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16. Abstract
In the Texas Department of Transportation, flexible base construction is governed by a series of stockpile and field tests. A series of concerns with these existing methods, along with some premature failures in the field, led to this project investigating the current system of flexible base acceptance. Specifically, concerns over the lack of moisture control during compaction, and the lack of stiffness or modulus parameters in the field testing stage, led to this project that investigated new mechanistic-based methods for flexible base acceptance. This report summarizes the concerns expressed with the current TxDOT methods, presents approaches some TxDOT districts have taken to overcome problems, and summarizes the current status of other agencies' efforts at mechanistic-based acceptance for flexible base. Next, this report presents results and findings from a full-scale compaction experiment, where a Grade 1 and Grade 2 flexible base were placed and tested with new non-density based devices. The results to date indicate acceptance with non-density based devices should be feasible. Additionally, the results indicate that flexible bases should not be worked significantly wet of optimum, because when the base is worked in that manner inferior mechanical properties result even though high density is achieved. To guide the second year's work, possible approaches for non-density based acceptance, and a field test plan, are outlined.

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ALTERNATIVE METHODS OF FLEXIBLE BASE COMPACTION ACCEPTANCE

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DISCLAIMER

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CHAPTER 1: CONCERNS AND APPROACHES TAKEN FOR FLEXIBLE BASE ACCEPTANCE

SUMMARY

This chapter presents a summary of concerns that have been reported with flexible base specifications within the Texas Department of Transportation (TxDOT). With regard to TxDOT's specifications, concerns exist over testing frequency, lift thickness, testing low-fines bases, moisture content requirements, and easing the minimum percentage compaction requirement to less than 100 percent. Additionally, the test timing presents a major concern; in many cases, offices wait up to 72 hours after compaction prior to testing. Finally, the lack of mechanistic-based acceptance results in a disconnect between design and construction philosophy. Some additional concerns resulting from querying multiple TxDOT districts include the testing of stockpiles, what to do with materials that barely fail specifications, the level of moisture control required during construction and testing, and ensuring curing and stability.

While all of these problems are important, this project specifically seeks to address the testing method(s) used for compaction acceptance. Specifically, this project is investigating alternatives to the nuclear density gauge. The Minnesota DOT (MnDOT) is the most progressive in this area, where both the dynamic cone penetrometer (DCP) and lightweight deflectometer (LWD) are already in their specifications. Additionally, a recent National Cooperative Highway Research Program (NCHRP) project evaluated several non-density based devices and recommended the Geogauge for acceptance of flexible base layers.

CONCERNS WITH FLEXIBLE BASE ACCEPTANCE IN TXDOT

An initial review of TxDOT's procedures and specifications for testing, constructing, and accepting flexible bases revealed the following concerns:

- Testing frequency.
- Obtaining adequate compaction with thick lifts.
- Working with low fines bases.
- Working material at the proper water content.
- Accepting less than 100 percent density, acceptance test timing.
- Lack of mechanistic acceptance testing.

Test Frequency

The TxDOT Guide Schedule requires an in-place density test on flexible base at least once per 3000 cu. yd., or 3000 linear feet. While TxDOT clearly must balance the required testing frequency with workload, the test frequency results in large portions of the constructed area untested. In many forensic investigations, the failed areas are confined to a relatively short section of the project.

Thick Lifts

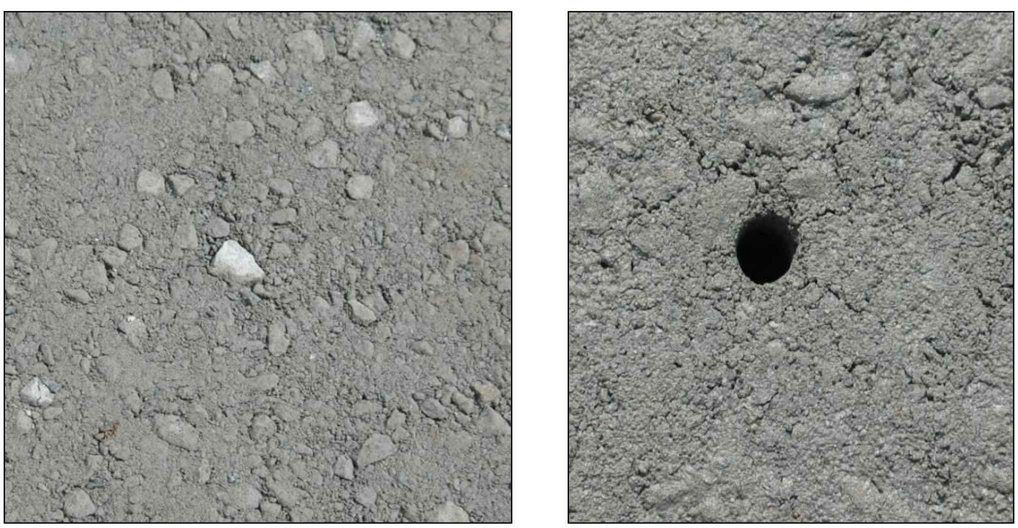
When placing thick lifts, vertical density gradients can exist, and the nuclear gauge will only determine a composite value for the entire depth of the test. The nuclear gauge could therefore miss localized weak zones in the vertical profile of the base. It may be advantageous, particularly with thick lifts, to employ a test device that provides a measurement profile with depth.

Many states employ specification restrictions on lift thickness. A query of states revealed 6 inches as a common key thickness within states that specifically address lift thickness. A selection of how some states address base lift thickness follows:

- Oklahoma: layers of 4 to 8 inches compacted thickness.
- Arkansas: if thickness ≤ 6 inches, one layer. If thickness > 6 inches, use 2 or more layers.
- Lousiana: 4-12 inches, with multiple lifts as determined by the Contractor and Engineer.
- Virginia: Maximum of 6 inches per layer, which may be increased with approval of Engineer.
- Minnesota: 3 inch layers, which can be increased to a maximum of 6 inches per layer with approval.
- California: if thickness ≤ 6 inches, one layer. If thickness > 6 inches, use 2 or more layers.

Low Fines Bases

Low fines bases, with less than 12 percent passing the No. 200 sieve, can prove difficult to test with the nuclear density gauge because the base may crack and loosen when driving the spike to create the access hole for the gauge's source rod. This event during driving the spike results in erroneously low density readings. Figure 1.1 illustrates a base where this problem occurred.



a) Finished base b) Cracks induced before density test

Figure 1.1. Problems with Nuclear Density on Low Fines Bases.

Lack of Moisture Content Requirement

Up until SP 247-033, TxDOT specifications did not contain moisture content requirements. This meant that contractors could work the base significantly on the dry side of optimum, which typically meant a shorter wait time until applying prime since the base was compacted dryer. However, to meet Tex-113-E density when working on the dry side of optimum, Figure 1.2 illustrates that the compaction effort must be increased, which could increase the potential for aggregate breakdown during compaction. To address these concerns, current SP 247-033 requires contractors to maintain water content during compaction at no less than 1 percentage point below the optimum water content as determined by Tex-113-E.

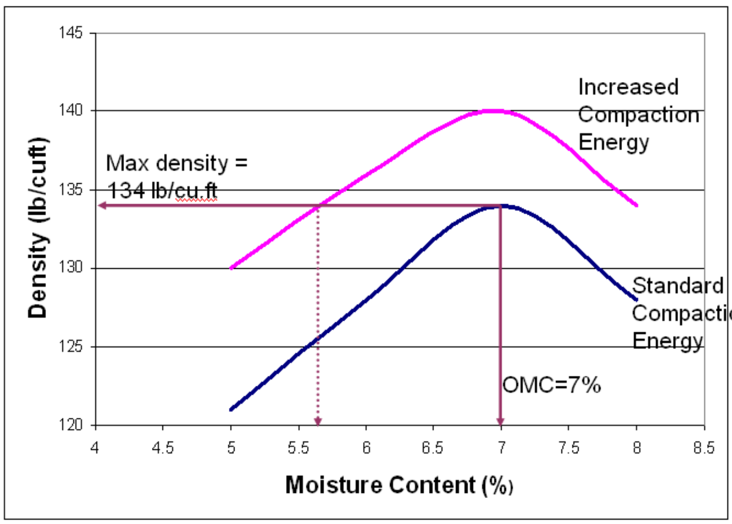


Figure 1.2. Achieving Density when Significantly Dry of Optimum Requires Increased Compaction Energy.

The new SP 247-033 does require contractors to maintain moisture during compaction at not less than 1 percentage point below the optimum moisture content to address the concerns with working base on the dry side of optimum; however, no upper limit is specified. This means slush rolling still could be performed, which essentially can result in vertical segregation of the base. Working significantly on the wet side of optimum is especially appealing if the Area Office will accept density results lower than 100 percent of the Tex-113-E maximum, because passing density values may be obtained with reduced compaction effort.

Accepting Less than 100 Percent Density

In some instances, offices will accept densities of 98 or even 95 percent. This practice can result in premature failures because accepting reduced density provides an incentive for the contractor to work on the wet side of optimum and slush roll. Moreover, this practice results in a base layer where the mechanical properties at the reduced density are unknown. Figure 1.3 illustrates base failures that occurred under construction traffic on a project. In this case, the base was accepted at 95 percent density, and the edge was backfilled with material with a plasticity index exceeding 30. During the forensic investigation it was discovered that water was trapped in the base, and the top half of the base was 3 percent above Tex-113-E optimum.

Figure 1.3. Base Failure during Construction where Base Accepted at 95 Percent Density.

Test Timing

The current TxDOT specifications governing flexible base construction, 2004 Standard Specification Item 247, and Special Provision 247-033, do not provide guidance on how long to wait after compaction before conducting density acceptance tests in the field. A common thought with many Texas bases is that these materials shrink and increase in density through desiccation. Without criteria on test timing, incentive exists to work the base wet of optimum (or even slush roll); if the results do not pass, the contractor simply suggests waiting until the next day for the material to dry back.

Lack of Mechanistic Testing

All of the concerns mentioned thus far could be summarized by the fact that field acceptance does not measure any mechanical properties of the base material. A disconnect exists between design assumptions (based on modulus) and testing in the field (based on density). For example, Figure 1.4 below shows premature rutting and cracking on a project where all field densities collected exceeded the Tex-113-E maximum. FWD data, shown in Figure 1.5, supports the hypothesis that the base layer was the source of the problem. The first two sensors at the distressed locations measured much higher deflections, while the deflections at sensors 4 through 7 (which primarily measure the subgrade) were essentially identical between distressed and nondistressed locations. Although density may be the easiest item to hold a contractor accountable for, the attainment of density does not always equate to acceptable field performance.

Figure 1.4. Premature Failure where 100 Percent Density Was Achieved.

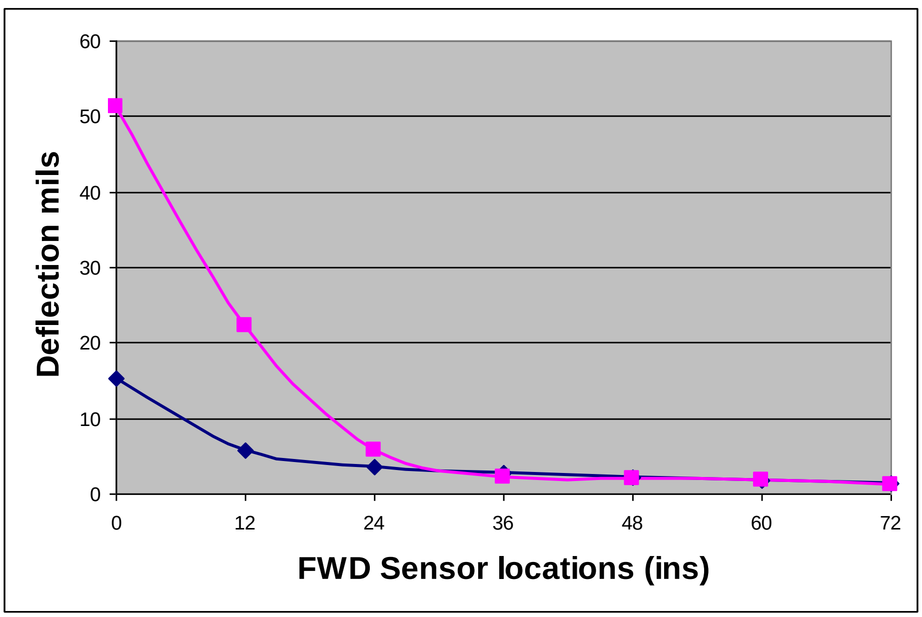


Figure 1.5. Deflection Bowls of Good (Blue) and Poor (Pink) Locations.

Feedback from TxDOT Districts on Base Acceptance Problems

In addition to the review of specifications conducted, TTI researchers queried the Lubbock, Fort Worth, Austin, Bryan, Odessa, and El Paso Districts, and TxDOT-CST, to identify additional concerns with flexible base acceptance. This query yielded the following concerns shown in Table 1.1. In some cases, contradictory problems are reported. For example, the Odessa District reported a problem with excessive testing at optimum moisture, while the Bryan District reported a problem was ensuring both moisture and density requirements were met.

Table 1.1. Feedback from TxDOT Regarding Concerns with Flexible Base.

Concern	Originating TxDOT Source
How to test stockpiles without tearing up the stockpile	Bryan, Lubbock
What to do with material that barely fails specifications	Lubbock
Excessive testing at optimum moisture	Odessa
Best way to construct multiple lift sections	Bryan
Ensuring both moisture and density are met	Bryan
Making sure the base has cured back to 2% below optimum	Bryan
Ensuring inspectors understand testing requirements	Bryan
Moisture control	Austin
Enforcing stability	Austin

Steps Taken in TxDOT to Overcome Flex Base Acceptance Issues

Table 1.2 presents steps TxDOT reported are in use for dealing with some of the reported problems. These steps include revised test procedures, changing the grade of the material, general notes, in-house training, or employing "best practices."

Table 1.2. Steps Taken in TxDOT to Address Concerns with Flexible Base.

Problem	Steps Taken	Originating TxDOT Source
How to test stockpiles without tearing up the stockpile	Modified Method Tex-400-A	CST
What to do with material that barely fails specifications	No clear solution—can change to Grade 4	Lubbock
Excessive testing at optimum moisture	Modify Special Provision 247-XXX Article 247.4.C.2	Odessa
Best way to construct multiple lift sections	No feedback	No feedback
Testing to ensure moisture and density are met	In-house training	Bryan
Testing to make sure the base has cured back to 2% below optimum	In-house training	Bryan
Ensuring inspectors understand testing requirements	In-house training	Bryan
Moisture control	Good Practices	Austin
Enforcing stability	Good Practices	Austin

Appendix A presents the general notes used in the Lubbock District for employing Grade 4 material. Appendix B presents the general notes used in the Odessa District to eliminate the need for testing at optimum moisture. Additionally, the Lubbock District reports that they will not allow sheep's foot, Rex, or similar rollers with projecting studs or feet if, in the opinion of the Engineer, the roller is damaging the flex base.

M-E APPROACHES FOR FLEXIBLE BASE ACCEPTANCE

One lingering concern with flexible base acceptance in TxDOT is the fact that the pavement design is based on modulus, while the field construction is accepted based on density. The field acceptance program in most DOTs does not include a mechanistic component. The Minnesota DOT and the recently completed NCHRP Project 10-65 provide the most current literature on what is being done with mechanistic testing for flexible pavement acceptance.

MnDOT Approach with Mechanistic-Based Acceptance

MnDOT currently allows both the lightweight deflectometer and the dynamic cone penetrometer for acceptance testing. The LWD is currently specified suitable for excavation and embankment, and MnDOT sets a target deflection value using one of two options:

- Target value using a calibration area:
  - The moisture content must be between 65 and 95 percent of the target moisture content.
  - Quality compaction is performed to obtain the required lift thickness.
  - LWD testing begins prior to achieving the desired compaction.
  - The target LWD value is obtained when the moisture content is within the acceptable range, and the average deflection for three consecutive passes does not significantly change. The target value becomes the lowest average deflection from these three passes.
- Target value using Modified Penetration Index:
  - Used when compaction must comply with Modified Penetration Index (Mod PI) or Specified Density Method.
  - Comparison tests are performed between the LWD and Mod PI or Specified Density.
  - The LWD target value is the deflection at the comparison location with the highest penetration index or lowest density (recall the penetration index or density must meet specification values).

Table 1.3 presents MnDOT's required test location for the LWD depending on material type and embankment thickness.

Table 1.3. Test Location of LWD Required by MnDOT.

Granular Materials (Meeting Spec. 3149)	
Embankment Thickness	**Test Layer Location**
≤ 600 mm (**2 feet**)	Top of Embankment
> 600 mm (**2 feet**) and ≤ 1.2 m (**4 feet**)	Mid-point and Top of Embankment
> 1.2 m (**4 feet**)	600-mm (**2-foot**) Intervals (Starting from Bottom to Top) and Top of Embankment
Non-Granular Materials	
Embankment Thickness	**Test Layer Location**
≤ 300 mm (**1 foot**)	Top of Embankment
> 300 mm (**1 foot**)	300-mm (**1-foot**) Intervals (Starting from Bottom to Top) and Top of Embankment

MnDOT's test method using the DCP is now approved for use with compaction acceptance of all granular materials. This method uses the DCP to determine the following:

- Seat value (the penetration depth in the first two blows).
- Penetration index (the penetration rate of three additional blows after the seating).
- Adequate layer (the cumulative penetration of all five blows; if this penetration exceeds the test layer thickness, then the layer is not adequate).

Table 1.4 shows the requirements for MnDOT's method using the DCP. Most Texas bases will be at the lower extreme of MnDOT's grading number system, so the applicability of the MnDOT criteria to Texas bases is currently unknown.

Table 1.4. MnDOT Criteria for Compaction Acceptance Using the DCP.

