specification after only the first sequence of rolling.
- The nuclear gauge showed a slight (but not statistically significant) increase in density from the first to the fifth rolling sequence. The water content measured with the nuclear gauge averaged 8 percent, which was approximately 1 percent below optimum.

The data indicate it should be feasible to set an NDT compaction target by using a control strip in the field. All devices (the PSPA, PFWD, and DCP) showed the layer was mechanically superior after rolling sequence 5 as compared to rolling sequence 1; however, the nuclear gauge showed no significant change in density after any of the rolling sequences. These observations support prior lab and field observations that at least with some materials, improved mechanical properties result from additional compaction, even if statistically significant increases in density are not realized.

With regard to the influence of water content on the NDT target-setting process, the PSPA did not agree with the PFWD when additional water was added to the material during the course of rolling sequences. The PFWD showed continued improvement in the layer's mechanical properties, despite the addition of water, while the PSPA showed a reduction in modulus after the addition of water. The PSPA modulus decrease likely resulted from sensitivity to the addition of water; however, moisture content data to prove or disprove this hypothesis were not available due to time constraints between the contractor's rolling operations. The PFWD modulus seemed insensitive to water content within the range of measured moisture contents at the project site. This discrepancy between the devices may result from the significantly different levels of strain between the PFWD and PSPA. The most prudent approach may be to begin the target-setting process over again if the water content is changed during the course of rolling passes.

With the DCP, the MnDOT penetration criteria were met after the first rolling sequence. Since all devices detected improvements in the layer mechanical properties after rolling sequence 5 as compared to after the first rolling sequence, the MnDOT criteria may be too permissive, or at a minimum, may not optimize compaction, for Texas flexible bases.

CHAPTER 3:
TEST RESULTS FROM FM 1460

OVERVIEW

On March 14, 2011, TTI researchers performed an evaluation of flexible base compaction on FM 1460 in Williamson County. Researchers performed the testing to evaluate using NDT as a surrogate for density, where the NDT target was set as the least restrictive value in a section that passed density control. This approach assumes a relationship between NDT properties and density such that once the most easily obtained NDT value is identified that corresponds with passing density control, locations with stronger/stiffer NDT characteristics will also meet density control. After identifying the NDT target in a short control strip, researchers next conducted parallel testing with the nuclear gauge and NDT on a long section to shadow test the targets set for the NDT devices.

The project employed three 6 in. lifts of Grade 4 flexible base, which had a Tex-113-E maximum density of 135.1 pcf at 7.6 percent moisture. Table 3.1 presents the Item 247 specification test results for this base material.

Table 3.1. Item 247 Specification Test Results for Base Used on FM 1460.

Gradation		Compaction Test		Wet Ball Mill		Plasticity Index		Strength Test	
Sieve Size	Cumulative Percent Retained	Max Density (pcf)	135.1	Ball Mill Value	38	Liquid Limit	*	Lateral Pressure (psi)	Strength (psi)
1 3/4	0	Percent Water	7.6	Increase in - #40	12	Plastic Limit	*	0	31
7/8	26					Plasticity Index	10	3	91
3/8	49					Linear Shrinkage	7	15	204
#4	60	*This space intentionally left blank*							
#40	77								
#200	85								

* Not available

Researchers performed the testing on the top lift between stations 858 and 835. The section was accepted as meeting density control requirements on March 11, 2011.

TESTING SEQUENCE

TTI researchers collected data between stations 858 and 856 as a control strip to set NDT targets. Next, data were collected at 100 ft intervals from station 855 to 835 as an evaluation section as annotated in Figure 3.1. Figure 3.2 shows the project location.

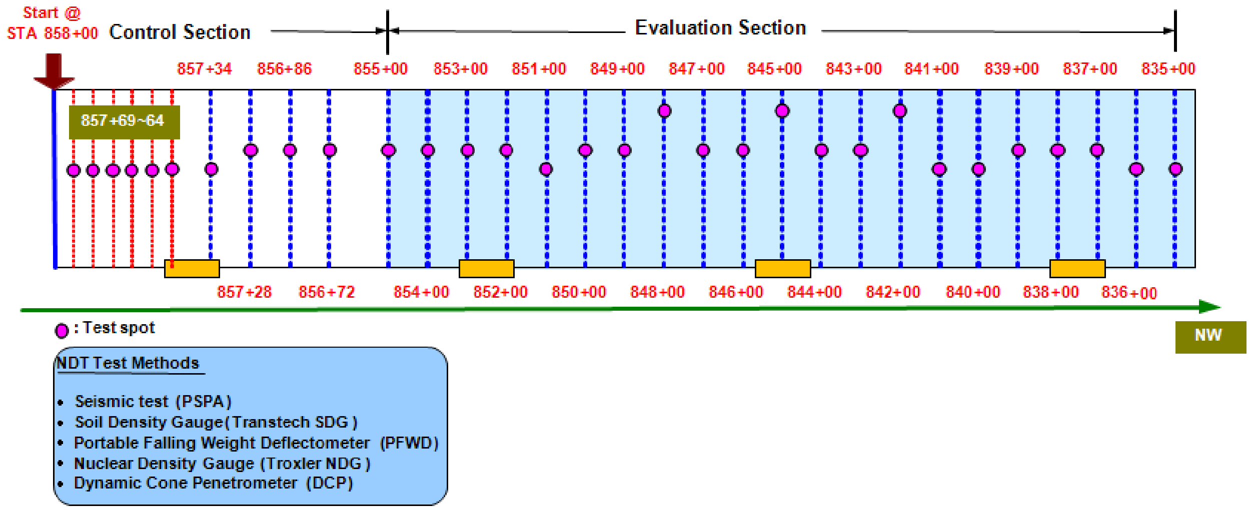

Figure 3.1. Test Sequence on FM 1460.

Figure 3.2. Location of Testing on FM 1460.

Results from Control Strip on FM 1460

Table 3.2 presents the results from the control strip testing on FM 1460. These data were used to set the NDT targets by first highlighting the passing nuclear density values. Next, researchers identified the targets for other test devices as the most permissive NDT value that had a corresponding passing nuclear density. In Table 3.2, the NDT targets are highlighted in green.

Table 3.2. Results from Control Strip on FM 1460.

Station	Nuclear			PSPA	PFWD		DCP		
	Dry Density (pcf)	Moisture (%)	Percent Compaction	Modulus (ksi)	D1 (mils)	E1 (ksi)	PR (in/blow)	CBR	E (ksi)
857+69	137.0	4.5	101.4	116	4.17	83.3	0.049	228.5	82.5
857+68	134.0	4.8	99.2	233	5.18	67.6	0.048	233.9	83.7
857+67	134.4	4.7	99.5	142	5.92	58.3	0.063	172.5	68.9
857+66	136.0	4.6	100.7	85	5.33	64.1	0.054	205.0	76.9
857+65	132.2	5.1	97.9	115	4.04	85.7	0.047	239.5	85.0
857+64	129.7	4.5	96.0	123	3.88	90.4	0.042	271.6	92.1
857+34	135.9	4.7	100.6	130	6.10	55.5	0.051	218.5	80.1
857+28	131.7	5.0	97.5	159	5.77	58.8	0.034	344.1	107.2
856+86	136.4	4.7	101.3	135	4.75	71.5	0.032	368.3	111.9
856+72	140.0	4.6	103.6	173	4.78	70.7	0.021	590.3	151.4
AVG	134.7	4.7	99.8	141.1	5.0	70.6	0.0	287.2	94.0
Variance	8.9	0.036	5.0	1636.8	0.640	150.0	0.000149	15016.3	580.6
St. Dev.	3.0	0.189	2.2	40.5	0.800	12.2	0.012	122.5	24.1

Note: Cells highlighted in green used to set NDT targets.

Based on the results in Table 3.2, the target values for the evaluation section were identified as:

- Nuclear (reference value): 100 percent compaction minimum.
- PSPA modulus: 85 ksi minimum.
- PFWD deflection: 6.1 mils maximum.
- PFWD E1 modulus: 55.5 ksi minimum.
- DCP PR: 0.054 in/blow maximum.
- DCP CBR: 205 minimum.
- DCP E: 76.9 ksi minimum.

Results from Evaluation Section on FM 1460

Using the targets set from the control section, researchers tested an evaluation section from station 855 to 835. Figure 3.3 shows the devices used for the testing. Table 3.3 presents the results from the evaluation section. Table 3.3 shows the measured moisture content typically well below optimum, which was because of drying that had taken place between the time of compaction and the time of testing.

Figure 3.3. Collecting Test Data on FM 1460.

Table 3.3. Results from Evaluation Section on FM 1460.

