2011-01-01

Evaluation and Recommendation of Mix Design for Emulsion Stabilized Bases

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EVALUATION AND RECOMMENDATION OF MIX DESIGN FOR EMULSION STABILIZED BASES

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Dedication

There are a number of people whom without; this thesis would not have been possible. First and foremost I would like to thank God for the many blessings I have in my life. If it were not for all that he has given me none of this would be possible. I would like to thank my mother and father, Mary S. and Guillermo D. Franco (may the latter rest in peace). Their unwavering faith in their children has always been a guiding light for me. They instilled a respect for education and knowledge that has led me down the path I am on today. I would also like to thank my three siblings Guillermo Jr, Eduardo, and Patricia Marie who were very supportive of me throughout all of my time spent at UTEP. I am certain that we could take a 3 month family vacation around the globe staying at the Four Seasons every night on just the interest from the loans they granted me during college. And finally, I would like to thank all my friends who were very understanding on those occasions when I could not spend time with them, yet were always there after finals with a much welcomed "*cold one*".

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by

SAMUEL FRANCO, B.S.C.E.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Civil Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

May 2012

Acknowledgements

The author as well as the rest of the research team would like to express their sincere appreciation to the Project Management Committee of this project, consisting of Mykol Woodruff, Bobby Littlefield, Jr., Caroline Herrera, Miguel Arellano, Paul Jungen, Ken Dirksen and K.C. Evans for their support. We are grateful to a number of TxDOT district personnel, especially Eric Hall, Gregory Biediger, Gilbert Davila and Peter Groff in San Antonio District, Buster Sanders and Mike Podd in Amarillo District and John Clark in Yoakum District for their assistance in material collection and field testing.

We are also grateful to CEMEX of El Paso and Martin Marietta Materials of San Antonio for their continuous donations of materials used in this research project. We appreciate the help from Mr. Guillermo Marquez and the many other research assistants at CTIS of the University of Texas at El Paso.

Abstract

Asphalt emulsion has been used for base material stabilization in a few TxDOT districts. Results from these practices were quite different. The initial performance of two projects on US287 constructed around 2000 in the Amarillo District has been found to be satisfactory. However, the Yoakum District has reported problems with asphalt emulsion for base work in a project on FM 237. 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 emulsions. TxDOT has drafted a special specification for the use of asphalt emulsions 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, a guideline 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.

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Chapter 1 - Introduction

1.1 BACKGROUND

Rehabilitation of highway pavements through full-depth reclamation (FDR) is a cost-effective option that reduces the use of virgin base aggregates and eliminates the effort as well as cost associated with disposal of the old aggregates. The process of FDR consists of in-place cold grinding of the existing asphalt along with a predetermined amount of unbound granular base material, stabilizing the material with additives and compacting the new layer to a proper density level. 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 implemented properly, this process 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. One other common stabilizer used in the FDR process is asphalt emulsion. It has been found that the bituminous based mixture tends to enhance the mechanical properties of the aggregate skeleton. 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 mix asphalt when compacted under optimum total liquid content, defined as the total amount of added water plus asphalt emulsion. 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, there are some uncertainties that need to be addressed when using asphalt emulsion alone or the blend of calcium-based additives with asphalt emulsion as stabilizers in FDR. These include:

- Determining the optimum mix design to ensure that the recycled materials are properly coated with the additive
- Establishing the proper laboratory procedure/protocols to achieve the optimum mix design

In addition, curing time is another issue that has not been adequately evaluated. 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 time. In the past, contractors have relied heavily on guidelines from product and equipment manufacturers to address this subject. Hence, there is always an unknown element in the design and construction process with different contractors having their own methods to achieve each. 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.

1.2 OBJECTIVE

The main objective of this research project is to develop a laboratory test protocol for selecting the correct combination of additives for dual stabilization. To achieve this goal, the following tasks were proposed and completed. The first task of the project was to perform an information search relevant to the use of emulsion or dual stabilized bases. The information search included the current practices with regard to mix design and construction for these types of base materials. The second task required the selection of sites ready for construction to acquire materials for use in the study as well as the strength and performance of emulsion stabilized projects under realistic conditions. The third task was to select the amount and type of additives to be used in a parametric study of the selected materials. This task included an in-depth investigation on the effects of emulsion quantity as well as initial mixing water to be added to these types of materials. Also included in this task was an investigation into whether or not the addition of a cementitious additive should be introduced into the emulsion stabilized base. Task 4 was to establish laboratory testing procedures. In order to do so, a number of parametric studies were performed to gain a better understanding of the factors that affect strength and modulus of

the materials. A preliminary guideline for laboratory testing and mix design procedures was developed in Task 5 of this project.

1.3 ORGANIZATION OF REPORT

Chapter two contains a summary of the literature review and information search on the FDR process, additives used for FDR, consideration of mix design parameters and the effects of climactic conditions emulsion-treated bases. Chapter three provides a general overview of the testing procedures provided by TxDOT and SemMaterials. Both of them were closely scrutinized during the extent of this project. The fourth chapter presents the results of testing carried out on samples collected from quarries as well as actual construction sites and the description of laboratory tests performed in order to achieve a final mix design for each material.

Chapter five summaries the results from a comprehensive parametric executed over the course of this project. Included in this study were changes in gradation, curing regime, mixing temperature, mixing method and compaction method among others. A preliminary guideline for mix design and laboratory testing based on those results is presented in chapter six of this thesis. Chapter seven presents the results of lab tests conducted on a fifth material which was used as a validation of the preliminary guideline. And lastly, chapter 8 consists of the summary and conclusions of this project as well as recommendations for the changes to TxDOT specifications

Chapter 2 - Literature Review

2.1 FULL-DEPTH RECLAMATION

Full Depth Reclamation is a form of cold in-place recycling (CIR) of flexible pavements. During this procedure, the 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 even recycled asphalt pavement (RAP) are sometimes mixed with the pulverized materials. The result of this process is an entirely new base course. This method dates back to the early 20th century, however, it did not become widely used until around 1975 (Epps, 1990). 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. Similar to any other road rehabilitation procedure, FDR has both its pros and cons.

Recycling using the FDR process has many advantages encompassing 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, 2000). 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, 2000). 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 also be modified. This is possible since the entire layer of flexible pavement as well as part of the base is taken up. The advantages of FDR are not only limited to road improvements, most state transportation departments consider the process 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 emissions produced during the hauling of aggregates to and from 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.

Conversely, problem areas have also been associated with the use of FDR. No comprehensive guideline is currently in place which 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 in asphalt stabilized materials 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.

2.2 STABILIZERS USED FOR FDR PROCESS

During the FDR process, various types of stabilizing agents can be added to the mixture of 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.

2.2.1Asphalt 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 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.

There are many factors that affect the 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 quantity 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 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.

2.2.2 Portland Cement

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

2.2.3 Lime

Lime is another commonly utilized compound used for chemical stabilization of recycled asphalt and base courses. This material exchanges its higher valence cations with the mono-valent cations readily available in many soils. This exchange of ions between the two materials leads to an increase in strength of the mixture (Parsons and Milburn, 2003). 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 mix (Kandahl and Mallick, 1997). Lime has historically been added to recycled asphalt bases in the form of powder or slurry.

2.3.4 Fly Ash

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 portland cement, when fly ash is mixed with water cementitious bonds are formed which lead to an increase in impermeability and strength of the recycled mix. Fly ash is spread out by a separate machine and then mixed in with the reclaiming machine after initial pulverization has been performed (Kandahl and Mallick, 1997).

2.4 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
- Determination of material characteristics of road samples
- Selection of stabilizing agent
- Determination of optimum moisture content and/or total liquid content
- Mixing, compaction, and curing of specimens

2.5 Collection of Road Samples

For a mix design to be properly evaluated about 500 lbs of the in-place material are 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.

2.5 MATERIAL CHARACTERIZATION OF ROAD SAMPLES

The main characterization activity is the determination of the gradation and index properties of the retrieved materials with or without RAP. Of particular interest are the percentages of gravel, sand and fines as well as the plasticity index (PI) of the material. 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 new aggregate to the recycled material appears to be a widespread standard practice. According to his research, 66% of the agencies which were surveyed in the study did allow new aggregate to be combined into the existing recycled material. Adding thickness to the stratum and gradation corrections are two of the pavement layers characteristics that can be adjusted by the addition of new aggregate in to the mix (Epps, 1990).

Additional aggregate has also been used during FDR as a means of mechanical modification. When used in this context, the new aggregate is added to the mixture to supplement the strength of the material. According to Johnston et al. (2003), a small portion of additional aggregate was added to the mix design used in their study in order to improve the physical properties of the mixture; in this case strength. Other organizations allow for the addition of new aggregate to the mixture so as to increase the allowable amount of emulsion used. Pennsylvania reported allowing up to 50% new aggregate to be combined with RAP material in order to facilitate the use of additional emulsion in the mixture (Epps, 1990).

2.6 EMULSION SELECTION

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 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. Emulsions which utilize positively charged asphalt particles are known as cationic emulsions; while those which include 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 (RS), 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 CIR because of their superior ability to coat dense graded aggregates (Pouliot et al., 2003). 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 charges. An example of this was given by Lesueur and Potti (2004). In their study it was determined that siliceous aggregates are said to bear negative charges and therefore attract all positively charged droplets. As such, the compatibility of the emulsion and aggregates should be considered.

2.7 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 requirements 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. 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.

2.8 Water Content

Like all granular materials, water is added to the mix so that maximum density can be achieved. The total amount of mixing water required is not the same for every material combination. The water required for maximum dispersion of the emulsion to occur varies by type 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 specimen. The amount of mixing water is generally less than the optimum moisture content of the recycled base material without a bituminous additive (Ibrahim, 1998).

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 (by weight of dry material) to be added to the mix.

2.9 OVERVIEW OF VARIOUS MIX DESIGNS

An extensive review of the specifications of a number of highway agencies was carried out. For the most part, those specifications leave the mix design to the contractor. In this section, some typical specifications are reviewed.

2.9.1 Missouri

The Missouri DOT (MoDOT) utilizes a similar practice to Texas for determining the appropriate mix design. (Texas' guideline is described in chapter three of this report.) The differences are essentially in the method of sample preparation The MoDOT method utilizes the Superpave Gyratory Compactor (SGC) for compaction. Also, the allowable curing time for strength (2 hours) is less than that of Texas. This guideline also specifies that the additional water content should be 65% of the OMC of the raw material. Strength requirements for MoDOT are included in Table 2.1.

Table 2.1 - MoDOT Min Strength 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.
Thermal cracking (IDT), AASHTO TP 9-96 (Based on LTPP Binder for climate)	See note in appendix	

2.9.3 Maine

No specific mix design process is outlined in Maine's specification. The mix design is carried out following the recommendations made by Mallick et al. (2001). Compaction of the specimens is achieved using 50 gyrations of a SGC with a specially fabricated mold which has holes in it that allows loose water to escape during the compaction process. The specimens are tested after they are placed in a 40ºC oven for 7 days. They are then subjected to both resilient modulus and indirect tensile testing. The minimum strength and modulus requirements are not evident.

2.9.4 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 (*Pc*) is based on aggregate gradation and emulsion residue. Once these parameters have been determined, they are input into the following equation (Epps, 1990):

$$Pc = (0.5A+0.1B+0.5C)-Pa(Pp/R) \quad (2.1)$$

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 (%),

Pa = amount of asphalt in reclaimed asphalt pavement (%),

Pp = percent reclaimed asphalt pavement in the recycled mix, and

R = percent emulsion residue (normally 60% – 65%)

After 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 contain less than 2% emulsion. Laboratory testing is then carried out on all specimens. The emulsion quantity that meets the minimum requirements outlined in Figure 2.2 is then selected as the design emulsion content.

Test Method		Specification
Coating, %		75 min.
Resistance R,-Value @ 73 ± 5°F	Initial cure(1)	70 min.
	Final cure(2) + water soak	78 min.
Cohesiometer C-Value @ 73 ± 5°F	Initial cure(1)	50 min.
	Final cure(2) + water soak(3)	100 min.
Resilient Modulus, M_r psi @ 73 ± 3°F	Final cure(2)	150,000–600,000
Stabilometer S-Value @ 140 ± 5°F	Final cure(2)	30 min.
Cohesiometer C-Value @ 140 ± 5°F	Final cure(2)	100 min.

(1)Cured in the mold for a total of 24 hrs. @ a temperature of 73 ± 5°F.
(2)Cured in the mold for a total of 72 hrs. @ a temperature of 73 ± 5°F, plus 4 days' vacuum desiccation at 10-20 mercury.
(3)Vacuum saturation at 100mm of mercury.
NOTE: Besides meeting the above requirements, the mix must be reasonably workable (i.e., not too stiff or sloppy).

Figure 2.1 – Specifications of Chevron USA, Inc. for Mix Design (after Epps, 1990)

2.10 STRENGTH CHARACTERISTICS

A number of studies looking into the mechanical properties of recycled materials stabilized with emulsion and other additives have been carried out. In each of these studies, researchers employed

different test methods to quantify the effects of calcium-based additives on the emulsion stabilized material. However, since in-situ field evaluation is not common, laboratory testing is often used as a means 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 measure the effects of cement when mixed with emulsion and recycled aggregate. Various tests were run on emulsion-cement mixtures where the percentage of cement (by weight of total solids) varied. With respect to the mechanical tests performed on the specimens, the results are as follows:

- The modulus increased with an increase in cement content
- The specimen's resistance to permanent deformation was also increased after the addition of cement to the mixture

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 CIR 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).

2.11 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). Several studies have been performed in attempt to quantify the effects of climactic conditions on dual stabilized bases.

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 a calcium-based additive. Even additions of small amounts of cement to bituminous-RAP mixtures have shown to increase a material's modulus. The inclusion 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).

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).

2.12 Curing Time

Maximum strength gain is reached when dual-stabilized bases lose their initial water and are fully cured. It was shown by James et al. (1996) that the rate of strength gain with respect to curing time is directly related to increasing amounts of cement in the mixture. Coalescence tests performed by Brown and Needham (2000) showed that the breaking times of cement-emulsion mixtures decrease with increasing cement content. These findings suggest overall improved curing rates of the material.

An alternative approach to accelerate the curing process has been implemented by the Oregon Department of Transportation (ODOT). The agency has found that heating the mix water as well as the emulsion to temperatures between 49-60ºC helps to reduce cure times. 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).

Chapter 3 - Overview of Procedures Used in Texas

3.1 INTRODUCTION

Currently, all road rehabilitation projects with asphalt emulsion treatment in Texas follow the "Special Specification-Emulsion Treatment (Road Mixed)" drafted by TxDOT and "Mix Design Procedure-Emulsion Treatment (Road Mixed)" drafted by SemMaterials. The two procedures are similar to each other being that they share the same minimum strength. However the procedure of SemMaterials is more specific than that of TxDOT in the following aspects:

- Apparatus required to perform laboratory tests for the mix design
- Sieve analysis of constituent materials to be used in the mixture performed individually
- Determination of correct blend ratio of materials (RAP/old base/add-rock) used for construction is detailed
- Approximate starting emulsion contents for materials
- Mixing procedure
- Compacting procedure
- Curing regimens for strength testing of specimens

Both of these procedures were evaluated before the initiation of laboratory testing for this study; as such, a general overview of these two procedures is given in this chapter.

