Guideline for Pulverization of Stabilized Bases

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16. Abstract

Full-depth reclamation (FDR) is routinely carried out for rehabilitation of roads through the pulverization process. The primary stabilizers currently used in TxDOT districts for FDR are cement, lime, and fly ash. The optimum stabilizer content is currently determined either based on experience or through a series of laboratory tests that evaluates the strength, stiffness and durability of the base-stabilizer mix. For lab testing, base materials are retrieved from the site way before pulverization. The change in gradation due to pulverization can significantly impact the base strength and stiffness.

Phase I of this study consisted of an extensive laboratory study to determine the impact of changes in gradation on the desired stabilizer content of a base material. It was found that the change in gradation indeed impacts the properties of the mix and should be considered in the design stages of FDR.

In Phase II, the ways to address the impact of pulverization was investigated and reported through extensive laboratory tests and field observations. Recommendations for improving the quality of the pulverized materials are included in this report.

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Abstract

Full-depth reclamation (FDR) is routinely carried out for rehabilitation of roads through the pulverization process. The primary stabilizers currently used in TxDOT districts for FDR are cement, lime, and fly ash. The optimum stabilizer content is currently determined either based on experience or through a series of laboratory tests that evaluates the strength, stiffness and durability of the base-stabilizer mix. For lab testing, base materials are retrieved from the site way before pulverization. The change in gradation due to pulverization can significantly impact the base strength and stiffness.

Phase I of this study consisted of an extensive laboratory study to determine the impact of changes in gradation on the desired stabilizer content of a base material. It was found that the change in gradation indeed impacts the properties of the mix and should be considered in the design stages of FDR.

In Phase II, the ways to address the impact of pulverization was investigated and reported through extensive laboratory tests and field observations. Recommendations for improving the quality of the pulverized materials are included in this report.

Implementation Statement

In this report a number of recommendations have been made to improve the mix design, construction and quality management of pulverized layers from full-depth reclamation. The recommendations are based on the results from five sites.

At this time, the recommendations should be implemented on a number of new and ongoing projects to confirm the recommendations, and to adjust the limits and/or criteria. As part of the implementation, a guide should be developed to decimate to the TxDOT staff.

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Chapter 1

Introduction

Rehabilitation of highway pavements through full-depth reclamation (FDR) is a cost-effective option that reduces the use of virgin base aggregates. Pulverization of the asphalt layer with base material or base material alone may result in the formation of fine materials during the crushing action of the pulverizer with potentially negative impact on the strength of the material. Typically, a stabilizer is used in the FDR process which aids in strength gain for the base layer. The stabilizers mostly used by TxDOT are cement, lime and fly ash. The optimum stabilizer content is currently determined either based on the previous experience or through a series of laboratory tests that evaluates the strength, stiffness and durability of the base-stabilizer mix. For lab testing, base materials are retrieved from the site way before pulverization. The change in gradation due to pulverization can significantly impact the base strength and stiffness. This matter is addressed in this report.

Objective

The main objective of this research project is to evaluate the effects of pulverization on the base properties and to determine the optimum stabilizer content necessary to obtain a reasonably strong, stiff and durable base layer that will perform well for a long time.

The first task of the project was to perform an information search relevant to pulverization of pavements, utilization of the selected stabilizers, test procedures to determine base strength before and after pulverization, and nondestructive testing (NDT) methods to monitor the stabilized pavement sections. The second task required the selection of sites ready for construction to observe the construction method and to monitor the strength and performance of the FDR projects under realistic conditions. The third task was to establish test protocol to characterize the change in properties of stabilized bases due to change in gradation after pulverization. For this task, a limestone base often used in El Paso was utilized for testing. The impacts of change in gradation, as well as stabilizer type and content, moisture-density curve, modulus, unconfined compressive strength, moisture susceptibility and structural design were studied. Task 4 involved monitoring the construction and evaluating the materials collected from the test sites prior to and during construction, and performing the tests described in Task 3. The final tasks consist of developing guidelines and provide recommendations for upgrading the current TxDOT specifications. The focus of this report is on these final tasks.

Organization of Report

Chapter 2 contains a summary of background information and lessons learned from Phase I of this study.

Chapter 3 outlines the testing protocol for characterization of stabilized base material through an example. The topics discussed in this chapter are development of gradation curves, selection of stabilizer, test procedures, retained strength, modulus, retained modulus, moisture susceptibility and optimum stabilizer content.

Chapter 4 presents information and results from cases studies for six sites. The topics discussed in this chapter are the description of the sites, construction activities, laboratory and field testing to document the impact of pulverization and field structural evaluation.

Chapter 5 presents the observations and recommendations for obtaining a quality pulverized layer.

Chapter 2

Background

Introduction

Many highway agencies use full-depth reclamation (FDR) and soil stabilization with diverse additives to rehabilitate their roads more economically (Mallick et al., 2002). In FDR process, the existing base, often with the surface asphalt layer, is pulverized and mixed in-place. The concern with the pulverization is the crushing of coarse aggregates of the base; and, as a result, changes in the gradation. Changes in gradation, may adversely affect the strength and stiffness of the final product. The pulverized materials that do not meet specifications may be stabilized with additives (such as cement, lime or fly ash) to improve their workability during construction and to improve their strength to withstand expected loading from traffic.

Geiger et al. (2007), the first report developed for this project, contains an extensive literature review regarding pavement structure, soil stabilization, stabilizers, and coarse aggregate issues as well as construction processes. The reader is referred to that report for a review of those topics. A brief summary is included here.

Stabilization is achieved by adding proper percentage of additives such as cement or fly ash to the base. The selection of the type and determination of the percentage of additive depend on the soil classification and the desired degree of improvement. Generally, smaller amounts of additives are required to modify soil properties such as gradation, workability and plasticity. Larger quantities of additives are used to significantly improve the strength, stiffness and durability. Spreading and compaction are achieved by conventional means after the additive has been mixed with the base. The decision tree for selecting the appropriate types of stabilizer as per current TxDOT guideline (Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures, 2005) is shown in Figure 2.1. The two main factors used are the percentage of material passing the No. 200 sieve and the PI.

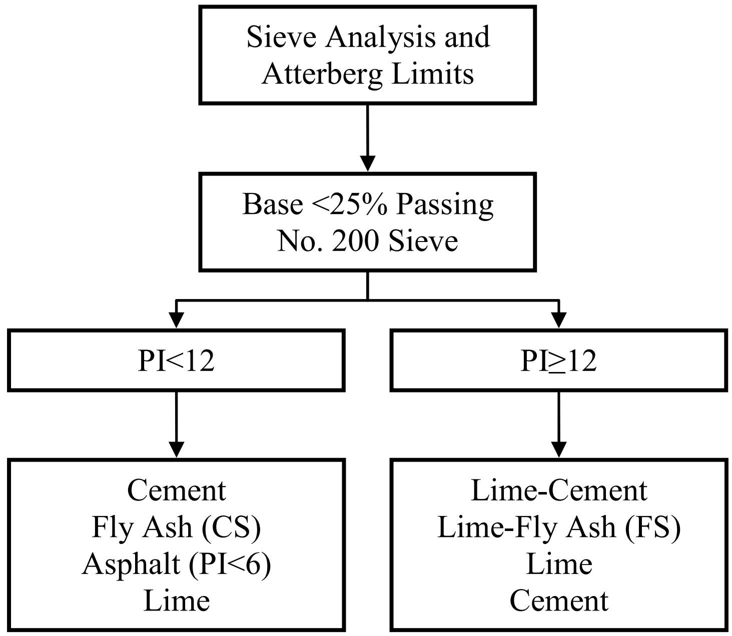

Figure 2.1 - TxDOT Stabilization Selection Decision Tree

A major concern during the construction of base layers is the degradation of aggregates due to handling, transportation and placement. An aggregate base must meet its purpose as the main structural layer of a pavement by performing the following three functions: subgrade protection, support for surfacing, and as a construction platform. In order to protect the subgrade, the base layer must be able to distribute loads sufficiently so that the subgrade can carry repeated traffic loads without significant deformation. While the base layer protects the layer below, it also has to provide adequate support for the surface layer. If the base fails to provide this support then upper pavement layers will be forced to perform a structural role for which they may not be designed. Therefore, the pavement will experience accelerated failure mechanisms such as wearing course slippage, map cracking and surface pot-holing (Dawson, 2003). Finally, the aggregate base must be able to withstand heavy machinery during construction. In order to apply the pavement surfacing, the base must be level and stable. If the base is not constructed properly then application of the surface layer will be problematic because sufficient compaction may not be achieved.

Aggregate properties are dependent on geologic and moisture characteristics, as well as, particle shape. At the macroscopic level, aggregate performs by being stiff, resistant to permanent deformation and having a balanced value of permeability (Dawson, 2003). The principle mechanism by which loads are distributed to the aggregate layer by stresses produced by vehicle tires is resilient modulus. Resilient modulus is the strength or stiffness of the base or subgrade layers resistant to severe deformation. The distribution or spreading of loads through the layers is the modular ratio. Should the modular ratio of the base be greater than that of the underlying layers, then the load spreading through the layer is satisfactory. Conversely, high stiffness is equivalent to a high stress gradient in the base that requires the base aggregate to be resistant to deformation.

Aggregate toughness can be measured in the laboratory by the British test procedures (British Standard 812-112:1990) of aggregate impact value (AIV) and aggregate crushing value (ACV). For AIV, a coarse aggregate sample contained within a mold is used to perform the test procedure. The sample of aggregates of sizes between 10 mm (3/8 in.) to 14 mm (1/2 in.) is subjected to successive blows from a falling hammer to simulate its resistance to rapid loading. The resulting sample is sieved with the AIV being the amount of fines passing the 2.36-mm sieve (No. 8 sieve); and, expressed as a percentage of the initial sample weight. The AIV is given by the following equation:

$$AIV = \frac{M_2}{M_1} \times 100\% \qquad (2.1)$$

where M_1 is the mass of test specimen and M_2 is the mass of the specimen passing No. 8 sieve. For weak aggregates (AIV>30) the test produces excessive fines which buffers the remaining particles thus preventing the completion of the test.

The ACV is a value which indicates the ability of an aggregate to resist crushing. The lower the figure is, the stronger the aggregate or the greater its ability to resist crushing will be. A sample of the same aggregate sizes as used for AIV test is placed in a steel mold and a steel plunger is inserted into the mold on top of the aggregate. The aggregate is then subjected to a force rising to 90 kip (400kN) over a period of 10 minutes. This test is typically performed by placing in a concrete crushing apparatus. The fine material, which is produced and passes the No. 8 sieve, is represented as a percentage of the original mass. This percentage is the ACV. Similarly, the ACV is also calculated by using Equation 2.1.

One of the major sources in reduction of strength and stiffness of most aggregate bases is moisture infiltration. To counteract pavement failure by moisture infiltration, an increase in stabilizer content is often utilized. But if the treated material is repeatedly exposed to moisture infiltration then the heavily stabilized base is prone to leaching. Leaching is a phenomenon that reverses the stabilizing influence of the chemical treatment (www.sspco.com). Increasing the stabilizer content to reduce the time required to leach the stabilizer from the base is a costly option that many organizations may not consider using. Although the use of cement, lime, and fly ash as stabilizers requires an increase in water to reach the optimum moisture content during compaction, the maximum dry unit weight is reduced. The problem with a reduction in dry unit weight is that the shear strength decreases, chance of future settlement increases, and permeability increases (Liu et al., 2003).

During construction, it is crucial to provide the required moisture to the stabilized base in order to achieve the maximum strength and to provide adequate compaction of the base. Two major factors that contribute to these items are construction practices and type of machinery used in the placement of the stabilized base. In some cases, the existing asphalt concrete pavement is completely removed and the base is prepared and treated. The removed pavement can be further processed by various milling, ripping or pulverizing equipment to produce reclaimed asphalt pavement (RAP).

Typically, there are seven steps in the construction of a stabilized base: 1) scarification and pulverization, 2) stabilizer spreading, 3) preliminary mixing and watering, 4) mellowing period (for lime), 5) final mixing, 6) compaction, and 7) final curing.

After the asphalt concrete pavement layer has been removed, the base can be scarified to the specified depth and width and then partially pulverized to loosen the soil for combination with stabilizers. If FDR is to be utilized then the asphalt pavement is ripped with a predetermined depth of base as well. A scarified or pulverized base offers more surface contact area for the stabilizer at the time of application.

For new construction there are gradation specifications that must be followed but just as importantly, there should be gradation specifications for the material after it has been pulverized. One of the concerns with the pulverization activity is the possibility of the change in gradation. Current TxDOT specifications for new bases are shown in Table 2.1. TxDOT has specification Item 265 (Fly Ash or Lime-Fly Ash Treatment Road Mixed) and Item 275 (Cement Treatment Road Mixed) that require 100% of the pulverized material to pass a 2.5 in. sieve, as shown in Table 2.2.

Table 2.1 - Specification Item 247: Base Material Requirements (TxDOT, 2004)

Property	Test Method	Grade 1	Grade 2	Grade 3	Grade 4
Master Gradation sieve size (% retained)	Tex-110-E				As shown on the plans
2½ in.		-	0	0	
1¾ in.		0	0-10	0-10	
⅞ in.		10-35	-	-	
⅜ in.		30-50	-	-	
No. 4		45-65	45-75	45-75	
No. 40		70-85	60-85	50-85	
Liquid limit, % max.	Tex-104-E	35	40	40	As shown on the plans
Plasticity index, max.	Tex-106-E	10	12	12	As shown on the plans
Plasticity index, min.		As shown on the plans			
Wet ball mill, % max	Tex-116-E	40	45	-	As shown on the plans
Wet ball max. Increase passing the No. 40 sieve		20	20	-	
Classification	Tex-117-E	1	1.1-2.3	-	As shown on the plans
Min. compressive Strength, psi Lateral pressure 0 psi Lateral pressure 15 psi		 45 175	 35 175	 - -	As shown on the plans

Table 2.2 - TxDOT Specifications for Road Mixed Stabilized Base (TxDOT 2004)

<table>
<tr><th rowspan="2">Stabilizer</th><th colspan="2">Gradation requirements</th><th colspan="2">Gradation after Pulverization</th><th rowspan="2">Mellowing</th><th rowspan="2">Compaction</th><th rowspan="2">Curing</th></tr>
<tr><th>Sieve Size, in.</th><th>Min. Percent Passing</th><th>Sieve Size, in.</th><th>Percent Passing</th></tr>
<tr><td>Cement</td><td rowspan="3">1.75
0.75</td><td rowspan="3">100
85</td><td rowspan="3">2.5</td><td rowspan="3">100</td><td>None</td><td>Within 2 hours of cement application</td><td>3 days, by sprinkling or asphalt prime coat</td></tr>
<tr><td>Lime</td><td>1-4 days</td><td>After mellowing, mix until friable consistency, then compact</td><td>Up to 7 days</td></tr>
<tr><td>Fly ash</td><td>None</td><td>Within 6 hours of fly ash application</td><td>Allow 48 hours to dry before applying prime coat, then allow 24 hours before opening to traffic</td></tr>
</table>

Cement, lime or fly ash can be applied in several ways. The most common method is to spread the dry stabilizer in measured amounts on a prepared soil/aggregate and blend it with a transverse single-shaft mixer to a specified depth. Another method is to spread cement, lime, or fly ash slurries using a slurry jet mixer with a recirculation pump. This method is used to reduce dusting and improve mixing with the base.

The stabilizers can be applied in dry or slurry form to the prepared base. More commonly, windrows are constructed along each side of the roadbed to prevent runoff and loss due to wind. Regardless of the method used, the amount of stabilizer applied to a site should not exceed the amount that can be mixed into the soil during the day of application.

Preliminary mixing is required to distribute the stabilizer throughout the soil in order to pulverize and add water to begin the chemical reaction process. This mixing can begin with scarification; however, this may not be necessary for some modern mixers. During this process or immediately after, water should be added. Rotary mixers should be employed to ensure thorough mixing of the stabilizer, soil, and water. With many rotary mixers, water can be added to the mix drum by attaching a water truck to the mixer during processing. This is the optimal method to add water to dry cement, lime, and fly ash and soil during the preliminary mixing and watering stage. Regardless of the method used for water addition, it is essential that adequate water be added before final mixing to ensure complete hydration and to bring the soil moisture content 3 to 5 percent above optimum for lime, ±2 percent of the optimum for cement and 1 to 3 percent below the optimum moisture content for fly ash before compaction.

While cement does not require a mellowing period, lime and lime-fly ash soil mixtures must be allowed to mellow sufficiently to allow the chemical reaction to change (break down) the material. The duration of this mellowing period should be based on engineering judgment and is dependent on soil type. The mellowing period is typically 1 to 7 days. After mellowing, the soil should be remixed before compaction. For low plasticity index soils, or when drying or modification is the goal, mellowing is often not necessary (www.lime.org).

Final mixing and pulverization is applicable to cement, lime and fly ash treated base materials. As mentioned previously, mixing and pulverization should continue until 100 percent of stone material passes the 1.75 in. sieve and at least 85 percent of material passes the 0.75 in. sieve. Additional water may be required during final mixing (prior to compaction) to bring the soil to the required optimum moisture content of the treated material. In the case of lime, if the previously mentioned gradation can be met during preliminary mixing, then the mellowing and final mixing steps may be eliminated (www.lime.org).

Cement stabilized base must be mixed and compacted within 2 hours of cement application. Smooth-wheeled vibrating rollers, sheepsfoot or tamping rollers can be used to provide initial compaction. Next, smooth-wheeled or pneumatic-tire rollers are used to provide a smooth surface. For lime, compaction must occur immediately after the mellowing period if there is one. Fly ash stabilized soil should be compacted to the density required by specification within 6 hours of fly ash application.

Before placing the next layer of pavement, the compacted base should be allowed to harden until heavy vehicles can operate without rutting the surface. During this time, the surface of the stabilized base should be kept moist to aid in strength gain. This curing can be done in two ways by moist curing and membrane curing. Moist curing consists of maintaining the surface in a moist condition by light sprinkling and rolling when necessary. Membrane curing involves sealing the compacted layer with a bituminous prime coat emulsion, either in one or multiple applications.

Curing of cement stabilized base requires a minimum of three days using sprinkling or prime coat (TxDOT Standard Specifications, 2004). Lime stabilized base requires a period of up to 7 days to cure before construction can continue. The strength gain and compacted density of fly ash-treated soil are sensitive to compaction delays. The compaction delay can significantly decrease compacted unit weight and strength gain. As the ash hydrates, the fly ash-soil mixture flocculates and agglomerates. While uncompacted, the mixture tends to become aggregated and requires more compaction effort to break up the cemented particles. According to White et al. (2005), compaction delay decreases the densities by 10 pcf or more. The study also found that the loss of strength is probably due to the loss of cementitious reaction products expended during hydration and the loss of particle to particle contact points that result from a lower compacted density. Materials compacted without delay after mixing show evidence of six to twelve times the strength of non-stabilized soils. Mixtures compacted at times exceeding one hour only show an increase in strength three to five times that of non-stabilized soils.

Field density of compacted soil-cement can be determined by the nuclear gauge method or sand-cone method or volumeter method (Tex-115-E). The optimum moisture and maximum density must be determined prior to start of construction and can be found by using TxDOT procedure Tex-113-E or ASTM D 558 or AASHTO T 134. Typically, the base is compacted to at least

95% of the maximum dry density achieved through laboratory tests. For TxDOT construction procedures, cement, lime or fly ash treated base must be compacted as stated in the given specification as shown in Table 2.3. One overlooked phenomenon is the need for calibrating the nuclear density gauge with the mix that contains the additives.

Table 2.3 - TxDOT Specifications for Stabilized Base Material (TxDOT, 2004)

Specification		Procedure
Item 260	Lime Treatment (Road Mixed)	Compaction of bottom course at least 95% of maximum dry density obtained from Tex-121-E, compact subsequent courses at least 98% of Tex-121-E
Item 265	Fly Ash or Lime-Fly Ash Treatment (Road Mixed)	Compaction of bottom course at least 95% of maximum dry density obtained from Tex-127-E, compact subsequent courses at least 98% of Tex-127-E
Item 275	Cement Treatment (Road Mixed)	Compact to at least 95% of maximum dry density obtained from Tex-120-E.

A typical curing practice for stabilized bases involves sealing the base layer after compaction with varying coatings. This allows the stabilizer to hydrate and gain the required strength per specifications prior to placing the remainder pavement layers. Availability of moisture, temperature during curing, and length of cure time all affect the strength gain of stabilized bases, particularly fly ash treated bases. Usually, mixtures are cured by sprinkling with water or by coating with a thin layer of emulsion or cutback asphalt. The Federal Highway Administration (FHWA) recommend that the sealer be applied within one day of completing the section and that multiple coats may be required (Singh, 2001). Completed sections can also be cured with water for a short time and then sealed with thin coats of asphalt products. Before heavy traffic or surface layers are placed, the completed sections should be cured for three to seven days. From observations by the Joint Departments of the Army and Air Force, paving can begin within a day or two after completing the stabilized section, so long as the subgrade can support paving traffic (Singh, 2001).

Monitoring of sections is very important because it allows for detection of pavement performance problems that may have developed during and after construction. While destructive testing provides a field sample for analysis of various strength parameters, nondestructive testing (NDT) is equally important in providing these parameters as well as surface properties but without disturbing the pavement and the underlying layers. The Falling Weight Deflectometer and seismic methods can be used for this purpose. Two destructive methods commonly used for testing during and after construction are Dynamic Cone Penetrometer (DCP) and coring. While nondestructive testing provides information of the response of a pavement to an applied load, destructive testing provides the in situ strength parameters of the soil through laboratory testing.

Geiger et al. (2007) studied the impact of the change in gradation on the performance of a base by artificially decreasing the amount of gravel and increasing the amount of sand and fines to a blend that met the Item 247 requirements. The blends and their designations are given in Table 2.4.

Table 2.4 – Aggregate Blends Used in Geiger et al. (2007) Study

Constituent	Avg. 247	Excess Sand	Excess Fines	Excess Sand & Fines
Gravel	55%	48%	42%	35%
Sand	40%	47%	38%	45%
Fines	5%	5%	20%	20%

Geiger et al. (2007) proposed the following test procedure as summarized in Figure 2.2. The first step, preliminary testing, consists of establishing the gradation, index properties and the hardness of the aggregates. The next step is to establish the moisture-density/moisture-modulus relationships for the raw materials as well as the blends with varying contents of stabilizers. Finally, the strength, stiffness and moisture susceptibility of the mixes are evaluated.

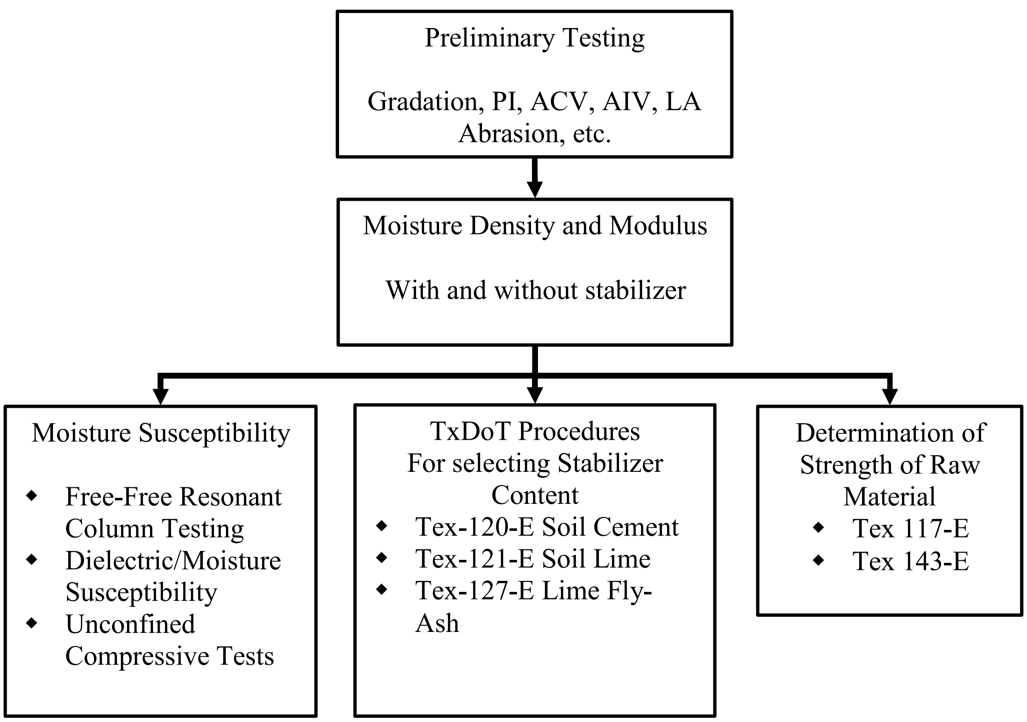

Figure 2.2 - Testing Procedure Developed Based on El Paso Limestone

Based on the knowledge gained from that study, the following observations were made:

- The optimum moisture content and the maximum dry unit weight for the stabilized materials may differ by as much as 2% and 10 pcf as the gradation and the stabilizer content changes.
- As the fine sand content of the mix increases, the strength and stiffness of the stabilized mix decreases. As such more additives are required if the pulverization turns gravel to fine sand.

When the fines content increases, the strength and stiffness of the mix is slightly compromised.

- The unconfined compressive strength (UCS) for cement stabilized material consistently increased as the cement content increased. Yet, for lime and fly ash stabilized specimens, the UCS decreased as the stabilizer content increased after the specimen was subjected to moisture conditioning. When specimens were tested prior to moisture conditioning, the lime specimens showed an increase in UCS with an increase in lime content.
- The retained strength ratio (RSR) of 85% for cement stabilized soil was readily achieved regardless of the blend or cement content. The lime and fly ash specimens did not achieve the RSR of 85%. The four-hour soak method for moisture conditioning typically yields greater RSR as compared to 10-day capillary moisture for cement.
- The dielectric constants for the stabilized specimens varied significantly as the percentage of stabilizer was changed.
- The final (10-day) moisture contents from specimens prepared for the tube-suction tests were normally greater than the initial moisture contents.

Chapter 3

Test Protocols

Introduction

The test procedure outlined in Research report 5223-1 (Figure 2.2) was utilized to evaluate a number of projects. Figure 3.1 contains a step-by-step procedure for this activity. The procedure is described briefly in this chapter through an example for a site along FM 303 in Tarry County, Texas. The construction activities at this project consisted mainly of scarifying the existing asphalt pavement (essentially several layers of surface treatment) and adding three inches of add rock, reclaiming and fly-ash-treating the in-place base down to 12 in., paving the finished based with a seal coat. The selected treatment for this site, which had been carried out before the initiation of this research study, consisted of adding 7% fly ash to the aggregate blend. This selection was based on the favorable performance that the District had with this type of treatment in previous projects.

The procedure illustrated in Figure 3.1 was followed for selecting the proper additive and additive content for pulverized base materials. The procedure was separated into the following two parts once a site is selected: a) laboratory testing and field testing. For the laboratory testing, raw material was sampled from the road using Tex-100-E. Based on experience, 350 lbs of material was necessary to complete all tests proposed. Once in the laboratory, the material was prepared for testing according to Tex-101-E. Index tests such as sieve analysis, Atterberg limits, ACV, AIV, and soil classification were performed. Based on the sieve analysis, the material passing the No. 200 sieve was determined to ensure that it was less than 25%. Test procedure Tex-113-E was then used to determine the moisture density curve of the raw materials. Strength tests such as Tex-117-E and Tex-143-E were carried out next in order to classify the material using Item 247. If the material met Item 247 Grade 1 requirements, the material was considered as a high-quality flexible base material that could be used without additives. Otherwise the possibility of stabilization was studied. The raw material was further tested for moisture susceptibility using the tube suction moisture conditioning protocol (proposed Tex-144).

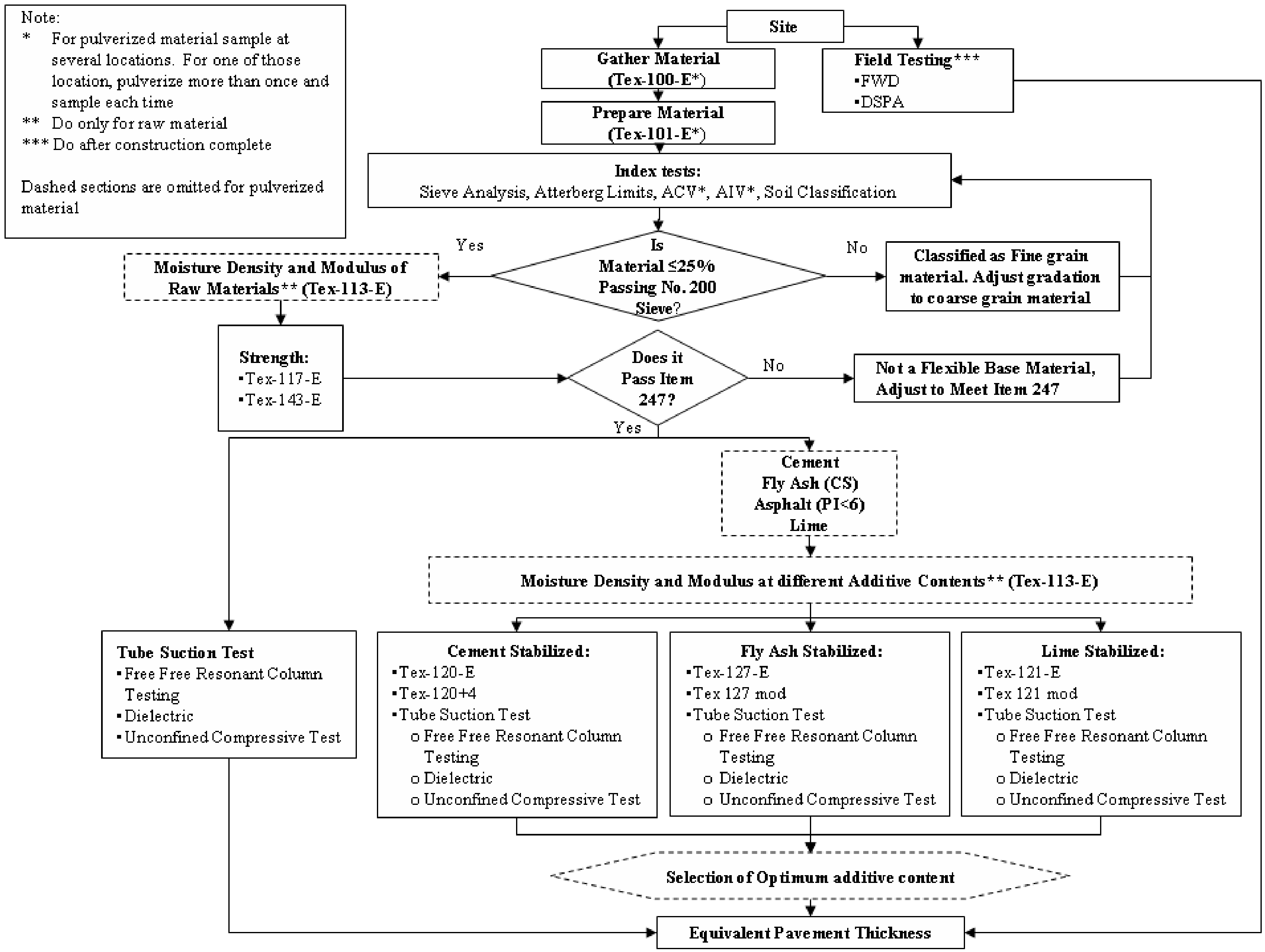

Figure 3.1 – Flow Chart for Testing Activities

The next step was to select the appropriate additive type such as cement or fly ash. Once the additive was chosen based on the fines content, PI and the experience of the District, the optimum moisture content for each additive content was obtained according to Tex-113-E. The optimum additive content was chosen by measuring several different parameters such as the unconfined compressive strengths, seismic modulus, retained strength/modulus ratios and dielectric constants. The minimum additive content that met the criteria in Table 2.2 was chosen as the optimum additive content.

The next step was to visit the site during construction and to retrieve pulverized materials at several locations. At one of those locations, the pulverization process was performed more than once and the material was sampled each time. Testing the pulverized materials followed the same procedure as used for the raw material except for a few steps. Test procedure Tex-100-E was used for sampling the pulverized materials. The selection of additive type and content was omitted since the goal was to verify the laboratory mix process. All pulverized specimens were prepared at the optimum additive content and corresponding optimum moisture content obtained from the mix design.
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The last step in the process was to use the results from the laboratory and the field to determine the equivalent pavement thickness using a layer elastic program. Moduli from FWD and PSPA (portable seismic pavement analyzer) were determined after the construction was completed. A number of different moduli measured in the laboratory during different curing and moisture conditioning processes were compared with the field moduli to propose a representative design modulus.

In summary, testing of the base materials consisted of the following four major steps:

1. Performing index tests (Gradation, Atterberg Limits, Moisture Density, ACV and AIV)
2. Determining strength of raw materials
3. Determining the appropriate stabilized content using materials retrieved before pulverization
4. Comparing the strength and stiffness of pulverized materials with those obtained before pulverization
5.

The results from lab and field tests are presented in this chapter.

Index Tests

The gradation curves for the in-place base and asphalt pavement layer, and selected add rock are compared to the minimum and maximum limits specified in Item 247 in Figure 3.2 and Table 3.1. The in-place base was slightly finer than the upper limits of the Item 247. On the other hand, the add rock was quite coarse. The gradation of the in palace asphalt pavement layer, after crushing, was much coarser than the limits of Item 247. The final gradation of the combined asphalt pavement, add rock and the in-place base, mixed proportionally lies between the Item 247 Grade 1 allowable limits.

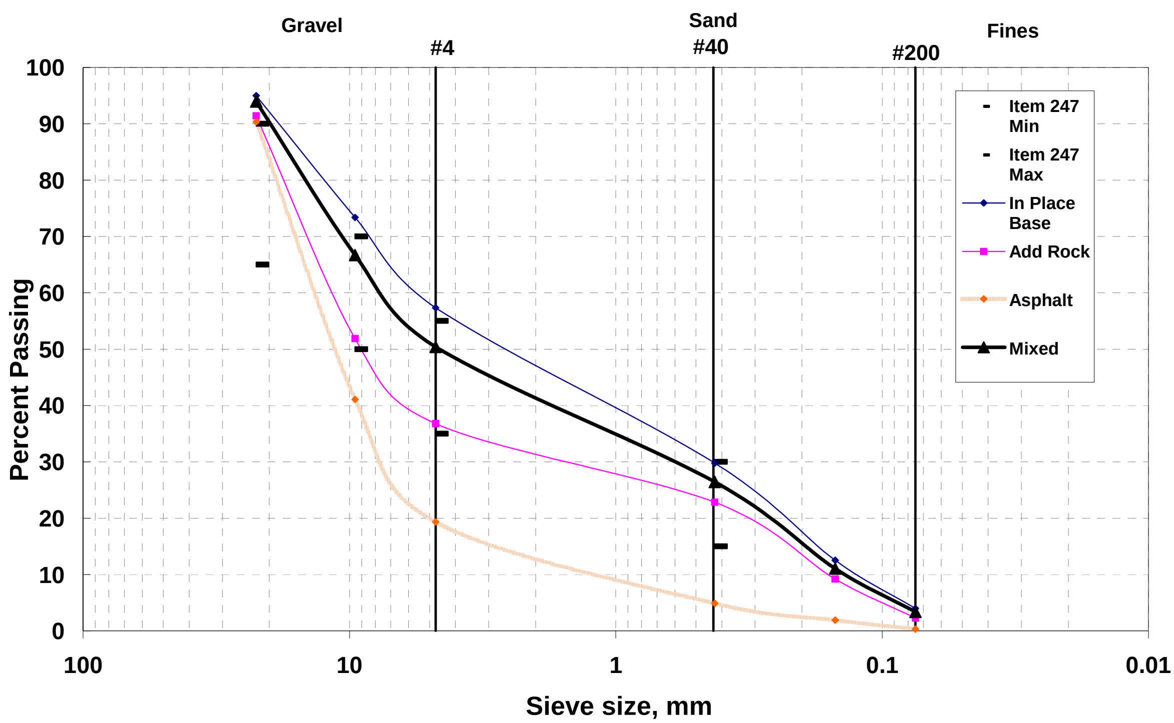


Figure 3.2 - Gradations for FM 303 Raw Materials

Table 3.1 - Gradation of FM 303 Raw Materials

Sieve Size	Percent Passing				Item 247 Min.	Item 247 Max.
	In Place Base	Add Rock	Asphalt	Mixed		
1¾ in.	100	100	100	100	100	100
⅞ in.	95	91	90	94	65	90
⅜ in.	73	52	41	67	50	70
No. 4	57	37	19	50	35	55
No. 40	30	23	5	27	15	30
No. 100	13	9	2	11	-	-
No. 200	4	2	0.3	3	-	-

The plasticity index (PI) of the mix were determined by the bar linear shrinkage to be 7 as per Tex-107-E.

The moisture-density (MD) curve for the mix is shown in Figure 3.3. The optimum moisture content (OMC) and the maximum dry density (MDD) were 9.3% and 123 pcf, respectively. The variation in the modulus of the specimens prepared for the MD tests (and cured for 24 hrs) with moisture content is also shown in Figure 3.3. The modulus at the OMC is about 70 ksi. However, the modulus about 2% above OMC is significantly lower than that at optimum, pointing at the need for a restrict moisture control during construction.

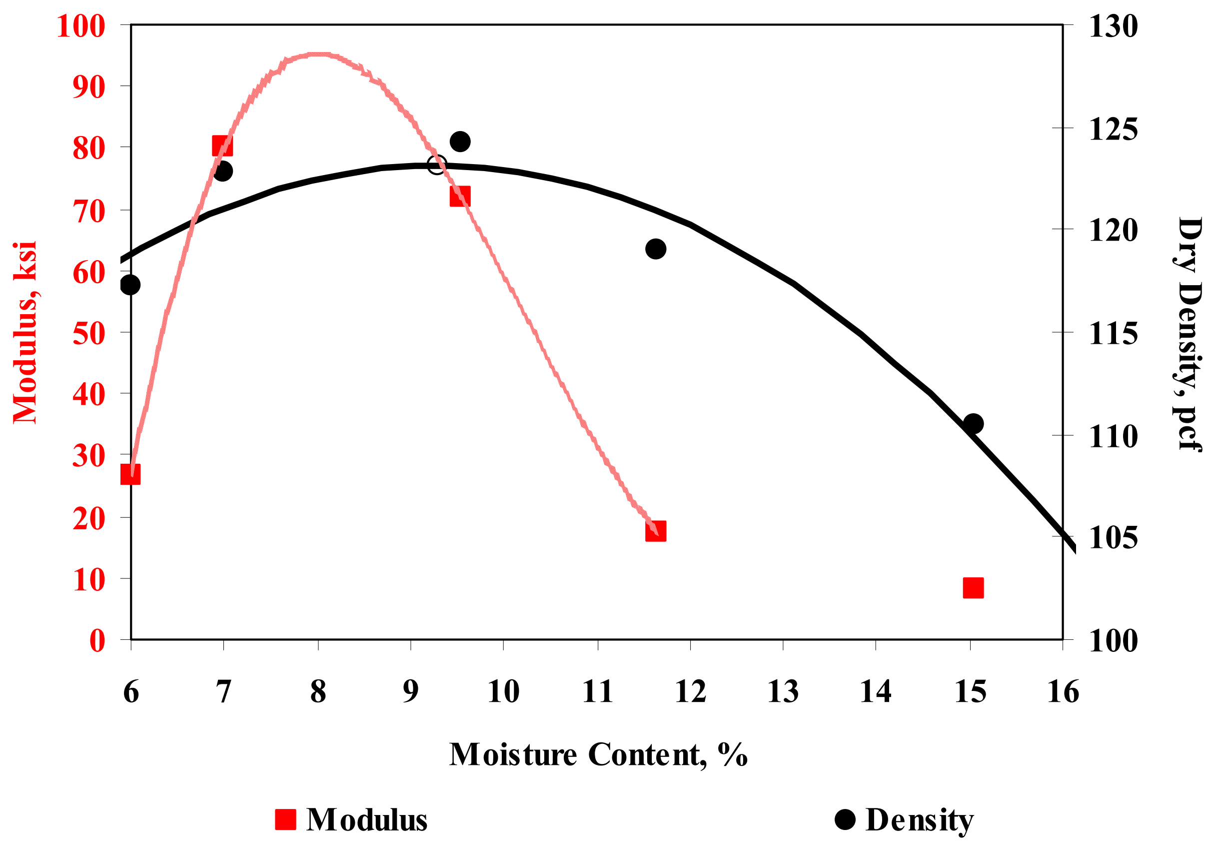


Figure 3.3 – Moisture Density/Modulus Curves for FM 303 Mix

Determining Strength of Raw Materials

Strength parameters were obtained by performing Texas Triaxial (Tex-117-E) and standard Triaxial (Tex-143-E) tests. The results from these tests are presented in Table 3.2. Based on the index tests and Texas triaxial classification of 3.4, the material can be classified as a Grade 3 as per Item 247, which is not suitable for a high-quality base without additives.