Station	Nuclear			PSPA	PFWD		DCP		
	Dry Density (pcf)	Moisture (%)	Percent Compaction	Modulus (ksi)	D1 (mils)	E1 (ksi)	PR (in/blow)	CBR	E (ksi)
855	131.0	4.6	97.0	77	4.65	75.0	0.031	381.6313	114.497
854	134.8	4.6	99.8	182	6.51	52.9	0.041	279.03017	93.7037
853	131.4	4.7	97.3	158	3.94	88.9	0.059	185.61575	72.1861
852	133.2	4.6	98.6	78	2.99	116.7	0.068	158.3285	65.2016
851	130.6	4.0	96.6	124	5.62	59.9	0.079	133.85258	58.5573
850	130.9	4.0	96.9	191	3.08	110.3	0.053	209.30525	77.9542
849	128.6	3.8	95.2	91	5.26	65.4	0.076	139.78413	60.2051
848	128.4	4.1	95.1	105	4.84	70.5	0.231	40.246088	27.1371
847	133.5	4.3	98.9	212	2.85	122.1	0.071	150.85501	63.2147
846	135.6	3.9	100.4	182	2.74	130.3	0.032	368.29949	111.92
845	133.7	4.5	98.9	157	3.12	108.7	0.092	112.85654	52.4998
844	138.9	4.2	102.8	202	3.35	100.7	0.05	223.42033	81.2791
843	139.5	3.9	103.2	163	2.28	149.4	0.033	355.82256	109.479
842	134.3	3.3	99.4	127	4.40	76.1	0.059	185.61575	72.1861
841	134.6	4.5	99.6	308	3.22	103.1		*	
840	139.2	4.3	103.0	397	4.29	78.0	0.032	368.29949	111.92
839	137.5	4.8	101.8	285	3.92	85.6	0.073	146.23371	61.9684
838	136.8	4.9	101.2	257	2.41	145.9		*	
837	142.8	4.4	105.7	255	2.32	145.2	0.035	333.12934	104.957
836	142.9	4.4	105.8	308	2.78	120.7		*	
835	135.2	4.1	100.1	150	4.08	81.8	0.064	169.45232	68.0974
AVG	134.9	4.3	99.9	190.9	3.7	99.4	0.066	219.0	78.2
Variance	17.2	0.1	9.4	7214.1	1.3	856	0.002	10679	608.5
St. Dev	4.1	0.4	3.1	84.9	1.2	29.3	0.045	103.3	24.7

Nuclear Gauge Results from Evaluation Section

Figure 3.4 illustrates the results from the nuclear gauge over the evaluation section. Approximately 57 percent of the tests failed to meet the minimum density requirement.

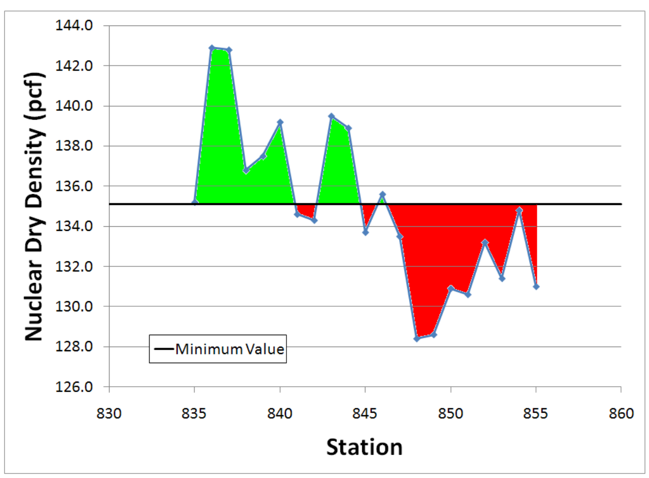

Figure 3.4. Nuclear Gauge Results from Evaluation Section on FM 1460.

PSPA Results from Evaluation Section

Figure 3.5 illustrates the results from the PSPA over the evaluation section. Approximately 10 percent of the tests failed to meet the minimum modulus set from the control strip. Figure 3.6 suggests, and statistical tests confirm, that within the range of measured moisture contents, no correlation existed between the measured water content and PSPA modulus.

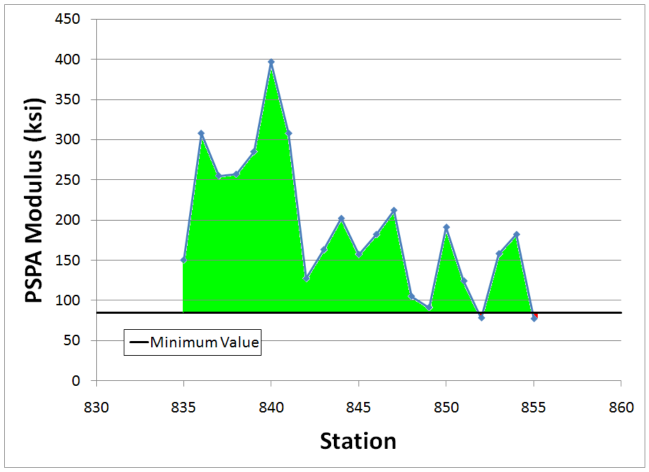

Figure 3.5. PSPA Results from Evaluation Section on FM 1460.

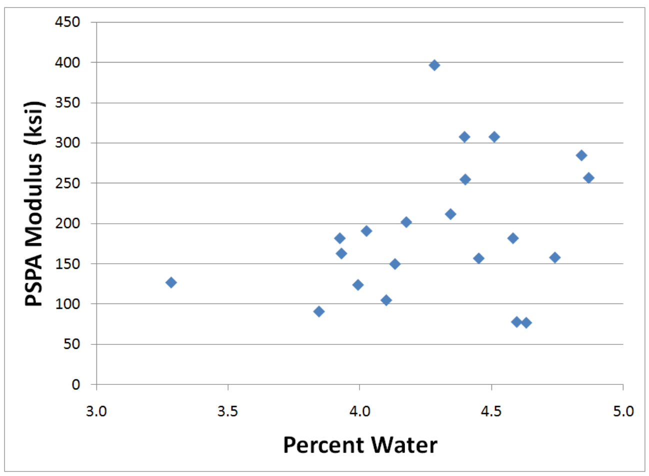

Figure 3.6. PSPA Modulus versus Percent Water on FM 1460 Evaluation Section.

PFWD Results from Evaluation Section

Figure 3.7 illustrates the results from the PFWD over the evaluation section. Approximately 5 percent of the tests failed to meet the maximum deflection set from the control strip. Figure 3.7 presents the results based only on deflection, since using the E1 modulus from the PFWD resulted in the same pass/fail results as using deflection. Figure 3.8 suggests, and statistical tests confirm, that within the range of measured moisture contents, no correlation existed between the measured water content and PFWD data.

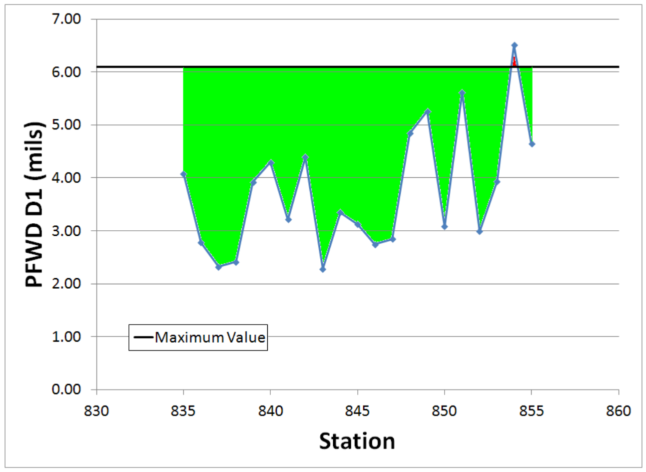

Figure 3.7. PFWD Results from Evaluation Section on FM 1460.

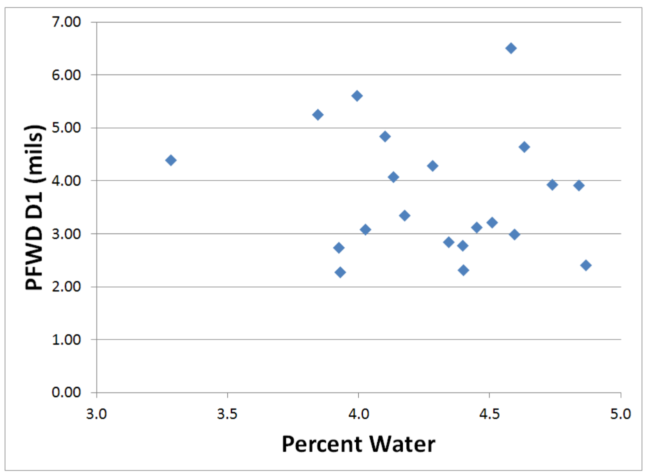

Figure 3.8. PFWD D1 versus Percent Water on FM 1460 Evaluation Section.

