Design, Constructability Review and Performance of Dual Base Stabilizer Applications

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16. Abstract

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Abstract

Asphalt emulsion has been used for base course stabilization through full-depth reclamation in a few TxDOT districts. Results from these practices were quite different. The preliminary conclusion from these trials has been that asphalt emulsion may not perform well in the high humidity/high rainfall areas like east Texas. On the other hand, using calcium-based additives to stabilize base courses in road construction has been a common practice in most TxDOT districts. It is expected that the blend of calcium-based additives with asphalt emulsion (dual stabilization) will produce a base which has an optimum combination of strength, stiffness, moisture resistance and flexibility. In this case, the calcium-based stabilizer may reduce the plasticity of the base fines making it a more friable material that accepts well the blending with emulsion. TxDOT has drafted a special specification for the use of asphalt emulsion treatment in road mixing. In this project, the trial version of the TxDOT special specification is evaluated. The output of this research project includes: laboratory test procedure for mix design with dual stabilization, guidelines for the construction of bases with dual stabilization, and results from a series of parametric studies that show which parameters may have significant impacts on the engineering properties of emulsion-treated base materials and on the performance of emulsion-treated bases.

Implementation Statement

In this report a number of recommendations have been made to improve the mix design, construction and quality management for asphalt-emulsion-treated base courses through full-depth reclamation.

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 for distribution to the TxDOT staff.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AEMA	Asphalt Emulsion Manufacturers Association
AIV	Aggregate Impact Value
ASTM	American Standard Test Method
CIR	Cold In-Place Recycling
COV	Coefficient of Variation
EF	Excess Fine
ES	Excess Sand
ESF	Excess Fine and Sand
FDR	Full-Depth Reclamation
FFRC	Free-Free Resonant Column
FWD	Falling Weight Deflectometer
GPR	Ground Penetrating Radar
HLS	Hydrated Lime Slurry
HMA	Hot-Mixed Asphalt
IDTS	Indirect Tensile Strength
ITS	Intelligent Transportation System
MDD	Maximum Dry Density
MMC	Mixing Moisture Content
MS	Medium Setting
NBL	Northbound Lane
NCAT	National Center for Asphalt Technology
NDG	Nuclear Density Gauge
OEC	Optimum Emulsion Content
OMC	Optimum Moisture Content
PI	Plasticity Index
PMC	Project Monitoring Committee
PSPA	Portable Seismic Pavement Analyzer
QA	Quality Assurance
QC	Quality Control
QS	Quick Setting
RAP	Recycled Asphalt Pavement
SBL	Southbound Lane

SGC	Superpave Gyratory Compactor
SS	Slow Setting
TLC	Total Liquid (or fluid) Content
TST	Tube Suction Test
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

Chapter 1

Introduction

Statement of Problem

Rehabilitation of highway pavements, particularly, low volume roads through full-depth reclamation (FDR) is a cost-effective option that reduces the use of virgin base aggregates and eliminates the effort on disposal of the old aggregates. The process of FDR usually consists of in-place cold grinding of the existing asphalt layer as well as a predetermined amount of unbound granular base material, stabilizing the material with additives and compacting the new layer to a proper density. FDR can be used to treat a wide range of problems, particularly problems related to weak base courses or pavements with insufficient structural capacity. If designed and constructed properly, FDR is capable of rectifying deep rutting problems, reflective fatigue and thermal cracking, deterioration of pavements due to maintenance patching and deterioration of ride quality caused by depressions and heaving.

Using calcium-based additives (cement, lime or fly ash) to stabilize base courses has been a common practice in road construction and rehabilitation through FDR. The strengths and weaknesses of each additive have been well documented. Asphalt emulsion provides the aggregate skeleton of base materials with distinct mechanical properties. The residual asphalt in an emulsified base selectively adheres to the smaller particles forming binding mastic which in turn binds the larger particles together. The granular matrix in the emulsified base has similar internal friction as hot-mixed asphalt (HMA) when compacted properly under the optimum water emulsion contents. Therefore, it is expected that the dual stabilization, blend of calcium-based additives with asphalt emulsion, will produce a base which has an optimum combination of strength, stiffness, moisture resistance and flexibility.

Currently, the major challenges of using asphalt emulsion alone or the blend of calcium-based additives with asphalt emulsion include determining the optimum mix design to ensure that the recycled materials are properly coated with the additive, establishing the test procedure for mix design and compacting the mix sufficiently during construction. In addition, curing time is another issue. In most cases, the curing time is based on an arbitrary number of days for which the recycled base should be left open before surfacing and is not related to any criteria or test that measures the development of strength with curing age. In many cases, contractors rely heavily on guidelines from product and equipment manufacturers. Hence, there is always an unknown element in the design and construction process with different contractors having their own methods of design and construction. Good results are not necessarily guaranteed when different materials at different climatic zones are used. This report represents the results from a systematic study on these matters.

Objective

The main objective of this research project is to develop a laboratory test protocol to help in mix design for dual stabilization of base materials and guidelines for the construction of bases with emulsion treatment. To achieve this objective, a number of tasks were completed. These tasks include:

- Perform information search relevant to asphalt emulsion or dual stabilized bases. The information search focused on the current practices with regard to mix design and construction for this type of bases.
- Select sites ready for construction to acquire materials used in the study as well as to evaluate the performance of emulsion stabilized projects under realistic conditions.
- Conduct an in-depth investigation on the effects of emulsion content and mixing water content.
- Determine the amount and type of calcium-based additives to be used in the selected materials and evaluate the effects of the addition of calcium-based additives on the engineering properties of dual-stabilized bases.
- Perform a systematic parametric study to determine the factors that affect strength and modulus of emulsion-treated mixtures.
- Develop guidelines and procedures of laboratory testing for mix design and validate them.
- Conduct case studies on a number of construction projects and provide recommendations and guidelines for construction in the basis of the results and observations from these studies.

Organization of Report

Chapter 2 contains a summary of the literature review and information search on asphalt-emulsion treatment through FDR process, consideration of mix design parameters and the effects of climactic conditions and construction-related factors on emulsion-treated base courses.

Chapter 3 provides an overview of the specifications and testing procedures provided by TxDOT, SemMaterials and other highway agencies and institutions.

Chapter 4 presents the results from laboratory tests on the materials collected in quarries and actual construction sites and the description of laboratory tests performed in order to achieve a final mix design for the each material.

Chapter 5 summaries the results from a comprehensive parametric study carried out on the materials used in this project. Included in this study were the effects of gradation, curing regime, mixing temperature, mixing method and compaction method on emulsion treatment.

Chapter 6 provides a preliminary guideline for mix design and laboratory testing based on the results presented in Chapters 4 and 5.

Chapter 7 presents the results of lab tests conducted on a different material which was used as a validation of the preliminary guideline.

Chapter 8 presents the results from a number of case studies involving both field experiments and laboratory tests. In the basis of these studies, recommendations and guidelines for road construction with emulsion treatment are also included in this chapter.

Chapter 9 consists of summary and conclusions of this project as well as recommendations for the changes to TxDOT policies.

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Chapter 2

Background

Introduction

This chapter summarizes the results from an extensive literature review that documents the material collection, asphalt emulsion treatment, laboratory testing methods for mix design and the process of Full Depth Reclamation with asphalt emulsion. Some of the conventional and recently developed tests and mix designs are also described in this chapter.

Full-Depth Reclamation

Full depth reclamation (FDR) is a form of cold in-place recycling (CIR) of flexible pavements. During this procedure, the asphaltic surface hot mix layer and a predetermined amount of the underlying base course are pulverized simultaneously by special equipment. As a common practice, the two materials are mixed with asphalt emulsion or other stabilizing agents. Depending on the severity of structural problems of the original base course, additional virgin base material (add-rock) or RAP is sometimes mixed with the pulverized materials. The result of this process is an entirely new base material. This method dates back to the early 20th century, however, it did not become widely used until around 1975 (Epps, 1990). Increasing shortages of virgin aggregate, rising fuel costs, as well as environmental concerns have led to an increased utilization of FDR in many states and countries. Like many other road rehabilitation procedures, FDR has both its advantages and disadvantages.

Recycling using the FDR process has many advantages which encompass a broad range of engineering concerns, from improving the economics of the project to safeguarding the environment. FDR facilitates complete reconstruction of a pavement system while utilizing all or most of the existing material. The process allows for grade corrections and small adjustments in road geometry, but more importantly, remedies structural pavement problems (Kearney and Huffman, 1999). The ability to utilize almost 100% of the existing materials reduces project costs associated with the transportation of virgin material to the site while concurrently eliminating disposal costs of the old aggregates. This is a great benefit for states such as Texas, where fresh aggregate is sometimes shipped from locations as far as Guadalajara, Mexico. Aside from the obvious economic benefits, FDR addresses “deeper” pavement problems as well.

Cracking and other defects are sometimes caused by inadequate base materials in flexible pavement systems. In these cases resurfacing of the road with another hot mix layer will not solve the problem. FDR can be implemented on these roads to strengthen the base materials (Kearney and Huffman, 1999). The new base that is formed from the combination of the existing pavement and part or all of the base material along with a stabilizing agent is often times stronger than the original materials. For this reason, roads that have undergone the FDR process are often considered to be structurally sounder than the original flexible pavement.

Since the pulverization process reaches deep into the base material, changes in the profile of the road are attainable during the FDR process. Epps (1990) states that significant pavement structural improvements can be made in horizontal and vertical geometry and without shoulder reconstruction. Old pavement profile, crown, and cross slope may be improved. This is possible since the entire layer of flexible pavement as well as part of the base is reworked. The advantages of FDR are not only limited to road improvements, it is also an environmentally sound choice for pavement rehabilitation as well.

With the strategy of “greener” roads being advocated by policy makers worldwide, FDR fits in as a viable solution to flexible pavement problems. The process as a whole conserves energy. Roads can be recycled in-place without any fuel being expended for heating of bituminous materials. Also, extra fuel is not required nor added emission produced during the transportation of new aggregate to the job site. This in turn leads to overall project savings in transport costs. In terms of aggregate, scarce supplies are not depleted for reasons of structural improvements.

Some problem areas have also been associated with the use of FDR. No comprehensive guidelines are currently in place that governs the implementation of the process. This has lead to large variations in the results of such projects, even within the same state. Another concern with FDR is the curing time required for strength gain. Curing time is a major factor in the decision of when to let traffic back on that particular section of road. This in turn causes inconvenient disruptions in traffic. However, advances in equipment used for FDR has helped streamline the process so that road closures can be kept to a minimum (Epps, 1990). Also, the entire process is susceptible to climactic conditions, especially when asphalt emulsions are used as a stabilizing agent. Since the strength gain is dependent on the rate of moisture loss by the emulsion, it is not recommended that the process be carried out on days when heavy rainfall is expected.

Stabilizers Used for FDR Process

During the FDR process, various types of stabilizing agents can be added to the mixture of recycled asphalt pavement (RAP) and the existing base material. The process of adding chemicals to stabilize a soil is known as chemical stabilization. Some of the more common additives used in the process are asphalt emulsion, Portland cement, lime, and fly ash. The following section gives a description of the uses and mechanisms behind each.

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Asphalt Emulsion

An emulsion is a suspension of small globules of one liquid in a second liquid with which the first will not mix. The two liquids that comprise an asphalt emulsion are asphalt and water. Since oil and water do not mix well, an asphalt emulsion contains an emulsifier which prevents the separation of the two liquids. Unlike hot mix, emulsion is used as part of a cold process where no heating of either the aggregate or the emulsion is required. Since one of the components of emulsion is water, it can be combined with the base material even if the aggregate is wet. The final strength of the material develops as the emulsion "sets". The setting process is also known as the "breaking" of the emulsion. More simply put, the breaking of the emulsion it is the process in which the water initially mixed into the emulsion separates and eventually makes its way out of the mixture. This leaves behind only the bituminous portion of the original mix. Water can leave the emulsion mixture either by compaction or natural evaporation.

Asphalt emulsion provides various benefits to a recycled base mixture. According to Kandahl and Mallick (1997), it helps to increase cohesion and load bearing capacity of a mix. It also helps in rejuvenating and softening the aged binder in the existing asphalt material. Aside from the structural gains by the newly stabilized base, there are other benefits to using emulsion as well. The lack of heat needed for placement of the material allows for a safer working environment for those carrying out the process.

Many factors that affect the production, storage, use and performance of asphalt emulsion. Besides the rate of residual asphalt, the variables having a significant effect are the following (AEMA, 1997):

- Chemical properties of the base asphalt cement
- Hardness and quality of the base asphalt cement
- Asphalt particle size in the emulsion
- Type and concentration of the emulsion
- Manufacturing conditions such as temperatures, pressures, and shear
- The ionic charge on the emulsion particles
- The order of addition of the ingredients
- Type of equipment used in manufacturing the emulsion
- The property of the emulsifying agent
- The addition of chemical modifiers

The above factors can be varied to suit the available aggregates or to suit construction conditions. It is always advisable to consult the emulsion supplier with respect to a particular asphalt-aggregate combination as there are few absolute rules that will work the same under all conditions. An examination of the three main constituents (asphalt, water, and emulsifier or surface-active agent) is essential to an understanding of why asphalt emulsions work as they do.

Calcium-Based Additives

Three calcium-based additives, Portland cement, lime and fly ash, have been widely used for stabilizing granular base materials.

Portland cement is a multi-mineral compound made up of oxides of calcium, silica, alumina, and iron. The combination of water, cement, and soil can form cementitious bonds between the soil particles which facilitate a gain in strength over long periods of time (Kandahl and Mallick, 1997). In Texas, cement has been utilized in approximately 80% of the districts for base course stabilization of recycled mixtures (Scullion et. al., 2003).

Lime, in the form of dry or slurry, is another common additive used for chemical stabilization of recycled materials. This additive exchanges its higher valence cations with the mono-valent cations in many soils. Lime is generally used as an additive to mitigate the effects of some organics in base materials. When used as a stabilizing agent in soils, lime can lessen the effects of moisture damage by increasing tensile and compressive strengths of the recycled mixtures (Kandahl and Mallick, 1997; Parsons and Milburn, 2003).

Fly ash is an industrial by-product that comes from the combustion of fossil fuels in electricity generating plants (Parsons and Milburn, 2003). When coal is burned in these plants, the exhaust from the boilers contains fly ash. Class C fly ash is a pozzolanic material that contains silica, alumina, and calcium based minerals. Much like cement, when used as a stabilizing agent in the recycled mixtures, fly ash can lead to an increase in impermeability and strength of these mixtures

Dual Stabilization

Although the effects of each of the additives on the mechanical properties of a given material have been studied extensively, the benefits of their combination or dual stabilization when used for FDR are less known. The following section attempts to summarize the results found in previous studies of the dual stabilization process. Specifically, how can the optimum blend of calcium-based additives with asphalt emulsion be determined in the laboratory? What are the strength characteristics of the dual-stabilized materials and how can those strength characteristics be measured both in the laboratory and in the field? Also, what effect do climactic conditions have on the performance of these materials? Another fundamental aspect of the FDR process that will be covered is curing time. Specifically, what effect does dual stabilization have on the cure time required for a base course treated in this way? Also, how can the curing time be optimized to allow for rapid placement of traffic back on to the effected route? How can the dual stabilization process be carried out in the field? Finally, what are the long term effects of dual stabilization on the performance of the new flexible pavement and how can those parameters be quantified?

Mix Design Parameters

Various mix designs have been proposed and implemented by different agencies for use in FDR. Different mix design procedures have the following items in common (Newcomb and Salomon, 2000):

- Collection of road samples
- Material characterization of road samples
- Selection of stabilizing agent

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- Determination of optimum moisture content and/or total liquid content
- Mixing, compaction, and curing of specimens

Collection and Characterization of Road Samples

About 500 lbs of the in-place material is needed. The collection of road samples is typically done with opening a trench at a random location at the site. The HMA layer is also sampled if the construction plans require combining it with the base. One concern with this process is that the sampled material may not be representative of the entire project site.

Mallick et al. (2001) utilized a coring device to retrieve the materials from a number of locations throughout the site to sample the HMA and the base. Even though more cumbersome, this may be a more prudent way of sampling.

The main characterization activities are the determination of the gradation and index properties (such as liquid limit, plasticity index and aggregate stiffness) of the retrieved materials with or without RAP. Of particular interest are the percentages of gravel, sand and fines and the plasticity index (PI) of the materials. These parameters are used to determine the appropriate additives. If the gradation is not desirable, the addition of virgin materials to the mix will also be considered.

As stated by Epps (1990), the addition of virgin aggregate to the recycled material appears to be a widespread standard practice. According to his research, 66% of the agencies which were surveyed did allow virgin aggregate to be combined into the recycled existing material during FDR. When used in this context, the virgin aggregate is added to the recycled mixture to supplement the strength of the material. As shown by Johnston et al. (2003), a small portion of additional aggregate could improve the strength of a mixture.

Selection of Emulsion

The type and amount of emulsion selected is extremely important and thus becomes a matter which most mix designs often consider. A study by Clyne et al. (2003) for the Minnesota DOT has concentrated on the importance of the proper selection of emulsion for cold-in-place recycling of bases. Emulsions are categorized according to the electric charge which surrounds the asphalt particle. Positively charge asphalt particles are known as cationic emulsions; while negatively charged asphalt particles are known as anionic emulsions. A third category of emulsion known as nonionic, which is neutral, also exists. However, nonionic emulsions are not often used as stabilizing agents in base materials.

The two commonly used emulsions are then broken down by the speed at which they convert back into asphalt. Mean rapid setting (MRS), medium setting (MS), slow setting (SS) and quick setting (QS) are the terms used to further identify an emulsion (AEMA, 1997). Of these four types, SS emulsions are generally used for cold in-place recycling because of their better ability to coat dense graded aggregates (Pouliot et al., 2003). According to Kearney et al. (1999), for bituminous stabilization, slow or medium set emulsions usually are used, and they may be polymer modified.

With respect to aggregate-emulsion mixtures, the relationship between the aggregate electronic surface charge and the emulsion electronic charge heavily impacts the interaction of the emulsion with the aggregate (Ibrahim, 1998). This being said, emulsion droplets will be most attracted to aggregates which bear opposing droplet charges. An example of this was given by Lesueur and Potti (2004). They stated that siliceous aggregates are said to bear negative charges and therefore attract all positively charged droplets.

Pouliot et al. (2003) studied the chemical and physical properties of asphalt emulsion modified with small quantities of cement (less than 2%) to accelerate the breaking of the emulsion. Scanning electron microscope observations showed the good dispersion of the asphalt droplets inside the hydrated cement paste. A cationic emulsion (CSS-1) tended to entrain less air than anionic emulsion (SS-1). Results also indicate that the introduction of asphalt droplets inside a cement mortar matrix lead to a significant reduction in compressive strength and elastic modulus as well as a slight decrease in flexural strength. Mortars made with the cationic emulsion show higher strengths and elastic modulus than mortars made with anionic emulsion. As such, the compatibility of the emulsion and aggregates should be considered.

Selection of Calcium-Based Additives

Another parameter required to be submitted with the mix design is the percent calcium-based additive (lime or cement). According to the TxDOT trial specification and other states, additional additives can be added to the mix, if the emulsion alone would not provide adequate strength. These additives are typically around 1% or 2% by weight of total mix. The specification also lists guidelines on the type and quality of additional additive to be used. Also included are minimum strength requirements that must be achieved through the addition of supplemental additives to the emulsion-base mixture. However, specifications for the determination of the amount of additive are not discussed.

Optimum Emulsion Content

The optimum emulsion content for a material is defined by several agencies as the amount of emulsion added to a material which meets minimum strength requirement defined by the particular agency. However, some agencies chose to use empirical values based on emulsion type as their base emulsion content and adjust according to the materials characteristics. Some other agencies utilize the modulus of the mix to determine the optimum emulsion content, as the modulus is a more appropriate parameter for design of pavements. To meet the minimum strength requirement by TxDOT, SemMaterials has provided a set of suggested starting emulsion contents to be used depending on the region of state Texas after determination of the optimum moisture content (OMC) of the material.

Water Content and Total Liquid Content

The amount of mixing water required is not the same for every asphalt emulsion. The water required for maximum dispersion of the residual asphalt in an emulsified material varies depending on the type and content of emulsion. According to Mallick et al. (2001), the mixing water and the water contained in the emulsion work together to aid in compaction of the

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specimen. This amount of mixing water is generally less than the optimum moisture content of the recycled base material without a bituminous additive (Ibrahim, 1998).

It has also been found that, besides the water content, the total liquid (or fluid) content (TLC), defined as the total amount of added water plus asphalt emulsion, has a significant effect on the stiffness of emulsion-treated materials (Ibrahim, 1998; and Mallick et al., 2002).

No firm guideline for selecting the amount of additional mixing water is available. One of the more prevalent practices is to add a percentage of the traditional moisture content to the material first based on the sand equivalency of the material. This value is anywhere from 50% to 80% of the optimum moisture content. Some other organizations arbitrarily select anywhere from 0% to 3% water to be added to the mix.

Specimen Preparation

The preparation of specimens also varies. While a few agencies utilize the proctor method, some others prefer to utilize a gyratory compactor. For example, Maine DOT requires that the specimens be prepared in a Superpave gyratory compactor with 50 gyrations. This decision was made based on research by Mallick et al. (2001) that demonstrated that fifty gyrations represent field compaction the best.

Strength Characteristics

Various studies performed on the mechanical properties of recycled materials stabilized with emulsion and some other additives have been carried out. In each of these studies, researchers employed different test methods to quantify the effects of calcium-based additive on the emulsion stabilized material. However, since in-situ field evaluation is not common, laboratory testing is often used in order to quantify the effects of dual stabilization on in-place materials. A survey of those studies and their results are reported in this section.

James et al. (1996) performed a study to gain more insight into the behavior of emulsion in mixtures as well as quantify the effects of cement when mixed with emulsion and recycled aggregate. Various tests were run on emulsion-cement mixtures with the percentage of cement by weight different each time. With respect to the mechanical tests performed on the specimens, the results are as follows. The modulus increased with an increase in cement percentage. Overall, it was found that the addition of cement to aggregate-emulsion mixtures increased the rate and overall magnitude of modulus. The specimen’s resistance to permanent deformation was also increased after the addition of cement to the mixture (James et al., 1996).

Cement and lime have been found to be similar in their ability to improve the quality of base materials. Cross (2000) evaluated the effects of hydrated lime slurry (HLS) when used in conjunction with asphalt emulsion in cold-in-place recycling projects. In order to quantify the effects of lime on emulsion-RAP mixtures the specimens were subjected to various strength tests including indirect tensile strength, resilient modulus, and permanent deformation. The addition of HLS to emulsion stabilized base materials led to an improvement in the material properties that affect the performance of pavements. HLS resulted in an increase in tensile strength and resilient modulus. The addition of HLS to the mixture also aided in enhancing the materials ability to resist permanent deformation (Cross, 2000).

Climactic Conditions

FDR is influenced by weather conditions both during and after it is performed. Two factors that greatly affect the FDR process are the ambient temperature and moisture conditions of the surrounding area (Salomon and Newcomb, 2001). TxDOT trial specification outlines procedures that must be adhered to in the event of freezing temperatures or rain during construction of an FDR project. Emulsion application should be suspended if the seven-day weather forecast calls for freezing temperatures within one week of emulsion application. In the event of precipitation after initial moisture content readings have been taken, but before the addition of emulsion, sufficient aeration is required. Aeration must occur until the moisture content of the material is within 1% of the moisture content called for in the mix design.

A number of studies have been performed in an attempt to quantify the effects of climactic conditions on dual stabilized bases.

After initial compaction of a base material at its OMC, any subsequent moisture introduced to the mixture can have detrimental effects on the ultimate performance of the pavement. As stated by Mallick et al. (2002), “any additive that is recommended for use in FDR must be evaluated in terms of its effect on the moisture susceptibility of the resultant FDR mix.” The most common laboratory studies performed on dual stabilized bases attempt to quantify these effects by performing tests in both dry and wet conditions.

It has been shown that the addition of either lime or cement to emulsion-RAP mixes aids in increasing a materials resistance to moisture-induced damage. Mallick et al. (2002) performed indirect tensile tests on emulsion-stabilized base materials with the addition of either cement or lime to the mixture. Results from these investigations showed significant gains in indirect tensile strength when compared to emulsion only mixtures under wet conditions.

Brown and Needham (2000) also attempted to quantify the effects of both lime and Portland cement on emulsion stabilized mixtures. During this study specimens were tested for modulus after an initial soaking period and then again after a second soaking period. Results from these tests showed that the modulus increased with the addition of either cement or lime into the mixture when compared to specimens that did not have calcium-based additive.

Even additions of small amount of cement to bituminous-RAP mixtures have been shown to increase a material’s modulus. The introduction of 1% cement to RAP-emulsion mixtures can lead to increases in wet stiffness modulus of more than half when compared to the dry results (James and Needham, 1996).

An additional procedure by which moisture induced damage can be quantified is by evaluating the materials ability to resist permanent deformation; also under both dry and wet conditions. It has been shown that the addition of lime to emulsion stabilized bases significantly increases the materials resistance to permanent deformation (Cross, 1999).

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Another important factor that has been analyzed by researchers is the materials ability to withstand various freeze-thaw cycles throughout the course of its lifetime. Testing performed on emulsion-lime mixtures has shown that freeze-thaw damage resistance increases when compared to specimens that do not contain emulsion in the mixture. It has been suggested that this is true due to asphalts inherent ability to flex (Cross and Young, 1997).

Curing Time

Maximum strength gain is reached when dual-stabilized bases lose their initial water and are fully cured. It has been proposed that the addition of cement or lime to emulsion stabilized bases will result in accelerated curing times for these materials. Tests performed on RAP-emulsion mixtures with varying contents of cement exhibited positive results. It was shown that the rate of strength gain with respect to curing time is directly related to increasing amounts of cement in the mixture (James et al., 1996). The rate at which water leaves the bitumen emulsion can also be improved by the process of dual stabilization. Coalescence tests performed showed that the breaking times of cement-emulsion mixtures decrease with increasing cement content. These findings suggest overall improved curing rates of the material (Brown and Needham, 2000).

An alternative approach to accelerate the curing process has been implemented by the Oregon Department of Transportation (ODOT). The agency feels that by heating the mix water as well as the emulsion to temperatures between 49º-60ºC, problems resulting from slow emulsion curing times can be kept to a minimum. It is the opinion of ODOT field personal that this process reduces curing problems in construction projects being carried out under cool or damp ambient conditions (Rogue et al., 1992).

Construction

Concrete guidelines for the construction of a reclaimed road with asphalt emulsion do not exist. In most cases, the construction procedure is contractor-dependent. This has lead to large variations in the results of such projects, even within the same state. Mallick et al. (2001) provide a guideline for proper reclaiming, applying emulsion, mixing, grading and compacting. For mix designs that contain calcium-based additives, the additive should be applied either to the surface of the old road before reclamation/pulverization or the surface of the loose mixture after pulverization. FDR facilitates complete reconstruction of a pavement system while utilizing all or most materials in the existing road. The process allows for grade corrections and small adjustments in road geometry, but more importantly, remedies structural pavement problems (Mallick et al., 2002).

Other sequences of construction include the emulsion being transferred from a transport truck to the reclaimer on site. This reclaimer pumps the emulsion from the delivery truck and meters the emulsion through a spray bar with nozzles into the mixing chamber. This chamber encloses the milling head, which simultaneously mills through the road and mixes the base material with the asphalt emulsion (TXDOT Special Specification).

Slightly behind the road reclaimer, the fully processed base material is ready for breakdown rolling by a pad foot roller, which is then followed by a motor grader to trim the pad marks. The motor grader is then followed by a pneumatic roller and a steel drum roller for final compaction.

This process serves as a uniform stable foundation for a suitable wearing course which can typically be opened to traffic the same day and the final surface is placed on in two to seven days. Equipment used for compaction during a construction process varies depending on the contractors.

Since curing time is a major factor for the performance of an asphalt emulsion-treated base course, time delays in the field while construction is going on can be a major contributing factor to the performance of the newly constructed road. Pre-compaction is another factor that contributes to the performance of emulsion treatment (Johnston and Hogweide et al., 2003).

Quality Control and Quality Assurance

Currently, the nuclear density gauge (NDG) is almost the only tool used in Texas for quality control (QC) and quality assurance (QA) of the newly constructed flexible bases. The TxDOT Special Specification also requires the use of NDG for QC/QA of emulsion-treated bases. However, density or moisture content or both of them measured with a NDG in an emulsion-treated base are usually far away from what they really are. To resolve this problem, a large number of on- site specimens has to be prepared and tested as per ASTM D-4643 to calibrate the NDG readings. This practice has been applied to all TxDOT projects with the emulsion-treated bases, even the compaction effort for on-site specimens is definitely different from that for road mixing. Alternative tools/methods of QC/QA are needed for emulsion-treated bases.

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Chapter 3

Overview of Specifications and Procedures

Introduction

In this chapter, procedures and specifications for mix design and road rehabilitation with asphalt-emulsion treatment proposed by a number of highway agencies and contractors are overviewed. Two major documents considered were “Special Specification-Emulsion Treatment (Road Mixed)” drafted by TxDOT in November, 2005 and “Mix Design Procedure-Emulsion Treatment (Road Mixed)” drafted in by SemMaterials in February, 2007. Both the specification and the procedure were evaluated before the initiation of laboratory testing for this project.

TxDOT

The trial specification provided by TxDOT for the use of dual stabilization is a performance based guideline. As drafted for road mixing, this specification does not provide any details for laboratory testing and mix design. For the most part, this specification leaves the mix design to the contractors. This specification requires that a mix design must be submitted to the project engineer before actual construction can be initiated on a project. The general requirements for asphalt emulsion, strength and other relevant parameters are proposed in the specification (see Appendix A for its entirety).

TxDOT specifies Test Method Tex-113-E for determining the optimum moisture content (OMC) and the maximum dry density (MDD) of a recycled base material. The optimum emulsion content (OEC) for a given mixture is determined on the basis of the minimum strength requirements.

The performance tests required and the current TxDOT criteria for mix design are included in Table 3.1. The acceptance values for unconfined compressive strength (UCS) and indirect tensile strength (IDTS) and the retained unconfined compressive strength are specified. The tube suction test (TST) and the modulus (stiffness) test do not have the acceptance values specified.

Table 3.1 – Laboratory Mix Design Properties and Testing Methods

Property and Testing	Criteria
Unconfined Compressive Strength (UCS), Tex-117-E	150 psi min.
Indirect Tensile Strength (IDTS), Tex-226-F[1]	50 psi min.
Dielectric Constant, Tube Suction Test (TST), Tex-144-E	Report
Retained Unconfined Compressive Strength, Tex-117-E	80% min.
Resilient Modulus (AASHTO T-307)	Report
Modulus, Free-free Resonant Column Test (Tex-149-E)	Report

1. Specimens will be cured 72 hr. at 104°F before testing

The specification uses Tex-117-E as the procedure for sample preparation and UCS testing. Procedure Tex-117-E refers to Tex-113-E "Laboratory Compaction Characteristics and Moisture-density Relationships of Base Materials" as the proper method for preparing materials undergoing UCS testing.

With regards to IDTS testing, the specification requires the use of procedure Tex-226-F. In turn, this procedure specifies the use of Tex 241-F "Superpave Gyratory Compacting of Test Specimens of Bituminous Mixtures" in order to prepare the samples for testing. After compaction of the IDT specimens, the specification calls for a 3 day cure period in which the specimens are placed in an oven set at 104°F; after which, they are subjected to IDTS testing under a controlled rate of deformation (2 in./min) specified by Tex-226-F.

To determine the modulus of a specimen, a testing device known as the free-free resonant column (FFRC) is utilized as required by the TxDOT specification. The resilient modulus is measured by utilizing the AASHTO T-307 procedure.

For mix design, the TxDOT specification also requires the values of dielectric constant and retained UCS as per draft procedure Tex-144-E (Tube Suction Test). This procedure calls for a 10-day moisture conditioning period in which the specimen is placed on porous stones surrounded by a predetermined amount of water. The general idea is that the water will be distributed within the specimen through the natural capillary absorption process. During this process, the dielectric constant of the specimen is measured on a daily basis. The final dielectric value is then reported. Upon completion of the moisture conditioning period, the specimen is then subjected to compression testing. A ratio between the original UCS value and that of the specimen subjected to 10-day moisture conditioning is then found and defined as the retained strength. However, in terms of curing regime, the specification does not define what the original UCS is. In Tex-144-E, the original UCS is defined as the strength of a specimen cured under the optimum moisture content.

Asphalt emulsion treatment for road rehabilitation is commonly accomplished through the FDR process which always involves the use of RAP. As a specification for road mixing, another weakness of the TxDOT specification is that it ignores the aspects associated with RAP usage.

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SemMaterials

With the same requirements as shown in Table 3.1, the draft SemMaterials procedure (see Appendix B) is also performance-based, but more specific than that of TxDOT in the following aspects associated with mix design:

- Apparatus required to perform laboratory tests for the mix design
- Sieve analysis on the materials to be used in the mixture on an individual basis
- Determination of correct blend ratio which is proportional to the amount of materials (RAP/old base/add-rock) used for construction
- Determination of the optimum moisture content of the mixture
- Procedure for determining the required amounts of moisture and emulsion
- Approximate starting emulsion contents for materials for different TxDOT districts
- Mixing procedure with a high-shear mixer
- Compacting procedure with a Superpave Gyratory Compacter
- Curing regimes for UCS , IDTS and TST specimens

The SemMaterials procedure outlines the apparatus required for performing a mix design for emulsion treated base materials. For the most part, the apparatus required are the standard testing devices.

In the SemMaterials procedure, the correct blend ratio must be determined. This blend ratio is generally proportional to the amount of materials (RAP/old base/add-rock) which will be used in actual construction. After which, the correct amount of each material is gathered from the construction site and stockpiled before construction. The materials are then dried and the RAP is crushed (if it is retrieved from the road directly). A sieve analysis is then performed on all of the materials to be used in the mixture on an individual basis. The Plasticity Index and Sand Equivalency values of the old base and Add-Rock are determined using the TxDOT procedures. The Methelyne Blue Value is required for the old base and add-rock by using AASHTO TP-57.

A predetermined number of specimens are then batched according to the blend percentages previously determined. Different size batches are required depending on whether the material will be used for UCS or IDTS testing.

After batching the required number of specimens, the optimum moisture content (OMC) of the material is found utilizing a procedure similar to that of Tex-113-E. However, extra specimens prepared in a similar manner and at the same moisture contents as those used for determining the OMC of the material are prepared and allowed to cure for 48 hours in an oven set at 140°F. These specimens are then allowed to cool to ambient temperature and are then subjected to FFRC and UCS testing.

After the determination of the OMC of the material, the amount of emulsion required to meet the minimum strength requirement is decided. The SEM procedure provides a suggested starting emulsion content to be used depending on the region of the state from which the material was gathered (see Table 3.2).

Table 3.2 – Initial Emulsion Contents Suggested by SemMaterials Procedure

District	Abiline		Amarillo		Atlanta		Austin		Beumont	
Aggregate Type	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP
Emulsionn Content	TBD	TBD	5.0%	4.0%	TBD	TBD	5.0%	4.0%	4.5%	4.0%
District	Brownwood		Bryan		Childress		Corpus Christi		Dallas	
Aggregate Type	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP
Emulsionn Content	TBD	TBD	TBD	TBD	5.0%	4.0%	5.0%	4.0%	4.5%	3.5%
District	El Paso		Fort Worth		Houston		Laredo		Lubbock	
Aggregate Type	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP
Emulsionn Content	TBD	TBD	4.5%	3.5%	4.5%	4.0%	5.0%	4.0%	5.0%	4.0%
District	Lufkin		Odessa		Paris		Pharr		San Angelo	
Aggregate Type	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP
Emulsionn Content	TBD	TBD	5.0%	4.0%	TBD	TBD	TBD	TBD	TBD	TBD
District	San Antonio		Tyler		Waco		Wichita Falls		Yoakum	
Aggregate Type	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP	< 50% RAP	>50% RAP
Emulsionn Content	5.0%	4.0%	TBD	TBD	TBD	TBD	TBD	TBD	4.5%	3.5%

Water is then mixed into to the dry material. The amount of water to be used is a percentage of the OMC. The wetted material is then allowed to sit for a minimum of twelve hours before any stabilizer is added. The emulsion is then mixed into the material. The amount of emulsion used is equivalent to the suggested starting emulsion content found from Table 3.2. After the addition of emulsion to the material, the entire batch is mixed using a High-Shear Mechanical Mixer for approximately 60 seconds. The mixture is then transferred to a plastic container and placed in an oven set to 140°F for 30 minutes. The mixing process is the same for both UCS and IDTS specimens.

After allowing the emulsion/aggregate mixture to cure, the mixture is compacted utilizing the procedures outlined in Tex-113-E. In order to perform IDTS tests, the material is compacted using a Superpave Gyratory Compacter with 30 gyrations. The IDTS specimens should be 6 in. in diameter and 3.75 in. in height.

In order to determine the amount of calcium-based additive required, two extra UCS and IDTS specimens are also prepared. The initial moisture content to be added to the dry material is adjusted. After allowing the wetted mixture to sit for 12 hours the dry additive is then combined into the material. After which emulsion is added to the material according to the emulsion content previously selected.

After compaction, the specimens are allowed to cure for a given period of time and at a predetermined temperature, depending on the test being performed. For UCS testing, the specimens are allowed to cure at 140°F for 48 hours. IDTS specimens are subjected to a curing time of 72 hours at 104°F. After that, both sets of specimens are allowed to cool to ambient temperature before undergoing strength testing. Moisture susceptibly test is performed on specimens prepared in a similar manner as that described above for UCS testing. Procedure Tex-144-E should be adhered to in order to determine the moisture susceptibility of the material.

FFRC testing is also performed on the UCS specimens in order to determine the modulus of the material. One specimen prepared in a manner similar to that of those undergoing UCS testing is prepared for the purposes of carrying out resilient modulus test in accordance with AASHTO T-307 procedure.

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Missouri DOT

The Missouri Department of Transportation (MoDOT) utilizes a practice similar to TxDOT for determining the appropriate mix design. The differences are essentially in the method of specimen preparation (Superpave gyratory compactor), the method of curing for strength (2 hours) and using a cohesiometer for strength. MoDOT specifies that the add water content should be about 65% of the OMC of the raw material. The strength requirements for MoDOT are included in Table 3.3.

Table 3.3 - MoDOT Min Strength and Modulus Requirements

Property	Criteria	
	< 10% passing No. 200	> 10% passing No. 200
Compaction effort, SGC	1.25˚ angle, 600 kPa, 30 gyrations	
Short term strength test - modified cohesiometer, ASTM D 1560-92, psi	200 min.	150 min.
Indirect tensile strength test - ASTM D 4867 Part 8.11.1, 25 C, psi	45 min.	40 min.
Conditioned ITS, ASTM D 4867 (see note 1), psi	25 min.	20 min.
Resilient modulus, ASTM D 4123, 25 C, psi	175,000 min.	150,000 min.

Maine DOT

The Maine Department of Transportation (MaineDOT) has utilized emulsion treatment through FDR for road rehabilitation successfully for some time despite their wet climate and harsh winters. The implementation of the process in Maine has been under an extensive study carried out by a number agencies and institutions including the National Center for Asphalt Technology (NCAT).

The mix design for MaineDOT is carried out following the process recommended by Mallick et al. (2001 and 2002) as described in Chapter 2. Compaction of the specimens is carried out using 50 gyrations of a Superpave Gyratory Compactor (SGC) with a specially fabricated mold with holes in it that allows loose water to escape during the compaction process. The specimens are tested after they were placed in 104°F (40ºC) oven for 7 days. The specimens are subjected to both resilient modulus and indirect tensile testing.

Chevron

Chevron USA, Inc. makes use of an equation to estimate the initial emulsion content for use in FDR. Under the Chevron mix design system, the initial emulsion estimate (P_c) is based on aggregate gradation and emulsion residue. Once these parameters have been determined, they are input into the following equation (Epps, 1990):

$$P_c = (0.5A+0.1B+0.5C)-P_a(P_p/R) \qquad 2.1$$

where:

A = amount of aggregate retained on No. 8 sieve (%),
B = amount of aggregate passing the #8 sieve and retained on No. 200 (%),
C = amount of aggregate passing No. 200 sieve (%),
P_a = amount of asphalt in reclaimed asphalt pavement (%),
P_p = percent reclaimed asphalt pavement in the recycled mix, and
R = percent emulsion residue (normally 60% – 65%)

Test Method		SPECIFICATION
Coating, %		75 min
Resistance R-Value @ 73 ± 5ºF	Initial curve	70 min
	Final curve + water	78 min
Cohesiometer C-Value @ 73 ± 5ºF	Initial curve	50 min
	Final curve + water	100 min
Resilient Modulus, M psi @ 73 ± 3ºF	Final curve	150,000-600,000
Stabiolometer S-Value @ 140 ± 5ºF	Final curve	30 min
Cohesiometer C-Value @ 140 ± 5ºF	Final curve	100 min

Cured in the mold for a total of 24 hrs. @ a temperature of 73 ± 5ºF.
Cured in the mold for a total of 24 hrs. @ a temperature of 73 ± 5ºF, plus 4 days vacuum desiccation at 10-20 mercury.
Vacuum saturation at 100 of mercury.
NOTE: Besides meeting the above requirements, the mixing must be reasonably workable. (ie., net toe stiff or sloppy).

Figure 3.1 – Specification of Chevron USA, Inc. for Mix Design (Epps, 1990)

Once the initial emulsion quantity is determined, trial mixes are then prepared at 1% below and 1 and 2% above the estimated value. According to Chevron specifications, the trial mixes shall never be lower than 2% emulsion. Laboratory testing is then carried out on all specimens. The emulsion quantity that meets the minimum requirements outlined in Figure 3.1 is then selected as the design emulsion content. No specification for determination of mixing water is given under the Chevron mix design system.