3.2 TxDOT

The current Special Specification provided by TxDOT for the use of dual stabilization is a performance based guideline. There are no specific directions for determining the optimum emulsion content for the emulsion/base mixture. Likewise, nor are there any specifications which outline a procedure for determining the optimum amount of calcium-based additive. A list of general requirements for strength and other relevant parameters is proposed in the Special Specification. The specification can be viewed in its entirety in Appendix A provided at the end of this report.

The performance tests selected in the TxDOT Special Specification and the criteria for acceptance currently used to design are included in Table 3.1. Acceptance values for the unconfined compressive strength (UCS), indirect tensile strength (IDT) and the retained unconfined compressive strength are provided. The Tube Suction Test (TST) and the modulus (stiffness) tests do not have specified acceptance values but are required to be reported to the department.

Table 3.1 – Laboratory Mix Design Properties and Testing Methods

Property and Testing	Criteria
Unconfined Compressive Strength (UCS), Tex 117	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 procedure refers to Tex-113 "*Laboratory Compaction Characteristics and Moisture-Density Relationships of Base Materials*" as the proper method for preparing materials undergoing UCS testing. The TxDOT specification uses Tex-117-E "*Triaxial Compression for Disturbed Soils and Base Materials*" as the procedure for carrying out UCS testing. Stated within Tex-117 are the specifications for sample preparation. In the case of IDT testing, the specification requires the use of procedure Tex-226-F "*Indirect Tensile Strength Test*". In turn, this procedure specifies the use of Tex 241-F "*Superpave Gyratory Compaction 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 IDT testing under a controlled rate of deformation (2 in./min). The specific tests outlined have been historically used for classification of non-stabilized bases or materials that utilize a cementitious additive only.

According to the Special Specification, the retained UCS values are also found as per Tex-117-E and a procedure similar to that outlined by Tex-144-E "*Tube Suction Test*". This procedure calls for an 8-day saturation period in which the specimens are 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. Upon completion of the saturation period, the specimens are then subjected to compression testing. A ratio between the original UCS value and that of the specimen subjected to moisture susceptibility testing is then calculated.

During the saturation process, the dielectric constant of the material is read on a daily basis. The final dielectric value is then reported so as to comply with the requirements in the Special Specification. The modulus value of all the specimens undergoing strength testing is measured on a daily basis as well. In order to determine the modulus of an individual UCS specimen, a testing device known as the Free-free Resonant Column (FFRC) is utilized. Modulus values for IDT specimens are measured utilizing a device know as a V-Meter. Both methods are non-destructive forms of measuring the stiffness of both granular as well as non-granular materials and are common practice for TxDOT personnel. The resilient modulus of the material is measured by utilizing AASHTO T-307 "*Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials*". It should be noted that the curing regimens as well as general testing procedures outlined for each set of tests may not be the most suitable for these types of materials and are part the basis for this research.

3.3 SEM MATERIALS

The SEM Materials (SEM) procedure is also performance based; however, the guidelines are more specific with regards to achieving a final mix design than those of TxDOT. The minimum strength requirements for UCS and IDT are the same as those in Table 3.1. In addition, an exact process for determining the necessary amounts of moisture and emulsion are stated. A draft version of this procedure can be viewed in its entirety in Appendix B provided at the end of this report.

This procedure also outlines the equipment necessary for performing a mix design on any given emulsion treated base material. The apparatus required are for the most part standard testing devices and will not be mentioned here. As such, any device that is not generally used in laboratory testing of base materials will be described in the text.

It is stated in the SEM procedure that 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 during field construction. After which, the correct amount of each type of aggregate is gathered from the construction site. The materials are then dried and the RAP is crushed. A sieve analysis is run 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 existing standard TxDOT procedures. The Methelyne Blue Value of the materials is determined utilizing AASHTO TP-57. These values are considered as optional testing which is simply for characterization of the constituent aggregates and are not used for further mix design calculations.

Once these tests have been performed, a predetermined amount of specimens are then batched accordingly with respect to the design ratio. Different size batches are required depending on whether the material will be used for UCS or IDT testing. After batching the required number of specimens, the optimum moisture content (OMC) of the material is then found utilizing Tex-113-E. However, emulsion is added to the material along with the mixing water. According to the procedure, the amount of emulsion to be added is defined on an arbitrary basis as shown in Figure 3.1. This figure provides a suggested starting emulsion content to be used depending on the region of the state from which the material was gathered.

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%

Figure 3.1 – Initial Emulsion Contents Suggested by SEM's Procedure

Before adding the emulsion to the mixture water is combined with the dry aggregate. 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. After the addition of emulsion to the material, the entire batch is then mixed using a high-shear mechanical mixer for approximately 60 seconds. At that point the

mixture is transferred to a plastic container and placed in an oven set to 140°F for 30 minutes. The combination of additives as well as the mixing process is the same for both UCS and IDT specimens.

After allowing the emulsion/aggregate mixture to cure, the material is then compacted utilizing the procedures outlined in Tex-113-E for those specimens undergoing UCS testing. In order to perform IDT testing, the material is compacted using a Superpave Gyratory Compacter (SGC). The number of gyrations used for compaction is 30. Also stated in the SEM procedure are the final dimensions of the IDT specimens. These specimens should be 6 in. in diameter and 3.75 in. in height. Where as the TxDOT procedure calls for the use of specimen that is only 2.4 in in height.

After compaction, the specimens are then 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 cured at 140°F for 48 hours. IDT specimens are subjected to a curing regimen of 72 hours at 104°F similar to that of the TxDOT procedure. After which, both sets of specimens are allowed to cool to ambient temperature before undergoing strength testing. Moisture susceptibly tests are performed on specimens prepared in a similar manner as that described above for UCS testing. 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 those undergoing UCS testing is prepared for the purposes of carrying out the resilient modulus test in accordance with the AASHTO T-307 procedure.

In order to determine the amount of calcium based additive required, two extra specimens of each type (UCS and IDT) are prepared. The initial moisture content to be added to the dry material is not 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.

If the minimum strength requirements are met by the emulsion only specimens, that would be the design reported. In the case where a design is not achieved, this process is carried out again, increasing the amount of emulsion used in the mix until the minimum strength requirements are met. No mention of the use of the dual stabilized materials is made.

Chapter 4 - Laboratory Testing – Initial Mix Design

4.1 INTRODUCTION

The objective of the mix design is to determine the type and content of asphalt and/or calcium-based additives and to evaluate the improvement of engineering properties with varying contents of the selected additive(s). Due to the ambiguity of the current specification with regards to how a mix design procedure should be carried out, an "initial" mix design study was performed. In this section of the report a detailed description of how the final mix designs used in this study were selected.

4.2 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.

Materials from three sources were selected to generate a baseline for verification of the outcome of this project. These materials were selected after carefully reviewing the responses from the questionnaire. In addition, granite from a local quarry was included in this study to cover a wider spectrum of materials. A fifth material was selected also based on the responses from the initial questionnaire; this material was used as a verification of the preliminary guideline (the validation material is incorporated in another report provide to TxDOT and is not included in this thesis). The five base materials that were selected for the overall study were:

- El Paso Base from CEMEX McKelligon Canyon Quarry due to availability.
- Material from Martin Marietta Pit in San Antonio that is either used extensively as add rock or widening of shoulders in the San Antonio District.
- Materials from FM 154 project in Fayette County, Yoakum District which included the old RAP (18%) and base (53%) as well as add-rock (29%).

- Materials from US 287 project in Armstrong County, Amarillo District which include the old RAP (80%) and base (20%).
- Materials from FM 2790 project in Atascosa County, San Antonio District which included a mixture of old RAP (42%) old base (30%) and virgin aggregate from San Antonio Quarry (28%).

4.3 AGGREGATES PROPERTIES

The gradation, soil classification and index parameters of raw materials from the two quarries (El Paso and San Antonio) and from the in place base courses (FM 154 in Yoakum, US 287 in Amarillo 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
	Gravel	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
Yoakum Add-Rock	54	35	7	3	GP	A-2-6	21	12	13
Yoakum Base	43	31	24	2	SP	A-2-4	17	8	63
Amarillo 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 initial testing, the entire stock of material brought from a quarry or a project (including RAP and/or add-rock as per the blend ratio used in construction) was sieved to develop the global gradation curve which was used throughout the study for that particular material or material combination. The gradation curves for the El Paso, San Antonio, Amarillo, and Yoakum materials 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.

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. For AIV, a coarse

aggregate sample passing the 1/2 in. sieve and retained on the 3/8 in. sieve is placed within a mold (shown in Figure 4.2) 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:

$$AIV = M2/M1 \times 100\% \qquad (4.1)$$

where:

M1 is the mass of test specimen and

M2 is the mass of the specimen passing the No. 8 sieve.

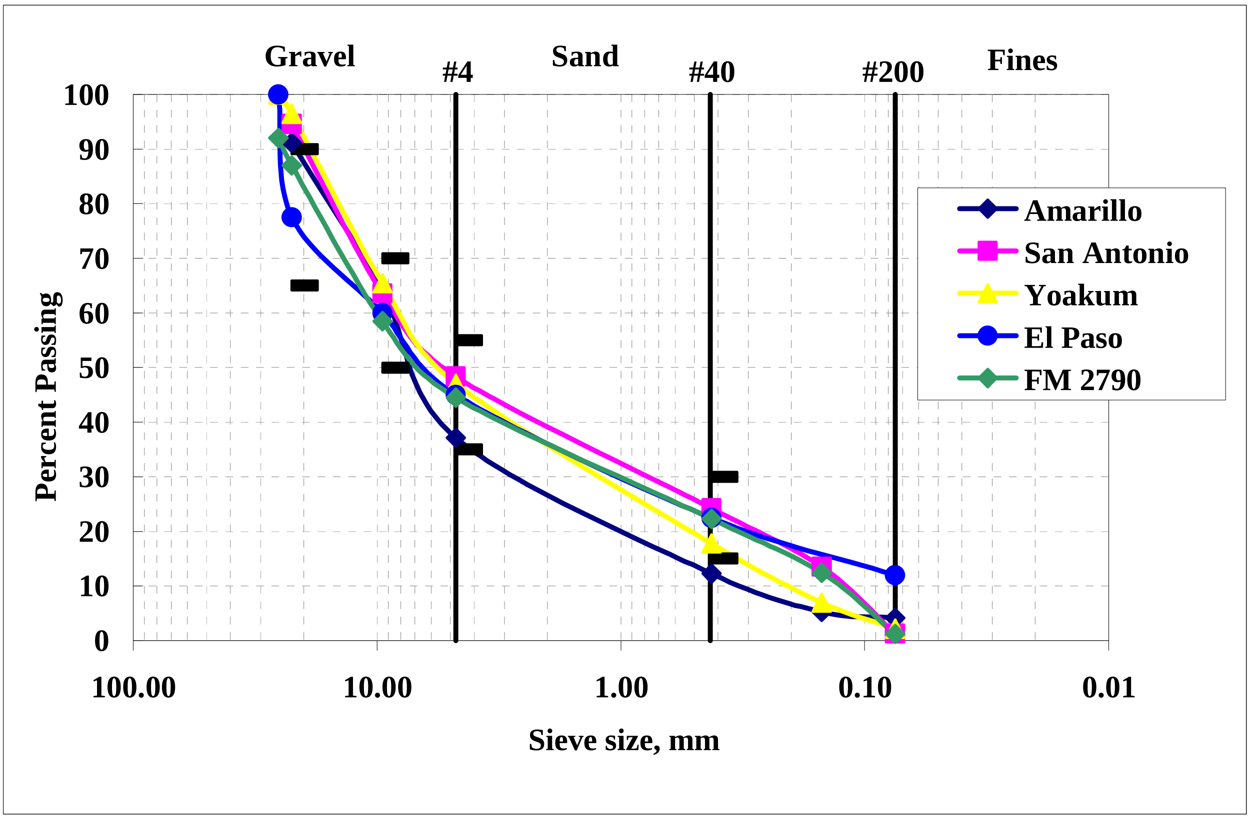


Figure 4.1 – Global Gradation Curves for materials Used in Preparing Specimens

The AIV can be performed either on a dry specimen (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 for each of the raw base materials used in this study are summarized in Table 4.2. Based on this criterion, the San Antonio material and the Amarillo material when wet may be of concern. With regards to the material which comprises FM 2790; it also shows cause for alarm. Both of its constituents resulted in high AIV values especially under wet conditions. The gradations of materials after performing the AIV tests are also shown in Table 4.2.

Figure 4.2 – Test Apparatuses for Aggregate Impact Value (Left) and Aggregate Crushing Value (Right)

On the other hand, the ACV of a material indicates the ability of an aggregate to resist crushing. The lower the value, the stronger the aggregate or the greater its ability to resist crushing will be. A sample of aggregate passing through the 1/2 in. sieve and retained on the 3/8 in. sieve is placed in a steel mold. A steel plunger is then inserted into the mold directly on top of the aggregate (see Figure 4.2).

The aggregate is then subjected to a force rising to 90 kip over a period of 10 min. This test is typically performed with a concrete compression machine.

Similar to the AIV procedure, the resulting sample is then subjected to a sieve analysis. Once again, the material passing the No. 8 sieve is represented as a percentage of the original mass. This percentage is known as the ACV of the aggregate. Equation 4.1 is also used to perform the calculation of ACV. The ACV values of the materials are summarized in Table 4.3. Under this test, the San Antonio material and the old base materials from Amarillo, Yoakum and FM 2790 are of concern.

Table 4.2 – AIVs of Materials along with Gradations after Testing

Material	AIV		Gradation, Individual Retained (%)			
			Gravel	Coarse Sand	Fine Sand	Fines
El Paso (Quarry)	Dry	14	78	16	3	3
	Wet	20	69	20	8	3
San Antonio (Quarry)	Dry	25	62	28	6	5
	Wet	29	59	24	5	12
Yoakum Add-Rock	Dry	13	71	23	4	2
	Wet	18	69	25	4	1
Yoakum Old Base	Dry	17	79	17	3	1
	Wet	19	72	23	4	1
Amarillo 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 New Base	Dry	25	62	28	6	5
	Wet	29	59	24	5	12

Table 4.3 – ACVs of Materials along with Gradations after Testing

Material	ACV	Gradation, Individual Retained (%)			
		Gravel	Coarse Sand	Fine Sand	Fines
El Paso (Quarry)	19	66	27	4	3
San Antonio (Quarry)	31	51	36	7	6
Yoakum Add-rock	21	54	38	7	1
Yoakum Old Base	27	66	27	6	2
Amarillo Old Base	34	51	32	12	5
FM 2790 Old Base	26	38	10	5	2.19
FM 2790 New Base	31	51	36	7	6

4.4 SPECIMEN PREPARATION

Several different tests were run on the materials used in this study including, UCS, IDT; TST, and resilient modulus. All testing conducted on the materials was performed in accordance with its respective TxDOT laboratory procedure. For UCS and resilient modulus tests, the samples were prepared as per 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 140oF for thirty minutes.