GN	MC (% dry)	Maximum Allowable SEAT (in)	Maximum Allowable DPI (in/blow)	Approximate Test Layer (in)	GN	MC (% dry)	Maximum Allowable SEAT (in)	Maximum Allowable DPI (in/blow)	Approximate Test Layer (in)
3.1-3.5	<5.0	1.6	0.4	4.0 - 6.0	4.6-5.0	<5.0	2.6	0.6	5.0 - 7.0
	5.0-8.0	1.6	0.5			5.0-8.0	3.0	0.7	
	>8.0	1.6	0.6			>8.0	3.4	0.9	
3.6-4.0	<5.0	1.6	0.4	4.0 - 6.0	5.1-5.5	<5.0	3.3	0.7	6.0 - 12.0
	5.0-8.0	1.7	0.6			5.0-8.0	3.7	0.8	
	>8.0	2.1	0.7			>8.0	4.1	1.0	
4.1-4.5	<5.0	2.0	0.5	4.0 - 6.0	5.6-6.0	<5.0	4.0	0.8	7.0 - 12.0
	5.0-8.0	2.4	0.7			5.0-8.0	4.5	0.9	
	>8.0	2.8	0.8			>8.0	4.9	1.1	

Note: GN = (1″ + ¾″ + #4 + #10 + #40 + #200)/100
Where percent passing is used for each respective sieve size.

RECOMMENDATIONS FROM NCHRP PROJECT 10-65

NCHRP recently examined non-destructive test (NDT) technologies for performing quality assurance on pavement construction. This project sought to evaluate technologies based on their ability to identify anomalies and their relevance to performance. Based on these criteria, the Humboldt GeoGauge was recommended for unbound layers because it had the highest success rate (86 percent) at identifying anomalies. Next were the portable seismic pavement analyzer (PSPA), DCP, and LWD, which identified approximately 79, 67, and 67 percent of anomalies, respectively. Other important conclusions included:

- The GeoGauge is minimally influenced by supporting materials.
- The DSPA and DCP responses represent the material being tested; however, the DCP can be impacted by varying amounts and sizes of aggregate.
- The LWD can be significantly affected by the supporting materials and thickness of the layer being tested.
- Laboratory repeated load resilient modulus tests were conducted to form adjustment ratios between the lab and field results. This work showed:
  - With stiff coarse-grained materials, the ration with the GeoGauge was near unity.
  - After adjustment, the GeoGauge and DCP resulted in the lowest standard error.
  - Even after adjustment, the LWD had the highest standard error.

Based on these results, this NCHRP project prepared a procedural manual including acceptance testing for unbound materials with the Humboldt GeoGauge. The basic procedure includes:

- Determine the moisture-density relationship.
- Determine the target modulus.
    - Should be the value used as the input in the MEPDG.
    - Resilient modulus should be determined in the lab on test specimens at 100 percent density and desired water content.
- Determine the field adjustment factor.
    - Construct a control strip to develop a modulus growth curve with increasing roller passes until the modulus remains the same.
    - Select 8–10 random locations from the control strip, and measure the field modulus.
    - Measure density and moisture content at three of these locations using the sand cone method.
    - Calculate or measure the resilient modulus of the in-place material using the average density and moisture contents measured. The ratio of the lab-measured modulus to the design modulus should be near unity.
- Proceed with using the GeoGauge per the manufacturer's instruction to measure in-place modulus on the project.
- Proceed with a statistical-based acceptance plan per AASHTO R 9-03.

CHAPTER 2: FLEXIBLE BASE COMPACTION EXPERIMENT AT TEXAS A&M RIVERSIDE CAMPUS

SUMMARY

Using a test site at Texas A&M's Riverside Campus, TTI researchers evaluated the acceptance test results from different devices on a Grade 1 and Grade 2 flexible base. The devices employed included the nuclear density gauge, portable falling weight deflectometer (PFWD), and dynamic cone penetrometer (DCP). The bases were placed at different water contents, with different target densities, and then the acceptance tests performed as the bases cured. Analysis of the data shows:

- Neither material significantly gained density through desiccation during the curing stage.
- Sites placed substantially wet of optimum consistently appeared in the highest categories of density, but the lowest categories of mechanical properties, even after curing.
- The DCP was better able to distinguish among the treatments than the PFWD.
- The influence of water content on stiffness and modulus properties overshadowed the influence of density.
- The mechanical properties of the Grade 1 material were less sensitive to increases in compaction effort than the Grade 2 material.

With these observations, the following should be considered during specification revision:

- Flexible bases should not be worked and compacted significantly wet of optimum.
- If pursuing alternatives to the nuclear gauge for compaction acceptance, consideration must be given to the impact of water content on the stiffness or modulus properties measured.
- While the PFWD should continue to be investigated, the results suggest the DCP may be a better device for field compaction acceptance.
- For high-quality well-graded materials, density control, or even ordinary compaction with proof rolling, should adequately ensure achievement of suitable compaction.
- For other materials such as many Grade 2 or Grade 4 bases, alternatives to density-based acceptance should definitely be considered. For such materials, increases in mechanical properties can be realized with increased compaction effort, even if no significant gains in density occur.

OVERVIEW OF TEST SITE

The site chosen for evaluating flexible base acceptance testing in a controlled environment under TxDOT Project 0-6587 was located at the Texas A&M University Riverside Campus. The testing site consisted of two side-by-side earthen runways allowing for two roadbeds each 150 ft long and 12 ft wide. These runways or pads were cement stabilized to a depth of 6 inches. This site was chosen for convenience of constructability, grade consistency, and realistic conditions simulating the placement of base materials. The flexible base materials in this test originated from the Centex Buda and Capitol Aggregates Marble Falls pits. Appendix C presents the flexible base test reports from these materials. The south runway was separated into three 50 ft sections; Figure 2.1 shows that the varying compactive efforts with a constant moisture content of base material were evaluated on this site. The compactive efforts applied were targeted to achieve densities of 90, 95, and 100 percent, respectively.

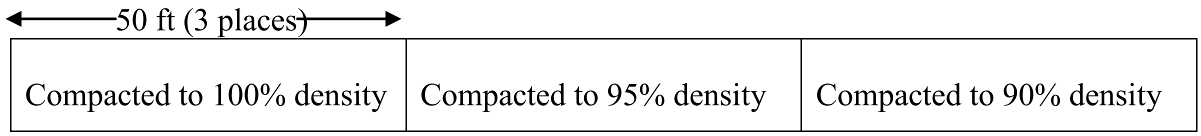


Figure 2.1. Flex Base Density Targets Compacted at Optimum Moisture.

The north runway was separated into two 75 ft sections. Figure 2.2 shows the target density on this north runway was 100 percent density with moisture content varied at +2 percent optimum and −2 percent optimum, respectively.

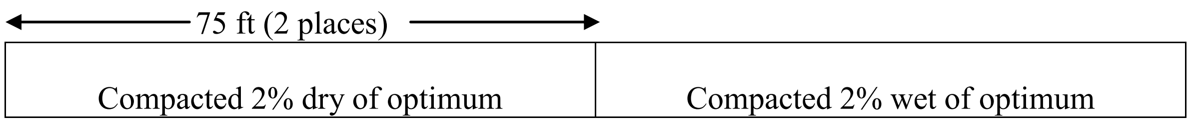


Figure 2.2. Flex Base Moisture Content Targets at Time of Compaction while Targeting 100 Percent of Tex-113-E Density.

Figure 2.3 illustrates the test site location; here, the north and south testing pads are delineated into sections. The outlined rectangles delineate each testing boundary, and the red dots indicate where spot tests were conducted. Nine test spots existed for each treatment, resulting in 27 test spots on the south pad and 18 test spots on the north pad. After construction was completed, the test plan called for testing at these spots on the day of placement, then at 1, 2, 3, and 7 days after placement.

Figure 2.3. Layout of Testing Site.

SITE PREPARATION—TTI PERFORMED

Upon visiting the site, the researchers cleaned the runways of old testing materials that existed on top of the cement-treated subbase. These materials needed to be removed so the researchers can obtain results pertaining only to the aforementioned flexible base materials. After renting a front-end loader, TTI personnel removed and stockpiled the existing overburden.

When the site was cleaned of overburden, researchers tested the existing material to ensure integrity of the cement-treated subbase. From left to right, Figure 2.4 illustrates the tests performed. These tests were conducted with the portable falling weight deflectometer (PFWD), portable seismic pavement analyzer (PSPA), falling weight deflectometer (FWD), and the dynamic cone penetrometer (DCP). The tests indicated that the cement treated sub-grade was suitable allowing base-placement operations to commence.

Figure 2.4. Subbase Testing.

MATERIAL PROCUREMENT—TTI PERFORMED

TTI purchased the materials for the test from Centex Materials and Capitol Aggregates. These materials were then delivered to the Knife River asphalt plant in Bryan, Texas. The researchers determined that 157 tons of the Centex Materials base and 164 tons of the Capital Aggregates base would be sufficient for testing. Appendices C and D, respectively, present the TxDOT stockpile test reports for the materials used.

PUGMILLING—CONTRACTOR PERFORMED

Discussion of bringing the materials to the desired moisture content with TTI personnel resulted in contracting Knife River to add moisture to the materials via means of pugmilling. Knife River agreed to pugmill the material but added a disclaimer stating they would not be responsible for material moisture contents.

From left to right, Figure 2.5 depicts the pugmill of Knife River and the various stages in the pugmilling process. Material was dumped into the hopper and transported up to the pug by means of conveyor belts. After the material was emptied into the pug, moisture was added and then checked against laboratory-made samples as a visual benchmark of moisture content. When the material was emptied into the truck, moisture contents were checked using a nuclear density gauge placed into the material in the truck. This method proved extremely accurate; the moisture contents generally varied within ±0.5 percentage points of the target moisture content.

Figure 2.5. Pugmilling Operations.

PLACEMENT AND MANIPULATION OF MATERIALS—CONTRACTOR PERFORMED

TTI contracted with Larry Young Paving of Bryan, Texas, to place and compact the base materials. Trucking contractors were hired to transport the material from the pugmill to the test site. The Centex Materials base was placed on July 21, 2010. After testing this material within seven days, TTI personnel then used a front-end loader to remove and stockpile that material, thus readying the site for placement of the Capitol Aggregates base on July 29, 2010. Upon completion of placement and compaction of the Capitol Aggregates base, contractor-performed work was ended.

From left to right illustrated in Figure 2.6, the paving machine was backed up to the west end of the runway allowing for trucks to back up to the paver, which then placed the base traveling west to east. The truck dumps material into the hopper of the paving machine, which then distributes the material evenly onto the paving surface. During construction, the initial plan of paving a 12 ft width was abandoned because the base material wore out the distributor gears on the auger. To resolve this issue, the contractor paved the width of the 8-ft paver screed. When the paving machine reached the end of the pad, a smooth drum vibratory roller compacted the material to the desired density. To achieve a compacted thickness of 6 inches, the contractor placed the base in two lifts. The paving machine would lay a lift of material at a depth of 6 inches and rolled to a compacted depth of 4 inches, then overlaid another 3 inches and rolled to attain a total material depth of 6 inches.

Figure 2.6. Placement of Base Material at Riverside Campus.

TESTING OF PLACED MATERIALS—TTI PERFORMED

Over the course of data collection, nine measurements were made on each treatment at each time of testing in a grid pattern (see Figure 2.3). Because of the hole that the DCP made, the testing grid was offset by approximately 14 inches at each test date. The data were then reduced and analyzed to evaluate:

- Did the flexible base increase in density with drying?
- Could the NDT devices detect differences in the treatments?
- How did water content and dry density impact the NDT measurements?
- How could the NDT be used for compaction acceptance?

Summary of Results from Buda Material

The Centex-Buda material met statewide Grade 2 and Austin District Grade 4 requirements. Table 2.1 presents the key base material properties, and Appendix C presents the complete stockpile test result.

Table 2.1. Material Properties of Centex-Buda Flexible Base.

Gradation		Compaction Test		Wet Ball Mill		Plasticity Index		Strength Test	
Sieve Size	Cumulative Percent Retained	Max Density (pcf)	133.4	Ball Mill Value	38	Liquid Limit	21	Lateral Pressure (psi)	Strength (psi)
1 ¾	0	Percent Water	8.5	Increase in – #40	20	Plastic Limit	19	0	35
7/8	18					Plasticity Index	2	3	103
3/8	42							15	199
#4	55	*This space intentionally left blank*							
#40	74								

Appendix E presents the data collected on the test sections of the Centex material; due to significant rainfall, the tests planned for seven days after placement could not be performed. Analyses of the data show:

- Increases in mean density after compaction did not occur with loss of moisture through time during the curing stage.
- On the day of placement, the DCP identified two statistically different categories, with the 100 percent density and −2 percent OMC treatments having the best mechanical characteristics. The PFWD could not identify among the different treatments. The nuclear density gauge identified three statistically different categories, with the +2 percent OMC and −2 percent OMC series statistically equivalent and having the highest density.
- After three days, the mean moisture contents were statistically equivalent among all treatments. At this time, the DCP identified the 100 percent density section superior to all others, the 90 percent density series inferior to all others, and the 95 percent, +2 percent OMC, and −2 percent OMC series statistically equivalent. The PFWD categorized the 100 and 95 percent density treatments as statistically equivalent and having the highest modulus values. The nuclear gauge identified the 100 percent density, 95 percent density, and +2 percent OMC series as statistically equivalent and having the highest densities.
- The influence of water content overshadowed the influence of density on the measured mechanical properties.

Impact of Drying on Density for Buda Material

Figure 2.7 presents the average dry density results for the Centex material at each time of testing. To evaluate if the density was changing through time, each treatment was evaluated with analysis of variance (ANOVA). These analyses showed that differences in mean densities only existed in two data series. In the 100 percent density series; the average density on July 24 was significantly different than the average density from July 22, and no significant differences in mean density existed among any other possible pairwise comparisons in this series. In the +2 percent OMC series, the average density on July 23 exceeded the average density from July 24, and no significant differences in mean density existed among any other possible pairwise comparisons in this series.

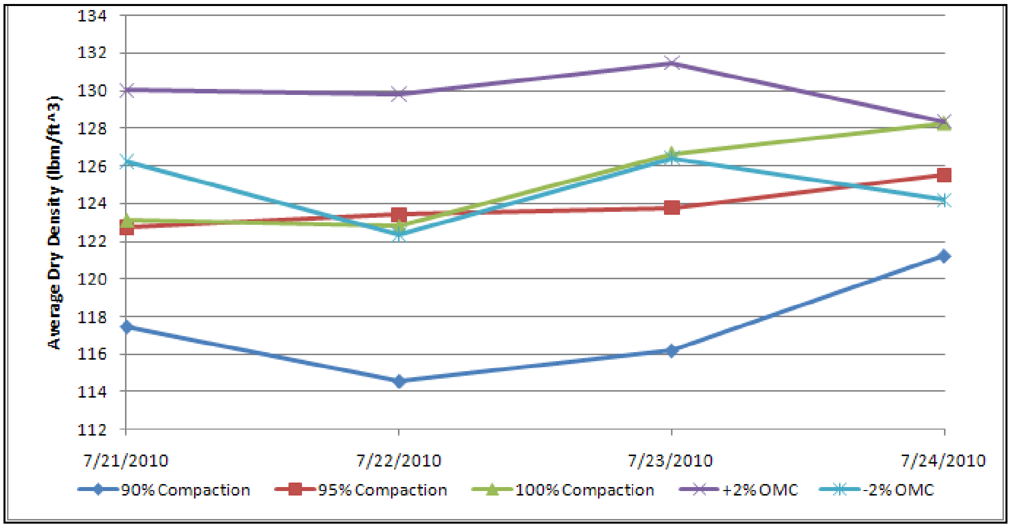


Figure 2.7. Dry Density Results from Buda Material.
Note: each data point the average of nine tests.

To further examine whether density changed with desiccation during curing, researchers regressed the average dry density on the average water content for each treatment. A non-zero slope in these regressions would suggest that density is changing with water content. While the data as presented in Figure 2.8 may suggest a negative correlation in some cases and a positive correlation in others, the analyses showed that the slope was not significantly different from zero for any treatment; the data do not provide sufficient evidence to conclude that changes in water content during curing are impacting the dry density of this base material.

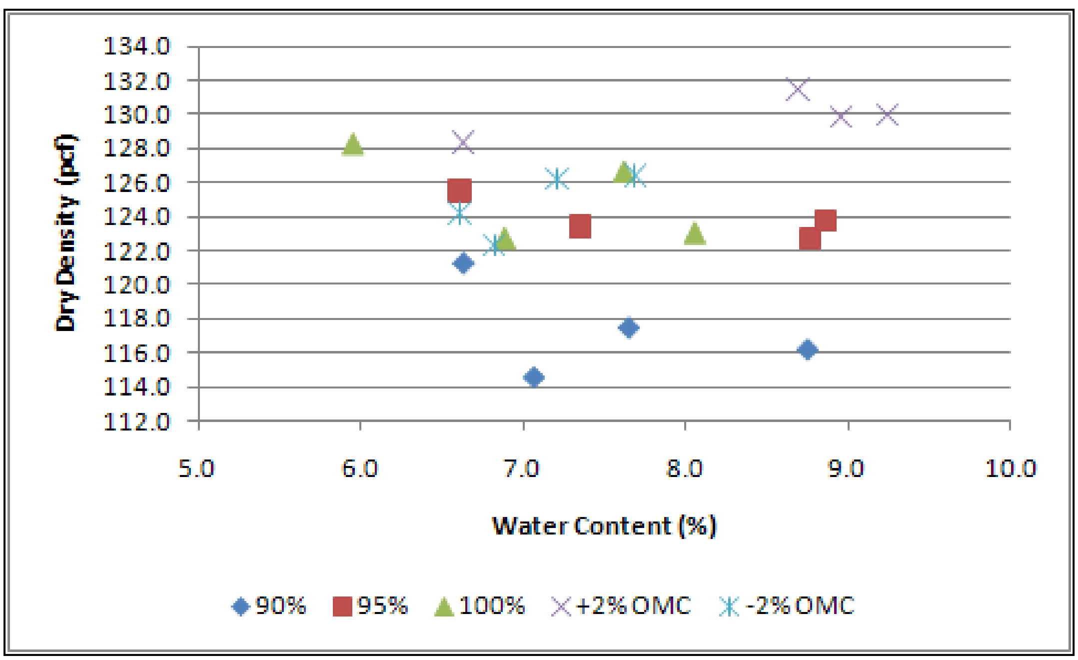


Figure 2.8. Average Dry Density versus Average Water Content for Buda Material.