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Chapter 4

Laboratory Testing – Mix Design

Introduction

As per the TxDOT Special Specification, two types of laboratory tests (durability and performance) are proposed to evaluate the following items for emulsion-treated base materials:

- Aggregate type and gradation
- Density
- Type and amount of asphalt emulsion
- Moisture or total liquid content-density relationship
- Strength and stiffness
- Long term performance

Material Selection

A survey was conducted to identify the activities related to the use of the dual-stabilized bases throughout Texas, as well as to identify possible sites to be incorporated in this study.

Survey responses were received from the following 19 districts: Abilene, Amarillo, Atlanta, Austin, Beaumont, Brownwood, Bryan, Childress, El Paso, Fort Worth, Houston, Lubbock, Lufkin, Odessa, Paris, San Angelo, Tyler, Waco, Wichita Falls, and Yoakum. Based on the interaction with the districts and the PMC of the project, materials from four sources in Amarillo, San Antonio and Yoakum districts were selected to establish the guideline and testing procedure for mix design. In addition, an El Paso base material was included in this study to cover a wider spectrum of materials. The five sets of base materials included in the study for mix design are:

- El Paso Base from CEMEX McKelligon Canyon pit.
- Material from Martin Marietta Pit in San Antonio that is either used extensively as add rock or widening the shoulder in San Antonio District.

- Materials from the existing US 287 at project site in Armstrong County, Amarillo District which included in-place RAP (80%) and base (20%).
- Materials from the existing FM 154 at project site in Fayette County, Yoakum District which included in-place RAP (18%) and base (53%) as well as add-rock (29%).
- Materials from the existing FM 2790 at project site in Atascosa County, San Antonio District which included in-place RAP (42%) and base (30%) as well as add-rock (28%).

The materials from the FM 2790 project were mainly used for verification of the preliminary testing procedure.

As stated above, the materials gathered from the construction sites vary with regard to RAP content as well as the inclusion of virgin aggregate or add rock. Initial mix designs were performed on these materials. The objectives of the mix design were to determine the content of asphalt emulsion and the type and content calcium-based additives in dual stabilization and to evaluate the variation of engineering properties with varying contents of the selected additive(s).

Aggregates Properties

The gradation, soil classification and index parameters of raw materials from the two pits (El Paso and San Antonio) and from the old base courses of FM 154, US 287 and FM 2790 as well as the add-rock used for FM 154 are summarized in Table 4.1.

Table 4.1 – Gradation, Soil Classification and Atterberg Limits of Raw Base Materials

Material	Gradation				Classification		Atterberg Limits		Sand Equivalency
	Grave l	Coarse Sand	Fine Sand	Fines	USCS	AASHTO	LL	PI	
El Paso	55	22	18	5	GW	A-2-4	27	8	53
San Antonio	51	25	23	1	GP	A-2-4	20	8	33
FM 154 Add-Rock	54	35	7	3	GP	A-2-6	21	12	13
FM 154 Base	43	31	24	2	SP	A-2-4	17	8	63
US 287 Base	26	32	27	15	SC-SM	A-2-6	26	18	13
FM 2790 Base	45	21	10	3	SP	N/A	N/A	N/A	N/A
FM 2790 Add Rock	51	25	23	1	GP	A-2-4	20	8	33

To prepare the materials for mix design, the entire stock of the materials collected from each source was sieved to develop a global gradation curve. The gradation curves for the virgin materials El Paso and San Antonio pits as well as the mixtures form US 287and FM 154 projects are included in Figure 4.1. For reference, the lower and upper limits of gradation required by TxDOT item 247 for Grade 1 base are also included in the figure.

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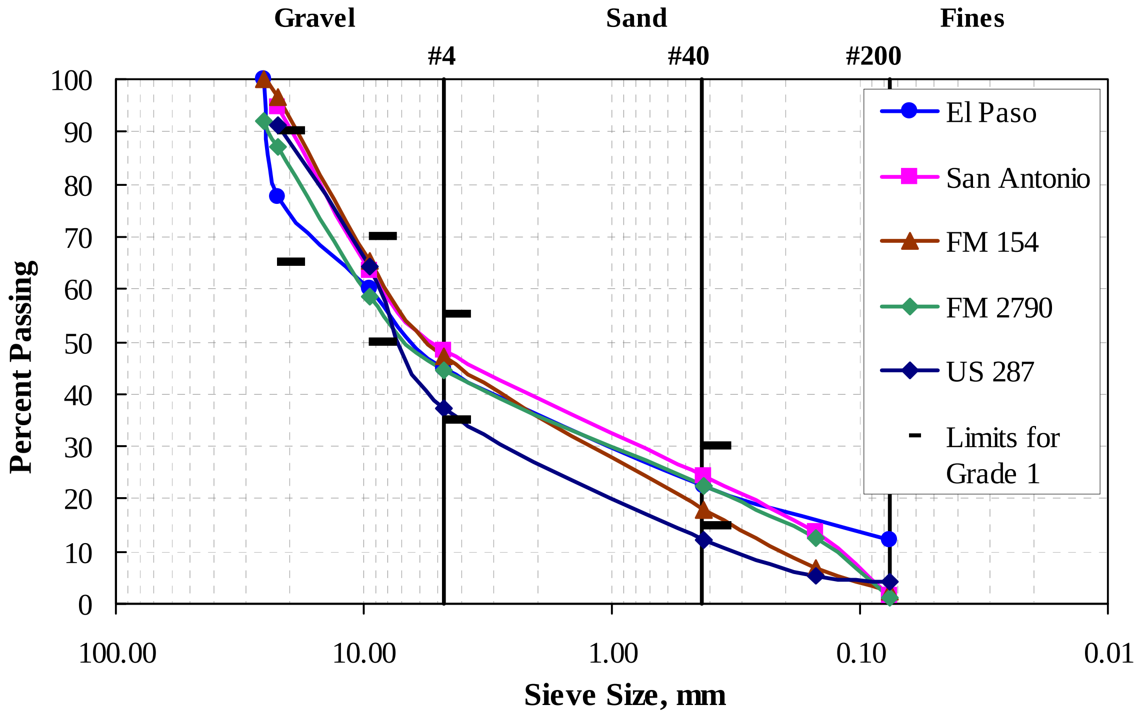

Figure 4.1 – Global Gradation Curves for Materials Used in Preparing Specimens

The toughness of coarse aggregates was measured through two tests called the Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV) under British Standard 812. In TxDOT Project 0-5223 dealing with pulverization, these two tests were found to be useful.

For AIV, a coarse aggregate sample passing the ½ in. sieve and retained on the 3/8 in. sieve is placed within a mold (shown in Figure 4.2a) to perform the test. The sample is subjected to 15 blows of a 30 lb falling hammer dropped from a height of 15 in. to simulate its resistance to rapid loading. A sieve analysis is then performed on the resulting sample. The AIV being the amount of material passing the No. 8 sieve; expressed as a percentage of the initial sample weight:

$$AIV = M_2/M_1 \times 100\% \qquad (4.1)$$

where M_1 is the mass of test specimen and M_2 is the mass of the specimen passing No. 8 sieve.

The AIV can be performed either on dry specimens (called the dry AIV) or on specimens soaked for 24 hours in water (called the wet AIV). A value of less than 30 is usually indicative of a reasonably good material. The AIV and the gradation after performing the test for each of the base materials used in this study are summarized in Table 4.2. Based on this criterion, the add rock from San Antonio pit and the old base material from US 287 (when wet) may be of concern. With regards to the materials from FM 2790, both the old base and the add rock show high AIV values, especially, under wet conditions.

(a) AIV **(b) ACV**

Figure 4.2 – Test Apparatuses for Aggregate Impact Value and Aggregate Crushing Value

Table 4.2 – AIVs of Materials along with Gradations after Testing

Material	AIV		Gradation, Individual Retained (%)			
			Gravel	Coarse Sand	Fine Sand	Fines
El Paso	Dry	14	78	16	3	3
	Wet	20	69	20	8	3
San Antonio	Dry	25	62	28	6	5
	Wet	29	59	24	5	12
FM 154 Add-Rock	Dry	13	71	23	4	2
	Wet	18	69	25	4	1
FM 154 Old Base	Dry	17	79	17	3	1
	Wet	19	72	23	4	1
US 287 Old Base	Dry	16	77	16	5	2
	Wet	22	67	24	7	2
FM 2790 Old Base	Dry	18	37	6	1	0
	Wet	22	34	6	1	1
FM 2790 Add-Rock	Dry	25	62	28	6	5
	Wet	29	59	24	5	12

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The ACV of an aggregate is a value which indicates the ability of the 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 aggregates passing ½ in. sieve and retained on 3/8 in. sieve 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 (400 kN) over a period of 10 minutes. This test is typically performed with a concrete compression machine (see Figure 4.2b). Similar to AIV, the material produced after the test passing the No. 8 sieve (2.36 mm) sieve, is represented as a percentage of the original mass. The ACV is also calculated by using Equation 4.1.

The ACVs of the same materials used for AIV testing are summarized in Table 4.3. Under this test, the San Antonio material and the old base materials from US 287, FM 154 and FM 2790 are of concern.

Table 4.3 – ACVs of Materials along with Gradations after Testing

Material	ACV	Gradation, Individual Retained (%)			
		Gravel	Coarse Sand	Fine Sand	Fines
El Paso	19	66	27	4	3
San Antonio	31	51	36	7	6
FM 154 Add-rock	21	54	38	7	1
FM 154 Old Base	27	66	27	6	2
US 287 Old Base	34	51	32	12	5
FM 2790 Old Base	26	38	10	5	2.2
FM 2790 Add rock	31	51	36	7	6

Selection of Mix Design

The determination of the OMC is particularly important when the material is mixed with the stabilizer. Once the OMC for a particular material was determined, the impact of emulsion on the strength parameters of the mix was established. Specimens were prepared at 45%, 60%, and 75% of the OMCs of the raw materials. Emulsion contents of 0%, 3%, 5%, and 7% were studied at the three different moisture levels.

A comparison of the TLC-density curves for the three selected moisture contents and the MD curves for each of the four materials used in this study is shown in Figure 4.3. For materials from El Paso, San Antonio and mixtures from the FM 154 project with 45% OMC, the TLC-density curves are similar to the MD curves. However, the corresponding MDDs are lower than when the specimens are prepared with water only. These TLC-density curves are much flatter than the MD curves. This indicates that the nuclear density gauge may not be sensitive enough to assess the quality of an emulsion-treated base.

For water contents of 60% and 75% of the OMC, it seems that the maximum density is obtained when no emulsion is added. In particular, pronounced peaks (MDD) do not appear on the TLC-density curves for mixture from US 287, which contains 80% of RAP as designed, at all three moisture contents (45%, 60%, and 75% of the OMC).

Specimen Preparation

For strength and modulus tests, the samples were prepared in accordance to Tex-113-E, with the following variations due to the addition of emulsion to the mixture. After allowing the wetted material to mellow in a sealed container for a minimum of 12 hours, the emulsion was then added to the mixture. The emulsion/aggregate combination was then blended in a high-shear mechanical mixer rotating at 60 revolutions per minute for 1 minute. The material was then transferred into 6 in. diameter containers and placed in an oven at 140°F for thirty minutes.

A total of three different sets of test specimens were prepared. For UCS and moisture conditioning (TST) tests, specimens of 6 in. in diameter and 8 in. in height were prepared according to Tex-113-E procedures. The IDTS specimens were 6 in. in diameter and 4.5 in. in height and compacted using a SGC for a total of 30 gyrations. For resilient modulus test, specimens measuring 6 in. in diameter and 12 in. in height were prepared as per Tex-113-E also.

Strengths of Specimens with Emulsion Only

The UCS tests were performed on all four materials for each moisture content and emulsion content. Before the tests were performed, the specimen was allowed to cool to room temperature. The results from these tests are shown in Figure 4.4. Only the El Paso mix with 3% emulsion and 60% of the OMC and the San Antonio mix with 5% emulsion and 60% of the OMC provide the strength of 150 psi.

As a comparison, the strengths with the corresponding moisture contents and with no emulsion at all were also measured. About 30 psi to 140 psi (average 100 psi) of strength can be achieved by simply curing the specimens under the same curing condition (at 140°F for 48 hrs) as used for emulsion mixes. For specimens with 60% and 75% of the OMC, the addition of emulsion generally results in a reduction in strength. This may be the result of excess of moisture (from both mixing water and emulsion) in the specimen.

The results from the IDTS tests are shown in Figure 4.5. None of the El Paso mixes provide the required tensile strength of 50 psi, even for the specimens with 3% of emulsion and 60% of the OMC which provided the required UCS. For the San Antonio material, a number of mixes, in particular, the mix with 5% emulsion and 60% of the OMC, provided the adequate IDT strength. With respect to the material from US 287, the addition of emulsion reduced the tensile strengths. Unlike the other three materials used in this study, one specimen without emulsion actually provided the 50 psi threshold required. This phenomenon could possibly be attributed to the high RAP content of the mix (80% RAP). It is likely that the high curing temperature used in this study actually causes the RAP to soften and bind the mix together. The FM 154 specimens with 18% RAP also provided higher IDTS as compared to the San Antonio and El Paso mixes. This trend however was not as pronounced as for the US 287 materials. The addition of emulsion did show increases in IDTS.

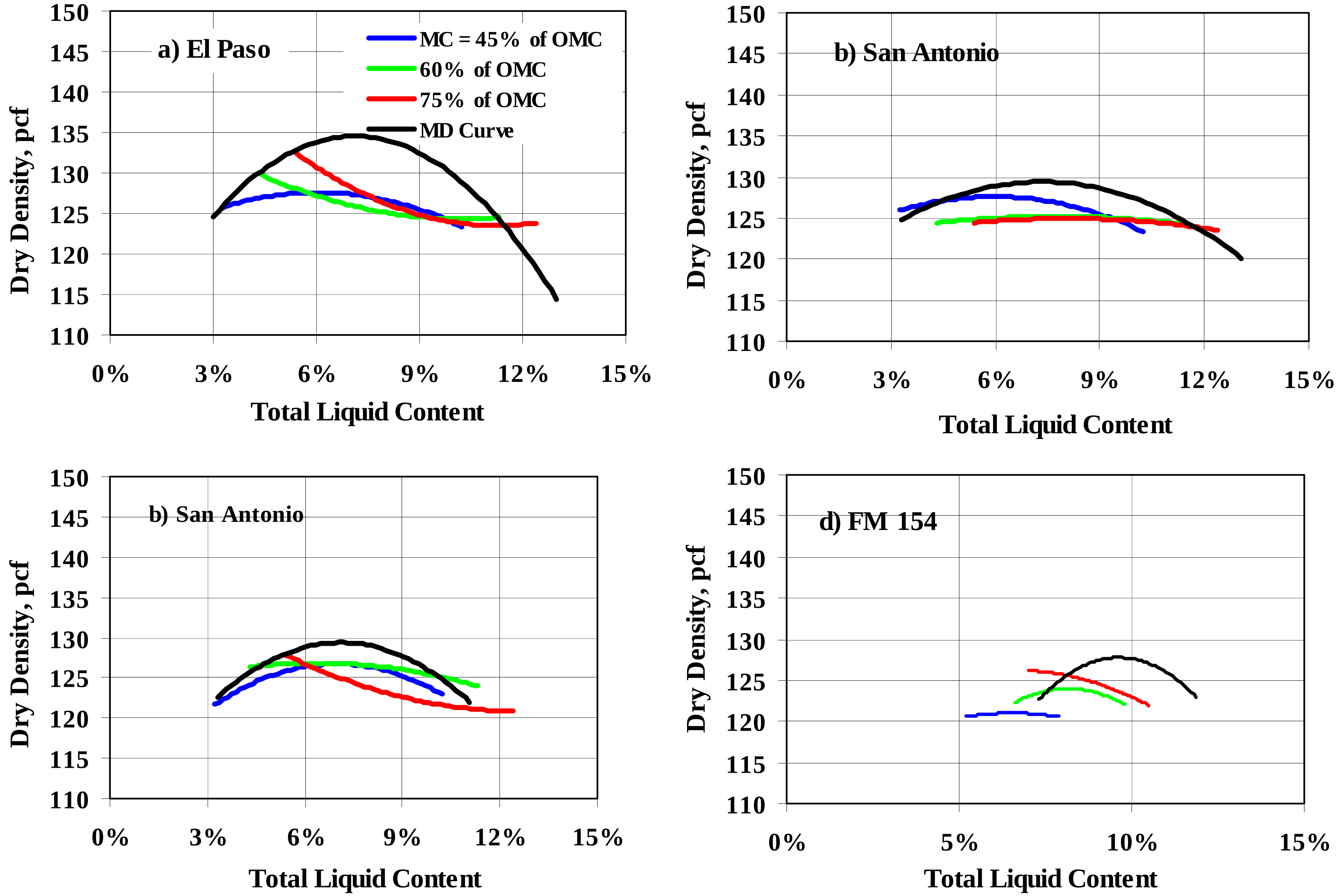

Figure 4.3 – Variations in Density with Total Liquid Content at Different Initial Water Content

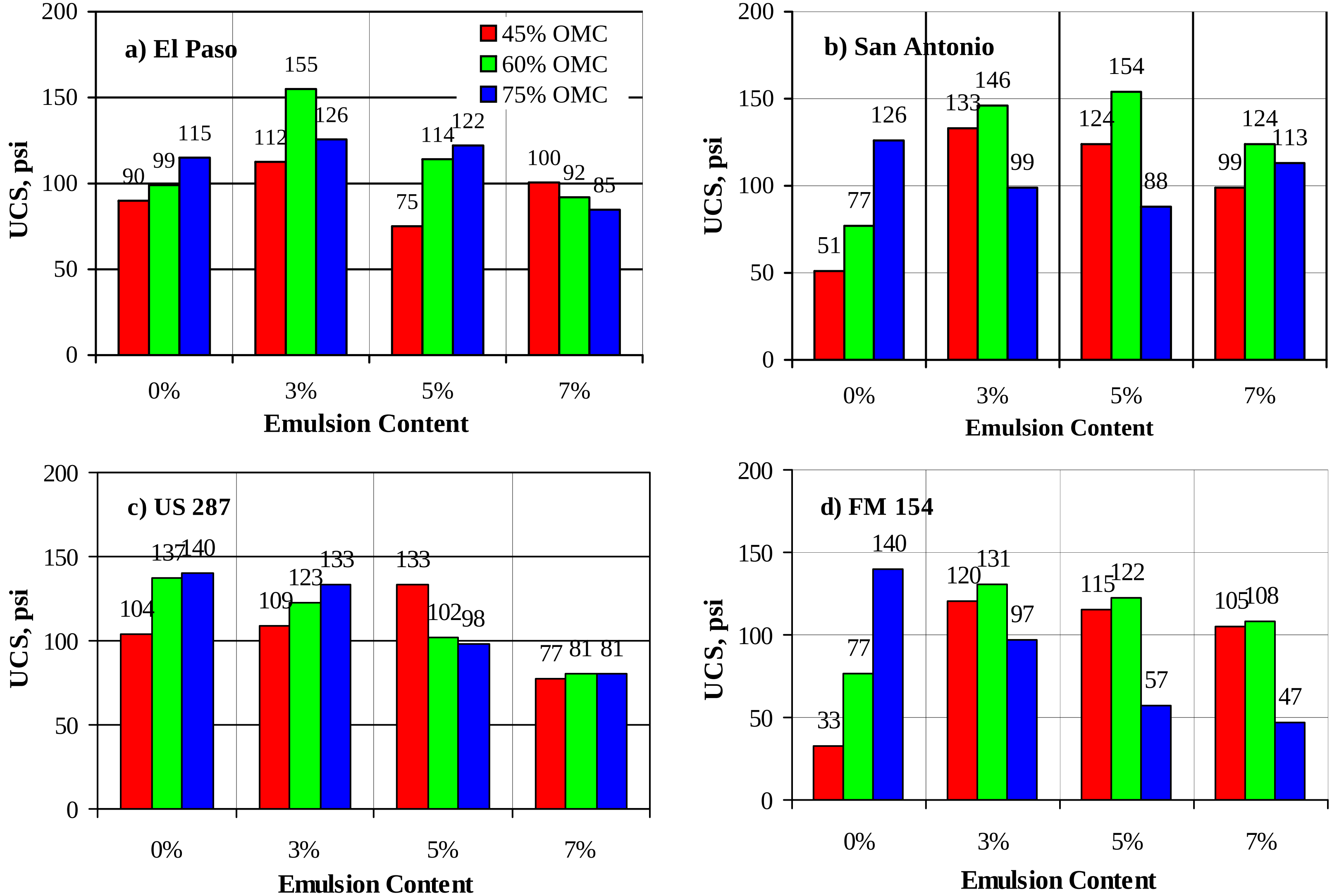

Figure 4.4 - Unconfined Compressive Strengths for Materials with Different Moisture and Emulsion Contents

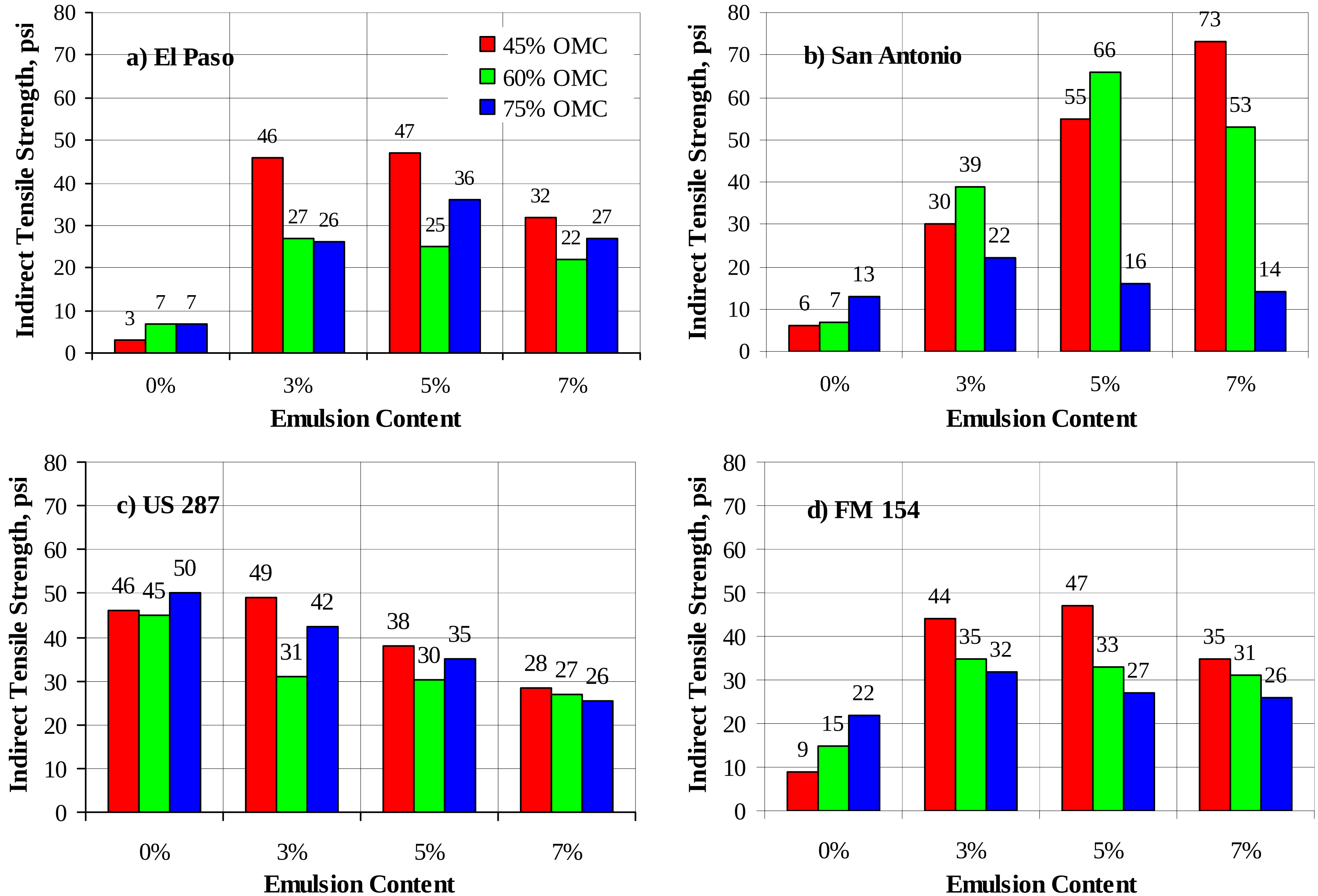

Figure 4.5 – Indirect Tensile Strengths for Materials with Different Moisture and Emulsion Contents

In general, one can observe the substantial increase in IDTS from the specimens with emulsion as compared to those without emulsion when RAP is not included or the RAP content is a small proportion of the mix. This can be considered the value-added benefit of using emulsion. The increased IDTS may impede the cracking of the pavement. At higher moisture contents and emulsion contents, the benefits of the emulsion are significantly diminished.

Another benefit of the addition of emulsion can be observed in Figure 4.6, where the strains at failure are plotted. The higher the strain at failure is, the less brittle the material will become, and the lower the potential for cracking can be anticipated. As the emulsion content increases, the strain at failure increases for almost all materials. The increase in strain seems to be independent of the added initial moisture content. This benefit is more pronounced for the El Paso and San Antonio materials because of their lower fine content and lack of RAP. For the mixture from US 287 with high RAP content, this benefit was not observed.

Based on the results from both UCS and IDTS tests, the possibility of improving the engineering properties of materials with dual stabilizer (asphalt emulsion plus the calcium-based additives such as lime or cement) was studied except for the San Antonio material).

Comparison of Strengths with Dual Stabilizer and Other Options

As shown in the previous section, only the San Antonio material without calcium-based additives passed the strength criteria. The other three materials required either lime or cement to achieve the required strengths. The UCS strengths for the El Paso material (without RAP) and the Yoakum material (with RAP) treated with dual stabilizer and other options are compared in Figure 4.7. For the El Paso material, the addition of 1% cement or lime to 3% emulsion provided adequate UCS strength (see Figure 4.7a). By way of comparison, the UCS results for the mix without any additive and for the mixes with 1% and 2% cement and lime (without emulsion) are also included in Figure 4.7a. Adding 2% cement without emulsion provides a strength value of 170 psi. Even though not shown here, the addition of 4% cement alone provided UCS strength in excess of 400 psi. These results are shown to provoke a discussion on the cost-benefit of considering different additives. For the FM 154 material, the UCS results for mixes with different additives or their combinations are shown in Figure 4.7b. The UCS values of all mixes are greater than 150 psi.

Similarly, the IDTS values for the mixes with different additives or their combinations are shown in Figure 4.8. For the El Paso material, only the mix with 2% cement satisfied the 50 psi as required by the TxDOT Special Specification (Again, TxDOT does have a required IDTS value for cement-treated base materials). For the FM 154 material, the mix either with 2% cement or with 3% emulsion plus 1% lime met the requirement.

For US 287 material, the optimum dual stabilization consists of 1% cement and 3% emulsion. With such a treatment, the UCS and IDTS are 195 psi and 63 psi, respectively, as compared to the highest values of 140 psi and 49 psi obtained for the specimens treated with emulsion only.

A minimum strain value to be achieved by the IDT specimens is not stated in the TxDOT Special Specification. However, a higher strain value at failure indicates that a material is more flexible

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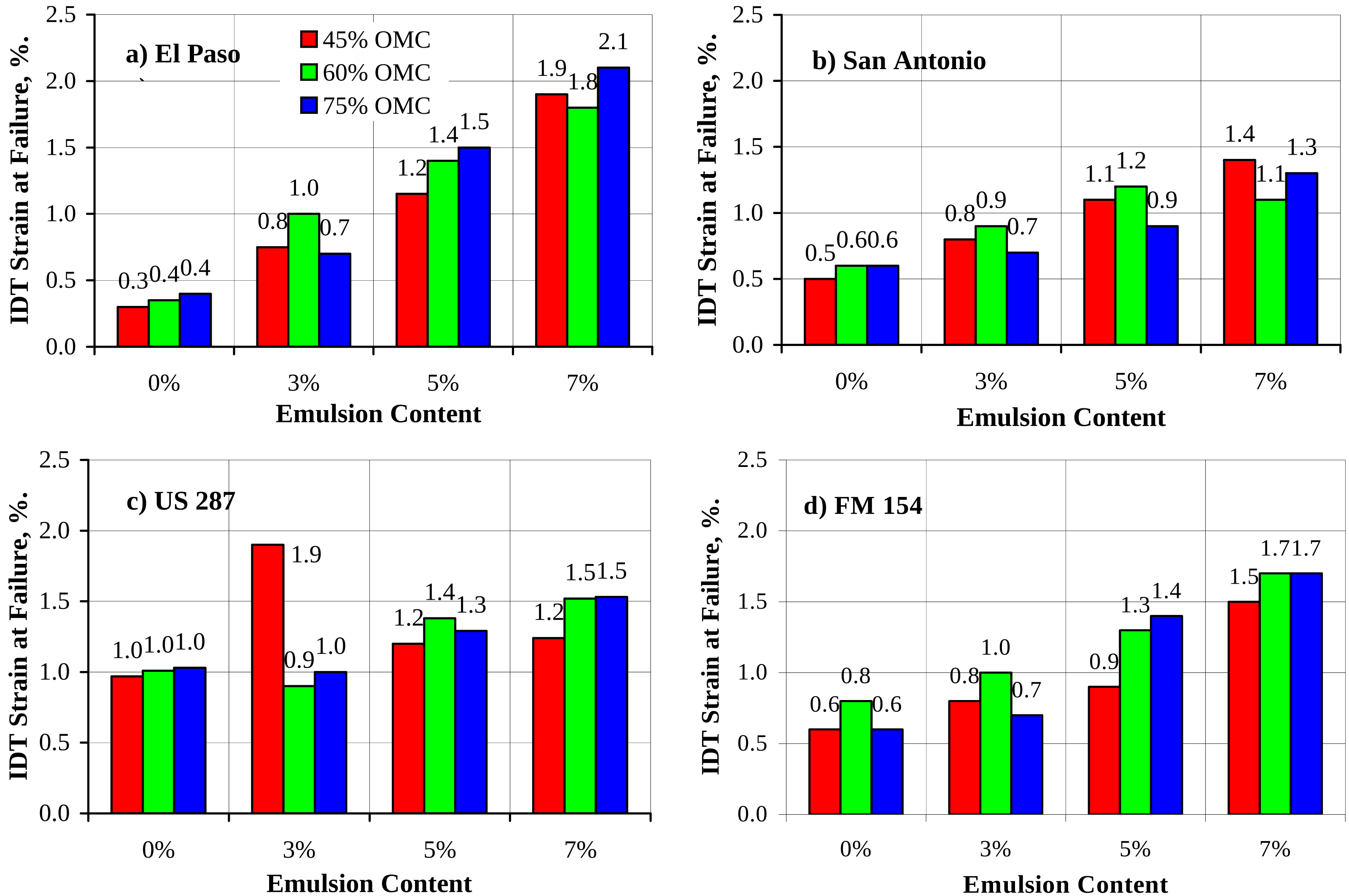

Figure 4.6 - Strains at Failure from IDTS Tests for Materials with Different Moisture and Emulsion Contents

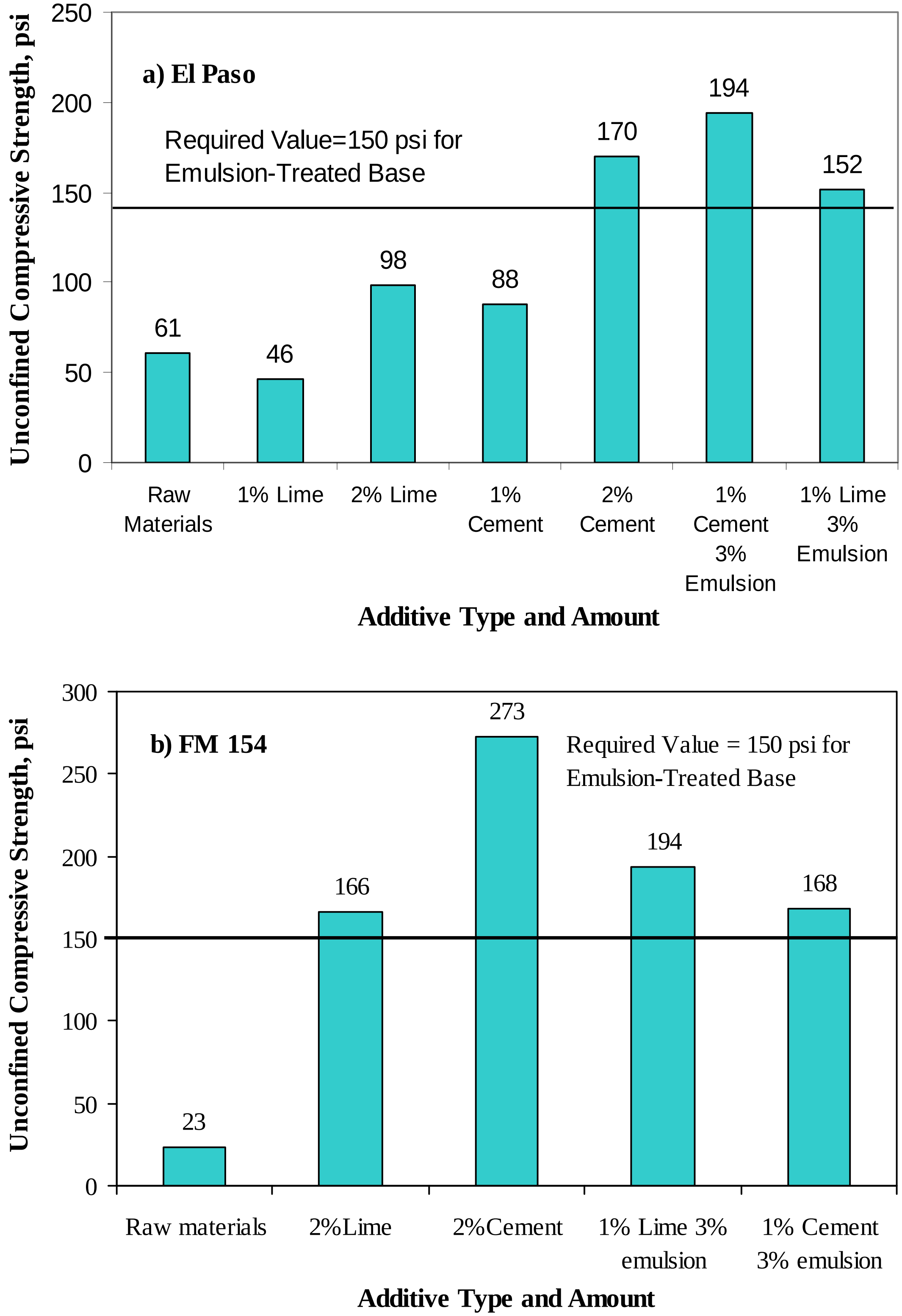

Figure 4.7 - Unconfined Compressive Strengths for El Paso and FM154 Materials with Different Treatments

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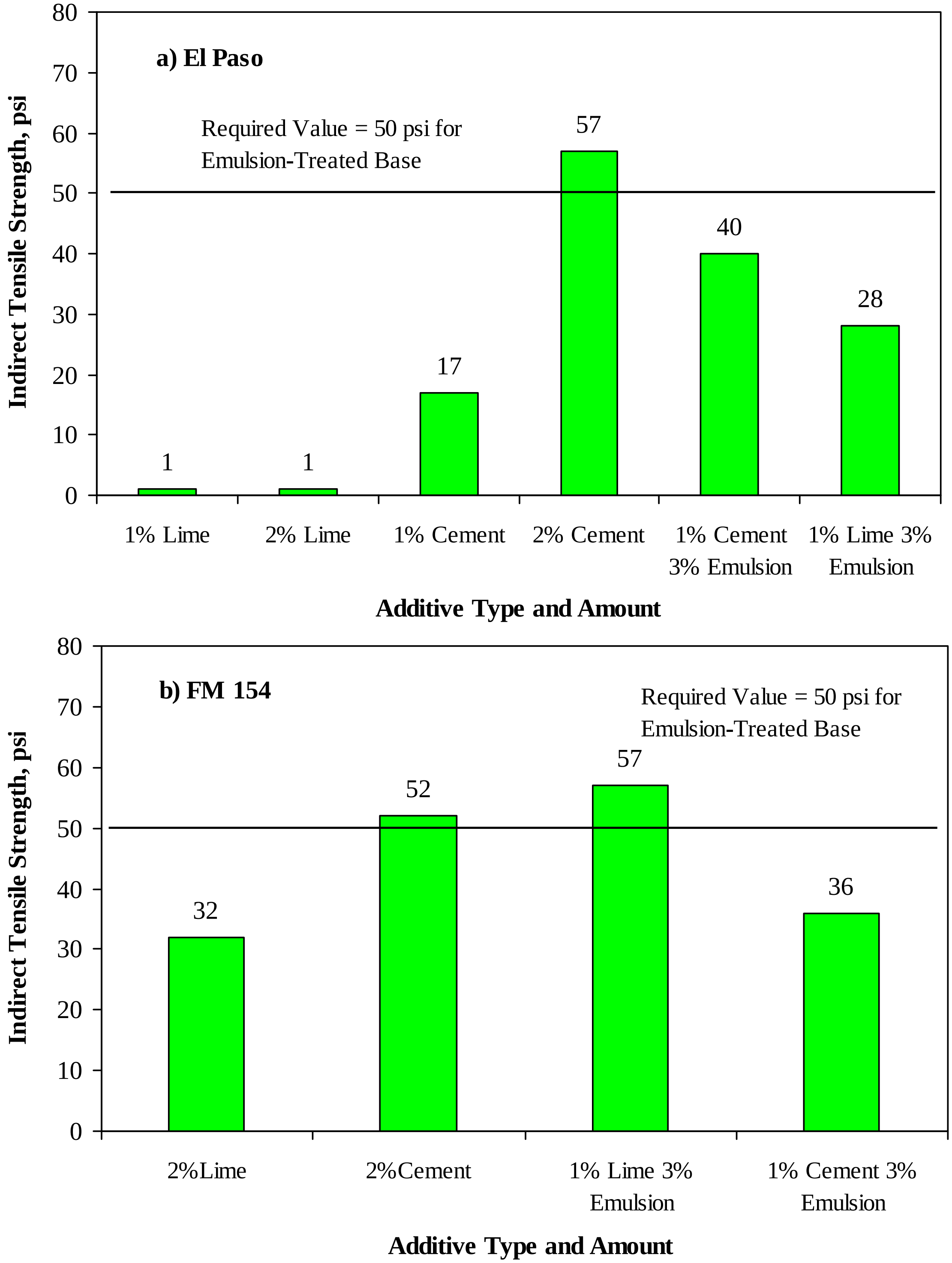

Figure 4.8 - Indirect Tensile Strengths for El Paso and FM 154 Materials with Different Treatments

The addition of 1% or 2% cement to both El Paso material and FM 154 mixture provided either similar or higher strains at failure than the use of the dual stabilization as shown in Figure 4.9.

Tube Suction Test

The tube-suction test (TST) basically provides two major parameters: the dielectric constant and the retained strength. Typically, a dielectric value of ten or less is desirable. As reflected in Figure 4.10, for all mixes and all emulsion contents, the dielectric values are less than 10. Comparing the dielectric values from the materials without emulsion, this is another value-added benefit of the emulsion. Soil suction, permeability and the state of bonding of water that accumulates within the aggregate matrix are the most important parameters impacting the dielectric constant. Preliminarily, a decrease in permeability will normally result in a reduction in dielectric constant.

The retained strength is actually the ratio of the UCS values from moisture conditioned and unconditioned specimens. As reflected in Figure 4.11, all retained strengths are above 100% for mixes with 5% and 7% emulsions. However, for the San Antonio material with 3% emulsion, the retained strength is below 80%, required by the specification. This occurs because of the excess fine content in the San Antonio mix which may provide adequate suction and permeability to allow moisture to be absorbed by the specimens with low emulsion content. With respect to the mixture from US 287, the entire matrix of test specimens attained adequate retained compressive strength values with exception of those which did not contain emulsion. Once again without any additives, the retained strengths of all materials are substantially lower than mixes with added emulsion.

The FFRC tests were performed shortly prior to carrying out compression testing for all specimens and the results are shown in Figure 4.12. Almost all mix designs from El Paso material provide a modulus of 350 ksi or greater. The mixes with initial water content of 75% of the OMC yield higher moduli than those with lower initial moisture contents. This is perhaps the manifestation of the curing of the specimens in the oven for 48 hours. The freely-available water allows the specimens to “bake” into a very stiff material. The moduli for the San Antonio virgin material, US 287 and FM 154 mixtures are less than 340 ksi.

The retained moduli from the TST specimens are shown in Figure 4.13. Similar to the retained strength, the retained modulus is defined as the ratio of the modulus values from moisture conditioned and unconditioned specimens. Once again, the retained moduli for mixes with emulsion generally yield a value greater than 100%, indicating that the specimens become stiffer with moisture conditioning. The mixes without emulsion perform quite poorly under the moisture conditioning circumstance with retained moduli of less than 15%.

In order to further investigate the possible benefits of emulsion treatment, IDT tests were carried out on specimens moisture-conditioned for 8 days after 2-day dry cure. A baseline value of 60% of OMC was used for all mixes, but the emulsion contents were varied. As shown in Figure 4.14, the retained tensile strengths for all mixes with emulsion are greater than 80% which is the value required by the TxDOT Special Specification for retained unconfined compressive strength.