Initially, a total of three different sets of test specimens were prepared. UCS and moisture conditioning tests were conducted on specimens of 6 in. in diameter and 8 in. in height. The IDT 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.

4.5 SELECTION OF OPTIMUM TOTAL LIQUID CONTENT

The current guideline is vague in terms of the selection of the optimum Total Liquid Content (TLC). The recommended moisture content (mixing water only not including emulsion) in the literature

is 50% to 75% of the traditional OMC for a base material treated with asphalt emulsion. To investigate the most appropriate initial moisture and emulsion contents for emulsion-treated materials, an experimental study was carried out. The matrix shown in table 4.4 was used for this portion of the study.

Table 4.4 – Testing Matrix to Evaluate TLC/Moisture/Strength Relationship

Initial Mixing Water	45% of OMC				60% of OMC				75% of OMC			
Emulsion Content	0%	3%	5%	7%	0%	3%	5%	7%	0%	3%	5%	7%
Tests Performed	UCS	UCS	UCS	UCS	UCS	UCS	UCS	UCS	UCS	UCS	UCS	UCS
	TST	TST	TST	TST	TST	TST	TST	TST	TST	TST	TST	TST
	IDT	IDT	IDT	IDT	IDT	IDT	IDT	IDT	IDT	IDT	IDT	IDT

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 evaluated. IStrength test specimens were prepared at 45%, 60%, and 75% of their OMC determined from the traditional moisture-density (MD) curves for each material. 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 Yoakum with 45% of the OMC, the TLC-density curves are similar to the MD curves. However, the corresponding maximum dry densities are lower than when the specimens are prepared with water only by several pounds per cubic foot. For water contents of 60% and 75% of the OMC, it seems that the maximum density is obtained when no emulsion is added. This phenomena is more than likely due to the water that is contained in the emulsion during initial compaction and will be discussed in a later chapter.

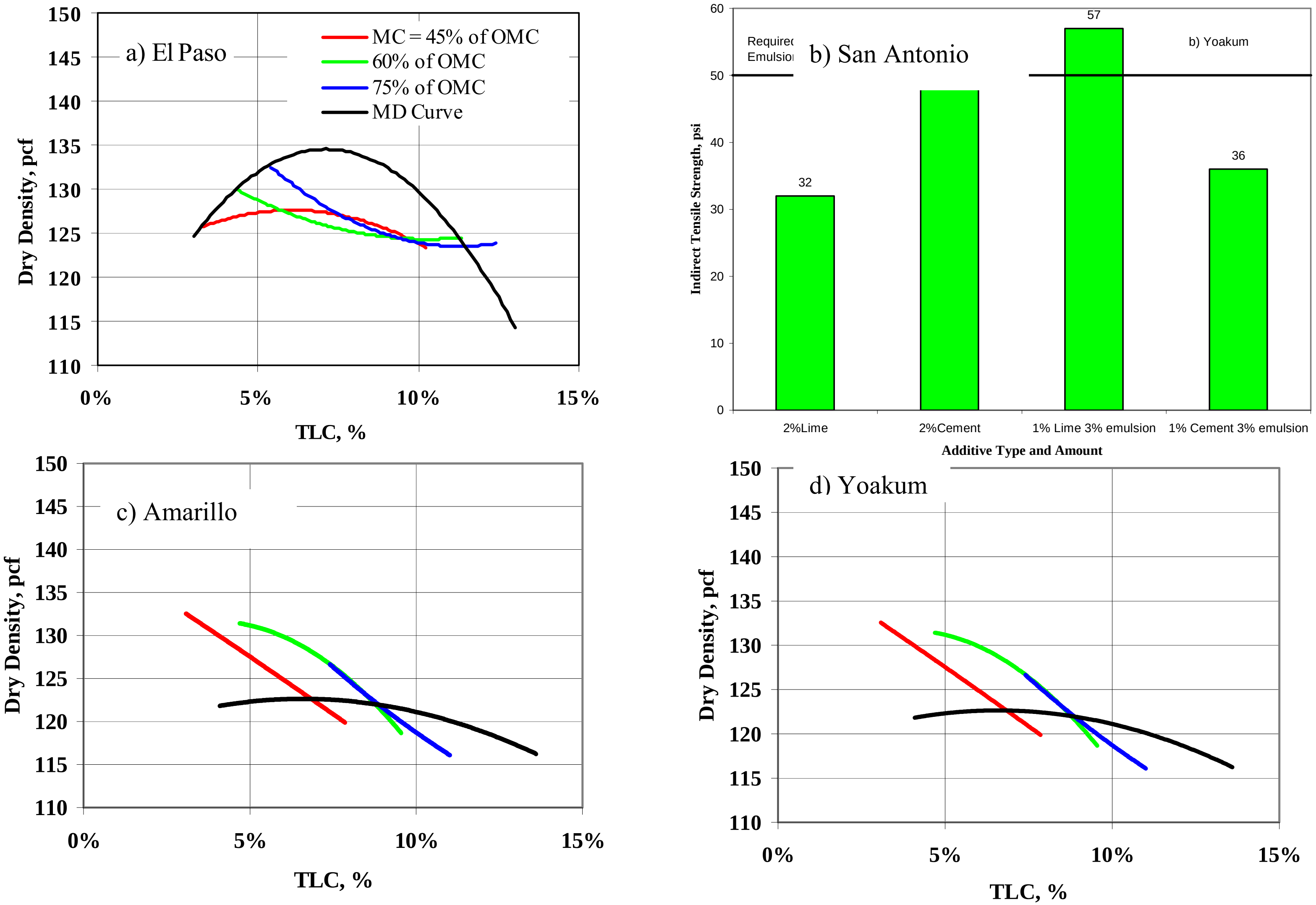


Figure 4.3 – Variations in Density with Total Liquid Content at Different Initial Water Contents

4.6 STRENGTHS OF SPECIMENS WITH EMULSION ONLY

The UCS tests were performed on all four materials for each moisture content and emulsion content. 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 provided the required strength of 150 pounds per square inch (psi). As a comparison, the strengths with the corresponding moisture contents and with no emulsion at all were also measured. An 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 effect of excess of moisture (from both mixing water and emulsion) in the specimen. The interaction of moisture introduced into the specimen from both the mixing water and emulsion is discussed in more detail in chapter 6.

The results from the IDT tests are shown in Figure 4.5. None of the El Paso mixes provided the required tensile strength of 50 psi, even for the specimens with 3% emulsion and 60% of the OMC which previously provided the required UCS strength. For the San Antonio material, a number of mixes, in particular, the mix with 5% emulsion and 60% of the OMC provided adequate IDT strength values. With respect to the Amarillo material, 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 occurrence could possibly be attributed to the high RAP content of the mix (80%). It is likely that the high curing temperature used in this study actually causes the RAP to soften and bind the mix together. The Yoakum 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 for the Amarillo materials.

In general, one can observe the substantial increase in IDT 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 tensile strength may impede the cracking of the pavement. At higher moisture 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 a lower 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 perhaps due to their lower fine content and lack of RAP.

In order to further investigate the possible benefits of emulsion treatment, IDT tests were carried out on specimens moisture-conditioned for 10 days after 2-day dry cure. As shown in Figure 4.7, 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. According to these results, it seems that improved moisture susceptibility may be another benefit of using emulsion. Based on the results from both UCS and IDT 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 next.

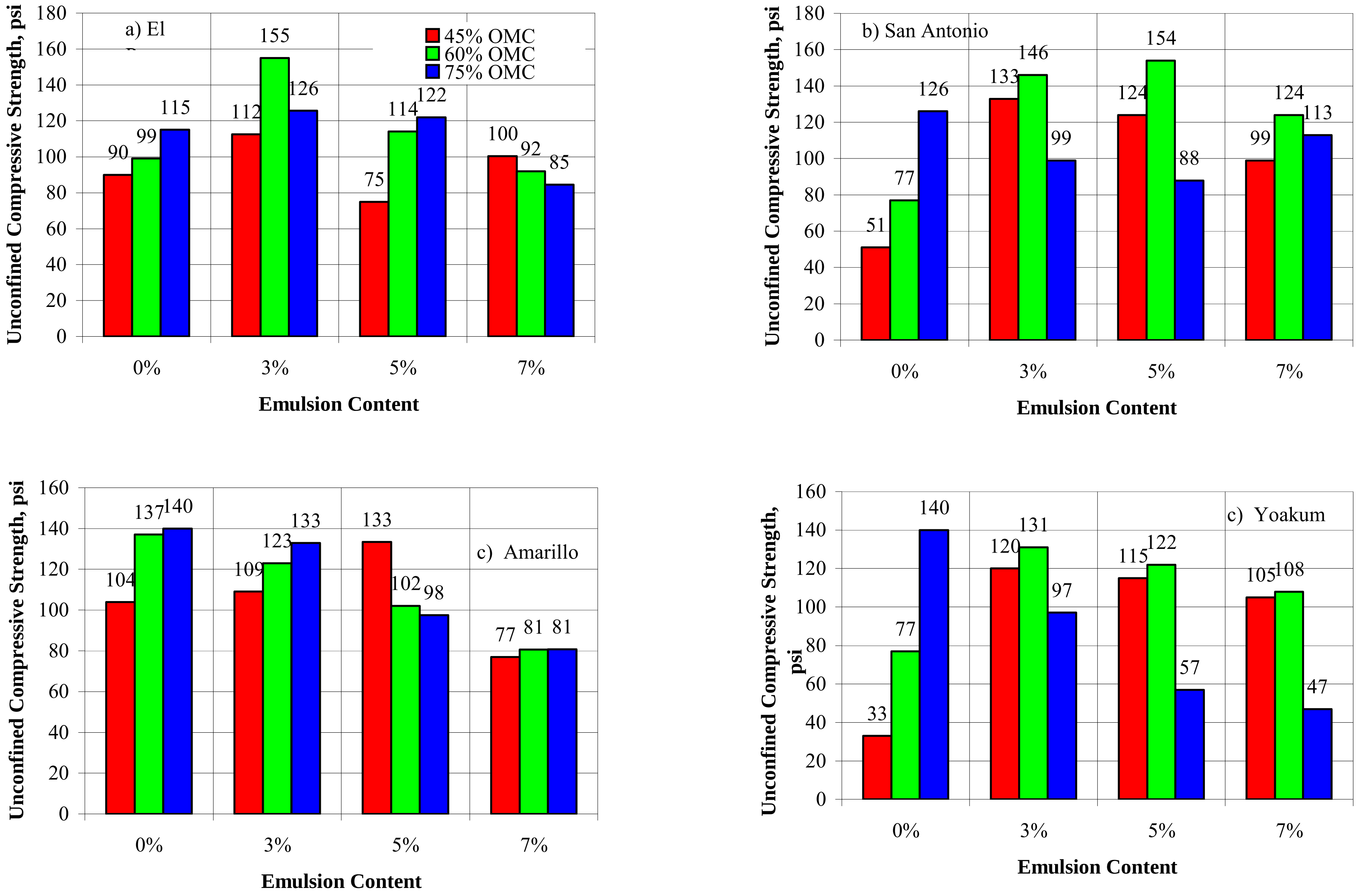


Figure 4.4 – Unconfined Compressive Strengths for Materials with Different Moisture and Emulsion Contents