Table 3.2 - Results of Triaxial Testing for FM 303 Mix

Parameter	Tex-117-E	Tex-143-E*
Classification	3.4	2.8
Angle of Internal Friction, φ	43	43
Cohesion, c, psi	6	13
Strength at Zero Lateral Pressure, psi	23	*
Strength at Lateral Pressure of 15 psi, psi	106	*
Grade as per Item 247	3	*
*Not Applicable		

Determining Optimum Additive Content

Based on TxDOT guideline and the index tests (see Figure 2.2). Cement and Fly ash are two of the additives appropriate for this material. Fly ash was selected since the actual construction project used that additive. The optimum additive content was determined by evaluating three different fly ash contents of 5%, 7%, and 9%. Table 3.3 shows the optimum moisture contents, maximum dry unit weights, and seismic moduli at the OMC for the three fly ash contents. The optimum moisture content varied from 9.0% to 9.3%, indicating that the moisture content does not vary much by increasing the fly ash content. The maximum dry unit weights also did not vary, since it ranged from 123 to 124 pcf. The seismic moduli at the OMC increased from 57 ksi for the raw material to more than 209 ksi at 5% fly ash. However, the increase in the fly ash content from 5% to.9% had a small impact on the moduli.

Table 3.3 – Variation in Optimum Moisture Content, Maximum Dry Unit Weight and Modulus for FM 303 Mix

Parameter	Fly Ash Content, %			
	0	5	7	9
Optimum Moisture Content, %	9.3	9.1	9.0	9.1
Maximum Dry Unit Weight, pcf	123	124	124	124
Seismic Modulus at OMC, ksi	70	209	231	238

Strength

The base-fly ash specimens were then prepared and cured as per Tex-127-E. The UCS increased from 44 psi to 74 psi as fly ash content increased from 5% to 9% (Figure 3.4). These strengths are clearly less than 150 psi strength required for these mixes. Therefore, fly ash may not be appropriate for this project.

To delineate the impact of curing of the mixes from the impact of moisture conditioning, UCS tests were also conducted on specimens that were cured for 7 days as per Tex-127-E but without the 10 day capillary saturation. These series of tests are called the "Tex-127 Modified." The unconfined compressive strengths with this process are almost constant at 110 psi as shown in Figure 3.4.

Finally, a number of specimens were prepared and moisture-cured following the TST protocol (2 days in an oven, eight days in a water bath). These specimens actually yield UCS values that were greater than the either of the previous two methods. For the 7% and 9% fly ash, the strengths from the TST moisture conditioned specimens are close to 140 psi.

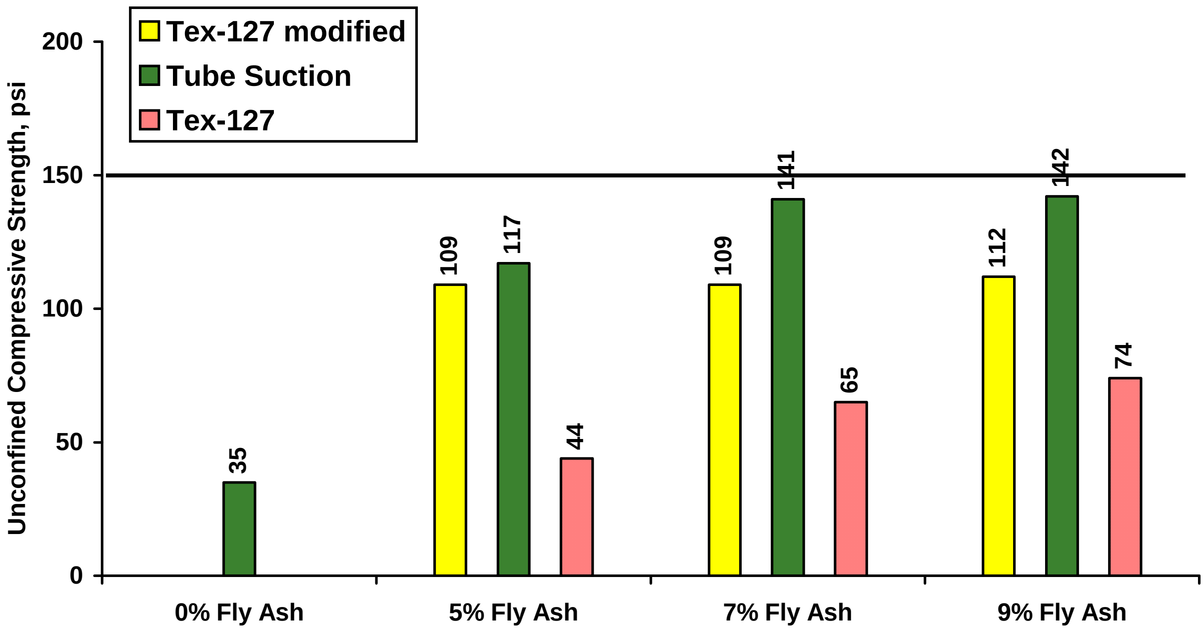


Figure 3.4 – Variation in Unconfined Compressive Strength with Fly-Ash Content Using FM 303 Mix

Modulus

The variation in seismic modulus with fly-ash content for the three sets of specimens prepared for UCS test above is presented in Figure 3.5. The results follow the same trend as the UCS results presented in Figure 3.4. None of the specimens pass the 500 ksi minimum for the seismic modulus except for the two TST specimens with 7% and 9% fly ash cured for 24 hours and one specimen subjected to the TST protocol.

Moisture Susceptibility

The moisture susceptibility of the mixes was evaluated in several ways. The retained strength, retained modulus, moisture absorption during moisture conditioning, and dielectric constant were considered.

The retained strength ratio (RSR) was calculated by the following formula:

$$RSR = \frac{\text{Compressive Strength after Moisture Conditioning}}{\text{Compressive Strength without Moisture Conditioning}}$$

The strengths obtained from the modified Tex-127-E modified (7 day curing but no moisture conditioning) were considered as strength without moisture conditioning. The RSRs for different fly ash contents are presented in Figure 3.6. The following two moisture-conditioned strengths were used:

1. Using the TST procedure for moisture conditioning
2. Using the standard Tex-127-E protocol for moisture conditioning.

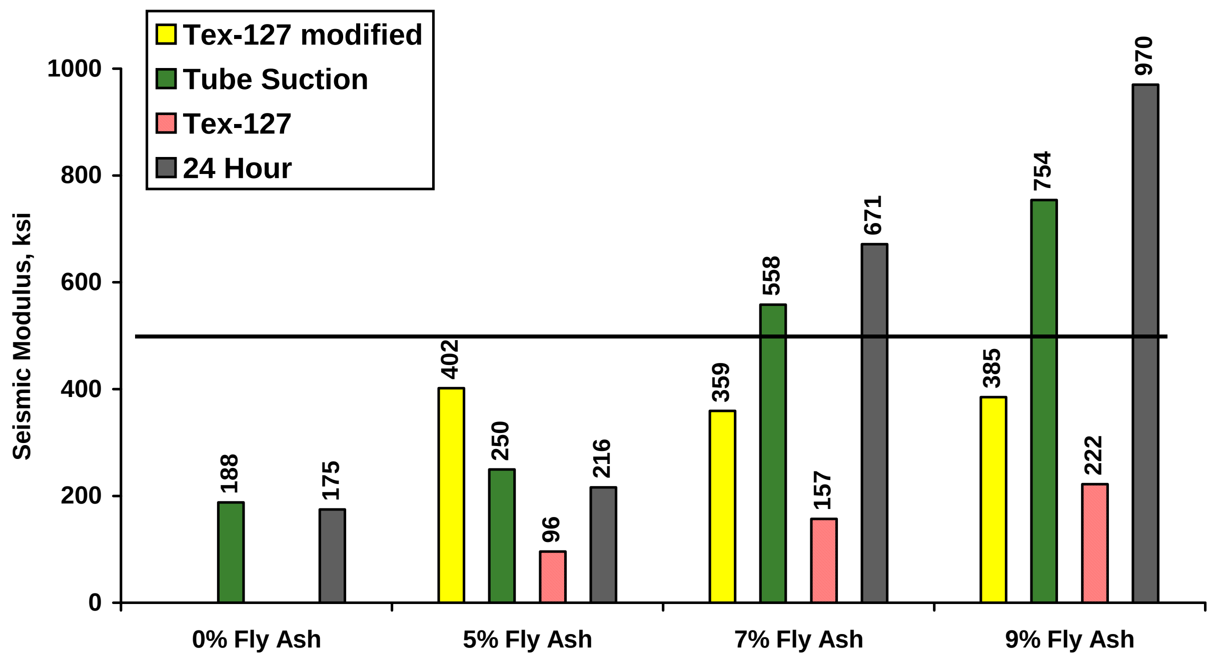


Figure 3.5 – Variation in Seismic Modulus with Fly-Ash Content Using FM 303 Mix

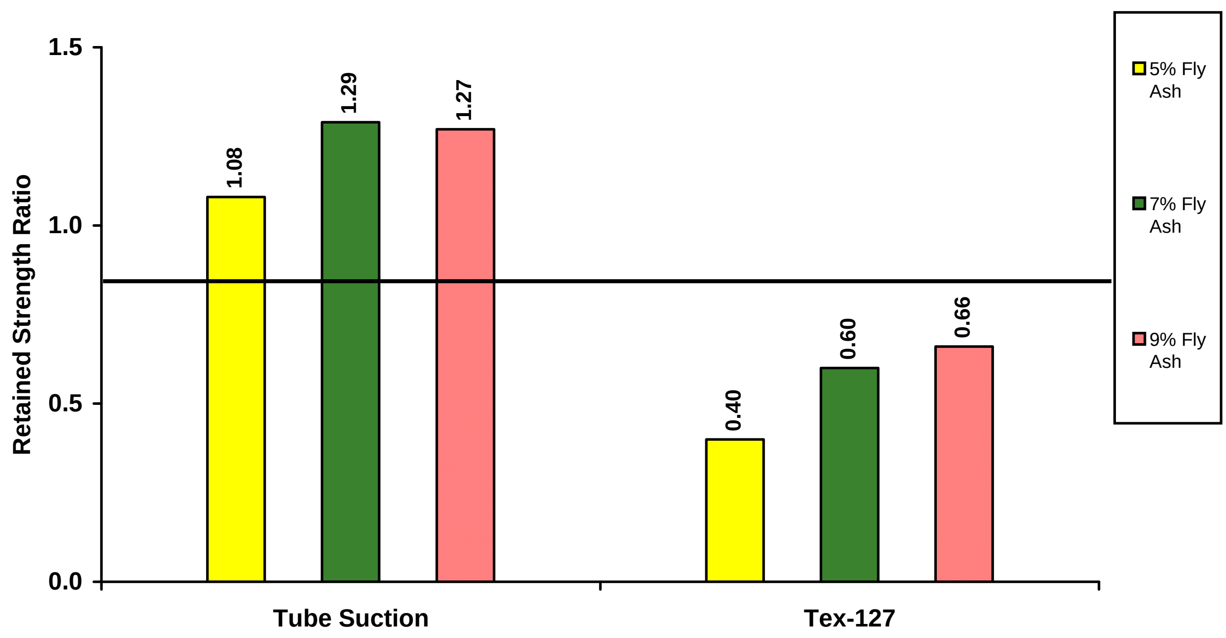


Figure 3.6 -Variations in Retained Strength Ratio with Fly-Ash Content for FM 303 Mix

The RSRs from the TST protocol are all greater than 100%, while the RSRs from the second method of moisture conditioning are all significantly less than 85%. For these specimens, the Tex-127-E protocol for moisture conditioning is significantly harsher than the TST capillary saturation.

The retained modulus ratio (RMR) with fly-ash content is shown in Figure 3.7. The retained modulus ratio is determined by:

$$\text{RMR} = \frac{\text{Seismic Modulus after Moisture Conditioning}}{\text{Seismic Modulus without Moisture Conditioning}}$$

The RMR for the TST moisture conditioned specimens containing 7% and 9% fly-ash exceeded the 85% RMR limit, while none of the Tex-127 moisture conditioned specimens met the 85% limit.

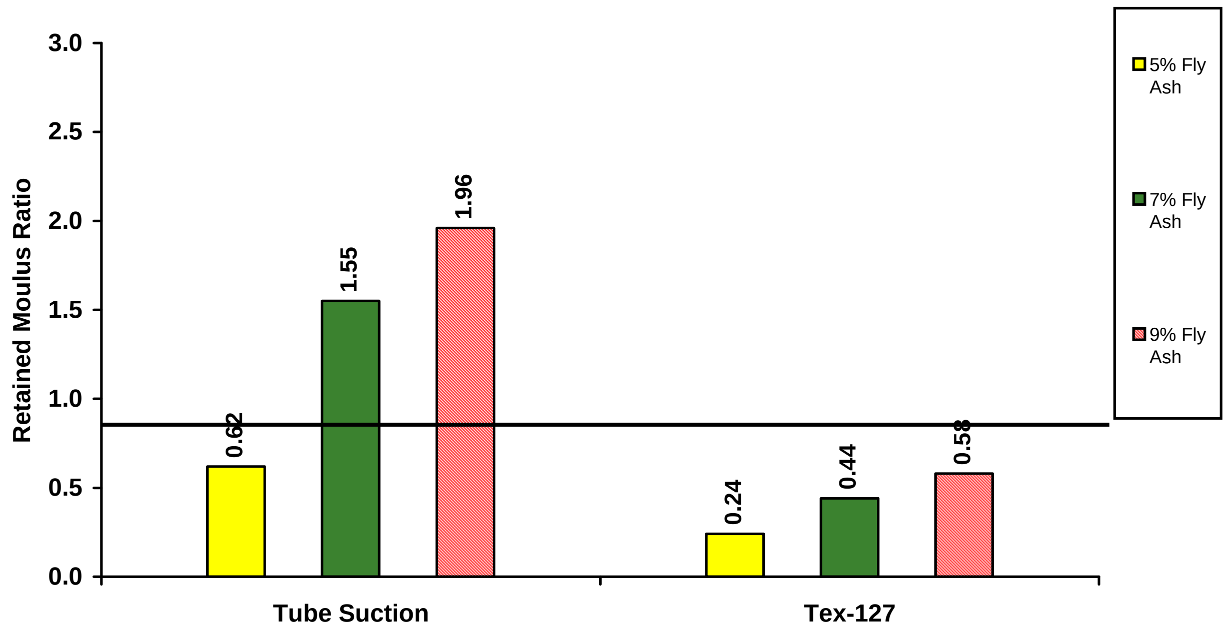


Figure 3.7 – Retained Modulus Ratios for Tube Suction Test and Tex-127

The variations in initial (as compacted) and final (after 10 day capillary saturation) moisture contents are reported in Figure 3.8. For the three different fly-ash contents, the initial moisture contents were greater than the final moisture contents. This demonstrates a lack of affinity to excess moisture for the TST specimens.

To evaluate the setting of the mix, the seismic modulus of the TST specimens after 24 hrs in 140°F oven are shown in Figure 3.9. These moduli are by far greater than the moduli obtained from seven days of curing of the specimens at room temperature for the 7% and 9% fly ash contents (see Figure 3.5 under Tex-127 Modified). The excess temperature accelerated the curing of specimens with high fly ash contents. The final seismic moduli after ten days are also presented in Figure 3.9. The specimens with 7% and 9% fly-ash exhibit a lower modulus at ten days relative to 1 day.

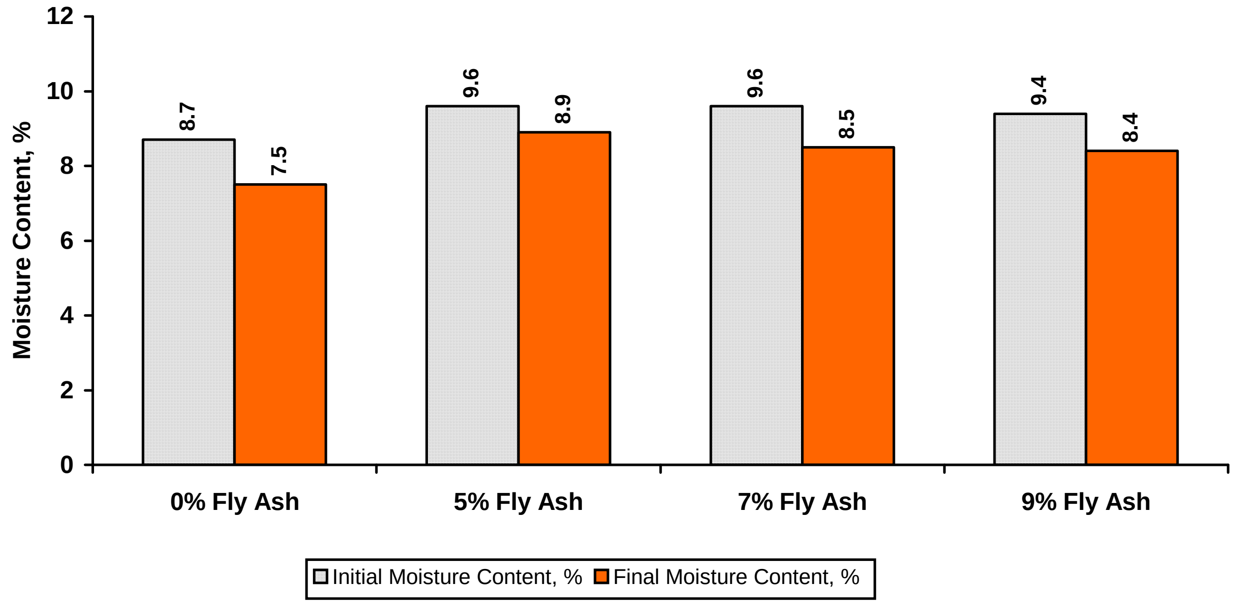


Figure 3.8 – Initial and Final Moisture Content for Tube Suction Test

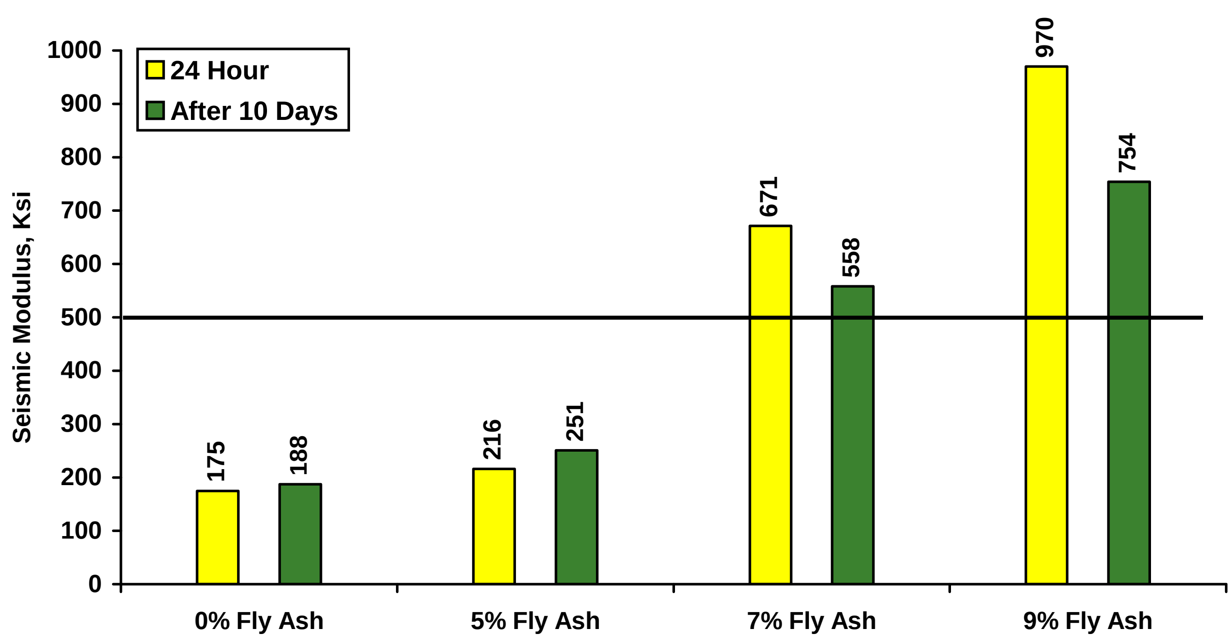


Figure 3.9 – Seismic Modulus for Tube Suction Test

Determination of Optimum Fly-Ash Content

The determination of the optimum fly-ash content is based on the requirements that must be met in terms of strength, modulus, and moisture susceptibility. These requirements are as follows:

- UC strength of 7 day cured specimen ≥ 150 psi
- Seismic modulus of 7 day cured specimen ≥ 500 ksi
- Retained strength and modulus ratios ≥ 85%
- Dielectric constant of capillary moisture conditioned specimens < 10

The test results for the FM 303 project are summarized in Table 3.4. The requirements that are not met for each mix are highlighted. None of the mixes met the requirements specified above. As such, the fly ash may not be the best alternative for this project.

Table 3.4 - Results for FM 303 Raw to Determine Optimum Fly-Ash Content

Criterion		Fly Ash Content, %		
		5	7	9
Tex-127 modified	Unconfined Compressive Strength, psi	109	109	112
	Seismic Modulus, ksi	425	359	385
Tex 127	Unconfined Compressive Strength, psi	44	65	74
	Seismic Modulus, ksi	96	157	222
Retained Strength Ratio	Capillary Saturation	1.08	1.29	1.27
	Tex 127	0.40	0.60	0.66
Retained Modulus Ratio	Capillary Saturation	0.59	1.55	1.96
	Tex 127	0.22	0.44	0.58
Tube Suction Test	Final Dielectric Constant	N/A	N/A	N/A
	Final Moisture Content,%	8.9	8.5	8.4
	Final Seismic Modulus, ksi	250	558	753

Field Monitoring

Gradation

The gradations of the pulverized materials are shown in Figure 3.10. The pulverized materials were finer than the in-place materials originally retrieved from the site. The gradations of materials from only two of the five pulverized spots were within the Item 247 Grade 1 allowable limits.

Changes in constituents of the materials due to pulverization are presented in Table 3.5. The gravel content (materials retained on No. 4 sieve) decreased on average by 9% (from 50% to 41%). This indicates that the gravel particles are being crushed the most. While the fine sand content (materials passing No. 40 and retained on No. 200 sieves) increased by 8% (from 24%

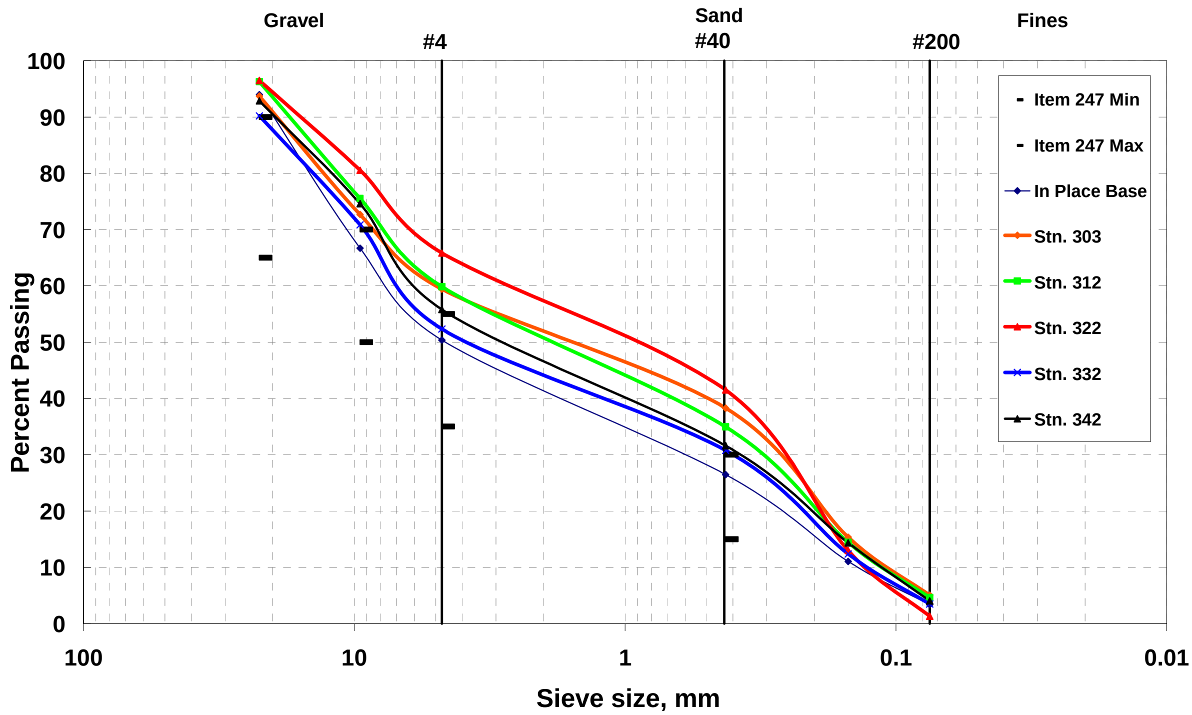


Figure 3.10 - Gradation for FM 303 Pulverized Materials

Table 3.5 – Changes in Constituents for FM 303 Materials

Material Type	Impact of Pulverization						
	Before Pulverization	Pulverized					
		Stn 303	Stn 312	Stn 322	Stn 332	Stn 342	Avg.
Gravel	50	41	40	34	48	44	41
Coarse sand	23	21	25	24	21	24	23
Fine Sand	24	33	30	40	27	28	32
Fines	3	5	5	2	4	4	4

before pulverization to 32% after pulverization). No significant change in the fines and coarse sand contents was observed.

Determination of Strength of Untreated Materials

The results from the Texas and Standard Triaxial tests for the pulverized materials are compared with those from the in-place base material in Table 3.6. The classifications from Tex-117-E tests range from 3.8 to 4.9 (as compared to 3.4 for the in place materials). All other parameters are also significantly lower than the in-place material. Similar patterns were also observed based on Tex-143 tests.

Table 3.6 - Results of Triaxial Testing for FM 303 Materials

a) Tex-117-E

Parameter	Before Pulverization	Pulverized					
		Stn 303	Stn 312	Stn 322	Stn 332	Stn 342	Avg.
Classification	3.4	4.9	4.4	3.8	4.6	3.8	4.3
Angle of Internal Friction, φ	43	21	29	34	22	32	28
Cohesion, c, psi	6	3	4	5	5	7	5
Strength at Zero Lateral Pressure, psi	23	11	11	16	10	21	14
Strength at Lateral Pressure of 15 psi, psi	106	42	52	67	41	67	54

b) Tex-143

Parameter	Before Pulverization	Pulverized					
		Stn 303	Stn 312	Stn 322	Stn 332	Stn 342	Avg.
Classification	2.8	2.4	3.0	4.1	3.5	3.9	3.4
Angle of Internal Friction, φ	43	47	41	33	38	36	39
Cohesion, c, psi	13	8	13	20	18	20	16

Determination of Strength of Stabilized Materials

Specimen preparation for the soil-fly-ash mix using the modified Tex-127-E was based on the optimum moisture and the fly-ash content used in the construction of the base. The UCS for the pulverized material with 7% fly ash ranges from 136 to 276 psi, as compared to the in-place base strength of 109 psi (Figure 3.11). All but one passed the 150 psi strength requirement.

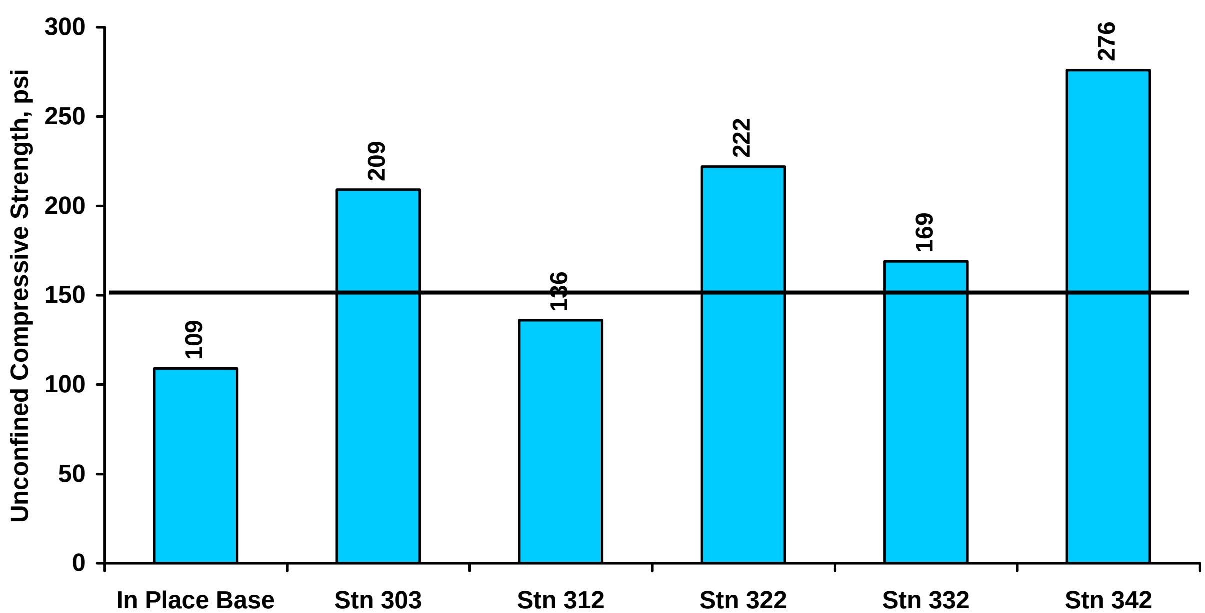


Figure 3.11 –Unconfined Compressive Strengths of Tex-127-E Modified Specimens for FM 303 materials

Retained Strength Ratio

Retained strength ratios with 7% fly ash for ten day tube suction test and Tex-127-E for the in-place and pulverized materials are compared in Figure 3.12. The retained strength ratio for the in place base material is 129% for the ten day capillary moisture conditioned specimen and 60% for the Tex-127-E moisture conditioned specimen. All of the moisture conditioned specimens had retained strength ratios which are substantially less than 129%. This occurs because the pulverized materials are finer than the in-place materials, and as such they can absorb water more efficiently. As shown in Figure 3.12b, most of the pulverized specimens had a retained strength ratio close to the in place base material of 60% except for Station 312. This shows that ten day capillary moisture conditioned specimens is material dependent.

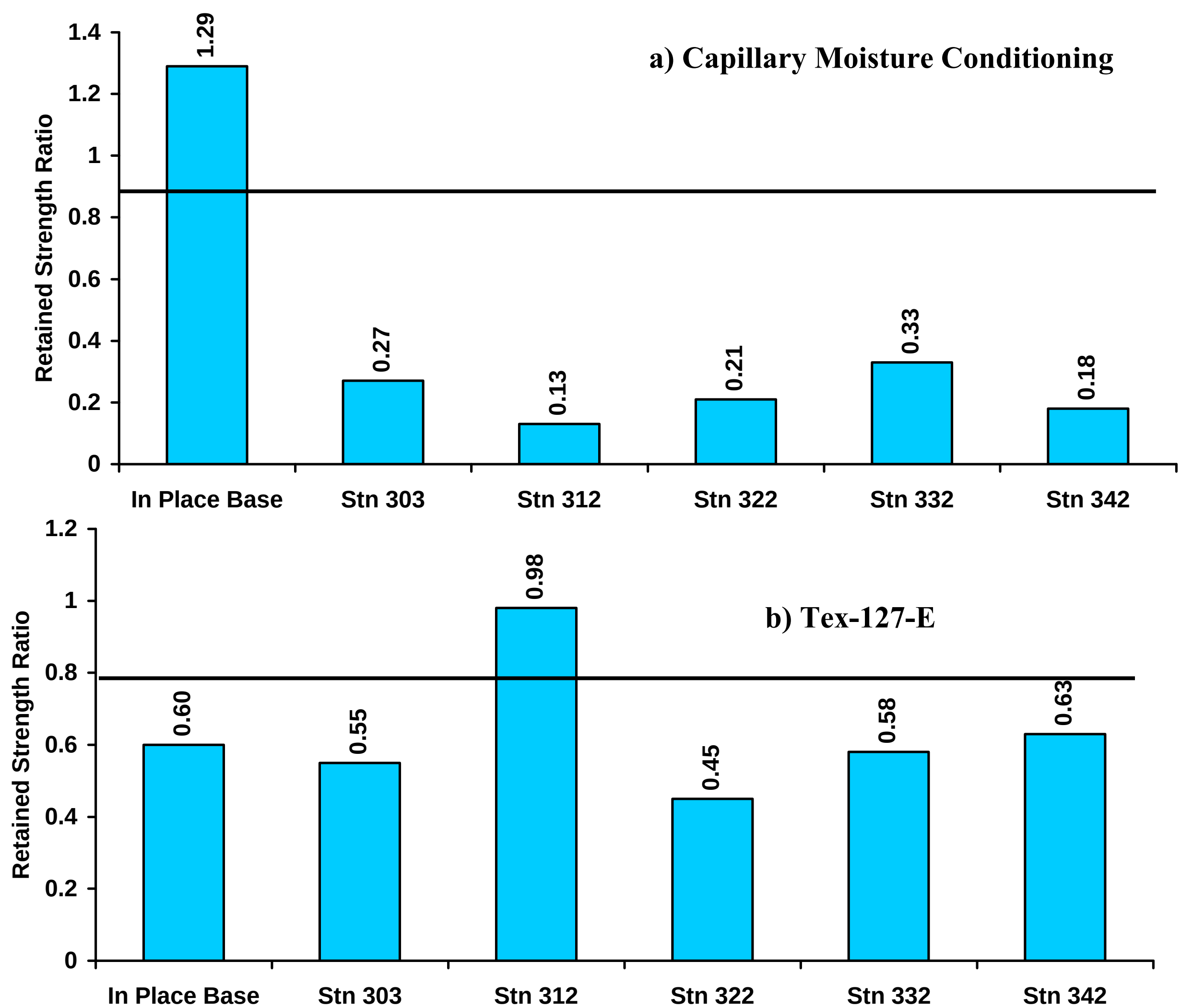


Figure 3.12 – Retained Strength Ratios for FM 303 Materials

Seismic Modulus

The seismic moduli from the modified Tex-127-E specimens are shown in Figure 3.13. Even though the UCS of all pulverized specimens were greater than the in-place materials (see Figure 3.11), the moduli of the pulverized materials were less than the in place materials. Increase in fine sand content would increase the strength but would reduce the modulus.

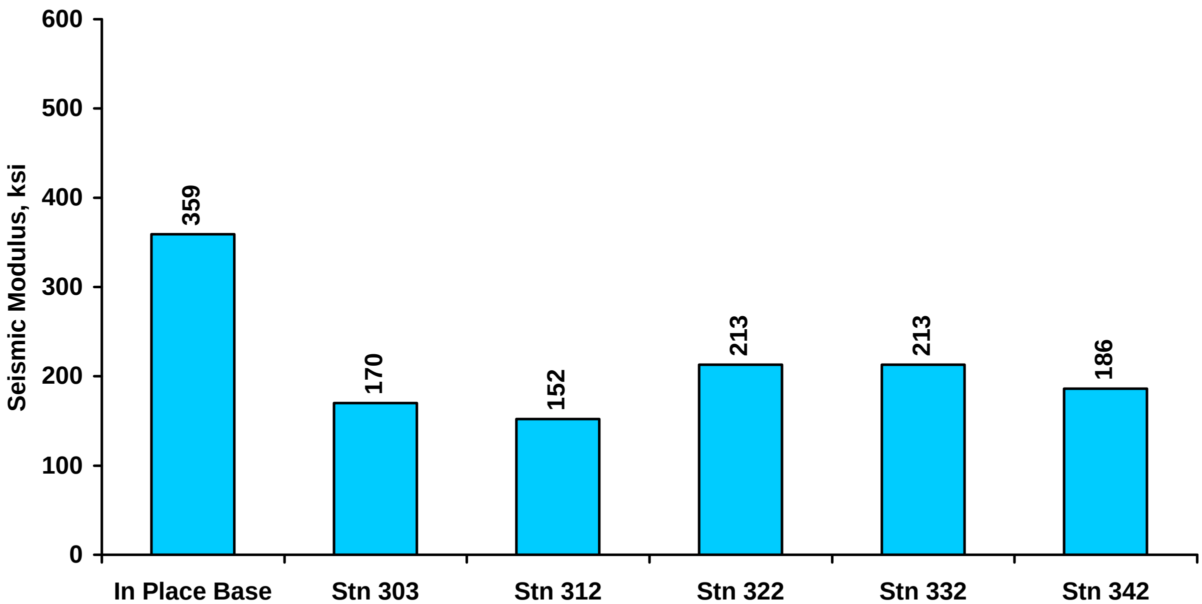


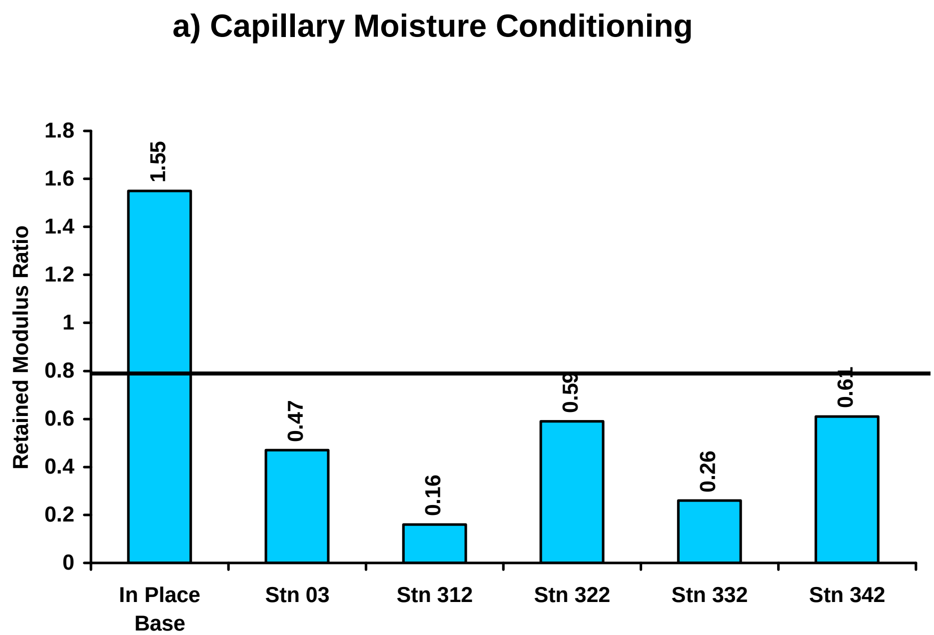
Figure 3.13 –Seismic Modulus of Tex-127-E Modified Specimens for FM 303 Materials

Retained Modulus Ratio

Retained modulus ratios (RMRs) for the pulverized materials are presented in Figure 3.14. The trends are similar to those from the retained strength ratios in Figure 3.12. However, the RMRs are somewhat higher than the RSRs for the capillary moisture conditioning and significantly higher based on modified Tex-127-E.

Final Seismic Modulus from Moisture Susceptibility Tests

The seismic moduli after 24 hours of curing and after ten days of moisture conditioning following the Tube Suction Test protocol (2 day drying, 8 day wetting) are shown in Figure 3.15. Only the in place base material reached the 500 ksi limit while the Pulverized materials had significantly lower moduli.