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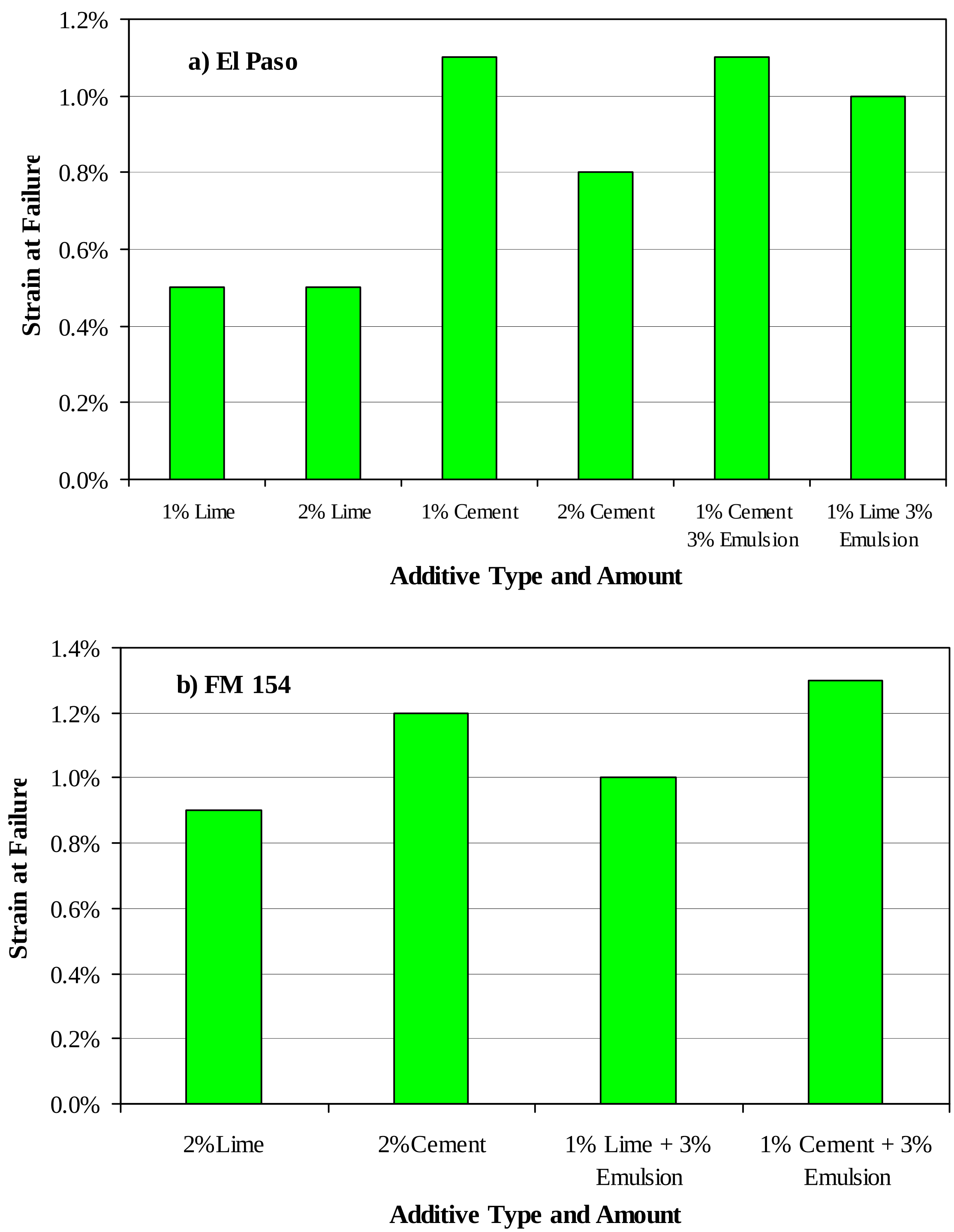

Figure 4.9 – Strains at Failure from Indirect Tensile Strength Tests on El Paso and FM 154 Materials with Different Treatments

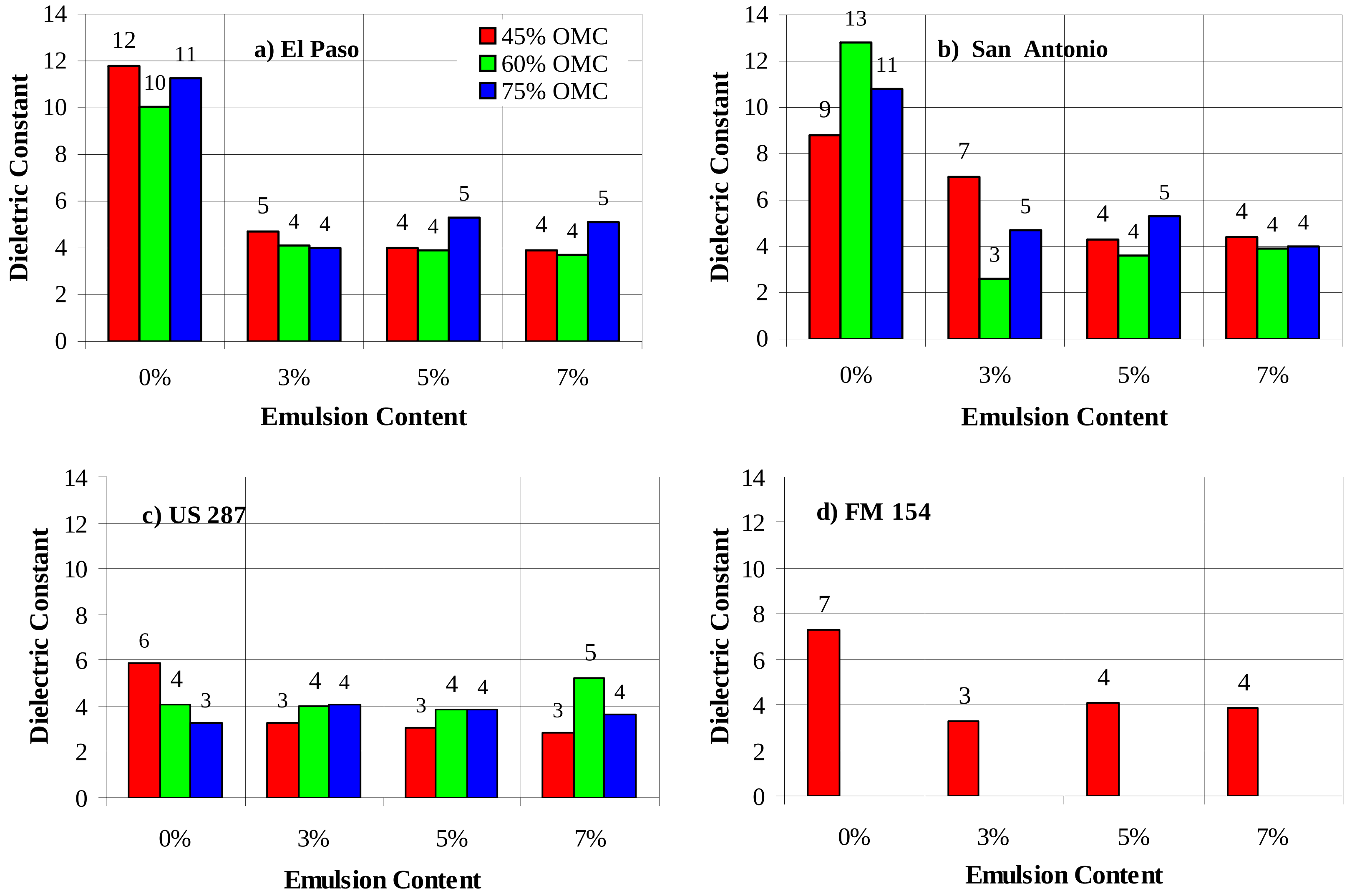

Figure 4.10 – Dielectric Constants for Materials with Different Moisture and Emulsion Contents from TST Specimens

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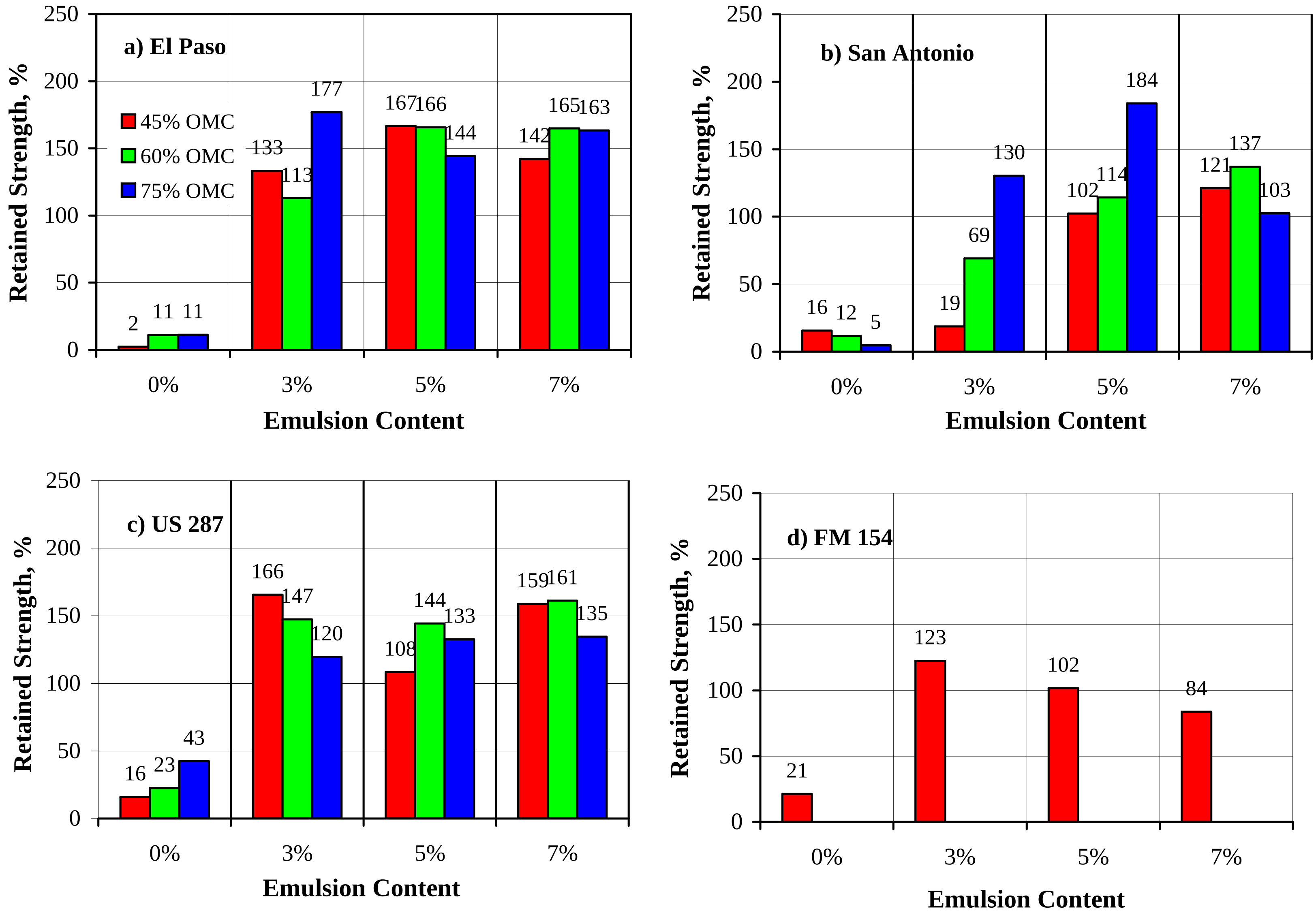

Figure 4.11 – Retained Strengths for Materials with Different Moisture and Emulsion Contents from TST Specimens

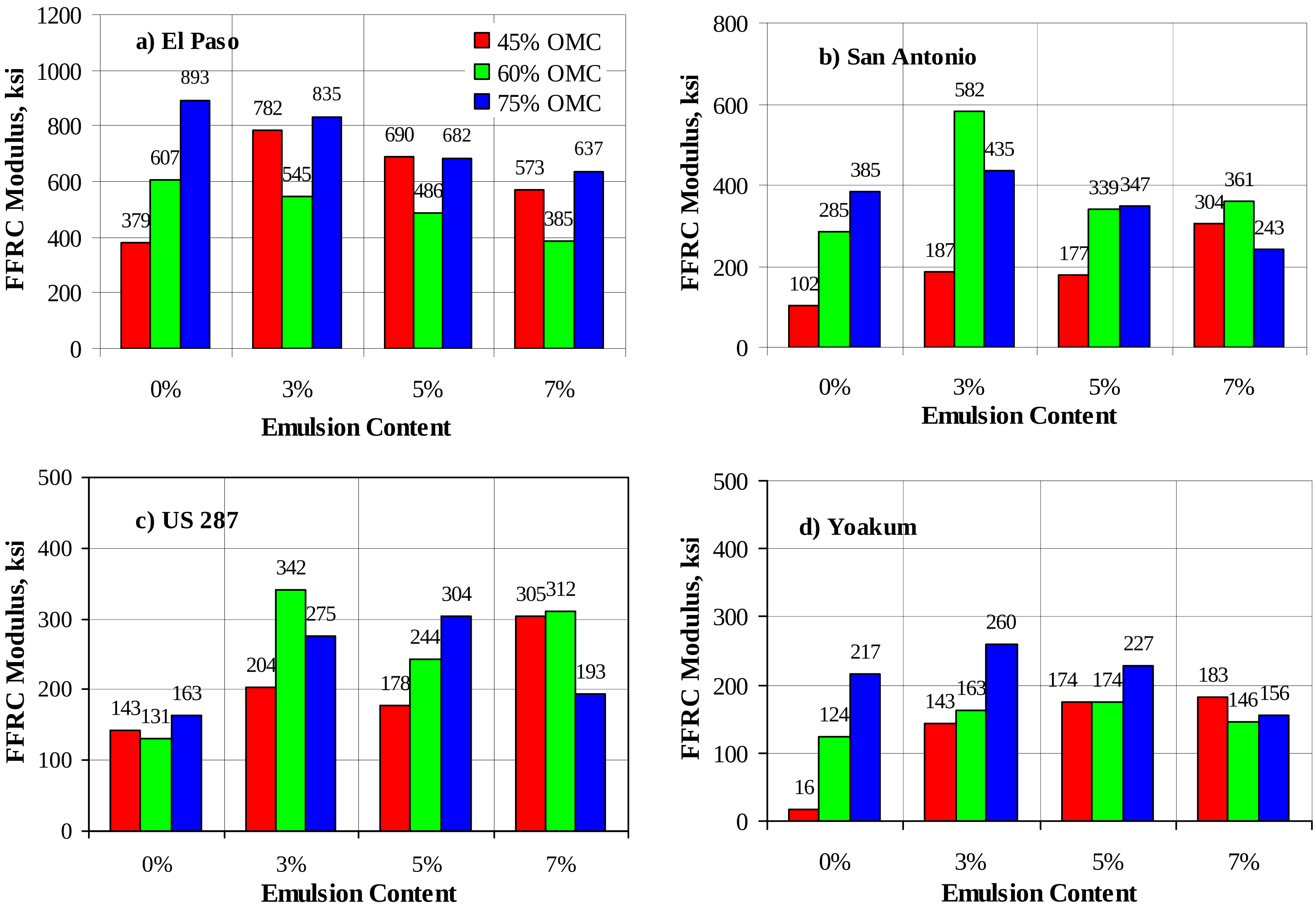

Figure 4.12 - Seismic Moduli for Materials with Different Moisture and Emulsion Contents from UCS Specimens

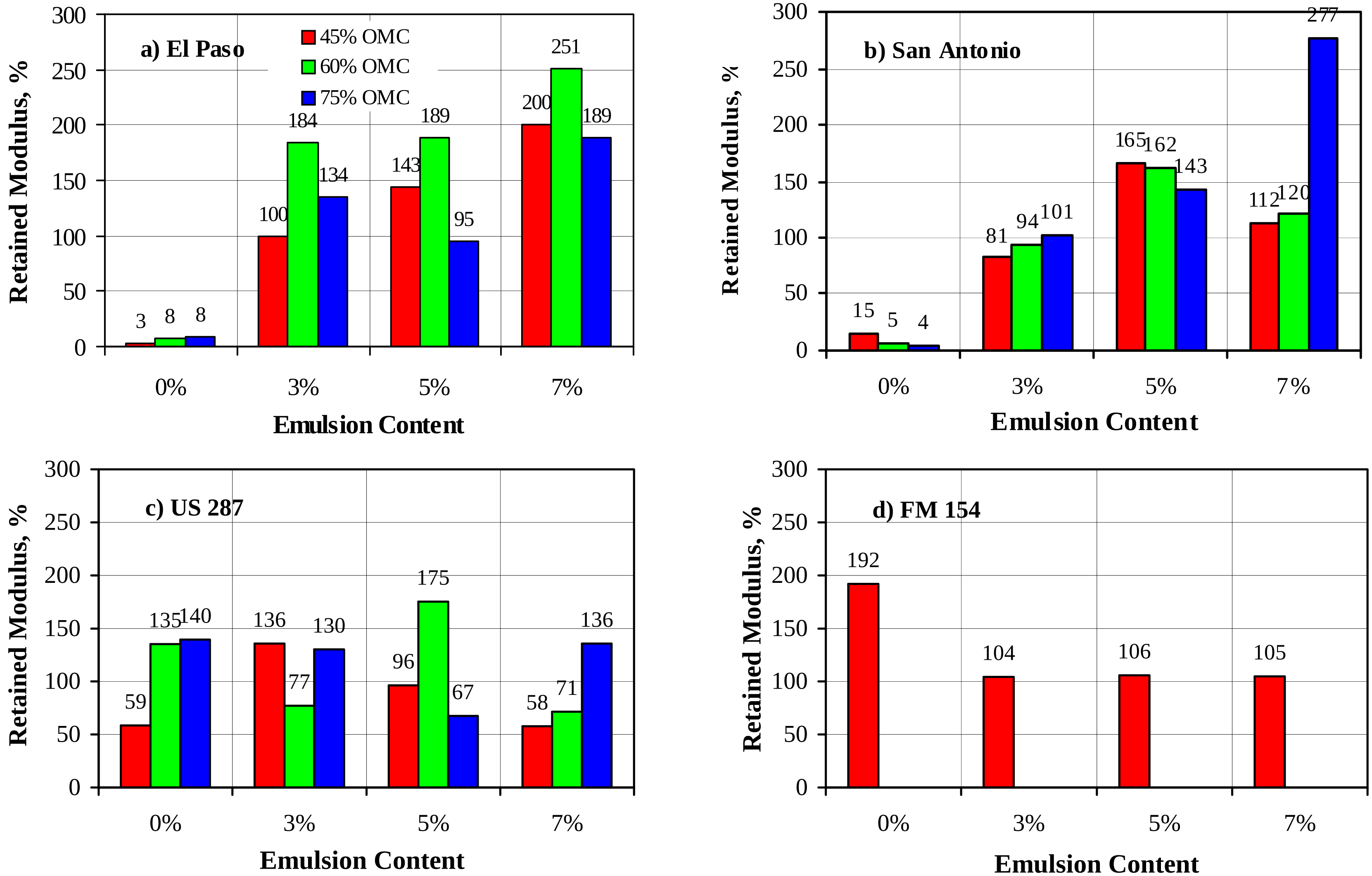

Figure 4.13 - Retained Moduli for Materials with Different Moisture and Emulsion Contents from TST Specimens

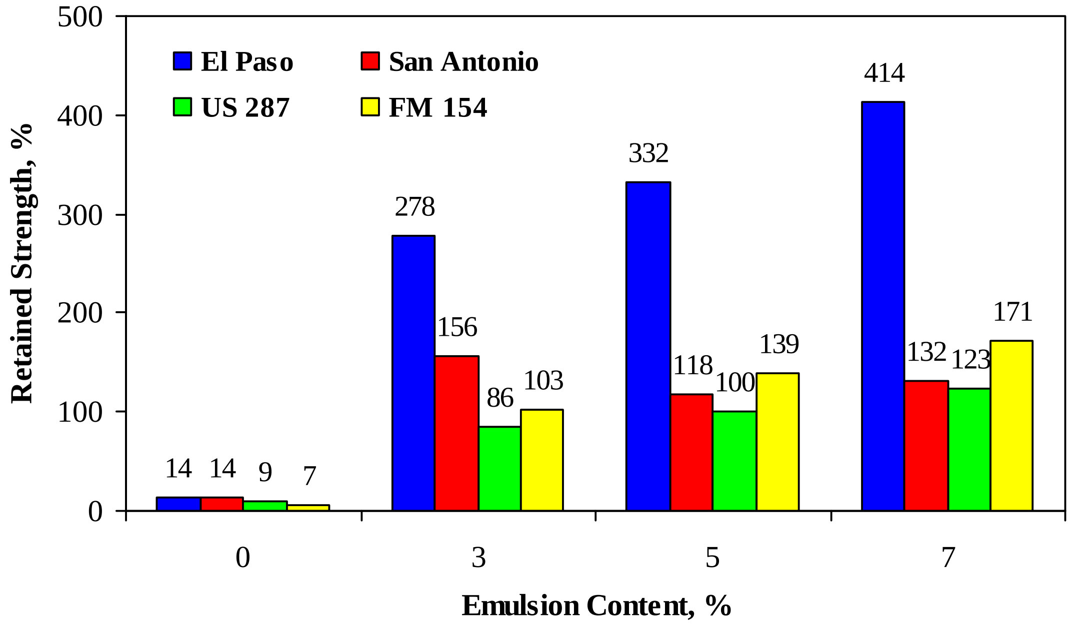

Figure 4.14 – Retained Indirect Tensile Strengths

Resilient Modulus Test

The resilient modulus test is advocated in almost all mechanistic-empirical design methods. TxDOT currently does not have a protocol for performing resilient modulus tests on base materials. AASHTO T-307 protocol describes the test procedure for the determination of resilient modulus. The step-by-step procedure used to determine the resilient moduli of different materials can be found in Nazarian et al. (1999). The setup required to carry out the tests is shown in Figure 4.15. A repeated axial cyclic stress of fixed magnitude, load duration (0.1 s), and cycle duration (1.0 s) is applied to a test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a static-confining pressure provided by means of a triaxial pressure chamber. The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus. The sequence used in this project is a modified version of the sequence provided in AASTHO T-307. The test is begun by applying 1000 repetitions of a load equivalent to a maximum axial stress of 15 psi at a confining pressure of 15 psi. This is followed by a sequence of loadings with varying confining pressures and deviator stresses. A combination of confining pressures of 3, 5, 10, 15 and 20 psi and deviatoric stresses of 1, 2, 3, 5, 6, 9, 10, 15, 20, 30, and 40 psi are used. To utilize the results in design, the resilient modulus is given by a nonlinear relationship in the form of

$$E = k_1 \; \sigma_c^{\;k_2} \; \sigma_d^{\;k_3} \tag{4.2}$$

where k_1, k_2 and k_3 are coefficients determined from laboratory resilient modulus tests and σ_c and σ_d are the confining pressure and deviatoric stress (applied axial stress), respectively. The advantage of this type of models is that it is universally applicable to fine-grained and coarse-grained base and subgrade materials.

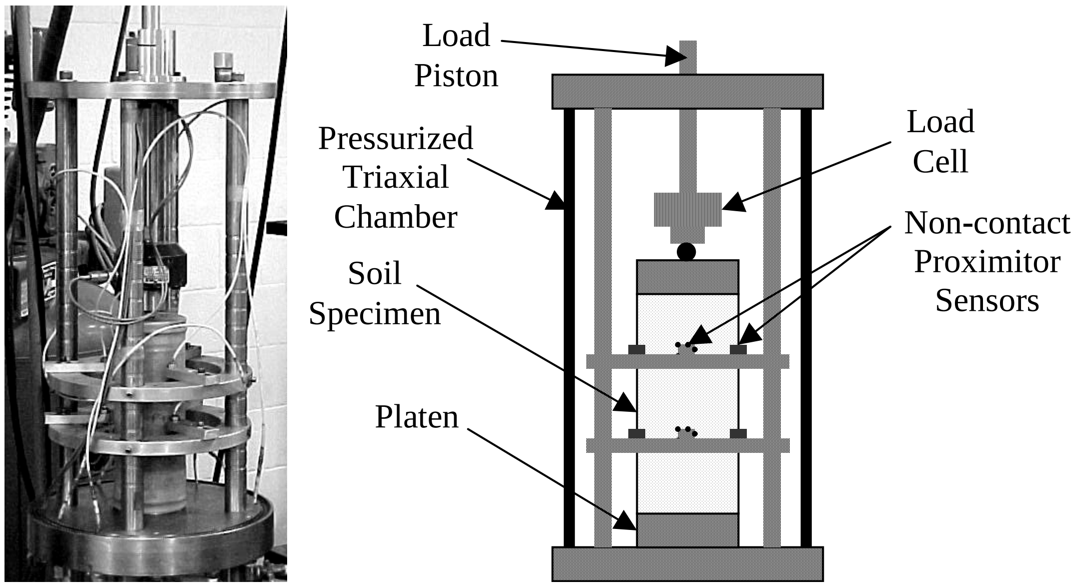

Figure 4.15 – Resilient Modulus Test Device and Setup

Typical results from two tests are shown in Figure 4.16. The resilient modulus of stabilized materials should be independent of the confining pressure and deviatoric stress. The results from the two tests, shown below, deviate from this trend. This might be due to the fact that the specimens might be too stiff for reliable resilient modulus tests as per AASHTO T-307. Based on these results and the fact that the resilient modulus tests are very time consuming and may not be suitable for day-to-day use of TxDOT, it is recommended that the FFRC tests instead of the resilient modulus tests be used.

Optimum Mix Designs

Based on the results shown, the optimum mix designs determined for El Paso and San Antonio virgin materials, US 287 and FM 154 mixtures are summarized in Table 4.4. These designs fulfill all the design requirements of the current specifications except for the indirect tensile strength for the El Paso material.

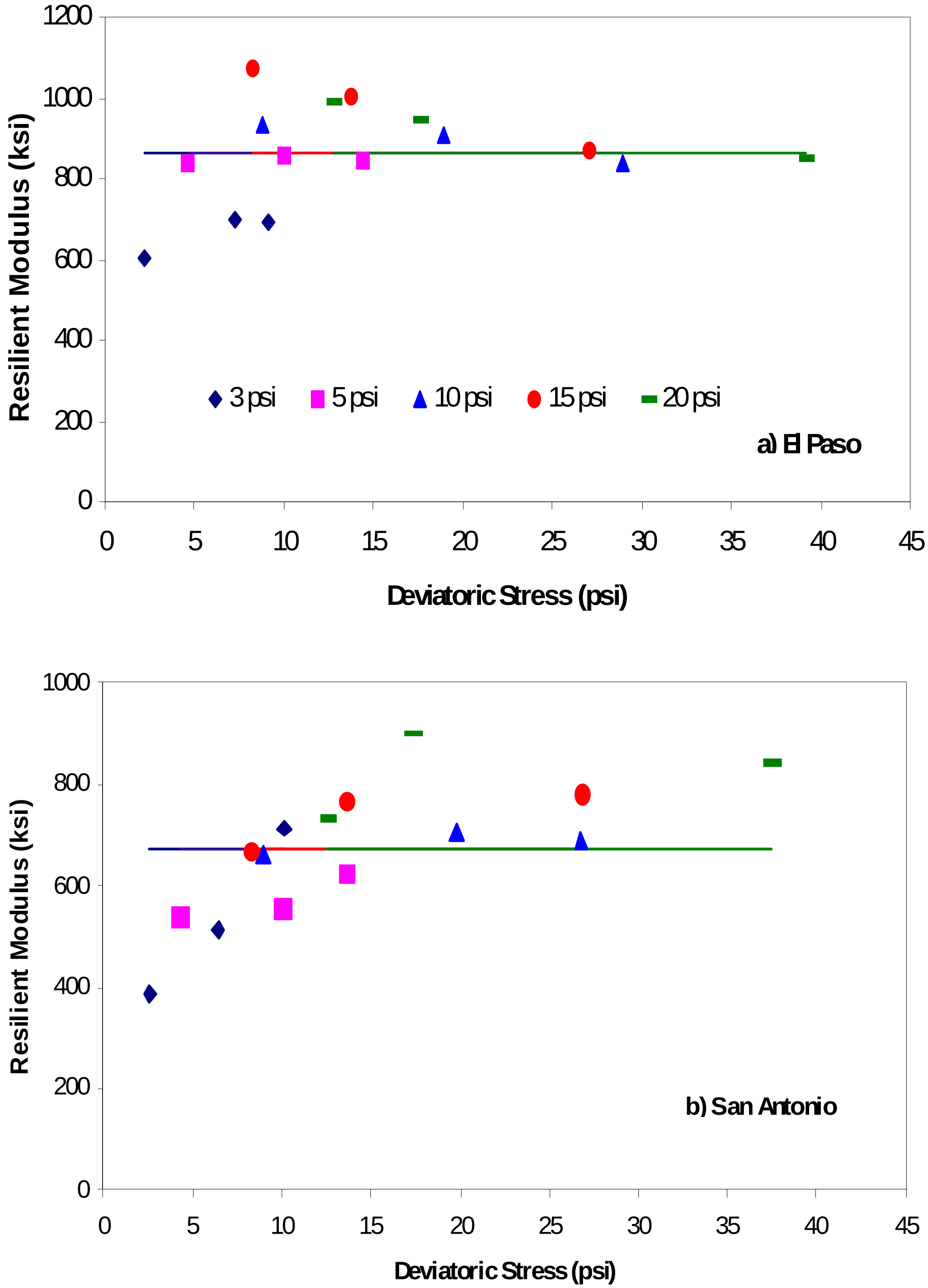

Figure 4.16 – Resilient Moduli of El Paso and San Antonio Materials from Specimens Prepared at Designed Total Liquid Contents

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Table 4.4 - Optimum Mix Designs and Properties for Materials under Study

Parameter	El Paso	San Antonio	US 287	FM 154
Asphalt Emulsion	3%	5%	3%	3%
Calcium-Based Additive	1% Cement	None	1% Cement	1% Lime
Mixing Water	60% of OMC	60% of OMC	75% of OMC	60% of OMC
Unconfined Compressive Strength	194 psi	154 psi	195 psi	194 psi
Indirect Tensile Strength	40 psi	55 psi	63 psi	57 psi
Retained Strength	122%	114%	115%	96%
Dielectric Constant	3	4	4	4
Resilient Modulus	863	673	N/A	N/A
FFRC Seismic Modulus	585 ksi	339 ksi	250 ksi	322 ksi
Retained Modulus	130%	162%	85%	92%

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Chapter 5

Laboratory Testing – Parametric Study

Introduction

One of the goals of this study was to document the impact of construction-related parameters on mix design results. As such, changes in mix design-related parameters were evaluated during the course of this research.

According to the TxDOT Special Specification, the aggregate in a base material should comply with TxDOT Item 247. Under this item, the nature, gradation and hardness of aggregates, the index parameters of each base material, and in some occasions the compressive strength should be evaluated. Based on the literature search, the percent passing No. 200 sieve also needs to be considered as well.

The density of a base material plays an important role in its overall performance as well. The TxDOT Special Specification recommends that the density of a material in the laboratory be determined as per Procedure Tex-113-E. However, work carried out by Mallick et al. (2002) has shown that the use of a Superpave Gyratory Compactor (SGC) is more appropriate for asphalt emulsion-treated base materials. Based on a comparison of the behaviors of the compacted materials in the field as well as in the laboratory, they have recommended 50 gyrations as appropriate.

The effects of curing time and temperature were also evaluated as part of this study. Emulsion type and its impact on the strength parameters of stabilized bases is another parameter which was taken into account during the course of these investigations. Lastly, in order to look at aggregate coating properties, the effects of initial mixing apparatus on these types of mixes were evaluated.

Based on the mix designs provided in Chapter 4, a number of parametric studies were carried out so that the significant parameters that impact the strength/stiffness and long-term durability of the mixes can be identified.

Impact of Gradation

Full-depth reclamation (FDR) for road rehabilitation is routinely carried out through the pulverization process which may change the material gradation. Usually, the change in gradation is the increase in either fine sand or fines or both. To test the impact of gradation, three additional gradations from each of the two quarry materials were considered. In one mix, it was assumed that the coarse aggregates will be crushed to the aggregates of sand size (Excess Sand or ES). In the "Excess Fine or EF" gradation, it is assumed that the coarser aggregates will be crushed to fines. Finally, in the last mix it is assumed that the coarse aggregates will be crushed to produce both fines and sand (Excess Fine and Sand or ESF). As an example, the four gradations for the El Paso material are shown in Table 5.1 and Figure 5.1.

Table 5.1 - Gradations Used in This Study

Sieve No.	Size, mm	Percent Passing per Sieve			
		Natural	Excess Sand (ES)	Excess Fines (EF)	Excess Sand and Fines (ESF)
$1^{3/4}$ in	44.450	100	100	100	100
7/8 in	22.225	78	78	78	82
3/8 in	9.525	60	60	60	65
No. 4	4.750	45	52	45	54
No. 40	.425	23	27	28	29
No. 100	.150	12	15	23	23
No. 200	.075	5	5	20	20

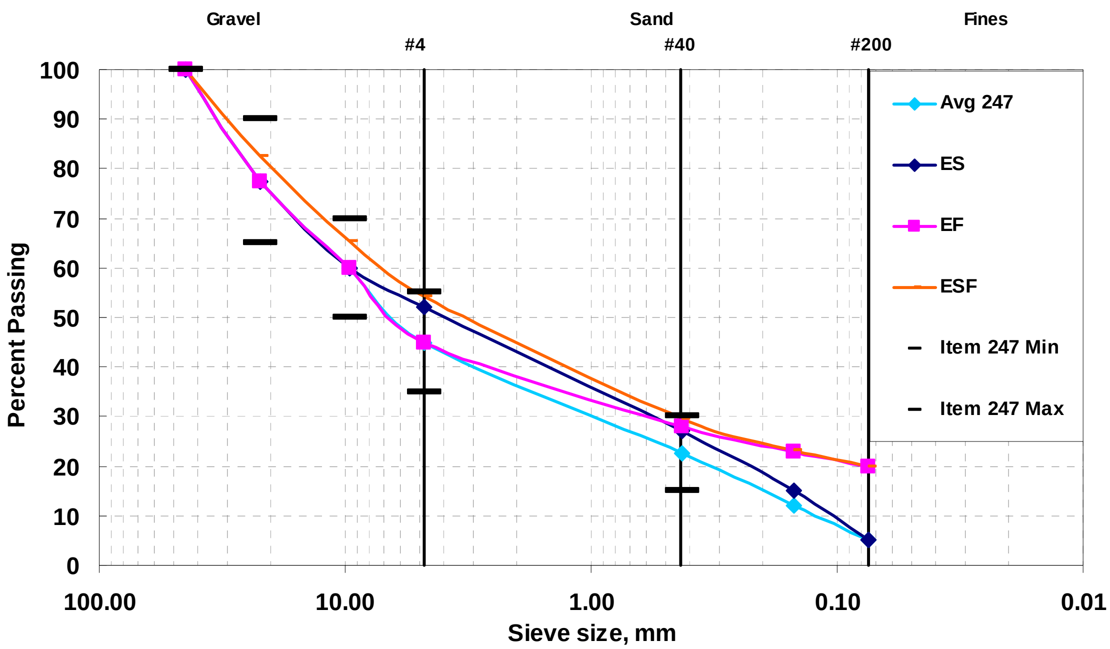

Figure 5.1 - Gradation Curves of Four Mixes from El Paso Material

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The unconfined compressive strengths of the specimens after two days of dry curing and after moisture conditioning, and indirect tensile strengths of the specimens after two days of dry curing for all gradations are shown in Figure 5.2. For the El Paso material, the addition of the excess sand or excess fine improved the UCS but adversely impacted the IDTS. For the San Antonio material, the addition of excess fines was detrimental to the quality of the mix. The variations in modulus for the same UCS specimens are shown in Figure 5.3. Similar trends to the strengths are observed.

This study indicates the importance of considering the change in gradation due to the effect of pulverization process for the mix design. The design should be carried out on a gradation that considers the change in gradation during pulverization.

Impact of Emulsion Type

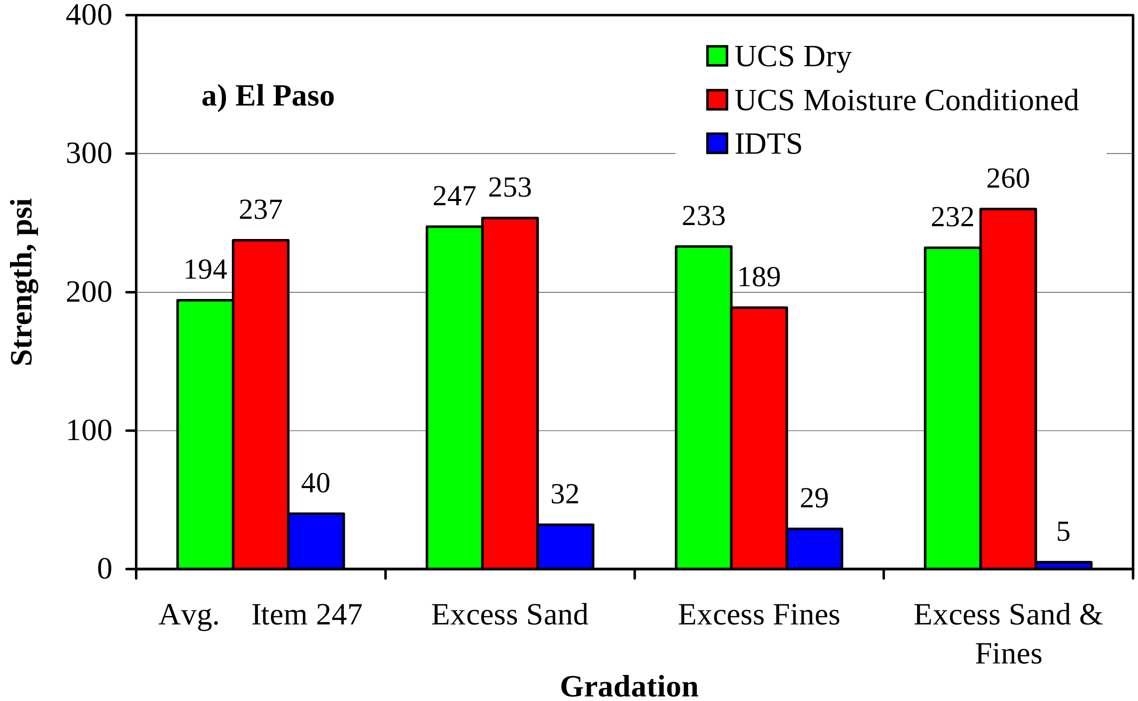
Besides the rate of residual asphalt, a number of other well known factors impact the quality of an emulsion, and as a result, emulsion mixes. Almost all emulsion projects currently utilize a proprietary emulsion. An anionic SS-1 generic emulsion that met the requirements of TxDOT specifications was also used. The residue from distillation was about 63% and the penetration at 77^{o}F about 91 dmm. Although several attempts were made, we could not locate a source of cationic emulsion within the surrounding area. The results from this study were mixed, as shown in Figure 5.4. For the El Paso material, the proprietary emulsion provided higher strengths, especially for IDTS. For the San Antonio material and US 287 mixture, the generic emulsion yielded higher dry compressive strengths but lower tensile strengths. The mixture from FM 154 did not perform as well with the introduction of the generic emulsion. The results for all strength tests showed lower values than with that of the proprietary emulsion.

For all materials used in this study, with the exception of FM 154 mixture, the moisture conditioned specimens with the proprietary emulsion exhibited higher strengths than the dry-cured specimens; whereas the mixes with the generic emulsion exhibited some moisture susceptibility by yielding lower strengths for moisture-conditioned specimens.

Impact of Curing Temperature and Time

The strength and stiffness development of emulsion-treated base materials are highly dependent on curing temperature and time. One of the arbitrary aspects in the current mix design procedures is the use of a temperature of 140^{o}F for curing the specimens before strength tests. In most cases, this temperature is very different from those at which the newly constructed bases are cured in the field. A number of specimens were prepared from El Paso and San Antonio materials as well as US 287 and FM 2790 mixtures in the same manners as described before but were cured at 140^{o}F, 104^{o}F, 70^{o}F and 50^{o}F, respectively.

Figure 5.5 shows the impact of curing temperature on strength parameters. Specimens were tested after two-day curing in this case. Generally, the strength decreases as the temperature decreases and the indirect tensile strength seems to be impacted more by curing temperature. Even though not shown here, the variations in modulus are similar to those observed with the indirect tensile strength test results.