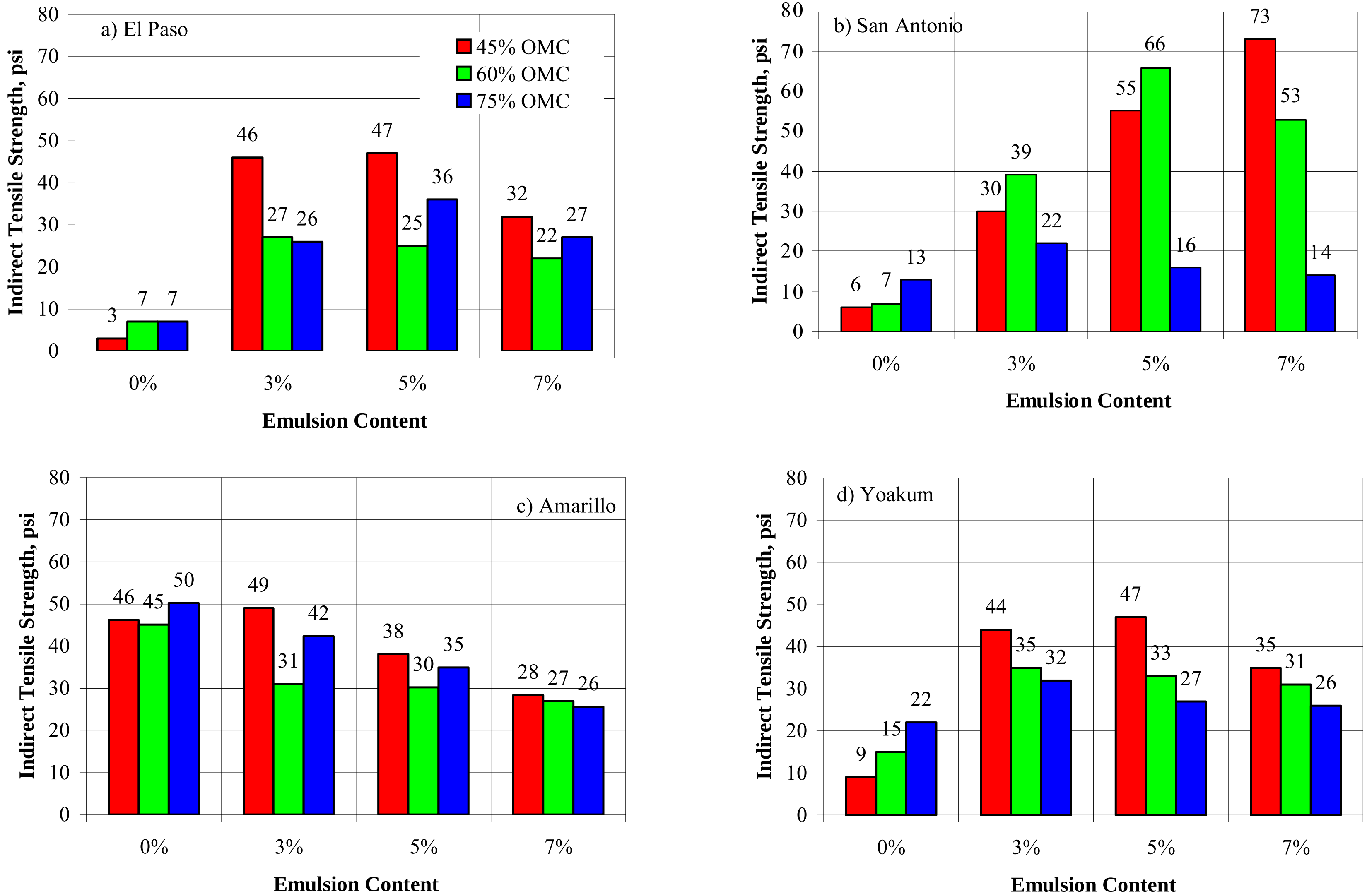
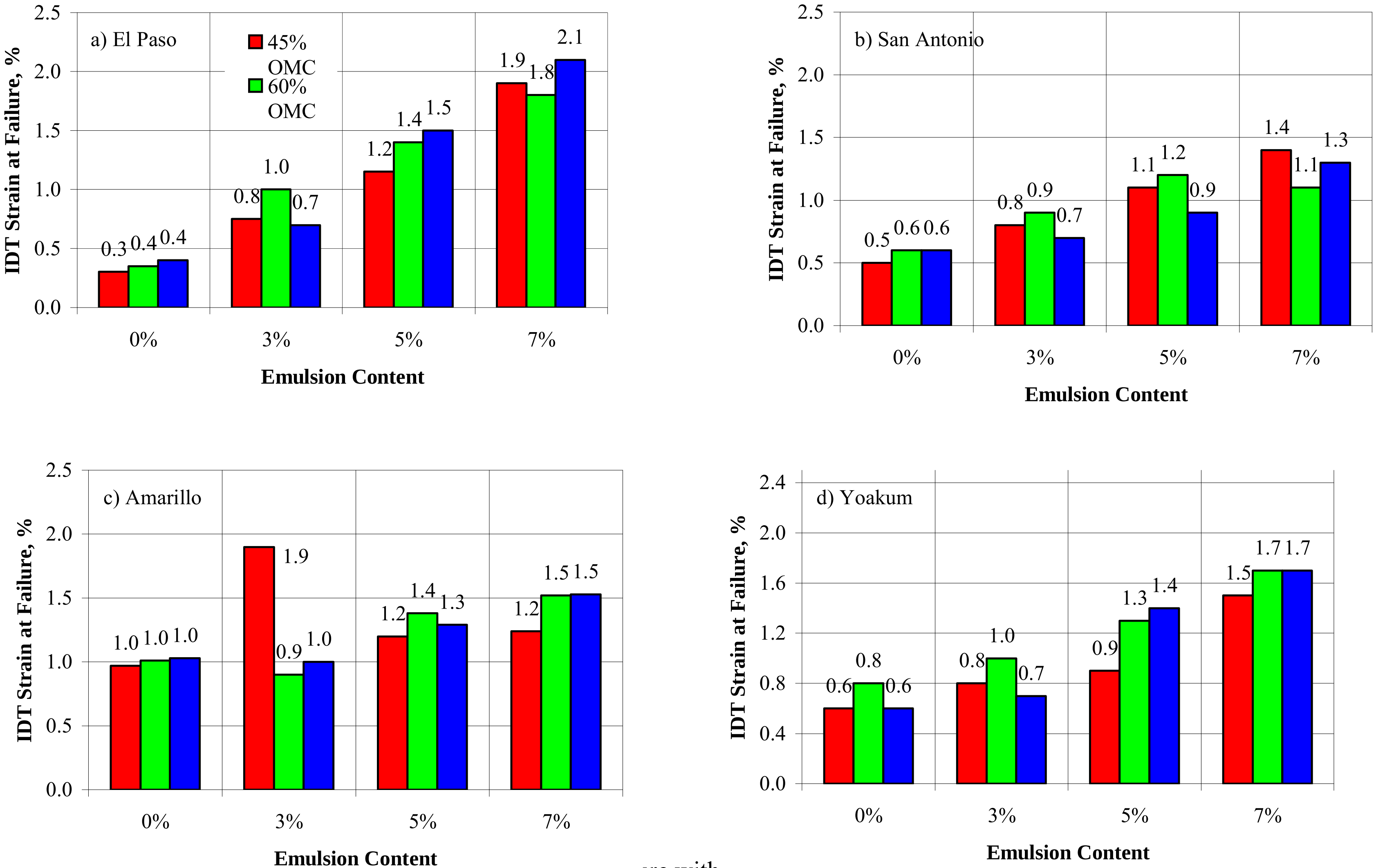


Figure 4.5 - Indirect Tensile Strengths for Materials with Different Moisture and Emulsion Contents



ure with Different Moisture and Emulsion Contents

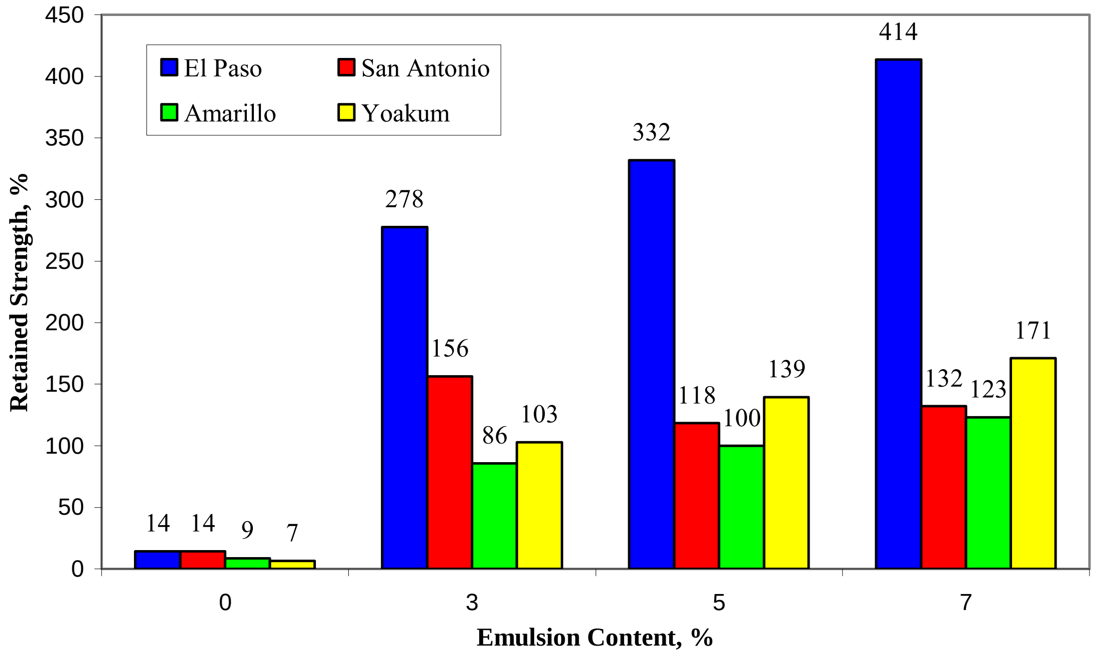


Figure 4.7 - Retained Indirect Tensile Strengths

4.7 COMPARISON OF STRENGTHS WITH DUAL STABILIZER AND OTHER OPTIONS

As shown in the previous section, only the San Antonio material met the required the strength criteria using only emulsion as a stabilzer. Due to the fact that most all of the materials attained marginal results with the addition of 3% emulsion, this quantity was used for the dual stabilization part of the research. Specimens were prepared which contained a combination of either 0 or 3% emulsion and 1 or 2% cement or lime.

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 4.8. For the El Paso material, the addition of 1% cement or lime to 3% emulsion provided adequate compressive strength (see Figure 4.8). By way of comparison, the UCS results for the mixes with 1% and 2% cement and lime (without emulsion) are also included in Figure 4.8. Adding 2% cement without emulsion provided a strength of 170 psi. Even though it is not shown 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 if climactic conditions permit and where emulsion costs may be high.

UCS results for the Yoakum material with different additives are shown in Figure 4.8 as well. 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 4.9. For the El Paso material, only the mix with 2% cement satisfied the 50 psi value as required by the TxDOT Special Specification. Of the Yoakum specimens, either 2% cement or 3% emulsion plus 1% lime met the requirement. For the Amarillo material, the optimum combination of additives consisted of 1% cement and 3% emulsion. With such a treatment, the UCS and IDT values 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.

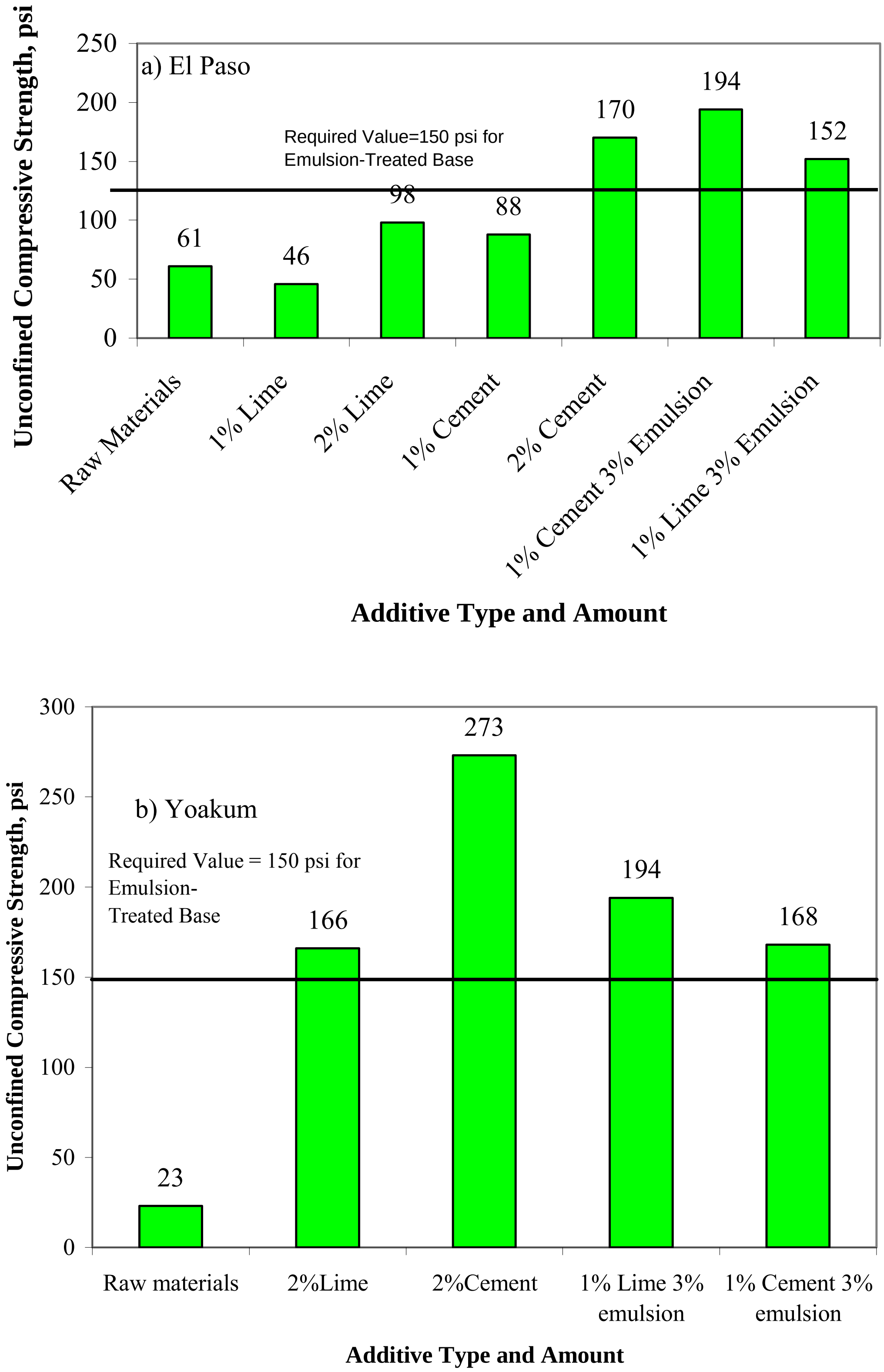
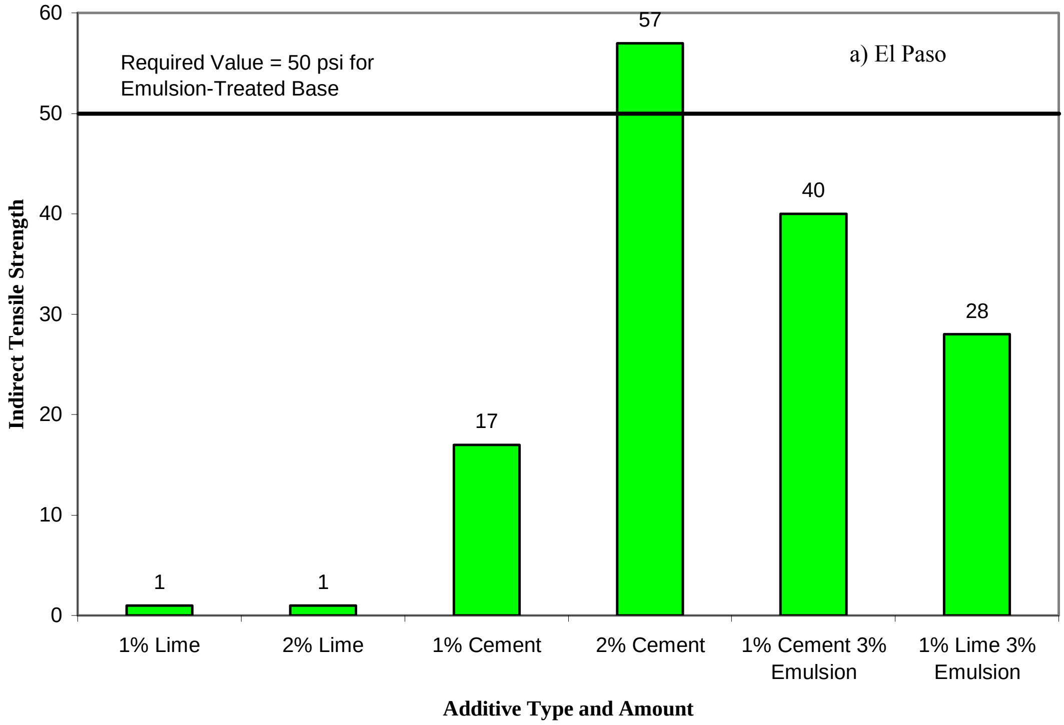