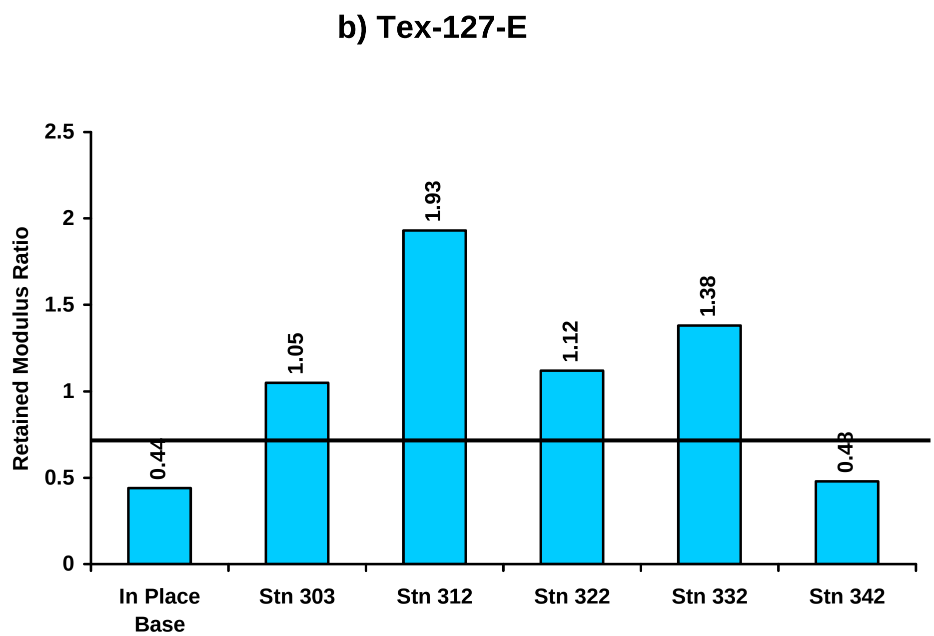


Figure 3.14 – Retained Modulus Ratios from Tube Suction Test and Tex-127-E for FM 303 Materials

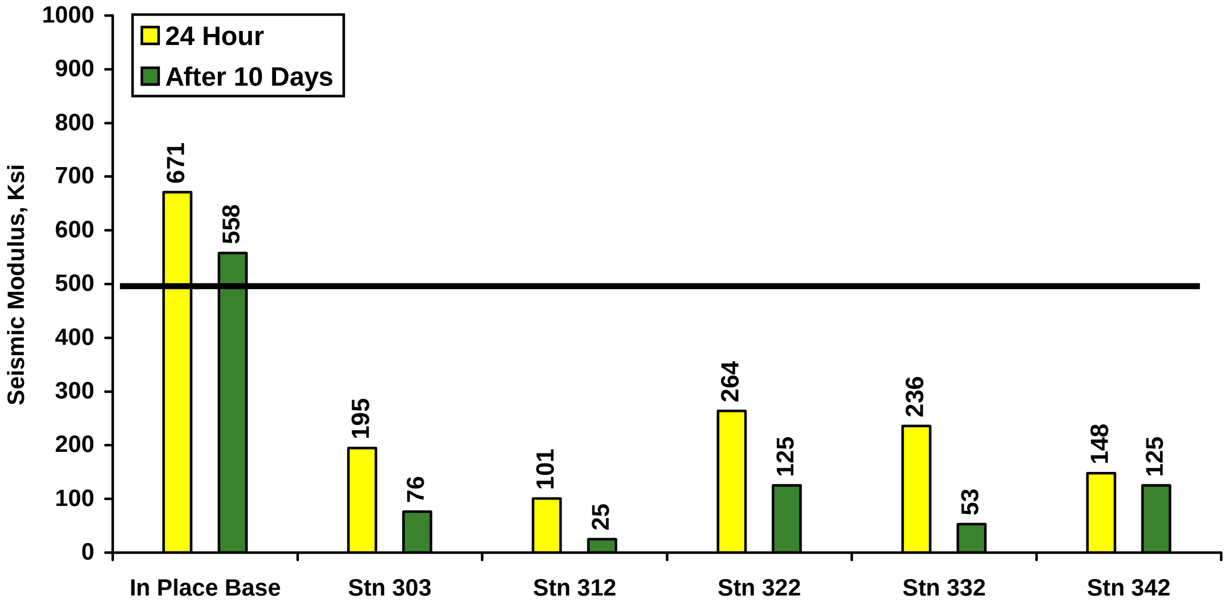


Figure 3.15 – Final Seismic Modulus after Moisture Conditioning for FM 303 Materials

Results from Field Tests

Field tests were conducted with the FWD and PSPA on the base after the construction was completed. The main goal of the FWD and PSPA tests was to characterize the stiffness of the new base. The PSPA tests were conducted three days after the completion of the base while the FWD tests were carried out several months after the completion of the project. The variations in modulus from the FWD and PSPA are shown in Figure 3.16. The average modulus backcalculated from the FWD was 37 ksi with a COV of 36%. Significant judgment required in backcalculating the moduli of the stabilized base. The average modulus from PSPA direct measurements was 118 ksi with a COV of 25%.

Average moduli from FWD and PSPA are compared to the various moduli obtained in the laboratory in Figure 3.17. The ratios of the FWD and PSPA moduli is about 3.2, which is higher than the result from a previous research that the seismic modulus is about 1.7 times the FWD modulus for a granular base (Nazarian et al., 1996). This occurs because the FWD tests were carried out few months after the construction was completed and due to heavy precipitation the base was wet.

All lab moduli obtained from the FFRC tests, which should be compatible to the field moduli obtained with the PSPA, are also summarized in Figure 3.17. The lab moduli vary significantly depending on the curing and moisture-conditioning. The minimum modulus is obtained from Tex-127-E; while the highest seismic modulus was determined 24 hours after oven drying of the TST specimens. The lab moduli from the pulverized materials are significantly different than those from the raw materials because of the finer mixes. These results are much closer to those obtained from the field tests with the PSPA

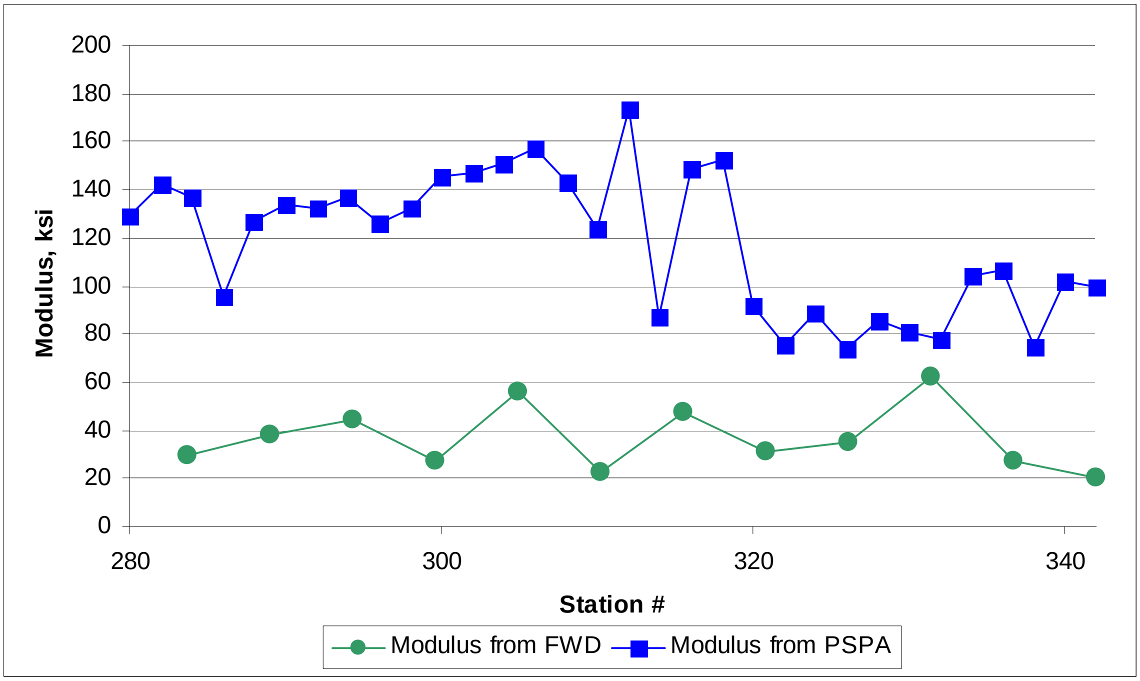


Figure 3.16 – Variations in Base Moduli along Project

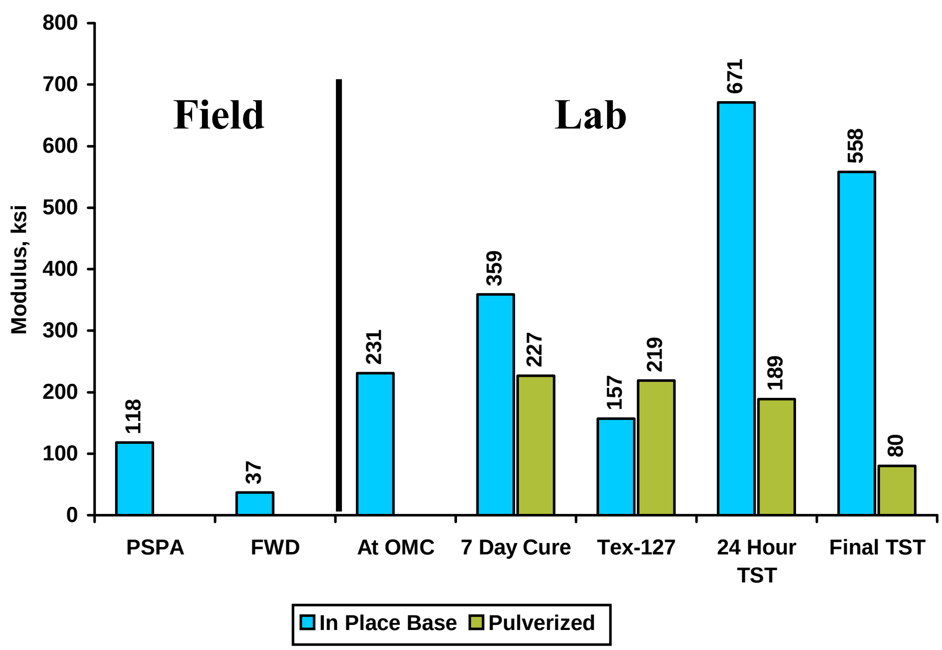


Figure 3.17 – Comparison of Moduli from Field and Laboratory Results

Structural Evaluation

Based on different moduli reported in Figure 3.17, adequate ACP and base thickness for the project were determined. The pavement at the site is a three-layer system as summarized in Table 3.7.

Table 3.7 – Pavement Layer Properties Used in Structural Analysis of FM 303

Layer	Thickness, in.	Modulus, ksi	Poisson Ratio
AC (Seal Coat)	0.5	500	0.33
Fly-Ash Stabilized Base	12	Based on FFRC, FWD and PSPA results	0.35
Subgrade	-	Based on FWD	0.35

For structural design, the lab seismic and PSPA moduli reported in Figure 3.17 were multiplied by 0.7 to convert them to resilient modulus (Hilbrich, and Scullion, 2007). The equivalent thicknesses from either FWD or adjusted PSPA field moduli assuming that the lab moduli from different tests indicated in Figure 3.17 were used to initially design the thicknesses of the stabilized base (12 in.) and HMA (0.5 in.) are presented in Table 3.8. Since all of the lab moduli are greater than the field moduli, both the HMA and base thickness should be increased (refer to Appendix L). The HMA thickness should be increased by 1.5 to 9 in., or the base thickness should be increased by 4 to 27 in. in order to have an equivalent thicknesses.

Table 3.8 – Layer Thicknesses Required for Equivalent Performance when Laboratory Moduli Used in Comparison to Field Results for FM 303 Base

Laboratory Moduli	HMA Thickness (in.) when Base Thickness Maintained Constant at 12 in.		Base Thickness (in.) when HMA Thickness Maintained Constant at 0.5 in.	
	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus
Original Design	0.5		12	
At OMC	3.5	5	16	33
7-Day Cured Moduli	5.5	6.5	27	37
Capillary Saturated Moduli	7	8	27	39
Tex-127	2	4	24	18
24 hr TST	8.5	9.5	27	38

Chapter 4

Case Studies

Introduction

Six sites were selected for the baseline study. The six sites were located in Odessa (2), Paris, Lubbock (2) and Austin districts, respectively.

The first site in the Odessa District was a section of I-20 in Ward County that ranged from mile markers 1554+00 to 1602+40. The construction of this project consisted mainly of excavating and discarding the old asphalt concrete pavement (ACP), pulverizing and cement-treating the in-place base down to 6 in., paving the finished based with hot-mix asphalt (HMA) and placing a rubber underseal. The pre-construction pavement profile consisted of 4.5 in of asphalt concrete and an 18-in. thick base. After construction the ACP layer was replaced at its original thickness of 4.5 in. The cement content of the new base was 2%.

The second site in the Odessa District was located near Fort Stockton on I-10 in Reeves County. This site mainly consisted of milling and discarding 4 in. of old asphalt pavement, reclaiming and cement-treating the in-place base down to 12 in. The pavement profile prior to construction consisted of 4 in. of hot-mix asphalt and a thick (more than12 in.) base. After construction the ACP layer was replaced at its original thickness of 4 in. The cement content of the new base was 2%.

The following two sites in the Lubbock District were evaluated: (1) FM 1939 in Yoakum County from Station 330+00 to 372+00 and (2) FM 303 in Terry County from Station 302+00 to 342+00. For both sites, several layers of seal coat were pulverized with the existing base material and 2 to 3 in. of add rock. About 7% fly-ash was added to the pulverized material. The pavement section prior to construction for FM 1939 consisted of 1.5 in. of seal coat and 8 in. of base material. After construction the pavement profile consisted of a seal coat and a fly-ash stabilized base layer that was 12 in. thick. Similarly, FM 303 pre-construction pavement profile consisted of 1.5 in. of seal coat and 7 to12 in. of base material. After construction, the pavement profile consisted of a seal coat over a 12 in.-thick fly-ash stabilized base for both FM 1939 and FM 303.

The site in the Paris District was located in Lamar County on FM 905 from Station 512+00 to 564+00. The pavement profile before construction consisted of 1 in. of seal coat and 12 in. of base. The construction activities for this site consisted of pulverizing the seal coat with the base material and stabilizing with 3% cement. A 4-in. layer of new base was added on top of the stabilized mix, which was covered by a seal coat.

The last site studied was the reconstruction of Parmer Lane in Austin. The pavement profile before construction consisted of 8 in. asphalt concrete pavement and 18 in. of base. Originally, the construction activities for this site consisted of stabilizing 12 in. of the existing base and asphalt layer materials with 4% cement through pulverization and adding 8 in. of ACP. The construction process at this site was later changed. The ACP layer was removed first and stock-piled. The base was also removed without pulverization. The appropriate proportions of the RAP and base were shipped to a near by pug mill, mixed with cement and delivered to the site for placement and compaction. As such, no degradation of the materials from the pulverization activity was anticipated or studied. Based on extensive laboratory and field tests by the Austin District laboratory, this project provided by far a higher quality final product than any other site.

The construction processes are shown in Figures 4.1 and 4.2. The equipment used on I-10 and I-20 for milling ACP was a Roto-Mill PR-800-7/12. The base material was pulverized using a CAT Rotary Mixer and finally compacted using a CAT CS-433E. The construction process for FM 1939, FM 303 and FM 905 are shown in Figure 4.2. Different equipment was used for pulverization at this site. A CAT 140H Motor Grader was used to grade the subgrade and to spread and grade the add rock, and a Wirtgen WR 2500 pulverizer was used to pulverize the material.

Base materials, along with the asphalt layer and add rock (when appropriate), were collected from these sites prior to and during construction (just after pulverization), and were subjected to a number of tests. In summary, testing of the base materials consisted of the following four major steps:

1. Performing Index Tests (Gradation, Atterberg Limits, Moisture Density, ACV and AIV)
2. Determining strength of raw materials
3. Determining the appropriate additive content using materials retrieved before pulverization
4. Comparing the strength and stiffness of pulverized materials with those obtained before pulverization

Additionally, nondestructive tests with the FWD and PSPA were performed on top of the new base at each site to determine the modulus of the base after construction.

The results from lab and field tests are presented in this chapter. For comparison, the results for FM 303 project reported in Chapter 3 are also summarized in this chapter.

Figure 4.1 – Construction Procedure used for I-10, and I-20

Figure 4.2 - Construction Procedure used for FM 1939, FM 303 and FM 905

Index Testing

The gradation curves of the mixes before pulverization are shown in Figure 4.3. All gradations lie within the gradation limits for a Grade 1 base as per Item 247, except for the I-20 project (marginally) and FM 1939 (significantly). As shown in Table 4.1, the FM 1939 materials contained the least amount of gravel but the most amount of fine sand. The Parmer Rd project contained the highest percentage of fines. The optimum moisture contents and dry unit weights are summarized in Table 4.2 for all sites.

In order to predict the degradation of the base materials during the pulverization, the aggregate crushing value (ACV) and aggregate impact value (AIV) tests were performed. The results of these tests are presented in Table 4.3. An ACV or AIV value of greater than 30 is an indication of an aggregate that is susceptible to crushing. From both the ACV and the AIV results, the Parmer Lane and I-10 materials are the most resistant to crushing and the FM 1939 material the most susceptible to crushing. The difference between the wet and dry AIV indicates the detrimental affects of moisture on the crushing of aggregates. In that sense, the material from FM 1939 is the most critical.

Strength of Raw Materials

The results from the Texas Triaxial (Tex-117-E) and Standard Triaxial (Tex-143-E) tests on raw materials are presented in Table 4.4. From Tex-117-E test results, the FM 905 is the highest quality with a classification of 2.1, and the materials from FM 1939 and FM 303 are the lowest quality with a classification of about 3.3. The results from the Tex-143-E tests again rank the FM 905 material as one of the best.

The main difference between the two triaxial test methods is essentially the moisture conditioning. The specimens tested under Tex-117-E are subjected to capillary saturation while the specimens for Tex-143-E methods are tested 24 hours after preparation. The differences in the angles of the internal friction and cohesions from the two methods essentially reveal the moisture susceptibility of the materials. The Parmer Lane materials are the most moisture susceptible.

The optimum additive content for each material was determined following either Tex-120-E or Tex-127-E as discussed in Chapters 2 and 3. Table 4.5 shows the relevant information from this study. The additive contents used were either determined by performing a mix design (I-20 and Parmer Lane) or were selected based on the past experience of the districts (I-10, FM 905, FM 1939 and FM 303). The verification of the additive contents was carried out at UTEP for all sites except I-10. The results from all sites except FM 303, which were described in Chapter 3, are reported in Appendix A through E. The data from the mix verification indicated that the cement contents for the Parmer Lane, I-20 and FM 905 were appropriate. The 2% cement content based on very limited test seems to be slightly lower than required for the I-10 project. The fly ash contents of 7% for both Lubbock District sections as specified in construction plans was not deemed adequate.

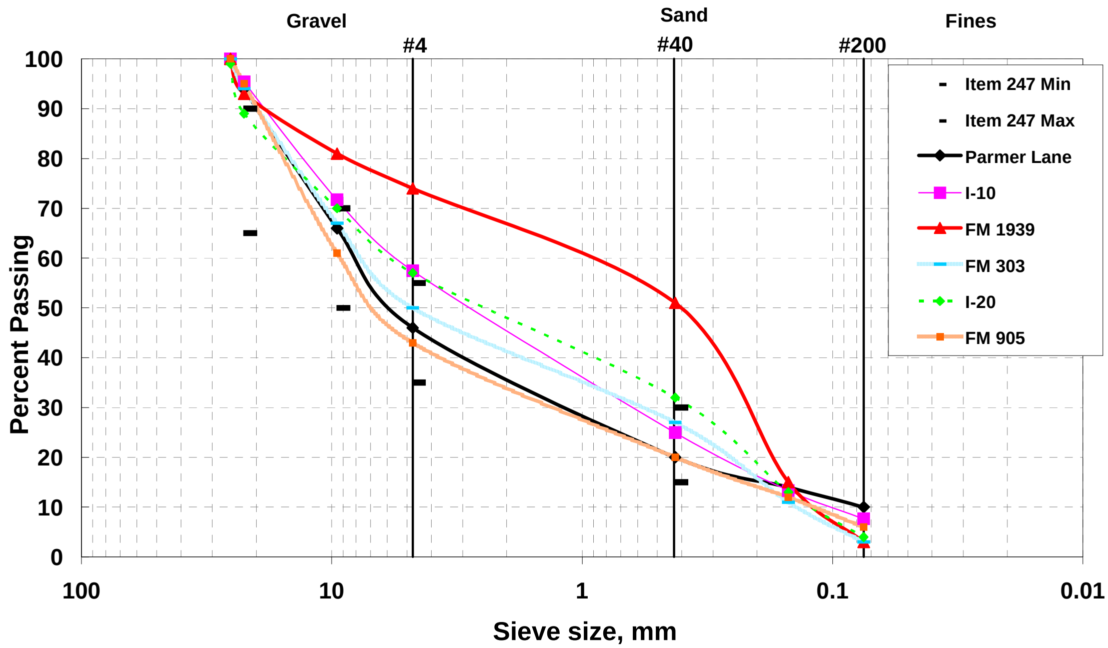


Figure 4.3 - Gradation for Raw Base Materials

Table 4.1 – Percentage Constituents of Raw Base Materials

Material Type	Parmer Lane	I-10	FM 1939	FM 303	I-20	FM 905
Gravel	54	43	26	50	43	57
Course Sand	26	33	23	24	25	23
Fine Sand	10	17	47	23	28	15
Fines	10	8	3	3	4	6

Table 4.2 - Results of Moisture-Density Tests for Raw Base Materials

Parameter	Parmer Lane	I-10	FM 1939	FM 303	I-20	FM 905
Optimum Moisture Content, %	7.7	11	10.2	9.3	9.6	11.5
Maximum Dry Unit Weight, pcf	128	123	121	123	124	122
Seismic Modulus at OMC, ksi	35	19	74	57	39	28

Table 4.3 – Aggregate Crushing and Aggregate Impact Values of Materials

Test	Parmer Lane	I-10	FM 1939	FM 303	I-20	FM 905
ACV	21	20	48	30	32	26
AIV (Dry)	15	15	29	27	19	17
AIV (Wet)	17	16	43	31	24	23

Table 4.4 - Results of Triaxial Testing for Raw Base Materials

a) Tex-117-E

Parameters	Parmer Lane	I-10	FM 1939	FM 303	I-20	FM905
Classification	3.0	3.0	3.3	3.4	2.9	2.1
Angle of Internal Friction, φ	44	47	48	43	53	55
Cohesion, c, psi	9	9	5	6	5.6	9
Strength at Zero Lateral Pressure, psi	32	42	25	23	34	41
Strength at Lateral Pressure of 15 psi, psi	103	144	131	106	168	183
Grade as per Item 247	3	3	3	3	3	2
Seismic Modulus, ksi	92	17.2	24	21	26	25

b) Tex-143-E

Parameters	Parmer Lane	I-10	FM 1939	FM 303	I-20	FM905
Classification	1.0	N/A	2.4	2.8	2.7	1.0
Angle of Internal Friction, φ	55	N/A	48	43	44	53
Cohesion, c, psi	3	N/A	8	13	18	9

As reflected in Table 4.5, the required unconfined compressive strengths of 300 psi as per Tex-120-E were achieved by all cement mixes except for I-10 project. The lower than expected 131 psi strength reported for that project seems to be due to an experimental error. Unfortunately, very limited amount of raw material was available for this project to repeat that test. None of the mixes with fly ash achieved the required strength of 150 psi as per Tex 127-E even when the fly content of 9% was used.

The retained strength ratios (RSR) and retained modulus ratios (RMR) for the cement stabilized projects are in most cases similar. As indicated before, two different moisture-conditioning schemes were used. When the ten-day capillary saturation was used, the RSRs and RMRs of all mixes were above 0.85 except for the Paris material. Once again, we feel that the RSR of 2.85 for I-10 project is erroneous because of the abnormal breakage of the UCS specimen before moisture conditioning. The RMR of 0.66 is more appropriate for this project.

The alternative moisture conditioning procedure for cement stabilized materials consisted of 4 hours of submerging the specimen. In that case, all the RSRs and RMRs were above the 0.85 limit, except for the Paris material where the RMR was 0.77. This indicates that if the time for mix design is critical, the four-hour soak can be used instead of the moisture capillary moisture conditioning of cement-stabilized mixes.

Table 4.5 – Properties of Stabilized Materials

a) Cement Stabilized

Parameter		Parmer Lane	I-10	I-20	FM 905
Cement Content, %		4	2	3	3
Optimum Moisture Content, %		7.7	9.9	10.4	11.4
Maximum Dry Unit Weight, pcf		130	124	121	124
Seismic Modulus at OMC, ksi		734	680	741	788
Tex-120-E	UCS, psi	296	131	573	431
	Seismic Modulus, ksi	1108	1092	1413	1929
Retained Strength Ratio	Capillary Saturation	0.97	2.85	1.81	0.76
	4-hour Soak	1.17	N/A	1.16	0.85
Retained Modulus Ratio	Capillary Saturation	0.85	0.66	3.16	0.92
	4-hour Soak	1.13	N/A	1.22	0.77
Tube Suction Test	Initial Moisture Content, %	6.9	11.1	11.9	11.4
	Final Moisture Content, %	3.4	8.2	8.8	9.0
	Final Dielectric Constant	3	6	4	5
	Final Seismic Modulus, ksi	1958	721	1201	1775

b) Fly-Ash Stabilized

Parameter		FM 1939	FM 303
Fly-Ash Content, %		7	7
Optimum Moisture Content, %		10	9
Maximum Dry Unit Weight, pcf		122	124
Seismic Modulus at OMC, ksi		118	231
Tex-127-E	UCS, psi	46	65
	Seismic Modulus, ksi	139	157
Tex-127-E Modified	UCS, psi	40	109
	Seismic Modulus, ksi	114	359
Retained Strength Ratio	Capillary Saturation	1.81	1.29
	Tex-127-Modified	1.16	0.60
Retained Modulus Ratio	Capillary Saturation	3.16	1.55
	Tex-127-Modified	1.22	0.44
Tube Suction Test	Initial Moisture Content, %	11.5	9.6
	Final Moisture Content, %	11.5	8.5
	Final Dielectric Constant	14	N/A
	Final Seismic Modulus, ksi	360	558

The four-hour soak method was too harsh for the fly ash-stabilized mixes. Instead, the RSRs and RMRs can be obtained by comparing the strengths or moduli from the standard 17-day cured method with the strengths/modulus of specimens cured for seven days but not subjected to capillary saturation (called modified Tex-127-E in this report). The advantage of this method is that the cement-stabilized and fly ash-stabilized mixes can be compared in the same fashion.

Based on this approach, the RSR/RMR of FM 1939 is greater than 1 but for FM 303 substantially less than 0.85.

Tube Suction Test

The final dielectric constants of all cement-stabilized mixes were less than 10 indicating that the mixes are not moisture-susceptible. For FM 1939 mix, the dielectric constant was about 14. The dielectric constant tests could not be performed on the FM 303 materials because of equipment malfunction. An example of the tube suction specimen is shown in Figure 4.4. In many instances the sample became super-saturated at the bottom, but the moisture migration stopped at the interface of the compaction layers. Since the dielectric probe is impacted by the properties of the top two inches of the specimen, the low dielectric constants in some cases can be attributed to the sample preparation. To compensate for this to some extent, the variations in initial (as compacted) and final (after 10 day capillary saturation) moisture contents are reported in Table 4.4 as an alternative means of measuring the moisture susceptibility of the mixes. The final moisture contents for the cement-stabilized materials were less than the initial moisture contents, indicating again that these mixes are not moisture-susceptible. For the FM 1939 mix, the initial and final moisture contents are similar, indicating affinity to moisture.

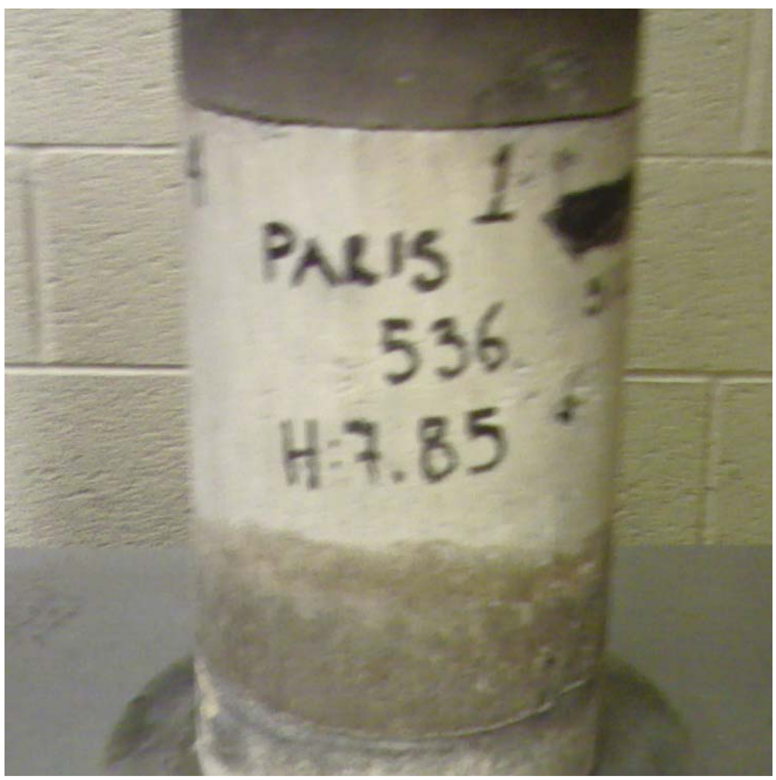


Figure 4.4 – Moisture Susceptibility Specimen

Field Monitoring

Gradation

At each site, the pulverized materials were sampled at five points after the first pass of the pulverizer but before adding the stabilizer. The average gradation curves for the pulverized materials are shown in Figure 4.5 and are compared to the respective gradations of the raw materials in Table 4.6. Changes in the constituents of the materials due to pulverization are presented in Table 4.7. The gravel contents (materials retained on No. 4 sieve) decreased by up to 10%. This indicates that the gravel size particles are being crushed the most. The gravel content of the FM 1939 did not change due to pulverization simply because of the low gravel content in the mix. The coarse sand contents (materials passing No. 4 and retained on No. 40 sieves) increased by 4% except for the two Lubbock materials where the change was minimal. The fine sand content (materials passing No. 40 and retained on No. 200 sieves) increased by 1% to 7%. The fine contents did not change appreciably except for the I-10 project where it actually decreased by 4%. The COVs associated with same sieves are rather high pointing out either to the variability of the final products after pulverization or more importantly the variability of the raw materials along the project.

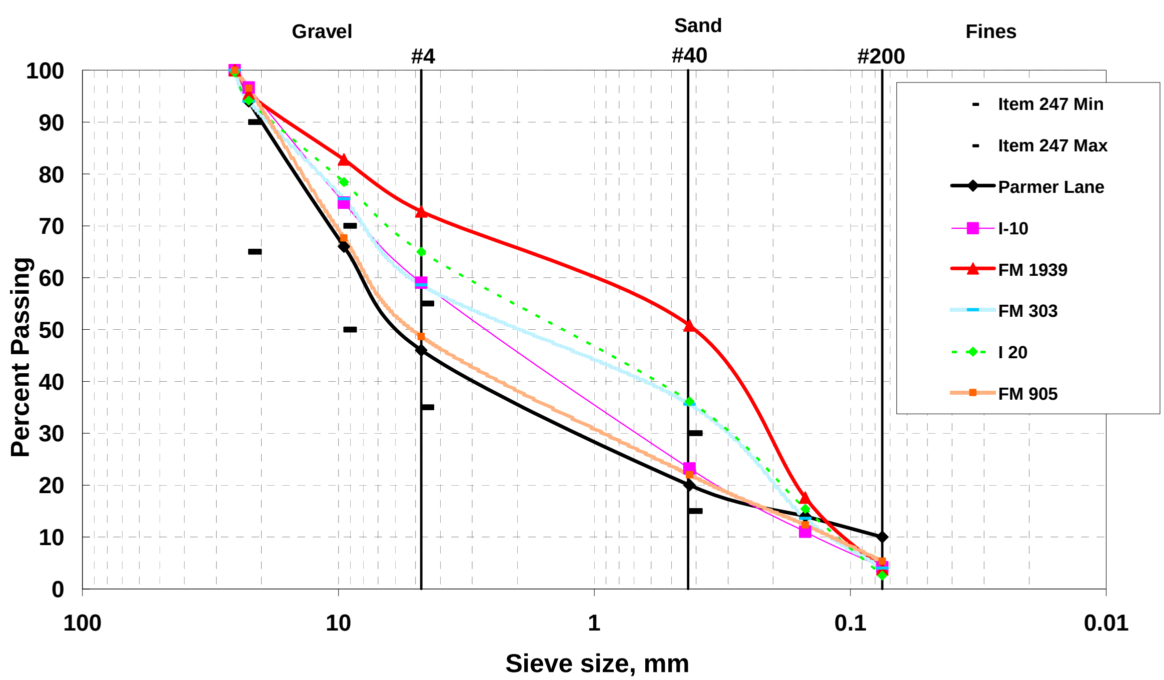


Figure 4.5 - Gradations for Raw Base Materials Compared to Item 247 Limits

Table 4.6 – Sieve Analysis for Materials from all Sites

Sieve Size	Percent Passing																	
	Parmer Lane			I-10			FM 1939			FM 303			I-20			FM 905		
	Raw	Pulverized	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV
1¾ in.	100	Materials was not pulverized		100	100	0	100	100	0%	100	100	0%	100	100	0%	100	100	0%
⅞ in.	94			95	97	0%	93	95	0%	94	94	3%	89	94	1%	95	96	0%
⅜ in.	66			72	74	2%	81	82	3%	67	75	5%	70	78	3%	61	67	4%
No. 4	46			57	59	3%	74	73	5%	50	59	9%	57	65	4%	43	49	5%
No. 40	20			25	23	8%	51	51	14%	27	35	13%	32	36	9%	20	23	13%
No. 100	14			13	11	14%	15	18	14%	11	14	9%	13	14	26%	12	13	18%
No. 200	10			8	4	61%	3	4	18%	3	4	39%	4	3	29%	6	5	11%

Table 4.7 – Material Constituents for all Sites

Constituent	Proportion, %																	
	Parmer Lane			I-10			FM 1939			FM 303			I-20			FM 905		
	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV
Gravel	54	Materials was not pulverized		43	41	4%	26	27	14%	50	41	12%	43	35	7%	57	51	5%
Course Sand	26			33	36	8%	23	22	14%	24	23	8%	25	29	4%	23	26	8%
Fine Sand	10			17	19	10%	47	47	13%	23	32	17%	28	33	9%	15	17	14%
Fines	10			8	4	61%	3	4	13%	3	4	39%	4	3	29%	6	6	11%

The changes in gradation after the first and the subsequent passes of the pulverizer are shown in Table 4.8. It seems that most of the changes in gradation occur after the first pass and the subsequent passes do not appreciably change the gradation.

Table 4.8 - Change in Gradation with Pulverization Passes

Sieve Size	Percentage Passing							
	I 20			I 10			FM 905	
	Pass 1	Pass 2	Pass 3	Pass 1	Pass 2	Pass 3	Pass 1	Pass 2
1¾ in.	100	100	100	100	100	100	100	100
⅞ in.	96	97	94	97	98	98	96	98
⅜ in.	80	79	82	73	75	77	65	71
No. 4	66	66	68	59	60	62	45	47
No. 40	37	37	38	23	23	24	18	18
No. 100	16	17	19	13	12	14	9	9
No. 200	3	2	2	7	6	8	5	3

Determination of Strength of Pulverized Materials without Additives

The results from the Texas and standard triaxial tests after pulverization are compared with the raw materials in Table 4.9. The triaxial classifications after pulverization are higher or similar to those from before pulverization. This indicates that pulverization reduces the performance of the flexible base material. The strengths at 15 psi lateral pressure are higher in the base material before pulverization. Once again, the COVs of a large number of parameters exceed 20% due to the variability of the materials sampled after pulverization.

Stabilized Base Strength

Specimen preparation for the soil-cement specimens using Tex-120-E was based on the optimum moisture and cement contents used in the construction of the base. The strength parameters for cement-stabilized sites from the pulverized points are compared to those before pulverization in Table 4.10. The unconfined compressive strengths of the pulverized materials are less or similar to those from the raw materials with COVs as high as 18% (UCS of I-10 raw material is ignored as discussed above). Except for I-10 pulverized materials, all UCS values are close or exceeding the 300 psi limit.

A similar process was followed for the soil-fly-ash specimens that were prepared using Tex-127-E procedures (Table 4.9b). The strengths as per Tex-127-E of the raw and pulverized materials were similar for the FM 1939 projects. However, the strengths from pulverized materials from FM 303 were higher than the raw materials. None of the values passed the 150 psi strength requirements.

Table 4.9 - Results of Triaxial Testing for Pulverized Base Materials

a) Tex-117-E

Parameters	I-10			FM 1939			FM 303			I-20			FM905		
	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV
Classification	3.0	2.9		3.3	3.3		3.4	4.3		2.9	2.9		2.1	3.0	
Angle of Internal Friction, φ	47	49	2.1%	48	30	9.2%	43	27	21.6%	53	52	4.4%	55	49	17.4%
Cohesion, c, psi	9	7	18.1%	5	8	17.3%	6	5	27.5%	6	6	20.3%	9	5	28.4%
Strength at Zero Lateral Pressure, psi	42	35	9.8%	25	29	16.4%	23	15	33.7%	34	32	27.5%	41	31	20.1%
Strength at Lateral Pressure of 15 psi, psi	144	139	2.9%	131	98	8.3%	106	54	23.8%	168	144	19.5%	183	121	35.2%
Seismic Modulus, ksi	17	18	20.2%	56	48	25.3%	21	33	22.0%	26	29	20.3%	25	31	1.9%

b) Tex-143-E

Parameters	I-10			FM 1939			FM 303			I-20			FM905		
	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV	Raw	Pulverized	COV
Classification	N/A	N/A	N/A	2.4	3.3		2.8	3.4		2.7	2.3		1.0	2.3	
Angle of Internal Friction, φ	N/A	N/A	N/A	48	42	18.4%	43	39	13.6%	44	48	5.1%	53	48	3.0%
Cohesion, c, psi	N/A	N/A	N/A	8	7	53.0%	13	16	33.9%	18.5	11	18.8%	9	10	21.9%

Table 4.10 – Strength and Modulus Parameters for Raw and Pulverized Base Materials

a) Cement Stabilized

Site		Parmer Lane			I 10			I 20			FM 905		
Parameter		Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV	Raw	Pulv.	COV
Tex-120-E	UCS, psi	296	N/A	N/A	131	245	8.4%	573	354	17.6%	431	391	18.0%
	Seismic Modulus, ksi	1108	N/A	N/A	1092	1101	11.1%	1413	1469	10.8%	1929	1392	22.4%
Retained Strength Ratio	Capillary Saturation	0.97	N/A	N/A	2.85	1.29	12.7%	1.81	1.23	34.9%	0.76	0.88	15.8%
	4-hr Soak	1.17	N/A	N/A	N/A	N/A	N/A	1.16	1.02	16.8%	0.85	0.91	12.0%
Retained Modulus Ratio	Capillary Saturation	0.85	N/A	N/A	0.66	0.65	5.6%	1.16	0.78	14.5%	0.92	0.77	20.8%
	4-hr Soak	1.13	N/A	N/A	N/A	N/A	N/A	1.22	0.88	32.0%	0.77	1.04	22.7%
Tube Suction Test	Initial Moisture Content, %	6.9	N/A	N/A	11.1	10.0	4.7%	11.9	10.9	5.9%	11.4	10.2	4.6%
	Final Moisture Content, %	3.4	N/A	N/A	8.2	7.3	6.0%	8.8	11.5	25.6%	9	6.3	8.8%
	Final Dielectric Constant	2.7	N/A	N/A	5.8	16.6	4.6%	4.2	10.5	48.5%	5.1	4.9	22.7%
	Final Seismic Modulus, ksi	1958	N/A	N/A	721	716	5.6%	1249	1087	12.0%	1774	1042	17.4%

b) Fly-Ash Stabilized

Site		FM 1939			FM 303		
Parameter		Raw	Pulverized	COV	Raw	Pulverized	COV
Tex-127	UCS, psi	46	40	19.6	65	125	24.9
	Seismic Modulus, ksi	139	191	8.0	167	119	39.6
Tex-127 Mod	UCS, psi	40	183	7.8	109	184	18.4
	Seismic Modulus, ksi	114	323	21.6	359	227	41.1
Retained Strength Ratio	Capillary Saturation	1.81	0.31	14.0	1.29	0.24	31.1
	Tex-127	1.16	0.22	27.0	0.60	0.70	34.1
Retained Modulus Ratio	Capillary Saturation	1.16	0.84	36.3	1.55	0.42	47.6
	Tex-127	1.22	0.62	28.3	0.44	1.19	44.3
Tube Suction Test	Initial Moisture Content, %	11.5	9	14.1	9.6	8.8	17.0
	Final Moisture Content, %	11.5	7.5	14.2	8.5	11.1	15.3
	Final Dielectric Constant	14.2	9.8	20.7	N/A	N/A	N/A
	Final Seismic Modulus, ksi	360	256	9.5	558	80	51.9

Except for the raw materials from FM 1939, the strengths obtained under the so-called modified Tex-127-E, where the ten days moisture conditioning was eliminated, were higher than those from the Tex-127-E procedure. However, given the moisture susceptibility of the material, these strengths are too close to the limit of 150 psi. The modified tests are advocated for two reasons. First, during the mix design, the strengths from Tex-120-E for cement and Tex-127-E modified can be used to compare the cost benefit of using fly ash versus cement. Secondly, if the strengths from the modified six-day tests do not meet the strength requirements, they are unlikely to pass the strength requirements under the actual Tex-127-E procedure. This cuts down about 10 days from the time required to perform mix design.