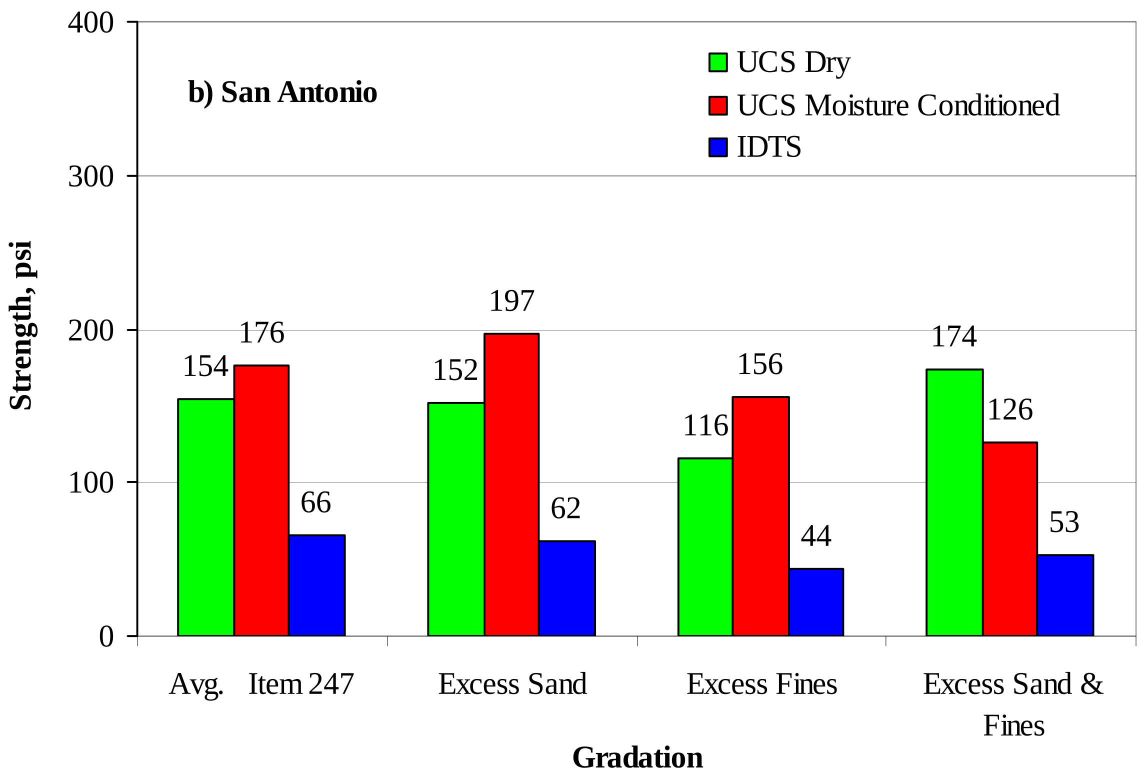


Figure 5.2 – Impact of Gradation on Strength Parameters

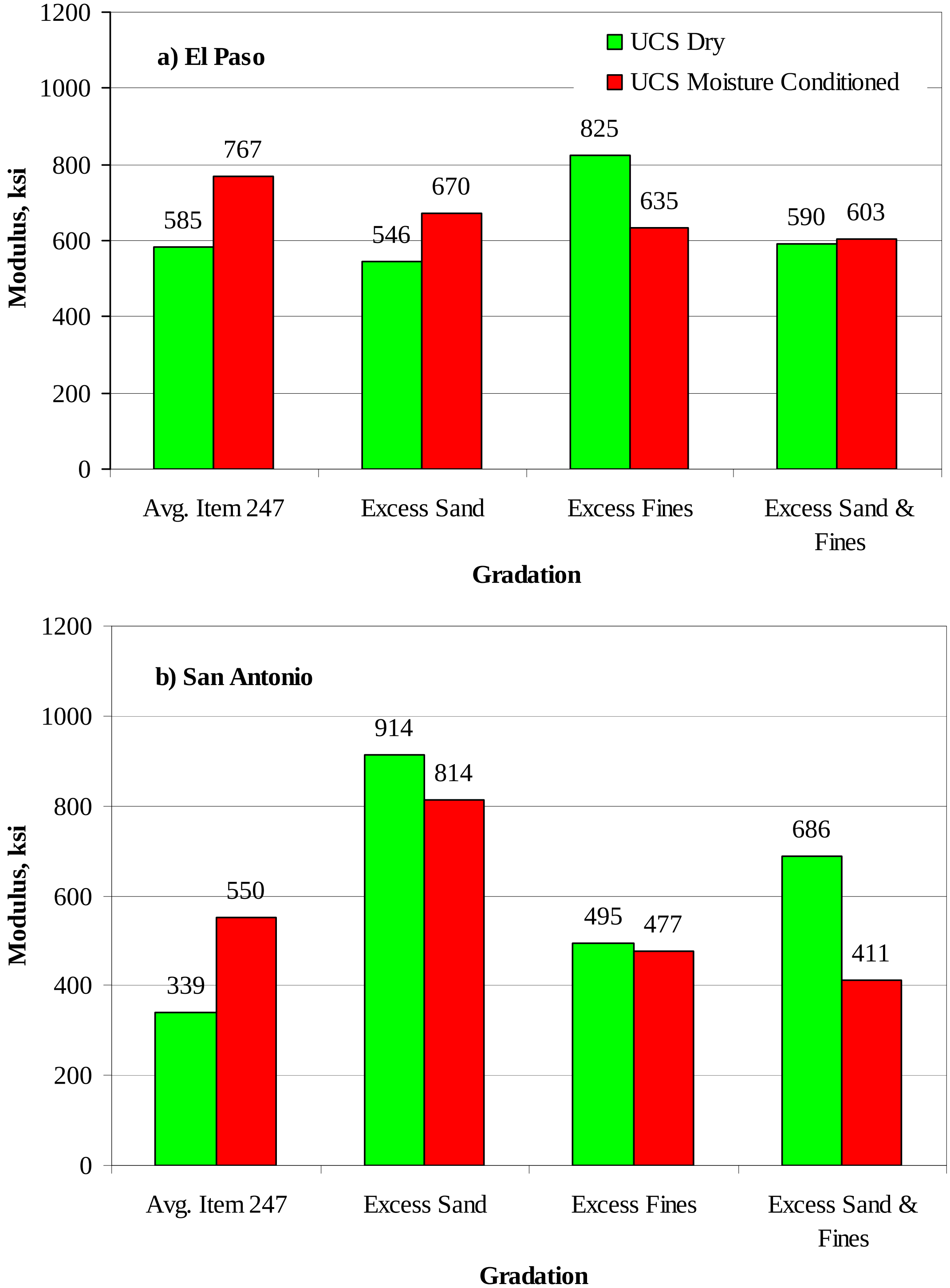


Figure 5.3 – Impact of Gradation on FFRC Modulus

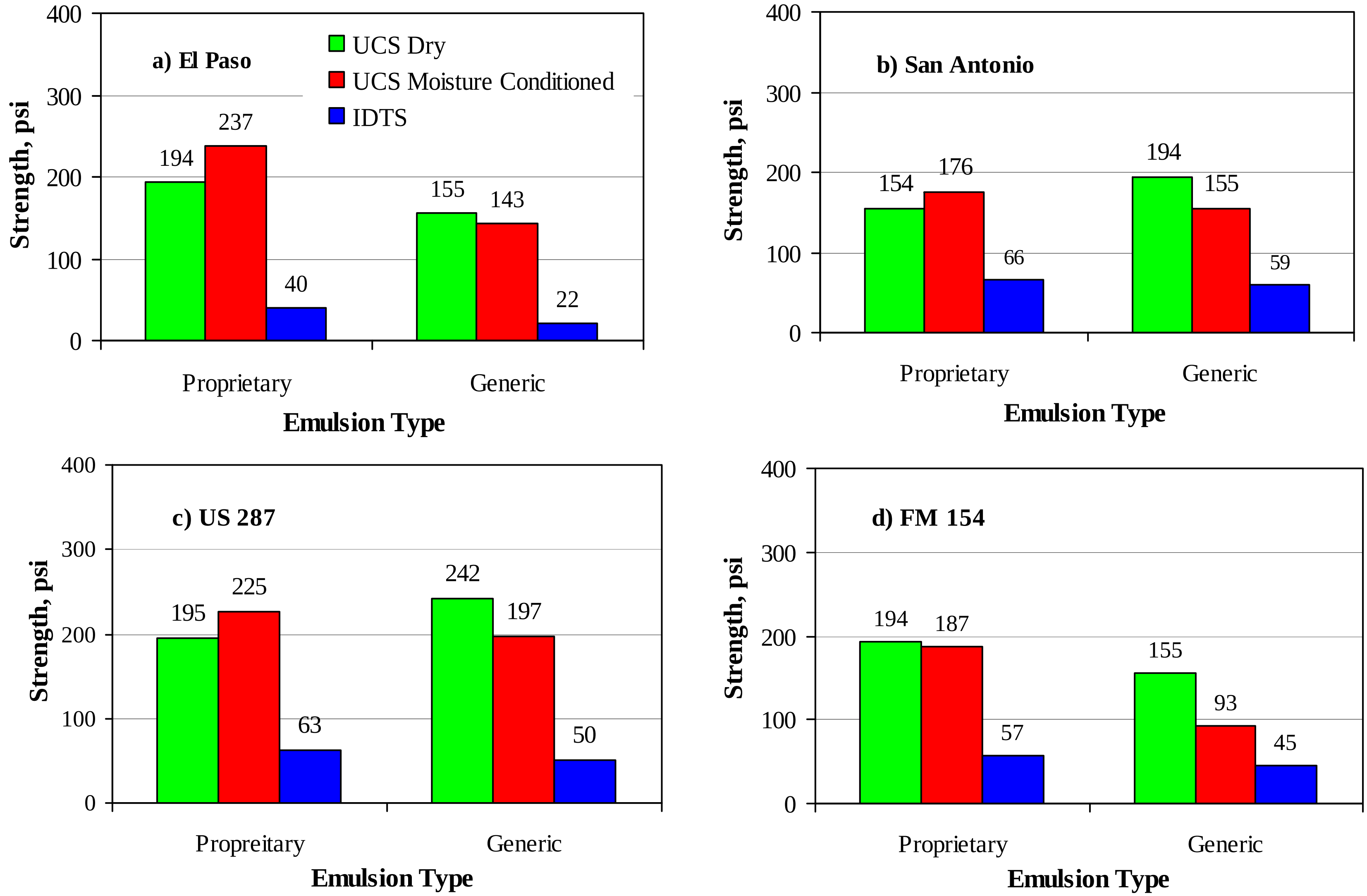


Figure 5.4 - Impact of Emulsion Type on Strength Parameters

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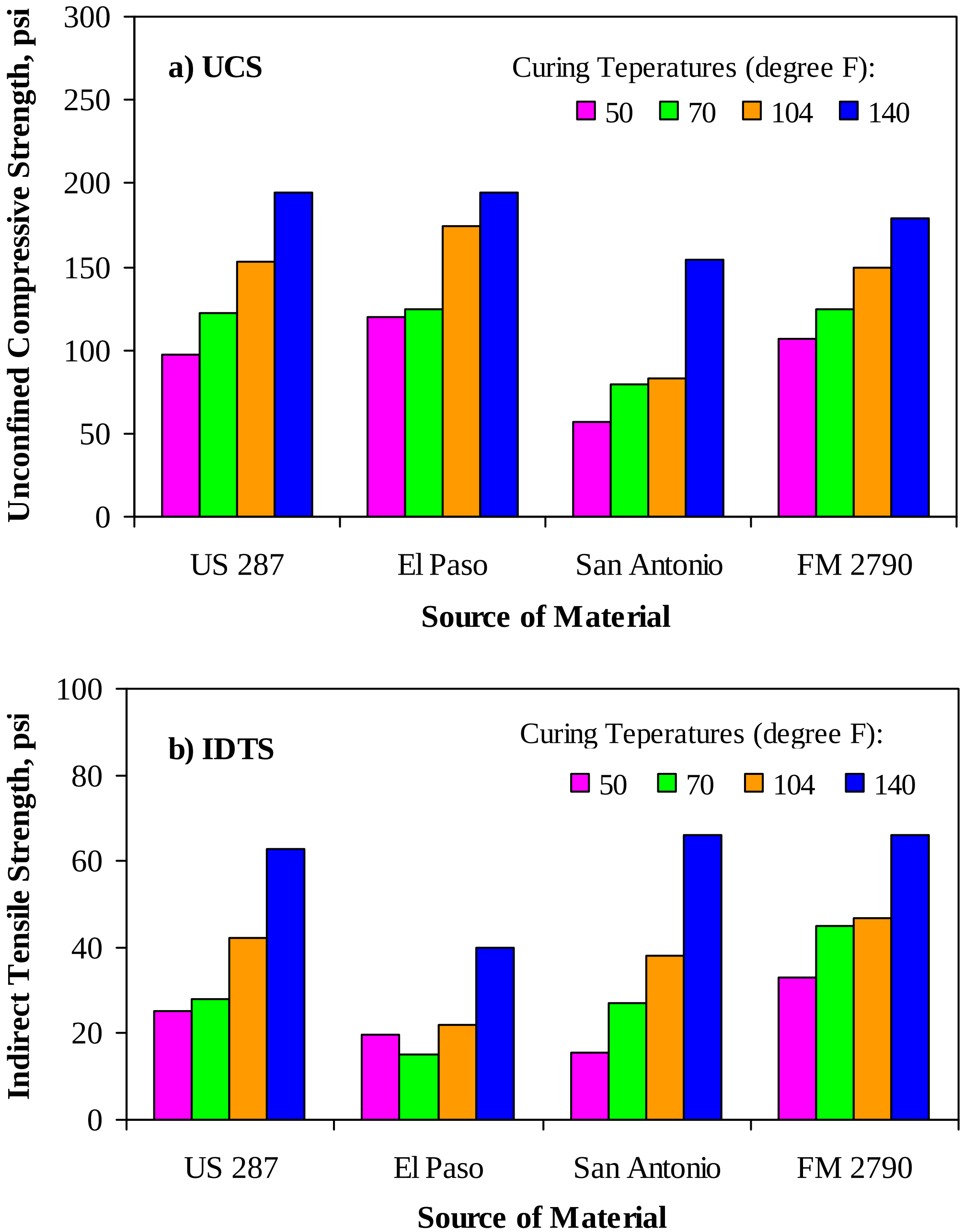

Figure 5.5 – Impact of Curing Temperature on Strength Parameters

To address the impact of curing time on strength parameters, specimens cured at 50°F and 104°F, which represent a cool and a hot ambient temperatures in Texas, were broken after two-day curing and ten-day curing without moisture conditioning. Figure 5.6 indicates that the impact of curing time on the compressive strength development of emulsion-treated materials is evident. As can be seen in Figure 5.7, a similar trend also appears for indirect tensile strength.

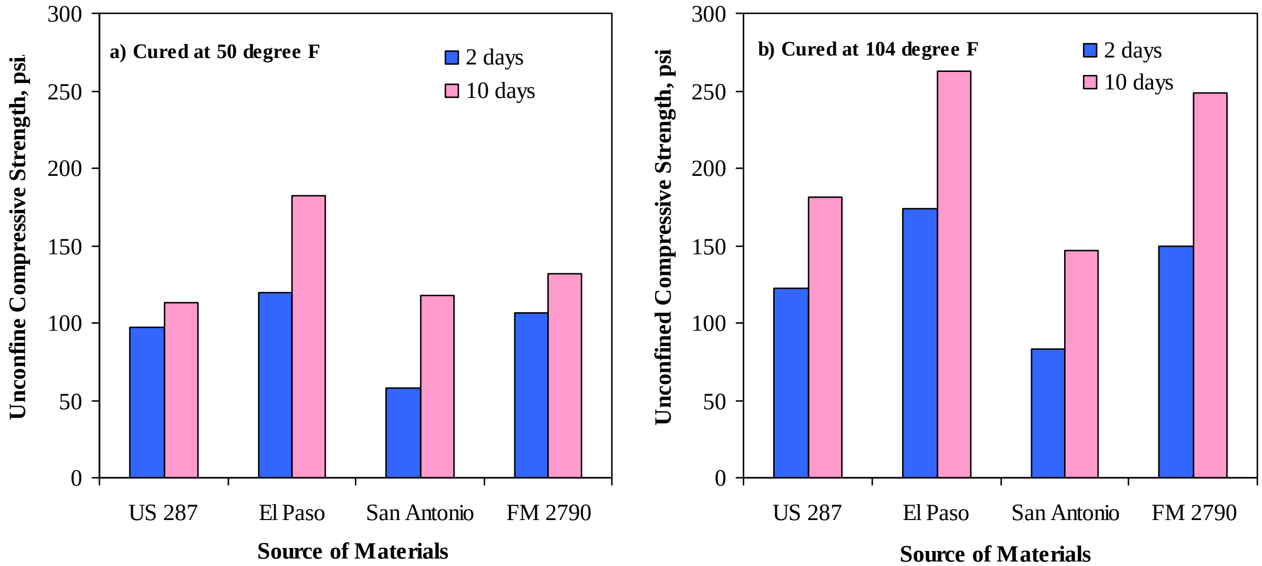

Figure 5.6 – Impact of Curing Time on Unconfined Compressive Strength

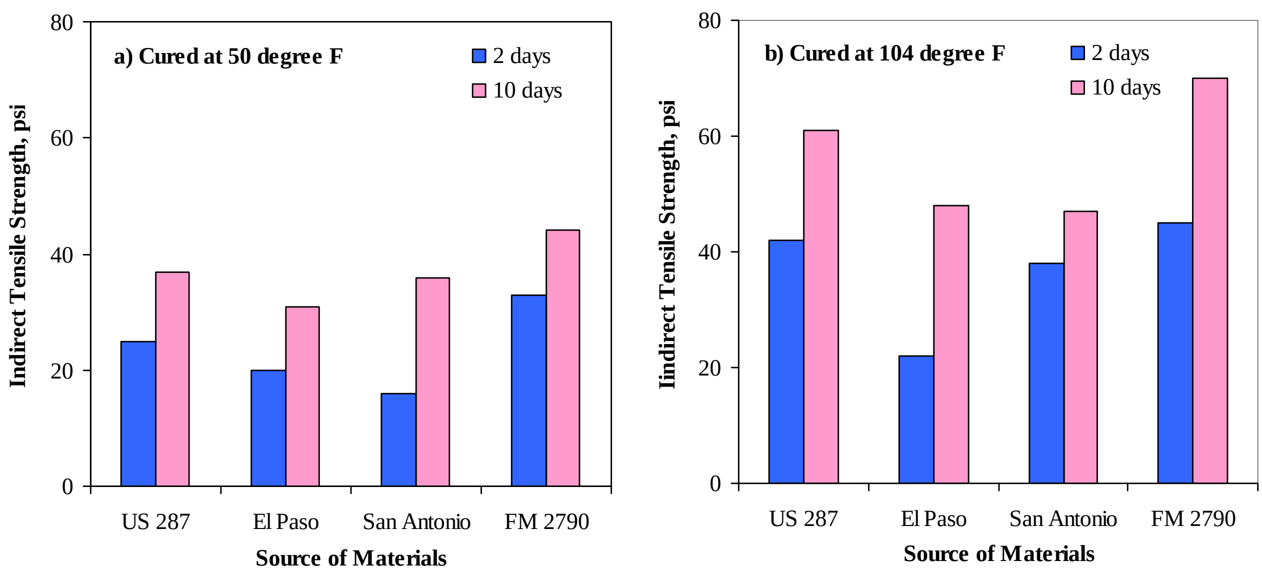

Figure 5.7 – Impact of Curing Time on Indirect Tensile Strength

Impact of Mixing Method

The current TxDOT Special Specification does not stipulate on the mixing method to be used for these types of materials. However, most mix designs are carried out using a new type of mixer known as a high-shear mixer. The goal of this portion of the study was to determine whether the quality of a mix is impacted by not using the high-shear mixer. Two alternatives, namely hand mixing and a small portable concrete mixer were used to prepare specimens.

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Figure 5.8 show a comparison of specimens prepared with the high-shear mixer and the concrete mixer (which looked very similar to the hand-mixed specimens). The specimens prepared with the high-shear mixer appear to be uniform with respect to asphalt coating of the aggregates. The specimens prepared utilizing the other two methods appeared “spotty” where the fine aggregates seem to absorb most of the emulsion. Also, the specimens mixed with the high-shear mixer tended to clump together. However, the mixtures from a concrete mixer seem to be more similar to those from field mixing.

Figure 5.8 – Appearances of Specimens Mixed with High-Shear Mixer (left) and Concrete Mixer (right)

The impact which mixing has on the gradation of the material was also studied. In order to develop a baseline for gradation changes after mixing, a sample of each material, batched according to its respective global gradation (see Figure 4.1) was placed in a high-shear mixer and was then mixed for 60 seconds. The gradations of the materials before and after this activity are shown in Table 5.2. The gradations of the El Paso materials before and after mixing are similar, whereas the San Antonio mix with the soft aggregates generated about 9% fines after mixing. The mixture from FM 154 does not exhibit much change in the gradation; but some of the gravel-sized materials in US 287 mixture changed to fine sands.

The variations in strength for specimens prepared with different mixing methods are shown in Figure 5.9. The strengths of the mixes with the high-shear mixer are greater than those obtained with the other two methods for all materials except for one case. The US 287 and FM 154 specimens seem to be affected less by the type of mixing method used because they contained RAP. The FFRC moduli of the same mixes are shown in Figure 5.10. The loss of stiffness is less pronounced for the El Paso materials than for the two alternative methods perhaps because of the addition of cement. Similar to the strength results for the US 287 mixture, the modulus remained relatively consistent despite the variations in mixing methods. In general, the hand-mixed specimens provided strengths that are closer to the high-shear mixer.

Table 5.2 – Changes in Gradation due to High-Shear Mixing

Material	Condition	Gradation, Individual Retained (%)			
		Gravel	Coarse Sand	Fine Sand	Fines
El Paso	Before	55	23	18	5
	After	55	21	17	7
San Antonio	Before	52	24	23	1
	After	50	21	19	10
FM 154	Before	53	29	16	2
	After	53	28	17	3
US 287	Before	63	25	9	4
	After	59	25	12	5

Impact of Compaction Method

Another contributing factor to strength and durability is the method of compaction. In this parametric study, three different compaction procedures, consisting of the standard Tex-113-E, a Superpave gyratory compactor with 30 gyrations and 50 gyrations, were investigated.

In general, specimens prepared with the gyratory compactor were more uniform than those prepared with the Tex-113-E. One complication with the gyratory compactor is that some of the liquid is lost during the compaction process. Typical dry densities obtained from the three methods of compaction are shown in Figure 5.11. For the UCS specimens, the dry density increases by using the gyratory compactor and by increasing the number of gyrations. This pattern is more pronounced for the El Paso materials where the aggregates are harder. For the IDTS specimens, the trend is mixed.

The differences in strength parameters amongst compaction method are shown in Figure 5.12. The specimens prepared with the gyratory compactor are stronger than those with Tex-113-E. Specimens prepared with 50 gyrations are still stronger than those with 30 gyrations. The differences are especially pronounced for the indirect tensile strength. The variations in modulus with the compaction method, as shown in Figure 5.13, are similar to the trends for strength.

Impact of Mixing Temperature

One of the steps in preparing specimens consists of placing the mixed base, water and emulsion in a 140^{o}F oven for 30 minutes before compaction. The rationale for this step was not clear. The impact of this step on the final product was studied by placing the mix in a chamber set at 50^{o}F, 70^{o}F and 140^{o}F for 30 minutes immediately after mixing yet before compaction. After compaction, all these specimens were cured in the normal fashion. The strength parameters for different mix temperatures are compared in Figure 5.14. No appreciable differences between the strength of specimens compacted at 140^{o}F and 70^{o}F were observed. However, the specimens compacted at 50^{o}F were in some instances weaker. In terms of stiffness, the moduli of the specimens prepared at 70^{o}F were similar to those at 140^{o}F (see Figure 5.15). This trend indicates that the 30-minute curing of the specimen before compaction may not be necessary.

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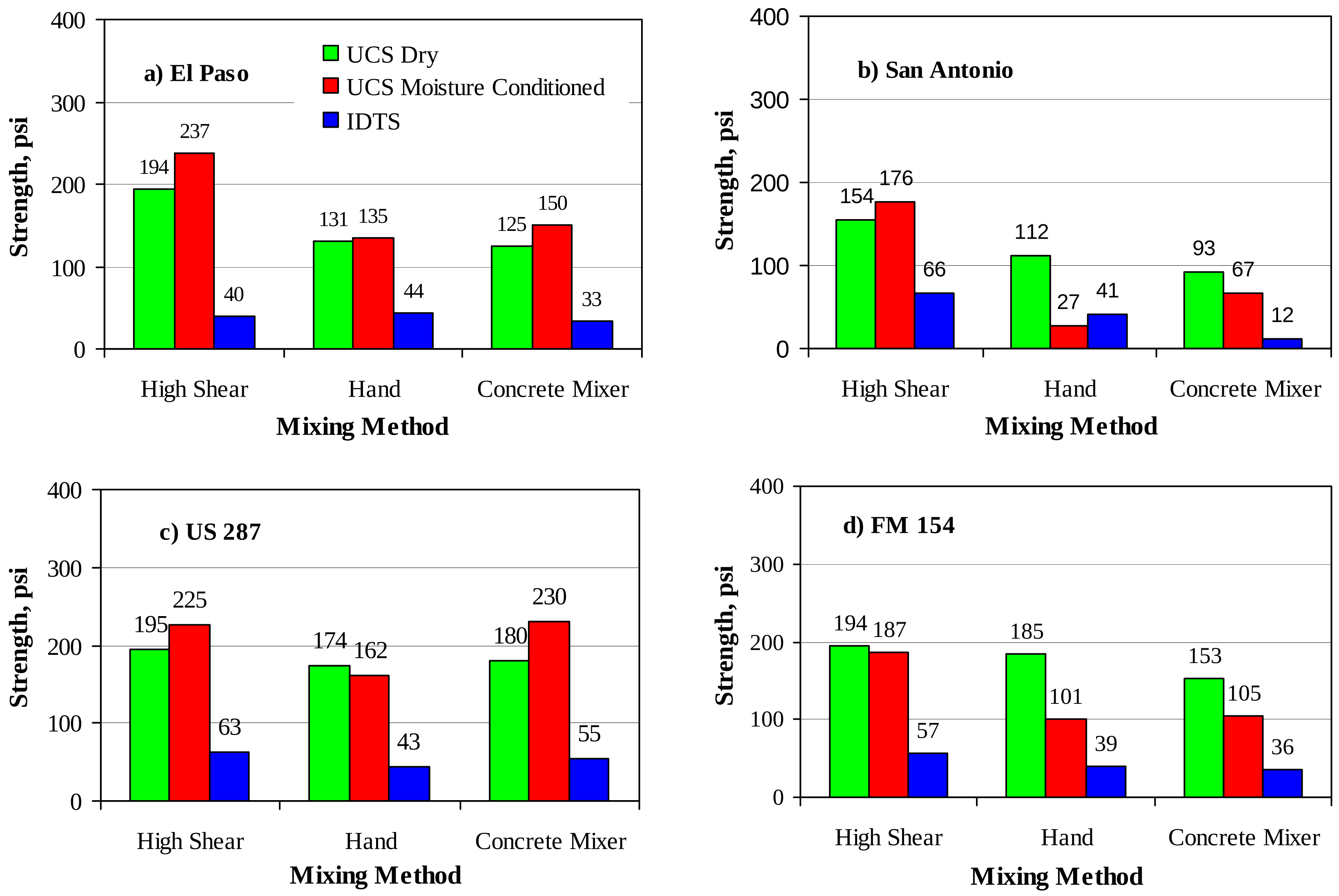

Figure 5.9 – Impact of Mixing Method on Strength Parameters

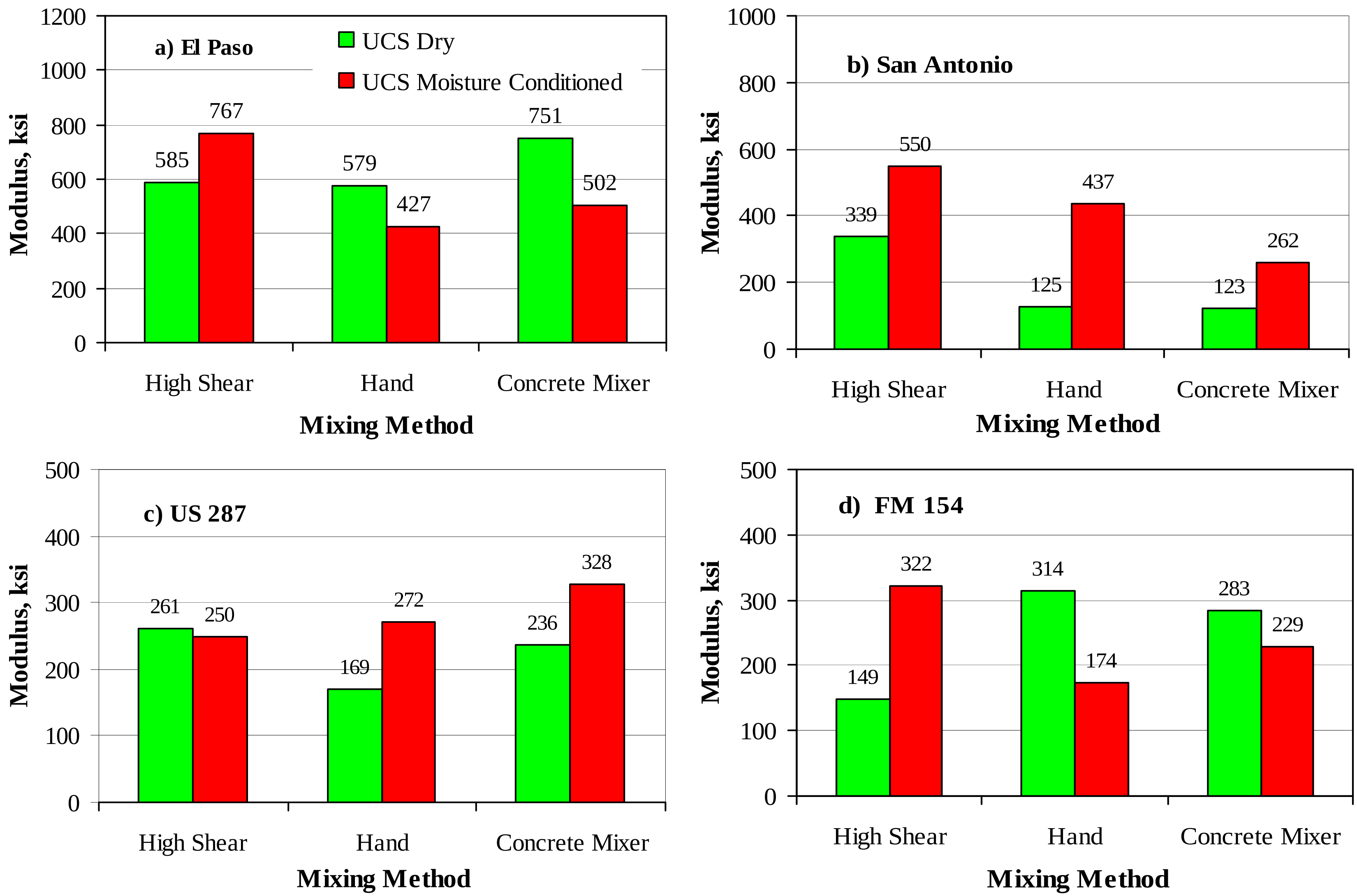

Figure 5.10 – Impact of Mixing Method on FFRC Modulus

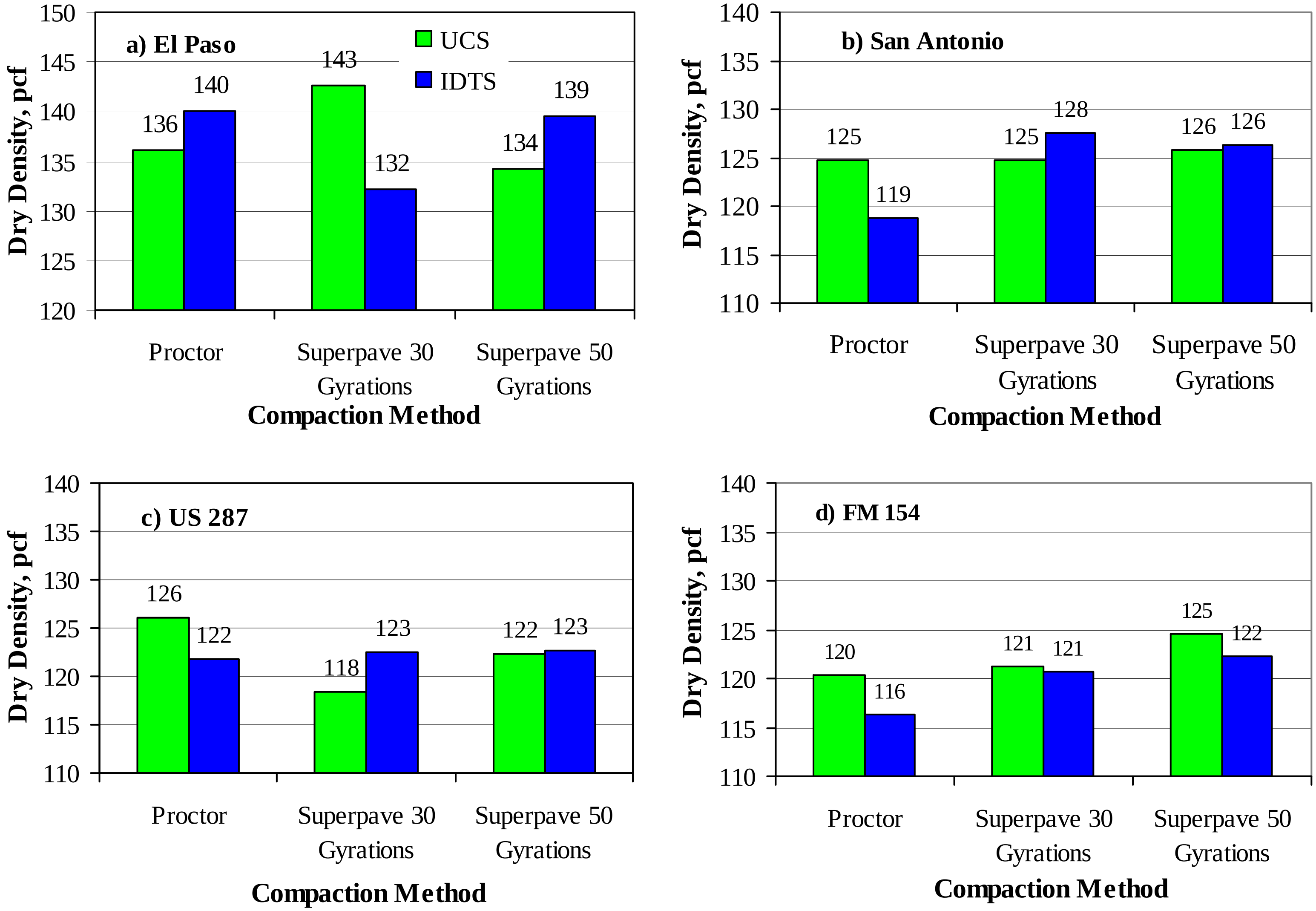

Figure 5.11 – Impact of Compaction Method on Dry Density

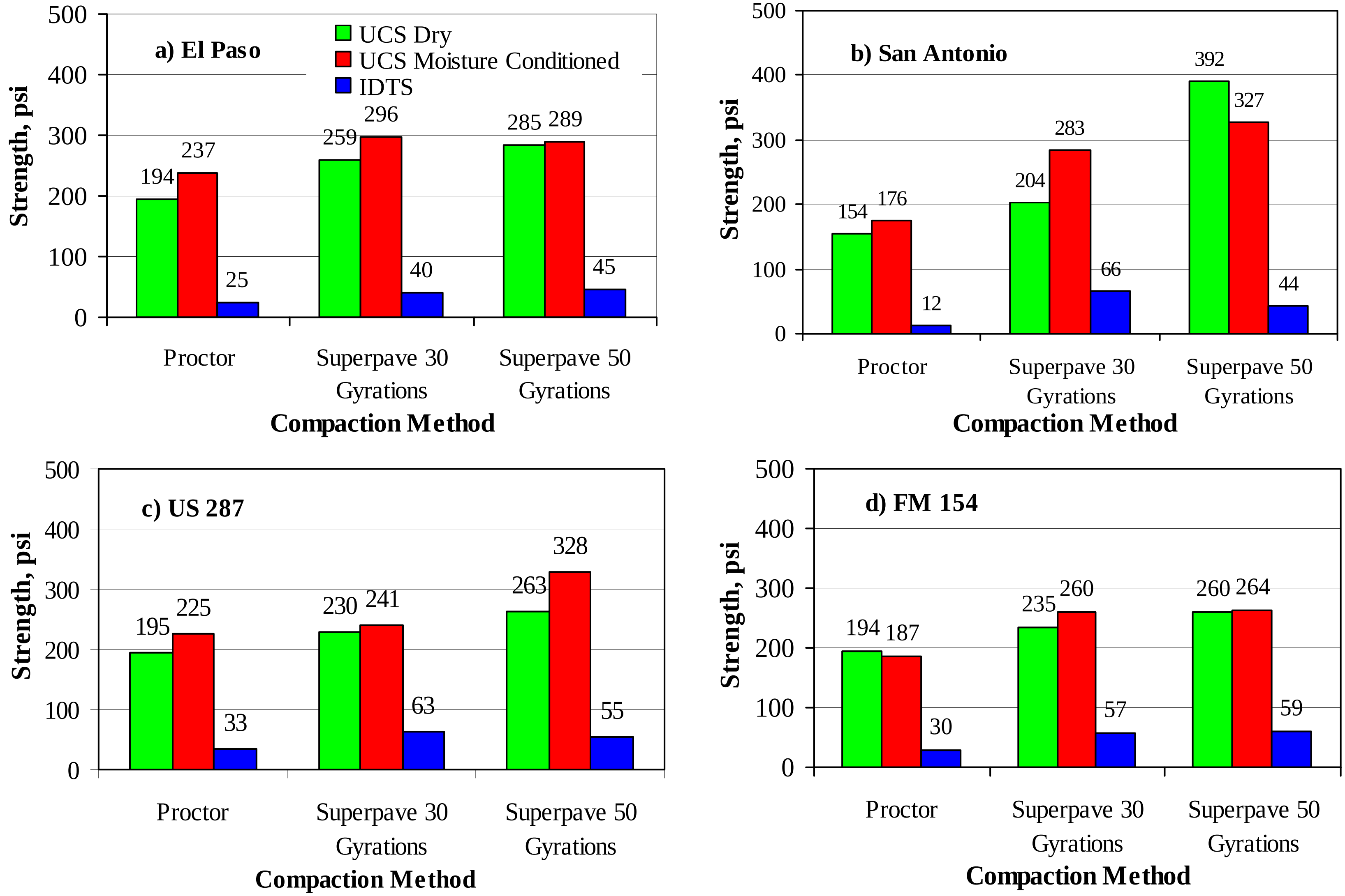

Figure 5.12 – Impact of Compaction Method on Strength Parameters

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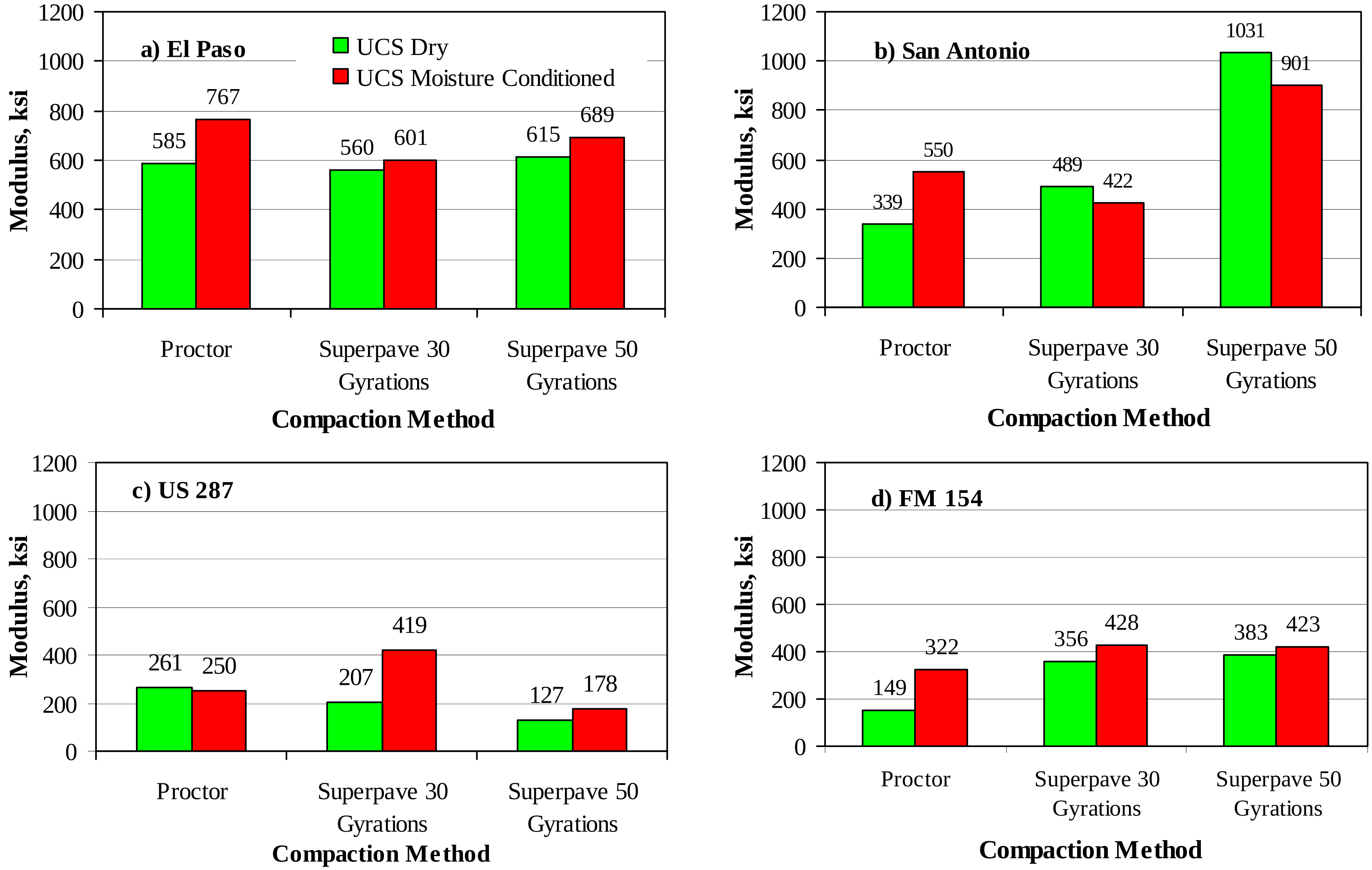