Discernment of Treatments with NDT for Buda Material

To evaluate if the NDT can distinguish the different field treatments, researchers performed ANOVA across the test series for the data collected on the day of placement (July 21, 2010). Table 2.2 presents the DCP results and ANOVA output. The ANOVA showed that differences in means did exist. Using the Tukey multiple comparison procedure, Figure 2.9 illustrates that although the DCP could not distinguish among all the treatments, the DCP did categorize the treatments into two statistically equivalent groups as the bold horizontal lines in Figure 2.9 show.

Table 2.2. DCP Penetration Rate (in./blow) for Buda Material on Day of Placement.

Test	At OMC			2% Above OMC	2% Below OMC
	90%	95%	100%		
1	-0.39	-0.34	-0.29	-0.37	-0.29
2	-0.45	-0.29	-0.22	-0.54	-0.29
3	-0.38	-0.31	-0.36	-0.43	-0.24
4	-0.54	-0.34	-0.30	-0.36	-0.21
5	-0.35	-0.47	-0.22	-0.46	-0.23
6	-0.41	-0.37	-0.22	-0.56	-0.23
7	-0.36	-0.50	-0.28	-0.41	-0.26
8	-0.41	-0.59	-0.38	-0.76	-0.18
9	-0.41	-0.28	-0.19	-0.52	-0.28

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
90%	9	-3.704	-0.41152	0.00315
95%	9	-3.479	-0.38658	0.01174
100%	9	-2.443	-0.27147	0.00417
2% Above OMC	9	-4.393	-0.48809	0.01565
2% Below OMC	9	-2.209	-0.24546	0.00138

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.366497	4	0.09162	12.6927	9.3E-07	2.606
Within Groups	0.288745	40	0.00722			
Total	0.655242	44				

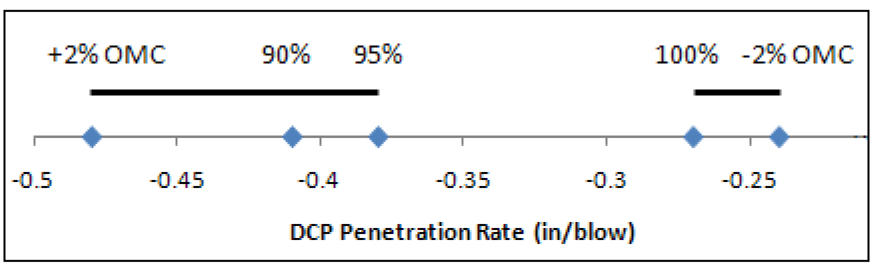


Figure 2.9. Discernment of Treatments with DCP for Buda Material on Day of Placement.

The research team performed similar analysis with the PFWD data collected the day of placement. Table 2.3 shows that the PFWD could not distinguish among the treatments, since the tabulated *F* statistic does not exceed the critical value; Figure 2.10 illustrates this result. It is also important to note that the PFWD was deemed unsuitable to test the section placed wet of optimum because the base was too unstable, resulting in overloading the PFWD sensors even when the weight was dropped from the lowest possible drop height.

Table 2.3. PFWD Modulus (MPa) for Buda Material on Day of Placement.

E Modulus (PFWD) - July 21, 2010

Test	At OMC 90%	At OMC 95%	At OMC 100%	2% Above OMC	2% Below OMC
1	83	111	138	Too wet to test, overloaded sensors	62
2	79	110	117		147
3	201	108	165		65
4	171	90.5	180		106
5	90	66	201		61
6	131	150	81		59
7	147	66	71.5		100
8	63	20	86		303
9	72	122	73		193

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
90%	9	1037	115.222	2413.694
95%	9	843.5	93.7222	1464.569
100%	9	1113	123.611	2454.986
2% Below OMC	9	1096	121.778	6713.194

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5083.69	3	1694.56	0.519548	0.67187	2.901
Within Groups	104372	32	3261.61			
Total	109455	35				

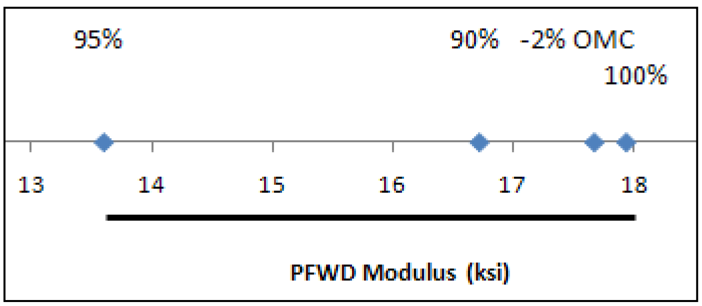


Figure 2.10. PFWD Results for Buda Material on Day of Placement.

Note: +2 percent OMC series not tested with PFWD due to sensor overload.

The nuclear density gauge is the typical method used in TxDOT for compaction acceptance, so researchers also analyzed the density data, which yielded three statistically equivalent categorizations as Figure 2.11 illustrates. Interestingly, on the day of placement the nuclear gauge categorized 90, 95, and 100 percent series as statistically equivalent, while the DCP did categorize the 100 percent series separately.

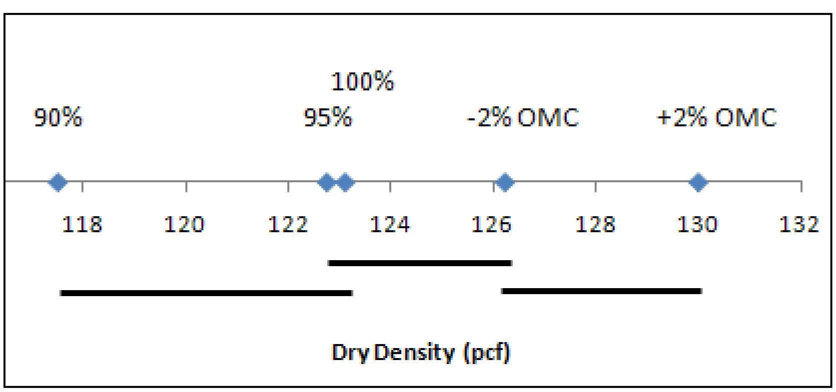


Figure 2.11. Discernment of Treatments with Nuclear Gauge for Buda Material on Day of Placement.

Tests after Moisture Content Equalization

Since moisture content can significantly impact stiffness and modulus test results, perhaps an even more interesting analysis results when examining the data from July 24, 2010, which is three days after placement. As Table 2.4 shows, by that date the moisture contents of all sections were statistically equivalent. Therefore, an evaluation of the NDT can be made without the complication of a water content factor.

Table 2.4. Moisture Content Results for Buda Material 3 Days after Placement.

Moisture Content Results - July 24, 2010

Test	At OMC 90%	95%	100%	2% Above OMC	2% Below OMC
1	6.4	6.4	6.4	6.4	6.4
2	7.0	6.6	6.5	7.0	6.6
3	6.4	7.1	4.7	6.4	7.1
4	5.8	6.3	5.2	5.8	6.3
5	6.7	8.2	6.5	6.7	8.2
6	6.1	6.1	5.6	6.1	6.1
7	7.6	6.0	5.9	7.6	6.0
8	7.7	7.2	7.6	7.7	7.2
9	6.0	5.6	5.2	6.0	5.6

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
90%	9	59.7	6.633333	0.4625
95%	9	59.5	6.611111	0.613611
100%	9	53.6	5.955556	0.792778
2% Above OMC	9	59.7	6.633333	0.4625
2% Below OMC	9	59.5	6.611111	0.613611

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.204444	4	0.801111	1.360121	0.2649	2.606
Within Groups	23.56	40	0.589			
Total	26.76444	44				

Table 2.5 shows that the DCP could distinguish among treatments, so the Tukey multiple comparison procedure was used to determine which means significantly differed. Figure 2.12 shows that the DCP found the 100 percent section superior to all others, the 90 percent section inferior to all others, and no significant difference among the 95 percent, +2 percent of OMC, and −2 percent of OMC series.

Table 2.5. DCP Results for Buda Material after Moisture Equalization.

DCP Penetration Rate (inches per blow) Results - July 24, 2010

Test	At OMC 90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.30	-0.23	-0.13	-0.17	-0.18
2	-0.24	-0.14	-0.11	-0.22	-0.15
3	-0.26	-0.16	-0.14	-0.17	-0.14
4	-0.38	-0.19	-0.13	-0.16	-0.24
5	-0.27	-0.15	-0.12	-0.24	-0.15
6	-0.27	-0.13	-0.07	-0.18	-0.19
7	-0.32	-0.19	-0.12	-0.18	-0.24
8	-0.20	-0.17	-0.10	-0.21	-0.14
9	-0.25	-0.17	-0.10	-0.20	-0.21

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
90%	9	-2.497	-0.27745	0.00274
95%	9	-1.528	-0.16977	0.00098
100%	9	-1.019	-0.11321	0.00038
2% Above OMC	9	-1.725	-0.19169	0.00064
2% Below OMC	9	-1.639	-0.18212	0.00168

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.12572	4	0.03143	24.4939	2.7E-10	2.606
Within Groups	0.051327	40	0.00128			
Total	0.177048	44				

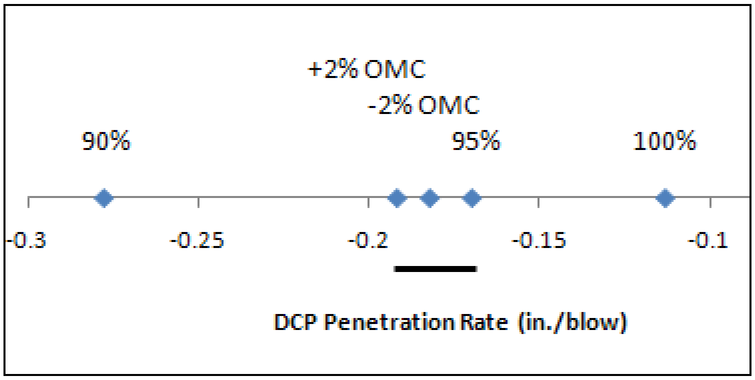


Figure 2.12. Discernment of Treatments for Buda Material with DCP after Moisture Equalization.

The PFWD data also showed the 100 percent series to have the highest average modulus; however, the PFWD could not distinguish the 100 percent from the 95 percent series. Figure 2.13 presents the Tukey multiple comparison output for the PFWD data on July 24, 2010, after the moisture contents among the different sections had equalized.

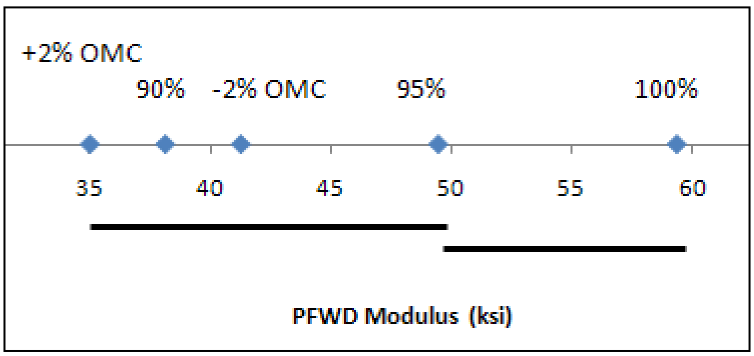


Figure 2.13. Discernment of Treatments for Buda Material with PFWD after Moisture Equalization.

Examining the nuclear density data in conjunction with the DCP and PFWD data proves even more interesting, as Figure 2.14 shows the nuclear density measurements categorized the 95 percent, 100 percent, and 2 percent above OMC series as statistically equivalent, while the DCP clearly showed the 100 percent series superior to the others, and the PFWD found the 100 percent series equivalent to only the 95 percent density series. These results highlight the disconnect that can exist between density and performance. While the +2 percent OMC section consistently appeared in the highest categories of density, that section consistently appeared in the worst categories of mechanistic properties.

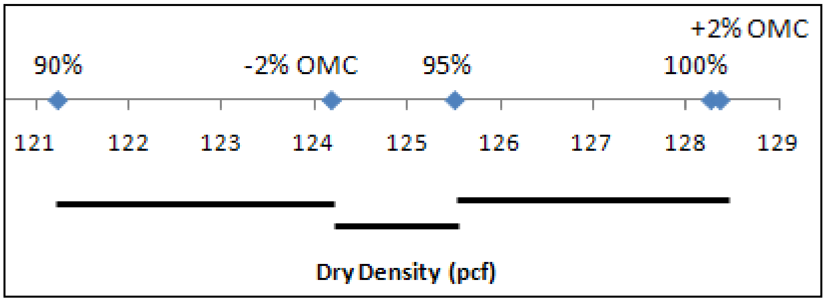


Figure 2.14. Nuclear Density for Buda Material after Moisture Equalization.

Impact of Water Content and Density on NDT with Buda Material

Impact of Water Content on NDT

Researchers evaluated the data to examine for impacts of water content and density on the DCP and PFWD results. To isolate the general form of the trend between water content and NDT, researchers examined the relationship between water content and NDT for each series when mean density in that series were equivalent through time. Figure 2.15 presents the DCP result, and Figure 2.16 presents the PFWD result. The data suggest that, within the range of observed water contents, a linear relationship can be used in both cases.

Fitting a least-squares equation through the DCP data in Figure 2.15 results in the slope coefficients presented in Table 2.6. Table 2.7 also presents the standard error of the estimated slope values; the output suggests the tabulated coefficients do not significantly differ among the treatment; the average slope coefficient is −0.085. This means that for each percent increase in water content, the DCP is expected to penetrate 0.085 in./blow faster.

Similarly, fitting a least-squares equation through the PFWD data in Figure 2.16 results in the slope coefficients presented in Table 2.8. As with the DCP, the output suggests the tabulated coefficients do not significantly differ among the treatment; the average slope coefficient is −12.9. This means that for each percent increase in water content, the PFWD E1 modulus is expected to decrease by 12.9 ksi.

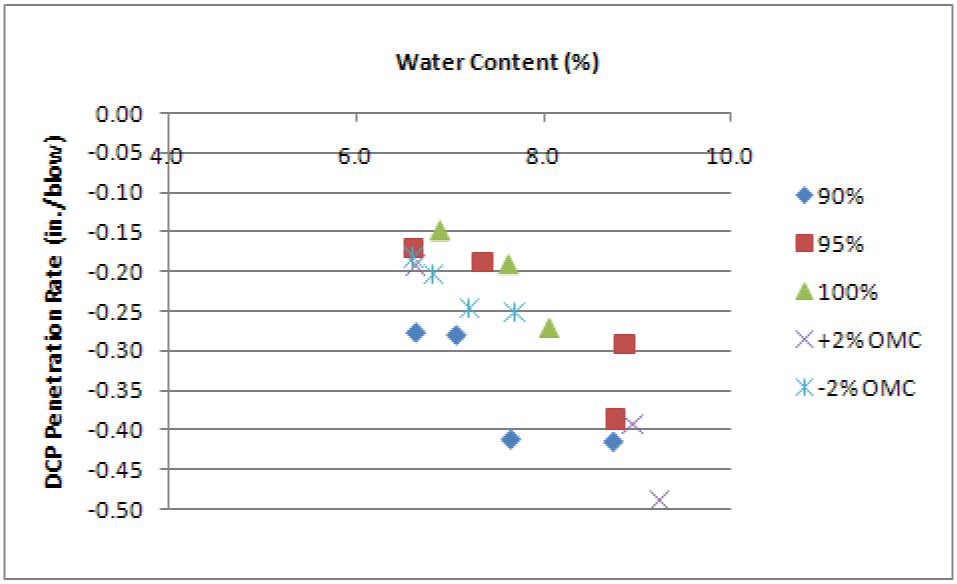


Figure 2.15. DCP Penetration Rate versus Water Content for Buda Material.
Note: To isolate the impact of water content on the NDT, data presented are when mean densities within each series are equivalent.

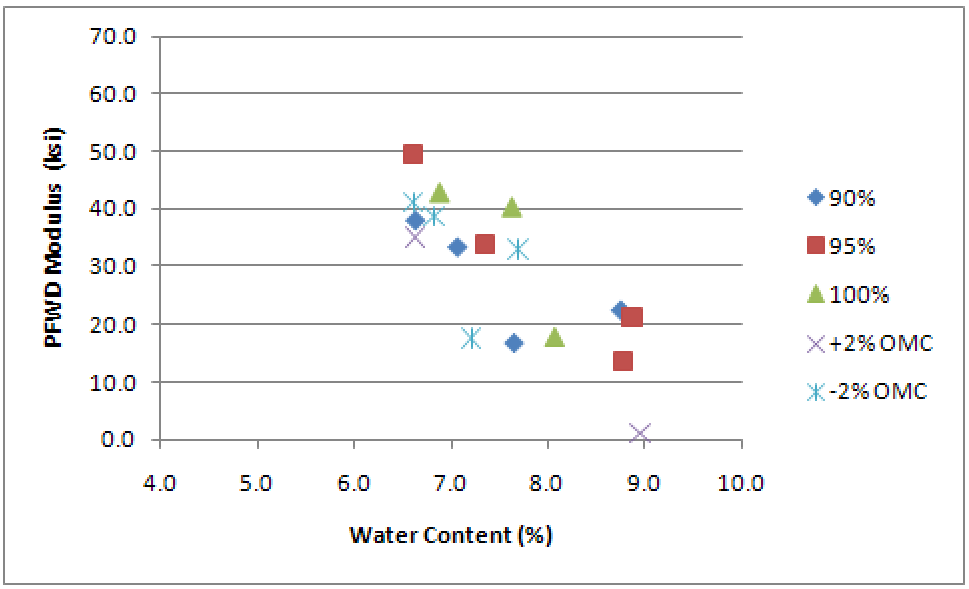


Figure 2.16. PFWD Modulus versus Water Content for Buda Material.
Note: To isolate the impact of water content on the NDT, data presented are when mean densities within each series are equivalent.