Figure 4.8- Unconfined Compressive Strengths for El Paso and Yoakum Materials



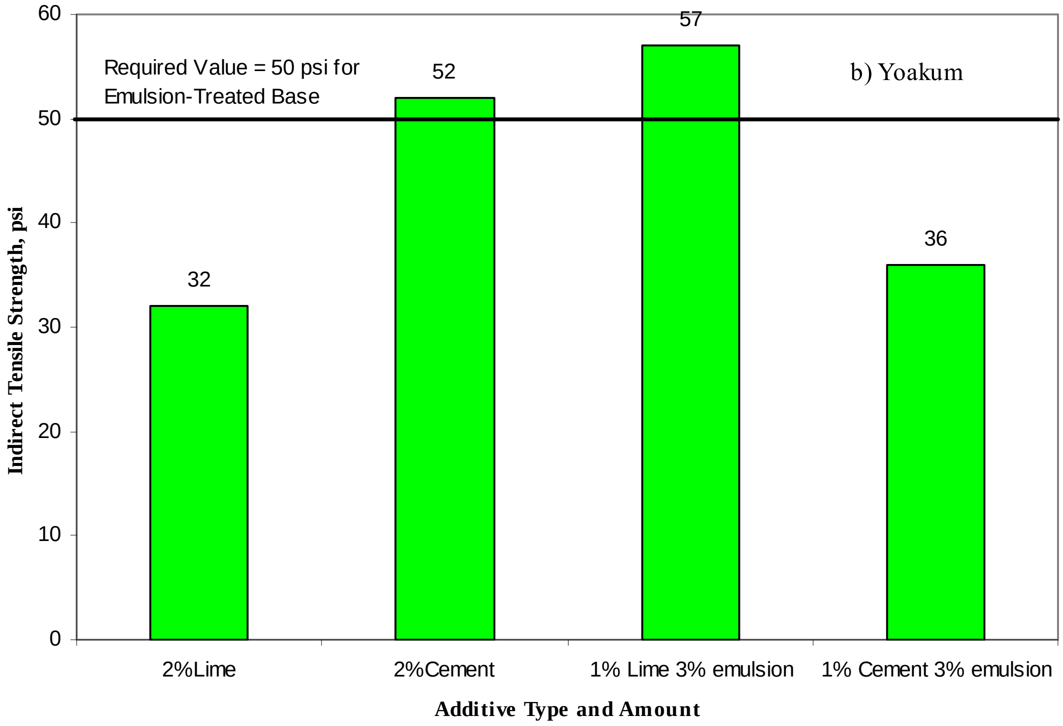


Figure 4.9- Indirect Tensile Strengths for El Paso and Yoakum Materials

4.8 MOISTURE CONDITIONING TESTING

As stated earlier, moisture conditioning testing was performed on the materials using Tex-144-E "Tube Suction Test" This test provides two major parameters: the dielectric constant and retained strength. During this process, the dielectric constant is measured on a daily basis and recorded. Typically, a dielectric value of ten or less is desirable (the dielectric constant of water is 80). As reflected in Figure 4.10, for all mixes and emulsion contents, the dielectric values are less than 10. Whereas, the dielectric values from the materials without emulsion are greater. 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. These results confirm that the moisture susceptibility of these materials is decreased with the addition of emulsion.

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 were 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 Amarillo material, the entire matrix of test specimens attained adequate retained compressive strength values with the 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. Similar to the retained strength, the retained modulus is defined as the ratio of the modulus values from moisture conditioned and non-moisture conditioned specimens. The retained moduli from the TST specimens are shown in Figure 4.13. It can be seen that the mixes with emulsion generally yield a value greater than 100%. The mixes without emulsion perform quite poorly under the moisture conditioning circumstance with retained moduli of less than 15%..

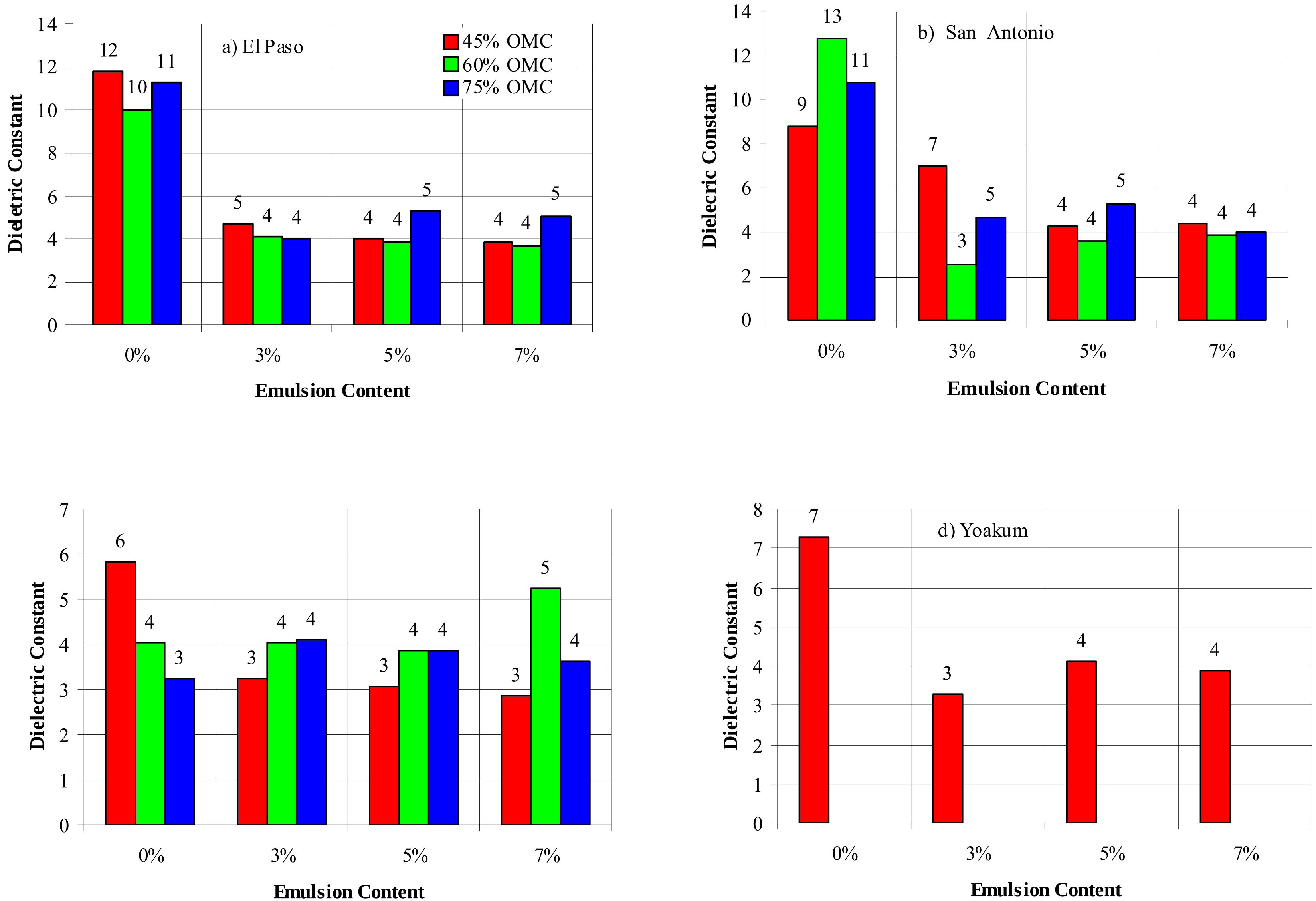


Figure 4.10 – Dielectric Constants for Materials with Different Moisture and Emulsion Contents from TST Specimens

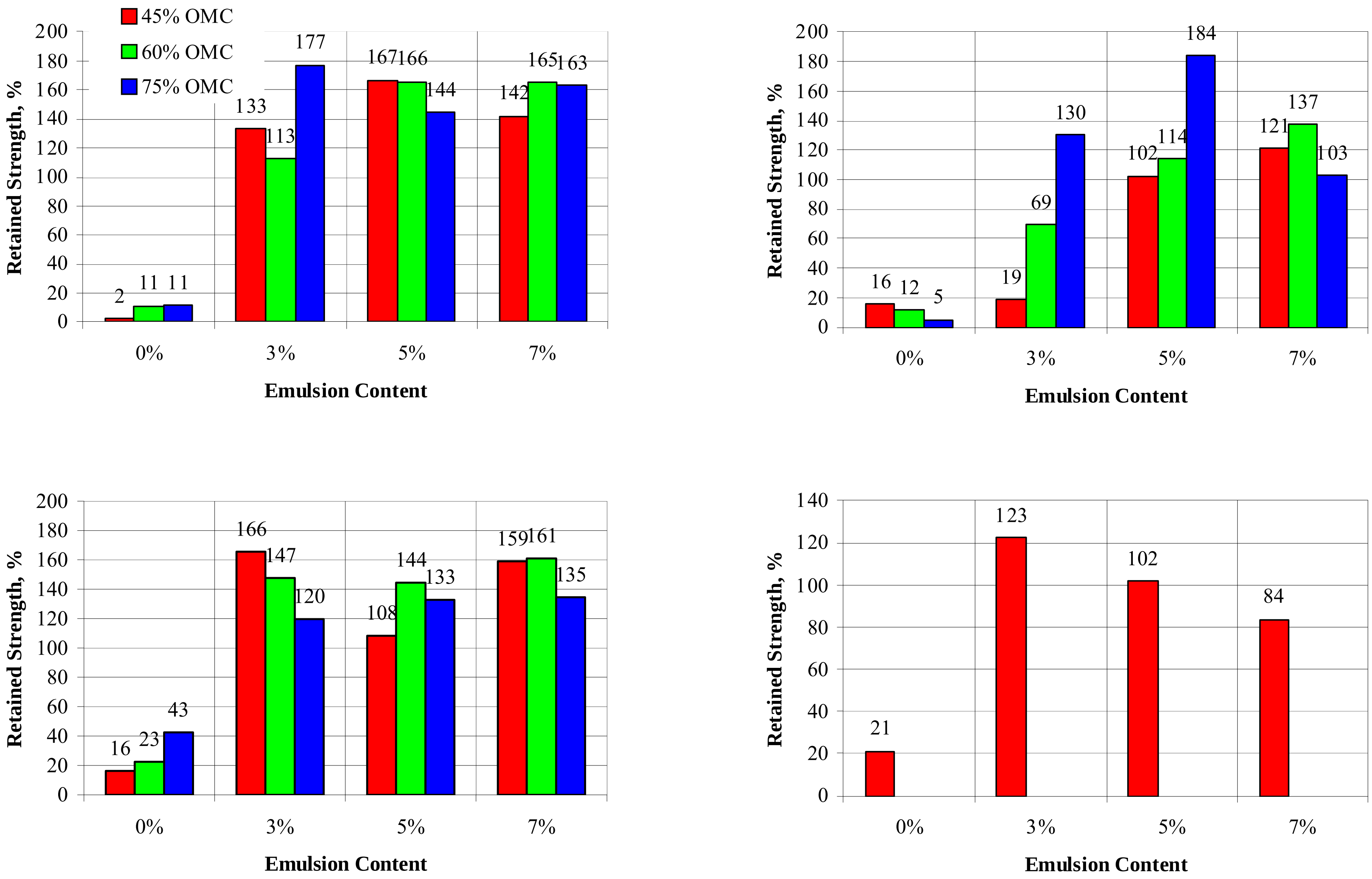


Figure 4.11 – Retained Strengths for Materials with Different Moisture and Emulsion Contents from TST Specimens

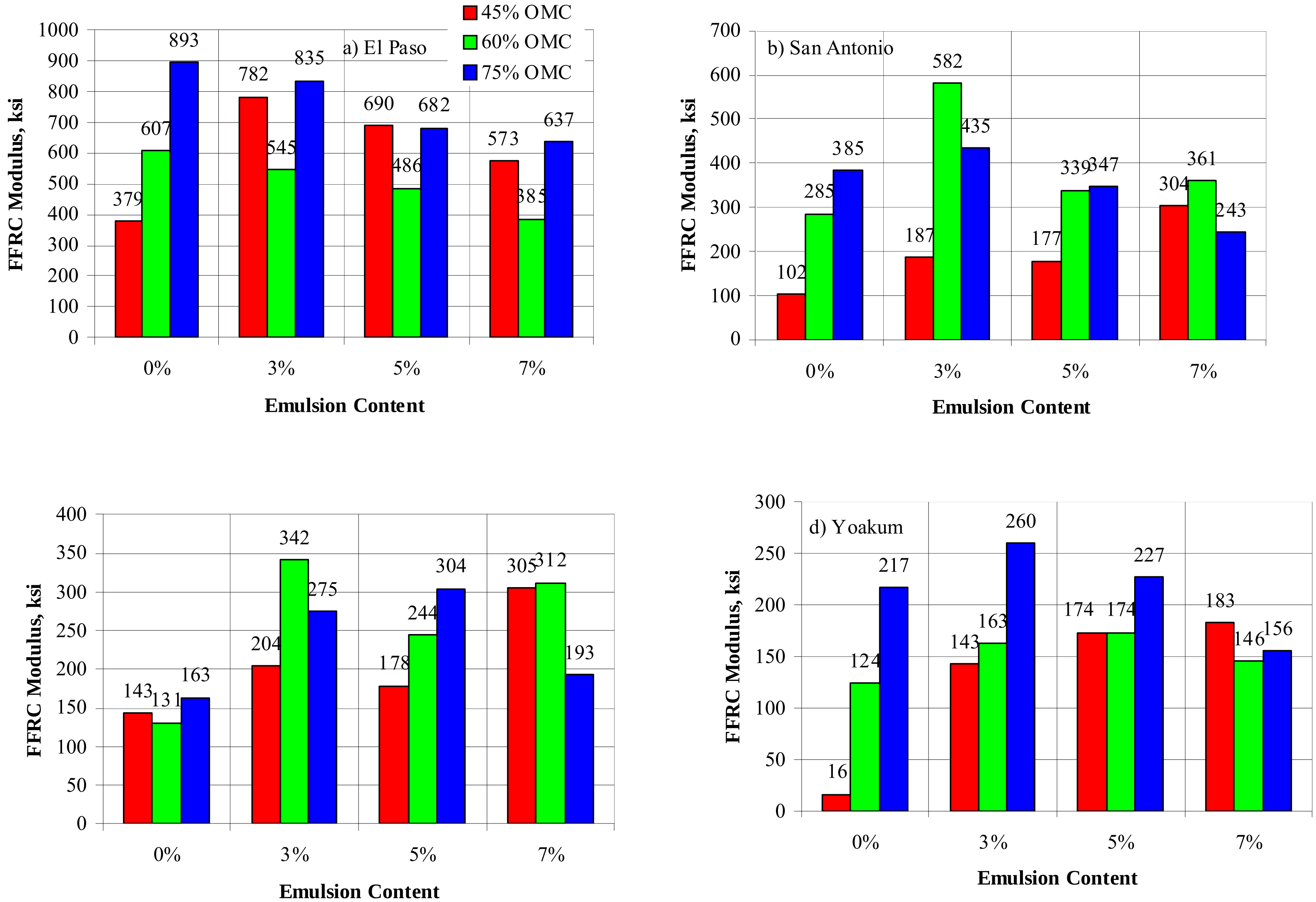


Figure 4.12 - Seismic Moduli for Materials with Different Moisture and Emulsion Contents from UCS Specimens