In terms of seismic modulus, all cement-stabilized materials achieved a modulus of 1000 ksi. For the FM 905 project, the seismic modulus for the raw material was significantly higher than the pulverized material. None of the fly-ash specimens achieved a modulus greater than 360 ksi. Unlike the FM 1939, the seismic modulus from FM 303 did not follow the same trend as the unconfined compressive strength. The raw base material had a higher modulus than the pulverized base material. As indicated before, as the fine content increases, the strength would increase but the modulus will decrease.

The retained strength and modulus ratios for the cement stabilized specimens using either the capillary moisture conditioning or 4 hour soak tests were above or close to 0.85. For the fly ash projects, in a number of cases the RSRs and RMRs are less than the limit of 0.85 pointing towards their moisture susceptibility.

Specimens were also prepared and tested as per the Tube Suction Test protocol (2 day drying, 8 day wetting) are shown in Table 4.10 for the cement stabilized and fly-ash stabilized materials. The major difference between this protocol and Tex-120-E or Tex-127-E is that the specimens are cured in an oven for two days (as opposed to six days on the countertop or moisture room). The final moduli from the TST process are somewhat different than those from the Tex-120-E for the cement stabilized specimens due to differences in the curing regime. As reflected in Table 4.10a, the moduli after the TST conditioning are greater than 1000 ksi except for I 10 were the RMRs were lower than 0.85. The fly-ash stabilized specimens in most instances yield final moduli that are substantially greater than those from Tex-127-E. The dielectric constants measured on the TST specimens could not be correlated to the strength or modulus trends.

The average moduli from the FWD and PSPA are compared to the various moduli obtained in the laboratory in Table 4.11. For comparison purposes, the lab seismic and PSPA moduli reported in Table 4.10 are multiplied by 0.7 to convert them to resilient modulus (as per Hilbrich, and Scullion, 2007). The lab moduli vary significantly depending on the curing and moisture-conditioning. For both the cement-stabilized materials and the fly-ash stabilized materials the moduli from the specimens prepared for the moisture-density curves tested after 24 hours (called "at OMC" in Table 4.10a) seems to provide the closest moduli to the field moduli. Given the size of the sites tested, the achievable field moduli are preliminary about 50% of the lab moduli measured at the OMC. For the fly ash stabilized materials, the estimated achievable modulus is about 70% to 100% of the lab moduli measured on the MD specimens.

Table 4.11 - Comparison of Moduli from Field and Laboratory Tests

a) Cement Stabilized

Site		Parmer Lane	I 10	I 20	FM 905
FWD	Modulus	-	184(26%)	288(35%)	126(22%)
DSPA	Modulus	-	263(26%)	330(25%)	270(35%)
At OMC		360	476	445	552
7 Day Cure		776	764	989	1350
4 Hour Soak		878	-	683	1033
24 Hour TST		416	508	552	935
Final TST		662	505	874	1242

b) Fly-Ash Stabilized

Site		1939	303
FWD	Modulus	45(36%)	36(36%)
DSPA	Modulus	138(19%)	118(25%)
At OMC		83	162
7 Day Cure		80	25
4 Hour Soak		97	110
24 Hour TST		178	470
Final TST		252	391

Values in parenthesis are COV

Chapter 5

Observations and Recommendations

Introduction

The goal of this study was to document the impact of pulverization on the quality of the base in a pavement. As part of this study, changes in gradation due to pulverization were documented based on the materials from several sites. The impact of these changes on the final base quality was quantified through laboratory and field tests. Comparative studies were also carried out to document the differences in performance of bases before and after pulverization. The changes in the stabilization design due to pulverization were also documented. In this chapter, recommendations on all aspects of FDR projects with calcium additives are included. The recommendations and observations are categorized by activities from the beginning of the project to completion. Recommendations on the modifications to TxDOT specifications and test methods are included in Appendices F through I.

Step 1: Material Retrieval for Mix Design

Under the current practice at TxDOT, the material retrieval from the site for mix design is carried out by randomly selecting a location within the project limit, digging a test pit and sampling the in place base for laboratory testing. As reflected in Table 4.5 and as we observed in the field substantial variability in the base material may occur throughout the project. More upfront investment in site evaluation is recommended.

We propose that the project should be surveyed with an FWD and GPR before material retrieval to capture the variability of the site. The FWD data can be utilized to assess the strength of the subgrade to ensure that it can carry the traffic load after the FDR. If the subgrade is too soft, the improvement of the base with the FDR may not be advisable. The FWD data can also be used to qualitatively judge the variability in the base.

The GPR can provide information about the gross changes in a base layer, the intrusion of moisture and the variability in the base and hot mix or surface treatment thickness. In projects were the hot mix or the surface treatment is combined with the base, the variability in the thickness of that layer contributes to the variability in the final product since the RAP/base proportions change. Based on the results from the FWD and GPR the location(s) for material retrieval should be established to ensure that a representative mix design can be carried out.

Alternatively, borings should be placed at regular intervals (say every 0.1 to 0.2 mile), so that the base and hot mix can be sampled, and that the variability of the material can be established. In that case, the materials from different boreholes should be maintained separately. These materials will be used for laboratory testing as discussed in the next section.

We realize that this activity would increase the initial budget of the project for mix design. Given that this cost increase is a small fraction of cost of construction, in our opinion it is justified.

Step 2: Mix Design

The material retrieved from the site will then go through several steps as discussed below:

- ***Sieve Analysis:*** The material should be sieved first as per Tex-110-E. Under the current TxDOT requirements, the finest sieve is No. 40. This will not permit to delineate between fine sands and fines. It is recommended that a No. 200 sieve be added so that the fine sand content can be delineated from the fines content. If the in-place material is sampled from multiple locations, the gradation from each location should be established separately.

  Hot Mix/Surface Treatment: If the hot mix/surface-treatment layer has to be pulverized into the mix, the material should be crushed and sieved and proportionally added to the gradation as shown in Figure 3.1. Figure 5.1 shows the hot mix/surface-treatment layer retrieval from a construction site. One item that needs to be standardized is the method of crushing these materials. For I-10 and I-20, the hot mix was milled separately and was not used. In the other projects, we internally standardized the opening of the crusher and the duration of crushing. However, coordination with the CST is needed to harmonize this activity within TxDOT.

  Add Rock: Add rock is usually recommended when additional thickness is needed or when the project has to be widened. The addition of add rock is shown in Figure 5.2. We recommend the inclusion of add rock in some projects to improve the gradation of the in-place material as discussed below. The add rock should be sieved separately, and proportionally added to the gradation as shown in Figure 3.2.

  Based on the gradation, the material should be divided into the four categories shown in Table 5.1. For materials with lower than recommended values, the addition of high-quality (to be defined in the next section) add rock is recommended. For materials with high fine sand and high fine contents, especial attention should be placed in selecting the appropriate additive and concentration to ensure long-term durability. The excel worksheet included in Appendix L, can help to optimize the gradation of the add rock to be acquired.

Figure 5.1 – Hot Mix/Surface-Treatment Layer Retrieved from the Construction Site

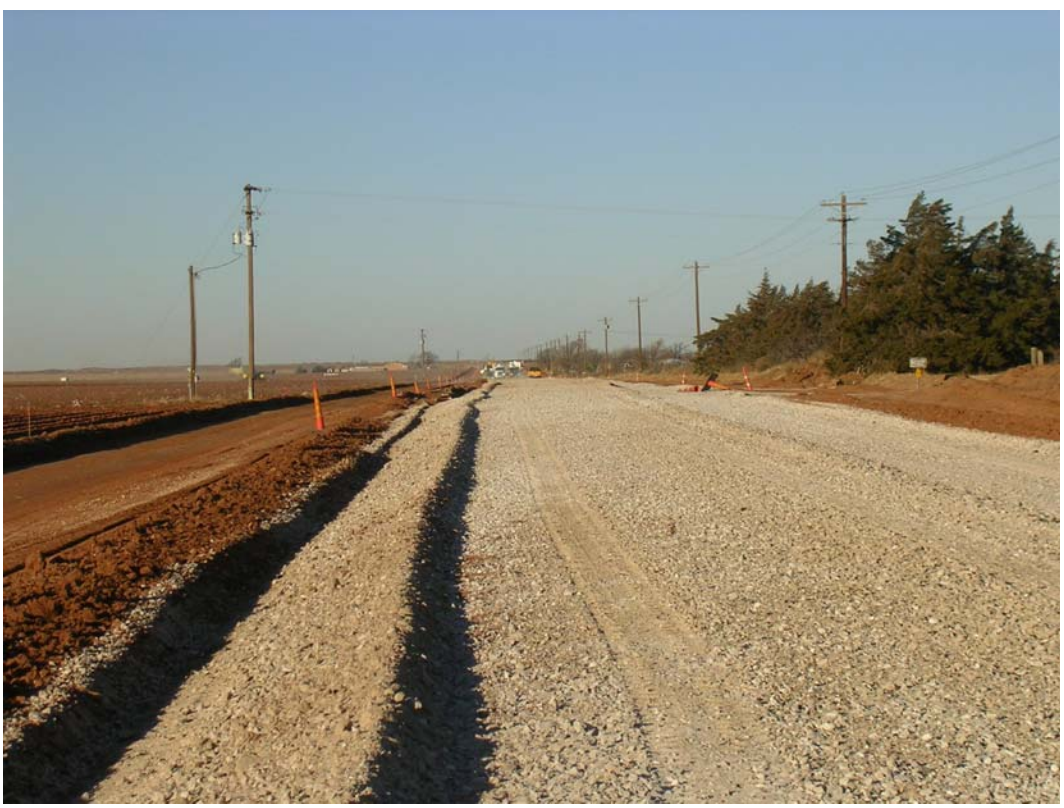


Figure 5.2 – Addition of Add Rock

Table 5.1 – Recommended Gradation for Bases

Category	Definition	Limits as per Item 247	Suggested Values
Gravel	Retained on No. 4 Sieve	35% to 55%	45%
Coarse sand	Passing No. 4 and Retained on No. 40 Sieves	15% to 40%	30%
Fine Sand	Passing No. 40 and Retained on No. 200 Sieves	Not Available	15%
Fines	Passing No. 200 Sieve		<10%

- ***Atterberg Limits:*** The liquid limit and plasticity index of the mix should be assessed for the proper selection of the additives. It is recommended that they are done separately for each dissimilar sample retrieved to ensure that the selected additive is appropriate for the entire project.

- ***Assessing Quality of Aggregates:*** As shown in Chapters 3 and 4, the major impact of the pulverization process is that gravel-size aggregates break into fine sands. The Aggregate Crushing Value (ACV) and/or the Aggregate Impact Value (AIV) seem to provide a good indication of the crushing potential of aggregates. The two test apparatus are shown in Figure 5.3, on the left AIV and ACV to the right. Preliminary protocols for conducting these tests are included in Appendices J and K. For aggregates with ACV or AIV values greater than 30, the potential for crushing is rather high. The limit of 30 is rather conservative. As more data become available, this limit can be reevaluated.

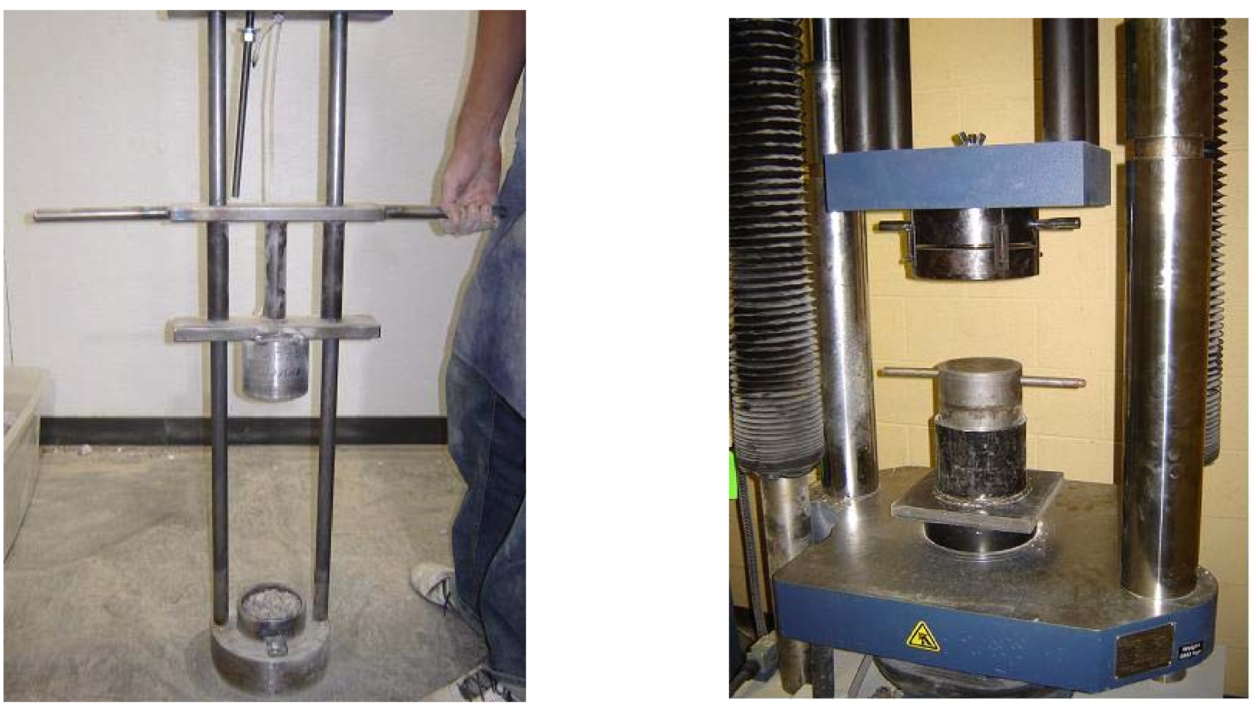


Figure 5.3 – ACV and AIV Testing Apparatus

The correlation between the fine sand contents from the ACV tests and the proportional change in the fine sand contents from the pulverization activities is included in Figure 5.4. There is a reasonably good correlation between the two parameters. As such, the changes in gradation from the ACV tests can be utilized to estimate the changes in the gradation due to pulverization. The excel worksheet included in Appendix L, can help to adjust the gradation for this purpose.

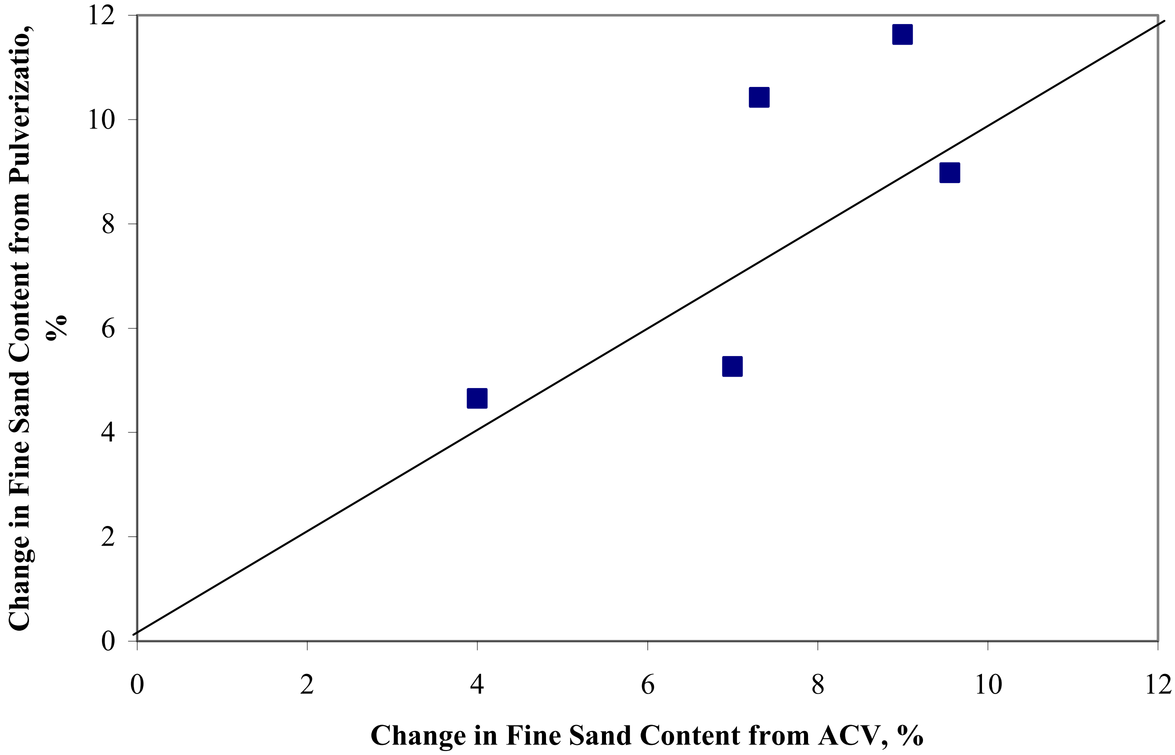


Figure 5.4 – Comparison of Changes in Fine Sand Contents between ACV and Pulverization Activity

If add rock is added, the crushing potential of these aggregates should be assessed as well. The use of add rock with ACV and AIV of more than 30 is discouraged. The excel worksheet included in Appendix X would allow for the consideration of change in gradation due to pulverization.

- ***Blending of Aggregates:*** If the in-place materials are sampled from multiple places, it is recommended the materials be mixed together at this point so that one mix design can be carried out. Mix design for each in place material does not seem to be practical. By mixing all the materials from all locations, the best compromise mix is developed. For long projects where the base materials significantly change throughout the project, the feasibility of more than one mix design may be considered by the Engineer.

  The mixed materials from different locations can then go through a splitting process to obtain adequate amount of material for mix design. In the absence of the ACV tests, we recommend that the gravel-size particles be reduced by 8% and the fine sand content be increased by 8%

to account for the crushing potential of the material These are the average values we observed from the sites with ACV and AIV values of less than 30.

- ***Moisture-Density of Raw Materials:*** The next step is to obtain the moisture-density curve of the material following Tex-113-E. The optimum moisture content can be used as a guideline for selecting the moisture content for the material when additives are added.

  If equipment is available to the districts, we recommend that the specimens prepared for the moisture-density tests be preserved for 24 hours by wrapping them in cellophane or placing a membrane around them and be subjected to the unconfined compressive strength tests and/or free-free resonant column modulus tests. As shown in Figures 5.5 and 5.6, these values can be used to judge the properties of the raw mix. Since the samples have been already prepared, this task just adds a small overhead to the activities of the lab personnel. The strength at the traditional optimum moisture content can be used to judge the quality of the raw material. If the strength is close to 45 psi (or the seismic modulus is close to 80 ksi), the raw material may have the potential of acting as a reasonably high-quality base. Those districts that utilize pulverized materials with out additives can then proceed with the tests recommended in Item 247 to estimate the quality of the base. Since the change of gradation may impact the moisture susceptibility, a tube suction test as discussed in Chapter 4 is also recommended.

- ***Selection of Additives:*** The selection of candidate additives can be carried out as per current TxDOT guideline (see Figure 2.2). Based on the gradation recommendation above, the likely additives will be cement, fly ash and/or lime. The selection of the appropriate additive type can be made by the district based on the cost and availability. If more than one additive is selected, and the complete laboratory tests are not carried out for each additive, a rapid test is recommended below to ensure the compatibility of the additive with the base.

  As reflected in Table 4.11, the moduli obtained from specimens with additives at the OMC maybe an indication of the ultimate modulus of the cured specimens. We propose that specimens with a presumptive amount of additives (say 4% for cement and 7% for fly ash), be prepared as per Tex-120-E for cement or Tex-127-E for fly ash. These specimens should be subjected to the unconfined compressive tests after 24 hours of curing on counter top. If the UCS strength is substantially less than half the 300 psi limit for cement or 150 psi limit for fly ash, the compatibility of the additive is in doubt.

- ***Selection of Additive Content:*** For the most part the current process of selecting additive content is reasonable. However, the strengths/stiffnesses of the cement-stabilized mixes obtained following the curing method in Tex-120-E are as much as four times greater than those obtained in the field. For the fly ash projects, the samples cured for seventeen days as per Tex-127-E yielded properties that were comparable to those obtained in the field (see Table 4.10).

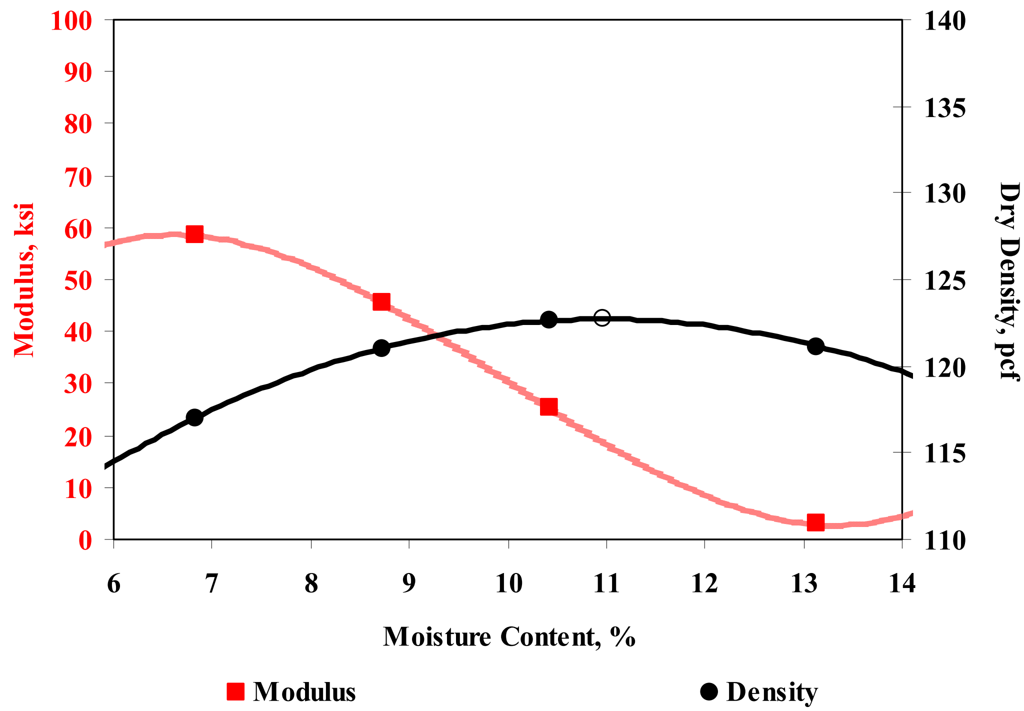


Figure 5.5 – Moisture-Density and Modulus for Raw Material

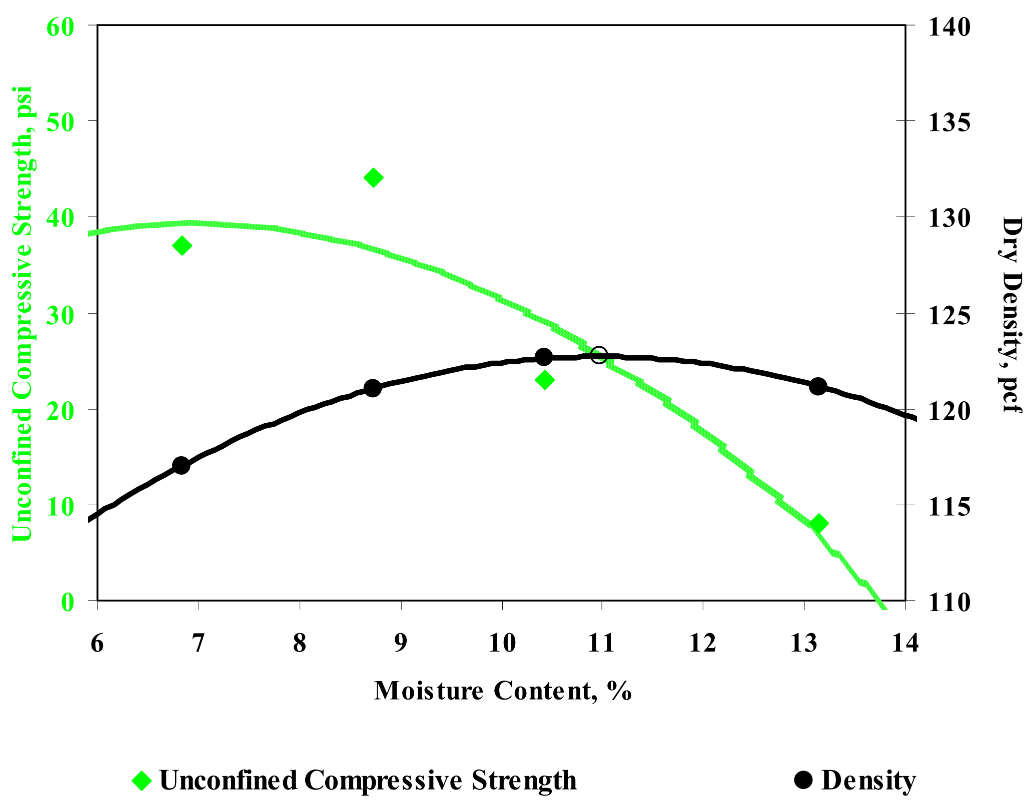


Figure 5.5 – Moisture-Density and Unconfined Compressive Strength for Raw Material

There is no provision for estimating the moisture susceptibility of the mixes in the current specifications. Since due to pulverization the fine sand content may increase, the possibility of absorption of water by the mix would increase.

For cement-stabilized projects, the moisture susceptibility may be of concern at lower concentrations, but at the optimum cement contents, this does not seem to be a problem. The retained strength ratio (RSR) or retained modulus ratio (RMR) can be used for this purpose. To assess the RSR/RMR at the optimum moisture content the 4-hr soak method seems to provide adequate information for higher cement contents (greater than 4%). At lower cement contents (less than 4%) this method should be used with caution, since the specimen may disintegrate during soaking.

For the projects with the fly ash, the moisture susceptibility seems to be an issue (Table 4.10), and should be carefully considered. Under the current standards, the curing of specimens takes about 17 days. We introduced a modified concept to expedite the design (called modified Tex-127-E, Part II). In that method, the specimens are only cured for six days on a table top and then subjected to the UCS tests. The optimum fly ash content for this approach is determined based on a target UCS of about 200 psi as justified next. Under current TxDOT specification, the moisture-conditioned strength should be above 150 psi, and the retained strength should be 85%. The 200 psi is approximately equal to the ratio of these two numbers (150 psi/85%) with a margin of safety. As soon as the optimum fly ash content is obtained, specimens at that fly ash content can be subjected to the moisture susceptibility tests to ensure that the RSR/RMR is adequate.

- ***Final Moisture-Density Curve:*** With the addition of the additives, the moisture-density curve of the mix may change. The optimum moisture content and maximum dry density may change depending on the additive content. However, the most significant change is in the shape of the MD curve. An example is shown in Figure 5.7. The change in the dry density with moisture is less pronounced than for the raw materials. This has significant implication, when the acceptance of the material is based on the density as discussed below.

Step 3: Construction Practices

Based on the field observation of the projects in this study and others, the following recommendations are made.

Hot Mix/Surface Treatment: In three projects the asphalt layer was milled before pulverization. In I-10 and I-20 projects, the RAP was used on other projects while for the Parmer Lane project the RAP was added to the base. In the other projects, the RAP was directly pulverized with the base. For the FDR projects where the base and the hot mix/ surface treatment were pulverized into bases, the RAP was much larger in size than allowed in the current TxDOT specifications. This is shown in Figure 5.7. These large size pieces may impact the final quality of the mix and may contribute to the variability in the field results observed. For thicker hot mix asphalt layer we recommend that the material be milled separately, sorted and then be added to the base similar to add rock.

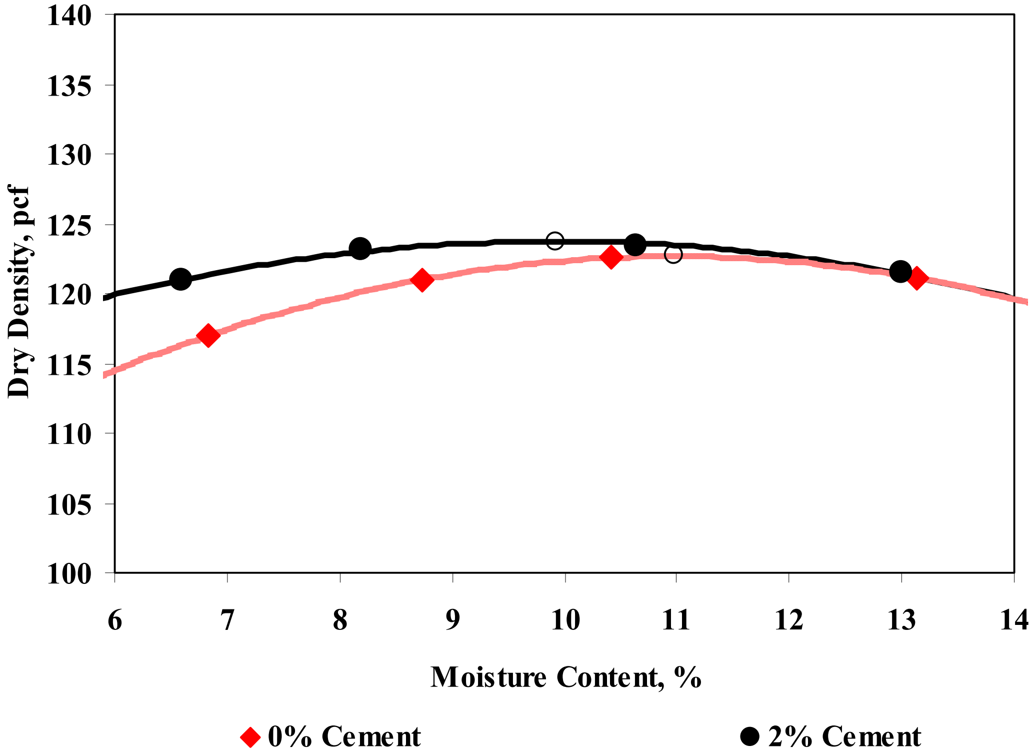


Figure 5.6 – Moisture-Density Curve for 0% and 2% Cement

Figure 5.7 - Large-size HMA after pulverization

- *Add Rock:* Characteristics of desirable add rock were discussed above. Especial attention to the quality and gradation of the add rock as delivered is recommended. The mixing of the add rock and in place materials should also be monitored to ensure that they are uniformly mixed. In the cases when the road is widened, it is of utmost important that the add rock and in place materials are thoroughly mixed and spread uniformly throughout the width of the new road. In some instances, dissimilar materials are used for the existing road and the widened portion. This similarly may negatively contribute to the performance of the road.

- *Addition of Additives:* The stabilizing additives were added dry in all projects. Based on our observations, the uniform distribution of the additives should be carefully observed. The amount of water added before and/or after spreading the additives should also be considered as discussed below.

- *Pulverization Activity:* The initial perception of the research team and the PMC of the project was that each pass of the pulverizer would progressively change the characteristics of the in place materials. As reflected in Table 4.8, most of the change in the gradation of the material occurred after the first pass. For the sites used in this study, the second and subsequent passes changed the gradation only minimally. More sites should be observed to validate this observation. However, preliminarily the number of passes does not seem to be of concern.

- *Compaction Activity:* The current methods of compaction seem to be adequate for pulverization projects provided all the required rollers are used. The amount of water in the mix has a significant impact on the final product. As indicated before, the variation in density with moisture is rather small for stabilized materials. The moisture content before compaction should be of great concern. Deviation from the design moisture content, especially wet of optimum would have negative impact on the strength of the final product. We propose that the moisture content of the material be determined as a quality control measure before compaction as has already been incorporated in Items 265 and 261. The microwave oven method of Tex-103-E may be an efficient way of evaluating the moisture content.

  The so-called "slush rolling" to produce a smooth final product should not be permitted at all. The finishing should be done with appropriate blading methods.

- *Quality Management:* The current specification for quality management of the stabilized layers is primarily based on the adequate density and moisture content before and after compaction. As indicated above the moisture of the mix during compaction is of utmost importance. The moisture content before compaction is typically not enforced rigorously. The final moisture is measured with a nuclear density gauge (NDG). The importance of calibrating the NDG for a particular base with stabilizer should be emphasized, and regularly checked by Tex-113-E method.

  As indicated before, the density of the stabilized mixes vary little with moisture. For instance in Figure 5.6, the density of the material with 2% cement varies by 4% for the range of moisture of ±3% of optimum. As such, achieving the density may not ensure a high quality material. Therefore, it is desirable to supplement the acceptance based on the density requirements with some alternative means of quality control. Two alternatives are proposed below.

- <u>*Laboratory Tests*</u>: In this approach, the loose material is sampled before compaction. Some of the material is used to measure the moisture content using a microwave to ensure that the material is at the appropriate moisture content for compaction. If the moisture content is reasonable, a specimen is compacted in the field using Tex-113-E to check for density. The specimen is then tested after 24 hours to ensure adequate UCS by comparing it to the anticipated UCS obtained from the MD samples during the mix design.

- <u>*Field Tests:*</u> Nondestructive field tests such as the PSPA to be used to measure the quality of the finished layer. This process is provisionally included in a few of TxDOT special provisions already.

Once again, we are aware that these suggestions may increase the work load on the District staff. However, the costs of such activities relative to the total construction cost and possible extended life achieved is quite small.

- ***Opening to Traffic:*** In most projects the opening of the road to traffic after pulverization and compaction is dictated either by the need to minimize the traffic disruption to motoring public or by presumptive times in TxDOT specification (e.g., three days for cement or 24 hours for fly ash). Since a number of factors, such as the ambient temperature, the quality of the additive, the moisture content at compaction, impact the rate of increase in strength/stiffness of the finished material, a more objective way of deciding on the opening of the roads under construction is needed. The opening should be established by setting a minimum limit for the strength/stiffness before traffic is allowed. This is especially critical for late season construction activities.

- ***Design Modulus:*** Scullion et al. (2003) recommended presumptive values for the modulus of stabilized layers based on evaluating a number of projects. Our study shows that the actual modulus of the stabilized layers is highly dependent on the stabilizer content and the construction practices. Based on the results obtained from the sites in this study (see Table 4.11), either 50% of the PSPA modulus of the field sections, or 33% of the modulus obtained from the mixes design at OMC may be a reasonable design modulus. More sites are needed to refine this suggestion.

  Also since the in place modulus of the material is quite construction dependent, the concept of a test strip, similar to those done for the hot mix asphalt, may be prudent for big projects. In that matter, the final quality of the mix given the equipment and practices of the contractor can be established and the mix design can be adjusted if necessary.