DCP Results from Evaluation Section

Figure 3.9 illustrates the results from the DCP over the evaluation section. Approximately 56 percent of the tests failed to meet the maximum penetration rate set from the control strip. Figure 3.10 suggests, and statistical tests confirm, that within the range of measured moisture contents, no correlation existed between the measured water content and DCP data.

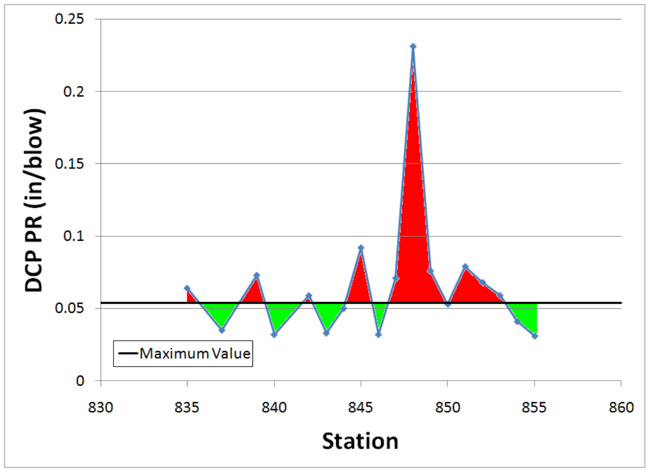

Figure 3.9. DCP PR Results from Evaluation Section on FM 1460.

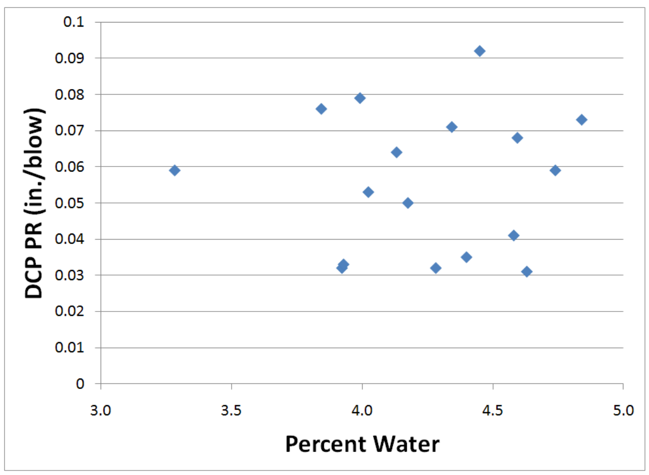

Figure 3.10. DCP Penetration Rate versus Percent Water on FM 1460 Evaluation Section.

Comparison of Pass/Fail Results on FM 1460 Evaluation Section

Figure 3.11 presents a summary comparison of the pass/fail results on the evaluation section from each of the devices. The results show that the DCP most closely matches the pass/fail results from the nuclear gauge. Pass/fail results from the PFWD and PSPA are similar to each other but dissimilar to the density and the DCP result.

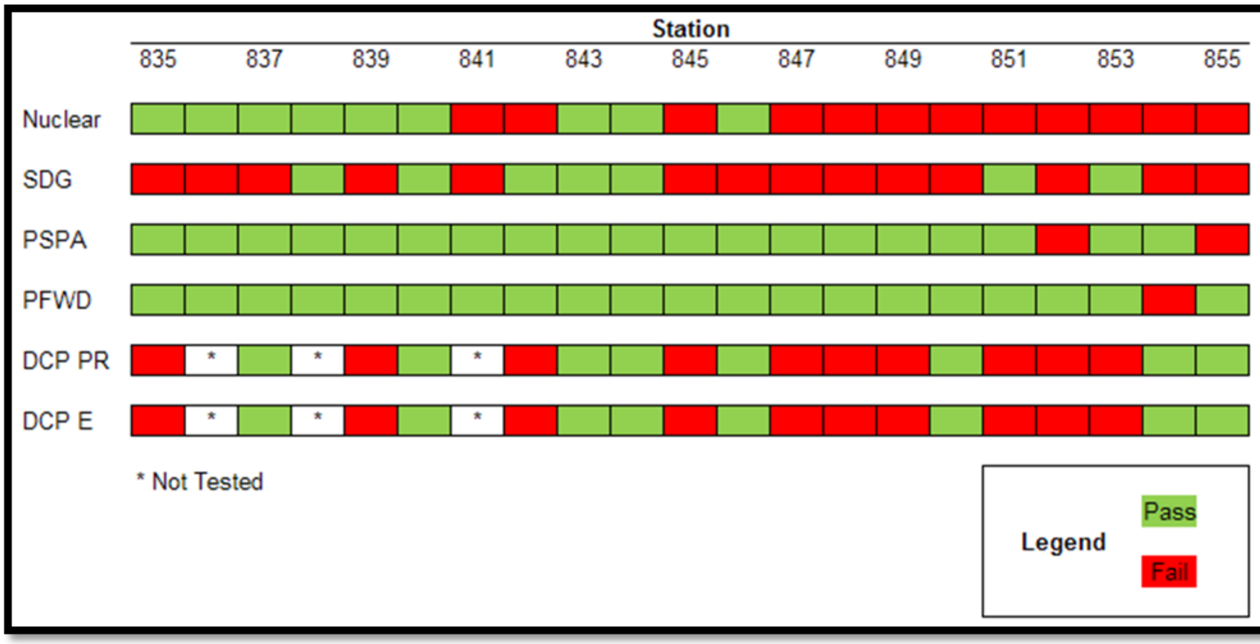

Figure 3.11. Comparison of Results from Devices on FM 1460 Evaluation Section.

CONCLUSIONS

The purpose of the evaluation on FM 1460 was to evaluate setting an NDT acceptance target based upon the prior achievement of 100 percent density and then use that NDT target to evaluate a long section in parallel with the nuclear density gauge. In shadow testing on the evaluation section, analysis of the data the DCP as the preferred device in lieu of the nuclear density gauge.

One problem with this test site was at the time of testing, the base was several percentage points below optimum due to the field practice of long delay times (often several days) between completing compaction and acceptance testing. The research team believes the intent of TxDOT's specifications is that the compacted section should meet requirements upon cessation of rolling. Testing and data analysis on projects at the time of completing compaction (when the base is at or near optimum water content) may or may not produce results that lead to the same conclusions.

CHAPTER 4: TEST RESULTS FROM ROSE LANE

OVERVIEW

On April 7, 2011, TTI researchers performed an evaluation of flexible base compaction on Rose Lane in Bell County. Researchers performed the testing to evaluate setting an NDT acceptance target based upon the prior achievement of 100 percent density and then using that NDT target to evaluate a longer section in parallel with the nuclear density gauge. The Grade 4 flexible base on this project had a Tex-113-E maximum density of 131.3 pcf at 8.8 percent moisture. Table 4.1 presents the Item 247 specification test results for this base material.

Table 4.1. Item 247 Specification Test Results.

Gradation		Compaction Test		Wet Ball Mill		Plasticity Index		Strength Test	
Sieve Size	Cumulative Percent Retained	Max Density (pcf)	131.3	Ball Mill Value	36	Liquid Limit	*	Lateral Pressure (psi)	Strength (psi)
1 1/2	0	Percent Water	8.8	Increase in - #40	13	Plastic Limit	14	0	44.7
7/8	23.5	*This space intentionally left blank*				Plasticity Index	2.4	3	123.3
3/8	49.5					Linear Shrinkage (%)	1.5	5	117.2
#4	61.9							7	160.5
#40	78.8							10	178.3
								15	216.6

* Not available

Due to miscommunications, a section of flexible base fully ready for acceptance testing did not exist upon the research team's arrival at the project site. However, researchers proceeded to evaluate a section identified by TxDOT. The section evaluated employed two 4 in. lifts of flexible base, and the bottom lift had already been accepted. The testing was performed on the top lift, which was placed on April 4, but as of April 7 had not been tested yet for acceptance.

TESTING SEQUENCE

TTI researchers selected locations between stations 25+00 and 26+00 as a control section to set NDT targets. Next, data were collected at 50 ft intervals from station 26+50 to 32+00 as an evaluation section.