Table 2.6. Slope Coefficients for Impact of Water Content on DCP Penetration Rate for Buda Material.

	90%	95%	100%	+2% OMC	−2% OMC
Estimated Slope Coefficient	−0.072	−0.081	−0.101	−0.103	−0.066
Standard Error of Slope Coefficient	0.0303	0.0293	0.0334	0.0227	0.0176
Overall Estimated Coefficient*	**−0.085**				

**This is the average value since the data suggest the estimated slopes among the series do not significantly differ.*

Table 2.7. Slope Coefficients for Impact of Water Content on PFWD Modulus for Buda Material.

	90%	95%	100%	+2% OMC	−2% OMC
Estimated Slope Coefficient	−7.8	−13.6	−19.4	*	−10.8
Standard Error of Slope Coefficient	5.17	2.78	12.7	*	13.8
Overall Estimated Coefficient**	**−12.9**				

**Not evaluated due to series only containing 2 valid data points.*
***This is the average value since the data suggest the estimated slopes among the series do not significantly differ.*

Impact of Density on NDT

To examine the impact of density on the NDT, researchers used the data set collected on July 24, 2010, at which time the mean water contents were statistically equivalent among all treatments. Figures 2.17 and 2.18 present the DCP penetration rate and PFWD modulus versus density, respectively. Both figures suggest a curvilinear relationship between the NDT and density, and in both figures, the data from the series worked 2 percent wet of optimum appears to not fit the general trend. It is suspected that working so wet of optimum may have resulted in an altered sample structure with less effective particle interlock; therefore, the relationships presented in Figures 2.17 and 2.18 do not use the data from the series worked 2 percent above optimum. Additionally, taking the first derivative of the equations in Figures 2.17 and 2.18 yields the expected change in NDT value per unit change in density.

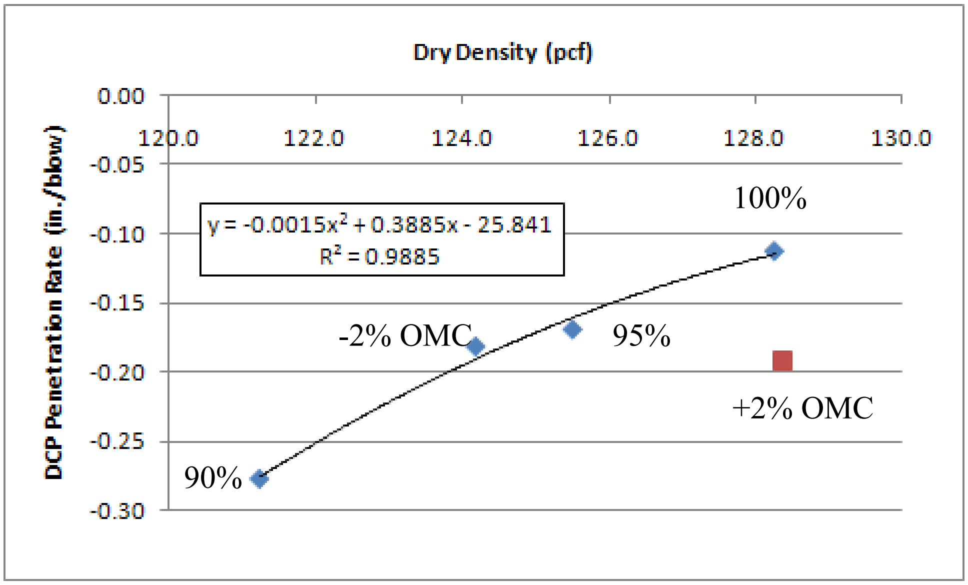


Figure 2.17. DCP Penetration Rate versus Density for Buda Material.
Note: To isolate the impact of density on the NDT, data presented are when mean water content among all series are equivalent.

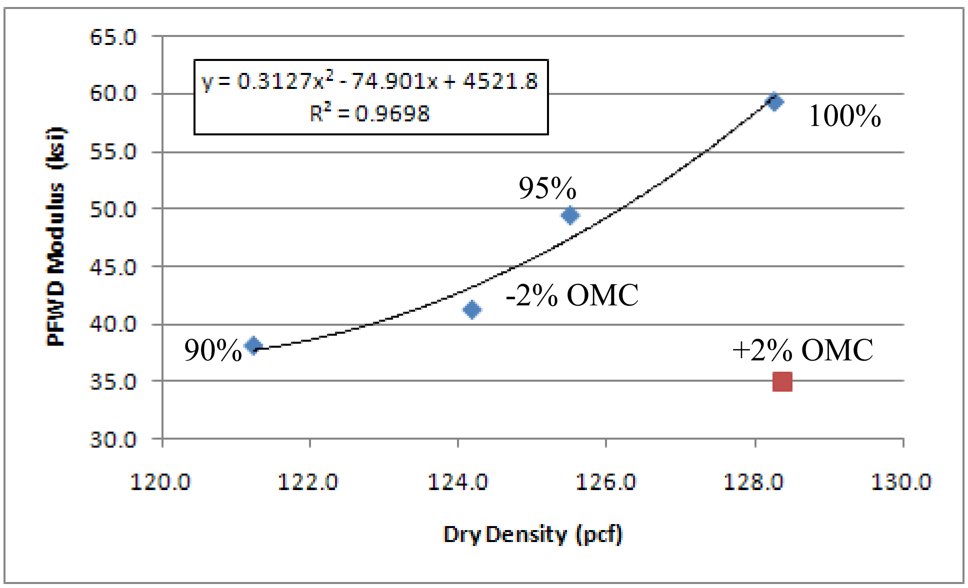


Figure 2.18. PFWD Modulus versus Density for Buda Material.
Note: To isolate the impact of density on the NDT, data presented are when mean water content among all series are equivalent.

Multiple Regression Estimation of NDT

Based on the observed general forms of the relationships between moisture content, density, and the NDT, Tables 2.8 and 2.9 show the output from modeling the NDT as a function of the dry density and water content. Interestingly, of the estimated coefficients, this output shows only the estimated coefficient for water content is significantly different from zero. For both analyses, the coefficient for the impact of water content essentially matches the estimates shown previously in Tables 2.6 and 2.7.

Table 2.8. Estimation of DCP Penetration Rate from Dry Density and Water Content for Buda Material.

Regression Statistics	
Multiple R	0.868598769
R Square	0.754463822
Adjusted R Square	0.708425789
Standard Error	0.055520506
Observations	20

Regression Equation:

$$PR = -12.7 - 0.000814(DD^2) + 0.207(DD) - 0.0860(\%M)$$

where

PR = DCP penetration rate (inches/blow)

DD = dry density (pcf)

%M = gravimetric water content, dry basis (percent)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.151547839	0.050516	16.38784	3.89899E-05
Residual	16	0.049320426	0.003083		
Total	19	0.200868266			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-12.70965862	8.595404818	-1.47866	0.158649	-30.9311027	5.511785485
DD^2	-0.000814429	0.000565928	-1.4391	0.169397	-0.00201414	0.000385284
DD (pcf)	0.206726388	0.139226809	1.484817	0.157027	-0.08842126	0.501874036
%M	-0.086042419	0.014826225	-5.80339	2.69E-05	-0.11747261	-0.054612227

Table 2.9. Estimation of PFWD Modulus from Dry Density and Water Content for Buda Material.

Regression Statistics	
Multiple R	0.813568283
R Square	0.661893351
Adjusted R Square	0.594272021
Standard Error	9.241377731
Observations	19

Regression Equation:

PFWD E = -454 - 0.0376(DD^2) + 9.38(DD) – 13.1(%M)
where
PFWD E = Modulus from PFWD (ksi)
DD = dry density (pcf)
%M = gravimetric water content, dry basis (percent)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2507.835293	835.9451	9.788233	0.000797292
Residual	15	1281.045935	85.40306		
Total	18	3788.881228			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-454.177838	1445.436819	-0.31421	0.757686	-3535.05347	2626.697798
DD^2	-0.03764663	0.095394746	-0.39464	0.698663	-0.24097572	0.165682458
DD (pcf)	9.379188084	23.44845727	0.399992	0.694801	-40.6000153	59.35839144
%M	-13.14042782	2.596019834	-5.06176	0.000141	-18.6737131	-7.60714255

Summary of Results from Marble Falls Material

The Marble Falls material met statewide Grade 1, Austin District Grade 4, and statewide Grade 5 requirements. Table 2.10 presents the key base material properties, and Appendix D presents the complete stockpile test result.

Table 2.10. Material Properties of Marble Falls Flexible Base.

Gradation		Compaction Test		Wet Ball Mill		Plasticity Index		Strength Test	
Sieve Size	Cumulative Percent Retained	Max Density (pcf)	150.7	Ball Mill Value	29	Liquid Limit	20	Lateral Pressure (psi)	Strength (psi)
1 ¾	0	Percent Water	5.2	Increase in – #40	10	Plastic Limit	14	0	49
7/8	21					Plasticity Index	6	3	110
3/8	46							15	229
#4	55								
#40	80	*This space intentionally left blank*							
#200	92								

Appendix F presents the data collected on the test sections constructed with the Marble Falls material. Analyses of the data show:

- Increases in mean density after compaction did not occur with loss of moisture through time during the curing stage.
- On the day of placement, and after moisture content equalization among the treatments, the DCP identified two statistically different categories. At both timeframes the 100 percent, 95 percent, and treatment 2 percent below optimum were statistically equivalent.
- The PFWD could not identify among the different treatments on the day of placement, and identified 2 statistically different groups after moisture equalization.
- The +2 percent OMC series consistently showed up in the highest categories of density, yet consistently showed up in the poorest categories of mechanistic properties.
- The −2 percent OMC series consistently showed up in the lowest categories of density but highest categories of mechanical properties, even after moisture content equalization.
- Within the range of measured densities and water contents, variations in moisture influenced the mechanical properties much more than changes in density.

Impact of Drying on Density for Marble Falls Material

Figure 2.19 depicts the average density values over the testing period for each treatment applied to the Marble Falls material. To evaluate the effects of drying on each treatment, ANOVA was applied to each data series to examine for statistical differences in each treatment's mean density over the testing period as the base cured. These ANOVA analyses showed two treatment series existed with significant differences in mean densities: the +2 percent OMC site and the −2 percent OMC treatment site. In both cases, the data show the mean density on August 5 was significantly greater than the mean density on any other testing day, and no significant differences in mean density existed among any other possible pairwise comparisons.

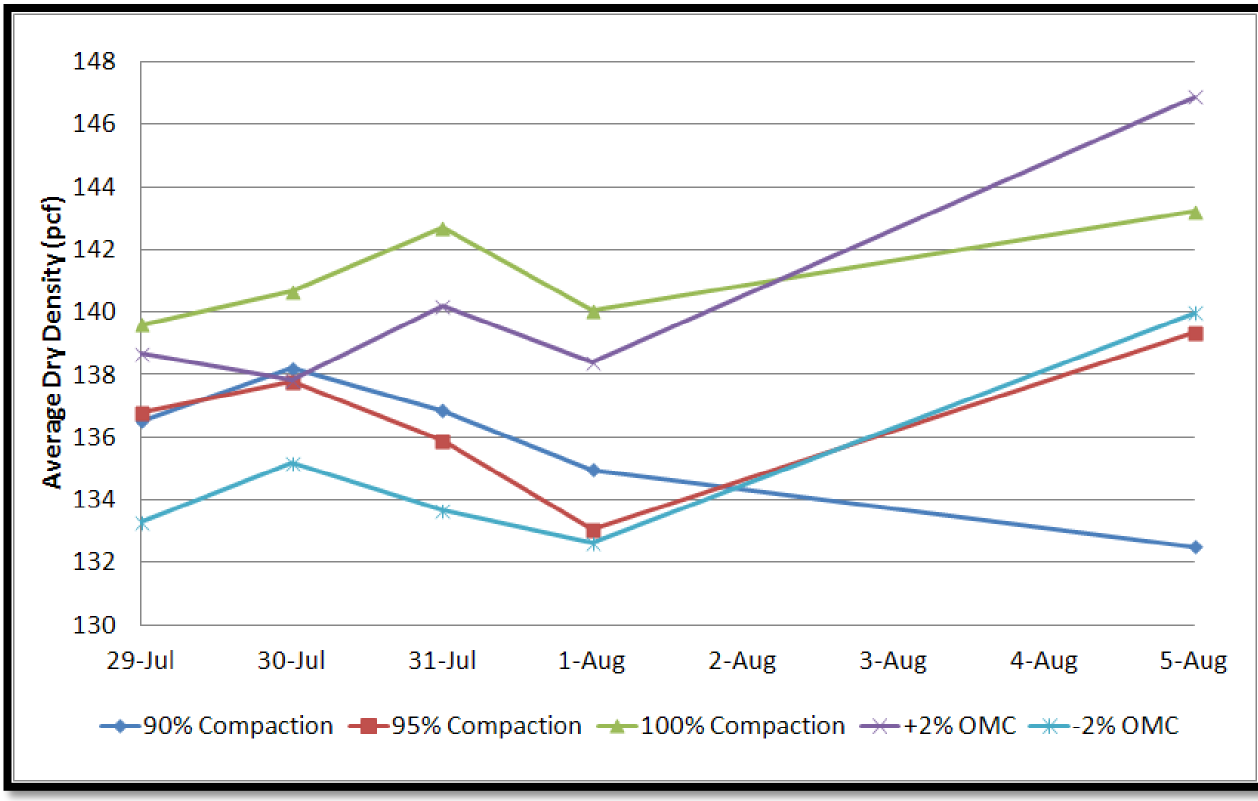


Figure 2.19. Dry Density Results from Marble Falls Material.
Note: each data point the average of 9 tests.

To further investigate whether mean density changed with drying of the base after compaction, researchers regressed the densities on the moisture contents for each treatment series. Figure 2.20 shows the average density values versus the average moisture content for each treatment. Although some series appear to have a positive trend while others appear to have a negative trend, the regression results showed the slope coefficients were not significantly different from 0 (with a level of significance of 0.05) for any series. The data show no statistically significant trends existed; the data do not provide sufficient evidence to conclude that changes in water content during curing are impacting the dry density of this base material.

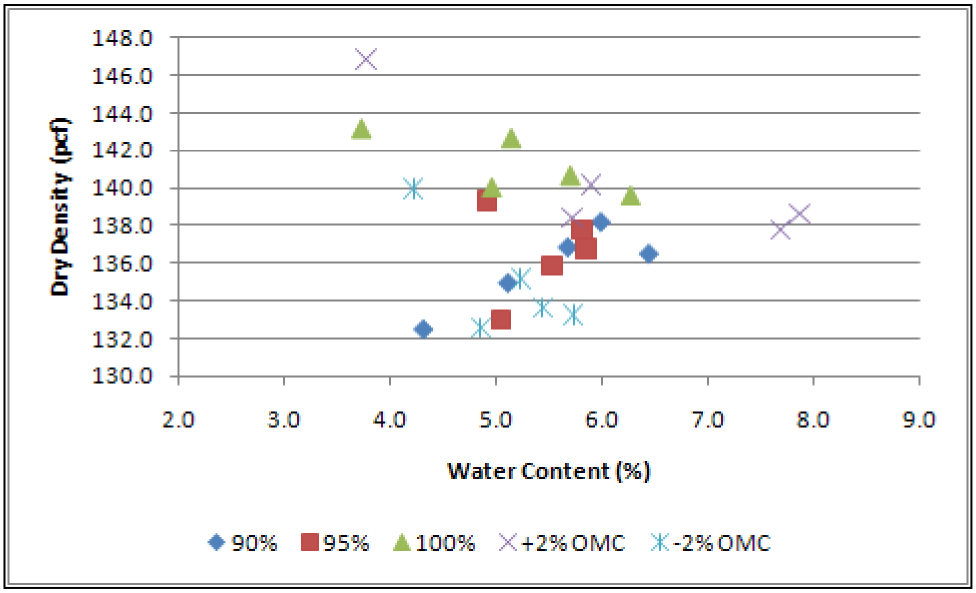


Figure 2.20. Average Dry Density versus Average Water Content for Marble Falls Material.

Discernment of Treatments with NDT for Marble Falls Material

Tests on Day of Placement

To evaluate for statistical differences between treatments on the day of placement (July 29, 2010), ANOVA evaluations were performed across the treatments. Table 2.11 presents the DCP results and ANOVA output. Since the tabulated F value exceeds the F critical value, Tukey's multiple comparison procedure was applied to identify which means significantly differed. Two statistically equivalent categories exist as Figure 2.21 illustrates.

Table 2.11. DCP Penetration Rate (in./blow) on Day of Placement for Marble Falls Material.