Figure 5.13 – Impact of Compaction Method on FFRC Modulus

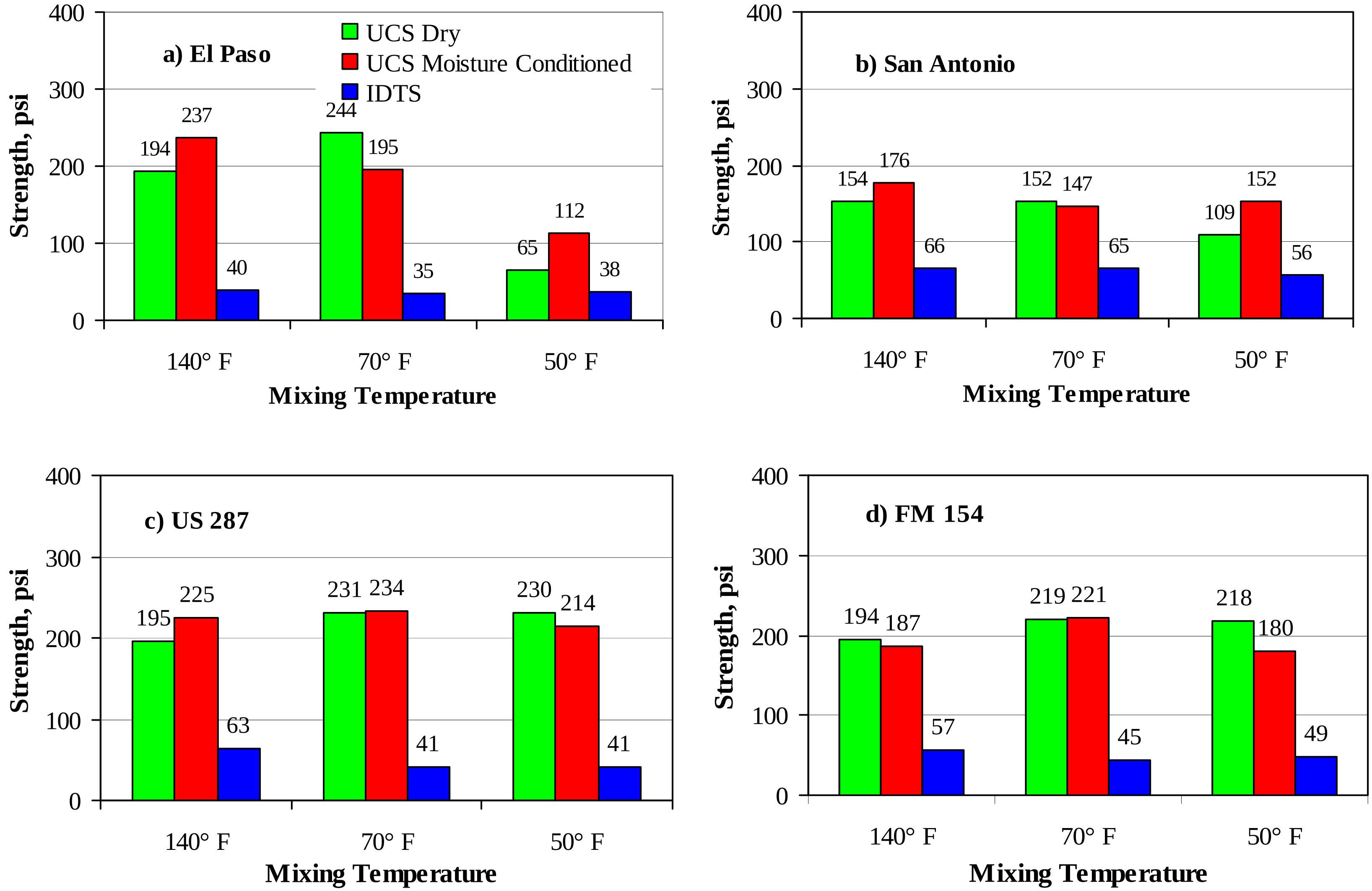

Figure 5.14 – Impact of Mixing Temperature on Strength Parameters

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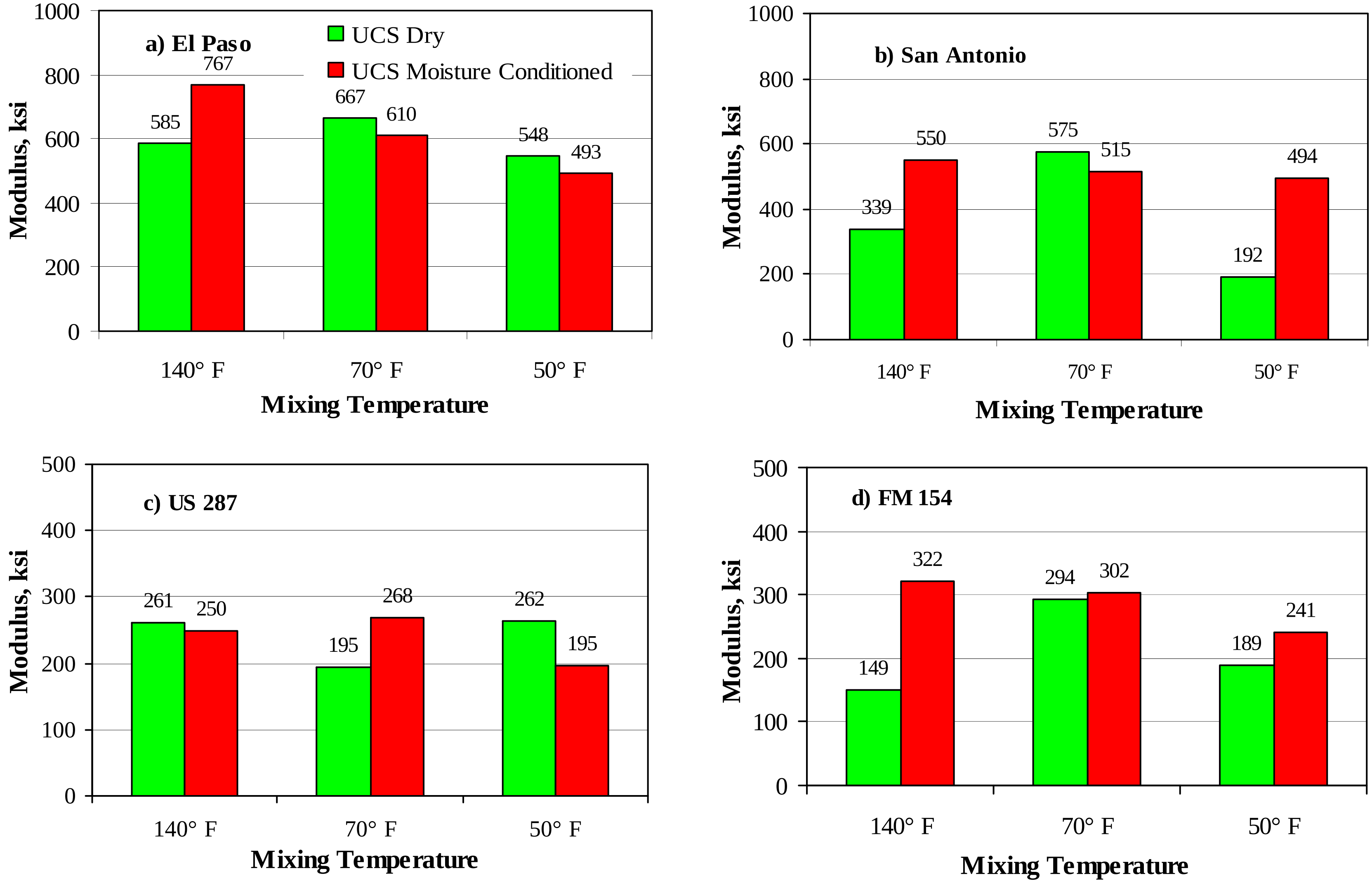


Figure 5.15 – Impact of Mixing Temperature on FFRC Modulus

Chapter 6

Preliminary Guideline for Mix Design

Introduction

As part of this project, a preliminary guideline for mix design and required tests for emulsion-treated base materials were developed. The preliminary guideline was based on the results from both phases of laboratory testing (mix design and parametric studies).

Sampling and Preparation of Material

For each construction project, the materials from the existing hot mix asphalt (HMA) or seal coat layer and base course are collected. The add-rock or additional RAP, if applicable, are also identified and collected at the quarry or stockpile. The sampling process proposed by Garibay et al. (2008) is adopted. Based on the existing pavement structure and the design for the new base, the proportions of the materials used for mix design are determined.

The existing base material and add-rock are oven-dried. Once these materials reach a constant moisture content, sieve analysis and index tests are performed on them. RAP materials are dried outside under direct sunlight since even a relatively low oven temperature may lead to clumping of what little fines that are present in the RAP. After drying, the RAP is placed in a freezer before crushing. Sieve analysis is then performed on the RAP. For all sieve analyses, a No. 200 sieve is included in the sieve stack.

After obtaining the gradations of the individual materials being used in the mixture, they are combined into a batch mix according to their proportions identified. The global gradation of the mixture is used for preparing all specimens required for testing.

Determination of OMC and TLC

The steps outlined in Tex-113-E are followed to obtain the optimum moisture content (OMC) as well as the maximum dry density (MDD).

An optimum amount of mixing water (water not already included in emulsion) is required in order to achieve good blending of both emulsion and aggregate. The adequate emulsion content is controlled by two parameters: strength and constructability. On one hand, increasing emulsion content in a mix should ideally increase the minimum strength of the mix. On the other hand, if for a given mixing water content an excessive amount of emulsion is added, the voids will be saturated, which will compromise the compactability of the mix. For a mix to be constructible under field conditions, the degree of saturation of the mix should not exceed 80% to 90%. For a given amount of water added to the mix, there is a theoretical maximum amount of emulsion that can be added to the mix before this threshold degree of saturation is exceeded. This matter is discussed in detail next.

A schematic of the basic constituents of an emulsion-treated base is provided in Figure 6.1. The material is composed of three ingredients: solids, liquid and air. The proportions of each of these in a given sample are directly related to the engineering properties of a mix. To achieve a high-quality and constructible untreated base, the desirable moisture content is generally close to the optimum moisture content. At the optimum moisture content the degree of saturation is typically between 80% and 90%. About 10% to 20% of the volume of the voids not occupied by aggregates in the mix should be air. The degree of saturation of a mix, S, is obtained by determining the moisture content, ω, the dry density, γ_d, and the specific gravity, G_s, of the solids from:

$$S = (\gamma_d \, \omega \, G_s) / (G_s \, \gamma_w + \gamma_d) \tag{6.1}$$

where γ_w is the density of water.

The moisture content is determined in the laboratory by measuring the weight of a wet specimen, W_{wet}, drying it in a 230^{o}F oven for 24 hours, and measuring the weight of the dried specimen, W_{dry}. The moisture content is determined from the well-known equation:

$$\omega = (W_{wet} - W_{dry}) / W_{dry} = W_{water} / W_{aggregates} \tag{6.2}$$

Given that for untreated bases the only liquid in the material is provide by water, any loss in weight observed during moisture content testing can be assumed to be due to moisture loss. As such, W_{wet} is equal the weight of aggregates ($W_{aggregates}$) and water (W_{water}), and W_{dry} is the weight of aggregates ($W_{aggregates}$). The same is not true for emulsion-treated materials, since the asphalt in the emulsion does not evaporate along with water during the drying process. In this case its weight ($W_{asphalt}$) becomes part of the weight of solids. As such, the measured total liquid content ($TLC_{measured}$) obtained for the emulsion-treated bases is calculated as:

$$TLC_{measured} = (W_{water} + W_{water\ in\ emulsion}) / (W_{aggregates} + W_{asphalt} + W_{additives}) \tag{6.3}$$

which is typically lower than the assumed, $TLC_{assumed}$, which is calculated from:

$$TLC_{assumed} = (W_{water} + W_{water\ in\ emulsion} + W_{asphalt}) / (W_{aggregates} + W_{additives}) \tag{6.4}$$

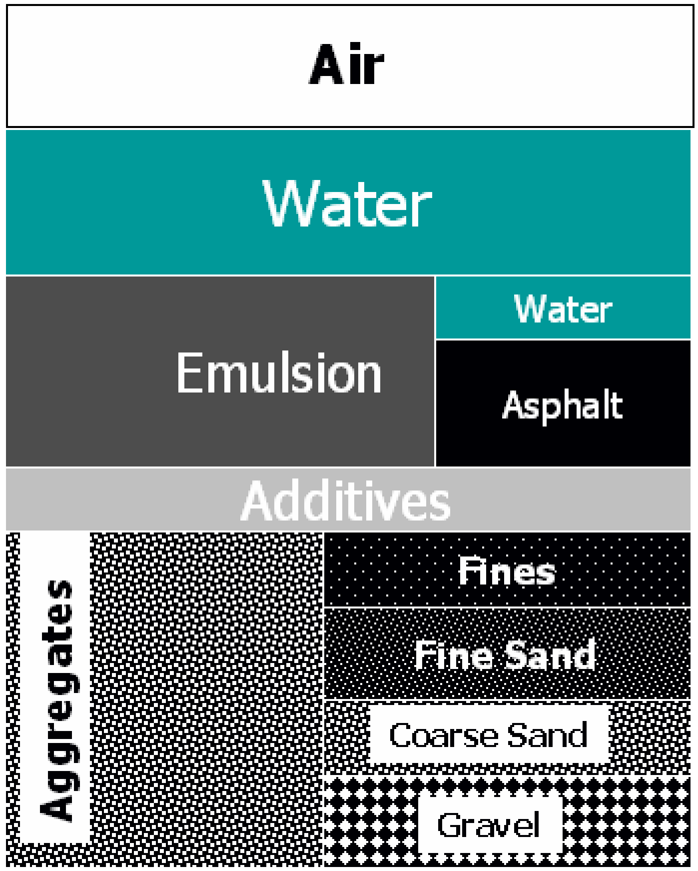


Figure 6.1 –Constituents of an Emulsion Treated Base

The difference between the assumed and measured TLC has several significant implications in the mix design as well as the construction quality control. The first implication is demonstrated in Figure 4.4 where the MD curves from the emulsion-treated materials are significantly different than those from the untreated materials.

The dry density is also required to estimate the degree of saturation in Equation 6.1. The dry density is typically estimated from the total density, γ_{total}, and the moisture content using

$$\gamma_{dry} = \gamma_{total} / (1 + TLC_{measured}) \quad (6.5)$$

The specific gravity of the emulsion-treated bases can either be estimated or preferably measured.

The values of the $TLC_{measured}$ (from Equation 6.3), dry density (from Equation 6.5) and the specific gravity of the mix can be used in Equation 6.1 to estimate the degree of saturation of the mix. However, as indicated before, the goal is to limit the emulsion content for a given mixing water to ensure that the degree of saturation of the emulsion-treated mixes would not exceed a threshold value for constructability (say 85%). As such, Equation 6.1 can be rewritten in the form of:

$$TLC_{max} = [(\gamma_w / \gamma_d) + (1 / G_s)] S_{threshold} \quad (6.6)$$

Knowing the TLC_{max}, and the assumed mixing moisture content (MMC), the maximum allowable emulsion content, (EC_{max}), can be determined from

$$EC_{max} = TLC_{max} - MMC \quad (6.7)$$

Based on this study, it seems that the addition of about 60% of the OMC as mixing water to the dry aggregate is sufficient for optimum blending of most materials.

These calculations are incorporated into an excel worksheet as described in Appendix C. An example is shown in Figure 6.2. For a mixing water content of 60% OMC, the maximum recommended emulsion content is 5.2%, whereas for initial mixing water contents of 45% and 75% of OMC, the maximum recommended emulsion contents are 7.7% and 2.8%, respectively.

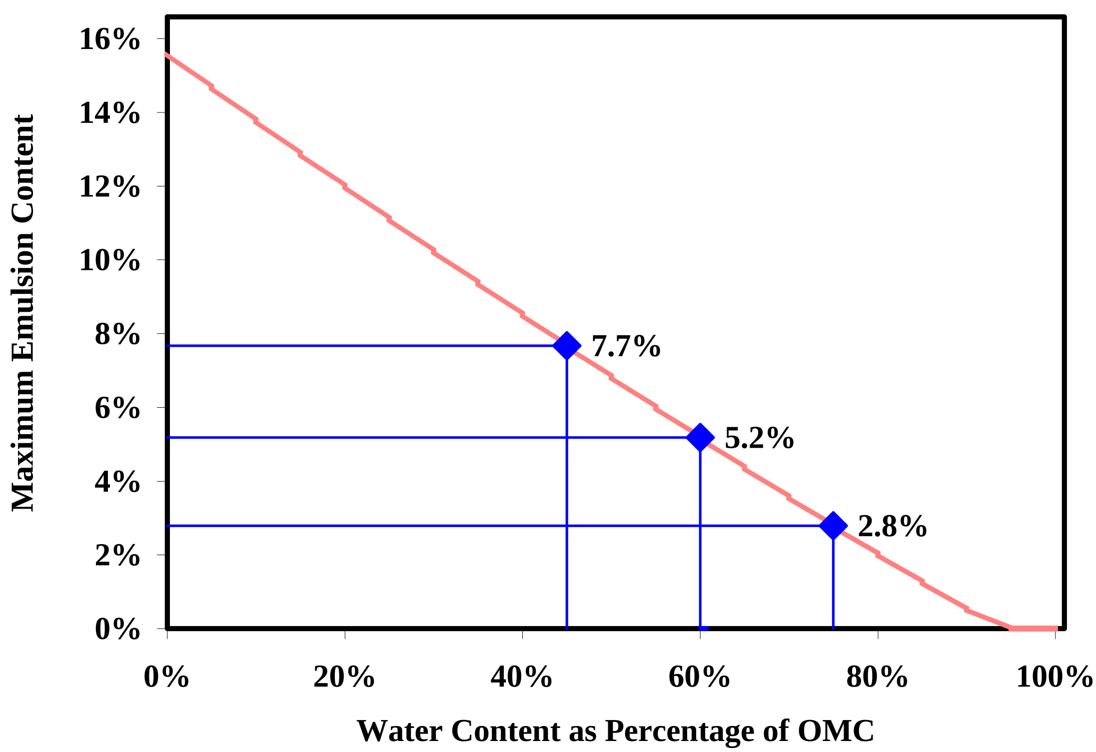


Figure 6.2 – Variation in Mixing Moisture Content with Maximum Allowable Emulsion Content

Based on this criterion, the optimum emulsion content is determined by preparing specimens at different emulsion contents and subjecting them to the IDTS testing. The minimum emulsion content is 0% (no emulsion) and the maximum emulsion content is obtained from the excel sheet. Two intermediate emulsion contents are also proposed. After being subjected to IDTS testing, the results are analyzed to ensure that the minimum strength requirement is met. The specimen with the lowest emulsion content that did reach a value of at least 50 psi is then further evaluated to ensure that the other strength and stiffness parameters in the provision are met as discussed below. Adequate numbers of specimens of the mix design that met the IDTS requirements are prepared for UCS and moisture susceptibility related tests. If the test results for a given material indicate that no specimens meet the requirements specified, dual-stabilization (asphalt emulsion plus calcium-based additive) must be considered for mix design.

Addition of Calcium-Based Additive

The addition of calcium-based additive to asphalt emulsion-treated base materials is for the following two major reasons:

1. To ensure that the strength/stiffness criteria are met for mixes that do not pass the requirements even with the maximum allowable emulsion content alone
2. To minimize the use of emulsion which is much more expensive than cement, lime or fly ash

In the course of this study, the addition of calcium-based additives to the emulsion mixes did not always yield positive effects. If Item 1 is the main reason for adding the calcium-based additives, one option would be to explore the possibility of eliminating the emulsion and utilizing the calcium-based additives (such as cement) alone during the FDR. This is quite critical since FDR with calcium-based additives alone is less costly than the emulsion-based FDR.

According to the TxDOT Special Specification, no more than 1% by weight of either cement or lime should be used in the mix design for emulsion-treated base materials. In the case of fly ash, no more than 2.5% should be added to the material. After determining the optimum emulsion content for a given material, two more specimens are prepared with their emulsion content reduced by a percentage equivalent to that of added cement or lime. These specimens are then subjected to IDTS testing to ensure that the minimum strength requirement is met. If the requirement was met, this became the new mix design of the dual-stabilized material after verified with other required tests. During the course of this research project, it was found that any mix design which passed the minimum IDTS requirement, usually also met the UCS requirement.

It should be noted that the addition of calcium-based additives did not always yield positive effects. In those cases, the possibility of utilizing calcium-based additives alone should be explored.

Curing

During the course of this project and related studies, two curing regimes were applied to the IDTS specimens, 140°F for 48 hours and 104°F for 72 hours, to investigate the effect of curing temperature on initial strength gain. It was found that the difference in initial strength gain was significant.

The preliminary guideline for mix design and required the laboratory tests for emulsion-treated base materials is provided in Appendix D.

Chapter 7

Validation

Introduction

In order to verify the mix design procedure previously described, a validation practice was carried out. Materials (the in-place base and HMA) were retrieved from the existing road of FM 2790 in Atascosa County, Texas which consisted of a HMA layer of about 4 in. and a base course of 4 to 5 in. over a subgrade. Also, the specified add-rock for this construction project was also collected from a quarry in San Antonio. The results of this validation testing are presented in this chapter.

Material Preparation and Blending of Aggregates

The materials were first sieved individually and then combined together in accordance with actual field pulverization depth. Figure 7.1 illustrates the results of the sieve analysis performed on the materials. Also shown in this figure is the gradation curve of the new mixture. The global gradation of the new mixture consisted of 42% RAP, 30% existing base, and 28% add rock as specified in the mix design for the construction of this project. The add rock was necessary because the in-place materials did not provide adequate amount of materials to accommodate the needs of the project as specified in the pavement design.

Determination of OMC and MDD without Emulsion

After determining the global gradation of the mixture, a set of specimens were batched accordingly to determine the OMC. The actual MD curve for this mixture is shown in Figure 7.2. The OMC and the MDD of the material were 8.6% and 130.8 pcf, respectively.

Determination of TLC and Emulsion Content

All of the relevant data was entered into the excel spreadsheet described in Appendix C and the variation in the mixing moisture content with maximum theoretical emulsion content was

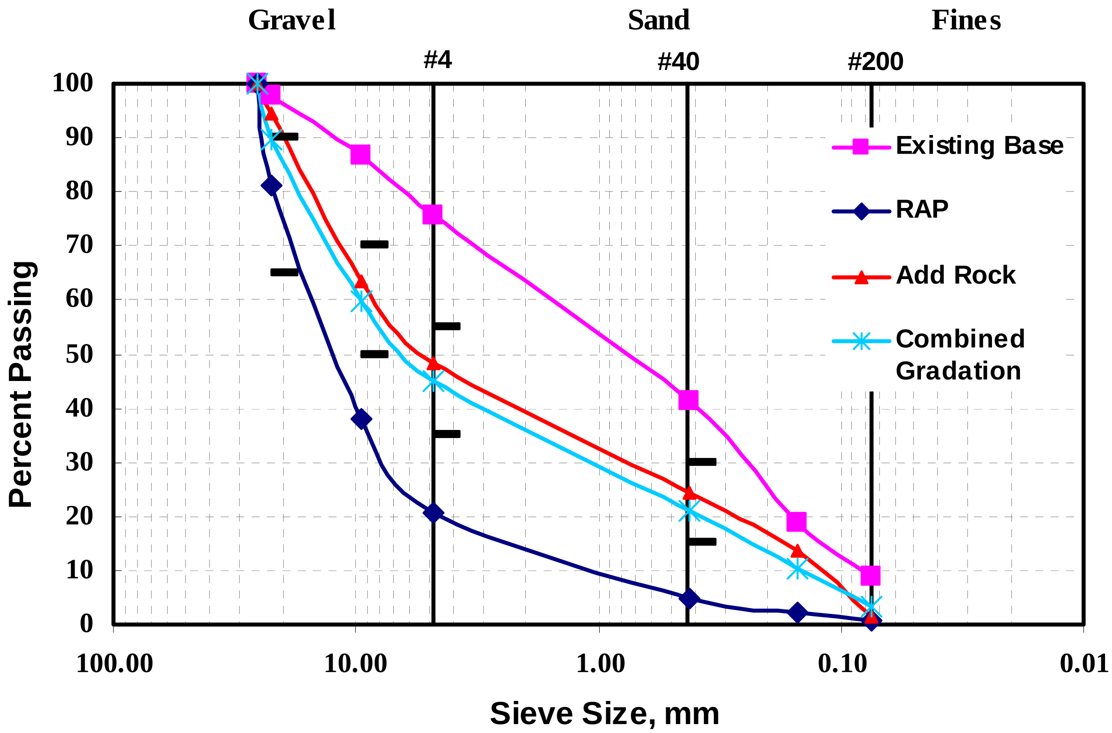


Figure 7.1 – Gradation Curves of FM 2790 Materials

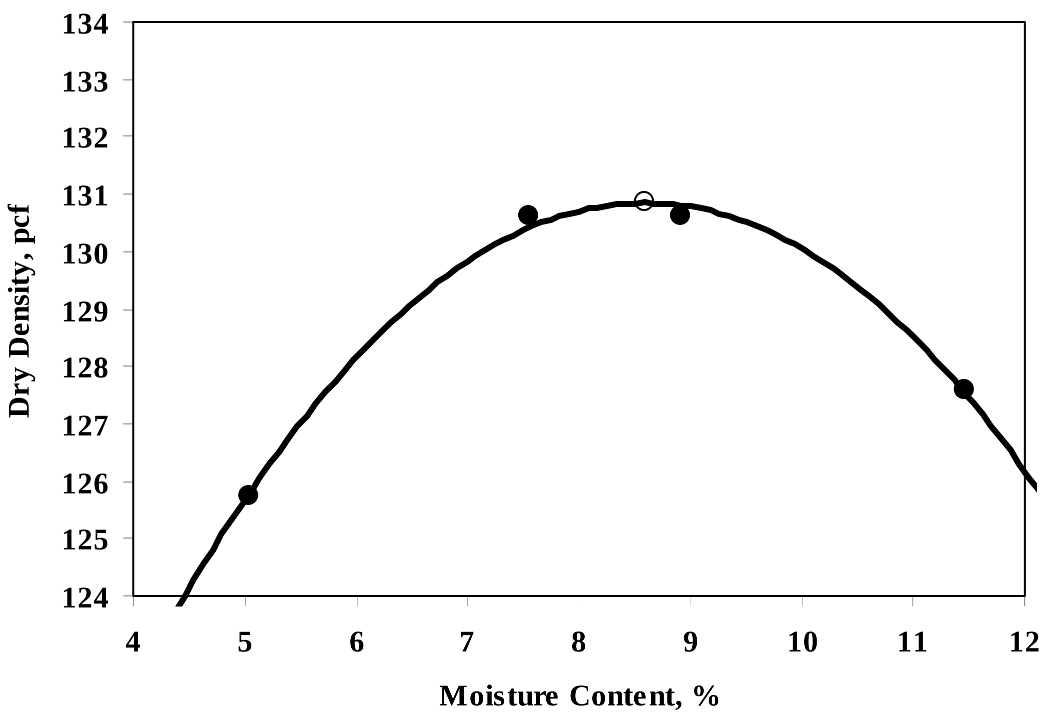


Figure 7.2 – MD Curve of FM 2790 Mixture

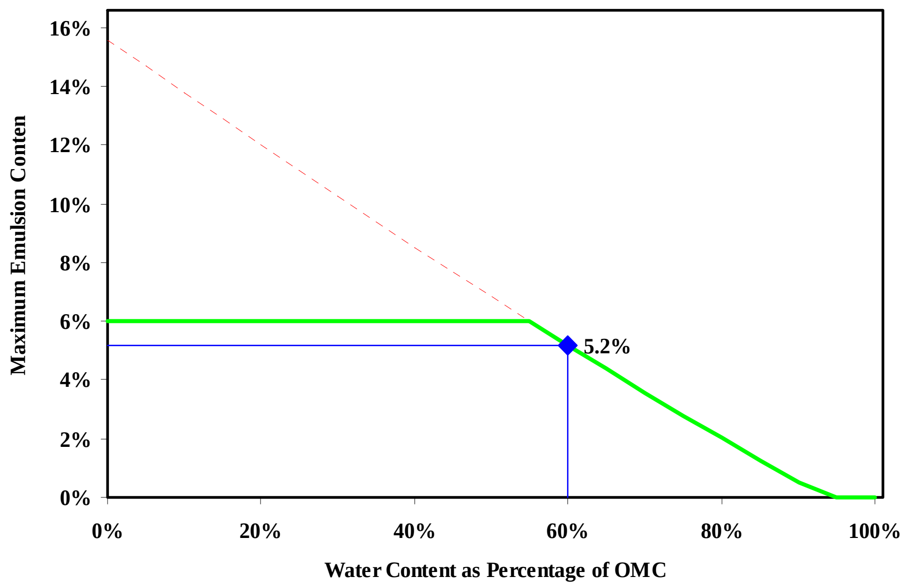


Figure 7.3 – Maximum Emulsion Content vs. Percentage of OMC

determined. As shown in Figure 7.3, for an initial moisture content of 60% of OMC, a maximum emulsion content of 5.2% should not be surpassed.

The excel sheet was used on the other four materials previously used in this study as well. As shown in Table 7.1, the higher the mixing water content is, the lower the maximum emulsion content will be. Based on the materials tested in this study, for a given mixing moisture content, the optimum emulsion content is about 1% to 2% less than the maximum emulsion content.

Table 7.1 – Maximum Recommended Emulsion Contents Based on Initial Mixing Water

Initial mixing water	Maximum Recommended Emulsion, %				
	El Paso	San Antonio	US 287	FM 154	FM 2790
45% OMC	5.7	7.2	5.8	8.1	2.8
60% OMC	3.5	5.1	4.1	4.6	5.2
75% OMC	1.3	3.2	2.5	1.2	7.7

IDTS Testing

Based on the selected 60% mixing water, the maximum emulsion content for this material is about 5.2%. Therefore, based on our observation the optimum emulsion content should be between 3% and 4%. The results from the IDTS tests on a matrix of different mixing moisture contents and emulsion contents are shown in Table 7.2. In general, the IDT strengths were rather insensitive to the moisture content and emulsion content of the mix. This is perhaps due to the high RAP content and high asphalt content (about 6%) of the RAP. None of the specimens provided the 50 psi requirement for IDTS. Nevertheless, the IDT strengths decrease as the maximum emulsion content is exceeded as highlighted in the table. Based on the results from the IDT testing, an initial mixing water content and emulsion content of 60% of OMC and 3%, respectively were chosen for the next phase of testing.

Table 7.2 – Variation in Indirect Tensile Strength with Moisture and Emulsion Contents

Mixing Moisture Content as Percentage of OMC	**Emulsion Content, %**			
	0	3	5	7
45	35	31	28	19
60	34	30	27	24
75	33	25	24	18

Addition of Calcium-Based Additive

The next step in the mix design process was to consider the dual stabilization of the material. Two sets of IDT specimens were prepared with 1% lime or cement added to the mix. The IDT strengths for the lime and cement specimens were 79 psi and 69 psi, respectively.

Verification by UCS Testing

Upon selection of the amounts of emulsion, water and other additive based upon IDT testing; the final mix design was verified for compressive strength. In order to stay consistent with the other four materials used in this study, UCS testing was also performed on specimens that had lime or cement added to the mixture. The UCS values of the mixes with lime or cement were 172 psi and 106 psi, respectively. However, the UCS strength for a specimen prepared at the same initial mixing water and emulsion contents without the inclusion of any calcium based additive was 167 psi.

Verification by Moisture Susceptibility Testing

Two sets of specimens were compacted for both the IDT and UCS testing. As described earlier, both of these test specimens were subjected to eight days of moisture conditioning after 48 hours of oven curing. The dielectric constant after moisture conditioning was 6.4, indicating that the mix may not be moisture susceptible. The IDT and UCS results after moisture conditioning were 15 psi and 175 psi, respectively. As such the retained UCS and IDT strengths were 101% and 19%, respectively. Even though the mix design with 1% lime, 3% emulsion and 60% of OMC moisture content would have passed the existing criteria, it fails the retained IDT strength under the proposed mix design. Another alarming result from this mix design was the modulus of the mix with the FFRC device. For the selected mix design, the modulus was about 200 ksi which seems quite low for a treated base.

Chapter 8

Case Studies

Introduction

Three rehabilitation projects of the base courses treated with asphalt emulsion were selected for this study to verify the effectiveness of stabilization and observe construction practices. These projects were located on US 287 in Amarillo District, FM 154 in Yoakum District and FM 2790 in San Antonio District, respectively. Since the FM 154 project stopped the emulsion treatment after the initial trial, and since the FM 2790 project had not started by the August, 2008, the emulsion project on FM 740 in Dallas District was selected for the experimental studies. In addition, during the period of this research project, the research team conducted similar activities for the rehabilitation projects on SH 16 and FM 479 in San Antonio District. Results from these activities are also included in this chapter.

For each project, the major research activities included material collections, observation of the construction practices, laboratory tests on the collected materials and field tests on the newly-constructed base courses. This chapter presents the results from these tests.

In general, materials collection at each project site consisted of two steps. First, the materials including the RAP and the base material were retrieved from the existing pavement. The add-rock or additional RAP, if specified, were also collected from the appropriate stockpile. Results from the tests and analyses on these materials have been presented in Chapters 4 through 6. For the second step, the pulverized materials were sampled at several locations at each project site before emulsion and/or other additives were added. The materials collected in this way from each project site were tested in the laboratory for the following items:

- Sieve analysis
- Unconfined compressive strength (UCS)
- Indirect tensile strength (IDTS)
- Seismic Modulus (with FFRC device and/or V-meter)
- Retained strength/modulus

- Dielectric constant
- Resilient modulus (not for every project)

Field modulus tests were performed with a portable seismic pavement analyzer (PSPA) on the newly-constructed base at each project site. Based on the results from the experimental studies, the preliminary relationship between the modulus obtained from a FFRC test in the laboratory and the modulus measured with a PSPA in the field is discussed in this chapter. Finally, the minimum moduli required for this type of base courses are proposed.

SH 16 Project

The rehabilitation project of SH 16 was located between RM 337 and West of Winans Crossing in Bandera County of San Antonio District as shown on Figure 8.1.

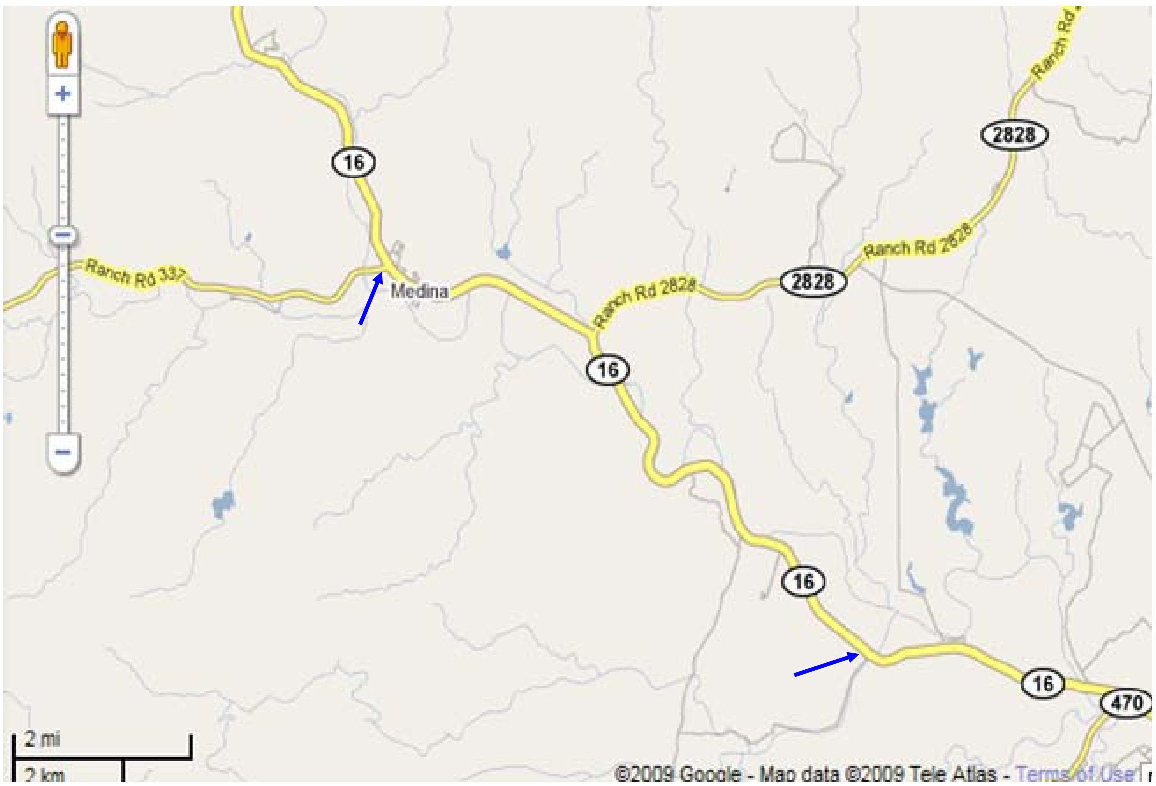


Figure 8.1 – Location of SH 16 Project

The original roadway of SH 16 consisted of two 12-ft-wide traffic lanes (without shoulders). The major tasks of this rehabilitation project included:

- Adding shoulders to the old roadway using the hauled-in base materials
- Pulverizing both the old pavement down to 6 in. in the main lane and the new material in the shoulder and mixing them with asphalt emulsion (see Table 8.1 for the mix design)
- Finishing the new emulsion-treated base and covering it with a seal coat

Table 8.1 – Mix Design for SH 16 Project

Parameter	Value	Remark
Existing RAP (seal coats)	33%	Main Lane
Existing Base	67%	
New Base Material	100%	Shoulder only
Asphalt Emulsion	5%	Main Lane and Shoulder
Adding Water	3.8%	

Material Collection

Pulverized materials were collected from both the main lane and the shoulder at eight locations of this project. Small samples were also retrieved at 30 locations on both the main lane and the shoulder for moisture content tests to examine the control of adding water amount during construction. They included the loose materials (without emulsion) just after pulverization and the materials from the compacted base. In addition, four 6 in. by 8 in. cylindrical specimens prepared by the contractor at the site from the emulsion-treated loose material on the main lane were saved for modulus and strength tests. Originally, these specimens were prepared for quality management in terms of density and moisture content due to the ineffectiveness of NDG tests.

Sieve Analysis

Before starting construction of the project, the contractor had conducted a sieve analysis on the blended mix of 1/3 RAP and 2/3 base. Result from the sieve analysis on the blended material is compared to the average gradation of the eight samples from the main lane in Figure 8.2. The difference is quite evident.

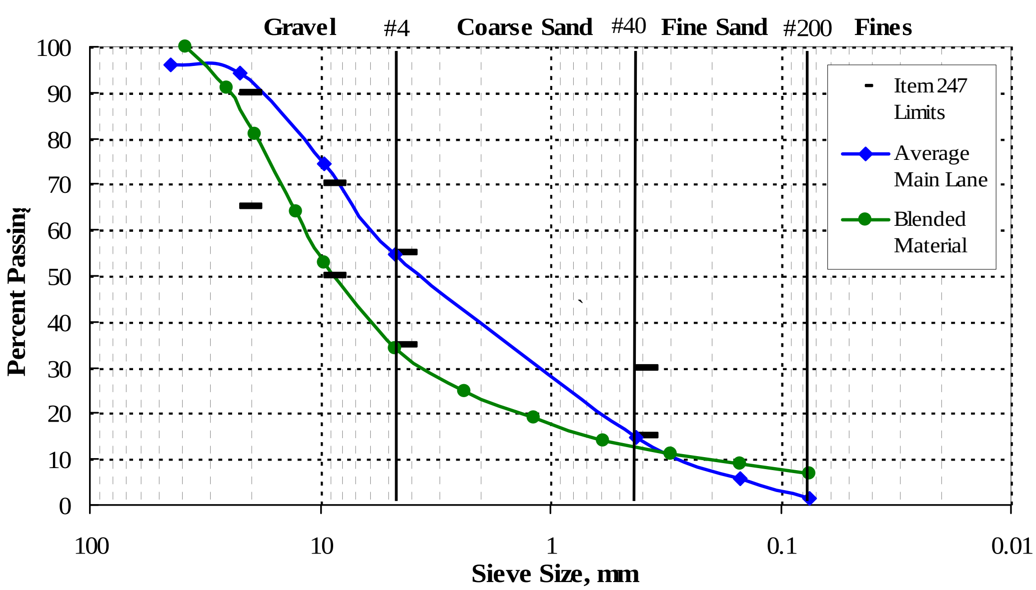


Figure 8.2 – Gradation Curves of Blended Raw Material Used for Mix Design and Material after Pulverization for SH 16 Project

Results from the sieve analysis on the materials from individual locations are compared in Figure 8.3. In general, the gradations of the materials from most locations lie within or marginally outside the allowable limits for Grade 1 specification by TxDOT Item 247. There is a relatively large variation in gradation for the materials retrieved from the shoulder.