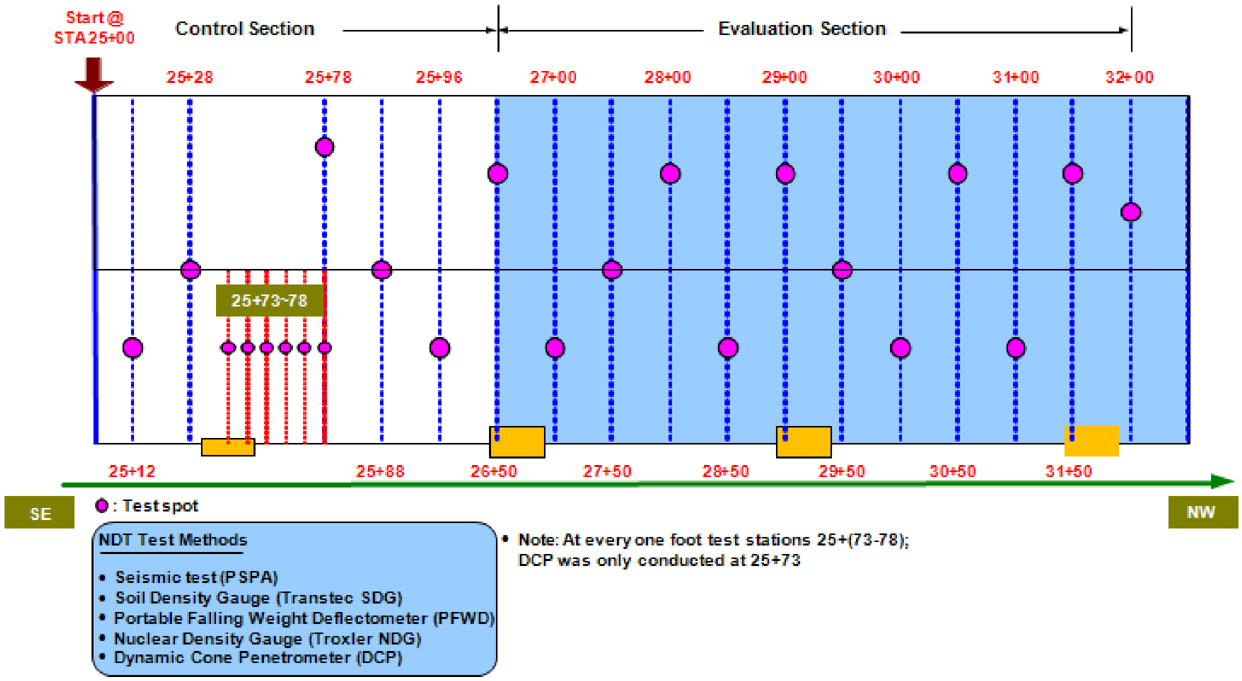

Figure 4.1. Test Sequence on Rose Lane.

Figure 4.2 shows the test site. As Figure 4.2 shows, the base was not completely finished, so special efforts were made to obtain a testable surface. Under the circumstances, the approaches taken were the best available options to collect test data; in reality, the section was not complete and required further work by the contractor before acceptance testing should have been performed.

Figure 4.2. Location of Testing on Rose Lane and Site Preparation Required.

Results from Control Strip on Rose Lane

Table 4.2 presents the results from the control strip testing on Rose Lane. Researchers used these data to set the NDT targets by first highlighting the passing nuclear density values. Next, the targets for other test devices were identified as the most permissive NDT value that had a corresponding passing nuclear density. This approach assumes a relationship between NDT properties and density such that once the most easily obtained NDT value is identified that corresponds with passing density control, locations with stronger/stiffer NDT characteristics will also meet density control. In Table 4.1, the NDT targets are highlighted in green.

Table 4.2. Results from Control Strip on Rose Lane.

Station	Nuclear				PSPA	PFWD		DCP		
	Dry Density (pcf)	Wet Density (pcf)	Moisture (%)	Compaction (%)	Modulus (ksi)	D1 (mils)	E1 (ksi)	PR (in/blow)	CBR	E (ksi)
25+73	129.2	137.0	6.1	98.4	87	5.47	55.4	0.115	87.6	44.7
25+74	135.4	143.6	6.1	103.1	99	6.85	43.7	Not Tested		
25+75	136.5	144.5	5.8	104.0	127	6.73	44.7			
25+76	136.8	144.6	5.7	104.2	73	7.60	39.7			
25+77	137.6	145.7	5.9	104.8	113	7.05	42.8			
25+78	134.5	143.0	6.3	102.4	89	6.61	45.7			
25+12	131.3	139.4	6.2	100.0	86.3	7.89	38.8	0.098	104.3	49.9
25+28	137.0	144.8	5.7	104.4	123.3	5.14	58.2	0.075	141.0	60.5
25+78	131.9	140.5	6.5	100.4	86.7	7.44	40.7	0.098	104.6	50.0
25+88	133.8	141.9	6.1	101.9	123.3	6.43	47.4	0.109	93.3	46.5
25+96	133.4	141.9	6.4	101.6	85.3	6.14	49.0	0.147	66.7	37.5
Avg.	134.3	142.4	6.1	102.3	99.4	6.67	46.0	0.1	99.6	48.2
Variance	7.2	7.0	0.073	4.3	358.2	0.72	38.5	0.001	604.5	57.7
St. Dev.	2.7	2.6	0.3	2.1	18.9	0.85	6.2	0.024	24.6	7.6

Note: Cells highlighted in green used to set NDT targets.

Based on the results in Table 4.2, the target values for the evaluation section were identified as:

- Nuclear: 100 percent compaction (reference value).
- PSPA modulus: 73 ksi minimum.
- PFWD deflection: 7.89 mils maximum.
- PFWD E1 modulus: 38.8 ksi minimum.
- DCP PR: 0.147 in./blow maximum.
- DCP CBR: 67 minimum.
- DCP E: 38 ksi minimum.

Results from Evaluation Section on Rose Lane

Using the targets set from the control section, researchers tested an evaluation section from station 855 to 835 at 50 ft intervals. Figure 4.3 shows the devices used for the testing. Table 4.3 presents the results from the evaluation section.

Figure 4.3. Collecting Test Data on Rose Lane.

Table 4.3. Results from Evaluation Section on Rose Lane.

	Nuclear				PSPA	PFWD		DCP		
Station	Dry Density (pcf)	Wet Density (pcf)	Moisture (%)	Compaction (%)	Modulus (ksi)	D1 (mils)	E1 (ksi)	PR (in/blow)	CBR	E (ksi)
26+50	129.4	137.4	6.1	98.6	92.7	5.13	61.4	0.093	111.5	52.1
27+00	136.3	144.1	5.8	103.8	99.7	6.97	44.0	0.131	76.1	40.8
27+50	137.4	144.8	5.4	104.7	58.3	4.67	68.2	0.102	100.2	48.7
28+00	133.9	141.4	5.6	102.0	79.3	5.67	55.3	0.124	80.6	42.3
28+50	135.4	143.5	6.0	103.1	113.7	6.98	43.8	0.108	94.8	47.0
29+00	134.1	142.2	6.1	102.1	93.7	5.17	59.4	0.113	89.6	45.3
29+50	137.0	144.0	5.1	104.3	145.0	6.00	50.5	0.090	115.4	53.2
30+00	134.3	143.0	6.5	102.3	106.7	7.81	39.3	0.114	88.6	45.0
30+50	134.8	143.2	6.2	102.7	65.0	6.69	44.5	0.124	80.9	42.4
31+00	135.9	144.7	6.5	103.5	94.0	7.14	42.9	0.105	97.8	47.9
31+50	135.9	144.7	6.5	103.5	103.3	4.49	69.3	0.128	77.7	41.3
32+00	132.3	139.3	5.3	100.8	163.3	5.70	70.3	0.100	102.5	49.3
Avg.	134.7	142.7	5.9	102.6	101.2	6.03	54.1	0.111	93.0	46.3
Variance	4.9	5.3	0.2	2.8	889.0	1.15	130.1	0.000	169.5	17.1
St. Dev.	2.1	2.2	0.5	1.6	28.5	1.03	10.9	0.013	12.5	4.0

Comparison of Pass/Fail Results on Rose Lane Evaluation Section

Figure 4.4 presents a comparison of the pass/fail results on the evaluation section from each of the devices. The results show that the PFWD and DCP most closely match the pass/fail results from the nuclear gauge.