DCP Penetration Rate (inches per blow) Results - July 29, 2010					
		At OMC			
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.33	-0.43	-0.40	-0.38
2	-0.72	-0.32	-0.54	-0.73	-0.45
3	-0.60	-0.31	-0.31	-0.61	-0.44
4	-0.42	-0.28	-0.25	-0.56	-0.30
5	-0.50	-0.50	-0.54	-0.69	-0.32
6	-0.50	-0.56	-0.35	-0.80	-0.38
7	-0.52	-0.42	-0.30	-0.64	-0.42
8	-0.48	-0.26	-0.36	-0.80	-0.31
9	-0.53	-0.36	-0.35	-0.56	-0.48

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.9	9	-4.52373	-0.50264	0.01527
0.95	9	-3.3489	-0.3721	0.010452
1	9	-3.42931	-0.38103	0.010136
2% Above OMC	9	-5.78614	-0.6429	0.016813
2% Below OMC	9	-3.49071	-0.38786	0.004125

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.48962	4	0.122405	10.77606	5.07E-06	2.605975
Within Groups	0.454359	40	0.011359			
Total	0.943978	44				

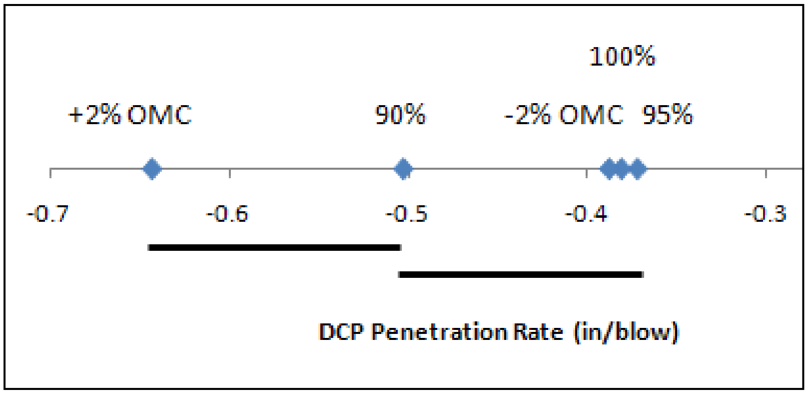


Figure 2.21. Discernment of Treatments with DCP for Marble Falls Material on Day of Placement.

With the Marble Falls material, the PFWD could not distinguish differences in treatments. Table 2.12 presents the results. The research team was not able to test the +2 percent OMC site on the day of placement due to sensor overloading in the PFWD.

Table 2.12. PFWD Modulus (MPa) for Marble Falls Material on Day of Placement.

	E Modulus (PFWD) - July 29, 2010				
	At OMC				
Test	90%	95%	100%	2% Below OMC	2% Above OMC
1	93	100	69	154	not tested
2	42	31	11	135	too unstable
3	46	140	218	155	
4	150	162	120	215	
5	55	38	15	115	
6	90	68	60	118	
7	258	219	129	116	
8	150	160	100	133	
9	226	242	92	169	

No statistical difference exists

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.9	9	1110	123.3333	6174.25
0.95	9	1160	128.8889	5685.861
1	9	814	90.44444	4014.278
2% Below OMC	9	1310	145.5556	1046.028

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14398.56	3	4799.519	1.13461	0.349853	2.90112
Within Groups	135363.3	32	4230.104			
Total	149761.9	35				

Table 2.13 presents the density results on the day of placement, and Figure 2.22 displays two groups of equivalent mean densities identified. When compared with the DCP results, the categorization in Figure 2.22 is similar to the DCP results with the exception of the sites placed at water contents significantly different from optimum. The site significantly wetter than optimum is in the highest category of density but in the weakest DCP category. The site significantly drier than optimum is in the lowest density category but in the strongest DCP category.

Table 2.13. Density Results for Marble Falls Material on Day of Placement.

Dry Density Results - July 29, 2010

Test	At OMC 90%	At OMC 95%	At OMC 100%	2% Above OMC	2% Below OMC
1	140.8	139.1	137.8	136.5	134.9
2	138.2	142.2	140.4	138.7	137.6
3	138.1	131	139.4	139.4	134.8
4	140	136.8	140.6	139.3	129.3
5	139.5	143.2	142.9	135.3	138.3
6	132.1	136.1	140.6	138.7	136.7
7	135	129.4	139.2	142.6	127
8	134.2	140.9	140	134	133.6
9	130.7	132.3	135.5	143.5	127.3

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.9	9	1228.6	136.5111	13.21611
0.95	9	1231	136.7778	25.16944
1	9	1256.4	139.6	4.2425
2% Above OMC	9	1248	138.6667	9.6975
2% Below OMC	9	1199.5	133.2778	18.95444

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	213.08	4	53.27	3.736672	0.011253	2.605975
Within Groups	570.24	40	14.256			
Total	783.32	44				

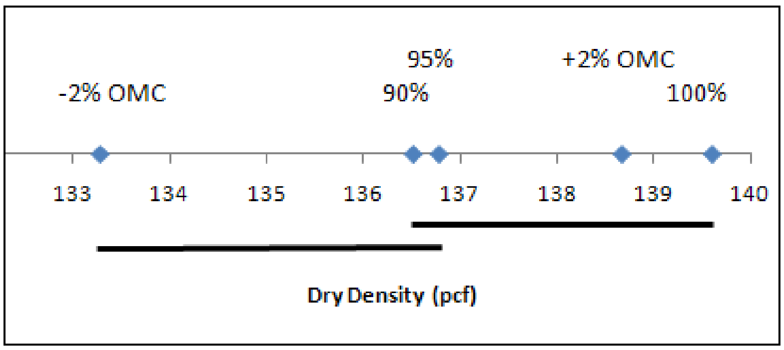


Figure 2.22. Discernment of Treatments with Nuclear Gauge for Marble Falls Material on Day of Placement.

Tests after Moisture Content Equalization

The research team also completed analysis of data gathered from NDT devices after the moisture contents had equalized throughout each treatment. Moisture equalization means that there is no statistical difference between the mean water content values of each treatment. Table 2.14 shows that the mean water contents were equivalent among all treatments with the Marble Falls material on July 31, 2010, which was two days after placement. With the moisture contents equivalent among treatments, the data can be evaluated without concern of water content influence on the NDT.

Table 2.14. Moisture Content Results for Marble Falls Material 2 Days after Placement.

Moisture Content Results - July 31, 2010

Test	90%	95% (At OMC)	100%	2% Above OMC	2% Below OMC
1	6.5	6.6	6.3	7.1	4.9
2	5.3	5.4	5.7	6.5	5.2
3	5.9	5.4	4.0	5.2	4.5
4	5.9	6.2	6.8	5.1	5.7
5	6.4	6.3	6.1	6.4	5.8
6	4.7	4.4	4.3	5.0	5.1
7	6.1	5.1	3.9	5.9	6.3
8	5.7	6.1	4.9	6.7	6.6
9	4.4	4.1	4.2	5.3	4.7

No statistical difference exists

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.9	9	51.047	5.671889	0.543305
0.95	9	49.704	5.522667	0.779092
1	9	46.275	5.141667	1.199874
2% Above OMC	9	53.052	5.894667	0.60858
2% Below OMC	9	48.885	5.431667	0.524215

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.822478	4	0.70562	0.965262	0.43714	2.605975
Within Groups	29.24053	40	0.731013			
Total	32.06301	44				

Table 2.15 displays the DCP results and ANOVA output for the Marble Falls material after moisture equalization. The DCP categorized the sites into two categories as Figure 2.23 shows, with the highest mechanical performance belonging to the 95 percent compaction, 100 percent compaction sites, and −2 percent OMC sites. The poorest mechanical performance belongs to the +2 percent OMC site, which is statistically equivalent to the 90 percent compaction site. Note that these results are similar when compared with the DCP results on the first day of testing shown in Figure 2.21; there is no change of order with respect to mechanical performance, and at both times of testing the 95 percent compaction, 100 percent compaction, and −2 percent OMC sites were found to be statistically equivalent.

Table 2.15. DCP Results for Marble Falls Material after Moisture Equalization.

DCP Penetration Rate (inches per blow) Results - July 31, 2010

Test	90%	95% (At OMC)	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.16	-0.18	-0.24	-0.28
2	-0.29	-0.20	-0.20	-0.30	-0.27
3	-0.31	-0.16	-0.25	-0.34	-0.27
4	-0.26	-0.13	-0.19	-0.33	-0.20
5	-0.29	-0.19	-0.26	-0.22	-0.20
6	-0.30	-0.27	-0.13	-0.25	-0.21
7	-0.29	-0.21	-0.16	-0.39	-0.19
8	-0.26	-0.19	-0.20	-0.28	-0.18
9	-0.30	-0.29	-0.25	-0.24	-0.12

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0.9	9	-2.54555	-0.28284	0.000334
0.95	9	-1.79724	-0.19969	0.002761
1	9	-1.82248	-0.2025	0.001933
2% Above OMC	9	-2.5831	-0.28701	0.003072
2% Below OMC	9	-1.93089	-0.21454	0.002665

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.069194	4	0.017299	8.034864	7.48E-05	2.605975
Within Groups	0.086117	40	0.002153			
Total	0.155311	44				

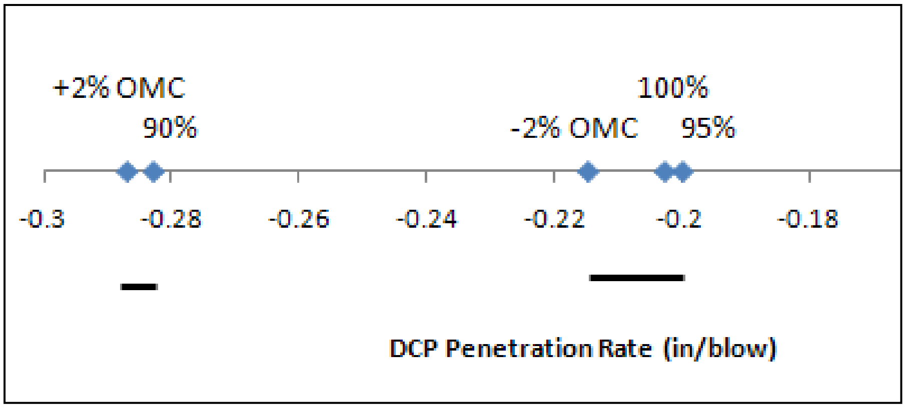


Figure 2.23. DCP Categorization of Treatments after Moisture Equalization for Marble Falls Material.

Figure 2.24 presents the categorization of treatments for the Marble Falls after moisture equalization with the PFWD. The PFWD did not distinguish the 100 percent section from any of the other treatments and grouped the remaining treatments as Figure 2.24 shows.

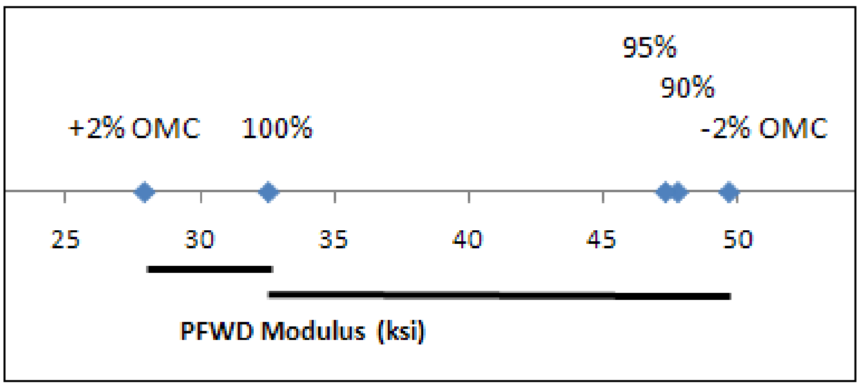


Figure 2.24. PFWD Categorization of Treatments after Moisture Equalization for Marble Falls Material.

Figure 2.25 illustrates how the nuclear gauge identified three statistical groups after moisture content equalization. As compared to the data collected on the day of placement illustrated in Figure 2.22, the order of the treatments remains unchanged.

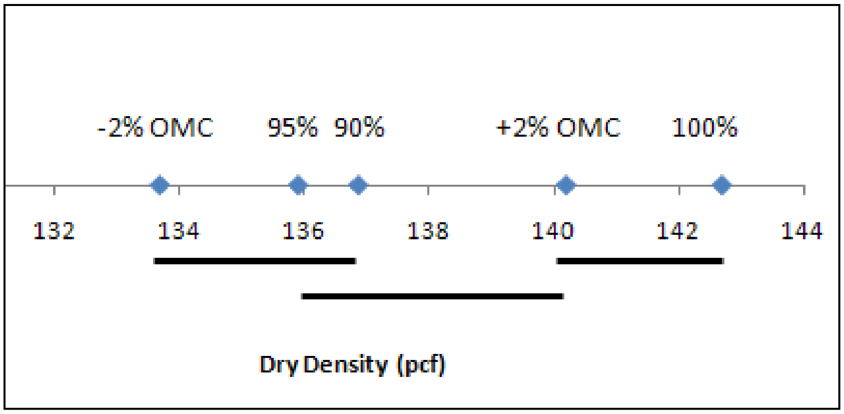


Figure 2.25. Nuclear Density for Marble Falls Material after Moisture Equalization.

Impact of Water Content on NDT

Researchers evaluated the data to examine for impacts of water content and density on the DCP and PFWD results. To isolate the general form of the trend between water content and NDT, researchers examined the relationship between water content and NDT for each series when mean density in that series were equivalent through time. Figure 2.26 presents the DCP result, and Figure 2.26 presents the PFWD result. The data suggest that, within the range of observed water contents, a linear relationship can be used in both cases.

Fitting a least-squares equation through the DCP data in Figure 2.26 results in the slope coefficients presented in Table 2.16. Table 2.17 also presents the standard error of the estimated slope values; the output suggests the tabulated coefficients do not significantly differ among the treatment; the average slope coefficient is −0.147. This means that for each percent increase in water content, the DCP is expected to penetrate 0.147 in./blow faster.

Similarly, fitting a least-squares equation through the PFWD data in Figure 2.27 results in the slope coefficients presented in Table 2.17. For the 90 and 100 percent series, the PFWD modulus decreased approximately 24 ksi for each percent increase in water content. For the 95 percent series, the PFWD modulus decreased approximately 59 ksi for each percent increase in water content.

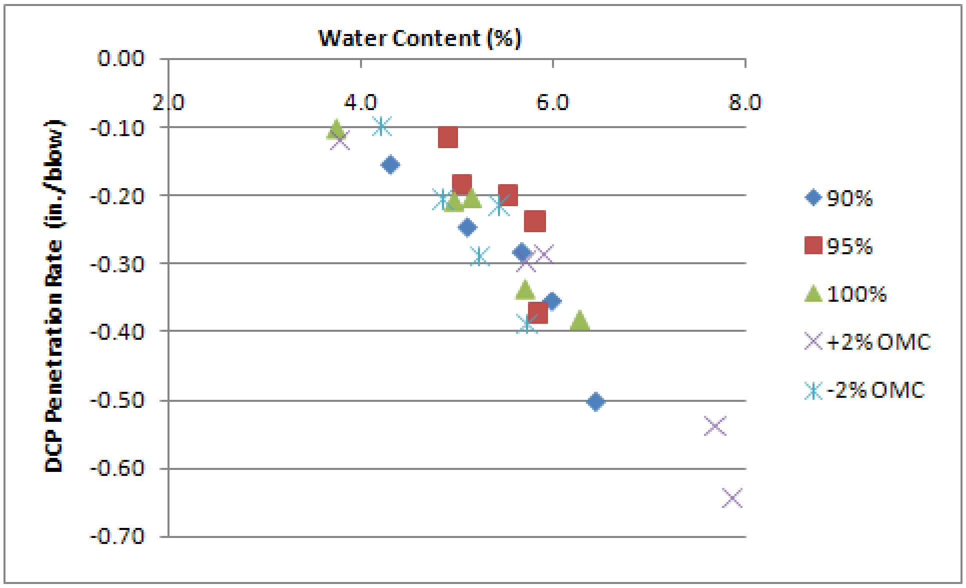


Figure 2.26. DCP Penetration Rate versus Water Content for Marble Falls Material.

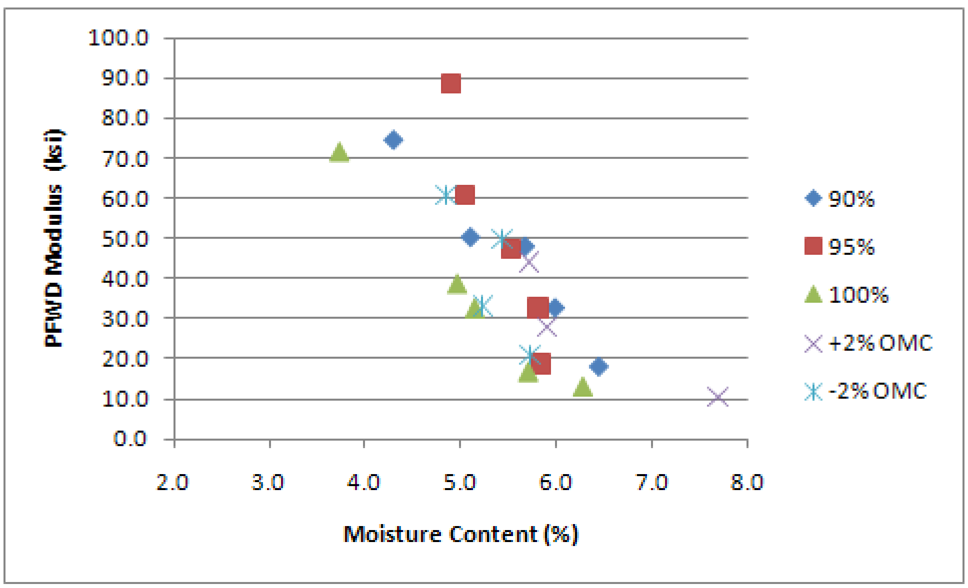


Figure 2.27. PFWD Modulus versus Water Content for Marble Falls Material.

Table 2.16. Slope Coefficients for Impact of Water Content on DCP Penetration Rate for Marble Falls Material.

	90%	95%	100%	+2% OMC	−2% OMC
Estimated Slope Coefficient	−0.150	−0.184	−0.114	−0.122	−0.164
Standard Error of Slope Coefficient	0.0287	0.0700	0.0172	0.0164	0.0477
Overall Estimated Coefficient*	**−0.147**				

**This is the average value since the data suggests the estimated slopes among the series do not significantly differ.*

Table 2.17. Slope Coefficients for Impact of Water Content on PFWD Modulus for Marble Falls Material.