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Appendix A

Comprehensive Results from Parmer Lane

Table A.1 – Properties of Cement Stabilized Materials from In-Place Materials

Cement Content, %		2	4	6
Optimum Moisture Content, %		7.0	7.7	8.0
Maximum Dry Unit Weight, pcf		130	130	126
Seismic Modulus at OMC, ksi		462	734	861
Tex-120-E	UCS, psi	218	296	557
	Seismic Modulus, ksi	795	1108	1910
Retained Strength Ratio	Capillary Saturation	1.0	1.0	1.2
	4-hour Soak	1.4	1.2	1.0
Retained Modulus Ratio	Capillary Saturation	0.8	0.9	1.0
	4-hour Soak	1.3	1.1	0.7
Tube Suction Test	Initial Moisture Content, %	7.0	6.9	7.4
	Final Moisture Content, %	4.2	3.4	4.2
	Final Dielectric Constant	4.2	2.7	3.7
	Final Seismic Modulus, ksi	608	945	1958

Table A.2 – Sieve Analysis of In-Place Materials

Sieve Size	Percent Passing
	In Place Base
1¾ in.	100
⅞ in.	94
⅜ in.	66
No. 4	46
No. 40	20
No. 100	14
No. 200	10

Table A.3 –Constituents of In-Place Materials

Constituent	Proportion, %
	In Place Base
Gravel	54
Course Sand	26
Fine Sand	10
Fines	10

Table A.4 - Results of Triaxial Testing of In-Place Materials

a) Tex-117-E

Parameters	In Place Base
Classification	3
Angle of Internal Friction, φ	44
Cohesion, c, psi	9
Strength at Zero Lateral Pressure, psi	32
Strength at Lateral Pressure of 15 psi, psi	103
Seismic Modulus, ksi	92

b) Tex-143-E

Parameters	In Place Base
Classification	1
Angle of Internal Friction, φ	55
Cohesion, c, psi	3

Table A. 5 – Strength and Modulus Parameters of In-Place Materials

Parameter		In Place Base
Tex-120-E	UCS, psi	296
	Seismic Modulus, ksi	1108
Retained Strength Ratio	Capillary Saturation	0.97
	4-hour Soak	1.17
Retained Modulus Ratio	Capillary Saturation	0.85
	4-hour Soak	1.13
Tube Suction Test	Initial Moisture Content, %	6.9
	Final Moisture Content, %	3.4
	Final Dielectric Constant	3.0
	Final Seismic Modulus, ksi	1958

Appendix B

Comprehensive Results from I 10

Table B.1 – Properties of Cement Stabilized Materials from In-Place Materials

Cement Content, %		2
Optimum Moisture Content, %		9.9
Maximum Dry Unit Weight, pcf		124
Seismic Modulus at OMC, ksi		680
Tex-120-E	**UCS, psi**	131
	Seismic Modulus, ksi	1092
Retained Strength Ratio	**Capillary Saturation**	2.85
Retained Modulus Ratio	**Capillary Saturation**	0.66
Tube Suction Test	**Initial Moisture Content, %**	11.1
	Final Moisture Content, %	8.2
	Final Dielectric Constant	5.8
	Final Seismic Modulus, ksi	721

Table B.2 – Sieve Analysis of Materials

Sieve Size	**Percent Passing**							
	In Place Base	**Stn. 1**	**Stn. 2**	**Stn. 3**	**Stn. 4**	**Stn. 5 Pass 1**	**Stn. 5 Pass 2**	**Stn. 5 Pass 3**
1¾ in.	100	100	100	100	100	100	100	100
⅞ in.	95	97	96	97	97	96	98	98
⅜ in.	72	73	74	75	77	73	75	77
No. 4	57	57	58	60	61	59	60	62
No. 40	25	25	22	25	21	23	23	24
No. 100	13	13	10	10	10	13	12	14
No. 200	8	7	2	3	2	7	6	7

Table B.3 – Constituents of Materials

Constituent	Proportion, %							
	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5 Pass 1	Stn. 5 Pass 2	Stn. 5 Pass 3
Gravel	43	43	42	40	39	41	40	38
Course Sand	33	32	36	36	40	35	37	38
Fine Sand	17	18	20	22	19	17	17	16
Fines	8	7	2	3	2	7	6	7

Table B.4 - Results of Triaxial Testing of Materials before Stabilization

Parameters	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5 Pass 1	Stn. 5 Pass 2	Stn. 5 Pass 3
Classification	3.0	3.2	3.1	2.6	2.6	3.0	2.8	2.5
Angle of Internal Friction, φ	47	47	49	50	48	49	49	47
Cohesion, c, psi	9	6	6	8	9	6	7	9
Strength at Zero Lateral Pressure, psi	42	32	32	37	40	35	38	44
Strength at Lateral Pressure of 15 psi, psi	144	133	139	144	138	141	148	138
Seismic Modulus, ksi	17	20	22	17	18	12	13	15

Table B.5 – Strength and Modulus Parameters of Materials

Parameter		In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5 Pass 1	Stn. 5 Pass 2	Stn. 5 Pass 3
Tex-120-E	**UCS, psi**	131	217	218	272	272	245	241	298
	Seismic Modulus, ksi	1092	958	1158	1153	1178	1056	1161	1218
Retained Strength Ratio	**Capillary Saturation**	2.9	1.5	1.4	1.1	1.3	1.2	1.2	1.4
Retained Modulus Ratio	**Capillary Saturation**	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.8
Tube Suction Test	**Initial Moisture Content, %**	11.1	10.3	10.7	9.7	10.0	9.5	10.4	11.0
	Final Moisture Content, %	8.2	7.1	8.1	7.1	7.2	7.1	8.0	8.4
	Final Dielectric Constant	5.8	16.3	16.9	17.7	16.4	15.6	16.4	13.4
	Final Seismic Modulus, ksi	721	680	757	703	761	679	667	921

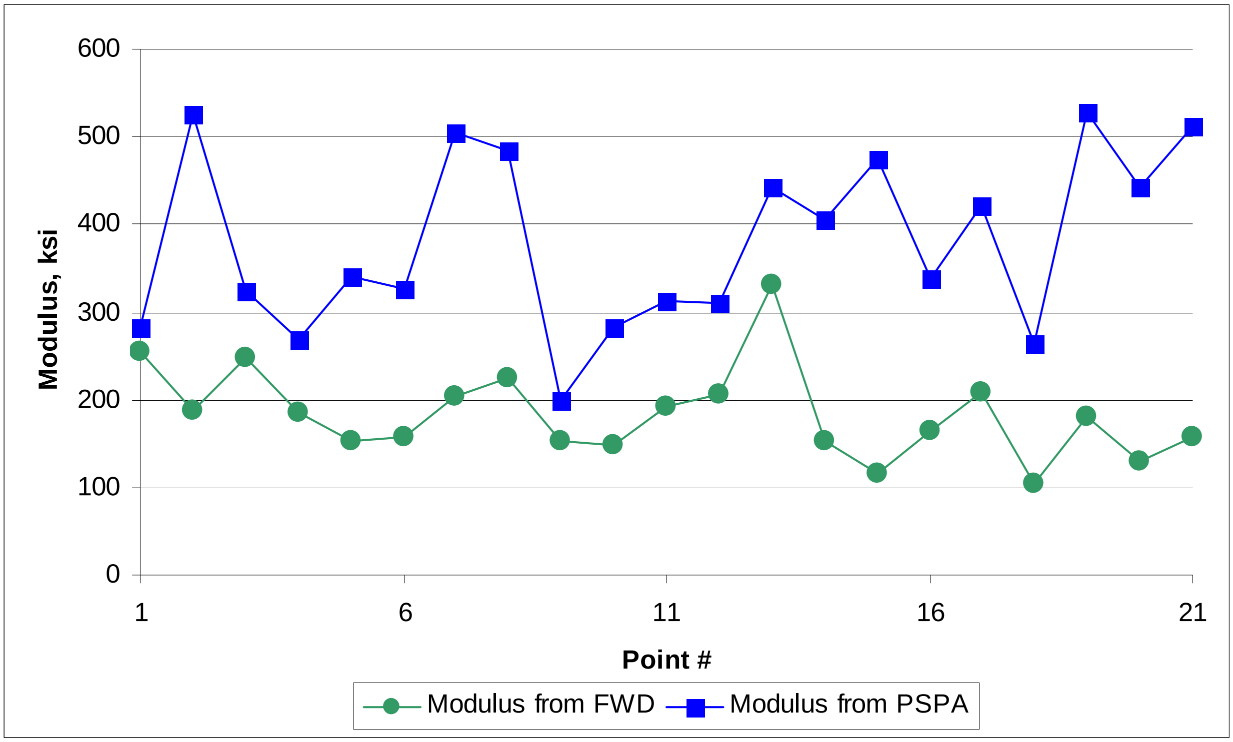

Figure B 1 - Variations in Base Moduli along Project

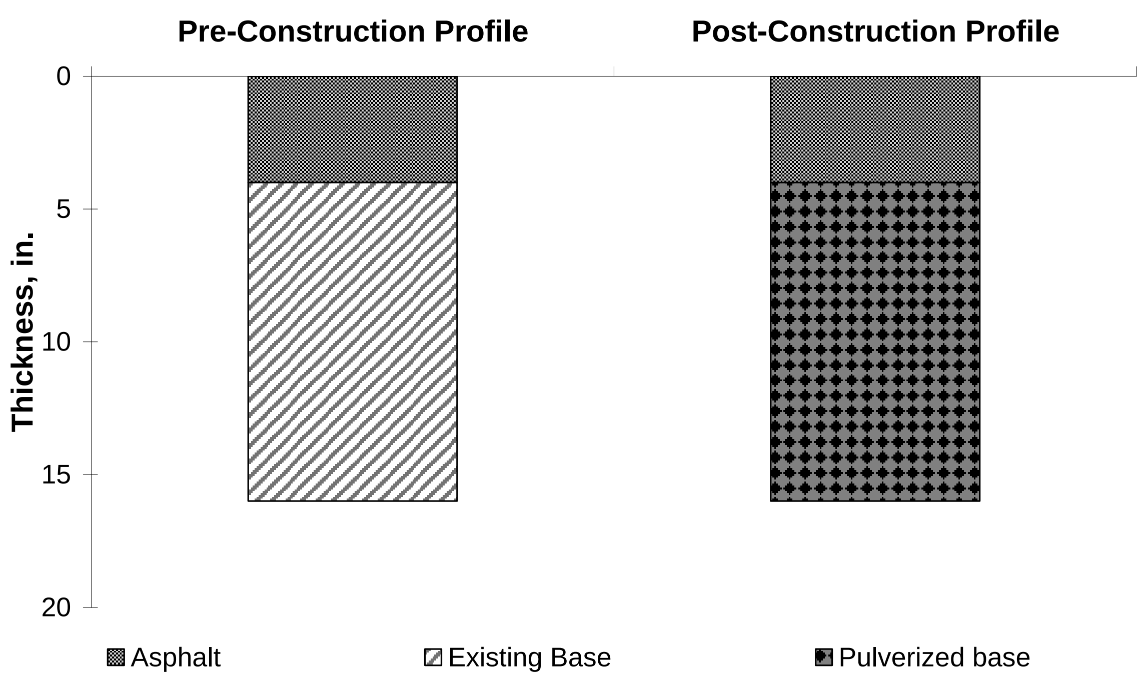

Figure B.2 – Pavement Cross-section Before and After Pulverization

Table B.6 – Layer Thicknesses Required for Equivalent Performance when Laboratory Moduli Used in Comparison to Field Results

Laboratory Moduli	HMA Thickness (in.) when Base Thickness Maintained Constant at 12 in.		Base Thickness (in.) when HMA Thickness Maintained Constant at 4 in.	
	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus
Original Design	4		12	
At OMC	8	10.5	17	20
7-Day Cured Moduli	12	14	21	25
Capillary Saturated Moduli	8.5	10.5	17	21
24 hr TST	8.5	11	18	21

Appendix C

Comprehensive Results from FM 1939

Table C.1 – Properties of Fly Ash Stabilized Materials from In-Place Materials

Fly-Ash Content, %		5	7	9
Optimum Moisture Content, %		11.0	10.0	10.8
Maximum Dry Unit Weight, pcf		122	122	122
Seismic Modulus at OMC, ksi		110	118	149
Tex-127-E	UCS, psi	31	46	33
	Seismic Modulus, ksi	133	139	132
Tex-127-E Modified	UCS, psi	38	40	38
	Seismic Modulus, ksi	108	114	100
Retained Strength Ratio	Capillary Saturation	0.91	1.81	0.99
	Tex-127-Modified	0.82	1.16	0.86
Retained Modulus Ratio	Capillary Saturation	1.67	3.16	3.25
	Tex-127-Modified	1.23	1.22	1.32
Tube Suction Test	Initial Moisture Content, %	12.5	11.5	12.4
	Final Moisture Content, %	12.0	11.5	12.0
	Final Dielectric Constant	15	14	15
	Final Seismic Modulus, ksi	179	360	325

Table C.2 – Sieve Analysis of Materials

Sieve Size	Percent Passing					
	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
1¾ in.	100	100	100	100	100	100
⅞ in.	94	96	96	95	95	95
⅜ in.	67	84	86	82	80	82
No. 4	50	76	77	71	67	72
No. 40	27	57	58	48	42	49
No. 100	11	19	21	15	15	18
No. 200	3	4	5	3	3	4

Table C.3 – Constituents of Materials

Constituent	Proportion, %					
	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Gravel	26	24	23	29	33	28
Course Sand	23	18	19	24	26	22
Fine Sand	47	53	54	45	39	46
Fines	3	4	5	3	3	4

Table C.4 - Results of Triaxial Testing of Materials before Stabilization

a) Tex-117-E

Parameters	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Classification	3.3	3.2	3.2	3.4	3.4	3.3
Angle of Internal Friction, φ	48	45	41	39	36	37
Cohesion, c, psi	5	6	8	7	8	9
Strength at Zero Lateral Pressure, psi	25	22	31	27	33	34
Strength at Lateral Pressure of 15 psi, psi	131	111	104	92	91	94
Seismic Modulus, ksi	56	58	35	35	59	51

b) Tex-143-E

Parameters	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Classification	2.4	2.3	2.2	4.2	4	2.7
Angle of Internal Friction, φ	48	49	49	33	35	44
Cohesion, c, psi	8	3	4	12	10	7

Table C.5 – Strength and Modulus Parameters of Materials

Parameter		In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Tex-127	UCS, psi	46	53	35	38	38	34
	Seismic Modulus, ksi	139	209	185	204	185	172
Tex-127 Mod	UCS, psi	40	166	198	192	170	189
	Seismic Modulus, ksi	114	334	346	372	201	362
Retained Strength Ratio	Capillary Saturation	1.81	0.24	0.33	0.34	0.36	0.3
	Tex-127	1.16	0.32	0.18	0.2	0.22	0.18
Retained Modulus Ratio	Capillary Saturation	1.16	0.79	0.63	0.73	1.38	0.68
	Tex-127	1.22	0.63	0.53	0.55	0.92	0.48
Tube Suction Test	Initial Moisture Content, %	11.5	7.0	9.2	9.0	10.3	9.1
	Final Moisture Content, %	11.5	6.0	8.7	7.5	8.8	7.6
	Final Dielectric Constant	14.2	12.3	11.1	7.9	7.5	8.1
	Final Seismic Modulus, ksi	360	264	218	273	277	246

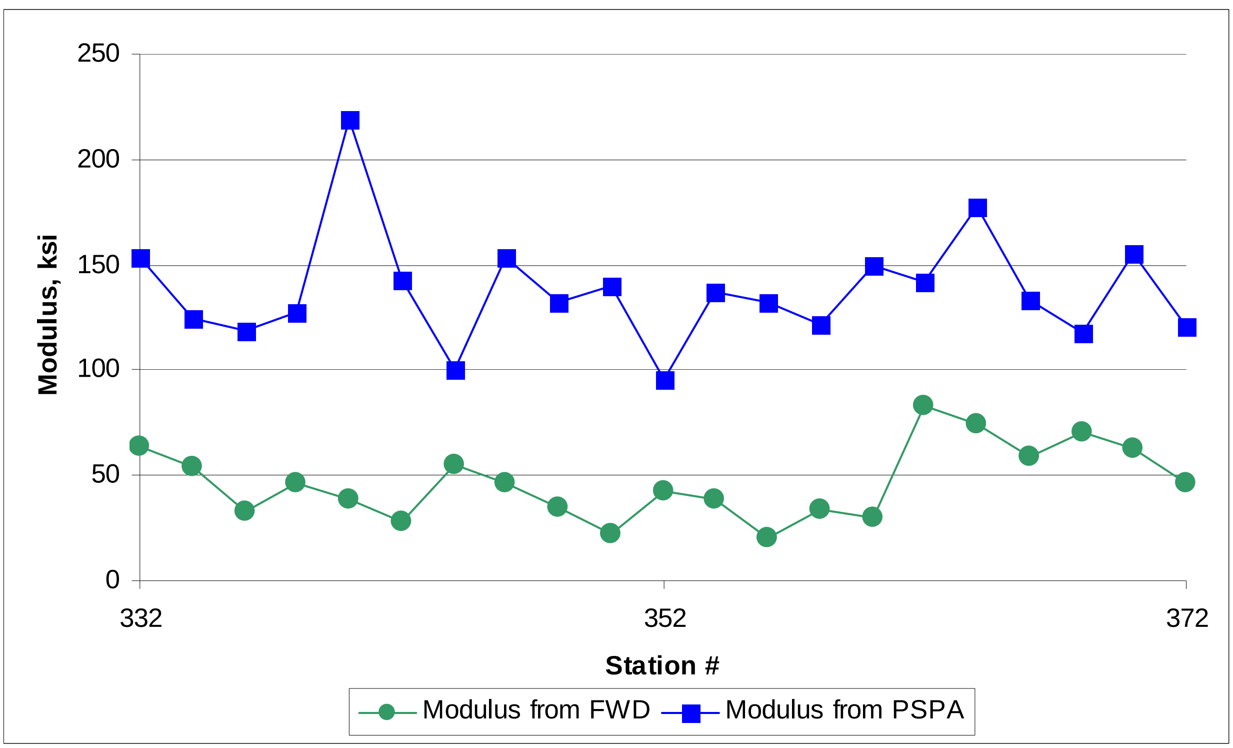

Figure C.1 – Variations in Base Moduli along Project

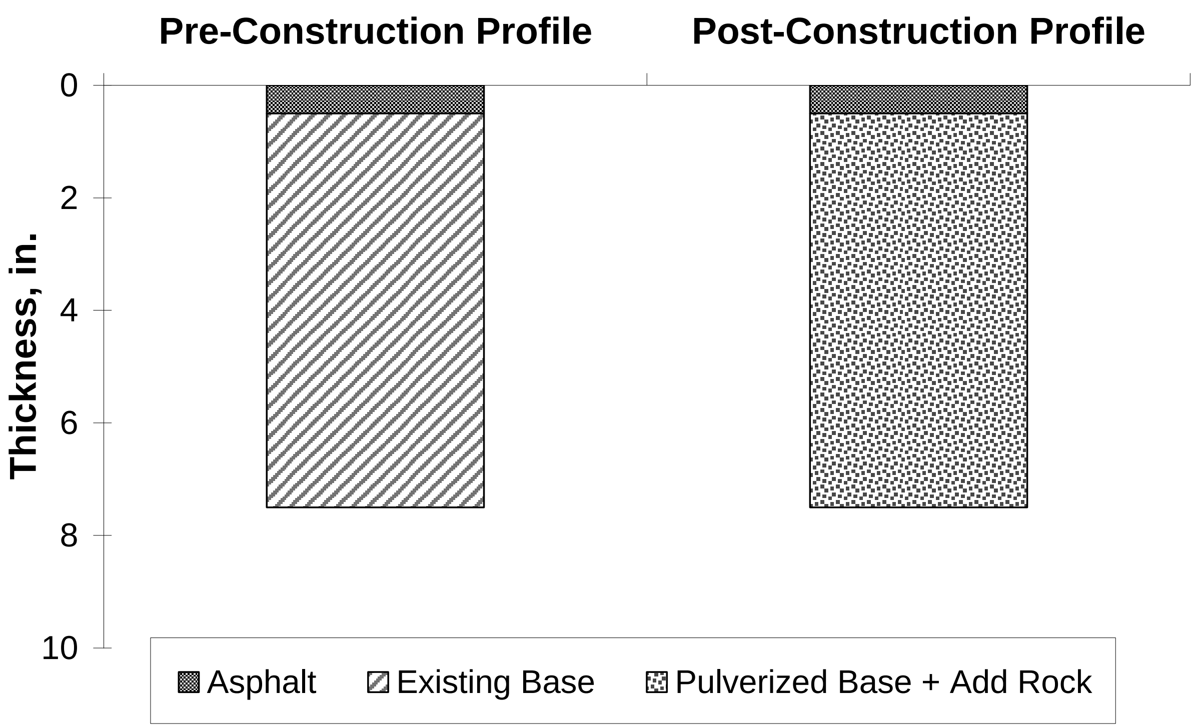

Figure C.2 – Pavement Cross-section Before and After Pulverization

Table C.6 – Layer Thicknesses Required for Equivalent Performance when Laboratory Moduli Used in Comparison to Field Results

Laboratory Moduli	HMA Thickness (in.) when Base Thickness Maintained Constant at 7 in.		Base Thickness (in.) when HMA Thickness Maintained Constant at 0.5 in.	
	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus
Original Design	0.5		7	
At OMC	0.5	2	7	10
7-Day Cured Moduli	0.5	2	7	10
Capillary Saturated Moduli	2.5	5	10	16
17 Day Cure	0.5	2.5	7	11
24 hr TST	1.5	4	8	14

Appendix D

Comprehensive Results from I 20

Table D.1 – Properties of Cement Stabilized Materials from In-Place Materials

Cement Content, %		1.5	3	4.5
Optimum Moisture Content, %		10.4	10.4	9.9
Maximum Dry Unit Weight, pcf		114	121	120
Seismic Modulus at OMC, ksi		237	141	211
Tex-120-E	UCS, psi	440	573	638
	Seismic Modulus, ksi	1241	1413	1568
Retained Strength Ratio	Capillary Saturation	0.79	0.87	0.9
	4-hour Soak	0.8	0.69	0.79
Retained Modulus Ratio	Capillary Saturation	0.89	0.85	0.98
	4-hour Soak	1.01	0.96	0.95
Tube Suction Test	Initial Moisture Content, %	10.4	11.9	10.9
	Final Moisture Content, %	12.0	8.8	8.3
	Final Dielectric Constant	13.5	4.2	4.0
	Final Seismic Modulus, ksi	1104	1201	1573

Table D.2 – Sieve Analysis of Materials

Sieve Size	Percent Passing							
	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4 Pass 1	Stn. 4 Pass 2	Stn. 4 Pass 3	Stn. 5
1¾ in.	100	100	100	100	100	100	100	100
⅞ in.	89	92	93	94	96	97	94	93
⅜ in.	70	76	75	78	80	79	82	79
No. 4	57	62	61	65	66	66	68	67
No. 40	32	33	33	35	37	37	38	40
No. 100	13	11	10	16	16	17	19	19
No. 200	4	2	3	4	3	2	2	2

Table D.3 – Constituents of Materials

Constituent	Proportion, %							
	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4 Pass 1	Stn. 4 Pass 2	Stn. 4 Pass 3	Stn. 5
Gravel	43	38	39	35	34	34	32	33
Course Sand	25	30	28	30	30	29	30	27
Fine Sand	28	31	30	31	33	35	36	38
Fines	4	2	3	4	3	2	2	2

Table D.4 - Results of Triaxial Testing of Materials before Stabilization

a) Tex-117-E

Parameters	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4 Pass 1	Stn. 4 Pass 2	Stn. 4 Pass 3	Stn. 5
Classification	2.9	3	3	2	3	2	3	3
Angle of Internal Friction, φ	53	52	51	56	54	52	52	50
Cohesion, c, psi	6	4	6	7	5	8	4	6
Strength at Zero Lateral Pressure, psi	34	24	26	42	42	37	28	27
Strength at Lateral Pressure of 15 psi, psi	168	126	116	176	173	164	169	131
Seismic Modulus, ksi	26	28	30	35	20	24	27	34

b) Tex-143-E

Parameters	In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4 Pass 1	Stn. 4 Pass 2	Stn. 4 Pass 3	Stn. 5
Classification	2.7	2	2	2	3	3	3	2
Angle of Internal Friction, φ	44	47	50	51	45	43	44	49
Cohesion, c, psi	19	12	8	13	11	17	18	13

Table D.5 – Strength and Modulus Parameters of Materials

Parameter		In Place Base	Stn. 1	Stn. 2	Stn. 3	Stn. 4 Pass 1	Stn. 4 Pass 2	Stn. 4 Pass 3	Stn. 5
Tex-120-E	UCS, psi	573	319	299	350	459	357	427	344
	Seismic Modulus, ksi	1413	1563	1267	1459	1306	1435	1263	1441
Retained Strength Ratio	Capillary Saturation	1.8	1.3	1.9	1.2	0.7	1.1	0.8	1.1
	4-hour Soak	1.2	1.1	1.1	1.1	0.7	1.3	1.0	1.1
Retained Modulus Ratio	Capillary Saturation	1.2	0.8	0.9	0.6	0.8	0.9	0.7	0.8
	4-hour Soak	1.2	0.5	0.6	1.0	1.1	1.0	1.0	1.1
Tube Suction Test	Initial Moisture Content, %	11.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Final Moisture Content, %	8.8	9.3	7.6	6.4	6.5	6.0	6.1	11.2
	Final Dielectric Constant	4.2	10.8	8.0	7.4	7.3	7.6	7.3	12.8
	Final Seismic Modulus, ksi	1249	51	96	152	105	165	232	27

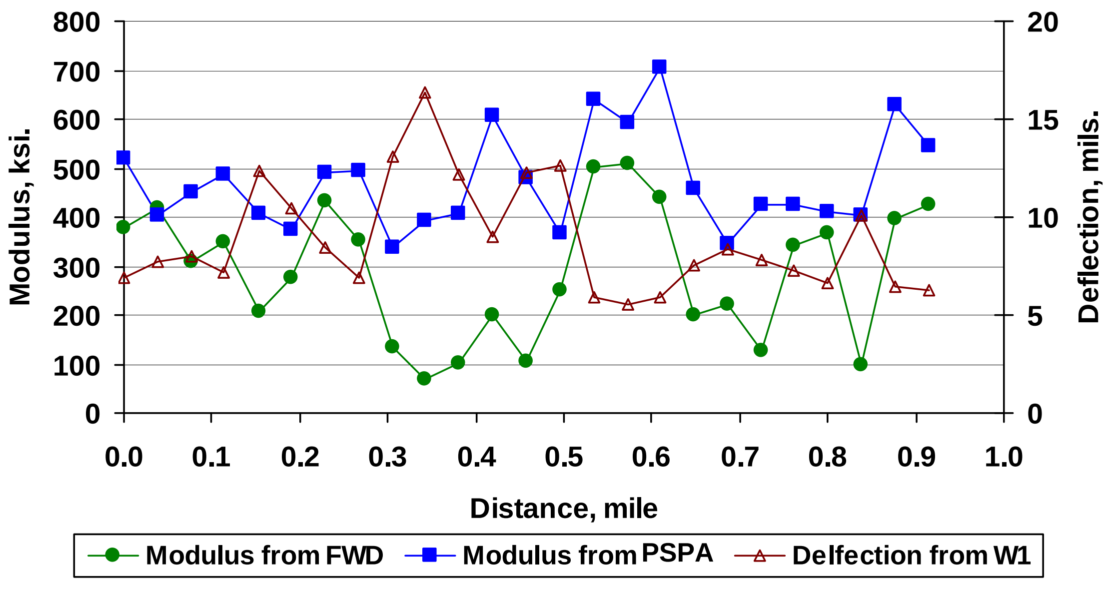

Figure D.1 – Variations in Seismic Modulus and Deflection at Odessa Site

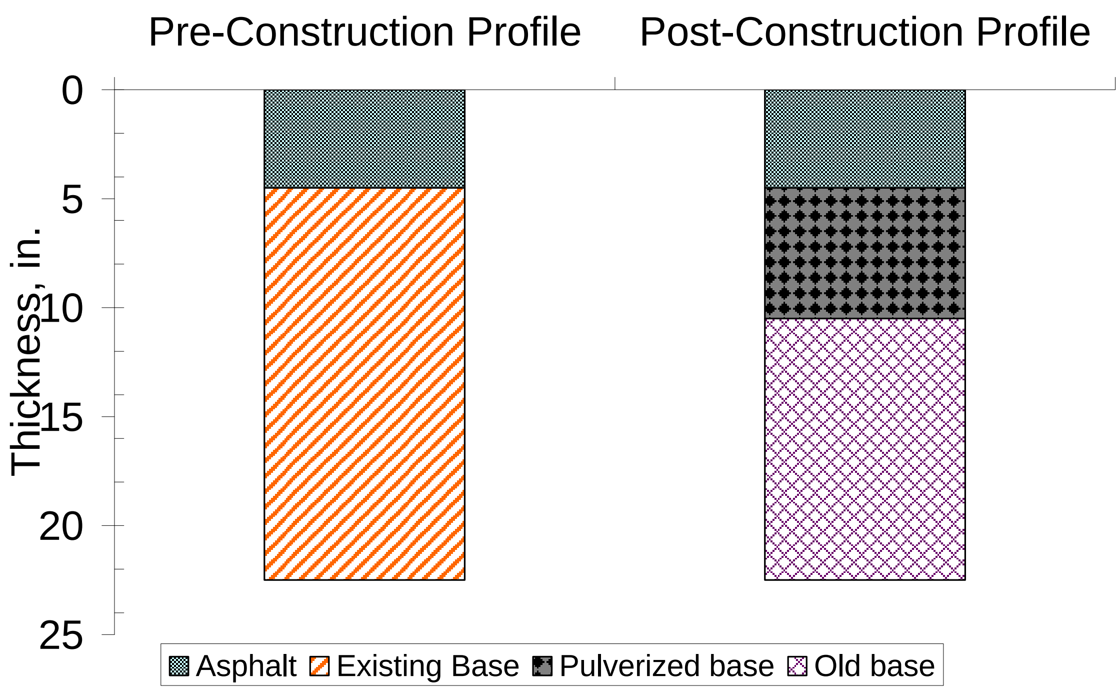

Figure D.2 – Pavement Cross-section Before and After Pulverization

TableD.6 – Layer Thicknesses Required for Equivalent Performance when Laboratory Moduli Used in Comparison to Field Results

Laboratory Moduli	HMA Thickness (in.) when Base and Sub-base Thickness Maintained Constant at 6 and 12 in.		Base Thickness (in.) when HMA and Sub-base Thickness Maintained Constant at 4.5 and 12 in.		Sub-base Thickness (in.) when HMA and Base Thickness Maintained Constant at 4.5 and 6 in.	
	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus
Original Design	4.5		6		12	
At OMC	4.5	4.5	6	6	12	12
7-Day Cured Moduli	7	7	9	9	16	16
Capillary Saturated Moduli	6.5	7	9	9	15	16
4 Hour Soak	6	6.5	8	8	14	15
24 hr TST	5.5	6	8	8	14	14

Appendix E

Comprehensive Results from FM 905

Table E.1 – Properties of Cement Stabilized Materials from In-Place Materials

Cement Content, %		1.5	3	4.5
Optimum Moisture Content, %		11.4	11.4	-
Maximum Dry Unit Weight, pcf		124	124	-
Seismic Modulus at OMC, ksi		435	788	-
Tex-120-E	UCS, psi	223	431	698
	Seismic Modulus, ksi	1318	1929	2165
Retained Strength Ratio	Capillary Saturation	0.76	0.76	0.73
	4-hour Soak	0.7	0.85	0.67
Retained Modulus Ratio	Capillary Saturation	1.05	0.92	0.91
	4-hour Soak	0.9	0.77	0.79
Tube Suction Test	Initial Moisture Content, %	10.5	11.4	11.3
	Final Moisture Content, %	8.3	9.0	8.0
	Final Dielectric Constant	4.3	5.1	3.0
	Final Seismic Modulus, ksi	1379	1775	1971

Table E.2 – Sieve Analysis of Materials

Sieve Size	Percent Passing						
	In Place Base	Stn. 521	Stn. 532 p1	Stn. 532 p2	Stn. 536	Stn. 545	Stn. 564
1¾ in.	100	100	100	100	100	100	100
⅞ in.	95	97	96	98	96	96	96
⅜ in.	61	65	65	71	66	68	71
No. 4	43	49	45	47	49	51	51
No. 40	20	25	18	18	24	25	22
No. 100	12	14	9	9	14	15	13
No. 200	6	6	5	3	6	6	6

Table E.3 – Constituents of Materials

Constituent	Proportion, %						
	In Place Base	Stn. 521	Stn. 532 p1	Stn. 532 p2	Stn. 536	Stn. 545	Stn. 564
Gravel	57	51	55	53	51	49	49
Course Sand	23	24	27	29	25	27	29
Fine Sand	15	19	13	15	18	18	16
Fines	6	6	5	3	6	6	6

Table E.4 - Results of Triaxial Testing Before Pulverization

a) Tex-117-E

Parameters	In Place Base	Stn. 521	Stn. 532 p1	Stn. 532 p2	Stn. 536	Stn. 545	Stn. 564
Classification	2.1	3.4	3.7	3.1	2.8	3	3
Angle of Internal Friction, φ	55	32	41	48	49	55	49
Cohesion, c, psi	9	9	4	6	7	4	6
Strength at Zero Lateral Pressure, psi	41	28	18	20	30	24	31
Strength at Lateral Pressure of 15 psi, psi	183	72	95	120	129	185	125
Seismic Modulus, ksi	25	38	40	39	40	38	39

b) Tex-143-E

Parameters	In Place Base	Stn. 521	Stn. 532 p1	Stn. 532 p2	Stn. 536	Stn. 545	Stn. 564
Classification	1	2.2	2.4	2.1	2.3	2.3	2.5
Angle of Internal Friction, φ	53	49	47	51	48	48	47
Cohesion, c, psi	9	8	11	7	12	12	11

Table E.5 – Strength and Modulus Parameters of Materials

Parameter		In Place Base	Stn. 521	Stn. 532 p1	Stn. 532 p2	Stn. 536	Stn. 545	Stn. 564
Tex-120-E	UCS, psi	431	389	394	308	520	359	375
	Seismic Modulus, ksi	1929	1115	1430	1368	1931	1054	1451
Retained Strength Ratio	Capillary Saturation	0.76	0.96	0.78	1.06	0.67	0.93	0.88
	4-hour Soak	0.85	0.94	0.95	1	0.99	0.84	0.72
Retained Modulus Ratio	Capillary Saturation	0.92	0.69	0.66	0.73	0.67	1.08	0.76
	4-hour Soak	0.77	1.12	0.95	0.98	0.99	1.47	0.76
Tube Suction Test	Initial Moisture Content, %	11.4	10.0	10.7	9.8	10.3	10.4	10.6
	Final Moisture Content, %	9.0	6.3	6.6	5.5	5.9	6.2	7.1
	Final Dielectric Constant	5.1	3.9	4.4	4.5	4	3.7	3.6
	Final Seismic Modulus, ksi	1775	767	949	993	1267	1140	1099

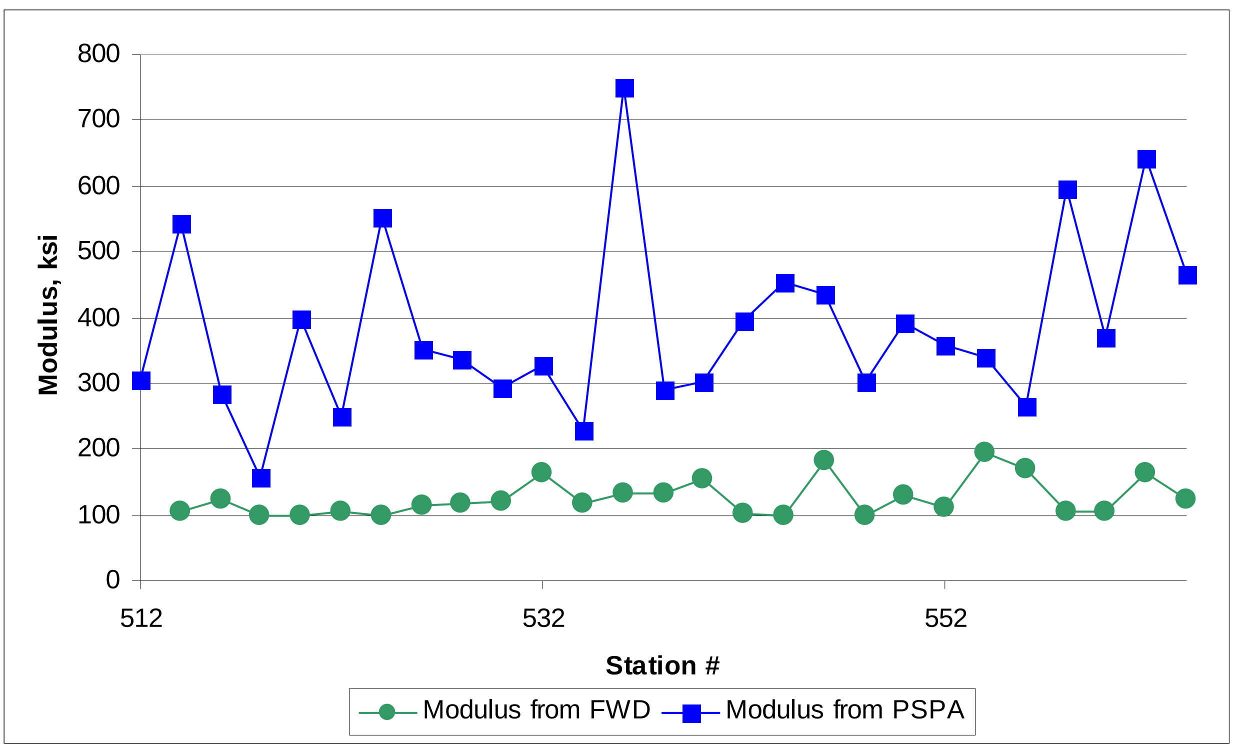

Figure E.1 – Variations in Base Moduli along Project

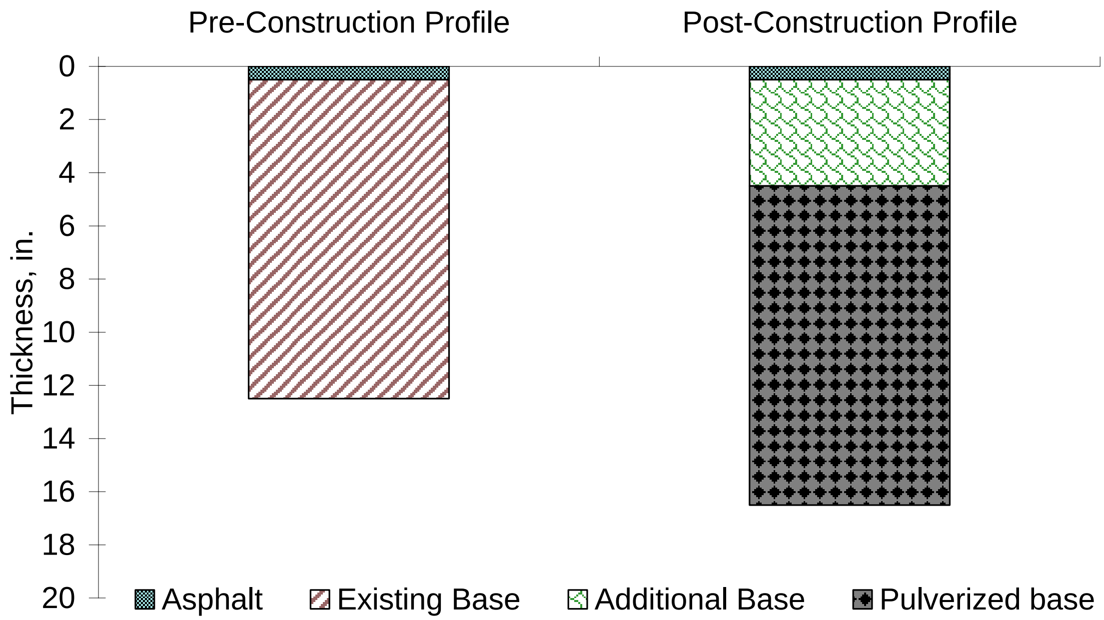

Figure E.2 – Pavement Cross-section Before and After Pulverization

Table E.6 – Layer Thicknesses Required for Equivalent Performance when Laboratory Moduli Used in Comparison to Field Results

Laboratory Moduli	HMA Thickness (in.) when Base and Sub-base Thickness Maintained Constant		Base Thickness (in.) when HMA and Sub-base Thickness Maintained Constant		Sub-base Thickness (in.) when HMA and Base Thickness Maintained Constant	
	at 4 and 12 in.		at 0.5 and 12 in.		at 0.5 and 4 in.	
	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus	PSPA Modulus	FWD Modulus
Original Design	0.5		4		12	
At OMC	5	7	11	15	17	21
7-Day Cured Moduli	10.5	12.5	20	25	25	31
Capillary Saturated Moduli	10	12	19	24	24	30
4 Hour Soak	8.5	10.5	17	22	22	27
24 hr TST	8	5	16	11	21	18

Appendix F

Modifications Made to Item 265

Draft, Not Endorsed by TxDOT

ITEM 265 (Modified)[1]

FLY ASH OR LIME—FLY ASH TREATMENT (ROAD-MIXED)

265.1. Description. Mix and compact water fly ash (FA) or lime and fly ash (LFA), and subgrade or base (with or without asphalt concrete pavement, ACP[2]) in the roadway.

265.2. Materials. Furnish uncontaminated materials of uniform quality that meet the requirements of the plans and specifications. Notify the Engineer of proposed material sources and of changes in material sources. The Engineer will verify that the specification requirements are met before the sources can be used. The Engineer may sample and test project materials at any time before compaction. Use Tex-100-E for material definitions.

A. **Lime.** Furnish lime that meets the requirements of DMS-6350, "Lime and Lime Slurry," and DMS-6330, "Lime Sources Prequalification of Hydrated Lime and Quicklime." Use hydrated lime, commercial lime slurry, or quicklime as shown on the plans. When furnishing quicklime, provide it in bulk.

B. **Fly Ash.** Furnish fly ash that meets the requirements of DMS-4615, "Fly Ash for Soil Treatment." Use Class CS or FS as shown on the plans.

C. **Flexible Base.** When required, furnish base material that meets the requirements of Item 247, "Flexible Base," for the type and grade shown on the plans, before the addition of lime or fly ash.

D. **Add Rock.** When required, furnish add rock that when proportionally added to the in place base meets the requirements of Item 247, "Flexible Base," for the type and grade shown on the plans, before the addition of lime or fly ash. Provide rock that is sufficiently hard with the Aggregate Crushing Value (ACV) and/or Aggregate Impact Value (AIV)[3] of less than 30.

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

F. **Asphalt.** When permitted for curing purposes, furnish asphalt or emulsion in accordance with Item 300, "Asphalts, Oils, and Emulsions," as shown on the plans or as directed.

Mix Design. Submit a mix design to the Engineer for approval, before the start of the project. Include the optimum moisture content, maximum dry density, percent and gradation of "add rock", percent existing material, and optimum percent additive required to meet the mixture requirements in Table 1. Prepare specimens for all tests in accordance with Tex-113-E. Perform additional mix designs based on existing material variability, as directed by the Engineer. ~~The Engineer will determine the target fly ash or limeflyash content and optimum moisture content in accordance with Tex127E or prior experience with the project materials.~~ Even though, the prior experience with the project materials can be used to select preliminary target additive content, the use of this target without proper verification is strongly discouraged. ~~The Contractor may propose a mix design developed in accordance with~~

[1] During this research, based on a statewide survey, none of the projects utilized lime or lime-fly ash. The changes recommended here is only applicable to **fly ash bases** until further research is carried out on lime and lime-fly ash projects.