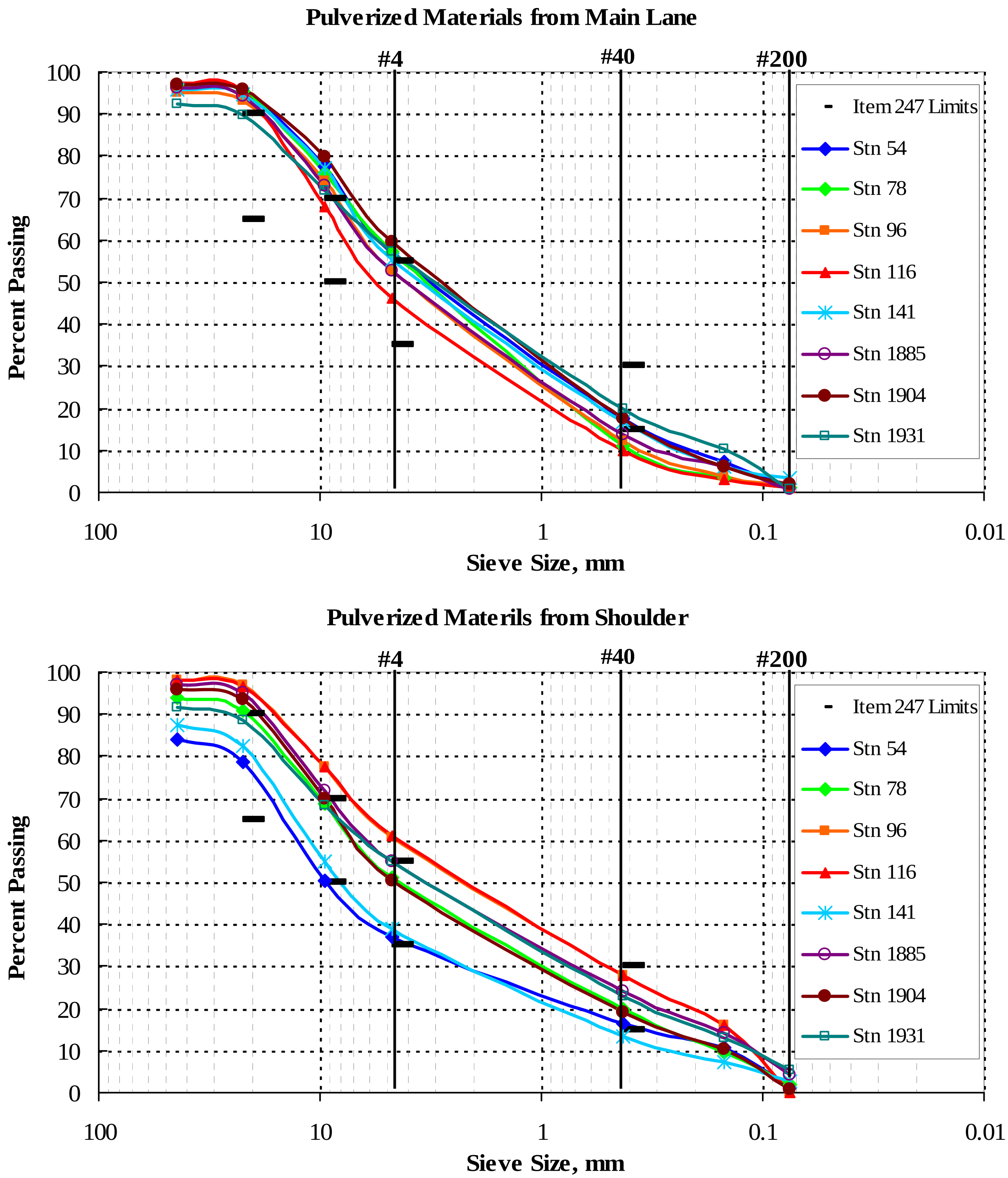


Figure 8.3 - Gradation Curves of Pulverized Materials from Main Lane and Shoulder of SH 16 Project

Strength and Modulus Tests

Specimens were prepared from each mix and tested for unconfined compressive strength (UCS) and indirect tensile strength (IDTS) tests as per the procedures described in Chapter 4. All specimens were first cured at 140°F for two days and then subject to modulus and strength tests when they were cooled down to a room temperature of about 70°F. Results from these tests are shown in Figure 8.4. The average IDTSs of 53 psi for both the main lane and the shoulder satisfy the required value of 50 psi. However, the average UCSs of 120 psi for the main lane and 118 psi for the shoulder are lower than the minimum required value of 150 psi.

Figure 8.4 – Strength Values for Materials from Individual Stations of SH 16 Project

Before performing strength tests, all UCS specimens were subject to modulus tests with a FFRC device and a V-meter. Results from these tests are shown in Figure 8.5. The average FFRC moduli of the specimens are 594 ksi for the main lane material and 505 ksi for the shoulder material. The average V-meter moduli of the specimens are 716 ksi for the main lane material and 573 ksi for the shoulder material. The V-meter moduli are about 15% greater than the FFRC moduli due to the differences in strain rate (54 kHz for v-meter and about 3 kHz for FFRC: the higher frequency is related to the lower strain rate). The UCS, FFRC modulus and V-meter modulus are consistently the lowest for the specimens made from the shoulder material at Station 141 which has the coarsest gradation (see Figure 8.3).

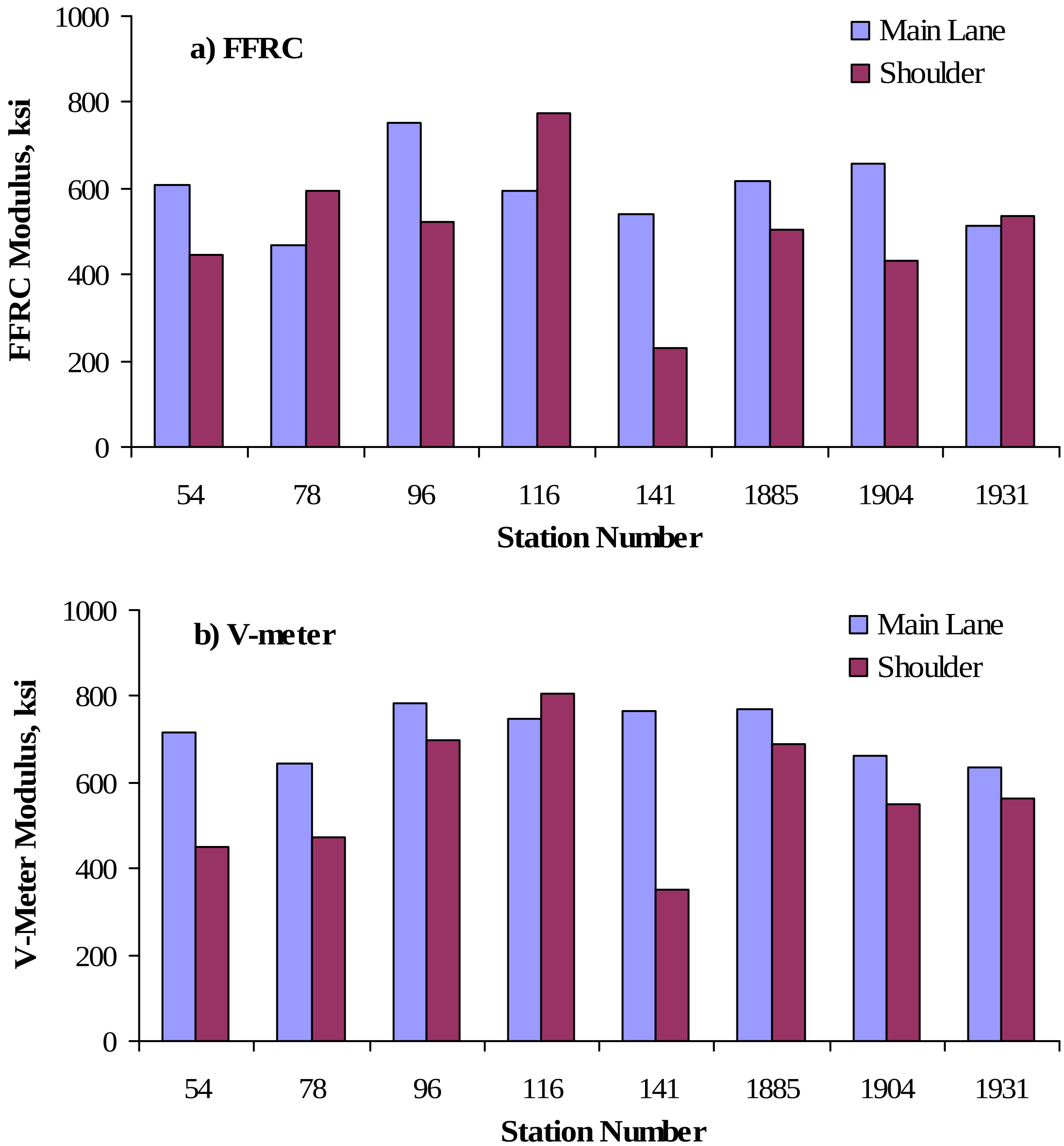


Figure 8.5 – Moduli Measured on UCS Specimens for SH 16 Project

Due to the height limitations, only the V-meter tests were carried out on the IDTS specimens. As shown in Figure 8.5, the V-meter moduli of IDTS specimens are systematically higher than those of UCS specimens. The difference could be attributed to the fact that the IDTS specimens were prepared with a Superpave Gyratory Compactor and the UCS specimens with a standard compactor. Consistently, the IDTS specimen made from the shoulder material at Station 141 shows the lowest modulus.

Four the specimens made at the construction site, which were cured at the room temperature after removing from the field, were tested for FFRC modulus and compressive strength. The average moduli of these specimens were 311 ksi, 388 ksi and 455 ksi at ages of about 1.5 days, 3 days and 7 days, respectively, with an average COV of about 14%. The average UCS at the age of 7 days was 108 psi with a COV of about 13%. Both the strengths and moduli of the field specimens are considerably lower than those of the lab specimens due to the difference in initial curing temperature.

Tube Suction Tests

The parameters obtained from tube suction tests include the retained strength, retained (FFRC) modulus and dielectric constant. Specimens were prepared from the materials collected from 6 stations and tested by following the procedure described in Chapter 4. Results from these tests are summarized in Table 8.2. The average retained strengths were less than the required value of 80%. The dielectric constants were similar and about 4 for all specimens.

Table 8.2 – Statistics of Modulus Measurements on UCS Specimens for SH 16 Project

Source of Material	Retained UCS, %		Retained FFRC Modulus, %		Final Dielectric Constant	
	Main Lane	Shoulder	Main Lane	Shoulder	Main Lane	Shoulder
SB Station. 54		68		123		4
SB Station. 78	141		91		4	
NB Station. 96		86		145		4
SB Station. 1885	52	40	82	99	4	4
NB Station. 1904	43		57		4	
NB Station. 1931	70		63		4	
Average	77	65	73	122	4	4

Resilient Modulus Tests

Resilient modulus tests were performed on four specimens: two were prepared from the treated materials used for the main lane and two for the shoulder. Specimen preparation and resilient modulus tests were performed as per the procedures described in Chapter 4. Representative results from these tests are summarized in Table 8.3. The moduli from the FFRC tests on these specimens shortly before the resilient modulus tests are also shown in this table. In general, the resilient moduli are less than the FFRC moduli.

Table 8.3 – Representative Resilient and FFRC Moduli for SH 16 Project

Source of Material	Main Lane		Shoulder	
	Resilient Modulus, ksi	FFRC Modulus, ksi	Resilient Modulus, ksi	FFRC Modulus, ksi
SB Station. 78	345	595	242	546
SB Station. 116			401	656
NB Station. 1904	906	773		

Moisture Content from Field Samples

Materials for moisture content determination were retrieved from the project in two ways: 1) freshly pulverized without emulsion (loose materials) and 2) after the completion of compaction with emulsion. Each type of materials was sampled from two sections. The moisture content of a sample from the compacted base reflects a combination of the adding water and the water contained the asphalt emulsion, which is about 1/3 of emulsion by weight. The average moisture contents of the materials and their variations for these subsections are summarized in Table 8.4.

The average moisture contents of the compacted base were 3.8% and 4.8% for the main lane and the shoulder, respectively. Both of them were considerably lower than the designed moisture content of 5.6% (3.8% added + 1.8% water in emulsion). The moisture contents of the base in the main lane were systematically lower than those in the shoulder. This could be attributed to the fact that the new base material in the shoulder absorbed more of the water applied (by a water truck) than the old pavement did. In addition, the variations of moisture content in the main lane were higher than those in the shoulder.

Table 8.4 – Summary of Average Moisture Contents with Coefficients of Variation for SH 16 Project

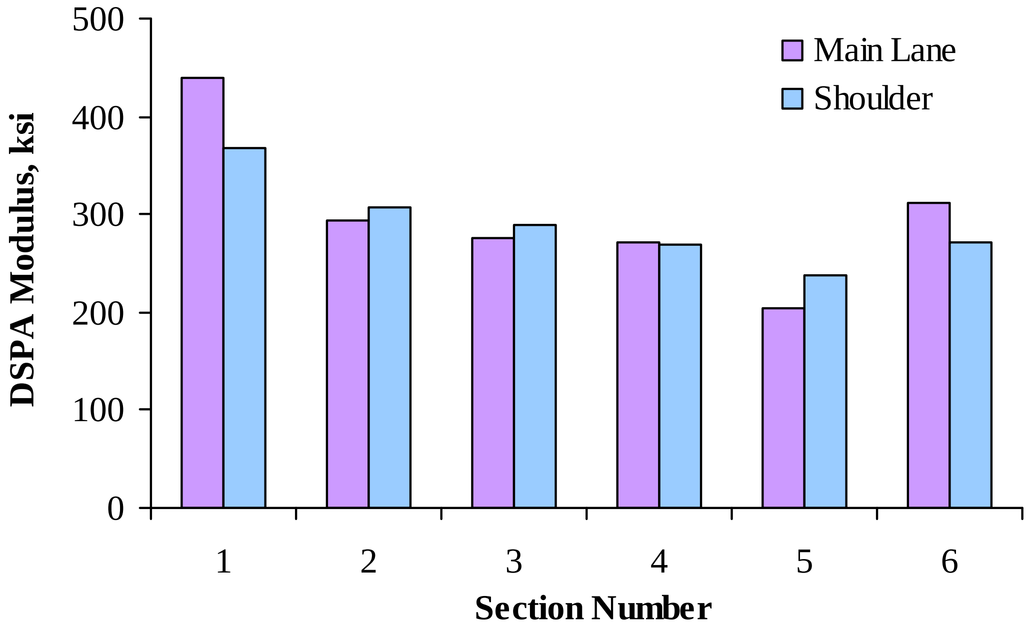
Material	Section	Number of Stations	Main Lane		Shoulder	
			Average (%)	CV (%)	Average (%)	CV (%)
Loose without Emulsion	SB 141 - 118	7	3.1	22	4.7	8
	SB 58 - 81	6	2.7	25	3.8	7
Compacted with Emulsion	SB 54 - 94	9	3.5	28	4.9	10
	NB 81 - 116	8	4.0	19	4.7	14

PSPA Measurements

PSPA measurements for the determination of the in-situ base moduli were conducted in 6 sections. Measurements were carried out at five points at each station (three on the main lane and two on the shoulder). The results of PSPA measurements are summarized in Table 8.5, and the average moduli measured in each section are shown in Figure 8.6.

Table 8.5 – Statistics of Results from PSPA Measurements on SH 16 Project

Section	Age (day)	Main Lane		Shoulder	
		Average (ksi)	CV (%)	Average (ksi)	CV (%)
NB 121 - 171	3	295	29	308	19
NB 81 - 116	2	277	29	289	23
SB 54 - 119	1	271	25	270	24
SB 2005 - 2015	7	438	13	370	27
NB 1864 - 1884	1	205	21	243	23
SB 1880 - 1904	1	311	27	260	23



1: SB 2005 - 2015 (7 days) 2: NB 121-171 (3 days)
3: NB 81 - 116 (2 days) 4: SB 54-119 (1 day)
5: NB 1864 - 1884 (1 day) 6: SB 1880 - 1904 (1 day)

Figure 8.6 – Average Base Moduli from PSPA Measurements on SH 16 Project

In general, the average base moduli obtained from PSPA measurements on this project were greater than 250 ksi after one day of curing and increased slightly with curing age. The lower than average one-day modulus obtained from Section NB 1864-1884 might be due to uneven emulsion spraying as observed during construction.

FM 479 Project

This dual-stabilization project was located on FM 479 between US 290 and IH 10 in Kerr County and Kimble County of San Antonio District (see Figure 8.7).

Figure 8.7 – Location of FM 479 Project

The original roadway of FM 479 had two 11-ft wide traffic lanes (without shoulders) and consisted of a seal-coated surface layer of about 2 in., a granular base of greater than 6 in. and the subgrade. The major tasks of this rehabilitation project included:

- Pulverizing the old pavement
- Mixing the pulverized material with additional RAP from a stockpile and spreading the new mix to 28 ft wide
- Treating the new mix with cement and asphalt emulsion down to a depth of about 6 in. (see Table 8.6 for the mix design)
- Finishing the new base and covering it with seal coat

Table 8.6 – Standard Mix Design for FM 479 Project

Existing RAP	Existing Base	Additional RAP	Adding Water	Cement	Asphalt Emulsion
1/3	1/3	1/3	6.2%	1%	4%

Material Collection

Materials collected from this project site included:

- The seal coat (RAP) and the base material from the existing road as well as additional RAP from the stockpile
- Pulverized material before adding additives from six locations with an interval of about 1000 ft

Sieve Analysis

Sieve analysis was performed on the pulverized materials retrieved from the six locations of the project as shown in Figure 8.8. The gradation curves of the raw and the pulverized materials from the six locations lie within or marginally outside the allowable limits for Grade 1 specification. A relatively large variation in gradation for the materials retrieved from different locations is observed.

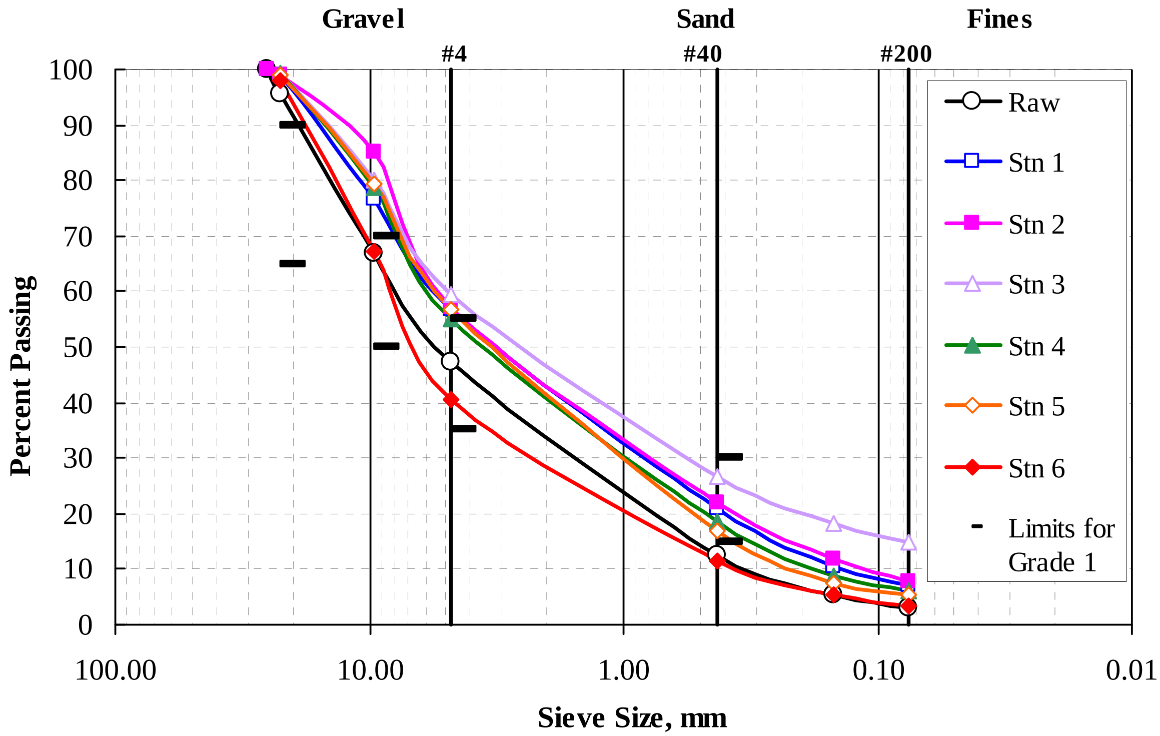


Figure 8.8 – Gradation Curves of Raw and Pulverized Materials from FM 479 Project

Strength and Modulus Tests

Specimens were prepared from the raw material and the pulverized material form each location mixed with 6.2% water 1% cement and 4% asphalt emulsion as specified in Table 8.6. All UCS specimens were first cured at 140^{o}F in an oven for 48 hrs before subjecting them to modulus and strength tests. Specimens for IDTS tests were divided into two groups: one was cured at 104^{o}F for 72 hrs and another at 140^{o} F for 48 hrs before testing. Results from the modulus and strength tests are summarized in Table 8.7, and are shown in Figures 8.9 and 8.10. The average UCS for all materials is 154 psi with a large CV of 39%. However, only the raw material and the pulverized materials from two stations passed the required UCS value of 150 psi.

Table 8.7 – Statistics of Strength and Modulus Parameters for FM 479 Project

Material Source	UCS Specimen		IDTS Specimen			
	UCS (psi)	FFRC Modulus (ksi)	104° F (72 hr Cure)		140° F (48 hr Cure)	
			IDTS (psi)	V-meter Modulus (ksi)	IDTS (psi)	V-meter Modulus (ksi)
Raw	161	338	29	924	49	945
Stn 1	92	559	45	1110	58	994
Stn 2	220	451	45	1065	53	909
Stn 3	250	472	39	1150	53	987
Stn 4	101	491	43	766	49	792
Stn 5	116	417	52	954	57	997
Stn 6	140	197	15	570	41	589
Average	154	418	42	934	51	888
CV, %	39	28	18	22	11	17

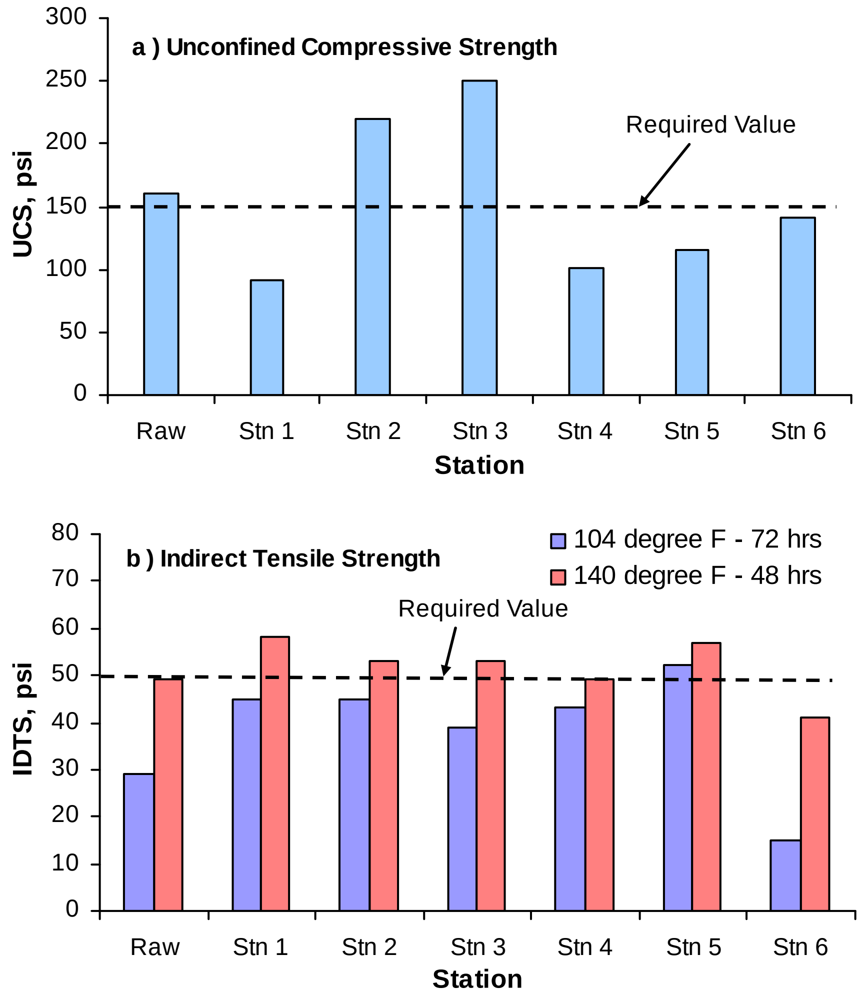


Figure 8.9 – Strengths of Raw and Pulverized Materials from FM 479 Project

For IDTS, the material from only one station did not meet the required value of 50 psi when the specimens were cured at 140°F for 48 hrs. On the other hand, when the specimens were cured at 104°F for 72 hrs, the material from only one station reached the required value. The lowest IDTS values were from Station 6 for both curing regimes. Most likely, this was caused by the low fine content in that material as shown in Figure 8.8. The low fine content seemed to not have a similar impact on the UCS. The average IDTS values were 51 psi with a CV of 11% for the specimens cured 140°F for 48 hrs, and 42 psi with a CV of 18% for the specimens cured 104°F for 72 hrs (it does not include the very low value for the material from Station 6 in the statistics). In general, the indirect tensile test provided more consistent results than those from the compression test.

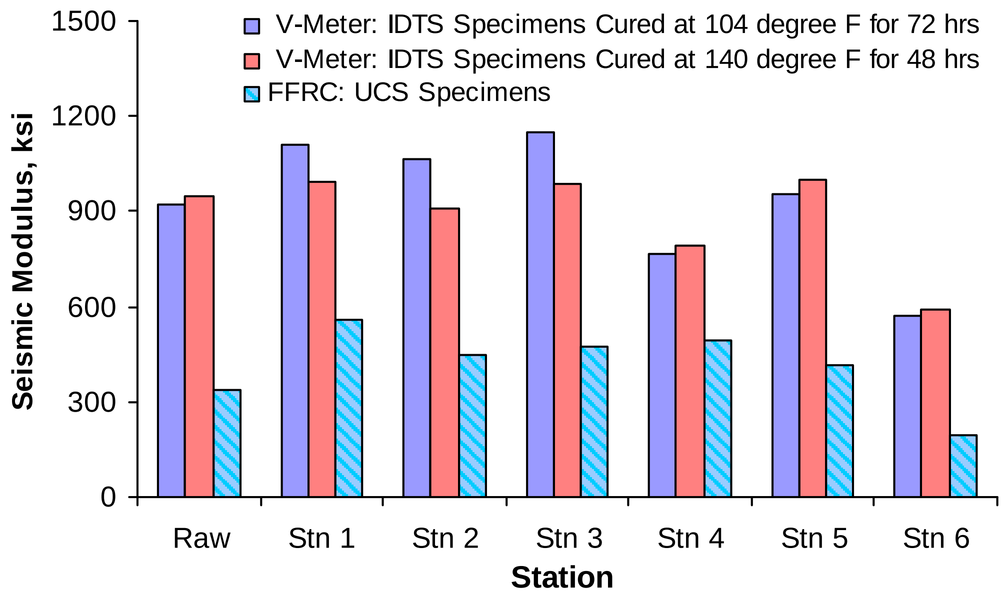


Figure 8.10 – Moduli of Raw and Pulverized Materials from FM 479 Project

An average FFRC modulus of 418 ksi with a CV of 28% was obtained from all UCS specimens. Again, as shown in Figure 8.10, both UCS and IDTS specimens prepared from Station 6 material exhibited the lowest FFRC and V-meter moduli. However, unlike the pattern observed for IDTS where the strengths of the specimens cured at 140°F are systematically higher than those of the specimens cured at 104°F (by an average of about 20%), the V-mater moduli of the specimens cured under the two regimes are quite similar, which means that the impact of initial curing temperature on modulus is less than the impact on strength.

Tube Suction Tests

Results from tube suction tests are summarized in Table 8.8. The moisture contents and the dielectric constants have similar patterns. Specimens made from the raw material and the materials from Stations 4, 5 and 6 lost some moisture after 8-day moisture conditioning. As a result, the corresponding dielectric constants dropped from an initial average of about 8 to a final average of about 4. On the other hand, specimens prepared from the materials retrieved from Stations 1 through 3 absorbed considerable amount of water after moisture conditioning, which resulted in a systematic increase in their dielectric constants.

Table 8.8 – Summary of Results from Tube Suction Tests for Materials from FM 479 Project

Material Source	Moisture Content (%)		Dielectric Constant		Retained Strength (%)	Retained Modulus (%)
	Initial	Final	Initial	Final		
Raw	8.3	3.5	8.2	3.9	94	97
Station 1	7.0	12.7	7.2	17.0	62	30
Station 2	7.1	9.8	7.7	18.7	43	34
Station 3	8.3	11.5	6.9	20.1	39	38
Station 4	7.4	4.9	6.5	3.6	172	105
Station 5	7.0	6.8	8.2	3.9	114	91
Station 6	6.5	4.1	7.2	3.5	111	98
Average	7.4	7.6	7.4	10.1	90.7	70.4
C.V., %	9	49	9	79	52	49

Retained strength and retained modulus are important parameters for stabilized base courses. The possible benefits of emulsion treatment may be best studied with these two parameters. Normally, they are inversely related to the final dielectric constant as shown in Figure 8.11.

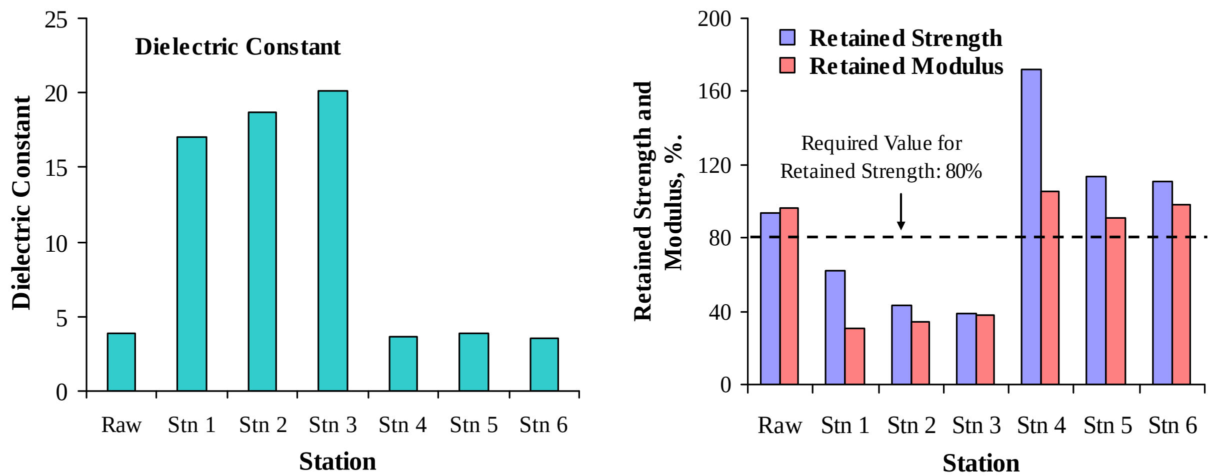


Figure 8.11 – Dielectric Constants, Retained Strengths and Retained Moduli Measured from TST Specimens for FM 479 Project

Resilient Modulus Test

Resilient modulus test was performed on a specimen prepared from the raw material with the standard mix design used the in this project. The test was performed under zero confining pressure since a specimen prepared from the stabilized material should be independent of confining pressure. Figure 8.12 shows the test result which is also independent of deviatoric stress and has a representative value of about 175 ksi.

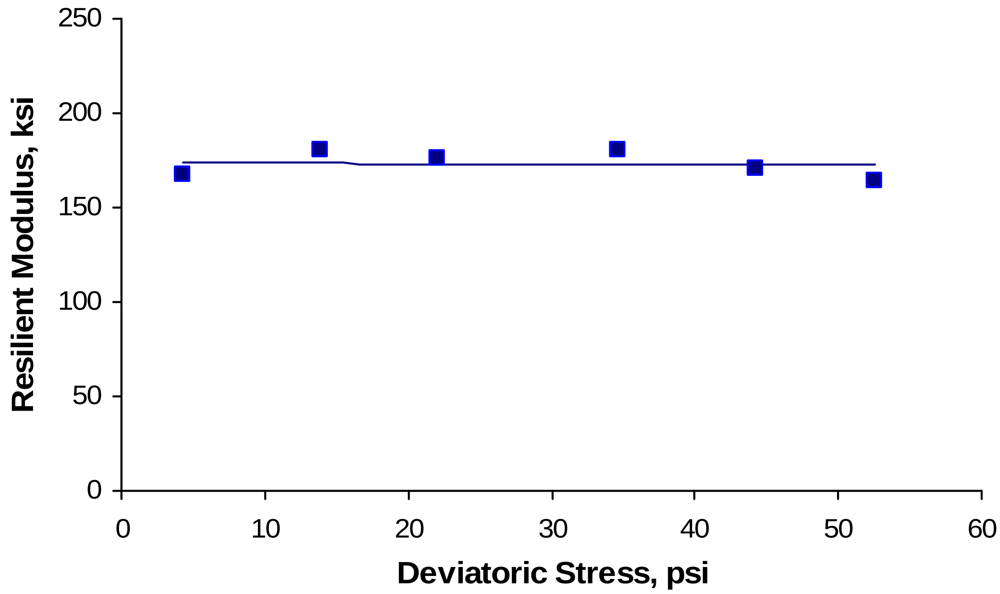


Figure 8.12 – Result from Resilient Modulus Test for FM 479 Project

PSPA Measurements

PSPA measurements were conducted on the new base in seven sections which distributed on both the northbound lane (NBL) and the southbound lane (SBL) of this project. Among the seven sections, five sections were constructed with the standard design as reflected in Table 8.6. Other two sections were constructed with different additive and emulsion contents as well as slightly different amount of adding water. The results from the measurement are shown in Figure 8.13 and summarized Table 8.9. The number in each of the parentheses in Figure 8.13 denotes the age of the section in day.

Table 8.9 – Summary of Results from PSPA Measurements for FM 479 Project

Section	Age (day)	Locations Tested	Average Modulus (ksi)	C. V. (%)	Additive
NBL 603-631	1	36	223	31	4% Emulsion 1% Cement
SBL 704-723	1	18	235	35	
NBL 977-1027	1	30	238	29	
NBL 631-659	2	27	275	22	
SBL 670-688	3	30	365	17	
SBL 678-704	2	42	408	16	5% Emulsion 2% Cement
SBL 659-670	7	42	487	17	6% Emulsion +2% Cement

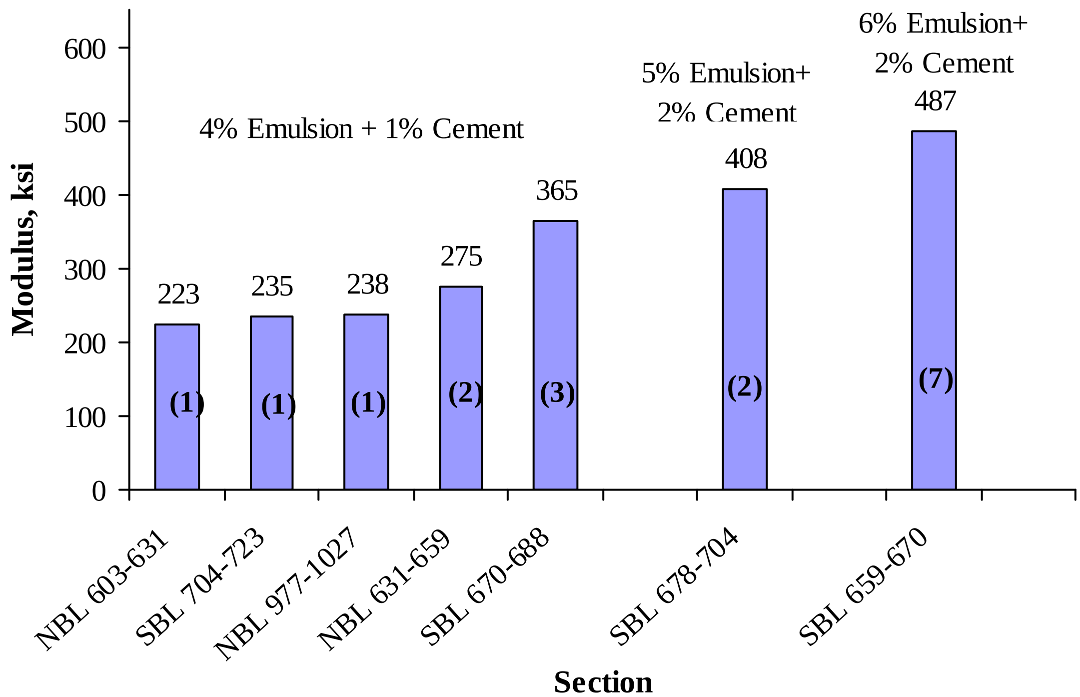


Figure 8.13 – Average Base Moduli from PSPA Measurements for FM 479 Project

As shown in Figure 8.13, the average moduli obtained in sections treated with 4% emulsion plus 1% cement are about 232 ksi, 275 ksi and 365 ksi at ages of 1 day, 2 days and 3 days, respectively. This trend indicates that the modulus increases with the curing age at least within the first few days after constructed.

On the other hand, the sections with higher cement and emulsion contents showed significantly higher moduli (even the section with 2% cement and 6% emulsion at 7-day age). No cracks were observed in these two sections.

US 287 Project

This is also a dual-stabilization project located on US 287 between FM 294 (at Goodnight) and Donley county line in Armstrong County of Amarillo District as shown in Figure 8.14.

The original roadway of US 287 along this project had four 12-ft wide traffic lanes and two shoulders and consisted of a HMA course of about 13 in., a granular base of about 6 in. and the subgrade. The major tasks of this rehabilitation project included:

- Removing the top 5 in. of HMA from the pavement
- Pulverizing the rest of the pavement down to 10 in. deep (8 in. of remaining HMA plus 2 in. of old base)
- Treating the pulverized mix with fly ash and asphalt emulsion (see Table 8.10 for the mix design)
- Finishing the new base and covering it with 6 in. HMA

Figure 8.14 – Location of US 287 Project

Table 8.10 – Mix Design for US 287 Project

Existing RAP	Existing Base	Asphalt Emulsion	Fly Ash	Adding Water
80%	20 %	6%	3%	5.2%

Material Collection

Materials collected from this project site included:

- The RAP and the base material from the existing road
- Pulverized material before adding additives from four locations at an interval of 1000 ft

Sieve Analysis

The RAP and the base material retrieved from the existing road were mixed according their portions specified in the mix design for this project. This mix is called “raw” to distinguish it from those sampled after pulverization. Sieve analysis was performed on the raw and the pulverize mixes sampled from each of the four locations along the project. As shown in Figure 8.15, the gradation curves of the raw and the pulverized materials are similar except for the material from Station 4. All materials show to contain less fine contents (particles smaller than #40 sieve).

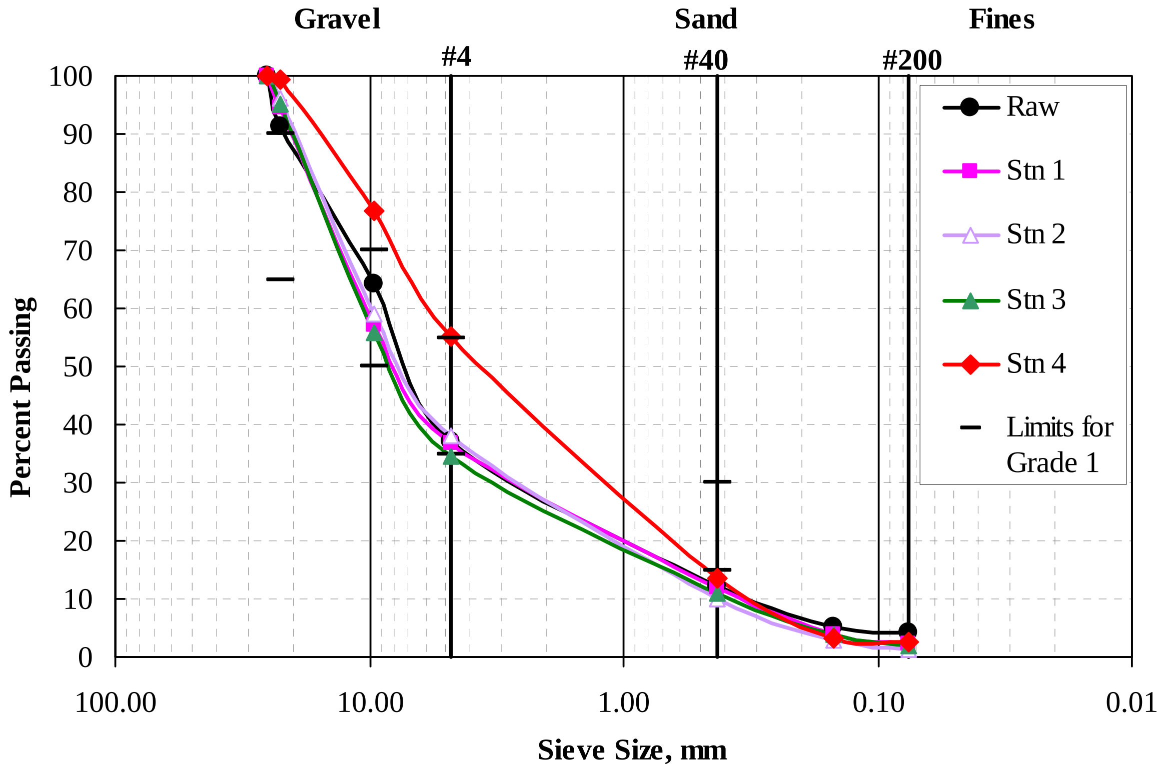


Figure 8.15 – Gradation Curves of Raw and Pulverized Materials from US 287 Project

Strength and Modulus Tests

Specimens were prepared from the pulverized material from each location, mixing with water, fly ash and asphalt emulsion as specified in Table 8.10. Results from strength and modulus tests are summarized in Table 8.11. None of the specimens met the 150 psi for UCS and 50 psi for IDTS. High RAP content might have impacted the UCS and IDTS values. The material from this project mixed with 3% emulsion and 1% cement could reach a UCS value of 195 psi and an IDTS of 63 psi (see Table 4.5 in Chapter 4).

Table 8.11 – Statistics of Strength and Modulus Parameters Measured for Materials from US 287 Project

Material Source	UCS Specimen		IDTS Specimen			
	UCS (psi)	FFRC Modulus (ksi)	104° F (72 hr Cure)		140° F (48 hr Cure)	
			IDTS (psi)	V-meter Modulus (ksi)	IDTS (psi)	V-meter Modulus (ksi)
Station 1	101	457	16	911	15	947
Station 2	99	462	13	941	18	753
Station 3	85	382	14	811	19	713
Station 4	141	589	14	977	13	822
Average	106	472	14	910	16	809
CV, %	23	18	7	8	15	13

Tube Suction Tests

Results from tube suction tests on the pulverized materials are summarized in Table 8.12. The final moisture contents and the final dielectric constants of all specimens are significantly lower than the initial ones, which indicate that all the specimens actually lost moisture after moisture conditioning. As a result, almost all retained strengths and retained moduli are greater than 80%.