	90%	95%	100%	+2% OMC	−2% OMC
Estimated Slope Coefficient	−24.9	−59.0	−24.1	−14.0*	−38.5*
Standard Error of Slope Coefficient	3.22	11.2	2.42	6.29	19.9

**Not statistically significant from zero due to the low number of observations in the data set.*

Impact of Density on NDT

To examine the impact of density on the NDT, researchers used the data set collected on July 31, 2010, at which time the mean water contents were statistically equivalent among all treatments. Figures 2.28 and 2.29 present the DCP penetration rate and PFWD modulus versus density, respectively. Figure 2.27 suggests, and statistical tests confirm, that no correlation or trend exists between the dry density and DCP penetration rate. Figure 2.29 oddly suggests, and analysis confirms, a negative correlation observed between dry density and the PFWD modulus that is statistically significant at the 95 percent confidence level. This observation contradicts theory, and given the limited size of the data set, must be viewed with suspicion.

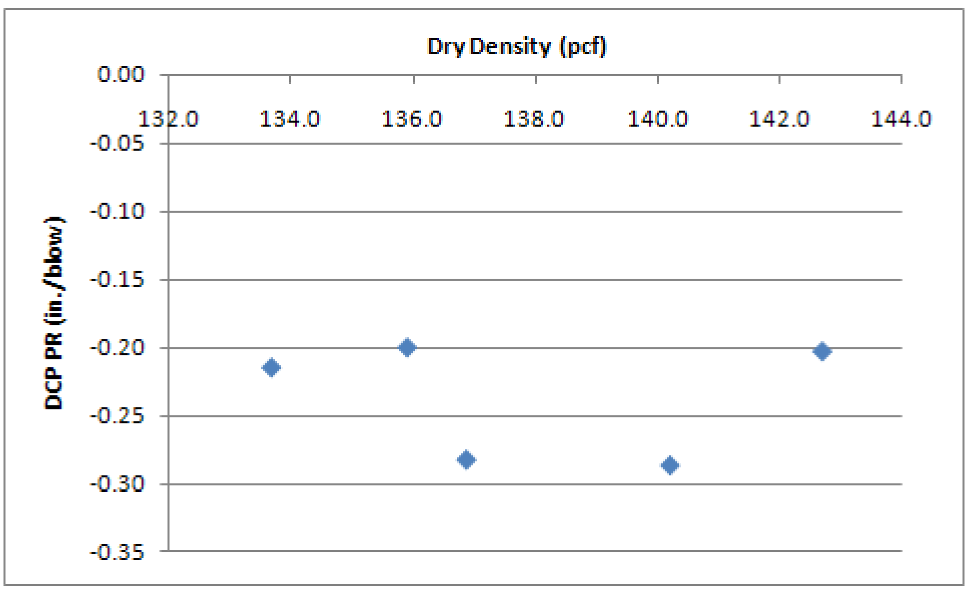


Figure 2.28. DCP Penetration Rate versus Density for Marble Falls Material.
Note: To isolate the impact of density on the NDT, data presented are when mean water content among all series are equivalent.

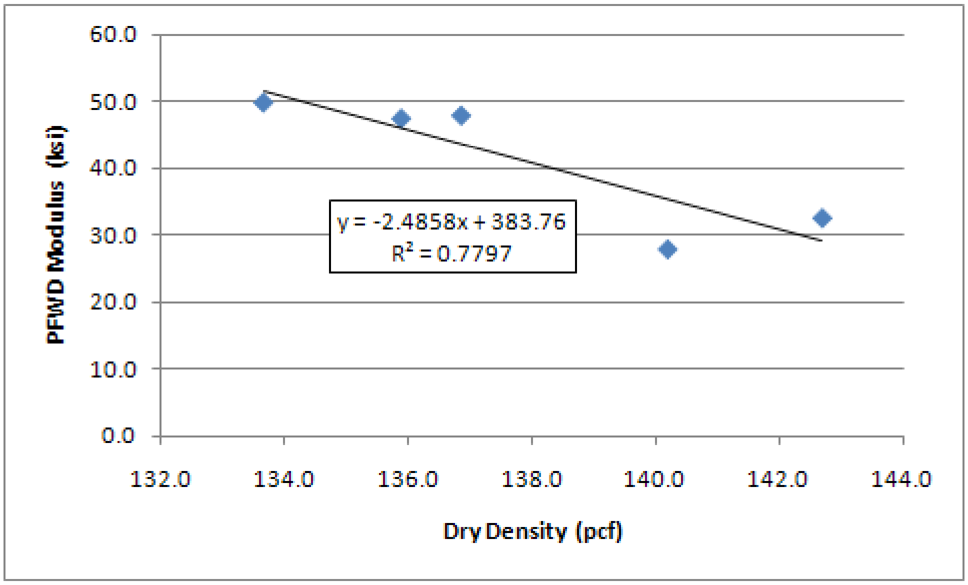


Figure 2.29. PFWD Modulus versus Density for Marble Falls Material.
Note: To isolate the impact of density on the NDT, data presented are when mean water content among all series are equivalent.

CONCLUSIONS FROM COMPACTION EXPERIMENT

The data collected from the full-scale compaction experiments with the Centex-Buda and Marble Falls flexible bases showed:

- Neither of the flexible bases evaluated exhibited statistically significant changes in mean density by drying during the curing stage.
- For both materials, placing the base significantly wet of optimum resulted in high density, but reduced mechanical properties even after curing.
- When placed substantially dry of optimum, low densities resulted with both materials.
- With both bases, the DCP was better able to distinguish among treatments than the PFWD.
- As contrasted with results from the Buda material, the mechanical properties of the Marble Falls material were less sensitive to increases in compaction effort. With the Marble Falls material, increased effort above 95 percent compaction did not produce better mechanical properties, even though increased density was obtained. With the Buda material, increased effort above 95 percent compaction produced increased mechanical properties, even though no significant density increases were realized.
- With both materials, moisture content influenced the mechanical properties much more than density. Within the range of moisture contents and densities evaluated, the mechanical properties of the Buda material were largely influenced by water content with some influence of density. In contrast, within the range of moisture contents and densities evaluated, the mechanical properties of the Marble Falls material were only influenced by water content.

With these observations in mind, the following should be considered in the revision of TxDOT's flexible base specification:

- Flexible bases should not be worked significantly dry or significantly wet of optimum.
- If pursuing alternatives to the nuclear gauge for compaction acceptance, the impact of water content on stiffness or modulus properties must be considered.
- The DCP currently appears better suited than the PFWD for field compaction acceptance of flexible bases. The DCP identified the 100 percent compaction treatment in the best categories of properties for both materials both on the day of placement and after curing. The PFWD could not distinguish among any treatments on the day of placement.
- For well-graded high-quality materials, density control, or even ordinary compaction with proof rolling, should adequately ensure achievement of suitable compaction.
- For other materials (such as Grade 2 or some Grade 4), alternatives to density-based acceptance could enable construction of base layers with better mechanical properties. For such materials, increases in mechanical properties can be realized with increased compaction effort, even if no significant gains in density occur.

CHAPTER 3: CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The background literature and experiments conducted under this research project to date suggest that it should be possible to use non-density-based acceptance for flexible base compaction. Regardless of flexible base material, the influence of water content on new NDT-based approaches must be considered. However, the specific approach best suited for acceptance could vary depending on the flexible base employed. Since the mechanical properties of higher-quality well-graded materials do not exhibit as great sensitivity to compaction effort, continuing on with density control, using a new NDT device as a surrogate for density, or even Ordinary Compaction with proof rolling may be suitable with these materials. Other materials such as Grade 2 or some Grade 4 may be best accepted by non-density methods. This is because the mechanical properties of these materials are more sensitive to compaction effort, where significant improvements in mechanical properties can result with increased compaction effort, even if significant increases in density do not occur.

The data also show that, regardless of material, working and compacting significantly wet of optimum should be avoided. The data collected show that working the base in this manner results in inferior mechanical properties, even though the resultant in-place density is high. Working significantly dry of optimum should be avoided because inferior density results.

To move forward with developing a non-density based method of compaction acceptance, the following potential approaches and future work should be considered in the second year of this research project.

POTENTIAL APPROACHES FOR FLEXIBLE BASE ACCEPTANCE WITH NDT

Based on the background information, and the experiments conducted at Texas A&M's Riverside Campus, the following approaches seem suitable for consideration to replace the nuclear density gauge for compaction acceptance. In all cases, controls on water content both above and below optimum should be included.

Approach 1—Set NDT Compaction Target with Field Test Strip

The most basic approach could involve compaction (while controlling moisture) until the NDT reaches an asymptote that could then become the target. This approach is similar to one method MnDOT uses. An important feature of this approach is it should maximize the material's mechanical properties for the given level of compaction effort available in the field. As the results from the field experiment suggest, materials such as Grade 2 and some Grade 4 could particularly benefit from this approach. For such materials, the data suggests mechanical improvements may be gained by increased compaction effort even though no significant increase in density may occur.

Additionally, with this approach, the risk of under-compaction is minimized because compaction and testing is performed at optimal water content. This feature of the method should minimize the risk of obtaining “good” NDT readings on a poorly consolidated material, which could rapidly accumulate permanent deformation under construction and/or public traffic.

Approach 2—Use NDT as Surrogate for Density

Another option for using NDT to control compaction is to set the NDT target based on the values achieved when the material reaches 100 percent density. This is another approach option in MnDOT’s specifications. When target density is obtained, NDT are collected, and the most permissive NDT value where density requirements were met becomes the NDT target.

An advantage of this method is that essentially, the approach is density-based, which is an approach familiar in industry. Additionally, as long as the water content at the time of acceptance testing is similar to the water content of the base material when setting targets, this approach could minimize concerns with the influence of water content on the new NDT devices.

One drawback to this approach is it may not ensure material mechanical properties are maximized, especially for materials where additional effort may significantly improve mechanical properties even though additional density may not result. Additionally, for high-quality well-graded materials, this approach may not adequately protect against permanent deformation since these materials seem to obtain and maintain peak stiffness properties beginning at densities significantly lower than 100 percent. For example, within the range of densities measured with the Marble Falls material, the density had no impact on the DCP penetration rate.

Approach 3—Set NDT Targets Based on Design Assumptions

This approach sets targets for NDT based on design assumptions and pavement response modeling. In this approach, the NDT targets are based on the design moduli values. The field acceptance tests are used to make sure the design modulus is achieved. Alternatively, pavement response modeling is used with the design assumptions to determine the maximum allowable deflection on the surface of the layer being tested.

Of the approaches mentioned, this approach most directly links field acceptance to design assumptions. However, the design assumptions are generally based on field FWD data from in-service pavements; the equilibrium state of moisture in pavement layers at time of FWD testing is likely different from a newly compacted layer at optimum water content. Consideration must be given to accounting for water content and the time frame to testing. These corrections for the impact of water content on the NDT results are labor-intensive to determine and material specific.

Approach 4—Modify MnDOT DCP Criteria for Texas Materials

This approach relies on the DCP and sets fixed targets based upon the material under testing. The advantage to this approach is no target setting is needed, and the test is simple and rapid to perform. This approach is already in use within MnDOT; however the applicability of the MnDOT requirements to Texas materials would need to be addressed. As with the other approaches, some type of moisture control or consideration of water content must also be included to account for the impact of water content on the material stiffness.

RECOMMENDATIONS FOR FUTURE WORK

The work conducted thus far in this research project shows the DCP most promising for evaluating flexible base compaction. MnDOT has already implemented the DCP; however, some discrepancy among MnDOT and Texas materials exist that requires further investigation if the MnDOT specifications are to be considered for Texas flexible bases. To develop and refine an approach for using new NDT in place of nuclear-density based acceptance, the following work should be performed in the second year of this research project:

- Evaluate the outlined approaches for new NDT-based acceptance on three TxDOT construction projects. Figure 3.1 illustrates the general field testing plan envisioned.
- Devices envisioned for testing include the nuclear density gauge, PSPA, PFWD, and DCP. The GeoGauge may be included, pending review by the TxDOT project monitoring committee. The nuclear density gauge will also be used as the current reference standard.
- After collection of data, the results from the evaluation section will be compared to the targets set from the control strip. This will serve as a shadow implementation of the new NDT devices in parallel with the nuclear density gauge.
- The results from the DCP on flexible bases will also be evaluated with MnDOT's existing DCP specifications. Some Texas bases will have a grading number outside those MnDOT used, so the results should be analyzed to evaluate if the MnDOT specification applies, or could be revised, to potentially apply to Texas flexible bases.

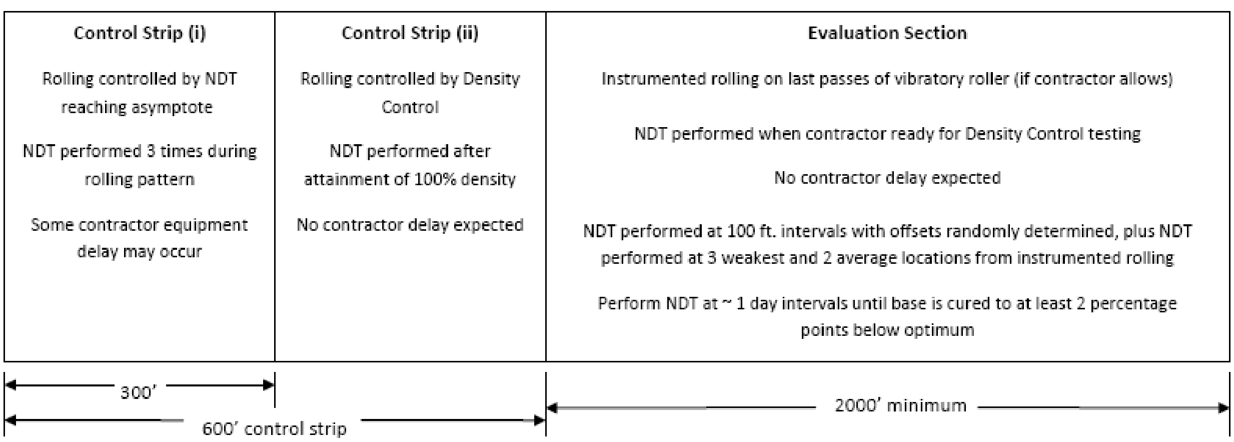


Figure 3.1. Proposed Field Test Arrangement to Evaluate New NDT for Flexible Base Compaction.

After the conclusion of these field evaluations, the second year of this research project should conclude with a new test procedure in TxDOT format for performing compaction acceptance of flexible base with non-density based methods. The specific device(s) used and approach taken depend on the outcome of the field projects where the new NDT devices will be shadow tested in parallel with the nuclear gauge.

APPENDIX A:
FLEXIBLE BASE PLAN NOTES FROM LUBBOCK DISTRICT

Item 247 - Flexible Base

REQUIRED: USE TYPE "A", GRADE 4
Tables required for Grade 4
Pick the pertinent table for the project.

SPECIFICATION DATA

TEST TO BE IN ACCORDANCE WITH TEXAS DEPARTMENT OF TRANSPORTATION STANDARD TEST METHODS

FLEXIBLE BASE SPECIFICATION DATA
F.M. Roads - Low Volume Roadways
0 - 750 Average Daily Traffic

GRADING REQUIREMENTS PERCENT RETAINED – SIEVES SIEVE SIZES INCHES					SOIL CONSTANTS		MAX WET BALL	MAX % INCREASE	MIN STRENGTH 15 PSI
1 3/4	7/8	1/2	#4	#40	L.L. MAX	P.I. MAX			
0	10-30	30-55	50-75	70-90	40	15	55	25	N/A

FLEXIBLE BASE SPECIFICATION DATA
S.H. Roads and Two Lane U.S. Roads
750 - 2000 Average Daily Traffic

GRADING REQUIREMENTS PERCENT RETAINED – SIEVES SIEVE SIZES INCHES					SOIL CONSTANTS		MAX WET BALL	MAX % INCREASE	MIN STRENGTH 15 PSI
1 3/4	7/8	1/2	#4	#40	L.L. MAX	P.I. MAX			
0	10-30	30-55	50-75	70-90	40	15	50	25	150

FLEXIBLE BASE SPECIFICATION DATA
Four-Lane Roadways and City Sections
Over 2000 Average Daily Traffic

GRADING REQUIREMENTS PERCENT RETAINED – SIEVES SIEVE SIZES INCHES					SOIL CONSTANTS		MAX WET BALL	MAX % INCREASE	MIN STRENGTH 15 PSI
1 3/4	7/8	1/2	#4	#40	L.L. MAX	P.I. MAX			
0	10-30	30-55	50-75	70-90	40	12	50	20	160

NOTE 1 recommended
The addition of field sand to reduce the plasticity index a maximum of three points below the original P.I. is permitted. Introduce field sand at the crusher on a feed belt prior to building the stockpile.

NOTE 2 recommended.
The addition of lime, or suitable material as approved by the Engineer, is permitted to reduce the plasticity index, if the mixture is mixed on the road or in a pugmill just prior to placement.

NOTE 3 required (Proof rolling must be paid separately under Item 216.)
Proof roll, as directed by the Engineer.

NOTE 4 recommended (for 2/3C surface treatment projects). Must include Spec. Prov. 247-021 Flexible Base. Values less than 100.0 in per mile must be discussed with Ron Baker or Benny Sanchez.
Use Surface Test Type B.

Correct 0.1 mile sections having an average international roughness index (IRI) value greater than 100.0 in. per mile.