[2] For the purpose of this document, the asphalt concrete pavement refers to hot mix asphalt or surface treatment.

[3] Protocols for these two tests are provided in subsequent appendices of this report. This limit can be refined when more data becomes available.

~~Tex127E. The Engineer will use Tex127E to verify the Contractor's proposed mix design before acceptance. Reimburse the Department for subsequent mix designs or partial designs necessitated by changes in the material or requests by the Contractor.~~ When treating existing materials, limit the amount of asphalt concrete pavement to no more than 50% of the mix unless otherwise shown on the plans or directed.

Table 1 - Laboratory Mixture Design Properties

Property	Curing Method/Test Method	Criteria
Unconfined Compressive Strength	Tex-127-M[4] Part 1/Tex-117-E or Tex-127-E Part II/Tex-117-E	150 psi minimum 200 psi minimum
Seismic Modulus	Tex-127-E Part II/ Proposed Tex-149[5]	Report
Retained Strength/Modulus Ratio	Proposed Tex-144[6]	0.85 minimum

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

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

B. Slurry Equipment. Use slurry tanks equipped with agitation devices to slurry hydrated lime or quicklime on the project or other approved location. The Engineer may approve other slurrying methods.

Provide a pump for agitating the slurry when the distributor truck is not equipped with an agitator. Equip the distributor truck with a sampling device in accordance with Tex-600-J, Part I, when using commercial lime slurry.

C. Pulverization Equipment. Provide pulverization equipment that:

- cuts and pulverizes material uniformly to the proper depth with cutters that will plane to a uniform surface over the entire width of the cut,
- provides a visible indication of the depth of cut at all times, and
- uniformly mixes the materials.

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

A. Preparation of Subgrade or Existing Base for Treatment. Before treating, remove existing asphalt concrete pavement in accordance with pertinent Items and the plans or as directed. Shape existing material in accordance with applicable bid items to conform to typical sections shown on the plans and as directed.

[4] Tex-127-M is a suggested modified version of Tex-127-E as enclosed in the subsequent appendix.
[5] Refers to the method for free-free resonant column tests
[6] Refers to the Tube Suction Test Method

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

When new base material or add rock is required to be mixed with existing base, deliver, place, and spread the new material in the required amount per station. Manipulate and thoroughly mix new base with existing material to provide a uniform mixture to the specified depth before the addition of lime or fly ash.

B. Pulverization. Pulverize or scarify existing material after shaping so that 100% passes a 2.5 in. sieve[7]. If the material cannot be uniformly processed to the required depth in a single pass, excavate and windrow the material to expose a secondary grade to achieve processing to plan depth.

If the hot mix asphalt layer is thicker than 4 in., or when the pulverization process yields asphalt concrete chunks that are greater than 2.5 in., the Engineer may require that the asphalt pavement layer be milled first, processed and mixed with the in place base.[8]

C. Application and Mixing of FA or LFA. When treating with LFA, apply, mix, and cure lime first unless otherwise directed.

Start treatment operations only when the air temperature is at least ~~35~~ 45°F and rising ~~or is at least 40°F~~and based on the weather forecast the chance of daily minimum temperature of less than 40°F for the following 3 days is very small[9]. The temperature will be taken in the shade and away from artificial heat. Suspend operations when the Engineer determines that weather conditions are unsuitable.

Stop the mixing operation during precipitation or when the risk of precipitation is immanent. After precipitation, the work can be resumed when the moisture content of the raw pulverized materials is at or below the desired optimum moisture content as determined from Tex-127-M.

Minimize dust and scattering by wind. Do not apply lime or fly ash when wind conditions, in the opinion of the Engineer, cause blowing lime or fly ash to become dangerous to traffic, would cause a non-uniform distribution of the additive,[10] or objectionable to adjacent property owners.

During the interval between application and mixing, sections treated with hydrated lime or fly ash that has been exposed to the open air for a period of 6 hr[11]. or more, or that experience excessive loss due to washing or blowing, will not be accepted for payment[12].

After mixing and required curing, the Engineer will sample the mixture at roadway ~~moisture~~ and test in accordance with Tex-103-E[13] to ensure that the moisture content is within ± 1% of

[7] In our opinion, this should be tightened to 1.5 in.
[8] This is especially of concern when the ACP temperature is high in the summer.
[9] The air temperature issue, especially with TyC FA is of great concern. The Lubbock District SS2041 specified 40°F and rising. Further investigation on the temperature requirement may be required.
[10] This occurred in a least one of the projects observed in this study.
[11] The industry representative as well as specifications from several states consider 6 hours to be excessive.
[12] This requires better enforcement during construction
[13] Microwave method can be used to expedite

the moisture content specified in the mix design, in accordance with Tex-101-E, Part III[14], to determine compliance with the gradation requirements in Table 2~~1~~[15], and similarity to the gradation used in the mix design to ensure that the requirements in Table 3 are met.

If the gradation requirements as per Table 3 are not met, specimens should be compacted as per Tex-113-E, cured for 24 hr and subjected to strength/modulus tests as per Tex-127-M. If the strength/modulus of the specimens is substantially lower than the mix design, remedial action should be taken, as instructed by the Engineer.

Table 2~~1~~
Gradation Requirements (Minimum % Passing)

Sieve	Base	Subgrade
1-3/4 in.[16]	~~100~~ 95	100
3/4 in.	85	85
No. 4	–	60

Table 3 – Base Gradation Requirements (Variation from Mix Design)[17]

Category	Definition	Maximum Variation
Gravel	Retained on No. 4 Sieve	5%
Coarse sand	Passing No. 4 and Retained on No. 40 Sieves	5%
Fine Sand	Passing No. 40 and Retained on No. 200 Sieves	5%
Fines	Passing No. 200 Sieve	10%[18]

1. **Application of Lime[19].** Uniformly apply lime using dry or slurry placement as shown on the plans or as directed. Add lime at the percentage determined in Section 265.2.F, “Mix Design.” Apply lime only on an area where mixing can be completed during the same working day. *Use of quicklime can be dangerous. Inform users of the recommended precautions for handling and storage.*
   a. **Dry Placement.** Before applying lime, bring the prepared roadway to approximately optimum moisture content. When necessary, sprinkle in accordance with Item 204, “Sprinkling.” Distribute the required quantity of hydrated lime or pebble-grade

[14] Since based on this study, most of the change in gradation due to pulverization is from gravel-size aggregate (retained on No. 4) to fine sands (retained on No. 200 and passing No. 40 sieves), sieves No. 40 and 200 are recommended to be added to Tex-101-E.

[15] If Table 3 is agreeable, Table 2 can be perhaps eliminated for bases except for the 1.75 in. sieve requirements.

[16] This sieve requirement conflicts with the requirements of Section 265.4.B where a 2.5 in. size is mentioned. The contractor is allowed to have aggregates as large as 2.5 in. during pulverization but quality control as per Table 2 disallows any aggregate greater than 1.75 in. The minimum passing of 1.75 sieve is relaxed to 95% to allow at least a small amount of aggregates larger than 1.75 in. Alternatively, the limit of 2.5 in. in Section 265.4 can be decreased to 1.75 in.

[17] If the gradation, especially the fine sand content, varies from those used in mix design, this research shows that the strength/stiffness may significantly vary.

[18] A higher tolerance is assigned here because in most of our case studies the fines content was small.

[19] No comments are provided on Lime because none of the projects statewide used lime in base pulverization.

quicklime with approved equipment. Only hydrated lime may be distributed by bag. Do not use a motor grader to spread hydrated lime.

b. Slurry Placement. Provide slurry free of objectionable materials, at or above the approved minimum dry solids content, and with a uniform consistency that will allow ease of handling and uniform application. Deliver commercial lime slurry to the jobsite or prepare lime slurry at the jobsite or other approved location by using hydrated lime or quicklime, as specified.

Distribute slurry uniformly by making successive passes over a measured section of roadway until the specified lime content is reached. Uniformly spread the residue from quicklime slurry over the length of the roadway being processed unless otherwise directed.

2. **Mixing of Lime.** Begin mixing within 6 hr. of lime application. Thoroughly mix the material and lime using approved equipment. Allow the mixture to mellow for 1 to 4 days as directed. When pebble-grade quicklime is used, allow the mixture to mellow for 2 to 4 days as directed. Sprinkle the treated materials during the mixing and mellowing operation, as directed, to achieve adequate hydration and proper moisture content. After mellowing, resume mixing until a homogeneous, friable mixture is obtained.

3. **Application of Fly Ash.** Uniformly apply fly ash in dry form unless otherwise approved. Apply at the percentage determined in Section 265.2.F, "Mix Design." Apply fly ash only on that area where the mixing and compacting operations can be completed during the same working day[20]. Do not use a motor grader to spread fly ash.

   For LFA treatment, begin fly ash application within 4 days after the lime mixing operation has been completed unless otherwise approved.

4. **Mixing of Fly Ash.** Thoroughly dry-mix the material and fly ash using approved equipment until a loose, homogeneous mixture is obtained. Sprinkle in accordance with Item 204, "Sprinkling," as directed, to achieve adequate mixing and hydration moisture. Prevent formation of fly ash balls.

D. Compaction. Compact immediately after mixing the last stabilizing agent. Use density control unless otherwise shown on the plans. Complete all compaction operations within 6 hr[21]. of fly ash application. Multiple lifts are permitted when shown on the plans or approved by the Engineer. Sprinkle the treated material in accordance with Item 204, "Sprinkling," or aerate to bring each layer to the moisture content directed. Determine the moisture content of the mixture ~~at the beginning and~~ during compaction in accordance with Tex-103-E to ensure that the moisture content is within ± 1% of the moisture content specified in the mix design. Tex-103-E Part III (microwave oven) can be used to expedite this activity[22].

Begin rolling longitudinally at the sides and proceed towards the center, overlapping on successive trips by at least 1/2 the width of the roller unit. On superelevated curves, begin

[20] This matter requires better enforcement.

[21] The "6 hours" is one of the major concerns regarding construction practices. Compaction within 2 hours is highly recommended within the industry, but needs to be confirmed.

[22] It is of utmost importance to enforce this item. This should be over-emphasized to the Area Engineers and Inspectors through education.

rolling at the low side and progress toward the high side. Offset alternate trips of the roller. Operate rollers at a speed between 2 to 6 MPH as directed.

Rework, recompact, and refinish material that fails to meet ~~or that loses~~ required moisture, density, stability, or finish before the next course is placed or the project is accepted. Continue work until specification requirements are met. Rework in accordance with Section 265.4.E, "Reworking a Section." Perform the work at no additional expense to the Department.

1. **Ordinary Compaction[23].** Roll with approved compaction equipment as directed. Correct irregularities, depressions, and weak spots immediately by scarifying the areas affected, adding or removing treated material as required, reshaping, and recompacting.
2. **Density Control.[24]** The Engineer will determine roadway density of completed sections in accordance with Tex-115-E[25]. The Engineer may accept the section if no more than 1 of the 5 most recent density tests is below the specified density and the failing test is no more than 3 pcf below the specified density.
   - **a. Subgrade.** Compact to at least 95% of the maximum density determined in accordance with Tex-127-E unless otherwise shown on the plans.
   - **b. Base.** Compact the bottom course to at least ~~95%~~98% of the maximum density determined in accordance with Tex-127-M~~E~~ unless otherwise shown on the plans. Compact subsequent courses treated under this Item to at least ~~98~~100% of the maximum density determined in accordance with Tex-127-M~~E~~ unless otherwise shown on the plans[26].

E. Reworking a Section. Reworking includes loosening, adding material or removing unacceptable material if necessary, mixing as directed, compacting, and finishing. The Contractor has the option of removing failing material and replacing it with acceptable material.

Add lime and fly ash when reworking LFA-treated sections, or fly ash when reworking FA-treated sections, at the rate of at least 25%[27]. of the percentage determined in Section 265.2.F, "Mix Design," as directed. When repulverization of the failing section is not achievable, remove failing material and replace with acceptable treated material.

When density control is specified, determine a new maximum density of the reworked material in accordance with Tex-127-M~~E~~, and compact in accordance with Section 265.4.D.2, "Density Control." Compact as directed when ordinary compaction is specified.

F. Finishing[28]. Immediately after completing compaction of the final course, clip, skin, or tight-blade the surface with a maintainer or subgrade trimmer to a depth of approximately 1/4 in. Remove loosened material and dispose of it at an approved location. Seal the clipped surface immediately by rolling with a pneumatic tire roller until a smooth surface is attained. When

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[23] Ordinary Compaction for bases should be more strongly discouraged.
[24] The use of alternate methods to NDG should be considered.
[25] The need to calibrate the NDG to the mix should be strongly conveyed to the Area Engineers and Inspectors.
[26] As shown in this research, the MD curve of stabilized material varies very little with moisture. It may be advisable to improve the density requirements.
[27] Even though outside the scope of this project, means of adjusting the additives if the section fails is desirable.
[28] The roller requirements may need better enforcement

finishing treated base, use a steel wheel roller before rolling with the pneumatic tire roller. Add small increments of water[29] as needed during rolling. Shape and maintain the course and surface in conformity with the typical sections, lines, and grades. Complete finishing operations within 2 hr. after final compaction.

Finished grade tolerances for subgrade will be in accordance with Section 132.3.F.1, "Grade Tolerances." Finished grade tolerances for base will be in accordance with Section 247.4.D, "Finishing."

G. Curing. Cure by maintaining in a thorough and continuously moist condition by sprinkling in accordance with Item 204, "Sprinkling." When permitted, cure with an asphalt material applied at a rate of 0.05 to 0.20 gal per square yard as approved. Do not allow equipment on the finished course during curing except as required for sprinkling, unless otherwise approved.

1. **LFA-Treated Sections.** Cure the finished section for 7 days before adding another course or opening to traffic unless otherwise directed. Apply subsequent courses within 14 calendar days of completion of final compaction of the underlying treated course unless otherwise approved.
2. **FA-Treated Sections.** Cure the finished section for 24 hr provided 50% of the design strength/modulus is achieved before opening to traffic unless otherwise directed. Curing may be accomplished by placing material to be used in the subsequent course instead of moist-curing. Allow the treated course to dry for at least 48 hr before applying a prime coat.

265.5. Quality Control. The Contractor is responsible for quality control (QC) of the process and the completed base. The Engineer will provide sampling frequencies.

A. Moisture Content. Use Tex-103-E to check moisture content shortly before the addition of additives. If rain has occurred after testing and before the addition of additives, recheck the moisture content. Adjust by moisture addition (water truck) or aeration if the average moisture content is not within 1% of the mix design recommendation. Recheck the moisture content if manipulation has occurred.

B. Additive Content. Apply the amount of additive recommended in the mix design. The Engineer must approve changes in the additive content or supplier[30].

C. Gradation. Obtain samples to the full depth of reclamation before rolling. Check the gradation in accordance to Tex-103-E[31] to ensure that the criteria in Tables 2 and 3 are met.

265.6. Measurement.

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

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[29] Area Engineers and Inspectors should be made aware of discouraging "slush rolling", instead of adding a small amount of water indicated in this item.

[30] A rapid way of estimating the additive content should be researched and added here.

[31] Microwave method can be used to expedite

When lime is furnished in bags, each bag must indicate the manufacturer's certified weight. Bags varying more than 5% from that weight may be rejected. The average weight of bags in any shipment, as determined by weighing 10 bags taken at random, must be at least the manufacturer's certified weight.

1. **Hydrated Lime.**
   a. **Dry.** Lime will be measured by the ton (dry weight).
   b. **Slurry.** Lime will be measured by the ton (dry weight) of the hydrated lime used to prepare the lime slurry at the jobsite.
2. **Commercial Lime Slurry.** Lime slurry will be measured by the ton (dry weight) as calculated from the minimum percent dry solids content of the slurry, multiplied by the weight of the slurry in tons delivered.
3. **Quicklime.**
   a. **Dry.** Lime will be measured by the ton (dry weight).
   b. **Slurry.** Lime slurry will be measured by the ton (dry weight) of the quicklime used to prepare the slurry, multiplied by a conversion factor of 1.28 to give the quantity of equivalent hydrated lime, which will be the basis of payment.

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

When fly ash is furnished in bags, each bag must indicate the manufacturer's certified weight. Bags varying more than 5% from that weight may be rejected. The average weight of bags in any shipment, as determined by weighing 10 bags taken at random, must be at least the manufacturer's certified weight.

C. **FA and LFA Treatment.** FA and LFA treatment will be measured by the square yard of surface area. The dimensions for determining the surface area are established by the widths shown on the plans and the lengths measured at placement.

265.7. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid in accordance with Section 265.6.A, "Lime"; Section265.6.B, "Fly Ash"; or Section 265.6.C, "FA and LFA Treatment."

Furnishing and delivering new base will be paid for in accordance with Section 247.6.B, "Flexible Base (Roadway Delivery)." Mixing, spreading, blading, shaping, compacting, and finishing new or existing base material will be paid for under Section 265.6.C, "FA and LFA Treatment." Removal and disposal of existing asphalt concrete pavement will be paid for in accordance with pertinent Items or Article 4.2, "Changes in the Work."

Asphalt used solely for curing will not be paid for directly, but will be subsidiary to this Item. Asphalt placed for curing and priming will be paid for under Item 310, "Prime Coat."

Lime and fly ash used for reworking a section in accordance with Section 265.4.E, "Reworking a Section," will not be paid for directly but will be subsidiary to this Item.

Sprinkling and rolling, except proof rolling, will not be paid for directly but will be subsidiary to this Item unless otherwise shown on the plans. When proof rolling is shown on the plans or directed by the Engineer, it will be paid for in accordance with Item 216, "Proof Rolling."

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

A. Lime. Lime will be paid for at the unit price bid for "Lime" of the specified type (Hydrated (Dry), Hydrated (Slurry), Commercial Lime Slurry, Quicklime (Dry), Quicklime (Slurry)). This price is full compensation for furnishing lime.

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

C. FA and LFA Treatment. FA and LFA treatment will be paid for at the unit price bid for "LFA Treated Subgrade," "FA Treated Subgrade," "LFA Treatment for Base Courses (Existing Base)," "FA Treatment for Base Courses (Existing Base)," "LFA Treatment for Base Courses (New Base)," "FA Treatment for Base Courses (New Base)," "LFA Treatment for Base Courses (New and Existing Base)," and "FA Treatment for Base Courses (New and Existing Base)," for the depth specified. No payment will be made for thickness or width exceeding that shown on the plans. This price is full compensation for shaping existing material, loosening, mixing, pulverizing, spreading, applying lime and fly ash, compacting, finishing, curing including curing materials, water, drying, blading, shaping and maintaining, replacing, disposing of loosened materials, processing, hauling, reworking if required, preparing secondary subgrade, equipment, labor, tools, and incidentals.

Appendix G

Modifications Made to Item 275

ITEM 275 (Modified)
CEMENT TREATMENT (ROAD-MIXED)[1]

275.1. Description. Mix and compact cement, water and subgrade or base (with or without asphalt concrete pavement, ACP[2]) in the roadway.

275.2. Materials. Furnish uncontaminated materials of uniform quality that meet the requirements of the plans and specifications. Notify the Engineer of the proposed material sources and of changes to material sources. The Engineer will verify that the specification requirements are met before the sources can be used. The Engineer may sample and test project materials at any time before compaction. Use Tex-100-E for material definitions.

A. Cement. Furnish hydraulic cement that meets the requirements of DMS-4600, "Hydraulic Cement," and the Department's Hydraulic Cement Quality Monitoring Program (HCQMP). Sources not on the HCQMP will require testing and approval before use.

B. Flexible Base. When required, furnish base material that meets the requirements of Item 247, "Flexible Base," for the type and grade shown on the plans, before the addition of cement.

C. Add Rock. When required, furnish add rock that when proportionally added to the in place base and meets the requirements of Item 247, "Flexible Base," for the type and grade shown on the plans, before the addition of cement. Provide rock that is sufficiently hard with the Aggregate Crushing Value (ACV) and/or Aggregate Impact Value (AIV)[3] of less than 30.

D. Water. Furnish water free of industrial wastes and other objectionable ~~material~~matter.

E. Asphalt. When permitted for curing purposes, furnish asphalt or emulsion ~~that meets the requirements of Item~~ in accordance with Item 300, "Asphalts, Oils, and Emulsions," as shown on the plans or as directed.

F. Mix Design. ~~The Engineer will determine the target cement content and~~ . Submit a mix design to the Engineer for approval, before the start of the project. Include the optimum moisture content ~~to produce a stabilized~~ , maximum dry density, percent and gradation of "add rock", percent existing material, and optimum percent additive required to meet the mixture ~~that meets the strength~~ requirements ~~shown on the plans. The mix will be designed~~ in Table 1. Prepare specimens for all tests in accordance with Tex ~~-120-~~ -113-E ~~or will be~~ . Perform additional mix designs based on existing material variability, as directed by the Engineer. ~~The Engineer will determine the target fly ash or limeflyash content and optimum moisture content in accordance with Tex127E or prior experience with the project materials.~~ Even though, the prior experience with the project materials can be used to select preliminary target additive content, the use of this target without proper verification is strongly discouraged. When treating existing materials, limit the amount of asphalt

[1] The proposed changes only apply to **the base materials**
[2] For the purpose of this document, the asphalt concrete pavement refers to hot mix asphalt or surface treatment.
[3] Protocols for these two tests are provided in subsequent appendices of this report. This limit can be refined when more data becomes available.

concrete pavement to no more than 50% of the mix unless otherwise shown on the plans or directed.

Table 1 - Laboratory Mixture Design Properties

Property	**Curing Method/Test Method**	**Criteria**
Unconfined Compressive Strength	Tex-120-M[4] Part 1/Tex-117-E	300 psi
Seismic Modulus	Tex-120-E Part II/ Proposed Tex-149[5]	Report
Retained Strength/Modulus Ratio	Proposed Tex-144[6]	0.85 minimum

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

A. Cement Storage Facility. Store cement in closed, weatherproof containers**.**

B. Cement Slurry Equipment. Use slurry tanks equipped with agitation devices to slurry cement on the project or other approved location. The Engineer may approve other slurrying methods. Provide a pump for agitating the slurry when the distributor truck is not equipped with an agitator. Equip the distributor truck with an approved sampling device.

C. Pulverization Equipment. Provide pulverization equipment that:

- cuts and pulverizes material uniformly to the proper depth with cutters that will plane to a uniform surface over the entire width of the cut,
- provides a visible indication of the depth of cut at all times, and
- uniformly mixes the materials.

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

A. Preparation of Subgrade or Existing Base for Treatment. Before treating, remove existing asphalt concrete pavement in accordance with pertinent Items and the plans or as directed. Shape existing material in accordance with applicable bid items to conform to the typical sections shown on the plans and as directed.

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

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

B. Pulverization. Pulverize or scarify existing material after shaping so that 100% passes a 2-1/2 in. sieve[7]. If the material cannot be uniformly processed to the required depth in a

[4] Tex-120-M is a suggested modified version of Tex-120-E as enclosed in the subsequent appendix.
[5] Refers to the method for free-free resonant column tests
[6] Refers to the Tube Suction Test Method
[7] In our opinion, this should be tightened to 1.5 in.

single pass, excavate and windrow the material to expose a secondary grade to achieve processing to plan depth.

If the hot mix asphalt layer is thicker than 4 in., or when the pulverization process yields asphalt concrete chunks that are greater than 1.5 in., the Engineer may require that the asphalt pavement layer be milled first, processed and mixed with the in place base.[8]

C. Application of Cement. Uniformly apply cement using dry placement unless otherwise shown on the plans. Add cement at the percentage determined in Section 275.2.E, "Mix Design." Apply cement only on an area where mixing, compacting, and finishing can be completed during the same working day.

Start cement application only when the air temperature is at least ~~35~~ 45°F and rising ~~or is at least 40°F~~and based on the weather forecast the chance of daily minimum temperature of less than 40°F for the following 3 days is very small. The temperature will be taken in the shade and away from artificial heat. Suspend ~~application~~operations when the Engineer determines that weather conditions are unsuitable.

Dry Placement. Before applying cement, bring the prepared roadway to approximately optimum moisture content. When necessary, sprinkle in accordance with Item 204, "Sprinkling." Distribute the required quantity of dry cement with approved equipment. Stop the mixing operation during precipitation or when the risk of precipitation is immanent. After precipitation, the work can be resumed when the moisture content of the raw pulverized materials is at or below the desired optimum moisture content as determined from Tex-120-M.

1. Minimize dust and scattering of cement by wind. Do not apply cement when wind conditions, in the opinion of the Engineer, cause blowing cement to become dangerous to traffic, would cause a non-uniform distribution of the additive[9] or objectionable to adjacent property owners.
2. **Slurry Placement.** Mix the required quantity of cement with water, as approved. Provide slurry free of objectionable materials and with a uniform consistency that can be easily applied. Agitate the slurry continuously. Apply slurry within 2 hours of adding water and when the roadway is at a moisture content drier than optimum. Distribute slurry uniformly by making successive passes over a measured section of the roadway until the specified cement content is reached.

D. Mixing. Thoroughly mix the material and cement using approved equipment. Mix until a homogeneous mixture is obtained. Sprinkle the treated materials during the mixing operation, as directed to maintain optimum mixing moisture. Spread and shape the completed mixture in a uniform layer.

After mixing, the Engineer will sample the mixture at roadway ~~moisture~~ and test in accordance with Tex-103-E[10] to ensure that the moisture content is within ± 1% of the moisture content specified in the mix design, in accordance with Tex-101-E, Part III[11], to

[8] This is especially of concern when the ACP temperature is high in the summer.
[9] This occurred in a least on of the projects observed in this study.
[10] Microwave method can be used to expedite
[11] Since based on this study, most of the change in gradation due to pulverization is from gravel-size aggregate (retained on No. 4) to fine sands (retained on No. 200 and passing No. 40 sieves), sieves No. 40 and 200 are recommended to be added to Tex-101-E.

determine compliance with the gradation requirements in Table 2~~.~~[12], and similarity to the gradation used in the mix design to ensure that the requirements in Table 3 are met.

If the gradation requirements as per Table 3 are not met, specimens should be compacted as per Tex-113-E, cured for 24 hr and subjected to strength/modulus tests as per Tex-120-M. If the strength/modulus of the specimens is substantially lower than the mix design, remedial action should be taken, as instructed by the Engineer.

Table 2 - Gradation Requirements (Minimum % Passing)

Sieve ~~Size~~	**Base**	**Subgrade**
1-3/4 in~~.~~..[13]	~~100~~ 95	100
3/4 in.	85	85
No. 4	–	60

Table 3 – Base Gradation Requirements (Variation from Mix Design)[14]

Category	Definition	Maximum Variation
Gravel	Retained on No. 4 Sieve	5%
Coarse sand	Passing No. 4 and Retained on No. 40 Sieves	5%
Fine Sand	Passing No. 40 and Retained on No. 200 Sieves	5%
Fines	Passing No. 200 Sieve	10%[15]

Compaction. Compact the mixture in one lift using density control unless otherwise shown on the plans. Complete compaction within 2 hours after the application of cement. Sprinkle or aerate the treated material in accordance with Item 204, "Sprinkling," to adjust the moisture content during compaction ~~so that it is within 2.0 percentage points of optimum as determined by Tex-120-E.~~ Determine the moisture content of the mixture at the beginning and during compaction in accordance with Tex-103-E~~. Adjust operations as required.~~ to ensure that the moisture content is within ± 1% of the moisture content specified in the mix design. Tex-103-E Part III (microwave oven) can be used to expedite this activity[16].

Begin rolling longitudinally at the sides and proceed towards the center, overlapping on successive trips by at least one-half the width of the roller unit. On superelevated curves,

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[12] If Table 3 is agreeable, Table 2 can be perhaps eliminated for bases except for the 1.75 in. sieve requirements.

[13] This sieve requirement conflicts with the requirements of Section 275.4.B where a 2.5 in. size is mentioned. The contractor is allowed to have aggregates as large as 2.5 in. during pulverization but quality control as per Table 2 disallows any aggregate greater than 1.75 in. The minimum passing of 1.75 sieve is relaxed to 95% to allow at least a small amount of aggregates larger than 1.75 in. Alternatively, the limit of 2.5 in. in Section 275.4 can be decreased to 1.75 in.

[14] If the gradation, especially the fine sand content, varies from those used in mix design, this research shows that the strength/stiffness may significantly vary.

[15] A higher tolerance is assigned here because in most of our case studies the fines content was small.

[16] It is of utmost importance to enforce this item. This should be over-emphasized to the Area Engineers and Inspectors through education.

begin rolling at the low side and progress toward the high side. Offset alternate trips of the roller. Operate rollers at a speed between 2 and 6 MPH, as directed.

Remove areas that loses required's expense.

1. **Ordinary Compaction[17].** Roll with approved compaction equipment, as directed. Correct irregularities, depressions, and weak spots immediately by scarifying the areas affected, adding or removing treated material as required, reshaping, and recompacting.
2. **Density Control[18].** Compact to at least 985%[19] of the maximum density determined in accordance with Tex-120-M. The Engineer will determine roadway density in accordance with Test Method Tex-115-E[20] and will verify strength in accordance with Tex-120-M. Remove material that does not meet density requirements. Remove areas that lose required stability, compaction, or finish. Replace with cement-treated mixture and compact and test in accordance with density control methods.

   The Engineer may accept the section if no more than 1 of the 5 most recent density tests is below the specified density and the failing test is no more than 3 pcf below the specified density.

E. Finishing[21]. Immediately after completing compaction, clip, skin, or tight-blade the surface of the cement treated material with a maintainer or subgrade trimmer to a depth of approximately 1/4 in. Remove loosened material and dispose of it at an approved location. RollSeal the clipped surface immediately by rolling with a pneumatic-tire roller until a smooth surface is attained. Add small increments of water[22] as needed during rolling. Shape and maintain the course and surface in conformity with the typical sections, lines, and grades shown on the plans or as directed.

Finish grade of constructedFinished grade tolerances for subgrade will be in accordance with Section 132.3.F.1, "Grade Tolerances." FinishFinished grade of constructedtolerances for base will be in accordance with Section 247.4.D, "Finishing." Do not surface patch.

F. Curing. Cure for at least 3 days by maintaining in a thorough and continuously moist condition by sprinkling in accordance with Item 204, "Sprinkling," or by applying ." When permitted, cure with an asphalt material applied at thea rate of 0.05 to 0.20 gal. per square yard , or as shown on the plans or directed. Maintain the moisture content during curing at no lower than 2 percentage points below optimum. Do not allow equipment on the finished course during curing except as required for sprinkling, unless otherwise approved. Continue curing until placing another course or opening the finished section to traffic.

275.5. Quality Control. The Contractor is responsible for quality control (QC) of the process and the completed base. The Engineer will provide sampling frequencies.

A. Moisture Content. Use Tex-103-E to check moisture content shortly before the addition of additives. If rain has occurred after testing and before the addition of additives, recheck the

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[17] Ordinary Compaction for bases should be more strongly discouraged.
[18] The use of alternate methods to NDG should be considered
[19] As shown in this research, the MD curve of stabilized material varies very little with moisture. It may be advisable to improve the density requirements.
[20] The need to calibrate the NDG to the mix should be strongly conveyed to the Area Engineers and Inspectors.
[21] The roller requirements may need better enforcement
[22] Area Engineers and Inspectors should be made aware of discouraging "slush rolling", instead of adding a small amount of water indicated in this item.

moisture content. Adjust by moisture addition (water truck) or aeration if the average moisture content is not within 1% of the mix design recommendation. Recheck the moisture content if manipulation has occurred.

B. Additive Content. Apply the amount of additive recommended in the mix design. The Engineer must approve changes in the additive content or supplier[23].

C. Gradation. Obtain samples to the full depth of reclamation before rolling. Check the gradation in accordance to Tex-103-E[24] to ensure that the criteria in Tables 2 and 3 are met.

275.6. Measurement.

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

When cement is furnished in bags, indicate the manufacturer’s certified weight. Bags varying more than 5% from that weight may be rejected. The average weight of bags in any shipment, as determined by weighing 10 bags taken at random, must be at least the manufacturer’s certified weight.

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

B. Cement Treatment. Cement treatment will be measured by the square yard of surface area. The dimensions for determining the surface area are established by the widths shown on the plans and lengths measured at placement.

275.7. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid in accordance with Section 275.5.A, “Cement,” or Section 275.5.B, “Cement Treatment.”

Furnishing and delivering new base will be paid for in accordance with Item 247.6.B, “Flexible Base (Roadway Delivery).” Mixing, spreading, blading, shaping, compacting, and finishing new or existing base material will be paid for under Section 275.6.B, “Cement Treatment.” Removal and disposal of existing asphalt concrete pavement will be paid for in accordance with pertinent Items or Article 4.2, “Changes in the Work.”

Sprinkling and rolling, except proof-rolling, will not be paid for directly but will be subsidiary to this Item, unless otherwise shown on the plans. When proof-rolling is shown on the plans or directed by the Engineer, it will be paid for in accordance with Item 216, “Proof Rolling.”

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

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[23] A rapid way of estimating the additive content should be researched and added here.

[24] Microwave method can be used to expedite

Asphalt used solely for curing will not be paid for directly, but will be subsidiary to this Item. Asphalt placed for the purpose of curing and priming will be paid for under Item 310, "Prime Coat."

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

B. Cement Treatment. Cement treatment will be paid for at the unit price bid for "Cement Treatment (Existing Material)," "Cement Treatment (New Base)," or "Cement Treatment (Mixing Existing Material and New Base)," for the depth specified. No additional payment will be made for thickness or width exceeding that shown on the plans. This price is full compensation for shaping existing material, loosening, mixing, pulverizing, providing cement, spreading, applying cement, compacting, finishing, curing, curing materials, blading, shaping and maintaining shape, replacing mixture, disposing of loosened materials, processing, hauling, preparing secondary subgrade, water, equipment, labor, tools, and incidentals.

Appendix H

Modifications Made to Tex-120-E

Test Procedure for

SOIL-CEMENT TESTING

TxDOT Designation: Tex-120-M~~E~~

Effective Date: ~~August 1999~~ For Review

1. SCOPE

1.1 This method consists of two parts.

1.1.1 'Part I, Compressive Strength Test Methods (Laboratory Mixed)' determines the unconfined compressive strength of compacted soil-cement specimens after seven days curing (10 lb. hammer, 18-inch drop, 50 blows/layer using 6 x 8 in. mold).

1.1.2 'Part II, Compaction Testing of Road Mixed Material' applies to cement treated materials sampled from the roadway during construction.

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

2. APPARATUS

2.1 As outlined in test methods:

- Tex-101-E
- Tex-113-E
- Tex-117-E

2.2 *Compression testing machine*, with capacity of 267 kN (60,000 lb.), meeting requirements of ASTM D 1633.

2.3 *Triaxial screw jack press* (Tex-117-E), used when anticipated strengths are not in excess of 2758 kPa (400 psi).

3. MATERIALS

3.1 *Hydraulic (Portland) cement.*

3.2 *Tap water.*

4. PREPARING SAMPLE

4.1 Select approximately 90 kg (200 lb.) of material treat with cement according to Part II of Tex-101-E.

PART I, COMPRESSIVE STRENGTH TEST METHODS (LABORATORY MIXED)

5. PROCEDURE

5.1 Determine the optimum moisture content and maximum dry density for a soil-cement mixture containing ~~6~~3%[1] cement, using Tex-113-E. The amount of cement added is a percentage based on the dry mass of the soil.

If desired, wrap the specimens prepared for MD curves in cellophane and let stand for 24 hours on the counter top. Obtain the specimens' unconfined compressive strengths as per Tex-117-E and/or moduli as per proposed Tex-149. These values can be used to estimate whether the cement is compatible with the soil.

5.2 Recombine the sizes prepared according to Part II of Tex-101-E to make three individual samples and add the optimum moisture content, from Tex-113-E to each sample. Mix thoroughly.

5.2.1 Cover the mixture without additive to prevent loss of moisture by evaporation. Allow the wetted ~~samples~~ mixtures to stand for at least 12 hours before compaction. When the PI is less than 12, the standing time may be reduced to not less than three hours. Split or referee samples should stand the full term.

5.2.2 Prior to compaction, replace any evaporated water and thoroughly mix each specimen.

5.2.3 Add cement uniformly and mix thoroughly.

5.3 Compact the specimen in four layers using Tex-113-E compactive effort.

5.3.1 Alter the percent molding water slightly as the percent cement is increased or decreased. Do this in order to mold nearer optimum moisture without running a new M/D curve for each percentage of cement.

Note 1—A new M/D curve for each percentage of cement may be performed, if desired.

5.3.2 Use the following rule to vary the molding water:

- % molding water = % optimum moisture from M/D curve + 0.25 (% cement increase), where

[1] For bases 6% is changed to 3% since most projects require 2% to 4% cement

- % cement increase = difference in cement content between curve and other cement contents.

5.4 Using the moisture contents outlined above, mold three specimens for each cement content using ~~4~~2, ~~8~~4, and ~~10~~6% [2]cement to complete the full set.

5.4.1 After the top surface of each specimen has been leveled and the specimen measured, carefully center over porous stone and remove specimen from mold by means of small press.

5.4.2 Place a card on each specimen showing the laboratory identification number and the percent of cement.

Note 2—In calculating the actual dry density of laboratory mix soil-cement specimens, the dry mass of material is the total mass of oven dry soil in the specimen plus the mass of cement. The amount of moisture should be the mass of hygroscopic moisture in the soil plus the amount of water added based on the dry mass of the soil plus cement. Road mixed and wetted materials and soil-cement cores shall have moisture and density determined from the oven dry masses.

5.5 Store test specimens the same day they are molded, with top and bottom porous stones, in the damp room for seven days. Do not subject specimen to capillary wetting or a surcharge. A triaxial cell is not used. A pan may be placed on top of the top porous stone to protect the specimen from dripping water.

Remove test specimens from the damp room and use a cloth to remove any free water on surface of specimen. The specimens are now ready for compressive strength test as per Tex-117-E. A compression testing machine of adequate range and sensitivity shall be used.

5.6 The moduli of the specimens can be obtained nondestructively as per proposed Tex-149 just before compression tests.

5.7 If the second specimen tests within ten percent of the first, the engineer may elect to test the third specimen in indirect tension.

6. TEST REPORTS

6.1 Molding moisture to the nearest 0.1%

6.2 Dry density to the nearest 1 kg/m^3 (0.1 pcf)

6.3 Unconfined compressive strength to the nearest whole kPa (psi) for each cement content tested

[2] Reduced to fit our observation

6.4 Seismic modulus to the nearest whole MPa (ksi) for each cement content tested (if available)

6.5 Recommended cement content to the nearest 0.5 percent

Note 3—Store cement in airtight container or use fresh supply from the project, if possibe.

Note 4—When comparing laboratory strengths with roadway strength, use the H/D correction factors in Table 1 of Tex-118-E on both laboratory and roadway specimens.

PART II, COMPACTION TESTING OF ROAD MIXED MATERIAL

7. PROCEDURE

7.1 Samples for moisture/density curve should be obtained just prior to the start of compaction operations on the roadway.

7.2 Cement stabilized materials taken from the roadway during construction should be screened over a 6.3 mm (1/4 in.) sieve at field moisture content, without drying.

7.2.1 Mix each of these two sizes, plus 6.3 mm (1/4 in.) and minus 6.3 mm (1/4 in.), for uniformity and weigh.

7.2.2 Cover each size fraction to maintain field moisture.

7.3 Recombine and mold one specimen at the field moisture condition and estimated mass to produce specimen compacted using Tex-113-E compactive effort. Molding should be accomplished using the same equipment and compactive effort as in Part I.

7.3.1 Adjust mass, if necessary, and weigh out not less than two additional specimens at the field moisture content for compaction. Molding moisture can be adjusted in each specimen by adding or removing moisture uniformly as needed.

7.3.2 Compact cement stabilized material in the laboratory in approximately the same timeframe as on the road. Compaction sample of cement stabilized material from the road mix should not be prepared by oven drying.