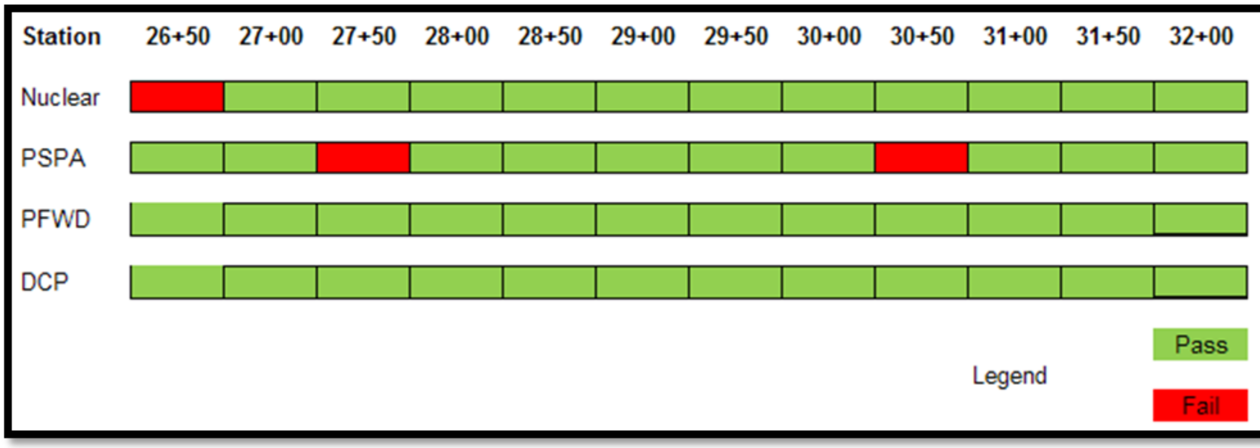

Figure 4.4. Comparison of Results from Devices on Rose Lane Evaluation Section.

CONCLUSIONS

The purpose of the evaluation on Rose Lane was to evaluate setting an NDT acceptance target based upon the prior achievement of 100 percent density and then use that NDT target to evaluate a long section in parallel with the nuclear density gauge. Within that context, the data from Rose Lane showed the PFWD and DCP as the preferred NDT devices in lieu of density testing. While these devices most closely matched the pass/fail results from the density gauge in parallel testing on this particular project, the reality was this site needed more work from the contractor prior to acceptance testing. It appeared the site was deficient on thickness, as evidenced by protruding blue top stakes in portions of the section. Additionally, at the time of testing, the base was several percentage points below optimum. While this moisture content state may be similar to common practice when testing using density control, the research team believes the intent of TxDOT specifications is to meet requirements immediately upon completion of compaction. Testing and data analysis on projects at the time of completing compaction (when the base is at or near optimum water content) may or may not produce results that lead to the same conclusions.

CHAPTER 5: CONSIDERATIONS FOR TESTING FREQUENCY

OVERVIEW

Determining an appropriate field testing frequency for flexible base construction must balance producer risk, consumer risk, and testing workload, while protecting the interests of the public. TxDOT's current guide schedule for flexible base acceptance requires a minimum of one test for each 3000 CY. According to the guide schedule, this test frequency results in producer and consumer risks somewhere between 20 and 40 percent.

DEFINITIONS OF TERMS

Evaluating alternative acceptance plans requires the following parameters:

- Producer's risk (α): the probability of a statistical Type I error.
- Consumer's risk (β): the probability of a statistical Type II error.
- Sample size (n): the number of samples evaluated by the sampling scheme.
- Maximum tolerable error (e): the maximum error between the observed mean from n samples and the true population mean value (with $1 - \alpha$ confidence).

Evaluation of Sampling Schemes

The number of samples required is determined with the following:

$$n = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \sigma^2}{e^2}$$

From the flexible base courses tested in this project (described both in Report 0-6587-1 and this report), the pooled standard deviation of in place percent density was 2.65, meaning $\sigma^2 = 7.02$. The appropriate Z values are determined from the standard normal distribution for given levels of α and β. For purposes of this analysis, researchers used levels of α and β from 0.05 to 0.4, and researchers also assumed that TxDOT would desire the producer and contractor risks to be equal.

Current TxDOT specifications allow acceptance of flexible base sections so long as the in-place density is no more than 3 pcf below the specified density. For most flexible base materials used in Texas, this would translate to between 2 and 2.5 percent low of 100 percent compaction. Therefore, TxDOT's current specification implies a maximum tolerable error of around 2 to 2.5 percent.

Based on the described assumptions, Table 5.1 presents the number of samples required for varying levels of α, β, and e. The results show TxDOT's current sequence of 1 test per 3000 CY results in producer and consumer risks of about 40 percent with a maximum error of 3 percent. To be consistent with the implications on error in TxDOT's current specification, the number of tests should be increased to 2 or 3, which would reduce the error but still result in high risk levels. In most statistical analyses, risk levels between 5 and 10 percent are generally used. Table 5.1 shows that to obtain a maximum error between 2 and 2.5 percent and reduce the contractor and TxDOT risk levels to between 0.05 and 0.10, between 10 and 23 samples must be tested.

Table 5.1 Number of Samples for In-Place Percent Density.

Producer (α) and Consumer (β) Risk	Maximum Error for Percent Density						
	1	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
0.05	92	41	23	15	11	8	6
0.1	61	27	16	10	7	5	4
0.2	32	15	8	6	4	3	2
0.3	18	8	5	3	2	2	2
0.4	9	4	3	2	1	1	1

Figure 5.1 illustrates how risk level and maximum error impact the required number of samples. The figure shows the exponential increase in the required number of samples as the maximum error is reduced.

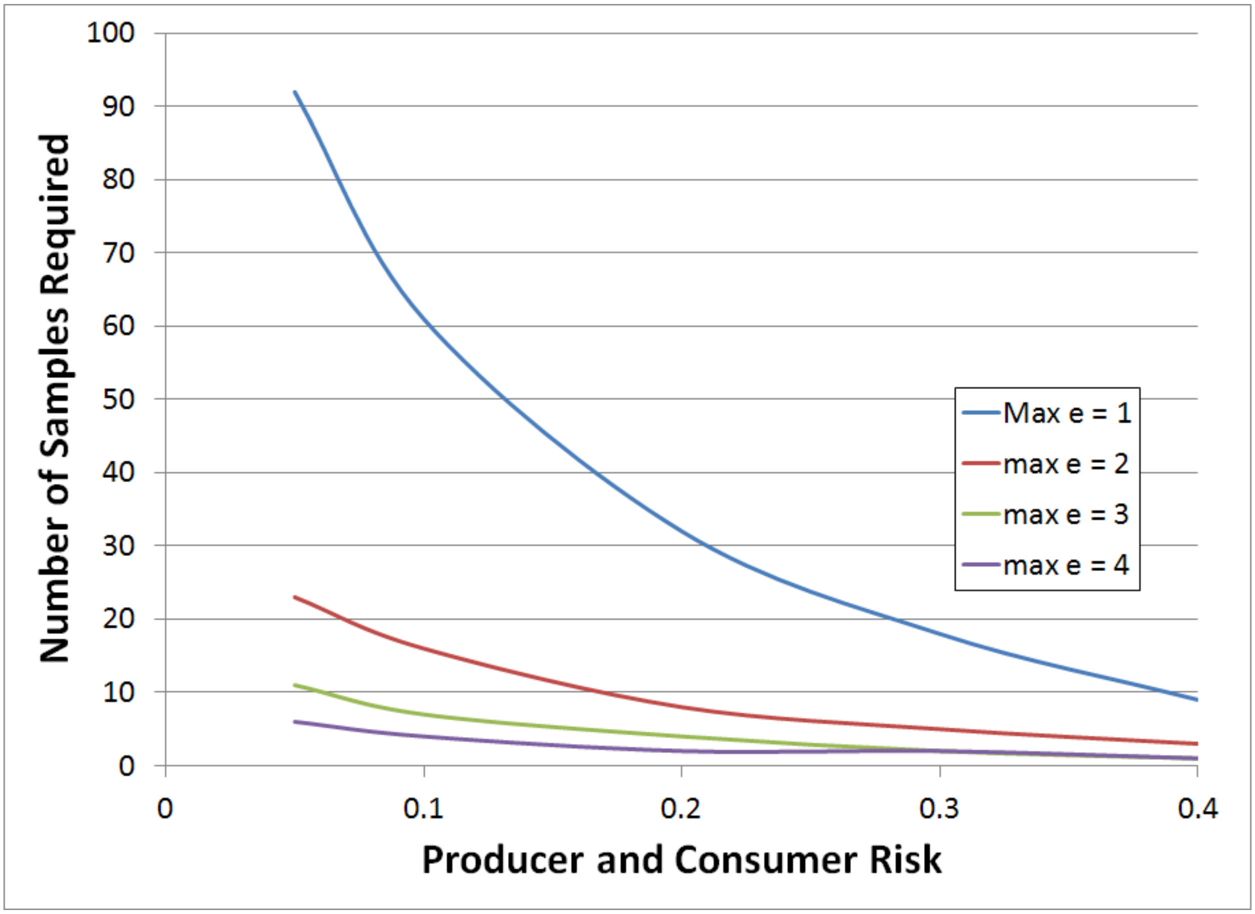

Figure 5.1. Impact of Risk and Maximum Error on Number of Required Samples.