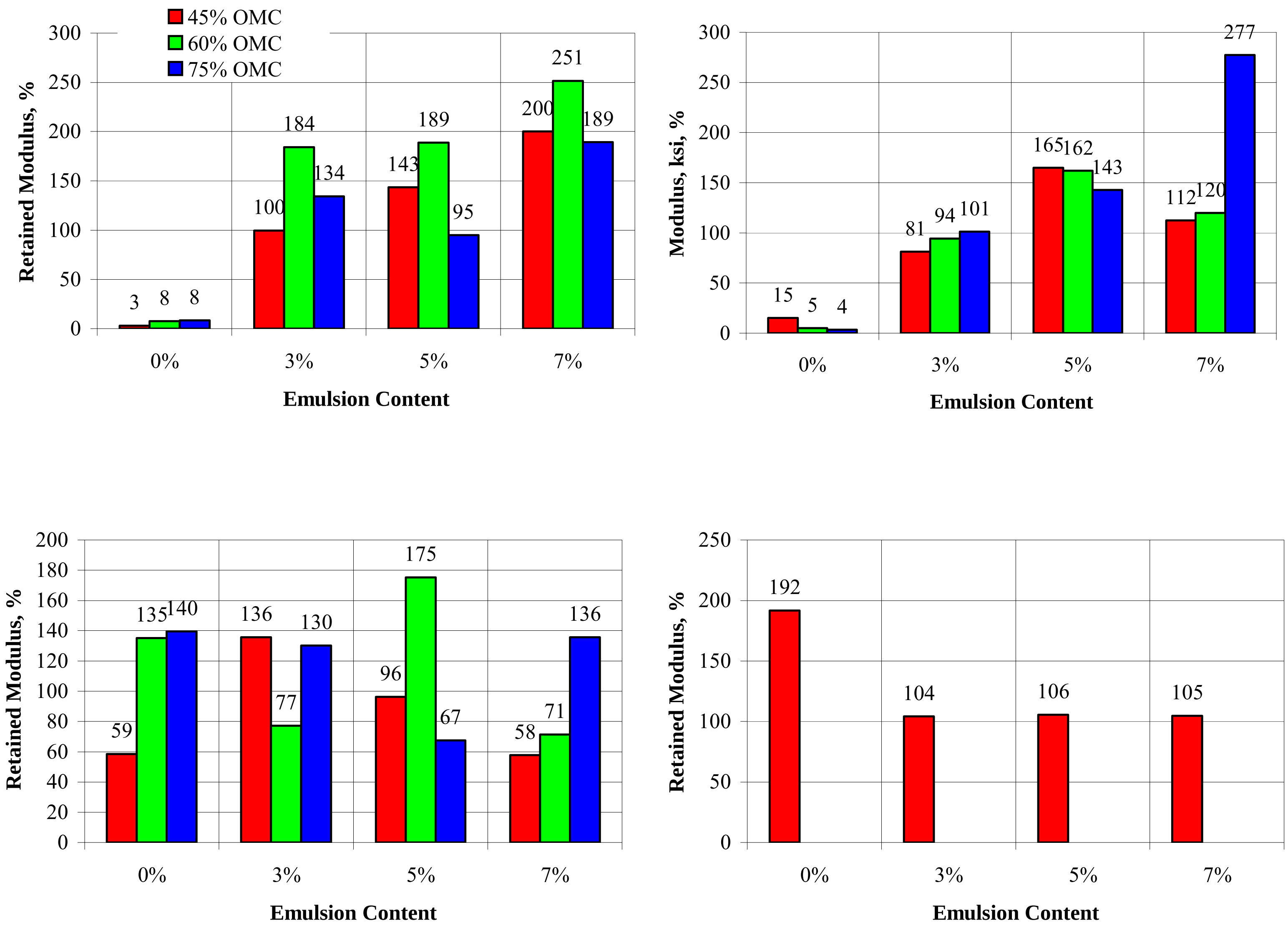


Figure 4.13 - Retained Moduli for Materials with Different Moisture and Emulsion Contents from TST

4.9 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 4.14. A repeated axial cyclic stress of fixed magnitude, load duration, and cycle duration 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. In this study 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 were 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:

k1, k2 and k3 are coefficients determined from laboratory resilient modulus tests

σc and σd are the confining pressure and deviatoric stress, respectively

The advantage of this type of model is that it is universally applicable to fine-grained and coarse-grained base and subgrade materials. Typical results from two tests are shown in Figure 4.15. The resilient modulus results on 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 are 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 FFRC tests be performed instead of the resilient modulus test..

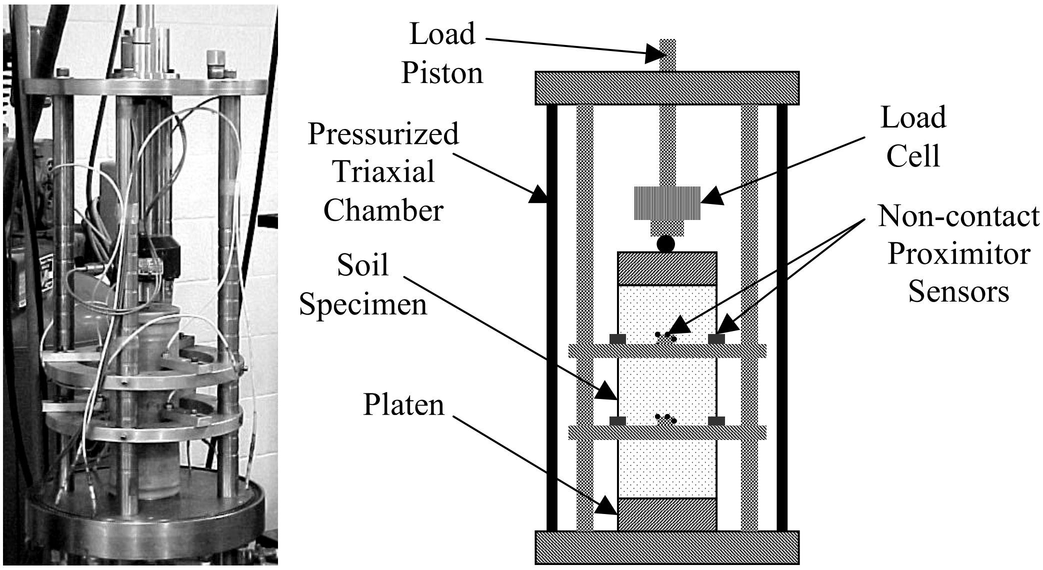
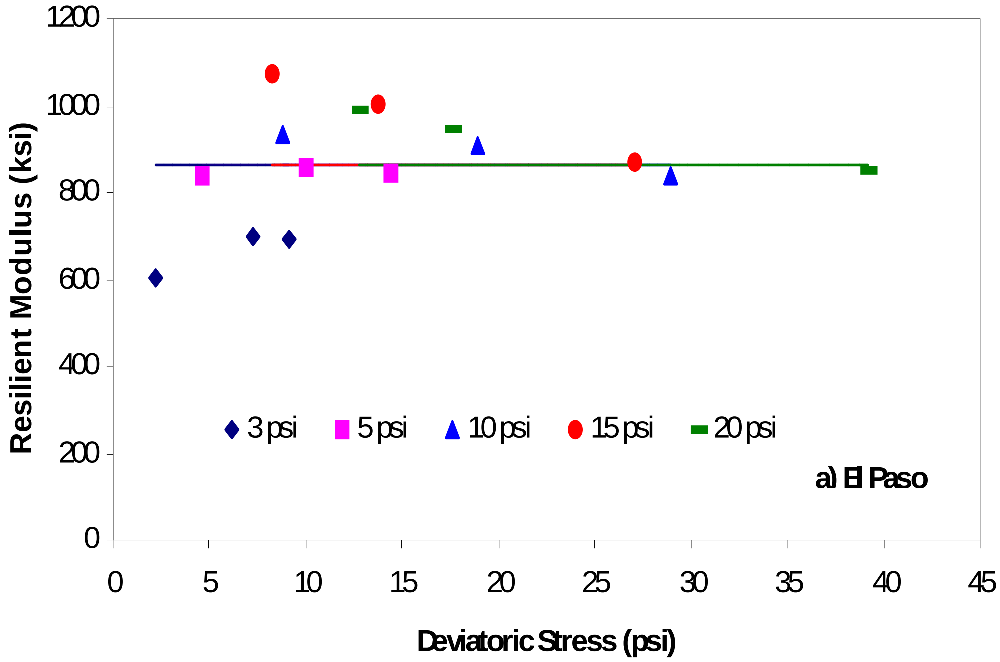


Figure 4.14 – Resilient Modulus Test Device and Setup



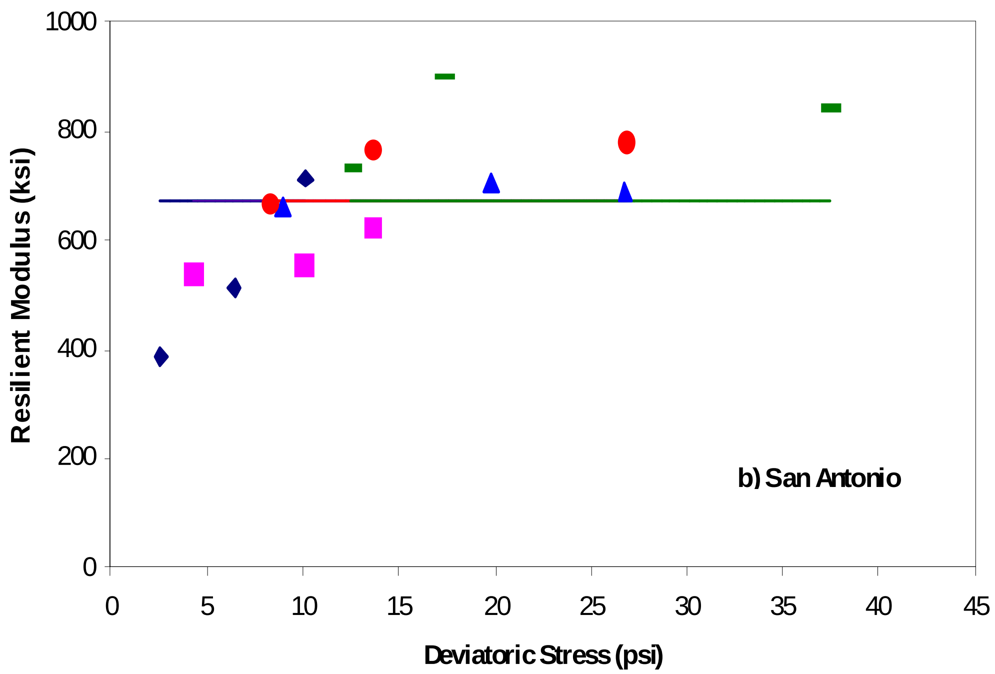


Figure 4.15 – Resilient Moduli of El Paso and San Antonio Materials from Specimens Prepared at Designed Total Liquid Contents

4.10 OPTIMUM MIX DESIGNS

Based on the results from the two phases of initial testing (with and without lime or cement) the final mix designs determined for the four materials used in the parametric study are summarized in Table 4.5 below. These designs fulfill all the design requirements of the current specifications except for the indirect tensile strength for the El Paso material.

Table 4.5 - Final Mix Designs and Properties for Materials under Study

Parameter	El Paso	San Antonio	Amarillo	Yoakum
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%

Chapter 5 - Laboratory Testing – Parametric Studies

5.1 INTRODUCTION

One of the goals of this study was to document the impact of construction-related factors on mix design results. As such, changes in mix design-related parameters were evaluated during the course of this research. Gradation changes and how they affect the overall accuracy of the mix design were looked at. Compaction of the material in the laboratory is a parameter that has not fully been explored with regards to type of equipment used and was explored more in 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 effect of initial mixing apparatus on these types of mixes was evaluated.

A number of parametric studies were carried out so that the significant variables that impact the mix design and in turn the long-term durability of the mixes could be identified. Specimens were made according to the optimum mix design and subjected to a number of strength tests similar to those used in the first phase of testing. Due to time constraints, not all tests were carried out on all of the mixes.

5.2 IMPACT OF GRADATION

FDR for road rehabilitation is routinely carried out through the pulverization process which has the ability to cause changes to the materials gradation. Usually, the change in gradation is an increase in either sands or fines or both. To test the impact of gradation, besides the natural gradation of the El Paso material and the San Antonio material, the mixes of three additional gradations made from each of those two 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 sands; Excess Fine and Sand or ESF. As an example, the four gradations for the El Paso material are shown in Table 5.1 and graphically in 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

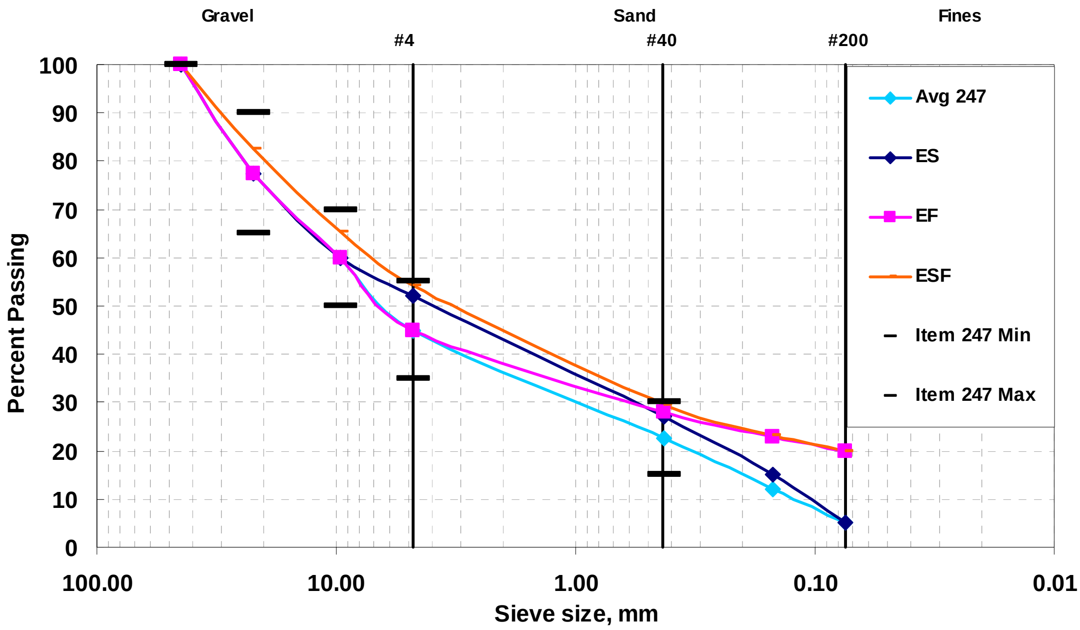


Figure 5.1 - Gradation Curves of Four Mixes from El Paso Material

The unconfined compressive strengths of the specimens after two days of dry curing and after moisture conditioning, as well as the 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 IDT. For the San Antonio material, the addition of excess fines is detrimental to the quality of the mix. The variations in modulus for the same UCS specimens are shown in Figure 5.3. Similar trends in those values were 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.