APPENDIX B:
FLEXIBLE BASE PLAN NOTES FROM ODESSA DISTRICT

ITEM 247: FLEXIBLE BASE

THE ESTIMATED QUANTITY OF FLEXIBLE BASE IS FOR THE ROADWAYS AS WELL AS INTERSECTING STREETS AND DRIVEWAYS. THE MEASURED AREA FOR PAYMENT WILL BE THE CROWN WIDTH ONLY. THE SIDE SLOPE TAPERS ARE NOT INCLUDED IN THE MEASUREMENTS FOR THE FLEXIBLE BASE BUT ARE CONSIDERED SUBSIDIARY TO THIS ITEM. (A247)

THE ESTIMATED QUANTITY OF FOUNDATION COURSE SHOWN IS FOR THE ROADWAY AS WELL AS INTERSECTING STREETS AND DRIVEWAYS. THE MEASURED AREA FOR PAYMENT WILL BE THE CROWN WIDTH ONLY. THE SIDE SLOPE TAPERS ARE NOT TO BE INCLUDED IN THE MEASUREMENTS FOR THE FOUNDATION COURSE BUT ARE CONSIDERED SUBSIDIARY TO THIS ITEM. (C247)

FOUNDATION COURSE MATERIAL WILL BE AS APPROVED. (D247)

ASSUME RESPONSIBILITY FOR THE DISPOSAL OF ALL BOULDERS NOT FRACTURED DURING ORDINARY ROLLING METHODS AND THOSE TOO LARGE TO BE INCORPORATED INTO THE FOUNDATION COURSE AS APPROVED. (E247)

THE SPECIAL PROVISION 247---XXX TO ITEM 247 FLEXIBLE BASE, ARTICLE 247.4, LAST SENTENCE, THIRD PARAGRAPH IS MODIFIED AS FOLLOWS: CORRECT 0.1-MILE SECTIONS HAVING AN AVERAGE INTERNATIONAL ROUGHNESS INDEX (IRI) VALUE GREATER THAN 100.0 IN. PER MILE TO AN IRI VALUE OF 100.0 IN. PER MILE OR LESS FOR EACH WHEELPATH. (H247)

THE SPECIAL PROVISION 247---XXX TO ITEM 247 FLEXIBLE BASE, ARTICLE 247.4.C.2, SECOND SENTENCE IS MODIFIED AS FOLLOWS: MAINTAIN MOISTURE DURING COMPACTION AS DIRECTED BY THE ENGINEER, THIRD SENTENCE IS MODIFIED AS FOLLOWS: DETERMINE THE MOISTURE CONTENT OF THE MATERIAL IN ACCORDANCE WITH TEX-115-E OR TEX-103-E AS DIRECTED BY THE ENGINEER. (I247)

APPENDIX C:
FLEXIBLE BASE TEST REPORT FROM CENTEX-BUDA MATERIAL USED ON COMPACTION EXPERIMENT AT TEXAS A&M RIVERSIDE CAMPUS

PaveTex Engineering & Testing, Inc.
3989 HWY 290 E., Dripping Springs Tx, 78620
Ph (512) 894-3040 Fax (512) 858 2921

PROJECT: Soils and Base Testing
Contract 14-6XXP0006

DATE: 5/7/2009

REPORT NO.: 6718

Report of:	**Physical Test for Flexible Base Material**
Specifications:	**TxDot Standard Specification Item 247 Type A, Grade 1 and Grade 4**
Test Methods:	TEX-100-E, TEX-101-E, TEX-104-E, TEX-105-E, TEX-106-E TEX-110-E, TEX-113-E, TEX-116-E, TEX-117-E
Sample Number:	91355
Producer:	Centex Buda
Stockpile ID#:	344
Sampled By:	Russell Briseno
Date Sampled:	4/24/09
Material Description:	Crushed Limestone Base
Technician:	Phillip New

Compaction Test		
Maximum Dry Unit Wt.	133.4	pcf
Optimum Moisture, OM	8.5	%

Wet Ball Mill	Test (1)	Test (2)	Gr. 1 & 4
Wet Ball Mill Value	38	37	Max. 40
Increase in (-)#40	20	20	Max. 20

TEX-117-E, Part II (Accelerated Method)

	Value in PSI	Gr 1	Gr 4(Mod)
Compressive Strength at 0 psi Lateral Pressure	35	Min. 45	
Compressive Strength at 3 psi Lateral Pressure	103		Min. 90
Compressive Strength at 15 psi Lateral Pressure	199	Min. 175	Min. 175
Triaxial Classification	2.3	1.0	

Sieve Analysis	Graded (1)	Split (2)	Split (3)	Split (4)	Split (5)	Split (6)	Average	Grade 1	Gr 4(Mod)
1-3/4"	0	0	0	0	0	0	0	0	0
7/8"	23	20	16	10	19	22	18	10-35	10-35
3/8"	49	49	37	28	41	45	42	30-50	30-60
#4	63	63	49	42	55	56	55	45-65	45-70
#40	80	80	70	67	74	75	74	70-85	70-85

Atterberg Limits	Graded (1)	Split (2)	Split (3)	Split (4)	Split (5)	Split (6)	Average	Grade 1	Gr 4(Mod)
Liquid Limit	20	22	20	20	21	20	21	Max. 35	Max. 40
Plastic Limit	18	18	19	19	19	18	19	--	--
Plasticity Index	2	4	1	1	2	2	2	Max. 10	Max. 12

Report Reviewed by:
PaveTex Engineering and Testing, Inc.

APPENDIX D: FLEXIBLE BASE TEST REPORT FROM MARBLE FALLS MATERIALS USED ON COMPACTION EXPERIMENT AT TEXAS A&M RIVERSIDE CAMPUS

TEXAS DEPARTMENT OF TRANSPORTATION
AUSTIN DISTRICT LAB
7901 N. IH 35 AUSTIN, TX 78753
FAX: (512) 832-7176 PHONE: (512) 832-7093

AUS LAB NUMBER: 102001 **REPORT DATE:** 1/29/2010

STOCKPILE ID# 205

Report of: **Physical Test for Flexible Base Material**
Specifications: **TxDOT Standard Specification Item 247 Type A, Grade 1, 2, 4, and 5**

Test Methods: **TEX-100-E, TEX-101-E, TEX-104-E, TEX-105-E, TEX-106-E**
TEX-110-E, TEX-113-E, TEX-116-E, TEX-117-E_Part II

Producer: Capital Aggregates Marble Falls
Sampled By: John Gordon
Date Sampled: 1/13/2010
Material Description: Crushed Limestone Base
Technician: John Gordon, Holly Elder, Mike Young

Moisture-Density Relationship

Maximum Dry Unit Wt.	150.7	pcf
Optimum Moisture, OM	5.2	%

Wet Ball Mill (Tx-116-E)

	Test (1)	Test (2)	Gr. 1,4,5
Wet Ball Mill Value	29	29	**Max. 40**
Increase in Minus #40	10	10	**Max. 20**

Texas Triaxial: TEX-117-E, Part II (Accelerated Method)

	Value in psi.	GRADE 1	GRADE 2	*GRADE 4	GRADE 5
Compressive Strength at 0 psi Lateral Pressure	49	**Min. 45**	**Min. 35**	**--**	**--**
Compressive Strength at 3 psi Lateral Pressure	110	**--**	**--**	**Min. 90**	**Min. 90**
Compressive Strength at 15 psi Lateral Pressure	229	**Min. 175**	**Min. 175**	**Min. 175**	**Min. 175**
Triaxial Classification	-	**1.0**	**2.3 or better**	**--**	**--**

Sieve Analysis (Tx-110-E)	1	2	3	4	5	6	Average	GRADE 1	GRADE 2	*GRADE 4	GRADE 5
1-3/4"	0	0	0	0	0	0	0	**0**	**0-10**	**0**	**0-5**
7/8"	17	21	22	23	20	22	21	**10-35**	**-**	**10-35**	**10-35**
3/8"	41	46	46	48	42	46	45	**30-50**	**-**	**30-60**	**30-65**
#4	52	55	58	58	52	56	55	**45-65**	**45-75**	**45-70**	**45-75**
#40	79	80	82	85	78	80	80	**70-85**	**60-85**	**70-85**	**70-90**
#200	91	91	92	94	91	92	92	-	-	-	-

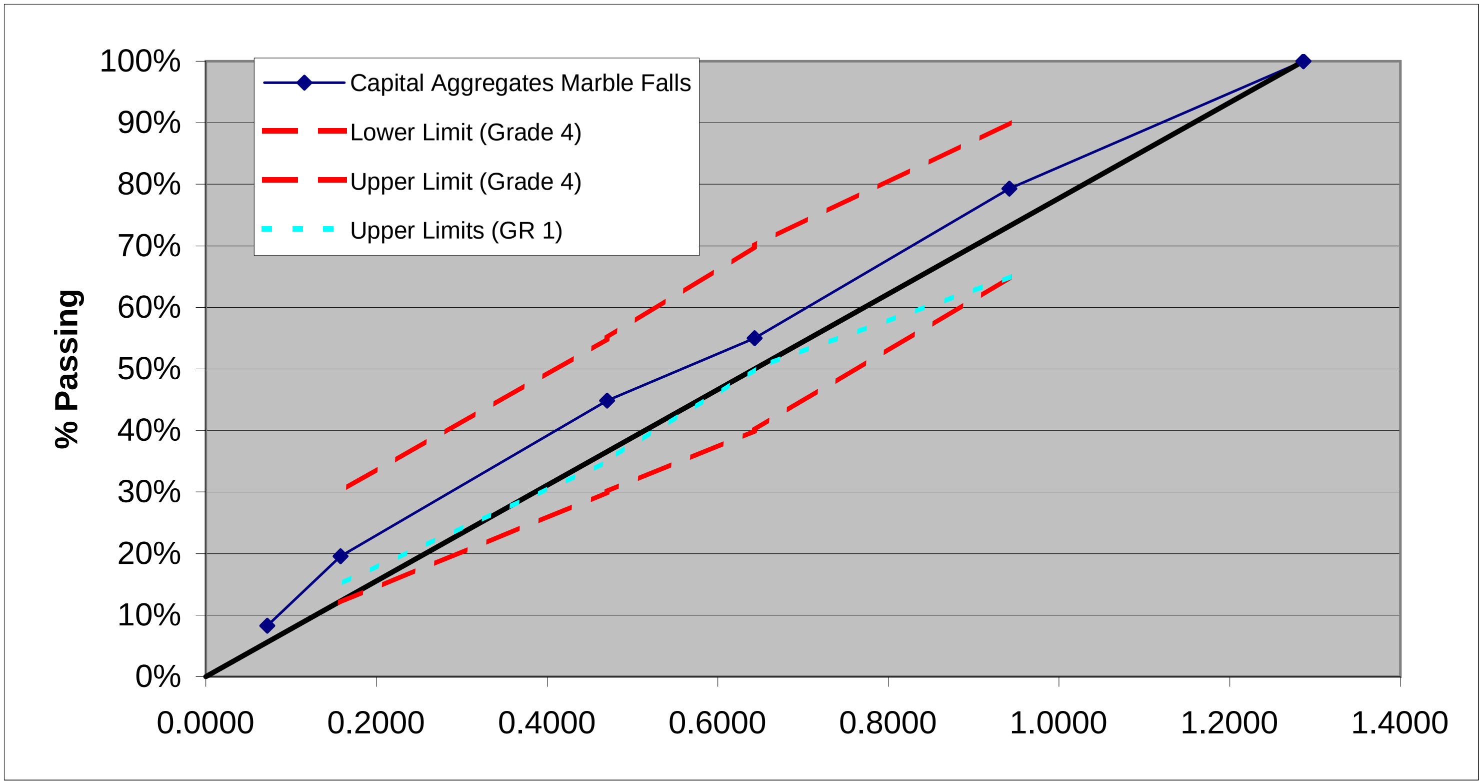
Atterberg Limits (Tx-104-106-E)	1	2	3	4	5	6	Average	GRADE 1	GRADE 2	*GRADE 4	GRADE 5
Liquid Limit	21	22	21	14	20	21	20	**Max. 35**	**Max. 40**	**Max. 35**	**Max. 35**
Plastic Limit	14	14	13	12	14	14	14	**--**	**--**	**--**	**--**
Plasticity Index	7	8	8	2	6	7	6	**Max. 10**	**Max. 12**	**Max. 10**	**Max. 10**
Linear Shrinkage (%)											

Reviewed By: **Miguel Arellano, P.E.**
Approval:
Grade 1: Meets specifications
Grade 2: Meets specifications
Grade 4: Meets specifications
Grade 5: Meets specifications

* ***These are Austin District Grade 4 requirements; Other District Grade 4 requirements may vary or differ, please refer to the plan notes of the project.***

This test report can not be used to represent any other material previously or subsequently produced from the source stated above or any other source. The material approved by this test report can only be used for TxDOT or TTA projects, unless otherwise approved by the Austin District Laboratory. This test report can not serve as verification of the material delivered to a project and must be verified with haul tickets. The approval status of the stockpile is subject to change, if specification requirements are violated or the material becomes incompliant with requirements. Material delivered to the project can be rejected based on project level testing, as required by specification. This test report can not be used for design or bidding purposes. Please contact the Austin District Laboratory (512) 832-7093, if there is any question to the approval status of this stockpile. This test report is only valid for twelve (12) months from the report date, after which the stockpile will be retested or ownership will be released by TxDOT.

Sieve Size		Retained	apital Aggregates Marble Fa	Power 45	Lower Limit (Grade 4)	Upper Limit (Grade 4)	Upper Limits (GR 1)
1 3/4	1.2864	0	100%	1.0000			
7/8	0.9417	21	79%		65%	90%	65%
3/8	0.6432	45	55%		40%	70%	50%
# 4	0.4703	55	45%		30%	55%	35%
# 40	0.1577	80	20%		12%	30%	15%
# 200	0.0721	92	8%				
	0			0			



APPENDIX E:
TEST RESULTS FROM CENTEX-BUDA MATERIAL ON COMPACTION EXPERIMENT AT TEXAS A&M RIVERSIDE CAMPUS

Dry Density Results - July 21, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	126.3	120.8	117.9	127.3	128.4
2	121.3	125.1	127.5	128.8	132.9
3	112.5	123.2	118.1	130.9	130.4
4	112.3	121	124.8	130.5	121.1
5	122.4	123.7	128.8	130.9	127.5
6	116.5	119.6	130.8	130.1	124.9
7	113.3	119.3	123.1	131.7	119.9
8	122.9	127.3	119.1	128.9	130.3
9	109.9	124.7	117.8	131	120.7
AVG	117.5	122.7	123.1	130.0	126.2
St. Dev	5.847	2.735	5.125	1.401	4.789

Dry Density Results - July 22, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	106.5	120.4	125.3	132.3	128.6
2	122.1	124.1	122.1	128.3	129.6
3	123.9	118.9	119	132	132
4	110.9	122.7	125.9	126.1	115.4
5	121	126.1	125.8	131.1	124.4
6	115.4	126.6	121.5	130.3	121.5
7	111.4	117.7	119.7	131.2	118.3
8	117.1	129.7	126	129.2	122
9	103	124.5	119.8	127.9	109.4
AVG	114.6	123.4	122.8	129.8	122.4
St. Dev	7.200	3.891	2.965	2.089	7.265

Dry Density Results - July 23, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	111	124	129.6	133.4	130.6
2	118.8	126.3	127.5	130.8	131
3	119.4	121.9	116	128.8	125.5
4	114.5	124.7	130.8	131.5	127.2
5	120.4	126.3	126.4	133.2	131.5
6	117.4	112.1	127.7	133.6	119.8
7	114	134.1	126.5	132.5	127.3
8	118.4	127	132.8	128.6	130.2
9	112	117.6	122.6	130.8	114.6
AVG	116.2	123.8	126.7	131.5	126.4
St. Dev	3.416	6.211	4.943	1.890	5.748

Dry Density Results - July 24, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	120.5	125.3	122.4	131.5	120.6
2	123.4	129	128.2	128.1	125.9
3	126.4	121.8	129.2	129.5	125
4	118.2	125	129.5	124.1	125.5
5	119.3	127.9	129.1	128.9	128.3
6	122	124.8	128.2	131.6	126.1
7	119.4	127	128.8	130.3	117.9
8	123.5	128.1	129.5	124.7	124.3
9	118.5	120.7	129.5	126.6	124.1
AVG	121.2	125.5	128.3	128.4	124.2
St. Dev	2.771	2.840	2.259	2.748	3.129

Moisture Content Results - July 21, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.040	8.850	7.114	8.044	7.805
2	8.037	8.876	7.644	9.979	8.843
3	6.879	8.308	5.999	8.722	7.102
4	5.875	8.953	7.329	9.466	7.693
5	9.031	10.120	9.758	9.519	8.243
6	7.344	8.331	7.951	8.95	7.196
7	7.982	7.941	8.205	9.465	5.683
8	10.140	10.900	10.320	10.07	6.525
9	7.540	6.640	8.228	8.972	5.78
AVG	7.7	8.8	8.1	9.2	7.2
St. Dev	1.361	1.227	1.318	0.639	1.071

Moisture Content Results - July 22, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.611	7.470	7.699	8.939	8.641
2	7.544	8.167	6.345	9.427	7.653
3	7.439	6.562	5.138	7.187	6.199
4	6.104	7.201	5.896	10.46	6.667
5	7.657	8.084	7.542	9.431	8.324
6	6.149	7.190	6.644	7.905	6.781
7	5.882	6.305	7.971	9.506	4.896
8	8.754	8.527	9.299	9.318	6.663
9	7.464	6.660	5.466	8.396	5.591
AVG	7.1	7.4	6.9	9.0	6.8
St. Dev	0.942	0.778	1.346	0.980	1.221

Moisture Content Results - July 22, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	7.029	7.692	6.984	8.7	8.2
2	8.531	8.072	8.293	8.7	8.3
3	8.123	7.962	7.008	8.4	7.3
4	9.138	9.306	7.094	9.0	8.2
5	9.645	9.702	8.537	8.8	8.5
6	8.497	8.945	7.941	7.9	7.5
7	9.748	10.70	7.800	9.2	7.7
8	10.77	9.611	8.600	9.3	7.5
9	7.303	7.791	6.362	8.2	6.0
AVG	8.8	8.9	7.6	8.7	7.7
St. Dev	1.204	1.049	0.793	0.459	0.761