Table 8.12 – Summary of Results from Tube Suction Tests for US 287 Project

Material Source	Moisture Content (%)		Dielectric Constant		Retained Strength (%)	Retained Modulus (%)
	Initial	Final	Initial	Final		
Station 1	6.5	4.2	7.4	4.8	127	81
Station 2	6.1	4.0	15.6	7.1	127	90
Station 3	6.0	3.8	15.2	7.1	126	98
Station 4	6.3	4.5	13.4	7.1	89	77
Average	6.2	4.1	12.9	6.5	117	86
C.V., %	4	7	29	18	16	11

PSPA and FWD Measurements

PSPA measurements were conducted at an interval of 200 ft on the newly constructed base along three lines (two on the left and right lanes and one on the shoulder) in a 3000-ft section on the westbound direction of the project. The age of the new base was 2 days when the measurements were conducted. FWD tests, as a monitoring program, ware conducted in the same section a year later after the project completed. The results from the two tests are compared in Table 8.13 and Figure 8.16. The average modulus from PSPA tests is about 1.4 times of that from FWD tests. Normally, the ratio should be about 1.7 based on a previous study for the granular bases (Nazarian at al., 1996). Most likely, the reasons for the lower ratio obtained for this experiment are that the moduli from PSPA tests reflect the status of the new base at its two-day age and the back-calculated moduli from FWD deflection measurements reflect the status of the base at its one-year age.

Table 8.13 – Summary of Results from PSPA and FWD Tests for US 287 Project

Section	Lane	PSPA		FWD	
		Average, ksi	CV, %	Average, ksi	CV, %
Westbound 172+200 - 175+200	Left	299	19.1	207	49.0
	Right	305	22.2	229	41.9
	Shoulder	269	18.9	184	33.4

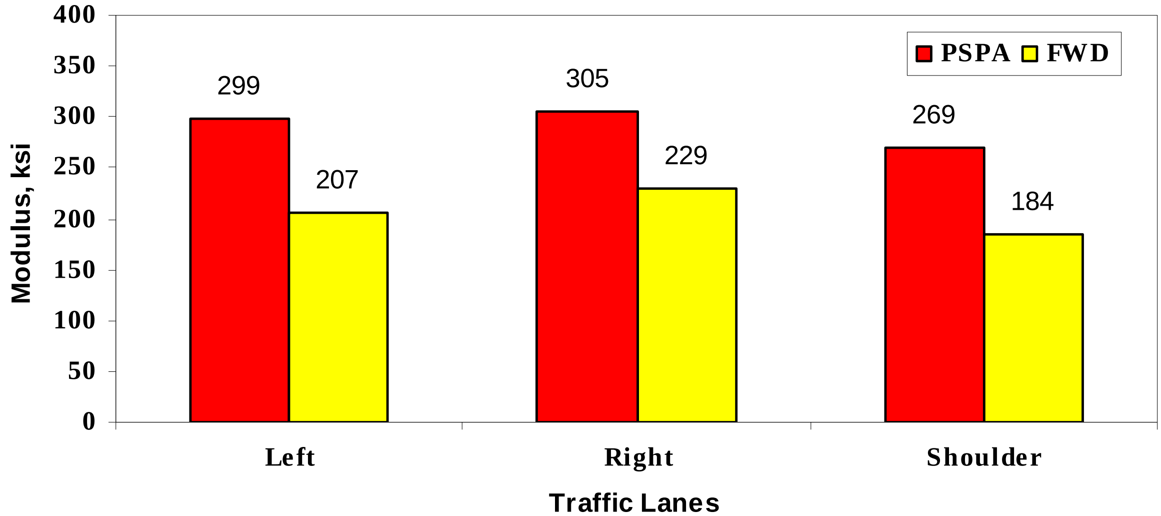


Figure 8.16 – Average Moduli from PSPA and FWD Tests for US 287 Project

FM 740 Project

This is a dual-stabilization project located on FM 740 between Downtown of Forney (south of US 80) and FM 548 in Dallas District. Figure 8.17 shows the location of this project.

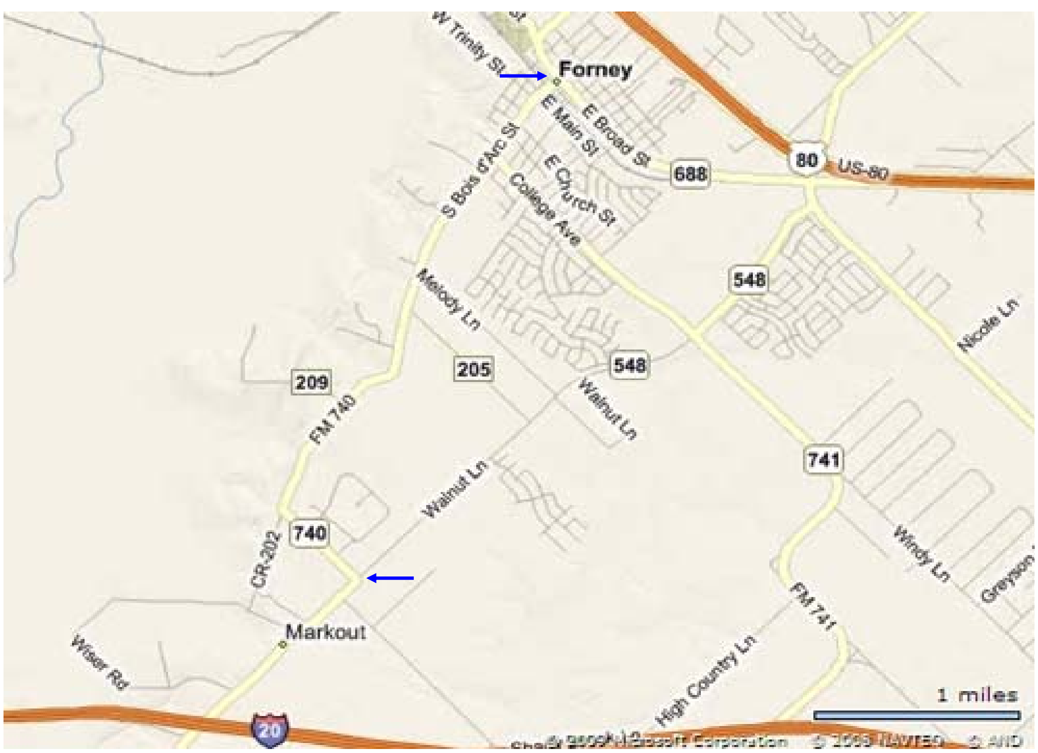


Figure 8.17 – Location of FM 740 Project

The original roadway of FM 740 along this project consisted of a multiple seal-coat surface course of 3 to 4 in., a granular base of more than 6 in. and the subgrade. The major tasks of this rehabilitation project included:

- Pulverizing the existing road down to about 8 in. deep and adding about 3-in. crushed concrete
- Treating the mix with cement and asphalt emulsion (see Table 8.13 for the mix design)
- Finishing the base and covering it with 2-in. HMA

Table 8.14 – Mix Design for FM 740 Project

Existing RAP	Existing Base	Add Rock (Crushed Concrete)	Adding Water	Cement	Asphalt Emulsion
40%	27%	33%	6%	1%	4%

Material Collection

Materials collected from this project site included:

- RAP and old base materials from the existing road as well as add rock (from which the raw mixture can be made)
- Pulverized mixture before adding additives from four locations
- Three 6 in. by 4.5 in. cylindrical specimens prepared by the contractor at the site

Sieve Analysis

The RAP and the base material retrieved from the existing road as well as the add rock were mixed according their portions shown in Table 8.13 for this project. Sieve analysis was performed on the raw and the pulverized mixes sampled from each of the four locations of the project. Figure 8.18 shows the gradation curves of all materials which lie within or marginally outside the allowable limits for Grade 1 bases. It is evidence that materials after pulverization were getting finer.

Strength and Modulus Tests

Specimens were prepared from the raw material and the pulverized material form each location following the mix design provided in Table 8.14. Results from strength and modulus tests are summarized in Table 8.15. In terms of unconfined compressive strength, most specimens meet or are close to the requirement of 150 psi specified by the TxDOT Special Specification. However, no specimen met the requirement of 50 psi for IDTS by the specification. These results are similar to that for US 287 project (see Table 8.11) where 80% RAP is used. For this project, the total RAP and crushed concrete are about 73% in the mixture.

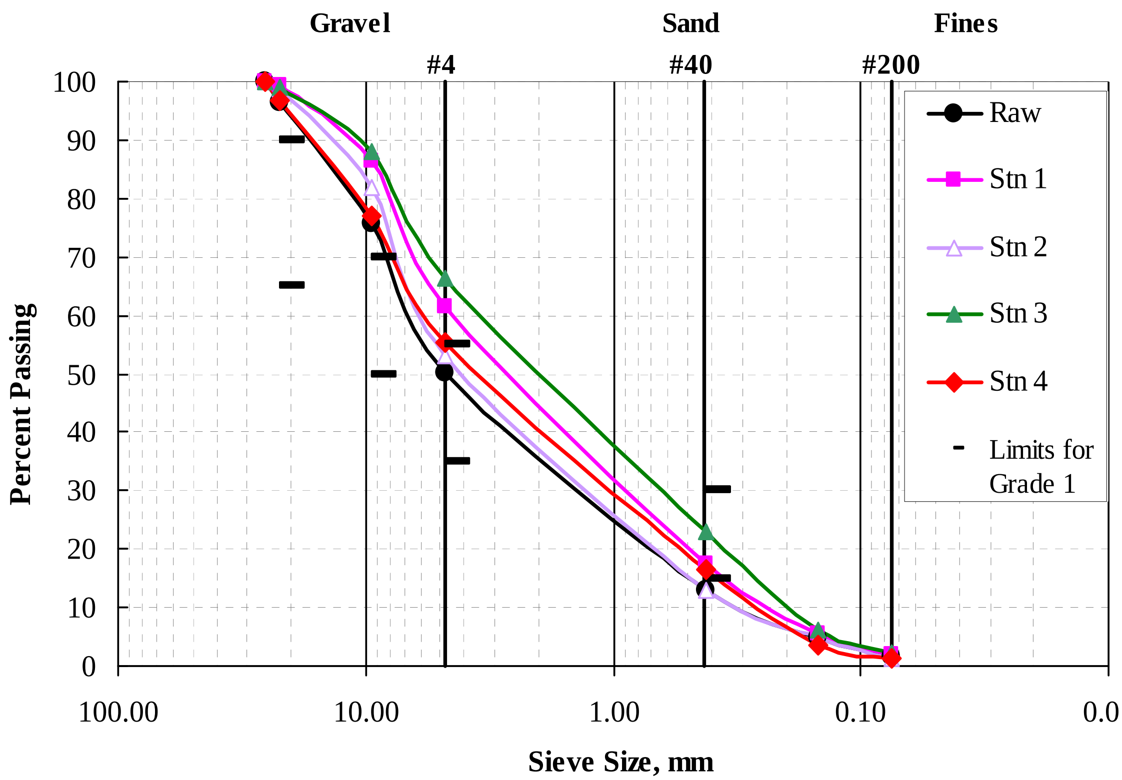


Figure 8.18 – Gradation Curves of Raw and Pulverized Materials from FM 740 Project

Table 8.15 – Statistics of Strength and Modulus Parameters Measured for FM 740 Project

Material Source	UCS Specimen		IDTS Specimen			
	UCS (psi)	FFRC Modulus (ksi)	104° F (72 hr Cure)		140° F (48 hr Cure)	
			IDTS (psi)	V-meter Modulus (ksi)	IDTS (psi)	V-meter Modulus (ksi)
Raw	149	395	34	653	41	981
Station 1	154	388	36	695	36	955
Station 2	94	292	31	819	32	833
Station 3	147	500	36	906	41	987
Station 4	164	478	36	854	36	938
Average	142	411	35	785	37	939
CV, %	19	20	6	14	10	7

Tube Suction Tests

The average final dielectric constant obtained from tube suction tests on the materials from this project is 6 with a small standard deviation. Figure 8.19 shows a comparison of the initial and retained values for both the UCS and IDTS. All retained UCS values, except for Station 2, are greater than 150 psi and all retained IDTS values reach or are close to 50 psi. In terms of percentage, all retained strengths are greater than 80% requirement; that is, 120 psi for UCS and 40 psi for IDTS. Such results are consistent with those from dielectric constant tests.

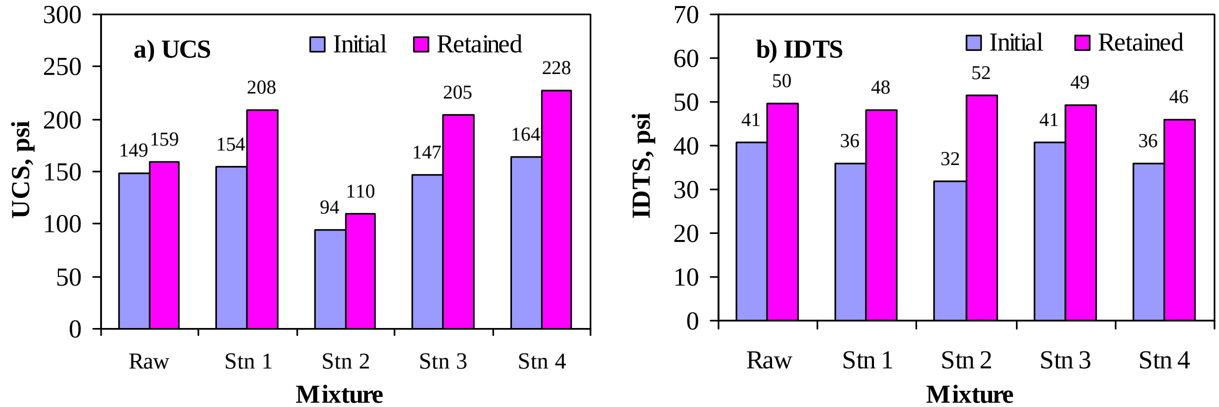


Figure 8.19 – Comparison of Initial and Retained Strengths for FM 740 Project

In addition, the three 6 in. by 4.5 in. on-site specimens were brought back and cured under moisture conditioning in the laboratory for a week. The average IDTS of the three specimens after moisture conditioning was about 44 psi which represents a retained strength of 88%.

PSPA Measurements

Field modulus tests with a PSPA were performed on the new base in four sections along the southbound lane of the project at their one-day age. The results from these tests are summarized in Table 8.16. The average values for the four sections are 244, 334, 356 and 504 ksi with coefficients of variation of 17% or less. Based on our field observations, the high moduli measured in Section 2 was most likely caused by the difference in cement added to that section. Modulus measurement is very sensitive to the cement content in a mixture and density measurement is not. The available NDG data indicated a change in dry density of less than 1%. This result from modulus measurements is very different from that of the FM 479 project where the new base is also treated with 4% emulsion and 1% cement, indicating the importance of mix design.

Table 8.16 – Summary of Results from PSPA Tests for FM 740 Project

Section*	Locations Tested	Average Modulus, ksi	CV, %
1	21	356	14.8
2	17	504	17.3
3	15	244	17.0
4	33	334	15.3

***:** No station marks were available for all sections during testing.

Alternative Measurements of QA/QC for Emulsion-Treated Bases

For the asphalt emulsion-treated bases, it has been experienced that the density and moisture content measurements with a NDG is of concern. This phenomenon has been predicted by the analysis of density-moisture content/total liquid content curves in Chapter 4. The problem is currently dealt with by measuring the density of specimens prepared at the construction site from the loose materials. However, the compaction effort made for such specimens may significantly differ from that for the in-situ base layers. For instance, the average dry density (unit weight) measured on the on-site specimens for the FM 740 project was 122.8 pcf that is 101% of the maximum dry density (121.4 pcf) obtained from the laboratory test and specified for this project. In addition, this activity also results in the extra construction cost. For this reason, certain alternative methods and tools are needed.

Based on the results from PSPA measurements on the newly constructed bases in the projects studied, there is potential to use the modulus measured with a PSPA as a QA/QC parameter for the emulsion-treated bases. Figure 8.20 summarizes the average moduli obtained from PSPA measurements on the four bases at their early ages (the section that had an unusually high average modulus due to extra cement for the FM 740 project is not included). To compare them with those from the laboratory tests, the moduli obtained from FFRC tests on the UCS specimens prepared from the materials collected from the four projects are also included in the figure.

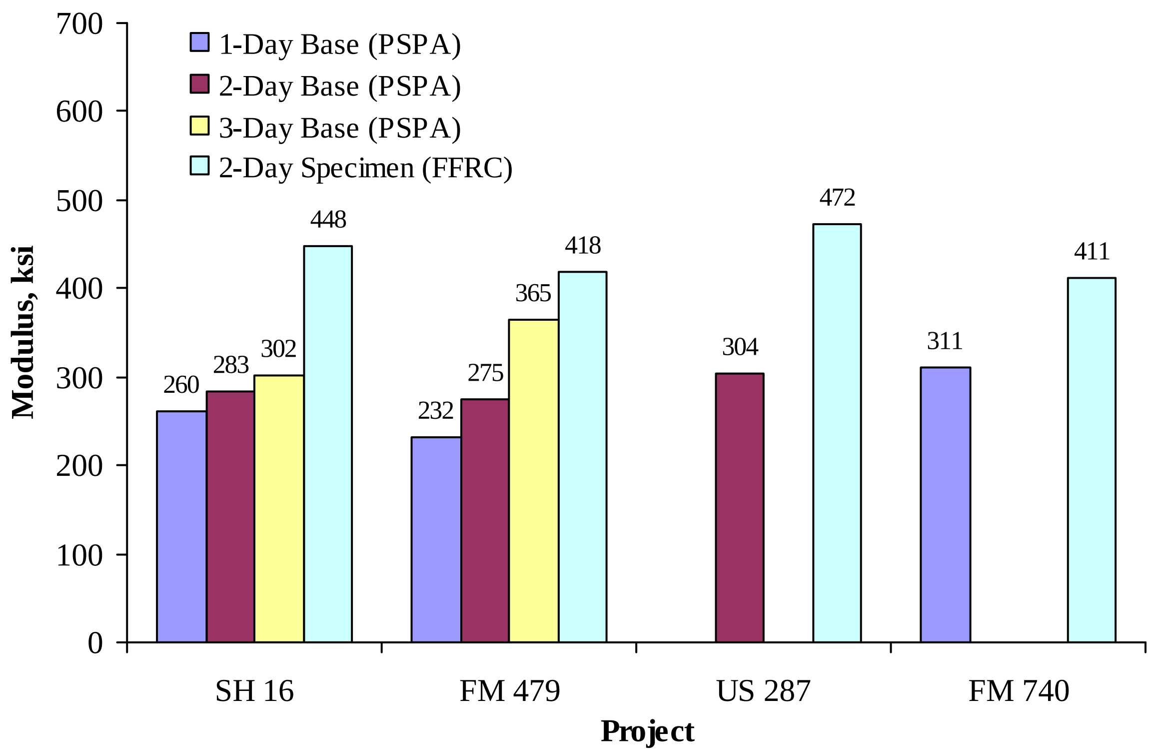


Figure 8.20 – Average Moduli Measured with PSPA and FFRC Device

With the current practice in mix design for emulsion-treated base materials for which the FFRC modulus is obtained from testing on the specimens after 2-day cure at 140^{o}F, the minimum required values of field modulus after one day of curing can be preliminarily set as about 60% of the seismic modulus from FFRC tests on 2-day cured UCS specimens. For the mixtures with less than 30% RAP and greater than 60% RAP, the required value can be 5% to 10% lower and higher, respectively.

Construction Practices

As reflected above, the impact of pulverization and construction activities on the quality of the base was documented. As part of this study, changes in gradation, density and moisture content from several sites were presented. The impact of these changes on the final base quality was quantified through laboratory and field tests. In this section, recommendations on all aspects of construction for emulsion stabilized bases are included. The recommendations and observations are categorized by activities from the beginning of a project to completion. Some of the observations confirmed the findings of Garibay et al. (2008) in Project 0-5223 dealing with pulverization. The experience gained in that very relevant project is also reflected in this section.

For the most part, the current TxDOT Special Specification for emulsion-treated bases is reasonable, if enforced during construction.

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 the above case studies, 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 improvements to the base 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.

  Add Rock: Add rock is usually recommended when additional thickness is needed or when the project has to be widened. The inclusion of add rock in some projects to improve the gradation of the in-place material should be considered. The add rock should be sieved separately, and proportionally added to the gradation.

- ***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. For the high fines content materials and materials with PI in excess of 10, the use of lime as the secondary additive is recommended. In turn, for materials will low fine contents, cement seems to be appropriate as the secondary stabilizer.

- ***Assessing Quality of Aggregates**:* As shown by Garibay et al. (2008), pulverization process turns gravel-size aggregates into fine sands. The Aggregate Crushing Value (ACV) and/or the Aggregate Impact Value (AIV) seemed to provide a reasonable predictor of the crushing potential of aggregates in that study. If add rock is added, the crushing potential of these aggregates should be assessed as well. The excel worksheet described in Appendix C would allow for the consideration of change in gradation due to pulverization.

- ***Mix Design:*** The mix design procedure recommended in Appendix D is proposed for the emulsion stabilized bases.

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:*** When the base and the hot mix/surface treatment are pulverized into bases, the gradation of the RAP should meet the current TxDOT specifications. The larger size pieces usually observed in the field may impact the final quality of the mix and may contribute to the variability in the field results observed. For thicker hot mix asphalt layers, Garibay et al. recommend that the material be milled separately, sorted and then be added to the base similar to add rock.

- ***Add Rock:*** Special 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 sequence of adding the water, calcium-based additives and emulsion was reasonable in all projects. Based on our observations, the uniform distribution of the additives should be carefully observed. The amount of water added before adding the additives should also be carefully observed as discussed below.

- ***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. Allowing the compaction when the moisture content is not within 1% of the design moisture content (especially wet of optimum), would have negative impact on the strength of the final product. Garibay et al. (2008) proposed that the moisture content of the material be determined as a quality control measure before compaction. 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. If the NDG is used, the importance of calibrating it for a particular base with stabilizer should be emphasized.

  Achieving the density, without controlling the moisture content, 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. Nondestructive field tests such as the PSPA to be used to measure the quality of the finished layer.

- ***Opening to Traffic:*** In most projects the opening of the road to traffic after pulverization and compaction is dictated by the need to minimize the traffic disruption to the motoring public. 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 constructions.

Chapter 9

Observations and Recommendations

Introduction

The goal of this study was to evaluate the current design specifications as outlined by TxDOT with regards to stabilization of base materials using asphalt emulsion. The end goal was to develop a laboratory test protocol for selecting the correct combination of additives for dual stabilization of base materials and draft a guideline for the construction of bases with dual stabilization. As part of this study, several different materials were sampled and subjected to various forms of testing in order to document the effects of several parameters on the engineering properties of dual stabilized bases. Parametric studies were also performed on all of the materials used in this study. In this chapter, recommendations on all aspects of emulsion only as well as dual stabilized base materials are included.

Mix Design Selection Based on Results from IDT Testing

TxDOT special specification specifies the UCS values as one of the main criteria for selecting the amount of emulsion to be added to the material. After performing an entire matrix of testing using both the UCS and IDT, it was observed that the IDT test results are more sensitive to the amount of emulsion. Also, the strain at failure of the mixes with emulsion tested under IDT increased significantly as compared to mixes without emulsion. This demonstrated one of the value added benefits of the emulsion that should be evaluated during mix design. Due to the fact that soils cannot hold tension, the increased strain which is seen by emulsion stabilized bases could have significant effects in reducing the cracking of the pavement. As such, it is proposed that the main strength criteria for mix design to be based on the IDT strength as opposed to the UCS strength. Using IDT as the first line of testing will also require less material.

Moisture Susceptibility Testing

Under the current specification, the retained compressive strength is the main indicator of the moisture susceptibility of the mixes, with the dielectric constant value from TST tests to be reported in the final mix design. The retained strengths based on compression tests were typically acceptable for almost all mixes that achieved the retained strengths based on tensile tests.. This is partly because of the lack of penetration of moisture into the specimen during moisture conditioning. However, in several cases, the retained IDT strengths were less than 80% due to the height of the specimen (4.5 in. as opposed to 8 in. for UCS specimens) and method of compaction (using gyratory compactor instead of kneading method for UCS specimens) the moisture could penetrate through the specimen. As such, it is recommended that the retained IDT be considered as the main criterion for moisture susceptibility.

Initial Mixing Water Content

During the course of this study, it was observed that an initial mixing water content of 60% of the OMC was sufficient for adequate compaction. Most materials used in this study followed this rule. All the emulsions used in this study contained about 35% water. It would be important to look at the index properties of the material or perhaps the RAP content in order to see why this is so.

Parametric Study Results

After reviewing various parametric studies performed on a number of materials, the following conclusion were drawn:

- Small Changes in gradation of the material have a minimal effect on the strength and stiffness of the specimens but impact their retained strengths.
- Emulsion type (proprietary or generic) has no significant effect on the final strength results of these types of stabilized bases. However, the retained strengths with the generic emulsion were generally lower.
- The use of the high shear mixer as opposed to other means does significantly affect the strength of these materials, especially in the case of materials with higher fine contents. However, a more uniform mix is supplied by the high shear mixer.
- Compaction method does affect the strength/stiffness parameters of emulsion stabilized bases. The mixes with the gyratory compactor exhibit higher strengths and moduli. The number of gyrations (30 and 50) also significantly impacts the moduli and strengths. However, the laboratory results should be further compared with those observed in the field so that the method which is more representative of the field conditions can be selected.
- The temperature at which the material is mixed does not impact the final strength values achieved as long as they are at or above the room temperature.
- The temperature at which the specimens are initially cured (2 to 3 days) has significant effect on the final strength and stiffness achieved. Two day curing at 140^{o}F was recommended here

Construction Practices

The TxDOT Special Specification provides a reasonable document for construction practices as long as those provisions are enforced during constructions. Some additional precautions are provided in Chapter 8.

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Appendix A

TxDOT Special Specification
Emulsion Treatment (Road Mixed)

SPECIAL SPECIFICATION
XXXX
Emulsion Treatment (Road Mixed)

1. **Description.** Mix and compact emulsion, additives, water, and base with or without asphalt concrete pavement, in the roadway.

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. **Emulsion.** Provide an asphalt-emulsion that meets the requirements of Table 2.

   B. **Flexible Base ("Add Rock").** 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 emulsion.

   C. **Additive.** Determine the amount and type of additive, if any, during the mix design. When an additive is required, the total amount in the mix will not exceed 1.0 % by weight of material.

      1. **Lime.** When lime is required, furnish lime that meets the requirements for DMS-6350, "Lime and Lime Slurry," and DMS-6330, "Lime Sources Prequalification of Hydrated Lime and Quicklime." Use hydrated lime or commercial lime slurry, as shown on the plans.

      2. **Cement.** When cement is required, 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.

   D. **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 additive, percent "add rock", percent existing material, and optimum percent asphalt emulsion required to meet the mixture requirements in Table 1. Prepare specimens for all tests except AASHTO T 307 in accordance with Tex-113-E. Perform additional mix designs based on existing material variability, as directed by the Engineer.

Table 1
Laboratory Mixture Design Properties

Property		Criteria
Min. indirect tensile strength (ITS),psi	Tex-226-F[1]	50
Dielectric value	Tube Suction Test (TST) (Appendix A)	Report
Min. unconfined compressive strength, psi	Tex-117-E	150
Min. retained unconfined compressive strength (UCS), psi	Tex-117-E[2]	80%
Resilient modulus	AASHTO T 307	Report
Seismic modulus	Free-free Resonant Column (Appendix B)	Report

1. Indirect tensile strength specimens will be cured 72 hr. at 104°F before testing.

2. After determination of the final dielectric value, conduct UCS in accordance with Tex-117-E on the dielectric specimens.

Table 2
Emulsified Asphalt Properties

Test	Method	Min	Max
Residue from distillation, %	ASTM D 244	63	-
Oil distillate by distillation, %	ASTM D 244	-	0.5
Sieve Test, %	ASTM D 244	-	0.1
Penetration, 25°C, dmm	ASTM D 5	55	95

E. **Water.** Furnish water free of industrial waste and other objectionable material.

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.

   Provide a self-propelled mixer capable of fully mixing the existing road to the depth required, incorporate the asphalt emulsion and water, and mix the materials to produce a homogeneous material. Provide a mixer with a minimum power of 400 HP. Provide a machine capable of mixing not less than 8 ft. (2.4 m) wide and up to 12 in. (30.5 cm) deep in each pass. The mixer must contain a system for adding asphalt emulsion with a full width spray bar consisting of a positive displacement pump interlocked to the machine speed so that the amount of emulsion being added is automatically adjusted with changes in machine speed. The emulsion injection system will be capable of incorporating up to 7 gal. per square yard of emulsion. Provide individual valves on the emulsion injection system spray bar that are capable of being turned off as necessary to minimize emulsion overlap on subsequent passes.

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. **Preshaping.** Shape the existing material in accordance with applicable bid items to conform to typical sections shown on the plans and as directed before the addition of asphalt-emulsion. Incorporate water and add rock during this operation, if needed. Compact the material to support equipment and / or traffic, and to provide depth control during mixing.

B. Mixing. Before mixing, aerate if too wet and add water if too dry. Add emulsion at the percentage determined in Section 2.D, "Mix Design." Monitor the required depth of mixing regularly.

Complete the entire operation of mixing the existing road, incorporating add rock, water, and asphalt emulsion in one pass. Ensure that each adjacent pass of the mixer overlaps the previous pass by a minimum of 6 in. Use multiple passes if the quality control requirements specified in Section 5 are not met. If an additional pass of the mixer significantly improves dispersion of the emulsion, use this additional pass for the entire project.

After mixing, the Engineer will sample the mixture at roadway moisture and test in accordance with Tex-101-E, Part III, to determine compliance with the following gradation requirements:

Sieve Size	Percent Passing
1-3/4 in.	100
3/4 in.	85

C. Application of Additive.

Uniformly apply additive in advance of the mixer. Minimize dust and scattering of additives by wind. Do not apply additives when wind conditions, in the opinion of the Engineer, cause blowing additive to become dangerous to traffic or objectionable to adjacent property owners.

1. **Lime.** Uniformly apply lime using dry or slurry placement as shown on the plans, or as directed. Add lime at the percentage determined in the mix design. Apply lime only on an area where mixing can be completed during the same working day.

   Start lime application only when the air temperature is at least 35°F and rising or is at least 40°F. The temperature will be taken in the shade and away from artificial heat. Suspend application when the Engineer determines that weather conditions are unsuitable.

   a. **Dry Placement.** When necessary, sprinkle in accordance with Item 204, "Sprinkling." Distribute the required quantity of hydrated lime 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 as specified.

Distribute slurry uniformly by making successive passes over a measured section of roadway until the specified lime content is reached.

2. **Cement.** Uniformly apply cement using dry placement unless otherwise shown on the plans. Add cement at the percentage determined in the mix design. Apply cement only on an area where mixing, compacting, and finishing can be completed during the same working day. 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.

3. **Emulsion.** Uniformly apply emulsion as specified in Section 3.A, "Mixing." Add emulsion at the percentage determined in Section 2.D, "Mix Design." Apply emulsion only on an area where mixing and compaction can be completed during the same working day.

   Suspend emulsion application if the weather forecast calls for freezing temperatures within 7 days after incorporation of the emulsion. Finish emulsion application before the historical weather database predicts freezing temperatures within 7 days after completion of the emulsion portion of the project. Suspend application when the Engineer determines that weather conditions are unsuitable.

D. Compaction. Compact the mixture using density control, unless otherwise shown on the plans. Multiple lifts are permitted when shown on the plans or approved.

Begin rolling longitudinally at the sides and proceed toward the center, overlapping on successive trips by at least one-half the width of the roller unit. On superelevated curves, begin rolling at the low side and progress toward the high side. Offset alternate trips of the roller. Operate rollers at a speed between 2 and 6 mph, as directed.

Perform initial compaction using a heavy tamping roller applying high amplitude and low frequency. Maintain the heavy tamping roller within 500 ft. of the mixer at all times. Continue rolling until the heavy tamping roller "walks out" of the material. Walking out for the heavy tamping roller is defined as light being evident between all of the pads at the material–heavy tamping roller drum interface.

After the completion of heavy tamping rolling, remove remaining tamping marks. Cut no deeper than the depth of the tamping marks. Achieve desired slope and shape to the lines and grades shown in the plans. Perform final surface shaping on the same day as the asphalt emulsion is incorporated.

Use a vibratory roller and pneumatic roller to compact the bladed material. Do not finish-roll in vibratory mode. If necessary, use a light spray of water to aid in final compaction density and appearance.

The Engineer will use a portable seismic pavement analyzer to determine field seismic modulus and compare to seismic modulus reported in the mix design.

Rework material that fails to meet or that loses required moisture, density, stability, or finish within 24 hours of completion of compaction. Add additional emulsion and additives at 100% of the percentages determined during mix design. Reworking includes loosening, adding material or removing unacceptable material if necessary, mixing as directed, compacting, and finishing. Continue work until specification requirements are met. Perform the work at no additional expense to the Department.

When an area fails to meet or loses required moisture, density, stability, or finish more than 24 hours after completion of compaction and before the next course is placed or the project is accepted, remove the unacceptable material and replace with new material that meets the mix design requirements. Compact and finish until specification requirements are met. Perform the work at no additional expense to the Department.

1. **Ordinary Compaction.** 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.** The Engineer will determine roadway density of completed sections in accordance with Tex-115-E. 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.

   Compact the bottom course to at least 95% of the maximum density determined in accordance with Tex-113-E, unless otherwise shown on the plans. Compact subsequent courses treated under this Item to at least 97% of the maximum density determined in accordance with Tex-113-E, unless otherwise shown on the plans.

E. **Curing.** Cure the finished section until the moisture content is at least 2 percentage points below optimum, or as directed before applying the next successive course or prime coat. Do not allow equipment or traffic on the finished course during curing, unless otherwise approved. The Engineer may allow traffic on the finished course during curing if proof rolling indicates adequate stability. Proof roll in accordance with Item 216, "Proof Rolling." If deformation occurs, do not allow traffic to return to the finished section until the mixed material is firm enough to accommodate traffic without deformation. Apply seals or additional courses within 14 calendar days of final compaction.

   When the plans show no specific detour, the Contractor will provide one-way traffic control until proof rolling permits the return of normal traffic to the compacted material.

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. **Asphalt Emulsion.** A representative from the asphalt emulsion supplier will check the mixing and curing properties at the beginning of the project, and will make recommendations for design changes to the Engineer.

B. Moisture Content. Use Tex-103-E to check moisture content before addition of emulsion. Check the moisture content on the same day emulsion is applied. If rain has occurred after testing and before emulsion addition, 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.

C. Emulsion Content. Apply the amount of asphalt emulsion recommended in the mix design. The Engineer must approve changes in asphalt emulsion content or supplier. Check the percentage of emulsion added using meter readings or truck weigh tickets, the quantity of material reclaimed (depth, width, and length) and estimated in-place density determined by Tex-113-E (mix design or field check) or nuclear density gauge. Determine emulsion content on the first day of processing during the first emulsion transport. Adjust equipment calibration if necessary. Check emulsion content again if adjustments are made. Determine subsequent emulsion content as directed by the Engineer, but not less than once per day.

D. Density. Obtain samples to the full depth of reclamation before rolling and store in a sealed container for no longer than 2 hours. Compact in accordance with Tex-113-E and adjust mixing and compaction operations to achieve maximum dry density established in the mix design.

6. Measurement.

A. Emulsion. Emulsion will be measured by the gallon.

B. Additive.

1. Lime. When lime is furnished in trucks, the weight of lime will be determined on certified scales, or the Contractor mush 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 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.

a. Hydrated Lime.

(1) Dry. Lime will be measured by the ton (dry weight).

(2) Slurry. Lime will be measured by the ton (dry weight) of the hydrated lime used to prepare the lime slurry at the jobsite.

b. 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.

2. **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 asset 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 ay shipment, as determined by weighing 10 bags taken at random, must be at least the manufacturer's certified weight.

C. **Emulsion Treatment.** Emulsion 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.

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 7.A, "Emulsion," Section 7.B, "Lime," Section 7.C, "Cement," and Section 7.D, "Emulsion 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 7.B, "Emulsion 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."

Additives and emulsion used for 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. **Emulsion.** Emulsion will be paid for at the unit price bid for "Emulsion." This price is full compensation for materials, delivery, equipment, labor, tools, and incidentals.

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

C. **Cement.** Cement will be paid for at the unit price bid for "Cement." This price is full compensation for furnishing cement.

D. Emulsion Treatment. Emulsion treatment will be paid for at the unit price bid for "Emulsion Treatment (Existing Base)," or "Emulsion Treatment (Mixing Existing Material and New 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 additives and emulsion, 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 B

SemMaterials Mix Design Procedure Emulsion Treatment (Road Mixed)

Date Revised: February 19, 2007

Mix Design Procedure – Emulsion Treatment (Road Mixed)

1. Scope

Use this procedure to determine the proper proportions of approved aggregates and/or RAP and asphalt emulsion, which, when combined, will produce a mixture that will satisfy the specification requirements outlined in Table 1. It may be necessary to incorporate various additives in order to meet the specification. It is the intent of this procedure to achieve a minimum of 150 psi compressive strength at the maximum dry density and the optimum percent moisture.

2. Apparatus

The following apparatus may be utilized to conduct Road Mixed Emulsion Treatment Mix Designs. Use of some of this equipment is not required but, suggested practice in order to obtain consistent results.

- High Shear Mechanical Mixer - A mechanical mixer shall be used that has a bowl of at least 10 inches in diameter. It shall rotate on its axis at 70 ± 10 revolutions per minute. A mixing paddle which is in close proximity with the bottom and side of the bowl (in order to prevent fine material from building up) shall rotate on its axis at twice the bowl rotation rate and in the opposite rotation direction as the bowl. (See www.pmw-wheeltracker.com/mixer.htm for an example of the mechanical mixer)
- drying oven, maintained at 60°C (140°F)
- crusher, which can be adjusted to produce material passing a 1¼" sieve
- Set of standard U.S. sieves, meeting the requirements of Test Method "Tex-907-K, Verifying the Accuracy of Wire Cloth Sieves"
- Scale, with a minimum capacity of 36 kg (80 lb.) with a minimum accuracy and readability of 5 g or 0.1% of the test load, whichever is greater
- Sample splitter, quartering machine, or quartering cloth
- Automatic tamper (compaction) device with base plate to hold 152.4 mm (6 in.) inside diameter (I.D.) forming molds, equipped with a 4.55 ± 0.01 kg (10 ± 0.02 lb.) rammer and adjustable height of fall
  - Striking face of the rammer should conform to a 43 ± 2° segment of a 74 ± 2.5 mm (2.9 ± 0.1 in.) radius circle.
  - The base plate of the tamper shall be secured to a rigid foundation such as a concrete block with a mass of not less than 91 kg (200 lbs.).
  - An alternate foundation support, such as a rigid stand or table, may be used if the DA produced is within 2% of that produced by an automatic tamper bolted to a concrete floor.
- a rigid metal compaction mold having a 152.4 mm, +1.59 or -0.40 mm (6 in., +1/16 or -1/64 in.) I.D. and 215.9 ± 1.6 mm (8.5 ± 1/16 in.) height with removable collar
- a metal stand with a set of standard spacer blocks and a micrometer dial assembly, with 50 mm (2 in.) travel, for determining height of specimens. Spacer blocks 25.4, 101.6, 152.4 and 279.4 mm (1, 4, 6 and 11 in.) accurate to 0.025 mm (0.001 in.).
- circular porous stones slightly less than 152.4 mm (6 in.) in diameter and 51 mm (2 in.) high

- a supply of small tools including a 1.8 to 2.3 kg (4 to 5 lb.) rawhide hammer, 0.5 to 0.9 kg (1 to 2 lb.) plastic mallet, level, finishing tool and others.
- Plastic Tubs, wide and shallow for mixing, curing, and drying materials
- drying oven maintained at 121°C (250°F)
- drying oven, maintained at 60°C (140°F)
- drying oven, maintained at 40°C (104°F)

3. Design Preparation

A. Establish a blend ratio and a preferred additive for the sampled materials utilizing information provided by field support staff.

B. Based on data from sampling and / or other determinations (i.e. pavement records, FWD deflection data, etc.); determine if more than one design is required. The mix design requires a minimum 500 pounds of material proportional to the blend ratio established in Step 1.A.

C. Crush bituminous materials to expected field gradation using a laboratory crusher. Freezing the cores prior to crushing is acceptable. Dry the crushed bituminous material at 60°C (140°F) or less until it reaches constant mass.

D. Dry the base material overnight not to exceed 121°C (250°F). If organic materials are present in the sample do not exceed 60°C (140°F) when drying.

E. Prepare materials for mix design by screening in order to have a maximum size passing the 31.25 mm (1.25 in) sieve.

4. Material Evaluation

A. Determine particle size distribution of the existing and/or virgin base material via Tex-110-E, Part I, Sieve Analysis of Material Retained on the 425 µm (No. 40) Sieve. Sieve the entire sample (in a mechanical shaker) according to the following series of sieves listed below for 5 minutes:

44.5 mm	(1 3/4 in.)
31.7 mm	(1 1/4 in.)
22.2 mm	(7/8 in.)
19 mm	(3/4 in.)
9.5 mm	(3/8 in.)
4.75 mm	(No. 4)
425 µm	(No.40)
75 µm	(No. 200) Optional[1]

Weigh the individual fractions retained on each sieve and calculate a "bulk gradation". This "bulk gradation" will become the basis for all other sample preparation used in the mix design. (See Appendix 1 for sample batch sheet.)

B. Determine particle size distribution of the existing, virgin, and blended material sample according to Tex-110-E, Part I, for use on the final report.

C. Optional – Determine Plasticity Index via Tex-106-E.

[1] Not Included in Tex-101-E, Part II, Step 6

D. Optional – Determine Sand Equvialency via Tex-203-F.

E. Optional – Determine Methylene Blue Value via AASHTO TP-57.

F. Optional – Determine particle size distribution of the crushed bituminous material using Step 2.A and 2.B as a guideline

5. Material Preparation

A. Prepare twenty-four (24) approximately 4,000 gram specimens (for 6"x 8" specimens). Prepare four (4) approximately 3,200 grams specimens (for 6"x 3 ¾" specimens) at the required blend percentages. (See Appendix 1 for a sample batch sheet calculation).