CONCLUSIONS

TxDOT should change the minimum test frequency for flexible base compaction acceptance to require at least 2 tests per 3000 CY. This sampling scheme would harmonize the acceptance scheme with the maximum error implied in TxDOT's construction specification. However, both contractor and TxDOT risk would remain around 40 percent. To achieve harmony among the acceptance scheme and construction specification while reducing contractor and TxDOT risks to 10 percent would require at least 10 tests. TxDOT should dialogue with industry to solidify whether buy-in exists for reduced risk levels.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This project explored the use of non-density-based NDT devices, including the PSPA, PFWD, and DCP, for compaction testing of flexible base, and employed testing with these devices in parallel with the nuclear density gauge. Data collected at the time of compaction showed that at least some Texas flexible bases improve in mechanical properties with an increased compaction effort even if statistically significant gains in density are not realized. This observation matches observations from prior work (*1*). The field evaluations also suggest that the DCP and PFWD are preferred to the PSPA for compaction acceptance, since the former two devices are better able to detect improvements in mechanical properties with increasing compactive effort in changing moisture content conditions. As compared to the PFWD, the DCP also has the added advantage of measuring properties through the depth profile of the material under test.

While field testing demonstrated the feasibility of setting NDT targets using a control strip, the field testing also suggested the existing MnDOT specifications for compaction acceptance with the DCP should be adjusted slightly for Texas bases. In general, the MnDOT criteria were too easily met on TxDOT projects.

The field evaluations also showed that the test timing is critical. Common practice in TxDOT seems to be to allow the base to dry back for several days prior to acceptance testing. This practice seems to contradict the intent of density control, and this practice makes implementation of non-density-based acceptance difficult due to the changing nature of flexible base mechanical properties at significantly different water contents. The research team believes any move to one of the new NDT devices must be accompanied with stricter moisture content and/or test timing requirements.

Recommendation for Alternative Test Device

While the field results described in this report suggest that the DCP and PFWD both may be acceptable for flexible base compaction acceptance, the DCP should be the preferred alternative device for the following reasons:

- In shadow testing, the DCP most closely matched the pass/fail results from the nuclear density gauge.
- In prior evaluation of these devices, the DCP better distinguished among locations of systematic differences in compaction effort (*1*).
- The DCP has already been implemented in another DOT for compaction acceptance of granular materials (*2-7*).

Recommendation for Specification Modifications

If TxDOT desires to perform compaction acceptance using a test device other than the nuclear density gauge, TxDOT should consider modifying the flexible base construction specification to allow for use of the DCP penetration index. The research team recommends an approach similar to that used by MnDOT, with the exception of making the acceptance criteria more stringent.

Over the course of two years, the data collected in this project on Texas flexible bases when tested shortly after compaction (typically within a few hours) and near optimum water content showed seat values (the depth of DCP penetration after two blows) ranging from 0.8 to 1.3 in., and penetration rates (the rate of penetration from the depth of seating through the remaining thickness of the base layer) ranging from 0.25 to 0.38 in. per blow, with typical values of well compacted layers around or below 0.3 in. per blow. With these observations considered, the research team recommends the following DCP criteria:

- The seat index should not exceed 1.3 in.
- The penetration index should not exceed 0.3 in. per blow.

Based upon other findings in this project, the following additional specification modifications should be considered:

- The maximum lift thickness should be restricted to 6 in.
- The moisture content during compaction should contain an upper limit of no more than 1.5 percentage points above optimum.
- Compaction acceptance testing should take place within 16 hours of the completion of compaction.
- Setting DCP target values through a field control strip should be allowed.

Finally, based upon past research projects and the expressed desires from producers and TxDOT for a flexible specification, the following modification to the approved grades of material should be considered:

- Provisions to allow restrictions on the minus No. 200 content (when shown on the plans) should be added (*8-11*).
- The grade of materials should be expanded to include a grade requiring tight control on gradation without a strength requirement. This grade would relieve the producer from strength testing while providing TxDOT some assurance of mechanical properties through tight quality management during production.
- The grade of materials should be expanded to include a grade with minimal requirements on material. This grade would allow the producer flexibility in production so long as he or she is willing to bear the risk of the material meeting the mechanical requirements imposed by the use of the DCP at the time of compaction acceptance.

Appendix A presents a draft flexible base construction specification incorporating the recommended construction specification modifications.

Recommendation for New Test Procedure

Based upon the recommendation for the DCP to serve as an alternative method of compaction acceptance in lieu of the nuclear density gauge, TxDOT should consider adopting a test procedure for the DCP. Appendix B to this report presents a draft test procedure using the DCP.

Recommendation for Test Frequency

The test frequency in TxDOT's guide schedule should be changed to at least 2 tests per 3000 CY. This sampling scheme would harmonize the acceptance scheme with the maximum error implied in TxDOT's construction specification. However, both contractor and TxDOT risk would remain around 40 percent. To achieve harmony among the acceptance scheme and construction specification while reducing contractor and TxDOT risks to 10 percent would require at least 10 tests. TxDOT should dialogue with industry to solidify whether buy-in exists for reduced risk levels.

Recommendation for Future Work

TxDOT should shadow test the revised flexible base specification and test procedure in Appendices A and B on upcoming construction projects in parallel with the existing construction specification. Projects of varying flexible base grades and rock types around the state should be included to determine what changes may be needed and whether any specific issues arise with different flexible base grades or mineralogy.

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APPENDIX A:
DRAFT FLEXIBLE BASE CONSTRUCTION SPECIFICATION

Note: highlighted text in draft specification indicates new or modified wordings.

Item 247

FLEXIBLE BASE

204.1. Description. Construct a foundation course composed of flexible base.

204.2. Materials. Furnish uncontaminated materials of uniform quality that meet the requirements of the plans and specifications. Notify the Engineer of the proposed material sources and of changes to material sources. The Engineer may sample and test project materials at any time before compaction throughout the duration of the project to assure specification compliance. Use Tex-100-E material definitions.

A. Aggregate. Furnish aggregate of the type and grade shown on the plans and conforming to the requirements of Table 1. Each source must meet Table 1 requirements for liquid limit, plasticity index, and wet ball mill for the grade specified. Do not use additives such as but not limited to lime, cement, or fly ash to modify aggregates to meet the requirements of Table A-1, unless shown on the plans.

Table A-1. Material Requirements.

Property	Test Method	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6[3]	Grade 7[3]
Master gradation sieve size (cumulative % retained)	Tex-110-E							
2-1/2 in.		–	0	0	As shown on the plans	0	0	0
1-3/4 in.		0	0–10	0–10		0–5	0–5	-
7/8 in.		10–35	–	–		10–35	10–45	-
3/8 in.		30–50	–	–		35–65	40–60	-
No. 4		45–65	45–75	45–75		45–75	45–70	-
No. 40		70–85	60–85	50–85		70–90	75–90	-
No. 200		When shown on the plans		-		When shown on the plans	90–100	-
Liquid limit, % max.[1]	Tex-104-E	35	40	40		35	25	As shown on the plans
Plasticity index, max.[1]	Tex-106-E	10	12	12		10	8	
Plasticity index, min.[1]		As shown on the plans						
Wet ball mill, % max.[2]	Tex-116-E	40	45	–	As shown on the plans	40	40	As shown on the plans
Wet ball mill, % max. increase passing the No. 40 sieve		20	20	–		20	15	
Min. compressive strength, psi	Tex-117-E							
Lateral pressure 0 psi		45	35	–	–	-	-	-
Lateral pressure 3 psi		–	–	–	As shown on the plans	90	-	-
Lateral pressure 15 psi		175	175	–		175	-	-

[1] Determine the plastic index in accordance with Tex-107-E (linear shrinkage) when liquid limit is unattainable as defined in Tex-104-E.
[2] When a soundness value is required by the plans, test material in accordance with Tex-411-A.
[3] Only compaction Method C or Method D can be used for this grade.

1. **Material Tolerances.** The Engineer may accept material if no more than 1 of the 5 most recent gradation tests has an individual sieve outside the specified limits of the gradation.

   When target grading is required by the plans, no single failing test may exceed the master grading by more than 5 percentage points on sieves No. 4 and larger or 3 percentage points on sieves smaller than No. 4.

   The Engineer may accept material if no more than 1 of the 5 most recent plasticity index tests is outside the specified limit. No single failing test may exceed the allowable limit by more than 2 points.

2. **Material Types.** Do not use fillers or binders unless approved. Furnish the type specified on the plans in accordance with the following.

   a. **Type A.** Crushed stone produced and graded from oversize quarried aggregate that originates from a single, naturally occurring source. Do not use gravel or multiple sources.

   b. **Type B.** Crushed or uncrushed gravel. Blending of 2 or more sources is allowed.

   c. **Type C.** Crushed gravel with a minimum of 60% of the particles retained on a No. 4 sieve with 2 or more crushed faces as determined by Tex-460-A, Part I. Blending of 2 or more sources is allowed.

   d. **Type D.** Type A material or crushed concrete. Crushed concrete containing gravel will be considered Type D material. Crushed concrete must meet the requirements in Section 247.2.A.3.b, "Recycled Material (Including Crushed Concrete) Requirements," and be managed in a way to provide for uniform quality. The Engineer may require separate dedicated stockpiles in order to verify compliance.

   e. **Type E.** As shown on the plans.