5.3 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 in the state of Texas currently utilize a proprietary emulsion. For this reason it (the proprietary emulsion) was one of the emulsions chosen to be incorporated in this study. Another emulsion provided by Gulf States Asphalt (GSA) that meets the requirements of TxDOT was also used. Both of these emulsions are ionic in nature. 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 IDT. With regards to the San Antonio and Amarillo materials, the GSA emulsion yielded higher dry compressive strengths but lower tensile strengths. The Yoakum material did not perform as well with the introduction of the generic emulsion. The results for all strength tests (UCS, IDT and moisture conditioning) showed lower values than with that of the proprietary emulsion. For all of the materials used in this study, with the exception of the Yoakum specimens, the moisture conditioned samples with the proprietary emulsion exhibited higher strengths than the dry-cured specimens; whereas the GSA mixes exhibited some moisture susceptibility by yielding lower strengths for moisture-conditioned specimens.

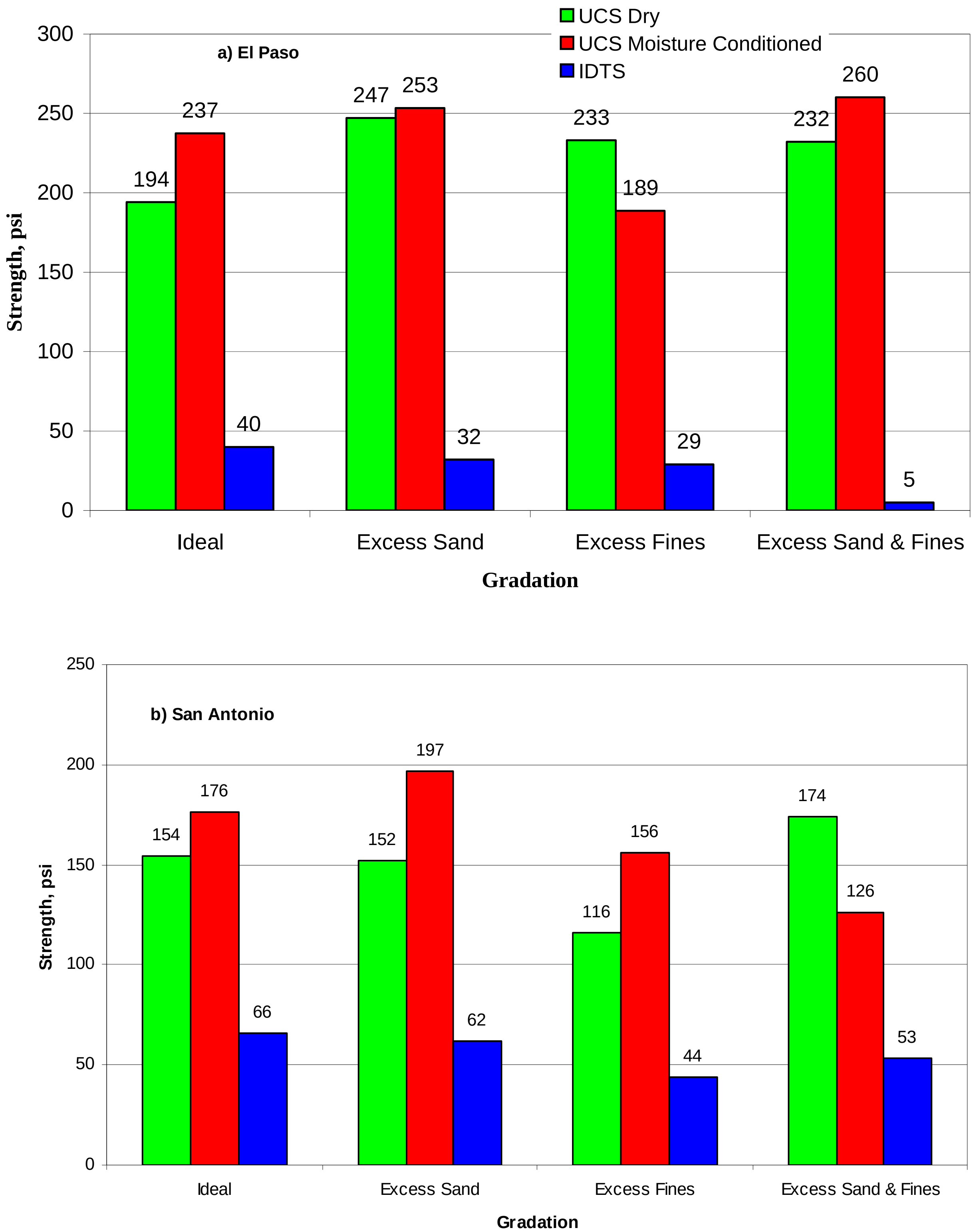


Figure 5.2 – Impact of Gradation on Strength of Different El Paso and San Antonio Mixes

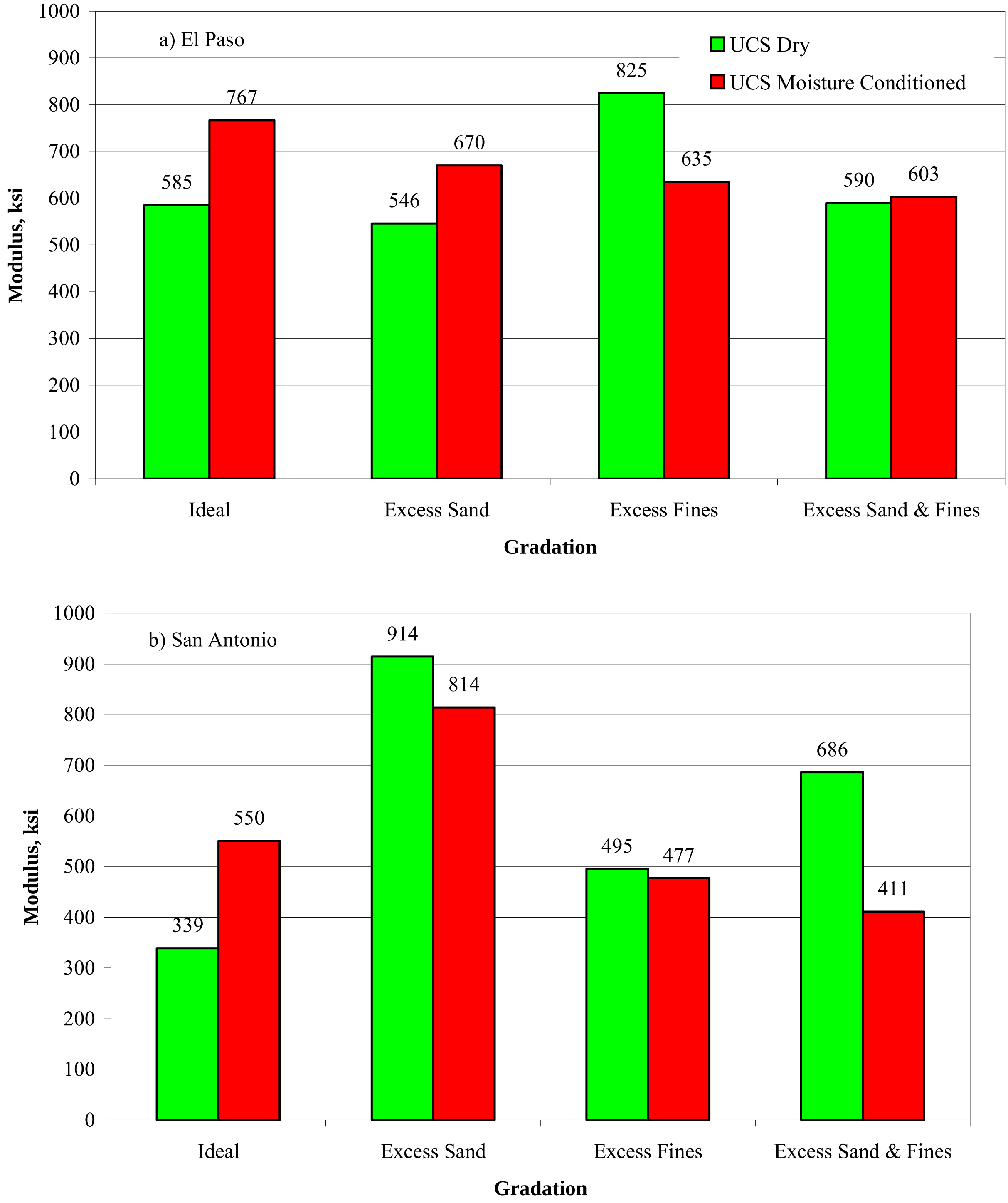


Figure 5.3 – Impact of Gradation on FFRC Modulus of Different El Paso and San Antonio Mixes

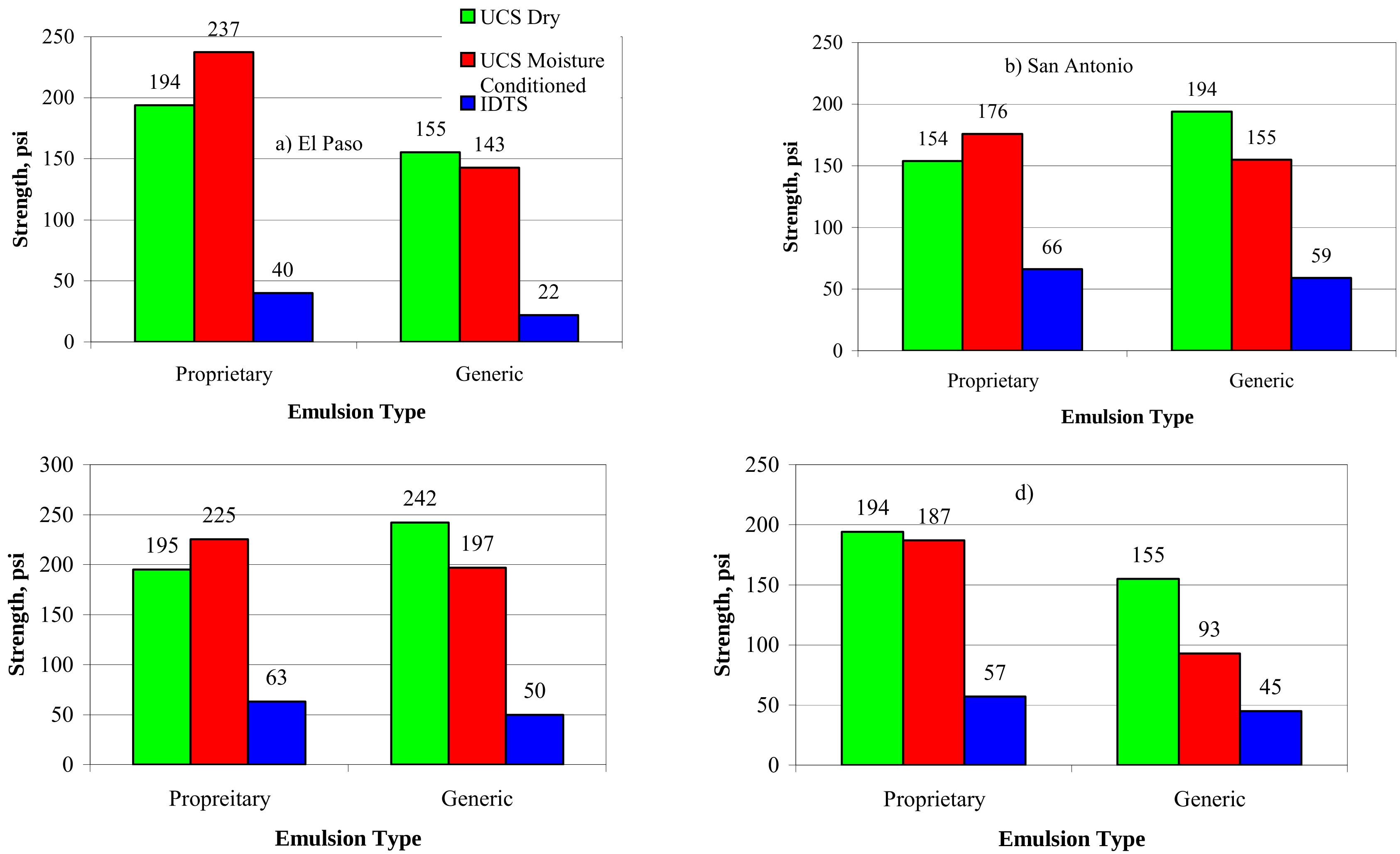


Figure 5.4 - Impact of Emulsion Type on Strength Parameters

5.4 IMPACT OF MIXING METHOD

The current TxDOT Special Specification does not stipulate one single 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 alsoused to prepare specimens.

The variations in strength for specimens prepared with different mixing methods are shown in Figure 5.5. 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 Amarillo and Yoakum specimens seem to be affected less by the type of mixing method used because they contained RAP. The moduli of the mixes are shown in Figure 5.6. The loss of stiffness is less pronounced for the El Paso materials for the two alternative methods perhaps because of the addition of cement. Similar to the strength results for the Amarillo material, 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. In the absence of a high-shear mixer, the hand-mixing process is preferable to the use of a concrete mixer

Figure 5.7 shows a comparison of specimens prepared with the high-shear mixer and the concrete mixer. Although not shown here, the specimens mixed by hand appeared very similar to those mixed with the concrete mixer. The materials prepared with the high-shear mixer appear to be uniform with respect to asphalt coating of the aggregates. The specimens which were mixed utilizing the other two methods appeared "spotty" where the fine aggregates seem to absorb most of the emulsion. However, the cases mixed with the high-shear mixer tended to clump together.

The impact which mixing has on the gradation of the material was also looked at during this portion of the study. 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 generated about % fines after mixing. The Yoakum mix does not exhibit much change in the gradation; but some of the gravel-sized materials in Amarillo mix changed to fine sands.