B. Batch the base material(s) according to the "bulk gradation" obtained in Material Evaluation.

C. Add the crushed bituminous material representatively by a mechanical splitter or equivalent alternative, as outlined in Tex-101-E, Part III, Step 2.

6. Emulsion/Additive Selection

A. Approximate starting emulsion contents (based on the weight of aggregate) can be found in Appendix 2, Table 1 "Approximate Starting Emulsion Contents". Aggregate mineralogy has an impact on starting emulsion content and the actual emulsion content must be determined by mix design.

B. Suggested additive(s) and the respective content can be found in Appendix 2, Table 2 "Table of additives / contents and OMC adjustments". Aggregate mineralogy can affect additive content and the actual additive content must be determined by mix design.

7. Sample Preparation

A. Thoroughly mix water into the blended material.

B. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

C. When using dry additives in the design, incorporate them into the blended material in a similar manner as they will be incorporated during construction.

Note: *Prior to mixing emulsion into the blended material, "butter" the container used for adding emulsion to the mixture. The purpose of "buttering" the container is to provide a coating of asphalt emulsion on the container to ensure accurate asphalt emulsion content. To butter the container, fill it completely full of emulsion and then pour the emulsion out of the container. The emulsion container is considered to be "buttered" when emulsion no longer drips from the container.*

D. Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

E. Cure each loose specimen in a plastic container. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

8. Determination of Maximum Dry Density

A. Estimate the percent moisture at optimum. Select the first water content approximately 2% to 4% below this estimate and adjust water content of the other specimens in approximately 2% increments.[2] Select a total of four moisture contents.

B. Prepare two (2) 6"x 8" specimens at each of the four moisture contents by adding water. Thoroughly mix the water into the blended material. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

C. Using the high shear mechanical mixer add the emulsion determined in "Emulsion / Additive Selection". Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

D. Cure each loose specimen in a plastic container of 6 inches (150 mm) diameter. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

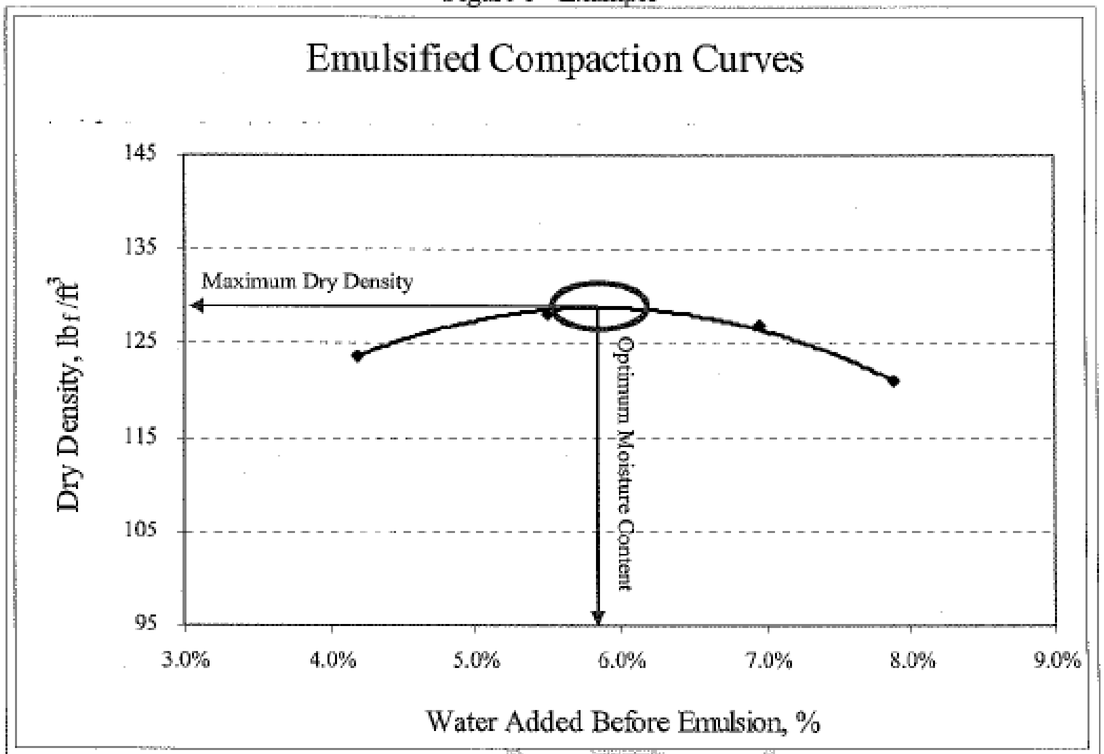
E. Repeat Step B through D for the remaining moisture contents.

F. Develop the emulsified moisture density curve utilizing Tex-113-E as a guideline neglecting Section 7, Step 38. *NOTE: The compacted sample will be used for testing in "Determination of Stabilized Base Properties".

G. Determine the Maximum Dry Density (D_A) and Optimum Moisture Content (OMC). See Figure 1.

[2] Tex-113-E, Section 7, Step 5 & 6

Figure 1 - Example



9. Determination of Stabilized Base Properties

A. Place one of the specimens, from each moisture content prepared in "Determination of Maximum Dry Density", on a two inch thick porous stone. Allow the specimens to sit for 4 hours ± 5 minutes on a bench top at ambient temperature. Break each specimen in Unconfined Compressive Strength and report the values as $UCS_{initial}$.

Note: After breaking in UCS, dry the specimens to constant mass for verification of moisture content added in "Determination of Maximum Dry Density".

B. Place the remaining specimens on two inch thick porous stones.

C. Cure the specimens for 48 hours at 60°C (140°F) after compaction.

D. After curing, cool specimens at ambient temperature (25°C or 77°F) for no more than 48 hours.

E. Test the cured specimens for Seismic Modulus / Free-Free Resonant Column (FFRC) testing according to Appendix B (Tex-147-E) of the Emulsion Treatment (Road Mixed) Special Specification.

F. Break the cured specimens in Unconfined Compression and report the values as UCS_{dry}.

G. Evaluate UCS_{dry} to ensure it meets Table 1 requirements. If UCS_{dry} does not meet the minimum required value in Table 1, then adjust % emulsion and/or add additives as needed to obtain the desired UCS_{dry} value.

10. Determination of Stabilized Base Properties at Optimum Moisture Content

Note: If an additive has already been used in "Determination of Stabilized Base Properties" to obtain a passing UCS_{dry} value, skip to Step G.

A. Prepare two (2) 6"x 8" and two (2) 6"x 3 ¾" specimens (according to "Sample Preparation") at the selected emulsion content and optimum moisture content determined in "Determination of Stabilized Base Properties".

B. Thoroughly mix the water into the blended material. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

C. Using the high shear mechanical mixer add the emulsion content selected. Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

D. Cure each loose specimen in a plastic container. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

E. Compact the 6"x 8" specimens using Tex-113-E as a guideline neglecting Section 7, Step 38.

F. Compact the 6"x 3 ¾" specimens in a Superpave gyratory compactor (SGC) at 30 gyrations, following the guidelines of Tex-241-F. Apply a vertical pressure of 600 ± 18 kPa (87 ± 2 psi) at an angle of 22.0 ± 0.35 mrad (1.25 ± 0.02°). Use a 150 mm (6 in.) diameter mold. After the last gyration, apply a 600 ± 18 kPa (87 ± 2 psi) pressure for 10 seconds. Do not heat the mold.

G. Prepare two (2) 6"x 8" and two (2) 6" x 3 ¼"" specimens (according to "Sample Preparation") by adjusting the OMC and adding the desired additive.

H. Thoroughly mix the water into the blended material. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

I. When using dry additives in the design, incorporate them into the blended material in a similar manner as they will be incorporated during construction.

J. Using the high shear mechanical mixer add the emulsion content selected in Step 4.A. Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

K. Cure each loose specimen in a plastic container. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

L. Compact the 6"x 8" specimens using Tex-113-E as a guideline neglecting Section 7, Step 38.

M. Compact the 6"x 3 ¾" specimens in a Superpave gyratory compactor (SGC) at 30 gyrations, following the guidelines of Tex-241-F. Apply a vertical pressure of 600 ± 18 kPa (87 ± 2 psi) at an angle of 22.0 ± 0.35 mrad (1.25 ± 0.02°). Use a 150 mm (6 in.) diameter mold. After the last gyration, apply a 600 ± 18 kPa (87 ± 2 psi) pressure for 10 seconds. Do not heat the mold.

N. Cure the 6"x 3¾" specimens for 72 hours at 40°C (104°F) after compaction.

O. After curing, cool specimens at ambient temperature (25°C or 77°F) for no more than 48 hours.

P. Test the cooled 6"x 3¾" for Indirect Tensile Strength (ITS) testing according to Tex-226-F and at the density achieved after 30-gyration compaction.

Q. Place the 6"x 8" specimens on two-inch thick porous stones.

R. Cure specimens from each set (with & without additive) for 48 hours at 60°C (140°F) after compaction.

S. After curing, cool specimens at ambient temperature (25°C or 77°F) for no more than 48 hours.

T. Break one specimen from each set (with & without additive) in Unconfined Compressive Strength and report the values as UCS_{dry}.

U. Test the remaining specimens for Seismic Modulus / Free-Free Resonant Column (FFRC) testing according to Appendix B[3] (Tex-147-E)[4] of the Emulsion Treatment (Road Mixed) Special Specification.

V. Test the 6"x 8" specimens for Resilient Modulus (M_r) testing according to AASHTO T-307[5] at 23 ± 2°C (73 ± 3°F).

Note: Materials can be sent to the Texas Transportation Institute for modified AASHTO T307 Resilient Modulus testing:

Contact Stacy Hilbrich at s-hilbrich@ttimail.tamu.edu

W. Test the 6"x 8" specimens for Tube Suction Testing (TST) according to Appendix A (Tex-144-E) of the Emulsion Treatment (Road Mixed) Special Specification. Perform this test after M_r testing. After conditioning specimens according to Appendix A (Tex-144-E), perform conditioned UCS testing according to Tex-117-E at a loading rate of 0.135 inches / minute.

Note: Running FFRC on TST Specimens daily may facilitate early completion of TST testing if values remain constant after 3 consecutive daily readings.

11. Report

Report the following minimum information:

- The name of the road and other pertinent project information
- Blend Percentages used
- Washed Gradation of Blended material obtained
- Roadway thickness to be reclaimed
- Sand Equivalent / PI values / Methylene Blue Value (if obtained)
- The emulsion content used in Step 6 to the nearest 0.1%
- Maximum Dry Density to the nearest kg/m^3 ($0.1\ lb/ft^3$)

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[3] Personal conversation with Soheil Nazarian, Ph.D., P.E. indicates that the FFRC testing can be conducted by placing the accelerometer and load cell on the same side of the specimen.

[4] Use of a mild carbon disk glued to the surface of the 6"x8" specimen greatly facilitates timely data collection.

[5] Modify AASHTO T-307 as follows: 1) 6 inch diameter by 8 inch tall specimens compacted according to Tex-113-E, 2) Table 2 testing conditions of T-307.

- Water added before emulsion to the nearest 0.1%
- FFRC modulus from Step 8.A to the nearest 1 ksi (MPa)
- Plot FFRC modulus vs. Water Added Before Emulsion
- UCS_{dry} to the nearest 1 psi
- Plot UCS_{dry} vs. Water Added Before Emulsion
- ITS from to the nearest 1 psi
- Resilient modulus according to AASHTO T-307 (modified).
- Final dielectric constant from the TST to the nearest 0.1 €
- $UCS_{retained}$ on TST specimens to the nearest 1 psi

Appendix 2 – Emulsion/Additive Selection

Table 1 – Approximate Starting Emulsion Contents

District	Abilene		Amarillo		Atlanta		Austin		Beaumont	
Aggregate Type	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP
Emulsion Content	TBD	TBD	5.0%	4.0%	TBD	TBD	5.0%	4.0%	4.5%	4.0%
District	Brownwood		Bryan		Childress		Corpus Christi		Dallas	
Aggregate Type	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP
Emulsion Content	TBD	TBD	TBD	TBD	5.0%	4.0%	5.0%	4.0%	4.5%	3.5%
District	El Paso		Fort Worth		Houston		Laredo		Lubbock	
Aggregate Type	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP
Emulsion Content	TBD	TBD	4.5%	3.5%	4.5%	4.0%	5.0%	4.0%	5.0%	4.0%
District	Lufkin		Odessa		Paris		Pharr		San Angelo	
Aggregate Type	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP
Emulsion Content	TBD	TBD	5.0%	4.0%	TBD	TBD	TBD	TBD	TBD	TBD
District	San Antonio		Tyler		Waco		Wichita Falls		Yoakum	
Aggregate Type	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP	< 50% RAP	> 50% RAP
Emulsion Content	5.0%	4.0%	TBD	TBD	TBD	TBD	TBD	TBD	4.5%	3.5%

Table 2 – Table of additives / contents and OMC adjustments

District	Abilene	Amarillo	Atlanta	Austin	Beaumont
OMC + __	TBD	+1/2	TBD	TBD	+1/4
Additive Type	TBD	"C" Fly Ash	TBD	TBD	Type I
% Additive	TBD	2.5%	TBD	TBD	1.0%
District	Brownwood	Bryan	Childress	Corpus Christi	Dallas
OMC + __	TBD	TBD	+1/2	+1/4	+1/4
Additive Type	TBD	TBD	"C" Fly Ash	Type I	Type I
% Additive	TBD	TBD	2.5%	1.0%	1.0%
District	El Paso	Fort Worth	Houston	Laredo	Lubbock
OMC + __	TBD	+1/4	+1/4	TBD	+1/2
Additive Type	TBD	Type I	Type I	TBD	"C" Fly Ash
% Additive	TBD	1.0%	1.0%	TBD	2.5%
District	Lufkin	Odessa	Paris	Pharr	San Angelo
OMC + __	TBD	+1/2	TBD	TBD	TBD
Additive Type	TBD	"C" Fly Ash	TBD	TBD	TBD
% Additive	TBD	2.5%	TBD	TBD	TBD
District	San Antonio	Tyler	Waco	Wichita Falls	Yoakum
OMC + __	+1/4	TBD	TBD	TBD	+1/4
Additive Type	Type I	TBD	TBD	TBD	Type I
% Additive	1.0%	TBD	TBD	TBD	1.0%

*Note: OMC adjustment for Type I Cement was obtained from Tex-120-E, Part I, Step 3b.

Appendix 3 – Optional Testing

3.1 – Ambient Cure Testing

A. Estimate the percent moisture at optimum. Select the first water content approximately 2% to 4% below this estimate and adjust water content of the other specimens in approximately 2% increments.[6] Select a total of four moisture contents.

B. Prepare two (2) 6"x 8" specimens at each of the four moisture contents by adding water. Thoroughly mix the water into the blended material. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

C. Using the high shear mechanical mixer add the emulsion determined from "Emulsion / Additive Selection". Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

D. Cure each loose specimen in a plastic container. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

E. Repeat Step B through D for the remaining moisture contents.

F. Place one of the specimens, from each moisture content prepared in Section 6, on a two inch thick porous stone. Allow the specimens to sit for 24 hours ± 1 hour on a bench top at ambient temperature. Break each specimen in Unconfined Compressive Strength and report the values as $UCS_{initial\ 24hr}$.

G. After breaking in UCS, dry the specimens to constant mass for verification of the moisture content added.

H. Place the remaining specimens, prepared from each moisture content, on a two inch thick porous stone. Allow the specimens to sit for 48 hours ± 1 hour on a bench top at ambient temperature. Break each specimen in Unconfined Compressive Strength and report the values as $UCS_{initial\ 48hr}$.

3.2 – Dunk Testing

A. Prepare two (2) 6"x 8" specimens (according to Section 5) at the selected emulsion content and optimum moisture content determined in Step 6.G.

B. Thoroughly mix the water into the blended material. Allow the wetted samples to stand for a minimum of 12 hours in a sealed container prior to emulsion addition.

C. Using the high shear mechanical mixer add the emulsion content selected. Mix the blended material and emulsion at ambient temperature. Mix emulsion into the moist material for no more than 60 ± 10 seconds in order to achieve an even dispersion of emulsion.

D. Cure each loose specimen in a plastic container. Cure specimens at 60°C (140°F) for 30 ± 3 minutes before compaction. Do not further mix or aerate during this curing.

E. Compact the 6"x 8" specimens using Tex-113-E as a guideline neglecting Section 7, Step 38.

F. Place each specimen on pourous stone. Cure the specimens for 48 hours at 60°C (140°F) after compaction.

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[6] Tex-113-E, Section 7, Step 5 & 6

G. After curing, cool specimens at ambient temperature (25°C or 77°F) for no more than 48 hours.

H. Submerge each specimen in a bath maintained at 25°C for 4 hours ± 5 minutes.

I. Remove the specimens and dry with a damp towel.

J. Break the specimens in Unconfined Compression and report the values as UCS_{dunk}.

Appendix C

Emulsion Analysis Tool Manual

Emulsion Analysis Tool Manual

Introduction

The Emulsion Analysis Tool is 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) guide the user on the initial estimate of the emulsion content.

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. The worksheet also considers the aggregate crushing potential due to pulverization. The Aggregate Crushing Value (ACV) test is proposed for this purpose. 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 Emulsion 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.

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 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 – 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 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 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 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 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 5 and 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 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 4 – In-Place Base Sieve Analysis

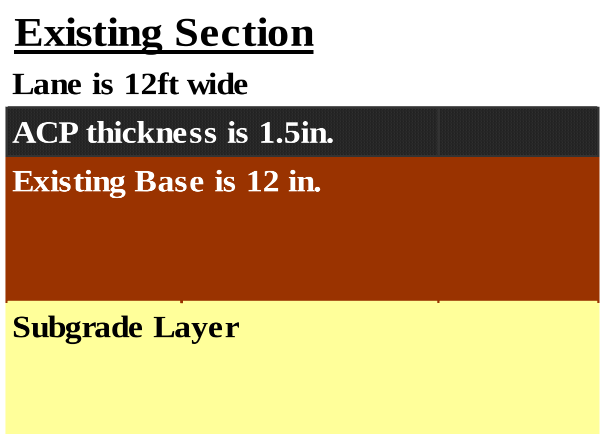


Figure 5 – Existing Pavement Profile

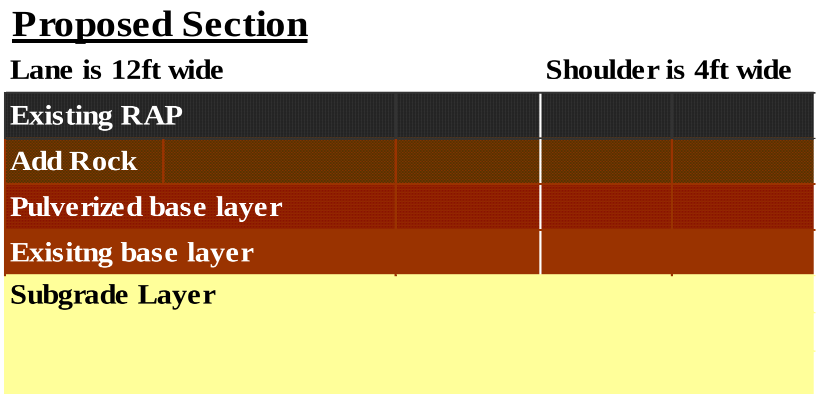


Figure 6 – Proposed Pavement Section

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 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.” As indicated before, a standard for crushing the RAP in the laboratory should be developed.

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.

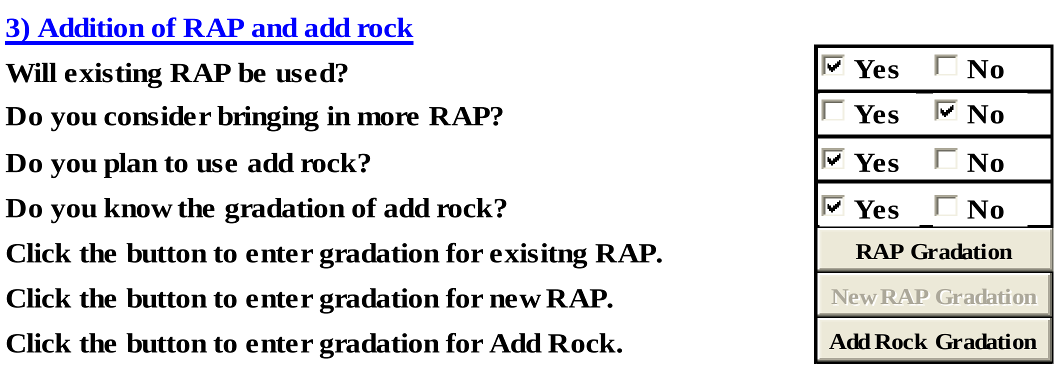


Figure 7 – Addition of RAP and Add Rock

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 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.

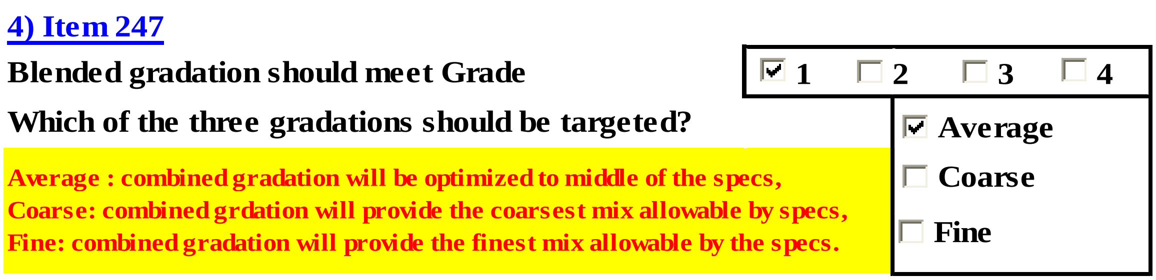


Figure 8 – Selection Options of Item 247

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 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.

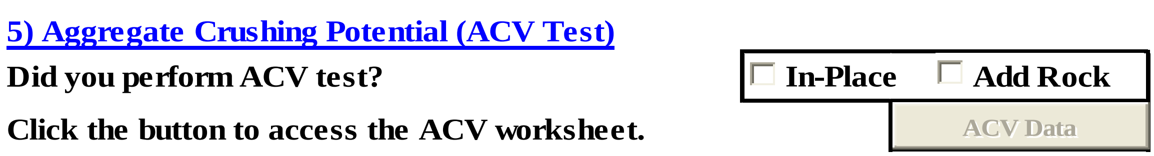


Figure 9 – Selecting the Option of Inputting ACV Test Results

If either one or both check boxes are checked, the user should depress the "ACV data" button shown in Figure 9 to provide the required information.

Figure 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 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 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 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 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.

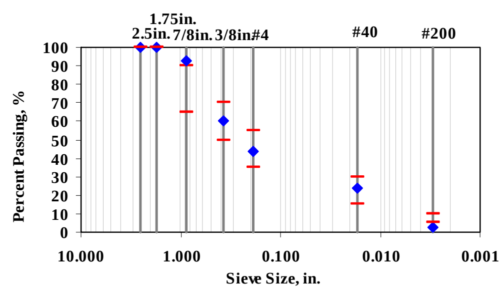
SUMMARY OF OPTIMIZATION RESULTS

1) Determine Blend Gradation | **Reset** | **View Details** | **Generate Report**

2) Modify Blend by Optimizing Add Rock Gradation

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 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 13 shows a blended gradation using this option. The difference between Figures 12 and 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

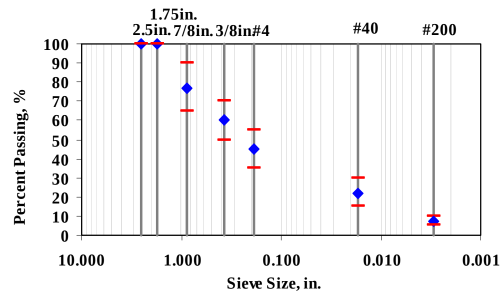
Reset | View Details | Generate Report

1) Determine Blend Gradation

2) Modify Blend by Optimizing Add Rock Gradation

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 13 – Blending Gradation Using Option 2

Section 7: Raw Material/Emulsion/Additive Information

Specific Gravities of Raw Materials

This item requires the user to input the specific gravities of the in-place base, existing and/or new RAP (if used) and add rock (if used). Such screen and default values are shown in Figure 14. However, the actual values can either be measured or requested from the supplier.

5) Material Specific Gravity

In-Place Material	2.65
RAP	2.20
New RAP	2.20
Add-Rock	2.65

Figure 14 – Inputting Specific Gravity of Aggregates

Information about Emulsion

A basic knowledge of the emulsion to be used during the actual construction is required for this item. The user is required to input the amount of residual asphalt within the emulsion itself. This value is the amount of asphalt that the emulsion is comprised of expressed as a percentage. The relevant screen for this information is shown in Figure 15. Although the user is free to assign the measured value of the specific gravity of the emulsion, the recommended value is 1.02.

6) Emulsion Information

Residual Asphalt Percentage	**65%**
Specific Gravity of Asphalt Emulsion	**1.02**

Figure 15 – Inputting Emulsion Information

Information about Cementitious Additive

For this item, the user is asked to choose between two different types of cementitious additives to used (cement or lime). The input screen is shown in Figure 16. It is recommended that the user first perform the analysis with no cementitious additive and then perform the analysis with the addition of a dual stabilizing agent to compare the results. Default values of specific gravity for both lime and cement (1.2 and 3.15, respectively) are used for any calculations, if one or the other is chosen to be included in the mix. For other additives such as fly ash, the user can simply either select the lime or cement provided the specific gravity of that additive is input. The concentration of the additive is set to 1% by default. However, the user can change this if needed.

7) Cementitious Additive

- ☐ **None**
- ☑ **Cement**
- ☐ **Lime**

Concentration

1%

Figure 16 – Inputting Additive Information

Section 8: Moisture Density Information of Raw and Treated Mixes

Desired Degree of Saturation

As indicated in the report, for a constructible mix, the degree of saturation of the treated mix after compaction in the laboratory should be on the order of 85% to 90%. The maximum allowable degree of saturation of the mix is input at this time as shown in Figure 17. A value greater than 90% or less than 80% is not recommended.

Moisture Density Curve Data

In order to ensure proper selection of emulsion content of the mixture, the user must first perform a moisture-density test on the raw material. . It is important that this testing is performed on the material proportioned according to the percentage of in-place base, RAP and add rock suggested in Section 6 of this manual. As shown in Figure 17, the moisture content and associated dry densities calculated during the moisture-density tested to be reflected in this screen.

8) Desired Degree of Saturation **90%**

9) Moisture Density Curve Data

Moisture Content	Dry Density, lb/ft^3
5.0	129.5
7.0	137.8
9.0	138.0
10.6	135.1

Figure 17 – Inputting Moisture Density Information of Raw Material

Section 9: Analysis of Maximum Recommended Emulsion

After entering all of the values required, the analyses are carried out automatically. The output as shown in Figure 18 consists of a graph of the maximum recommended emulsion content as a function of the initial mixing water content selected. The black dashed line on the graph is the maximum amount of emulsion that can be used in the mixture for the desired degree of saturation. The blue line on the graph represents the same value, however the emulsion content is limited to a value of 6% for economical reasons.

This graph gives the user a general idea of what emulsion content to start with during the initial mix design. The initial mixing moisture contents are expressed as percentages of the optimum moisture content for the material. It is important to note that the recommended emulsion contents is based on the maximum amount of emulsion that can be introduced into the mixture in order to optimize the compaction for a given degree of saturation. The required emulsion content may be less than this value.

What if analysis (Maximum Recommended Emulsion)

The user can vary the initial mixing water content as a percentage of the OMC in order to compare its effect on the maximum recommended emulsion content. After the desired value is entered into the required field, the analysis is performed by clicking on the button labeled "Calculate" (see right hand side of Figure 18).

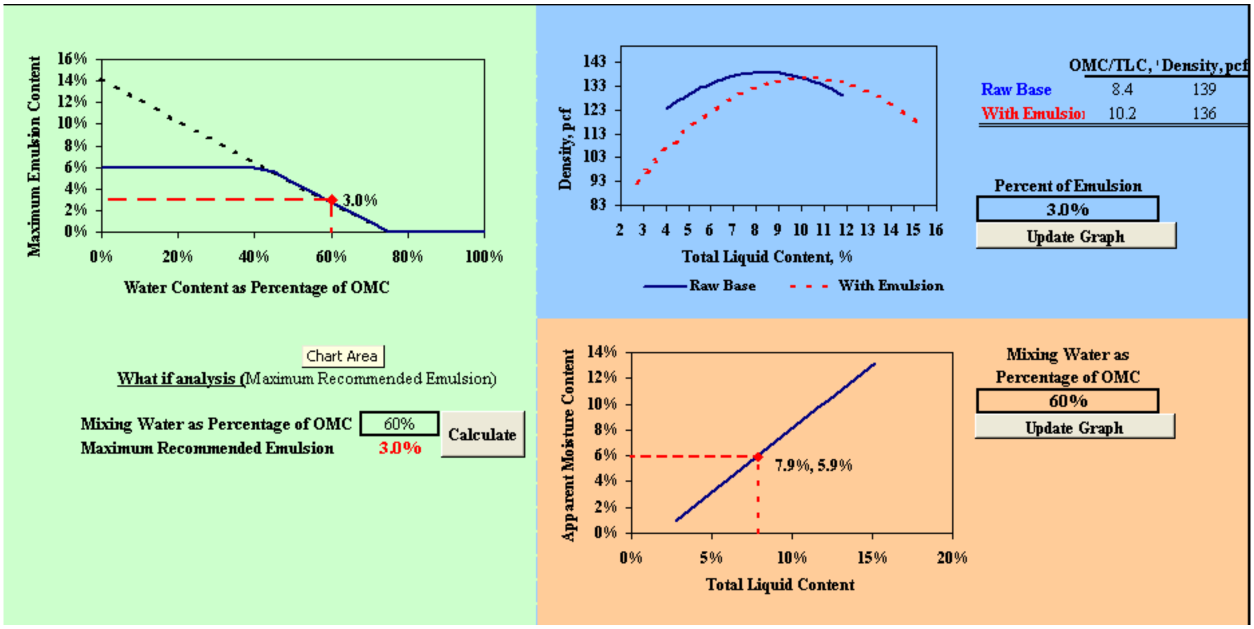


Figure 18 – Results of Analysis

MD Characteristics of Emulsion-treated Mix

This portion of the analysis is intended for use after the final mix design has been decided upon by the user. The percentage of the emulsion is entered in the required field and the button labeled "Update Graph" (see Figure 18 upper right hand side) is then clicked. A graph of the dry density as a function of the total liquid content is then superimposed on the MD curve of the raw material. The two curves can then be compared to evaluate the effects of emulsion on the moisture density anticipated in the field during construction.

The bottom right graph in Figure 18, illustrates the total liquid content for the material based on varying initial moisture contents. This graph is generated by clicking on the button labeled "Update Graph" after the initial mixing water content is entered into the required field. The final output gives the designer a general idea of the apparent moisture content which can be anticipated during field testing.

Section 10: Reports

The report is generated by clicking on the "Generate Report" button discussed above. Figures 19 and 20 show examples of the report summary. This report includes the project information, section profile and gradation summary, as well as other information discussed in the analysis section.

Summary of the Emulsion Analysis Tool

Date: 1/16/2009

Laboratory Results (page 1/2)

Project Information

Sample ID:	0
Sample date:	8/8/2007
Controlling CSJ:	0
County:	0
District:	0
Sampled by:	0
Sample location:	0

Section Profile

Lane is 12ft wide

Existing RAP with volume of 3 ft^3

Add Rock with volume of 5 ft^3

Pulverized base layer with volume of 7 ft^3

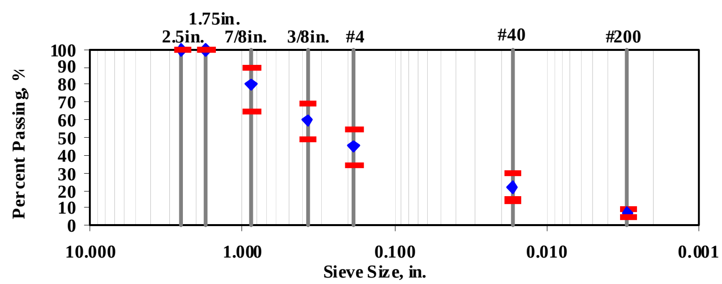
Exisitng base layer with thickness of 5 in.

Subgrade Layer

Gradation Summary

Percent Finer		Original Gradation				*Blending Results*
Sieve	Size, in.	Base	Old RAP	New RAP	Add Rock	
Blendig Ratio		47%	20%		33%	
2-1/2 in.	2.500	100	100		100	100
1-3/4 in.	1.750	100	100		100	100
7/8 in.	0.875	95	90		53	80
3/8 in.	0.375	73	41		53	60
#4	0.187	57	19		44	45
#40	0.017	30	5		22	22
#200	0.003	4	0		17	7

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



Summary of the Emulsion Analysis Tool

Date: 1/16/2009

Laboratory Results (page 2/2)

Analysis Results of Maximum Recommended Emulsion

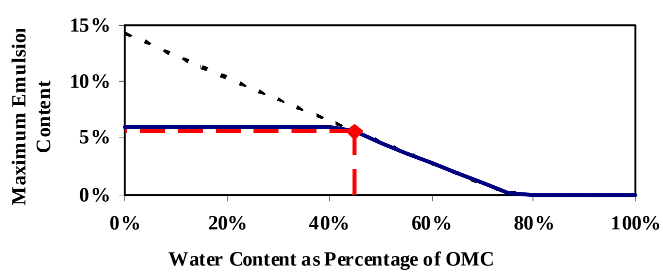


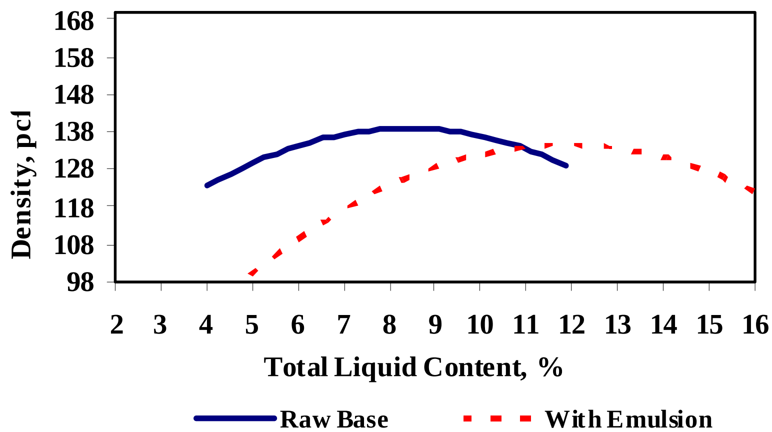
Figure 19 – Example of Report Sheet

Summary of the Emulsion Analysis Tool

Date: 1/16/2009

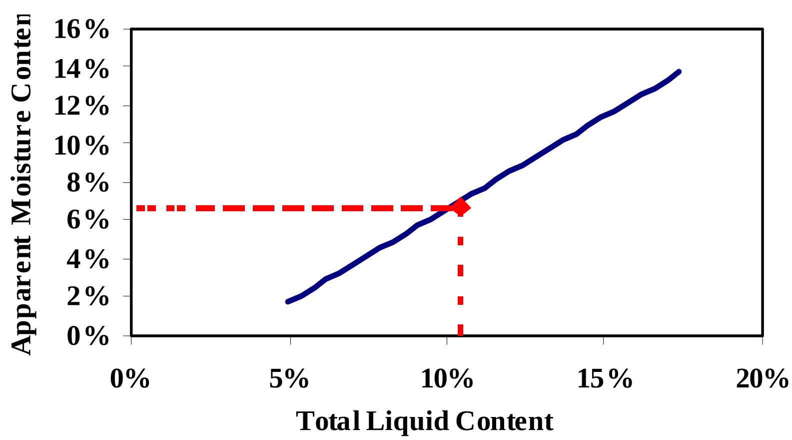
Field Results (page 1/1)

Moisture Density Curve



	OMC/TLC, %	Density, pcf
Raw Base	8.4	138.8
With Emulsion	12.0	134.5

Apparent Moisture Content Vs. Total Liquid Content



Apparent Moisture Content	6.7%
Total Liquid Content	10.4%

Figure 20 – Example of Report Sheet

Appendix D

Proposed Mix Design Procedure

Mix Design for Emulsion-Stabilized Bases

1) Scope

This guideline provides the laboratory procedures for determining the optimum amounts of water, asphalt emulsion and calcium-based additive (if required) for emulsion-treated base materials.

2) Material Preparation

Prepare the non-RAP materials (the in-place granular base and add-rock) as per procedure Tex-101-E, Part II. If RAP is used, the RAP should be crushed and dried to a constant mass without the use of an oven.

3) Blending of Aggregates

Blend the materials according to their percentages that will be mixed and used in road mixing.

Perform sieve analysis on the base, RAP and add-rock as per Tex-110-E. A No. 200 sieve should be added to the sieve stack. Develop the mixture gradation by combining the gradations of the individual constituents according to their percentages that will be used in road mixing.

4) Determination of OMC and MDD without Emulsion

Determine the OMC and MDD of the blended material without emulsion as per Tex-113-E.

5) Determination of TLC and Emulsion Content

A) Estimate the moisture content in the mix (preliminary 60% of OMC).

B) Estimate the maximum allowable emulsion content to ensure constructability (based on the volumetric calculations provided in Appendix C).

C) Prepare and test three (for allowable emulsion contents of less than 4%) or four specimens for the indirect tensile strength (IDTS) tests. The nominal emulsion contents of the four specimens are zero (no emulsion), 1/3 of maximum allowable emulsion content, 2/3 of maximum allowable emulsion content and maximum allowable emulsion content, respectively. If three specimens are prepared, the nominal emulsion contents are no emulsion, maximum allowable emulsion and half the maximum allowable emulsion content.

D) Determine the optimum emulsion content as the minimum amount of emulsion added to the material which meets or is closest to the minimum requirements by the TxDOT Special Specification.

Preparation of IDTS Specimens

a) Prepare approximately 12 lbs of materials for each specimen of 6 in. in diameter and 4.5 in. in length.

b) Thoroughly add mixing water to the material

c) Allow the wet material to cure for a minimum of 12 hours in a sealed container at ambient temperature.

d) Mix the material and emulsion of the given amount as described in Step 5C for 60 seconds (±10 seconds) at ambient temperature using a high-shear mixer. In the absence of a high-shear mixer, hand mixing is recommended.

Note: The emulsion shall be added to each mixture only after the entire sample is placed in a high-shear mixing bowl. Failure to do so may result in loss of emulsion.

e) Transfer the mixture to a plastic container and place the container in an oven set to 140°F for about 30 minutes (±3 min.).

f) Remove the mixture from the container and compact the mixture as per Tex-241-F, Section 5 "Compaction" for a maximum of 30 gyrations..

Note: Given that the density varies with the type of material and moisture content, a number of trial and error specimens may be needed, varying the amount of material placed into the gyratory mold, in order to ensure the proper specimen height is achieved.

IDTS Testing

a) After compaction, allow each specimen to cure in an oven set to 140°F for 48 hours,

b) Cool down the specimen to ambient temperature (about 77°F)

c) Perform IDTS testing on each specimen as per procedure Tex-226-F. Perform modulus testing on each specimen with a V-meter (if available) shortly before IDTS testing.

Addition of Calcium-Based Additive

Prepare and test two additional 6 in. by 4.5 in. specimens following the procedure described in "***Preparation of IDTS Specimens***": one with 1% cement and another with 1% lime. Each of them will contain the amount of emulsion which achieved the highest strength values after performing IDT testing as previously described as well as the same initial mixing water content. .

Note: The addition of calcium-based additive may not always yield positive results. In those cases, the possibility of utilizing calcium-based additives alone should be explored.

6) Verification by UCS Testing

A) Prepare two 6 in. by 8 in. specimens with the amounts of emulsion and calcium-based additive (if applicable) determined previously from IDTS tests following the procedure described in "***Preparation of IDTS Specimens***" except for compaction. Procedure Tex-113-E should be used for compaction.

B) Allow each specimen to cure in an oven set to 140°F for 48 hours.

C) Perform UCS tests on each specimen using the procedure described in Tex-117-E. Perform modulus testing on each specimen with a FFRC device (if available) shortly before UCS testing.

D) Ensure the mix design yields satisfactory results in accordance with the TxDOT Special Specification.

7) Verification by Moisture Susceptibility Testing

A) For each mixture, prepare two specimens in a manner similar to that as described in sections 5a and 6 of this preliminary guideline for IDT and UCS testing.

B) Cure the specimens at 140°F for 48 hours.

C) Subject the test specimen to moisture-conditioning for eight days in manner similar to that described in procedure Tex-144-E (Tube Suction Test).

Note: During this time period the specimens are monitored daily for changes in dielectric constant and modulus using a FFRC device (if available).

E) After final readings for modulus and dielectric constant, perform both IDT and UCS testing on the specimen after eight-day moisture conditioning using the procedures described in Tex-226-F and Tex-117-E, respectively.

F) Calculate both the retained UCS strength and the retained modulus (if modulus tests are performed) in manner similar to that as described in procedure Tex-144-E, ensure the mix design yields satisfactory results in accordance with the TxDOT Special Specification.

8) Determination of OMC and MDD with Emulsion and/or Additives

Determine the OMC and MDD of the blended material with emulsion and additives as per Tex-113-E.

9) Report

1. Blend percentages used and percent passing of material
2. Maximum dry density of material with emulsion to nearest 0.1 pcf

3. Optimum moisture content to nearest 0.1%
4. Optimum emulsion content to nearest 0.1%
5. Amount of calcium-based additive (if required) to nearest 0.1%
6. Unconfined compressive strength to nearest 1 psi
7. Indirect tensile strength to nearest 1 psi
8. Modulus to nearest 1 ksi (if available)
9. Retained UCS and IDT to nearest 1%