3. **Recycled Material.** Recycled asphalt pavement (RAP) and other recycled materials may be used when shown on the plans. Request approval to blend 2 or more sources of recycled materials.

   a. **Limits on Percentage.** When RAP is allowed, do not exceed 20% RAP by weight unless otherwise shown on the plans. The percentage limitations for other recycled materials will be as shown on the plans.

   b. **Recycled Material (Including Crushed Concrete) Requirements.**

      (1) **Contractor-Furnished Recycled Materials.** When the Contractor furnishes the recycled materials, including crushed concrete, the final product will be subject to the requirements of Table 1 for the grade specified. Certify compliance with DMS-11000, "Evaluating and Using Nonhazardous Recyclable Materials Guidelines," for Contractor-furnished recycled materials. In addition, recycled materials must be free from reinforcing steel and other objectionable material and have at most 1.5% deleterious material when tested in accordance with Tex-413-A. For RAP, do not exceed a maximum percent loss from decantation of 5.0% when tested in accordance with Tex-406-A. Test RAP without removing the asphalt. Provide recycled materials that have a maximum sulfate content of 3000 ppm when tested in accordance with Tex-145-E.

      (2) **Department-Furnished Required Recycled Materials.** When the Department furnishes and requires the use of recycled materials, unless otherwise shown on the plans:
      - Department-required recycled material will not be subject to the requirements in Table 1,
      - Contractor-furnished materials are subject to the requirements in Table 1 and this Item,
      - The final product, blended, will be subject to the requirements in Table 1, and
      - For final product, unblended (100% Department-furnished required recycled material), the liquid limit, plasticity index, wet ball mill, classification, and compressive strength is waived.

      Crush Department-furnished RAP so that 100% passes the 2 in. sieve. The Contractor is responsible for uniformly blending to meet the percentage required.

      (3) **Department-Furnished and Allowed Recycled Materials.** When the Department furnishes and allows the use of recycled materials or allows the Contractor to furnish recycled materials, the final blended product is subject to the requirements of Table 1 and the plans.

   c. **Recycled Material Sources.** Department-owned recycled material is available to the Contractor only when shown on the plans. Return unused Department-owned recycled materials to the Department stockpile location designated by the Engineer unless otherwise shown on the plans.

The use of Contractor-owned recycled materials is allowed when shown on the plans. Contractor-owned surplus recycled materials remain the property of the Contractor. Remove Contractor-owned recycled materials from the project and dispose of them in accordance with federal, state, and local regulations before project acceptance. Do not intermingle Contractor-owned recycled material with Department-owned recycled material unless approved by the Engineer.

B. Water. Furnish water free of industrial wastes and other objectionable matter.

C. Material Sources. When non-commercial sources are used, expose the vertical faces of all strata of material proposed for use. Secure and process the material by successive vertical cuts extending through all exposed strata, when directed.

204.3. Equipment. Provide machinery, tools, and equipment necessary for proper execution of the work. Provide rollers in accordance with Item 210, "Rolling." Provide proof rollers in accordance with Item 216, "Proof Rolling," when required.

204.4. Construction. Construct each layer uniformly, free of loose or segregated areas, and with the required density and moisture content. Provide a smooth surface that conforms to the typical sections, lines, and grades shown on the plans or as directed.

Stockpile base material temporarily at an approved location before delivery to the roadway. Build stockpiles in layers no greater than 2 ft. thick. Stockpiles must have a total height between 10 and 16 ft. unless otherwise shown on the plans. After construction and acceptance of the stockpile, loading from the stockpile for delivery is allowed. Load by making successive vertical cuts through the entire depth of the stockpile.

Do not add or remove material from temporary stockpiles that require sampling and testing before delivery unless otherwise approved. Charges for additional sampling and testing required as a result of adding or removing material will be deducted from the Contractor's estimates.

Haul approved flexible base in clean trucks. Deliver the required quantity to each 100 ft. station or designated stockpile site as shown on the plans. Prepare stockpile sites as directed. When delivery is to the 100 ft. station, manipulate in accordance with the applicable items.

A. Preparation of Subgrade or Existing Base. Remove or scarify existing asphalt concrete pavement in accordance with Item 105, "Removing Stabilized Base and Asphalt Pavement," when shown on the plans or as directed. Shape the subgrade or existing base to conform to the typical sections shown on the plans or as directed.

When new base is required to be mixed with existing base, deliver, place, and spread the new flexible base in the required amount per station. Manipulate and thoroughly mix the new base with existing material to provide a uniform mixture to the specified depth before shaping.

When shown on the plans or directed, proof roll the roadbed in accordance with Item 216, "Proof Rolling," before pulverizing or scarifying. Correct soft spots as directed.

B. Placing. Spread and shape flexible base into a uniform layer with an approved spreader the same day as delivered unless otherwise approved. Construct layers to the thickness shown on the plans. Maintain the shape of the course. Control dust by sprinkling, as directed. Correct or replace segregated areas as directed, at no additional expense to the Department.

Place successive base courses and finish courses using the same construction methods required for the first course.

C. Compaction. Compact in lifts not to exceed 6 inches unless otherwise shown on the plans or approved. Bring each layer to the moisture content directed. When necessary, sprinkle the material in accordance with Item 204, "Sprinkling."

Use approved rolling equipment complying with Item 210, "Rolling," to compact each layer. Begin rolling longitudinally at the sides and proceed toward the center, overlapping on successive trips by at least 1/2 the width of the roller unit. On superelevated 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.

Rework, recompact, and refinish material that fails to meet or that loses required moisture, density, stability, or finish before the next course is placed or the project is accepted. Continue work until specification requirements are met. Perform the work at no additional expense to the Department.

Before final acceptance, the Engineer will select the locations of tests and measure the flexible base depth in accordance with Tex-140-E when Complete in Place measurement is specified. Correct areas deficient by more than 1/2 in. in thickness by scarifying, adding material as required, reshaping, recompacting, and refinishing at the Contractor's expense.

Method A - Ordinary Compaction. Compact each lift until there is no evidence of further consolidation and adequate stability is achieved. Maintain moisture during compaction at not less than 1.0 percentage point below and not more than 1.5 percentage point above the optimum moisture content determined by Tex-113-E. Proof roll in accordance with Item 216 and correct irregularities, depressions, and weak spots immediately by scarifying the areas affected, adding or removing approved material as required, reshaping, and recompacting. The Engineer may waive proof rolling when intelligent compaction methods are used, in accordance with Tex-1XX-E, and compaction can be demonstrated using these methods on test strips.

Method B - Density Control. Compact to at least 100% of the maximum dry density determined by Tex-113-E, unless otherwise shown on the plans. Maintain moisture during compaction at not less than 1 percentage point below and not more than 1.5 percentage point above the optimum moisture content determined by Tex-113-E. Determine the moisture content of the material in accordance with Tex-115-E or Tex-103-E during compaction daily and report the results the same day to the Engineer, unless otherwise shown on the plans or directed.

The Engineer will determine roadway density of completed sections in accordance with Tex-115-E within 16 hours of the completion of compaction. The Engineer may accept the section if no more than 1 of the 5 most recent density tests is below the specified density and the failing test is no more than 3 pcf below the specified density.

Method C - Optimized Compaction. Using a control strip at least 300 ft. long, compact until the DCP seat and penetration index no longer decrease. Maintain moisture during compaction at not less than 1.0 percentage point below and not more than 1.5 percentage point above the optimum moisture content determined by Tex-113-E. Between successive rolling operations during construction of the control strip, the Engineer will determine the seat and penetration index in accordance with Penetration Index of Flexible Base (Draft). Construct a new control strip as a minimum each 6000 CY.

After construction of the control strip, compact until the DCP seat and penetration index meet the minimum values determined from the control strip. Maintain moisture during compaction at not less than 1 percentage point below and not more than 1.5 percentage point above the optimum moisture content determined by Tex-113-E. Determine the moisture content of the material in accordance with Tex-115-E or Tex-103-E during compaction daily and report the results the same day to the Engineer, unless otherwise shown on the plans or directed. The Engineer will determine the seat and penetration index of completed sections in accordance with Penetration Index of Flexible Base (Draft) within 16 hours of the completion of compaction.

Method D - Penetration Index. Compact until the seat and penetration index meet the requirements in Table A- 2. Maintain moisture during compaction at not less than 1.0 percentage point below and not more than 1.5 percentage point above the optimum moisture content determined by Tex-113-E. Determine the moisture content of the material in accordance with Tex-115-E or Tex-103-E during compaction daily and report the results the same day to the Engineer, unless otherwise shown on the plans or directed.