Moisture Content Results - July 24, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.4	6.4	6.4	6.4	6.4
2	7.0	6.6	6.5	7.0	6.6
3	6.4	7.1	4.7	6.4	7.1
4	5.8	6.3	5.2	5.8	6.3
5	6.7	8.2	6.5	6.7	8.2
6	6.1	6.1	5.6	6.1	6.1
7	7.6	6.0	5.9	7.6	6.0
8	7.7	7.2	7.6	7.7	7.2
9	6.0	5.6	5.2	6.0	5.6
AVG	6.6	6.6	6.0	6.6	6.6
St. Dev	0.680	0.783	0.890	0.680	0.783

DCP Penetration Rate (inches per blow) Results - July 21, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.39	-0.34	-0.29	-0.37	-0.29
2	-0.45	-0.29	-0.22	-0.54	-0.29
3	-0.38	-0.31	-0.36	-0.43	-0.24
4	-0.54	-0.34	-0.30	-0.36	-0.21
5	-0.35	-0.47	-0.22	-0.46	-0.23
6	-0.41	-0.37	-0.22	-0.56	-0.23
7	-0.36	-0.50	-0.28	-0.41	-0.26
8	-0.41	-0.59	-0.38	-0.76	-0.18
9	-0.41	-0.28	-0.19	-0.52	-0.28
AVG	-0.412	-0.387	-0.271	-0.488	-0.245
St. Dev	0.056	0.108	0.065	0.125	0.037

DCP Penetration Rate (inches per blow) Results - July 22, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.32	-0.24	-0.11	-0.27	-0.16
2	-0.23	-0.15	-0.10	-0.38	-0.15
3	-0.27	-0.18	-0.17	-0.40	-0.16
4	-0.38	-0.19	-0.24	-0.29	-0.22
5	-0.25	-0.14	-0.13	-0.49	-0.15
6	-0.25	-0.15	-0.11	-0.31	-0.26
7	-0.28	-0.28	-0.17	-0.38	-0.25
8	-0.27	-0.20	-0.18	-0.73	-0.17
9	-0.29	-0.16	-0.14	-0.30	-0.32
AVG	-0.281	-0.189	-0.147	-0.393	-0.204
St. Dev	0.044	0.047	0.045	0.141	0.061

DCP Penetration Rate (inches per blow) Results - July 23, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.44	-0.34	-0.21	-0.29	-0.23
2	-0.33	-0.24	-0.18	-0.32	-0.20
3	-0.43	-0.30	-0.29	-0.33	-0.18
4	-0.62	-0.33	-0.21	-0.23	-0.31
5	-0.30	-0.28	-0.18	-0.30	-0.16
6	-0.41	-0.23	-0.15	-0.38	-0.29
7	-0.41	-0.38	-0.18	-0.27	-0.41
8	-0.43	-0.26	-0.17	-0.33	-0.20
9	-0.36	-0.26	-0.15	-0.30	-0.30
AVG	-0.415	-0.291	-0.191	-0.305	-0.251
St. Dev	0.090	0.050	0.043	0.043	0.082

DCP Penetration Rate (inches per blow) Results - July 24, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.30	-0.23	-0.13	-0.17	-0.18
2	-0.24	-0.14	-0.11	-0.22	-0.15
3	-0.26	-0.16	-0.14	-0.17	-0.14
4	-0.38	-0.19	-0.13	-0.16	-0.24
5	-0.27	-0.15	-0.12	-0.24	-0.15
6	-0.27	-0.13	-0.07	-0.18	-0.19
7	-0.32	-0.19	-0.12	-0.18	-0.24
8	-0.20	-0.17	-0.10	-0.21	-0.14
9	-0.25	-0.17	-0.10	-0.20	-0.21
AVG	-0.277	-0.170	-0.113	-0.192	-0.182
St. Dev	0.052	0.031	0.019	0.025	0.041

E Modulus (PFWD) - July 21, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	83	111	138	Too wet to test, overloaded sensors	62
2	79	110	117		147
3	201	108	165		65
4	171	90.5	180		106
5	90	66	201		61
6	131	150	81		59
7	147	66	71.5		100
8	63	20	86		303
9	72	122	73		193
AVG	115.2	93.7	123.6		121.8
St. Dev	49.129	38.270	49.548		81.934

E Modulus (PFWD) - July 22, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	81	210	252	27	262
2	288	261	307	10	290
3	236	164	191	4	261
4	207	199	293	4	265
5	207	210	316	3	366
6	251	327	442	1	266
7	330	179	268	0	193
8	223	215	192		320
9	249	327	399	13	178
AVG	230.2	232.4	295.6	7.8	266.8
St. Dev	68.474	59.863	84.420	8.940	57.664

E Modulus (PFWD) - July 23, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	77	208	212	126	230
2	145	146	335	55	178
3	94	176	249	67	204
4	131	134	247	107	265
5	144	68	91	79	311
6	175	175	488	82	216
7	217	105	307	136	181
8	185	106.5	352	120	251
9	225	198	224	130	208
AVG	154.8	146.3	278.3	100.2	227.1
St. Dev	50.801	47.114	110.515	29.999	42.739

E Modulus (PFWD) - July 24, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	193	261	299	274	298
2	342	269	373	287	428
3	402	394	359.5	265	268
4	174	280	311	243	308
5	298.5	292	315	234	298.5
6	272	392	523	209.5	238
7	244	369	361	197	271
8	205	259	396	250	244
9	232	549.5	742	210	204
AVG	262.5	340.6	408.8	241.1	284.2
St. Dev	74.505	96.239	141.706	31.233	63.501

APPENDIX F:
TEST RESULTS FROM MARBLE FALLS MATERIAL ON COMPACTION EXPERIMENT AT TEXAS A&M RIVERSIDE CAMPUS

Dry Density Results - July 29, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	140.8	139.1	137.8	136.5	134.9
2	138.2	142.2	140.4	138.7	137.6
3	138.1	131	139.4	139.4	134.8
4	140	136.8	140.6	139.3	129.3
5	139.5	143.2	142.9	135.3	138.3
6	132.1	136.1	140.6	138.7	136.7
7	135	129.4	139.2	142.6	127
8	134.2	140.9	140	134	133.6
9	130.7	132.3	135.5	143.5	127.3
AVG	136.5	136.8	139.6	138.7	133.3
St. Dev.	3.635	5.017	2.060	3.114	4.354

Dry Density Results - July 30, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	140.1	143.5	142.6	138.4	136.7
2	142.7	139.3	145.5	138.8	136.8
3	138.6	139.5	138.5	138.2	133.8
4	142.1	139.7	143.6	138	132.9
5	141.1	138.7	143.4	137	139.4
6	130.1	133	142	139.5	136.1
7	138.1	138.6	136.4	131.2	136
8	136.5	135.8	144.2	138.8	133
9	134.4	131.9	129.8	140.4	131.9
AVG	138.2	137.8	140.7	137.8	135.2
St. Dev.	4.040	3.615	4.980	2.655	2.421

Dry Density Results - July 31, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	141.3	139.7	143	135.9	132.8
2	141.2	140.1	145.6	140.7	139.7
3	132.6	132.1	143.5	136	135.1
4	143.8	133.6	143	140.3	134.2
5	139.2	141.7	143.4	141.8	135.6
6	128.3	133.4	142.9	143.5	130.9
7	136.9	136.3	143	141.4	134.5
8	135	134.3	143.2	140.7	129.9
9	133.4	131.8	136.6	141.4	130.3
AVG	136.9	135.9	142.7	140.2	133.7
St. Dev.	4.988	3.729	2.432	2.573	3.104

Dry Density Results - August 1, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	141.5	137.1	138.6	136.7	132.5
2	139.1	139.4	145.8	142.2	130.1
3	132.2	128.4	144.1	137.6	126.6
4	136.6	134.9	130.9	142.9	132.8
5	138.3	132.3	143.2	138.5	134.9
6	129.3	118.8	140.5	145.4	129.9
7	132.6	136.8	136.7	134.9	133.1
8	135.8	133.8	141.5	134.4	140.6
9	129.3	135.8	139	132.9	133
AVG	135.0	133.0	140.0	138.4	132.6
St. Dev.	4.355	6.201	4.470	4.268	3.861

Dry Density Results - August 5, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	134	141.8	143.6	145.8	140.7
2	135.4	138.6	153.7	147.9	140.8
3	127.6	133	142.6	143.9	147.1
4	137.5	137.3	148.6	143.9	141.8
5	134.5	140	148.7	148	140.5
6	125.8	139.8	143.5	146.2	138
7	133.4	144.6	132.9	147.9	138.7
8	135.1	139.5	138.7	147.6	138.7
9	129.3	61.2	136.5	150.6	133.5
AVG	132.5	130.6	143.2	146.9	140.0
St. Dev.	3.974	26.231	6.534	2.153	3.617

Moisture Content Results - July 29, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	7.172	6.875	5.491	8.308	6.007
2	7.192	6.952	7.386	7.829	6.32
3	5.986	4.932	6.319	7.557	4.771
4	7.021	6.793	5.728	8.45	7.186
5	7.550	6.715	7.335	8.7	6.445
6	4.503	5.202	6.799	6.428	4.392
7	5.323	4.053	4.420	7.766	6.229
8	7.647	6.210	7.409	9.75	6.268
9	5.582	4.863	5.543	5.987	3.904
AVG	6.4	5.8	6.3	7.9	5.7
St. Dev.	1.122	1.090	1.049	1.145	1.098

Moisture Content Results - July 30, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.196	6.351	6.844	7.133	5.758
2	6.650	6.349	6.224	7.386	6.029
3	5.480	6.029	4.666	5.734	4.788
4	6.621	6.252	6.080	8.135	6.818
5	7.187	6.295	6.921	9.025	5.798
6	5.132	4.410	5.198	7.192	4.231
7	5.228	5.952	4.578	8.228	4.871
8	6.833	6.034	6.808	9.062	5.426
9	4.546	4.569	3.976	7.267	3.338
AVG	6.0	5.8	5.7	7.7	5.2
St. Dev.	0.914	0.761	1.118	1.049	1.043

Moisture Content Results - July 31, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.5	6.6	6.3	7.1	4.9
2	5.3	5.4	5.7	6.5	5.2
3	5.9	5.4	4.0	5.2	4.5
4	5.9	6.2	6.8	5.1	5.7
5	6.4	6.3	6.1	6.4	5.8
6	4.7	4.4	4.3	5.0	5.1
7	6.1	5.1	3.9	5.9	6.3
8	5.7	6.1	4.9	6.7	6.6
9	4.4	4.1	4.2	5.3	4.7
AVG	5.7	5.5	5.1	5.9	5.4
St. Dev.	0.737	0.883	1.095	0.780	0.724

Moisture Content Results - August 1, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	6.6	5.3	6.9	6.0	5.2
2	6.2	5.8	5.9	5.3	5.3
3	5.0	4.2	4.0	4.2	4.1
4	4.7	5.3	3.8	6.0	6.4
5	5.4	6.5	6.2	6.0	5.6
6	4.2	4.2	5.0	5.0	4.4
7	5.1	5.9	4.2	6.3	5.7
8	4.9	4.2	5.0	6.7	3.9
9	4.0	4.1	3.6	5.8	3.0
AVG	5.1	5.0	5.0	5.7	4.9
St. Dev.	0.840	0.901	1.152	0.753	1.056

Moisture Content Results - August 5, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	4.4	4.4	3.4	4.9	4.1
2	4.7	4.4	4.0	4.4	4.3
3	4.1	3.9	4.1	4.1	3.1
4	5.3	4.5	4.8	2.8	4.2
5	4.3	4.8	4.9	4.0	4.1
6	4.2	4.0	3.3	3.1	3.9
7	5.1	4.5	3.3	3.6	5.3
8	3.6	5.4	3.1	3.3	5.3
9	3.0	8.1	2.7	3.7	3.7
AVG	4.3	4.9	3.7	3.8	4.2
St. Dev.	0.717	1.279	0.771	0.662	0.707

DCP Penetration Rate (inches per blow) Results - July 29, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.33	-0.43	-0.40	-0.38
2	-0.72	-0.32	-0.54	-0.73	-0.45
3	-0.60	-0.31	-0.31	-0.61	-0.44
4	-0.42	-0.28	-0.25	-0.56	-0.30
5	-0.50	-0.50	-0.54	-0.69	-0.32
6	-0.50	-0.56	-0.35	-0.80	-0.38
7	-0.52	-0.42	-0.30	-0.64	-0.42
8	-0.48	-0.26	-0.36	-0.80	-0.31
9	-0.53	-0.36	-0.35	-0.56	-0.48
AVG	-0.50	-0.37	-0.38	-0.64	-0.39
St. Dev.	0.124	0.102	0.101	0.130	0.064

DCP Penetration Rate (inches per blow) Results - July 30, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.22	-0.34	-0.33	-0.31
2	-0.43	-0.24	-0.40	-0.27	-0.27
3	-0.34	-0.20	-0.25	-0.44	-0.27
4	-0.36	-0.18	-0.31	-0.37	-0.21
5	-0.40	-0.24	-0.44	-0.52	-0.24
6	-0.39	-0.40	-0.44	-0.80	-0.24
7	-0.35	-0.25	-0.37	-0.77	-0.30
8	-0.34	-0.20	-0.21	-0.70	-0.22
9	-0.32	-0.23	-0.25	-0.64	-0.55
AVG	-0.36	-0.24	-0.34	-0.54	-0.29
St. Dev.	0.050	0.064	0.085	0.199	0.104

DCP Penetration Rate (inches per blow) Results - July 31, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.16	-0.18	-0.24	-0.28
2	-0.29	-0.20	-0.20	-0.30	-0.27
3	-0.31	-0.16	-0.25	-0.34	-0.27
4	-0.26	-0.13	-0.19	-0.33	-0.20
5	-0.29	-0.19	-0.26	-0.22	-0.20
6	-0.30	-0.27	-0.13	-0.25	-0.21
7	-0.29	-0.21	-0.16	-0.39	-0.19
8	-0.26	-0.19	-0.20	-0.28	-0.18
9	-0.30	-0.29	-0.25	-0.24	-0.12
AVG	-0.28	-0.20	-0.20	-0.29	-0.21
St. Dev.	0.018	0.053	0.044	0.055	0.052

DCP Penetration Rate (inches per blow) Results - August 1, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.32	-0.18	-0.19	-0.22	-0.25
2	-0.22	-0.15	-0.24	-0.22	-0.18
3	-0.26	-0.14	-0.15	-0.23	-0.18
4	-0.21	-0.15	-0.29	-0.21	-0.13
5	-0.23	-0.16	-0.21	-0.30	-0.19
6	-0.29	-0.33	-0.17	-0.30	-0.26
7	-0.26	-0.25	-0.25	-0.52	-0.28
8	-0.18	-0.15	-0.16	-0.41	-0.13
9	-0.26	-0.14	-0.22	-0.27	-0.25
AVG	-0.25	-0.18	-0.21	-0.30	-0.21
St. Dev.	0.041	0.064	0.048	0.104	0.056

DCP Penetration Rate (inches per blow) Results - August 5, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	-0.26	-0.08	-0.13	-0.17	-0.14
2	-0.15	-0.09	-0.08	-0.10	-0.07
3	-0.15	-0.08	-0.04	-0.12	-0.08
4	-0.11	-0.10	-0.07	-0.22	-0.15
5	-0.15	-0.08	-0.12	-0.06	-0.09
6	-0.15	-0.18	-0.04	-0.06	-0.17
7	-0.16	-0.12	-0.12	-0.15	-0.07
8	-0.11	-0.10	-0.11	-0.10	-0.05
9	-0.16	-0.20	-0.21	-0.09	-0.06
AVG	-0.15	-0.11	-0.10	-0.12	-0.10
St. Dev.	0.045	0.044	0.051	0.051	0.044

E Modulus (PFWD) - July 29, 2010					
	At OMC				
Test	90%	95%	100%	2% Below OMC	2% Above OMC
1	93	100	69	154	not tested - too unstable
2	42	31	11	135	
3	46	140	218	155	
4	150	162	120	215	
5	55	38	15	115	
6	90	68	60	118	
7	258	219	129	116	
8	150	160	100	133	
9	226	242	92	169	
AVG	123.3	128.9	90.4	145.6	
St. Dev.	78.576	75.405	63.358	32.342	

E Modulus (PFWD) - July 30, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	192	167	65	125	144
2	71	132	28	52	240
3	186	333	94	105	251
4	183	199	173	134	290
5	173	127	17	100	215
6	299	105	65	0	240
7	336	289	179	42	200
8	317	387	217	29	302
9	260	288	205	69	174
AVG	224.1	225.2	115.9	72.9	228.4
St. Dev.	85.347	101.652	77.919	45.909	51.308

E Modulus (PFWD) - July 31, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	222	380	193	301	233
2	241	198	302	150	323
3	247	321	175	135	231
4	293	361	141	136	319
5	362	308	90	283	342
6	342	206	383	134	348
7	549	403	310	141	388
8	341	472	155	286	449
9	368	288	269	165	451
AVG	329.4	326.3	224.2	192.3	342.7
St. Dev.	99.080	89.416	96.017	74.027	79.506

E Modulus (PFWD) - August 1, 2010					
		At OMC			
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	154	408	234	383	475
2	331	554	162	445	305
3	235	549	215	155	376
4	320	389	212	294	608
5	390	319	214	260	592
6	228	175	410	394	341
7	433	408	206	162	209
8	564	559	424	301	564
9	453	405	322	344	293
AVG	345.3	418.4	266.6	304.2	418.1
St. Dev.	128.688	125.298	95.193	100.145	146.077

E Modulus (PFWD) - August 5, 2010					
	At OMC				
Test	90%	95%	100%	2% Above OMC	2% Below OMC
1	398	516	372	356	252
2	264	727	749	736	723
3	528	560	610	421	331
4	631	547	518	223	485
5	779	733	457	475	654
6	521	557	592	422	414
7	470	501	469	231	547
8	511	815	394	453	914
9	513	532	274	468	399
AVG	512.8	609.8	492.8	420.6	524.3
St. Dev.	142.323	115.608	143.146	152.029	209.048