Wrap the specimens prepared for MD curves in cellophane and let stand for 24 hours on the counter top. Obtain the specimens' unconfined compressive strengths as per Tex-117-E and/or moduli as per proposed Tex-149. These values can be used to estimate the quality of the base.

Note 5—To determine moisture-density relationship of fine-grained materials with less than 20% retained on the 6.3 mm (1/4 in.) sieve and 100% passing the 9.5 mm (3/8 in.) sieve, the engineer may elect to use a mold with approximate dimensions of 101.6 mm (4.0 in.) in diameter by 152.4 mm (6.0 in.) in height. The number of blows must be calculated when changing mold size to maintain a compactive effort of 1100 kN-m /m^3 (13.26 ft-lb/in^3).

Note 6—The contractor should be provided an initial optimum moisture based on preliminary laboratory tests.

8. TEST REPORT

8.1 Report density to nearest 1 k/m^3 (0.1 pcf).

8.2 Report moisture content to nearest 0.1 %.

8.3 Unconfined compressive strength to the nearest whole kPa (psi) for each specimen tested (if available)

8.4 Seismic modulus to the nearest whole MPa (ksi) for each specimen tested (if available)

9. GENERAL NOTES

9.1 *Testing Notes*

9.1.1 Store cement in an airtight container to ensure a fresh supply.

9.1.2 Wetted stabilized materials taken from the roadway during construction should be prepared for testing without drying back.

9.1.2.1 The desired intent is to have the capability of weighing identical samples for strength and density control specifications.

9.1.2.2 The sample may have moisture added and remixed or removed with a fan while stirring for developing compaction curves.

9.1.3 To determine the moisture-density relationship of fine-grained materials with less than 20% retained on the 6.3 mm (1/4 in.) sieve and 100% passing the 9.5 mm (3/8 in.) sieve, the engineer may elect to use a mold with approximate dimensions of 101.6 mm (4.0 in.) in diameter by 152.4 mm (6.0 in.) in height. The number of blows must be calculated when changing mold size to maintain a compactive effort of 1100 kN-m/mm^3 (13.26 ft-lb/in^3).

9.1.3.1 The district laboratory should develop design strength data for these and other conditioning procedures.

9.2 *Design Notes*

9.2.1 When water, cement, and material have been brought together during construction, the mixture should receive final mixing and compaction during that same working day.

9.2.2 Cement contents less than 2.0% are not recommended due to difficulty in obtaining distribution under construction conditions.

9.2.3 Unconfined compressive strengths of at least 210 kPa (300 psi) are suggested as adequate for FA or LFA stabilized bases.

9.2.4 Cement stabilized base courses will perform as semi-rigid pavement. The engineer should not specify this type of pavement design on a soft foundation where relatively large deflections are likely to occur.

9.2.5 Field density control should be based on testing road mixed samples according to Tex-113-E. A minimum of 95% of the maximum density should be obtained for both subgrade and 98% base course stabilized with cement.

9.2.6 A density control specification is recommended for this type of stabilization.

9.2.7 Provisions should be made in the contract to control dusting of cement.

9.2.8 It is recommended that cement base stabilization receive an asphaltic surface course from base crown to base crown to reduce erosion along the pavement edge.

9.2.9 Cement characteristics vary widely with source. The engineer should perform strength tests with the cement to be used on the project.

9.2.10 The Department will provide the contractor with an initial optimum moisture content based upon preliminary laboratory tests.

Appendix I

Modifications Made to Tex-127-E

Test Procedure for

LIME FLY-ASH OR FLY-ASH COMPRESSIVE STRENGTH TEST METHODS

TxDOT Designation: Tex-127-~~E~~M

Effective Date: ~~August 1999~~Review Copy

1. SCOPE

1.1 This method consists of three parts

1.1.1 'Part I, Compressive Strength Test Methods (Laboratory Mixed)' determines ~~This method determines~~ the unconfined compressive strength as an index of the effectiveness of lime-fly ash (LFA) or fly ash (FA) treatment in imparting desirable properties to flexible base and sub-grade materials (10 lb. hammer, 18 inch drop, 50 blows/layer using 6 x 8 in. mold).

1.1.2 Part II, 'Accelerated Compressive Strength Test Methods (Laboratory Mixed)' determines the unconfined compressive strength as an index of the effectiveness of lime-fly ash (LFA) or fly ash (FA) treatment in an accelerated manner

1.1.3 Part III, Compaction Testing of Road Mixed Material' applies to cement treated materials sampled from the roadway during construction.

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

2. APPARATUS

2.1 Apparatus outlined in test methods:

- Tex-101-E
- Tex-113-E
- Tex-117-E

2.2 *Compression testing machine*, with a capacity of 267 kN (60,000 lbs.) or equal, meeting the requirements of ASTM D 1633.

2.3 *Triaxial screw jack press*, as described in Tex-117-E, may be used when anticipated strengths are not in excess of 2757 kPa (400 psi).

3. MATERIALS

3.1 *Fresh supply of tested fly ash (FA),* meeting the specification requirements.

3.2 *Fresh supply of tested hydrated lime*, meeting the requirements of "Item 264, Lime and Lime Slurry" of the Department's *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.*

3.3 *Flexible base or soil*, to be stabilized.

3.4 *Good quality tap water*.

4. PREPARING SAMPLE

4.1 Select an adequate size representative sample of the material and prepare according to Part II' of Tex-101-E.

PART I, COMPRESSIVE STRENGTH TEST METHODS (LABORATORY MIXED)

5. PROCEDURE

5.1 Use the method described in Tex-113-E to determine the optimum moisture and maximum density for the LFA or FA treated mixtures. Each amount of lime or fly ash selected for investigation is a percentage based on the selected dry mass of the soil.

If desired, wrap the specimens prepared for MD curves in cellophane and let stand for 24 hours on the counter top. Obtain the specimens' unconfined compressive strengths as per Tex-117-E and/or moduli as per proposed Tex-149. These values can be used to estimate whether the LFA or FA is compatible with the soil.

5.1.1 Blend sufficient FA with each selected lime content to form several dry LFA ratios, if applicable.

5.1.2 Recombine the sizes prepared according to Part II of Tex-101-E to make three individual samples and add the optimum moisture content to each sample. Mix thoroughly.

5.1.3 Cover the mixture without additives to prevent loss of moisture by evaporation. Allow the wetted ~~samples~~ mixtures to stand for at least 12 hours before compaction. When the PI is less than 12, the standing time may be reduced to not less than three hours. Split or referee samples should stand the full term.

5.1.4 Prior to compaction, replace any evaporated water and thoroughly mix each specimen. Add LFA or FA uniformly and mix thoroughly.

5.2 Compact three specimens at the optimum moisture and density found by using four lifts and a compactive effort of 1100 kN-m/m^3 (13.26 ft-lb/in^3).

5.2.1 Other LFA ratios may be investigated using the optimum moisture determined for each LFA ratio.

5.2.2 These LFA treated materials should be compacted as nearly identical as possible.

5.3 Cover the test specimens with top and bottom porous stones and place in triaxial cells immediately after extruding from the forming molds.

5.3.1 Then store the specimens at room temperature for a period of seven days.

5.4 After the seven-day curing period, remove the cells and place the specimens in an oven and dry at a temperature not to exceed 60°C (140°F) for about six hours or until 1/3 to 1/2 of the molding moisture has been removed.

5.4.1 Dry all LFA/FA treated soils as given above even though a considerable amount of cracking may occur.

5.4.2 Allow the specimens to cool to room temperature before continuing the test.

5.5 Weigh, measure, and enclose the specimens in triaxial cells and subject to capillarity for ten days. Use a constant lateral pressure of 6.9 kPa (1 psi) and surcharge of 3.5 kPa (0.5 psi) for base and 6.9 kPa (1 psi) for subgrade.

5.6 Remove the specimens from the moist room and prepare for testing in unconfined compression as outlined in Tex-117-E.

5.6.1 A compression testing machine of adequate range and sensitivity will be used.

5.7 If the second specimen tests within ten percent of the first, the engineer may elect to test the third specimen in indirect tension.

5.8 The moduli of the specimens can be obtained nondestructively as per proposed Tex-149 just before compression tests.

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6. CALCULATIONS AND GRAPHS

6.1 The calculations are similar to those made for Tex-117-E.

6.2 A graph is normally prepared showing compressive strength versus percent stabilizer used.

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7. ~~REPORTING~~ TEST REPORTS

7.1 The laboratory report should include, but is not necessarily limited to:

- Soil constants
- Molding, curing, swell, strain and strength test data
- Plot strength graph if applicable

- Seismic modulus to the nearest whole MPa (ksi) for each cement content tested (if available)

PART II, ACCELERATED COMPRESSIVE STRENGTH TEST METHODS (LABORATORY MIXED)

8. PROCEDURE

8.1 Follow procedures discussed in Sections 5.1 through 5.3 of Part I.

8.2 Remove the specimens from the moist room and prepare for testing in unconfined compression as outlined in Tex-117-E.

8.2.1 A compression testing machine of adequate range and sensitivity will be used.

8.3 If the second specimen tests within ten percent of the first, the engineer may elect to test the third specimen in indirect tension.

8.4 The moduli of the specimens can be obtained nondestructively as per proposed Tex-149 just before compression tests.

9. CALCULATIONS AND GRAPHS

9.1 The calculations are similar to those made for Tex-117-E.

9.2 A graph is normally prepared showing compressive strength versus percent stabilizer used.

10. TEST REPORTS

10.1 The laboratory report should include, but is not necessarily limited to:

- Soil constants
- Molding, curing, swell, strain and strength test data
- Plot strength graph if applicable
- Seismic modulus to the nearest whole MPa (ksi) for each cement content tested (if available)

PART III, COMPACTION TESTING OF ROAD MIXED MATERIAL

11. PROCEDURE

11.1 Samples for moisture/density curve should be obtained just prior to the start of compaction operations on the roadway.

11.2 Mold one specimen at the field moisture condition and estimated mass to produce specimen compacted using Tex-113-E compactive effort. Molding should be accomplished using the same equipment and compactive effort as in Part I.

11.2.1 Adjust mass, if necessary, and weigh out not less than two additional specimens at the field moisture content for compaction. Molding moisture can be adjusted in each specimen by adding or removing moisture uniformly as needed.

11.2.2 Compact stabilized material in the laboratory in approximately the same timeframe as on the road. Compaction sample of stabilized material from the road mix should not be prepared by oven drying.

Wrap the specimens prepared in cellophane and let stand for 24 hours on the counter top. Obtain the specimens' unconfined compressive strengths as per Tex-117-E and/or moduli as per proposed Tex-149. These values can be used to estimate the quality of the base.

Note 1—To determine moisture-density relationship of fine-grained materials with less than 20% retained on the 6.3 mm (1/4 in.) sieve and 100% passing the 9.5 mm (3/8 in.) sieve, the engineer may elect to use a mold with approximate dimensions of 101.6 mm (4.0 in.) in diameter by 152.4 mm (6.0 in.) in height. The number of blows must be calculated when changing mold size to maintain a compactive effort of 1100 kN-m/m^3 (13.26 ft-lb/in^3).

Note 2—The contractor should be provided an initial optimum moisture based on preliminary laboratory tests.

12. TEST REPORT

12.1 Report density to nearest 1 k/m^3 (0.1 pcf).

12.2 Report moisture content to nearest 0.1 %.

12.3 Unconfined compressive strength to the nearest whole kPa (psi) for each specimen tested (if available)

12.4 Seismic modulus to the nearest whole MPa (ksi) for each specimen tested (if available)

13. GENERAL NOTES

13.1 Testing Notes

13.1.1 Store hydrated lime and fly ash in an airtight container to ensure a fresh supply.

13.1.2 Wetted stabilized materials taken from the roadway during construction should be prepared for testing without drying back.

13.1.2.1 The desired intent is to have the capability of weighing identical samples for strength and density control specifications.

13.1.2.2 The sample may have moisture added and remixed or removed with a fan while stirring for developing compaction curves.

13.1.3 To determine the moisture-density relationship of fine-grained materials with less than 20% retained on the 6.3 mm (1/4 in.) sieve and 100% passing the 9.5 mm (3/8 in.) sieve, the engineer may elect to use a mold with approximate dimensions of 101.6 mm (4.0 in.) in diameter by 152.4 mm (6.0 in.) in height. The number of blows must be calculated when changing mold size to maintain a compactive effort of 1100 kN-m/mm^3 (13.26 ft-lb/in^3).

13.1.3.1 The district laboratory should develop design strength data for these and other conditioning procedures.

13.2 Design Notes

13.2.1 When water, lime, FA, and material have been brought together during construction, the mixture should receive final mixing and compaction during that same working day.

13.2.2 Lime contents less than 2.0% are not recommended due to difficulty in obtaining distribution under construction conditions.

13.2.3 FA or LFA stabilized soils are not recommended at this time as final base courses in primary highways because of limited performance records.

13.2.4 Unconfined compressive strengths of at least 10003.5 kPa (150 psi) are suggested as adequate for FA or LFA stabilized subbase soils cured at room temperature and subjected to 10 days capillarity.as per Part I.

13.2.5 Unconfined compressive strengths of at least 1500 kPa (200 psi) are suggested as adequate for FA or LFA stabilized subbase soils cured as per Part II.

13.2.6 If the mix design is performed using curing of Part II, specimens at the optimum additive contents should be prepared and subjected to Part I curing for verification.

13.2.7 Unconfined compressive strengths for FA or LFA base courses should approach the strength requirements of soil cement.

13.2.8 FA/LFA stabilized base courses will perform as semi-rigid pavement. The engineer should not specify this type of pavement design on a soft foundation where relatively large deflections are likely to occur.

13.2.9 Field density control should be based on testing road mixed samples according to Tex-113-E. A minimum of 985% of the maximum density should be obtained for both subgrade and base course stabilized with FA or LFA.

13.2.10 A density control specification is recommended for this type of stabilization.

13.2.11 Provisions should be made in the contract to control dusting of FA and lime.

13.2.12 It is recommended that LFA base stabilization receive an asphaltic surface course from base crown to base crown to reduce erosion along the pavement edge.

13.2.13 FA should not be used alone to stabilize stiff clays or materials that will not be free from clods or lumps after pulverization without a stabilization additive being applied. FA has not been observed to aid pulverization.

13.2.14 FA cementing characteristics vary widely with source. The engineer should perform strength tests with the FA to be used on the project.

13.2.15 The Department will provide the contractor with an initial optimum moisture content based upon preliminary laboratory tests.

Appendix J

Aggregate Crushing Value (ACV)

Draft, Not for Distribution

Tex-1xx-E, Aggregate Crushing Value

Contents:

Draft, Not for Distribution

Section 1

Overview

The aggregate crushing value (ACV) is a method that gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. In this test an aggregate specimen is compacted in a standardized manner into a steel cylinder fitted with a freely moving plunger. The specimen is then subjected to a standard loading applied through the plunger. This action crushes the aggregate to a degree which is dependent on the crushing resistance of the material. This degree is assessed by a sieving test on the crushed aggregate and is taken as a measure of the aggregate crushing value (ACV).

The methods are applicable to aggregates passing at 1/2 in. (12.7 mm) sieve and retained on a 3/8 in. (9.5 mm) sieve.

A specimen is compacted in a standardized manner into a steel cylinder fitted.

Units of Measurement

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

Section 2

Definitions

The following terms and definitions are referenced in this test method.

Section 3
Apparatus

The following apparatus is required:

- *A steel cylinder*, open-ended, of nominal 150 mm (6 in.) internal diameter with plunger and base plate of the general form and dimensions shown in Figure 1 and given in Table 1.
- *A tamping rod*, made out of straight iron or steel bar of circular cross section, 16 ± 1 mm (0.63 ± 0.04 in) diameter and 600 ± 5 mm (23.5 ± 0.2 in) long, with both ends hemispherical.
- *A balance*, of at least 3 kg (6.6 lb) capacity, readable and accurate to 1 g (0.01 lb).
- *Square-hole perforated-plate sieves*, of sizes 12.7 mm (1/2 in.) sieve, a 9.5 mm (3/8 in.), a 4.76 mm (#4), a 0.42 mm (#40), and a 0.074 mm (#200) sieve.
- *A well-ventilated oven* thermostatically controlled at a temperature of 105 ± 5 °C (220 ± 10 °F).
- *A compression testing machine*, capable of applying any force up to 500 kN (112 kips) and which can be operated to give a uniform rate of loading so that this force is reached in 10 min. (a machine that can record the load and deformation is preferred).
- *A cylindrical metal measure*, for measuring the samples, of sufficient rigidity to retain its form under rough usage and having an internal diameter of 115 ± 1 mm (4.5 ± 0.04 in.) and an internal depth of 180 ± 1 mm (7 ± .05 in.).
- *A rubber mallet.*
- *A metal tray*, of known mass large enough to contain 3 kg (6.6 lb) of aggregate.
- *A brush*, with stiff bristles.

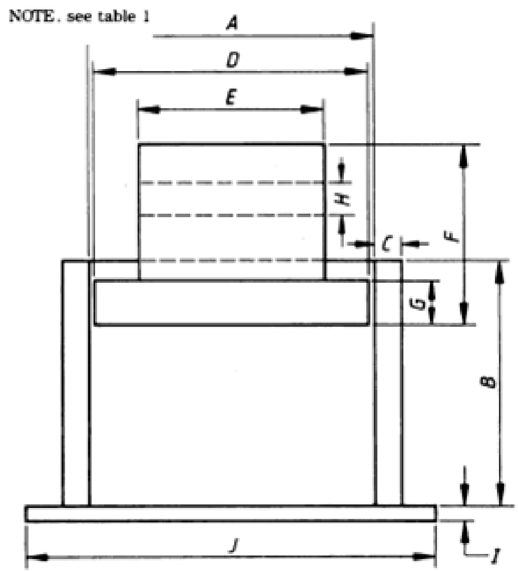


Figure 1 — Outline form of cylinder and plunger apparatus for the aggregate crushing value

Table 1 — Principal Dimensions of Cylinder and Plunger Apparatus

Component	Dimensions (see Figure 1)	Nominal 150 mm internal diameter of cylinder	
		mm	in
Cylinder	Internal diameter, *A*	154 ± 0.5	6.1 ± 0.02
	Internal depth, *B*	125 to 140	5.0 to 5.5
	Minimum wall thickness, *C*	16.0	6.3
Plunger	Diameter of piston, *D*	152 ± 0.5	5.9 ± 0.02
	Diameter of stem, *E*	< 95 to ≤ *D*	< 3.7 to ≤ *D*
	Overall length of piston plus stem, *F*	100 to 115	4.0 to 4.5
	Minimum depth of piston, *G*	not less than 25.0	not less than 1.0
	Diameter of hole, *H*	20.0 ± 0.1	0.75 ± 0.004
Base Plate	Minimum thickness, *I*	10.0	0.4
	Length of each side of square, *J*	200 to 230	8.0 to 9.0

Section 4

Preparation of Specimen

- Produce a sample of sufficient mass to acquire three specimens of 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) size fraction.
  NOTE: A single specimen is that quantity of material required to fill the cylinder
- Thoroughly sieve the entire sample on the 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) sieves to remove the oversize and undersize fractions. Divide the resulting 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) size fractions to produce three specimens each of mass such that the depth of the material in the cylinder is approximately 100 mm (4 in.) after tamping (see note 1).
  NOTE 1: The appropriate quantity of aggregate may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth. Tamp each layer 25 times, from a height of approximately 50 mm (2 in.) above the surface of the aggregate, with the rounded end of the tamping rod. Level off using the tamping rod as a straightedge.
  NOTE 2: Mechanical sieving should only be used for aggregates which do not degrade under this action.
- Dry the specimens by heating at a temperature of 105 ± 5 °C (220 ± 10 °F) for a period of not more than 4 hours. Cool to room temperature and record the mass of material comprising the specimens before testing.

Section 5

Procedure

This part explains the steps followed to perform the aggregate crushing value test.

Step	Action
1	Place the cylinder of the test apparatus in position on the base plate and add the specimen in three layers of approximately equal depth, each layer being subjected to 25 strokes from the tamping rod distributed evenly over the surface of the layer and dropping from a height approximately 50 mm (2 in.) above the surface of the aggregate. Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface. Take care to ensure that the plunger does not jam in the cylinder.
2	Place the apparatus, with the specimen prepared as described in **Section 4** and plunger in position, between the platens of the testing machine and load it at as uniform a rate as possible (see note) so that the required force of 400 kN (90 kips) is reached in 10 min ± 30 s. NOTE: When, during the early stages of the test, there is a significant deformation, it may not be possible to maintain the required loading rate and variations in the loading rate may occur especially at the beginning of the test. These variations should be kept to a minimum with the principal object of completing the test in the overall time of 10 min ± 30 s.
3	Record and save time, loading, and deformation of progress of the test.
4	Release the load and remove the crushed material by holding the cylinder over a clean tray of known mass and hammering on the outside of the cylinder with the rubber mallet until the particles are sufficiently disturbed to enable the mass of the specimen to fall freely on to the tray. NOTE: If this fails to remove the compacted aggregate other methods may be used but take care not to cause further crushing of the particles. Transfer any particles adhering to the inside of the cylinder, to the base plate and the underside of the plunger, to the tray by means of a stiff bristle brush. Weigh the tray and the aggregate and determine the mass of aggregate used ($M1$) to the nearest gram.
5	Sieve the specimen on the tray with the 4.76 mm (#4), 0.42 mm (#40), and 0.074 mm (#200) sieves until no further significant amount passes during a further period of 1 min. Weigh and record the masses of the fractions passing and retained on the sieve to the nearest gram. If the total mass of the individual fractions differs from the initial mass by more than 25 g (0.05 lb), discard the result and repeat the complete procedure using a new specimen. NOTE 1: In all of the procedures described in Steps 3 and 5 take care to avoid loss of fines and overloading the sieves. NOTE 2: Mechanical sieving should only be used for aggregates which do not degrade under its action.
5	Repeat the whole procedure described in Steps 1 to 5 with a second and third test specimen.

Section 6

Calculations

- Calculate the aggregate crushing value (ACV) expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

$$ACV = \frac{M_2}{M_1} \times 100\%$$

where

M_1 is the mass of the specimen (in g);
M_2 is the mass of the material passing the 4.76 mm (#4) sieve (in g).

- Calculate the aggregate passing the 4.76 mm (#4) and retained on the 0.42 (#40) sieve, ACV4, expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

$$ACV4 = \frac{M_3}{M_1} \times 100\%$$

where

M_3 is the mass of the material passing the 4.76 mm (#4) and retained on 0.42 mm (#40) sieve (in g).

- Calculate the aggregate passing the 0.42 mm (#40) and retained on the 0.074 (#200) sieve, ACV40, expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

$$ACV40 = \frac{M_4}{M_1} \times 100\%$$

where

M_4 is the mass of the material passing the 0.42 mm (#40) and retained on 0.074 mm (#200) sieve (in g).

- Calculate the aggregate passing the 0.074 mm (#200) sieve, ACV200, expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

$$ACV200 = \frac{M_5}{M_1} \times 100\%$$

where

M_5 is the mass of the material passing the 0.074 mm (#200) sieve (in g).

- Calculate the mean of the three results to the nearest whole number for ACV, ACV4, ACV40 and ACV200. Report the mean as the aggregate crushing value, unless the individual results differ by more than 0.1 times the mean value. In this case repeat the test on a fourth specimen, calculate the median of the four results to the nearest whole number, and report the median as the aggregate crushing value.
  NOTE: The median of four results is calculated by excluding the highest and the lowest result and calculating the mean of the two middle results.

- Quantify the behavior under loading by using the data recorded during the test (if available)
  - Plot the stress-strain curve as shown in Figure 2.
  - Fit two straight lines to the stress-strain curve as shown in Figure 2.
  - Calculate the compacting modulus by using two point on the straight line covering the initial part of the stress strain curve, using the following equation:

$$Compacting\ Modulus = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

where

σ_1 is the stress for the first point chosen (in psi)
σ_2 is the stress for the second point chosen (in psi)
ε_1 is the strain for the first point chosen (in in./in.)
ε_2 is the strain for the second point chosen (in in./in.)

  - Calculate the crushing modulus by using two point on the straight line covering the final part of the stress strain curve, using the following equation:
  -

$$Crushing\ Modulus = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}$$

where

σ_1 is the stress for the first point chosen (in psi)
σ_2 is the stress for the second point chosen (in psi)
ε_1 is the strain for the first point chosen (in in./in.)
ε_2 is the strain for the second point chosen (in in./in.)

  - Find the maximum compacting stress and strain from the stress-strain curve at the intersection of the two straight line as shown in Figure 2.

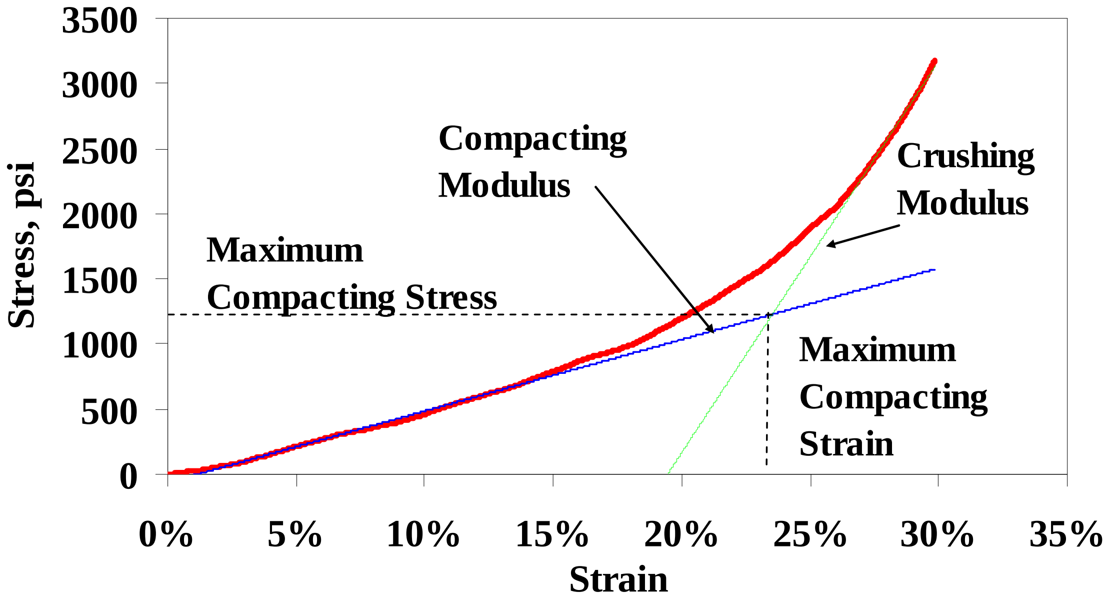


Figure 2 - Typical Results for the ACV Test

Section 7

Report

The report shall contain the following information:

- Material description of sample;
- The aggregate crushing value (ACV) of the aggregate;
- Parameters ACV4, ACV40 and ACV200
- Stress-strain curve and two lines fitted to it;
- Maximum compacting stress value;
- Maximum compacting strain value;
- Compacting modulus value;
- Crushing modulus value;

Appendix K

Aggregate Impact Value (AIV)

Draft, Not for Distribution

Tex-1xx-E, Aggregate Impact Value (AIV)

Contents:

Section 1

Overview

This specification describes methods for the determination of the aggregate impact value (AIV) which gives a relative measure of the resistance of an aggregate to sudden shock or impact.

Two procedures are described, one in which the aggregate is tested in a dry condition, and the other in a soaked condition.

The methods are applicable to aggregates passing at 12.7 mm (1/2 in.) sieve and retained on a 9.5 mm (3/8 in.) sieve.

A specimen is compacted, in a standardized manner, into an open steel cup. The specimen is then subjected to a number of standard impacts from a drop weight. This action breaks the aggregate to a degree which is dependent on the impact resistance of the material. This degree is assessed by a sieving test on the impacted specimen and is taken as the aggregate impact value (AIV).

Units of Measurement

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

Draft, Not for Distribution

Section 2

Definitions

The following terms and definitions are referenced in this test method.

Section 3

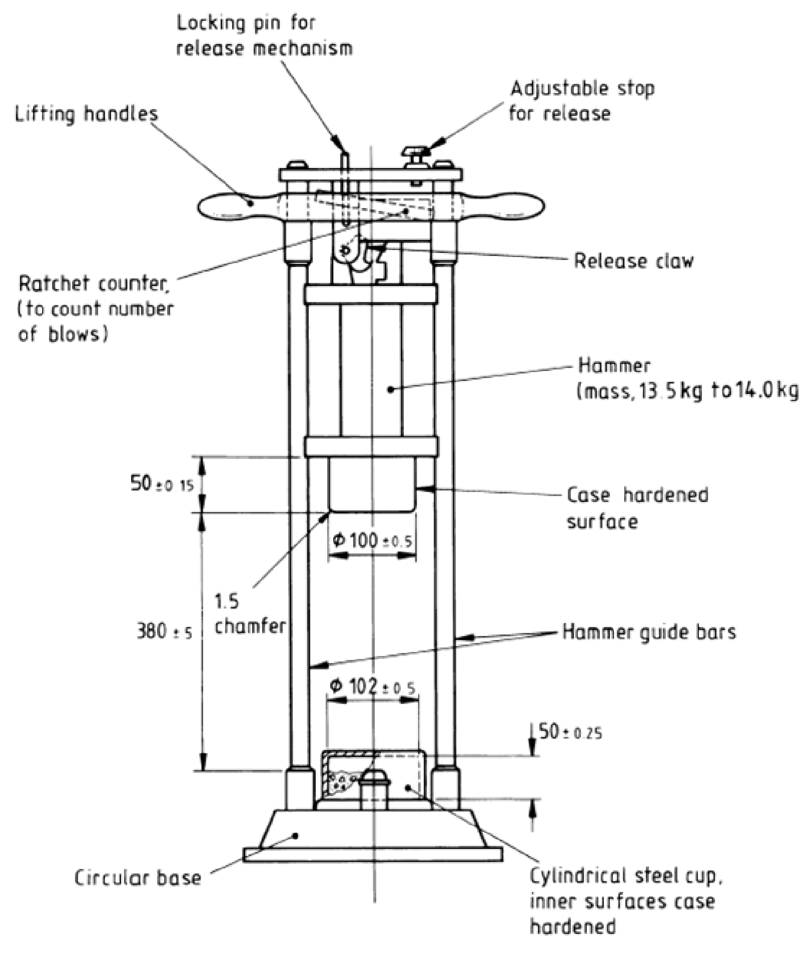
Apparatus

The following apparatus is required:

- The machine shall be of the general form shown, have a total mass of between 45 kg and 60 kg and shall comprise the parts described in **Figure 1**.
- A circular metal base, with a mass of 22.7 kg (50 lb), with a plane lower surface of not less than 200 mm (8 in.) diameter and shall be supported on a level and plane concrete or stone block floor at least 450mm (18in.) thick. The machine shall be prevented from rocking either by fixing it to the block or floor or by supporting it on a level and plane metal plate cast into the surface of the block or floor.
- A cylindrical steel cup, having an internal diameter of 102 ± 0.5mm (4.02 ± 0.02 in.) and an internal depth of 50.8 ± 0.25 mm (2 ± 0.01 in.). The walls shall be not less than 6.35 mm (0.25 in.) thick and the inner surfaces shall be case hardened. The cup shall be rigidly fastened at the centre of the base and be easily removed for emptying.
- A metal hammer, with a mass of 13.6 kg (30 lb), the lower end of which shall be cylindrical in shape, 100 ± 0.5 mm (3.94 ± 0.02 in.) diameter and 50 ± 0.25 mm (2 ± 0.01 in.) long, with a 1.5 mm (0.5 in.) chamfer at the lower edge, and case hardened. The hammer shall slide freely between vertical guides so arranged that the lower (cylindrical) part of the hammer is above and concentric with the cup.
- Means for raising the hammer, and allowing it to fall freely between the vertical guides from a height of 380 ± 5 mm (15 ± 0.2 in) on to the sample in the cup, and means for adjusting the height of fall within 5 mm (0.2 in.).
- Means for supporting the hammer, whilst fastening or removing the cup.
  NOTE: Some means for automatically recording the number of blows is desirable.
- Square-hole perforated-plate sieves, of sizes 12.7 mm (1/2 in.) sieve, a 9.5 mm (3/8 in.), a 4.76 mm (#4), a 0.42 mm (#40), and a 0.074 mm (#200) sieve.
- A tamping rod, made out of straight iron or steel bar of circular cross section, 16 ± 1 mm (0.63 ± 0.04 in) diameter and 600 ± 5 mm (23.5 ± 0.2 in) long, with both ends hemispherical.
- A balance, of capacity not less than 500 g (1 lb) readable to 0.1 g (0.01 lb).
- A well-ventilated oven, thermostatically controlled at a temperature of 105 ± 5 °C (220 ± 10 °F).
- A rubber mallet.
- A metal tray, of known mass large enough to contain 1 kg (2.2 lb) of aggregate.
- A brush, with stiff bristles.
- Additional items for testing aggregates in a soaked condition

Drying cloths or absorbent paper, for the surface-drying of the aggregate after it has been soaked in water, e.g. two hand-towels of a size not less

- than 750 mm × 450 mm (29.5 in × 17.7 in) or rolls of absorbent paper of suitable size and absorbency.
- One or more wire-mesh baskets, having apertures not larger than 6.5 mm (0.25 in) or a perforated container of convenient size with hangers for lifting purposes.
- A stout watertight container, in which the basket(s) may be immersed.
- A supply of clean water, of drinking quality.



All linear dimensions are in millimetres.

Figure 1 — Aggregate impact test machine

Section 4

Preparation of Specimen

For test specimens in a dry condition

- Produce a sample of sufficient mass to acquire three specimens of 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) size fraction.

- Thoroughly sieve the entire sample on the 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) sieves to remove the oversize and undersize fraction. Divide the resulting 12.7 mm (1/2 in.) and 9.5 mm (3/8 in.) size fractions to produce three specimens each of sufficient mass to fill the container.

- Dry the specimens by heating at a temperature of 105 ± 5 °C (220 ± 10 °F) for a period of not more than 4 h. Cool to room temperature before testing.

- Fill the cup to overflowing with the aggregate comprising the specimen by means of a scoop. Tamp the aggregate with 25 blows of the rounded end of the tamping rod, each blow being given by allowing the tamping rod to fall freely from a height of about 50 mm (2 in.) above the surface of the aggregate and the blows being evenly distributed over the surface. Remove the surplus aggregate by rolling the tamping rod across, and in contact with, the top of the container. Remove by hand any aggregate which impedes its progress and fill any obvious depressions with added aggregate. Record the net mass of aggregate in the cup and use the same mass for the subsequent specimens.

For test specimens in a soaked condition

- Prepare the sample using the procedure described for dry **condition** except that the sample is tested in the as-received condition and not oven-dried. Place each specimen in the wire basket and immerse it in the water in the container with a cover of at least 50 mm (2 in.) of water above the top of the basket. Immediately after immersion remove the entrapped air from the specimen by lifting the basket 25 mm (1 in.) above the base of the container and allowing it to drop 25 times at a rate of about once a second. Keep the basket and aggregate completely immersed during the operation and for a subsequent period of 24 ± 2 h and maintain the water temperature at 20 ± 5 °C (70 ± 4 °F).

- After soaking, remove the specimen from the basket and blot the free water from the surface with the absorbent cloths. Carry out the completion of preparation and testing immediately after this operation.

Section 5
Procedure

This part explains the steps followed to perform the aggregate impact value test.

Dry Condition	
Step	Action
1	Rest the impact machine, without wedging or packing, upon the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical. Before fixing the cup to the impact machine, place the specimen in the cup and then compact by 25 strokes of the tamping rod as discussed above. With the minimum of disturbance to the specimen, fix the cup firmly in position on the base of the machine. Adjust the height of the hammer so that its lower face is 380 ± 5 mm (15 ± 0.2 in) above the upper surface of the aggregate in the cup and then allow it to fall freely on to the aggregate. Subject the specimen to a total of 25 such blows. NOTE: No adjustment for hammer height is required after the first blow.
2	Remove the crushed aggregate by holding the cup over a clean tray and hammering on the outside with the rubber mallet until the particles are sufficiently disturbed to enable the mass of the specimen to fall freely on to the tray. NOTE 1: If this fails to remove the compacted aggregate other methods should be used but take care not to cause further crushing of the particles. Transfer fine particles adhering to the inside of the cup and the underside of the hammer to the tray by means of the stiff bristle brush. Weigh the tray and the aggregate and record the mass of aggregate used (M_1) to the nearest 0.1 g (0.01 lb).
3	Sieve the entire specimen on the tray with the 4.76 mm (#4), 0.42 mm (#40), and 0.074 mm (#200) sieves until no further significant amount passes during a further period of 1 min. Weigh and record the masses of the fractions passing and retained on the sieve to the nearest 0.1 g (0.01 lb), and if the total mass differs from the initial mass by more than 2 g (0.02 lb), discard the result and test a further specimen.
4	Repeat the procedure as described in **Steps 1** to **3** inclusive using a second specimen of the same mass as the first specimen.

Soaked Condition	
Step	Action
1	Follow the test procedure described in dry condition.
2	Remove the crushed specimen from the cup and dry it in the oven at a temperature of 105 ± 5 °C (220 ± 10 °F) either to constant mass or for a minimum period of 12 hrs. Allow the dried material to cool and weigh to the nearest gram and record the mass of the specimen (M_1). Complete the procedure as described in **Step 2 for dry condition**, starting at the stage where the specimen is sieved on the 4.76 mm (#4), 0.42 mm (#40), and 0.074 mm (#200) sieves.

Section 6

Calculations

- Calculate the aggregate impact value (AIV) expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

  $$AIV = \frac{M_2}{M_1} \times 100$$

  where

  M_1 is the mass of the specimen (in g);
  M_2 is the mass of the material passing the 4.76 mm (#4) sieve (in g).

- Calculate the aggregate passing the 4.76 mm (#4) and retained on the 0.42 (#40) sieve expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

  $$AIV4 = \frac{M_3}{M_1} \times 100\%$$

  where

  M_3 is the mass of the material passing the 4.76 mm (#4) and retained on 0.42 mm (#40) sieve (in g).

- Calculate the aggregate passing the 0.42 mm (#40) and retained on the 0.074 (#200) sieve expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

  $$AIV40 = \frac{M_4}{M_1} \times 100\%$$

  where

  M_4 is the mass of the material passing the 0.42 mm (#40) and retained on 0.074 mm (#200) sieve (in g).

- Calculate the aggregate passing the 0.074 mm (#200) sieve expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the specimen from the following equation:

  $$AIV200 = \frac{M_5}{M_1} \times 100\%$$

  where

  M_5 is the mass of the material passing the 0.074 mm (#200) sieve (in g).

- Calculate the mean of the two values from the above equations to the nearest whole number. Report the mean as the aggregate impact value, unless the individual results differ by more than 0.2 times the mean value. In this case repeat the on two further specimens, calculate the median of the four results to the nearest whole number, and report the median as the aggregate impact value.
  NOTE: The median of four results is calculated by excluding the highest and the lowest result and calculating the mean of the two middle results.

Section 7

Report

The report shall contain the following information:

- Material description of sample;
- Conditions under sample was tested, i.e. dry or soaked condition;
- Number of blows;
- The aggregate impact value (AIV) of the dry aggregate;
- The aggregate impact value (AIV) of the aggregate under soaked conditions;
- Parameters AIV4, AIV40 and AIV200

Appendix L

Tools for Evaluation of Pulverized Sections

Chapter 1 - Blending Analysis Tool Manual

Introduction

The Blending Analysis Tool was developed in Microsoft Excel in order to: 1) perform blending analysis of materials according to given gradations, volume of road construction, and combination of materials selected for blending and 2) take into account for the aggregate crushing potential of the aggregates. The blending analysis is carried out on the following materials: a) RAP from existing section, b) New RAP (additional RAP from offsite), c) Add Rock, and d) In-Place material. In situation where the gradations of all materials are known, the blended gradation is estimated and compared with the Item 247 limits. In situations where the gradation of the New RAP or Add Rock is not known the blending analysis uses a least squares routine to optimize the gradation of the new RAP and/or add rock to provide a blend gradation that meets Item 247 requirements.

In terms of aggregate crushing potential due to pulverization, the Aggregate Crushing Value (ACV) test is proposed. According to the results of the ACV test, if the material is susceptible to crushing, the gradation of that material is adjusted according to the ACV test results.