The Engineer will determine the seat and penetration index of completed sections in accordance with Penetration Index of Flexible Base (Draft) within 16 hours of the completion of compaction.

Table A-2. Penetration Index Requirements

Maximum Seat Index	Maximum Penetration Index
1.3 inches	0.3 inches

D. Finishing. After completing compaction, clip, skin, or tight-blade the surface with a maintainer or subgrade trimmer to a depth of approximately 1/4 in. Remove loosened material and dispose of it at an approved location. Seal the clipped surface immediately by rolling with a pneumatic tire roller until a smooth surface is attained. Add small increments of water as needed during rolling. Shape and maintain the course and surface in conformity with the typical sections, lines, and grades as shown on the plans or as directed.

In areas where surfacing is to be placed, correct grade deviations greater than 1/4 in. in 16 ft. measured longitudinally or greater than 1/4 in. over the entire width of the cross-section. Correct by loosening, adding, or removing material. Reshape and recompact in accordance with Section 247.4.C, “Compaction.”

E. Curing. Cure the finished section until the moisture content is at least 25 percent below optimum moisture or as directed before applying the next successive course or prime coat.

204.5. Measurement. Flexible base will be measured as follows:

- **Flexible Base (Complete In Place).** The ton, square yard, or any cubic yard method.
- **Flexible Base (Roadway Delivery).** The ton or cubic yard in vehicle.
- **Flexible Base (Stockpile Delivery).** The ton, cubic yard in vehicle, or cubic yard in stockpile.

Measurement by the cubic yard in final position and square yard is a plans quantity measurement. The quantity to be paid for is the quantity shown in the proposal unless modified by Article 9.2, “Plans Quantity Measurement.” Additional measurements or calculations will be made if adjustments of quantities are required.

Measurement is further defined for payment as follows.

A. Cubic Yard in Vehicle. By the cubic yard in vehicles of uniform capacity at the point of delivery.

B. Cubic Yard in Stockpile. By the cubic yard in the final stockpile position by the method of average end areas.

C. Cubic Yard in Final Position. By the cubic yard in the completed and accepted final position. The volume of base course is computed in place by the method of average end areas between the original subgrade or existing base surfaces and the lines, grades, and slopes of the accepted base course as shown on the plans.

D. Square Yard. By the square yard of surface area in the completed and accepted final position. The surface area of the base course is based on the width of flexible base as shown on the plans.

E. Ton. By the ton of dry weight in vehicles as delivered. The dry weight is determined by deducting the weight of the moisture in the material at the time of weighing from the gross weight of the material. The Engineer will determine the moisture content in the material in accordance with Tex-103-E from samples taken at the time of weighing.

When material is measured in trucks, the weight of the material 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.”

204.6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for the types of work shown below. No additional payment will be made for thickness or width exceeding that shown on the typical section or provided on the plans for cubic yard in the final position or square yard measurement.

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 will be at the Contractor’s expense. Where subgrade is not constructed under this project, correction of soft spots in the subgrade will be paid in accordance with pertinent Items or Article 4.2, “Changes in the Work.”

A. Flexible Base (Complete In Place). Payment will be made for the type and grade specified. For cubic yard measurement, “In Vehicle,” “In Stockpile,” or “In Final Position” will be specified. For square yard measurement, a depth will be specified. This price is full compensation for furnishing materials, temporary stockpiling, assistance provided in stockpile sampling and operations to level stockpiles for measurement, loading, hauling, delivery of materials, spreading, blading, mixing, shaping, placing, compacting, reworking, finishing, correcting locations where thickness is deficient, curing, furnishing scales and labor for weighing and measuring, and equipment, labor, tools, and incidentals.

B. Flexible Base (Roadway Delivery). Payment will be made for the type and grade specified. For cubic yard measurement, "In Vehicle" will be specified. The unit price bid will not include processing at the roadway. This price is full compensation for furnishing materials, temporary stockpiling, assistance provided in stockpile sampling and operations to level stockpiles for measurement, loading, hauling, delivery of materials, furnishing scales and labor for weighing and measuring, and equipment, labor, tools, and incidentals.

C. Flexible Base (Stockpile Delivery). Payment will be made for the type and grade specified. For cubic yard measurement, "In Vehicle" or "In Stockpile" will be specified. The unit price bid will not include processing at the roadway. This price is full compensation for furnishing and disposing of materials, preparing the stockpile area, temporary or permanent stockpiling, assistance provided in stockpile sampling and operations to level stockpiles for measurement, loading, hauling, delivery of materials to the stockpile, furnishing scales and labor for weighing and measuring, and equipment, labor, tools, and incidentals.

APPENDIX B:
DRAFT PENETRATION INDEX TEST PROCEDURE

Test Procedure for

PENETRATION INDEX OF FLEXIBLE BASE

TxDOT Designation: Draft

Effective Date: DRAFT

1. SCOPE

1.1 Use this test method to obtain the seat and penetration index of compacted flexible base with a dynamic cone penetrometer (DCP).

1.2 The DCP uses a sliding hammer to drive a conical point into the flexible base layer. This test procedure determines if the flexible base layer under test has been adequately compacted.

1.2.1 The seat index indicates if the surface of the flexible base layer is adequately compacted.

1.2.2 The penetration index indicates if adequate compaction exists throughout the depth profile of the flexible base layer.

1.3 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 *Dynamic Cone Penetrometer, consisting of:*

2.1.1 Handle, located at the top of the device, used to hold the DCP shafts and to limit the upward stop of the DCP hammer.

2.1.2 Hammer, weighing 17.61 lb (8 kg), guided by an upper shaft.

2.1.3 Upper shaft, allowing the hammer to drop a distance of 22.6 in. (575 mm).

2.1.4 Lower shaft, of variable length up to 3.3 ft. (1 m), which couples to the upper shaft and accepts the strike of the hammer drop.

2.1.5 Cone, 0.787 in. (20 mm) in diameter, which attaches to the bottom of the lower shaft. The cone tip has a 60 degree angle.

2.1.6 Graduated rule, attaching to the lower shaft, for measuring the depth of penetration of the DCP cone.

3. REPORT FORMS

3.1 Penetration Index of Flexible Base (Pen_Index_Draft.xlsx)

4. PROCEDURE

4.1 Locate a level, undisturbed area representative of the material to be tested.

4.2 Assemble the DCP, attach a conical tip to the lower shaft, and then place the DCP device on the flexible base surface with the conical tip pointing down and the shafts plumb to the surface of the material under test.

4.3 With the cone atop the flexible base surface, read the measurement from the graduated rule and record this value as the Surface Value.
Note 1 – Record measurements to the nearest 0.1 in.

4.4 Raise the DCP hammer up to the handle and then release the hammer. Repeat this process to apply a total of two blows.
Note 2 – Use caution to avoid pinch points on the DCP. Do not hold the DCP near the striking surface. Lift the hammer slowly and drop the hammer cleanly, allowing the hammer to rest in its lowest position for at least 1 sec. before initiating another drop.

4.4.1 After the two DCP blows, record the measurement from the graduated rule as the Seating Value.

4.5 Apply more DCP blows until the total depth of penetration is within 1 in. of the thickness of the layer under test. Total the number of blows (including the two seating blows) applied to reach the required depth of penetration and record that number as Total Drops.
Note 3 – The actual number of DCP blows to reach the required depth of penetration will vary by material properties and total layer thickness. For typical base materials with layer thickness of 6 in., the total number of blows will typically range between 6 and 25.

4.5.1 When the total DCP depth of penetration is within 1 in. of the thickness of the layer under test, record that measurement from the graduated rule as the Final Reading Value.

4.6 Remove the DCP from the layer under test by lifting the hammer up to the handle and raising the DCP.
Note 4 – Striking the DCP hammer lightly against the handle may be required to extract the DCP from the test layer.

4.7 Record the station number to identify the test location.

Note 5 – In lieu of station numbers, use GPS coordinates or other acceptable means of identifying the location.

4.8 After completing the DCP test, determine the moisture content at the DCP test location in accordance with Test Method Tex-103-E or Tex-115-E.

4.9 Proceed to Section 5.1.

5. CALCULATIONS

5.1 Calculate and record the seat index of the flexible base by using the following formula:

Seat Index (in.) = Seating Value – Surface Value

5.2 Calculate and record the penetration index of the flexible base by using the following formula:

Penetration Index (in./blow) = (Final Reading – Seating Value)/(Total Drops – 2)

6. REPORTING TEST RESULTS

6.1 Report the seat index and penetration index to the nearest 0.1 in.

6.2 Report the moisture content to the nearest 0.1 percent.