Initial Preparation

The Blending Analysis Tool is composed of several Excel worksheets and macros. In order to use the worksheet, there are few initializations that need to be carried out. First, the Excel package Solver needs to be activated (follow Microsoft Excel Help for instructions). Second, the Solver tool needs to be tested after the installation. To check this, select Solver from the tools menu. If the solver dialogue box appears, the Solver package is working properly. Proceed by closing the Solver dialogue box. Installing the Solver package needs to be performed once on the computer that this software is used. However and unfortunately, the second setup, where the Solver dialogue box needs to be opened and closed has to be performed every time you use the software.

Before proceeding with the analysis of any section, a button provided in the top left of the worksheet to initialize the sheet. This button as shown in Figure 1.1 has two functions; the first is to remind users to add Solver and the next is to clear all the values from the worksheet. If this button is not clicked the macros may not work properly.

Figure 1.1 – Initialize Sheet Button

The blending analysis tool contains five input sections: a) Project Information, b) Pavement Sections, c) Addition of RAP and Add Rock, d) Blend based on Item 247, and e) Aggregate Crushing Potential.

Section 1: Project Information

Section 1 (Project Information) is mainly for the documentation of the site. Figure 1.2 shows an example of the Project Information Section. The project information, such as Sample ID, Sample Date, Controlling CSJ, County, District, Sampled by and Sample Location should be filled.

1) Project Information

Sample ID:	**1-I10 sample 1**
Sample Date:	**11/12/1971**
Controlling CSJ:	**000-00-000**
County:	**El Paso**
District:	**El Paso**
Sampled by:	**John Doe**
Sample Location:	**LH-MM-121**

Figure 1.2 – Project Information

Section 2: Pavement Sections

In this section, the dimensions of the existing and proposed pavement sections are input. This information is used to estimate the proportions of different materials that are used in the project. Figure 1.3 shows an example of Section 2 with a typical example. The width of the existing lane, the thickness of the existing ACP layer, the base thickness of the existing section, the thickness of the base that will be pulverized, and the base thickness of the proposed section are input. If shoulder widening is anticipated in the project, the width and the base thickness of the proposed shoulder should be entered.

In addition, the representative gradation of the in-place base should be provided by depressing the button labeled "In-Place Gradation." Figure 1.4 shows the form that will appear when the button is depressed. The percent finer of the in-place base for each sieve size is input. Once the information is added, click on the "Back to main menu" button to return to the main input menu (see Figure 4). The results of Section 2 are pictorially documented on the worksheet as shown in Figures 1.5 and 1.6 and labeled as existing and proposed pavement profiles.

2) Pavement Sections

Width of the existing lane, ft	**12**
Total thickness of the existing ACP layer, in.	**1.5**
Base thickness of existing section, in.	**12**
Base thickness of existing section that will be pulverized, in.	**6**
Base thickness of proposed section, in.	**10**
Click the button to enter gradation of existing base	**In-Place Gradation**
Is shoulder widening involved in the project?	☑ **Yes** ☐ **No**
Width of proposed shoulder, ft	**4**
Base thickness of proposed shoulder, in.	**10**

Figure 1.3 – Pavement Sections Information

Please provide the in-place gradation information in the table to the right. When your are finished, please Click the back button below.

Back to main menu

In-place		Percent
Sieve	Size	Finer, %
2-1/2 in.	2.50	100
1-3/4 in.	1.75	100
7/8 in.	0.8750	95
3/8 in.	0.3750	73
#4	0.1870	57
#40	0.0169	30
#200	0.0030	4

Figure 1.4 – In-Place Base Sieve Analysis

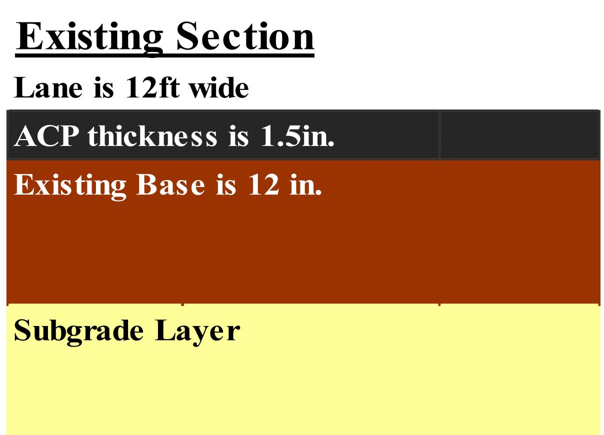


Figure 1.5 – Existing Pavement Profile

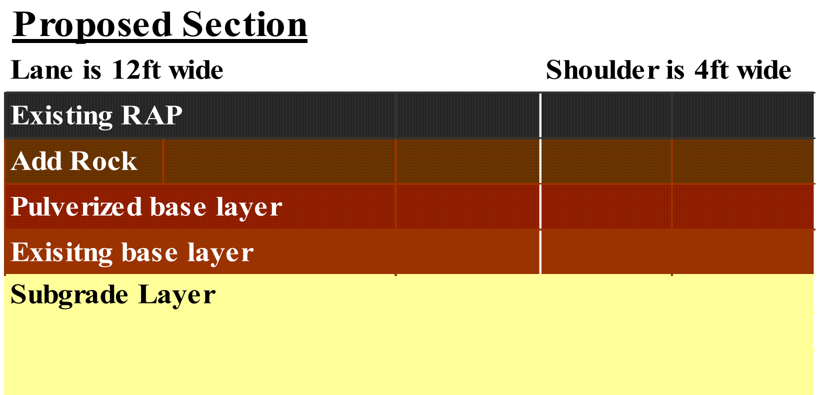


Figure 1.6 – Proposed Pavement Section

Section 3: Addition of RAP and Add Rock

The third section requests information regarding the addition of RAP, considering new RAP and/or Add Rock. The specific questions for this section are:

1. *Will existing RAP be used?*
2. *Do you consider bringing in more RAP?*
3. *Do you plan to use add rock?*
4. *Do you know the gradation of add rock?*

Figure 1.7 shows an example of Section 3. If the answer to any of the four questions above is positive, additional information from the user is needed. If the answer to any of these questions is negative, no further action is needed for that aspect of the mix proportioning. This is indicated by disabling (graying out) the gradation button related to either existing, New RAP or Add Rock.

If the existing RAP will be used in the project, its representative gradation should be provided by depressing the button labeled "RAP Gradation."

The same action is required, if additional RAP from another source will be used in this project. However, in this case the button labeled "New RAP Gradation" should be depressed.

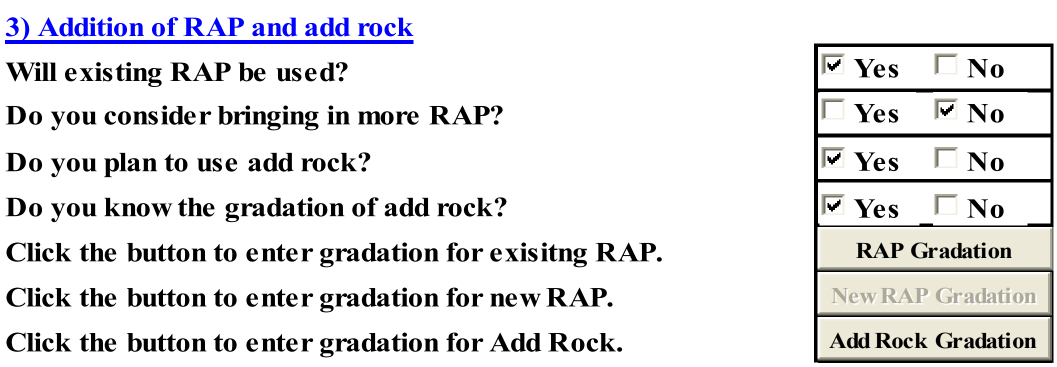


Figure 1.7 – Addition of RAP and Add Rock

If the gradation of add rock is known, it can be entered for further evaluation. Otherwise, the excel sheet will propose the optimal gradation for that material to achieve a balance blend gradation.

Note: This excel sheet only allows users to consider bringing in more RAP or add rock but not both.

Section 4: Selection of Criteria for Optimization of Blend

The next section of the input menu is referred to Item 247. This section allows the user to select the grade for Item 247 that should be followed for optimization of the base material. Figure 1.8 shows this section and the options for selection. The user can select between Grades 1 to 4. The three choices below the grade selection labeled as "Average," "Coarse" and "Fine" can be used to bias the optimized blend gradation. The "Average" option will bias the blend gradation toward the middle of the gradation band of the appropriate Item 247. This is the desirable option. In cases when the in-place base and RAP are too coarse or too fine, the user can select the other two options to bias the mix to the coarsest and finest allowable limits for the grade selected. These two options should only be used for economical reasons.

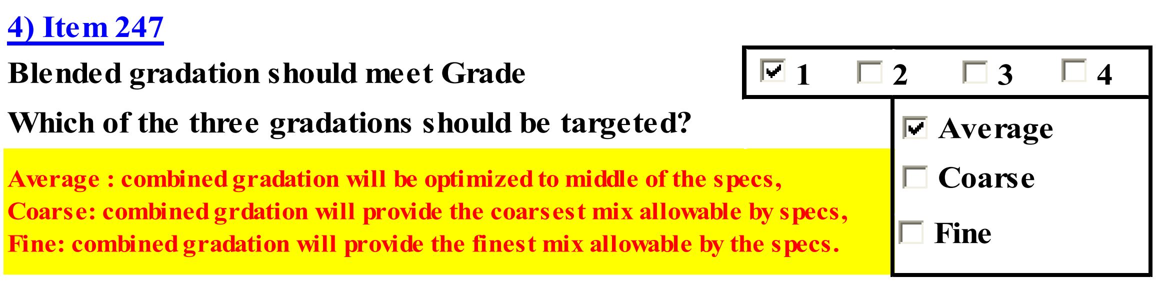


Figure 1.8 – Selection Options of Item 247

Section 5: Evaluation of Aggregate Crushing Potential due to Pulverization

In this section, which is optional, the aggregate crushing potential of the in-place base and/or add rock is assessed by the Aggregate crushing Value (ACV) test.

If the ACV test results are not available, the cells for in-place base and add rock should not be checked (see Figure 1.9). The optimization can be carried out without taking these values into consideration. If the user prefers to carry out the ACV tests, either the In-Place and or Add Rock or both check boxes are checked so that the relevant ACV test results can be input.

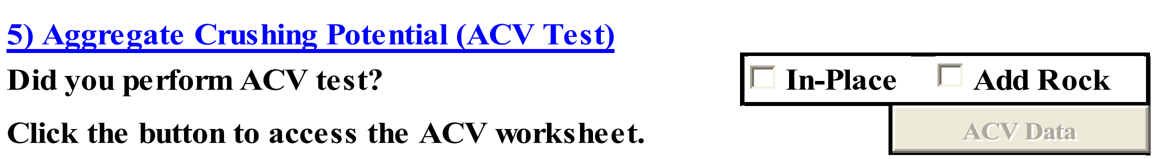


Figure 1.9 – Selecting the Option of Inputting ACV Test Results

If either one or both check boxes are checked, the user should depress the "ACV data" button shown in Figure 1.9 to provide the required information.

Figure 1.10 shows an example of the ACV table where the weight of the retained materials for each of the sieve sizes are input. Once the user provides these values, the "Back to main menu" button should be depressed to return to the main menu. Based on the results of the ACV tests, the user will be alerted of the crushing potential of the in place base and/or add rock. The indications range from a low probability of crushing to a moderate probability of crushing to crush susceptible. An example of these messages provided in the worksheet is shown in Figure 1.11.

Please provide the gradation information from the ACV test in the table to the right. When your are finished, please Click the back button below.

Back to main menu

ACV Test	Retained Weight, lb	
Sieve	In-Place*	Add Rock*
3/8	2.269	1.680
#4	1.525	1.456
#8	0.840	0.890
#40	0.866	0.500
#100	0.275	0.247
#200	0.150	0.140
pan	0.201	0.080

*- Please refer to the ACV test protocol for explana

Figure 1.10 – ACV Test Input Sheet

The ACV value for In-Place material is 24. Therfore, this is a marginal material

The ACV value for Add Rock is 19. Therfore, this material has low probability of crushing during pulverization

Figure 1.11 – ACV Crushing potential indicator

Section 6: Evaluation of Blend Gradation

Once all the information in the previous five sections has been provided, the users can carry out the blending analysis according to the selected specifications. There are two options provided for the blending analysis:

1) Determine Blend Gradation and
2) Modify Blend by Optimizing Add Rock Gradation.

These options are described below.

Determine Blend Gradation

The first option is used to provide the gradation of the blend when the gradation of the Add Rock is given by the user in *Section 3* (see Figure 1.12). The activities carried out in this section include:

- Estimates the proportions of the in-place base, RAP, New RAP and Add Rock, based on the geometrical information provided in Section 2 about the existing and proposed pavement sections, and the constituents of the mixture (i.e. existing RAP, New RAP and/or Add Rock) provided in Section 3. This information is reflected in the row labeled as "Blending Ratio."
- Summarizes the gradations of the constituents selected in Section 3. *If the ACV information is available, the gradations provided for the individual materials will be modified to consider the potential changes in gradation due to pulverization.*
- Provides the blend gradation (under the column labeled "Blending Results."
- Evaluates how the blend gradation follows the Item 247 permissible gradation band. If the gradation for any of the sieve sizes specified in Item 247 is out of range, the results are highlighted in red for emphasis.

To the right of the table, a graph is included to show the blended gradation with respect to the specification limits selected. Below the table several lines of information regarding the volume of material needed for each material is listed.

SUMMARY OF OPTIMIZATION RESULTS

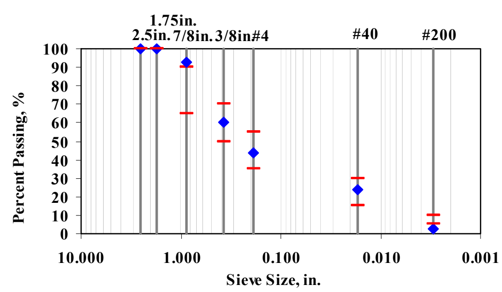
1) Determine Blend Gradation

2) Modify Blend by Optimizing Add Rock Gradation

Reset | **View Details** | **Generate Report**

Percent Finer		Original Gradation				*Blending Results*
Sieve	Size, in.	In-Place	RAP	New RAP	Add Rock	
Blending Ratio		45%	11%		44%	
2-1/2 in.	2.5000	100	100		100	100
1-3/4 in.	1.7500	100	100		100	100
7/8 in.	0.8750	95	90		91	93
3/8 in.	0.3750	73	41		52	60
#4	0.1870	57	19		37	44
#40	0.0169	30	5		23	24
#200	0.0030	4	0		2	3

Note : Cells highlighted in red are out of range based on Item 247 gradation



Based on the optimization results, the material required is as follows:
- Volume of additional RAP is 0 cubic feet (per linear foot)
- Volume of additional add rock is 5.8 cubic feet (per linear foot)

Figure 1.12 – Blending Gradation Using Option 1

Modify Blend by Optimizing Add Rock Gradation

This option can be used when the user desires to change Add Rock gradation or when the gradation of Add Rock is not known. In this option the goal is to modify the Add Rock gradation in order for the blend to meet the specified grade selections made for the Item 247 in

Section 4. Figure 1.13 shows a blended gradation using this option. The difference between Figures 1.12 and 1.13 is that all the blend gradation points in this option meet the Item 247 gradation (no red flags in the last column is shown) by proposing a new add rock gradation.

Note: An error flag with the text "Please check input" will appear, if the user does not desire to include Add Rock in the proposed pavement section and the volume of the material needed for the proposed section is more than the pulverized material volume of the existing section.

SUMMARY OF OPTIMIZATION RESULTS

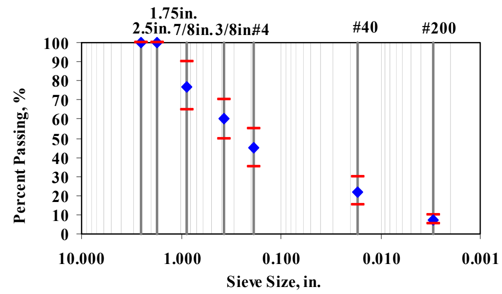
1) Determine Blend Gradation

2) Modify Blend by Optimizing Add Rock Gradation

Reset | **View Details** | **Generate Report**

Percent Finer		Original Gradation				*Blending Results*
Sieve	Size, in.	In-Place	RAP	New RAP	Add Rock	
Blending Ratio		45%	11%		44%	
2-1/2 in.	2.5000	100	100		100	100
1-3/4 in.	1.7500	100	100		100	100
7/8 in.	0.8750	95	90		56	77
3/8 in.	0.3750	73	41		52	60
#4	0.1870	57	19		39	45
#40	0.0169	30	5		19	22
#200	0.0030	4	0		13	7

Note : Cells highlighted in red are out of range based on Item 247 gradation



Based on the optimization results, the material required is as follows:

- Volume of additional RAP is 0 cubic feet (per linear foot)

- Volume of additional add rock is 5.8 cubic feet (per linear foot)

Figure 1.13 – Blending Gradation Using Option 2

In addition three additional buttons are provided: a) Reset, b) View Details, and c) Generate Report. These buttons are used respectively to a) reset the results section, b) enable users to view the detail results of the analysis, and c) generate a report. The last button is the most useful. A report sheet is generated that provides a summary.

Report

The report is generated by clicking on the "Generate Report" button discussed above. Figure 1.14 shows an example of the report summary. This report includes the project information, section profile and gradation summary.

Back

Project Information

Sample ID: 1-I10 sample 1
Sample date: 11/12/1971
Controlling CSJ: 000-00-000
County: El Paso
District: El Paso
Sampled by: John Doe
Sample location: LH-MM-121

Section Profile

Shoulder is 4ft wide

Existing RAP with volume of 1.5 ft^3

Add Rock with volume of 5.8 ft^3

Pulverized base layer with volume of 6 ft^3

Exisitng base layer with thickness of 6 in.

Subgrade Layer

Gradation Sunmmary

Percent Finer		Original Gradation				*Blending Results*
Sieve	Size, in.	In-Place	RAP	New RAP	Add Rock	
Blendig Ratio		45%	11%		44%	
2-1/2 in.	2.5000	100	100		100	100
1-3/4 in.	1.7500	100	100		100	100
7/8 in.	0.8750	98	90		84	77
3/8 in.	0.3750	90	41		78	60
#4	0.1870	67	19		53	45
#40	0.0169	33	5		23	23
#200	0.0030	5	0		13	8

Note : Cells highlighted in red are out of range based on Item 247 gradation

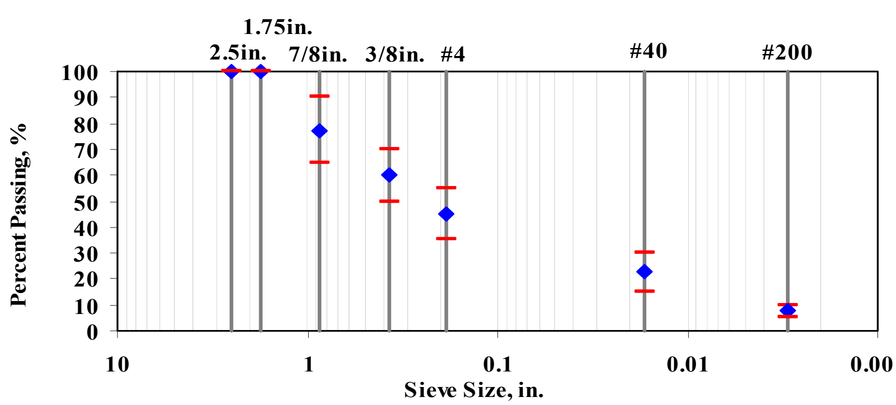


Figure 1.14 – Example of Report Sheet

Chapter 2 - Structural Analysis Tool Manual

Introduction

The Structural Analysis Tool (SAT) is used to estimate the equivalent pavement thicknesses by measuring the as-constructed modulus of the pulverized layer assuming that either a presumptive or laboratory-derived modulus was initially used to structurally design the pulverized pavement section.

Appendix A provides the background and methodology behind the Structural Analysis Tool. It should be emphasized that this tool by no means intended to replace the current pavement design methods (such as FPS19 or Texas Triaxial) used by the districts. This is a tool that can be used during the construction to evaluate the implication of the as-constructed modulus achieved on the integrity of the pavement section.

This chapter provides step-by-step instructions for using this tool. An example is provided to illustrate the results.

Initial Preparation

The first step is to install the program. The program installation is similar to a typical windows installation process. Once the program has been installed launch the program from the Start/Programs menu. The program should launch and show a window similar to one shown in Figure 2.1.

To illustrate the use of the program, a case study of an actual pavement section is presented here. This project mainly consisted of milling and discarding the existing hot-mix asphalt (HMA), pulverizing and cement-treating the in-place base down to 6 in., paving the finished base with a new HMA layer. The pre- and post-construction pavement sections are shown in Figure 2.2. Prior to construction, the existing base layer was about 18 in. thick. After the construction, the top 6 in. of the base was reclaimed and mixed with 2% cement. The asphalt concrete layer was replaced its original thickness of 4.5 in.

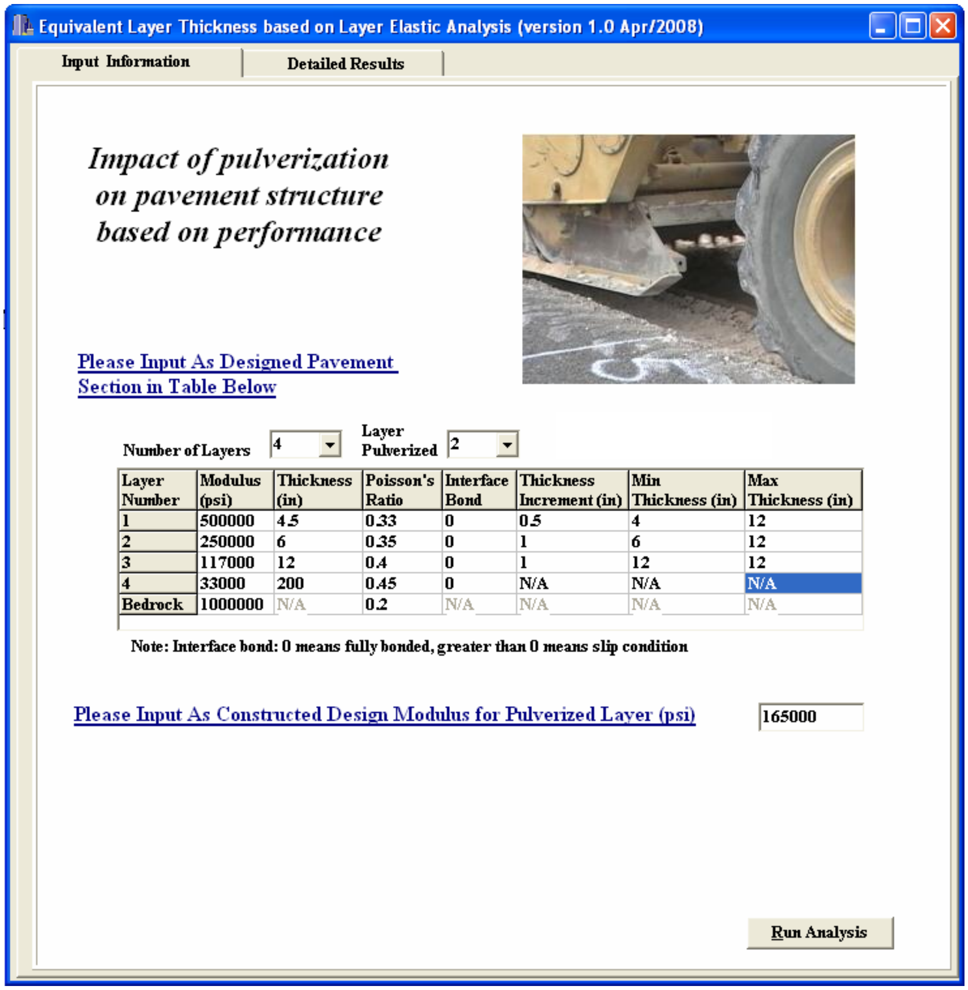


Figure 2.1 – Input Information Screen

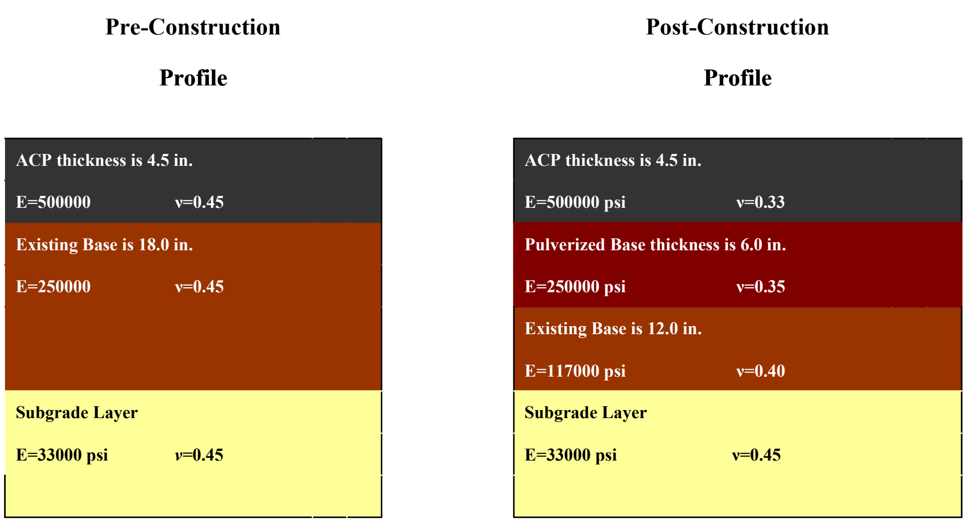


Figure 2.2 – Pavement Cross-section Before and After Pulverization

A mix design was carried out on the base material retrieved from the site to establish the cement content and the design modulus for the pulverized layer as discussed in Research Report 0-5223-2. The optimum cement content of 2%, yielded a modulus of the about 300 ksi, but during the structural design a modulus of 250 ksi was presumed. The moduli of different pavement layers were backcalculated from FWD tests performed before the construction they were 500 ksi, 117 ksi and 33 ksi for the HMA, base and subgrade layers, respectively. Nondestructive tests with the DSPA on top of the pulverized layer yielded an as-constructed design modulus of about 165 ksi.

Pavement Information Input

The first step is to provide the following information related to the pavement layer properties (Refer to Figure 2.1):

1) ***Number of layers***. The number of pavement layers upon completion of the project should be input.

   This program is restricted to three and four layer systems since it is specific to pulverization activities.

   The first layer can be either an HMA layer or a thin (0.5 in.) surface treatment layer

2) ***Layer selected for pulverization:*** The layer number counted from the pavement (typically Layer 2) that is being pulverized should be input.

3) ***As-Designed Pavement Layer Properties:*** The following information should be input

   - Moduli of the layers in psi (from the values used in the PFS19 or similar design program)
   - Thickness of the layers in inches
   - Poisson's ratio of the layers (from the values used in the PFS19 or similar design program)
   - Interface bond condition between the successive layers (typically zero for fully-bonded)
   - Three thickness control parameters to ensure reasonable results based on the district practices. These three parameters are:

     - Minimum acceptable thickness for each layer
     - Maximum acceptable thickness for each layer
     - Desired incremental changes in thickness for each layer

4) ***Representative modulus for the pulverized layer after construction***: The modulus of the pulverized layer after construction in psi should be input. This value can be determined in one of the following ways:

- by performing FWD tests on top of the pulverized layer and backcalculating the modulus of the pulverized layer
- by performing DSPA tests on top of the pulverized layer to measure the seismic modulus directly (multiply the seismic modulus by 0.7 to obtain representative design modulus)
- by compacting a specimen from field sample and performing FFRC tests on the specimen to measure the seismic modulus directly (multiply the seismic modulus by 0.7 to obtain representative design modulus).
- By performing resilient modulus tests on a specimen prepared from the field sample

Note: The program provides a set of default values for the inputs required. Please change the input values to suite the pavement system being analyzed.

Once the inputs are provided, the user can depress the button "Run Analysis" to execute the software.

Analysis and Output Screens

As thoroughly described in Appendix A, the analysis consists of utilizing a layered-elastic program and the provided inputs for the as-designed pavement section to determine the critical stresses and strains associated with three different performance criteria of:

a) Fatigue Cracking of HMA (if applicable)
b) Rutting in the subgrade, and
c) Rutting in the AC layer.

The software then replaces the modulus of the *as-constructed* pulverized layer for its as-designed modulus. Using an optimization technique, the thickness of different layers are then individually varied until the critical stresses and strains for the as-constructed section are equivalent or less than those of the *as-designed* section for all three performance criteria.

Note: See the Section on "Detailed Results" below for means of disabling one or two of the three performance criteria.

After the analysis is complete, the program presents the results in three ways:

a) Summary Results,
b) Detailed Results and
c) Text file for printing archiving the results.

Summary Results

An example of the summary results is shown in Figure 2.3. The summary results are displayed in the main window after the analysis is complete. Up to three options are provided.

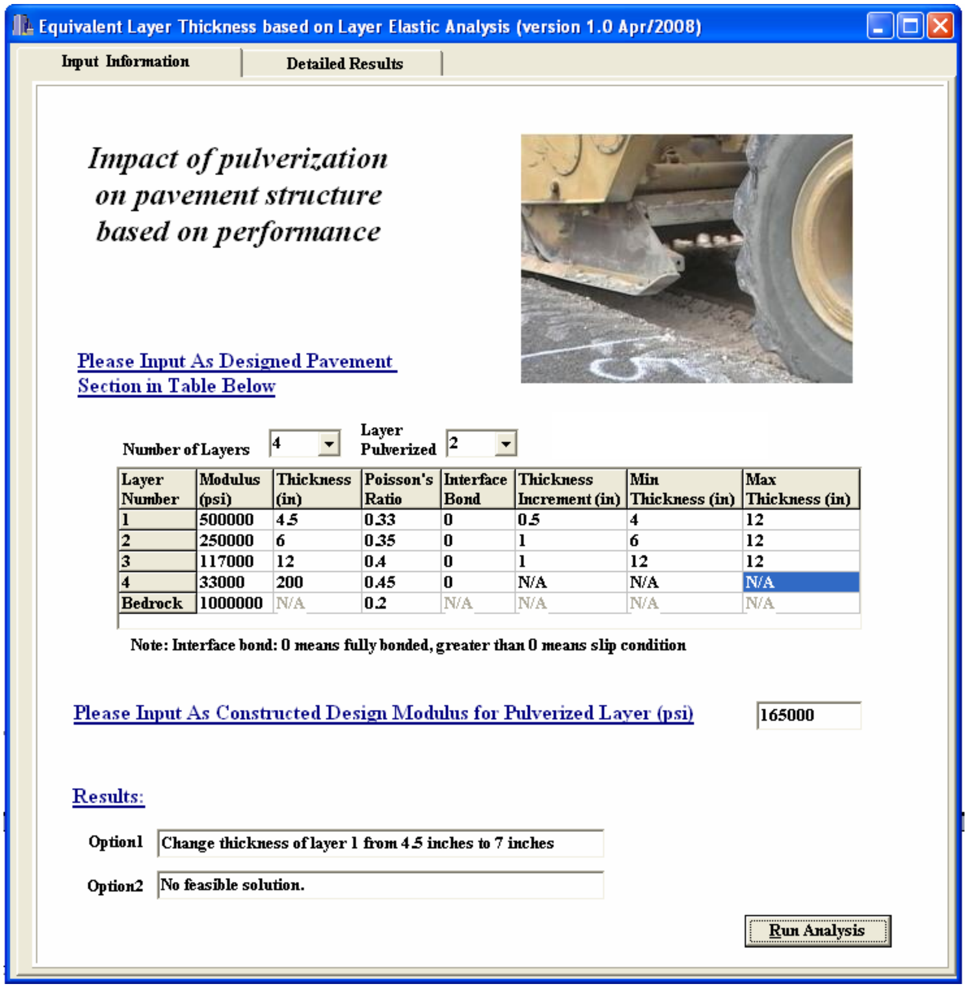


Figure 2.3 – Summary Results Screen

- ***Option 1*** provides guidance on the possible thickness of the HMA without changing the thickness of the lower layers to achieve the *as-designed* performance levels from the *as-constructed* pavement section.

- ***Option 2*** provides guidance on the possible thickness of the second layer without changing the thickness of the HMA or other pavement layers to achieve the *as-designed* performance levels from the *as-constructed* pavement section.

- ***Option 3 (which is only applicable to four-layer pavement systems)*** provides guidance on the possible thickness of the third layer without changing the thickness of the HMA or other pavement layers to achieve the *as-designed* performance levels from the *as-constructed* pavement section.

If the equivalent thicknesses based on the *as-constructed* modulus are equal or close to the *as-designed* values, the user should not be concerned about the quality of the pulverized layer. On the other hand, if the equivalent thicknesses are significantly different, the user can choose to modify the mix design of the pulverized layer, or increase the thickness of the overlying layers.

Detailed Results

An example of the detailed results is shown in Figure 2.4. This screen can be readily accessed by pointing and clicking at the "Detailed Results" tab on top of the main page (marked as A in Figure 2.4). The following paragraphs contain the explanation for each section of the "Detailed Results" screen.

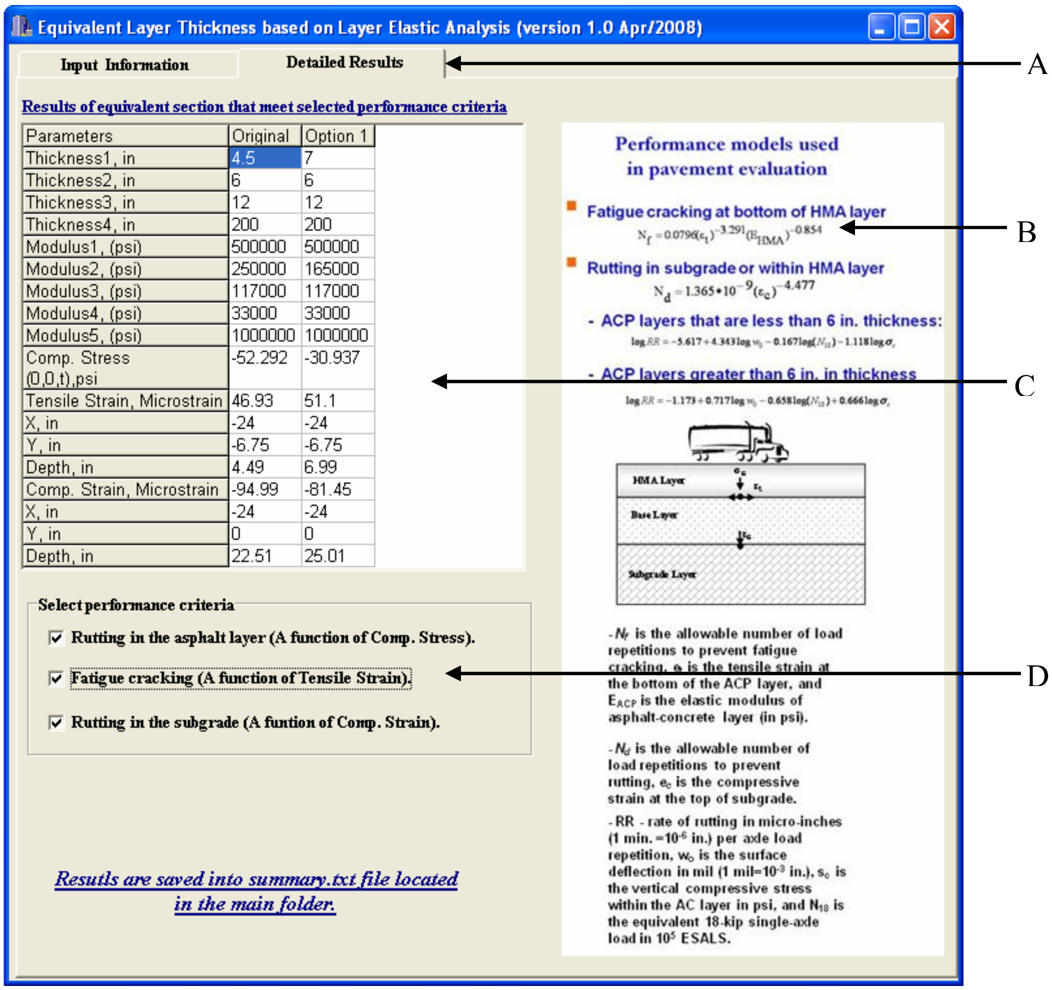


Figure 2.4 – Detailed Results Screen

- ***Explanation of Performance Models:*** For the convenience of the user, the right hand portion of the screen (marked as B) contains a summary of the performance models used.

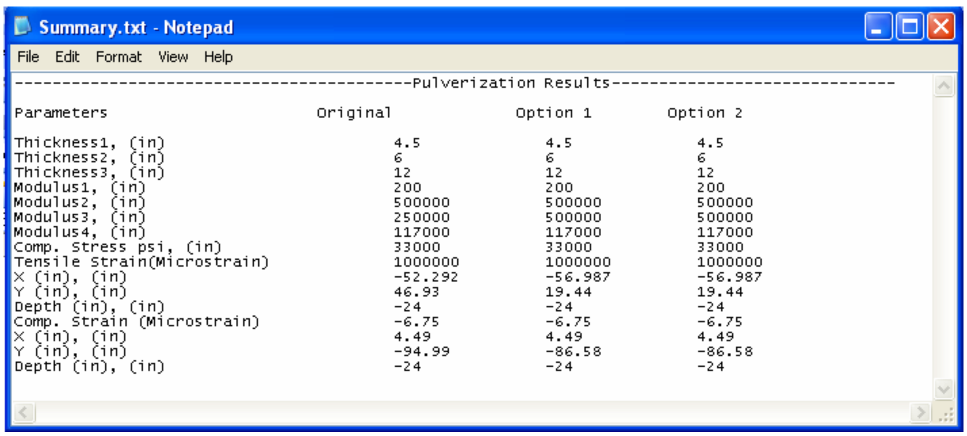
- ***Detailed Results:*** The upper left hand corner of the screen (marked as C) contains the *as-designed* and equivalent *as-constructed* information of the pavement sections. In addition, the critical stresses and strains associated with each performance model are provided for all options. This information includes the compressive stresses in the HMA layer, tensile strains at the bottom of the HMA (or pulverized layer if the modulus of the pulverized layer is greater than the modulus of HMA) and compressive strain on top of the subgrade.

- ***Selecting Relevant Performance Criteria:*** Immediately under the detailed results table, three check boxes are provided for deselecting the performance criteria that is not of interest to the user (marked as D in Figure 2.4). By default all three performance criteria are selected. However, the user can select any combination of the three performance criteria as long as at least one is selected.

  Note: As soon as this section is modified, the user should return to the "Input Information" Tab to re-execute the problem by depressing the "Run Analysis" button.

Text Output File

An example of the text output file is shown in Figure 2.5. The file name is "SUMMARY.TXT" and is located in the main folder of the program.



Summary.txt - Notepad

File Edit Format View Help

--Pulverization Results-----------------------------

Parameters	Original	Option 1	Option 2
Thickness1, (in)	4.5	4.5	4.5
Thickness2, (in)	6	6	6
Thickness3, (in)	12	12	12
Modulus1, (in)	200	200	200
Modulus2, (in)	500000	500000	500000
Modulus3, (in)	250000	500000	500000
Modulus4, (in)	117000	117000	117000
Comp. Stress psi, (in)	33000	33000	33000
Tensile Strain(Microstrain)	1000000	1000000	1000000
X (in), (in)	-52.292	-56.987	-56.987
Y (in), (in)	46.93	19.44	19.44
Depth (in), (in)	-24	-24	-24
Comp. Strain (Microstrain)	-6.75	-6.75	-6.75
X (in), (in)	4.49	4.49	4.49
Y (in), (in)	-94.99	-86.58	-86.58
Depth (in), (in)	-24	-24	-24

Figure 2.5 – Summary Text File