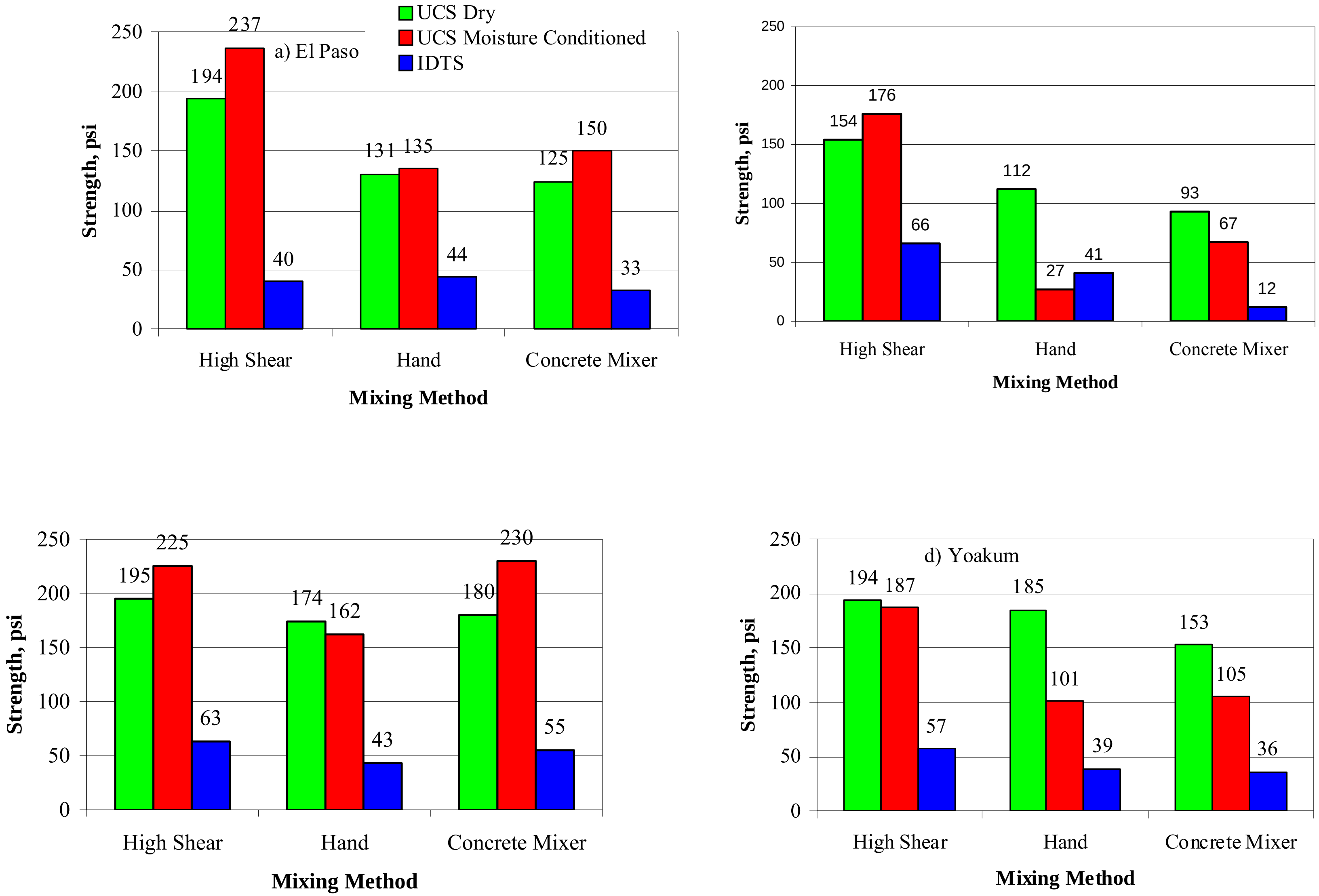


Figure 5.5 – Impact of Mixing Method on Strength Parameters

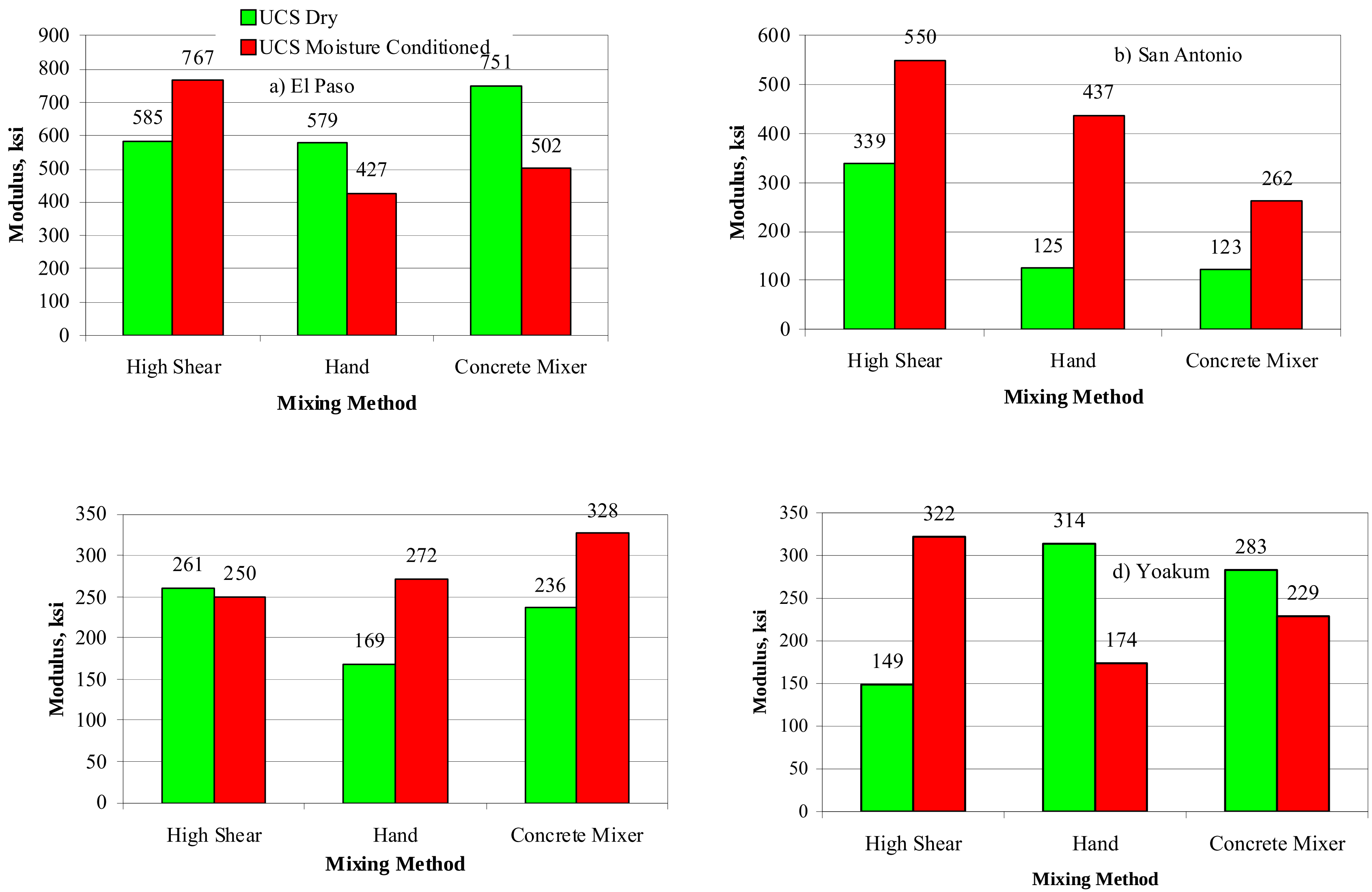


Figure 5.6 – Impact of Mixing Method on FFRC Modulus

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
Yoakum	Before	53	29	16	2
	After	53	28	17	3
Amarillo	Before	63	25	9	4
	After	59	25	12	5

Figure 5.7 – Appearances of Specimens Mixed with High-Shear Mixer (Left) and Concrete Mixer (Right)

5.5 IMPACT OF COMPACTION METHOD

Another contributing factor to strength and durability is the method of compaction. In this parametric study, three different methods of compaction were investigated. The standard Tex-113-E, a SGC with 30 gyrations as well as a SGC with 50 gyrations were utilized.

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 5.8. 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 the strength parameters amongst compaction method are shown in Figure 5.9. The specimens prepared with the gyratory compactor were stronger than those prepared with the Proctor method. Specimens prepared with 50 gyrations yielded higher strengths than those with 30 gyrations. The differences were especially pronounced for the indirect tensile tests. The variations in modulus with the compaction method, as shown in Figure 5.10, were similar to the trends for the strength tests.

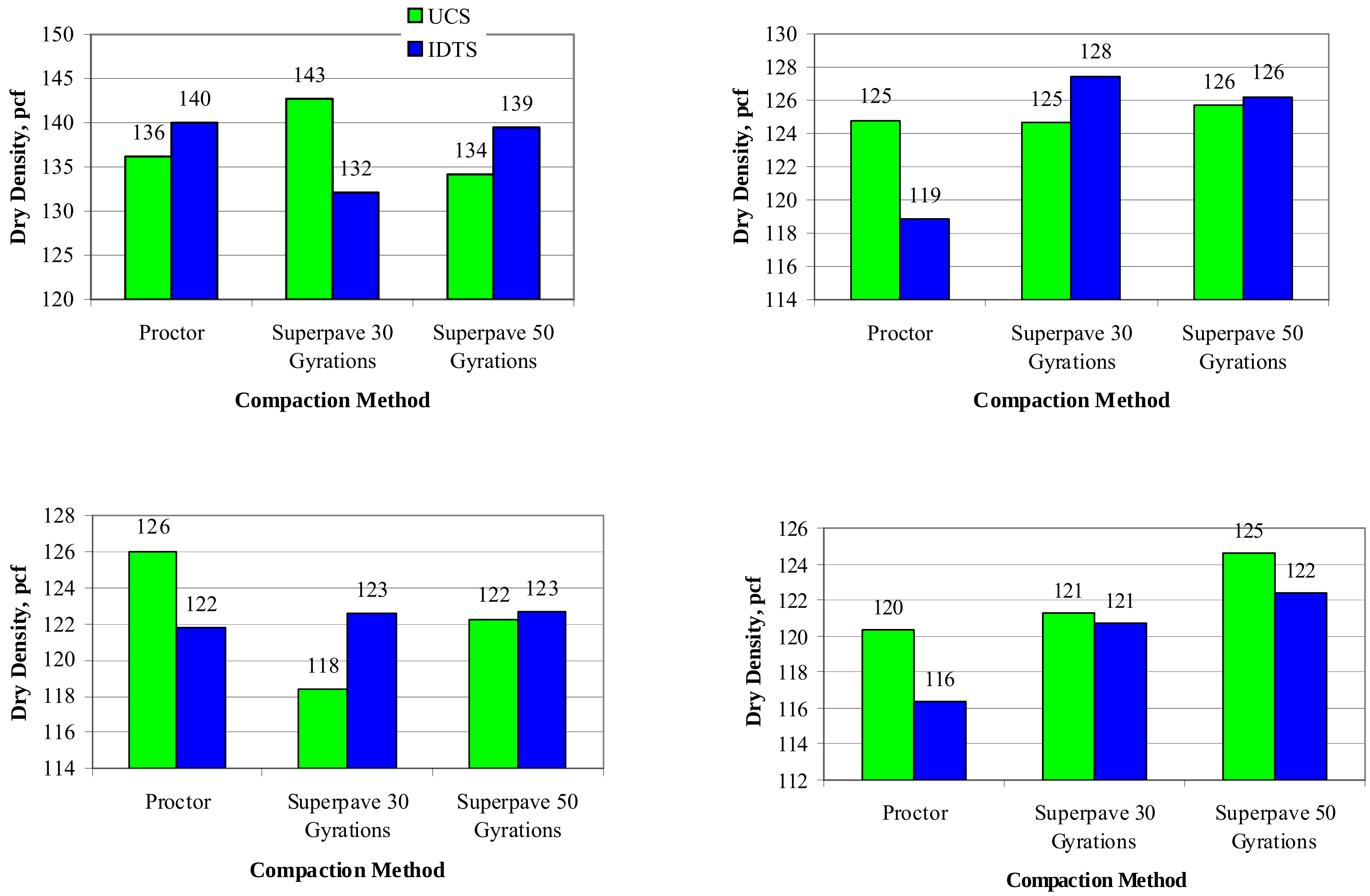


Figure 5.8 – Impact of Compaction Method on Dry Density

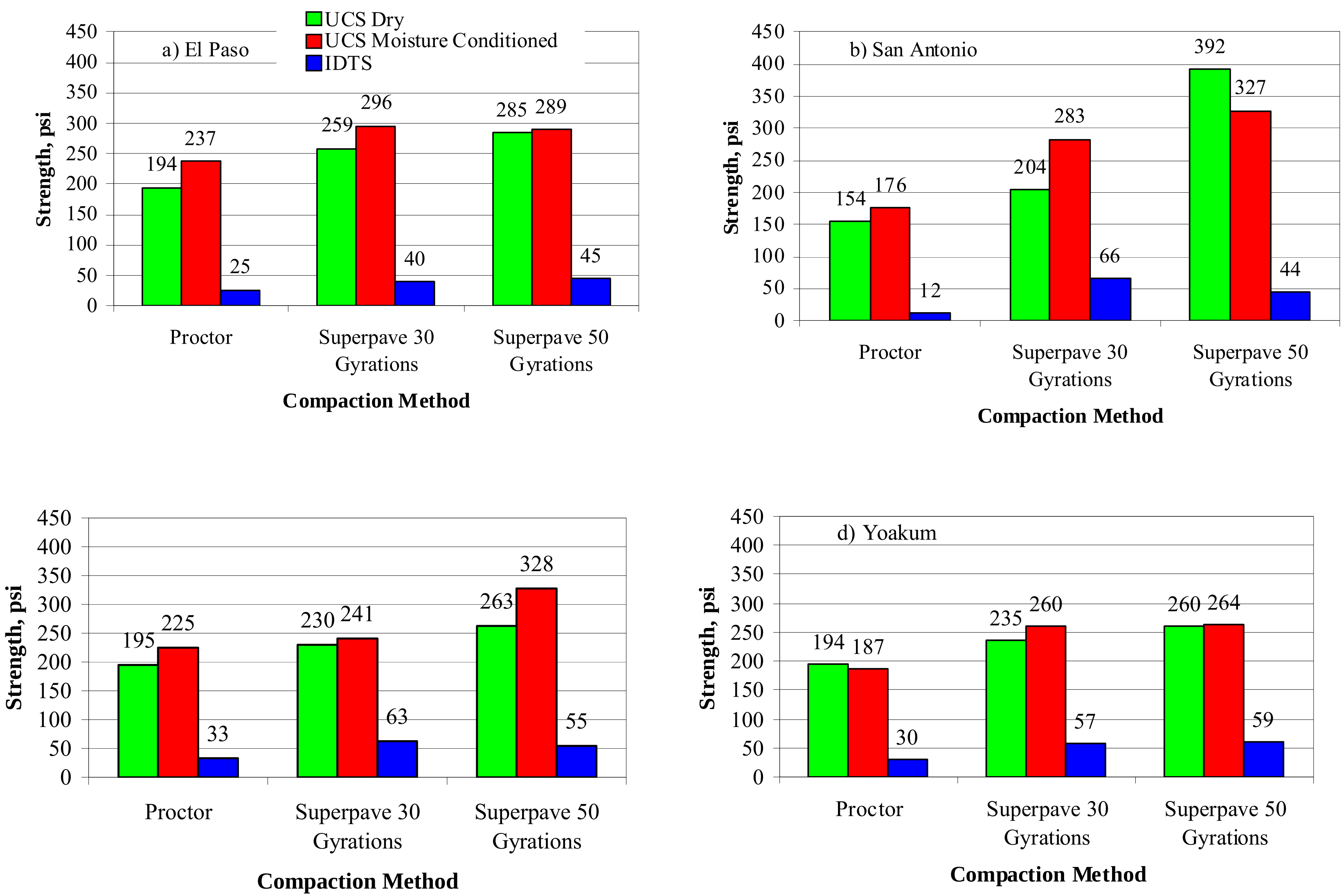


Figure 5.9 – Impact of Compaction Method on Strength Parameters

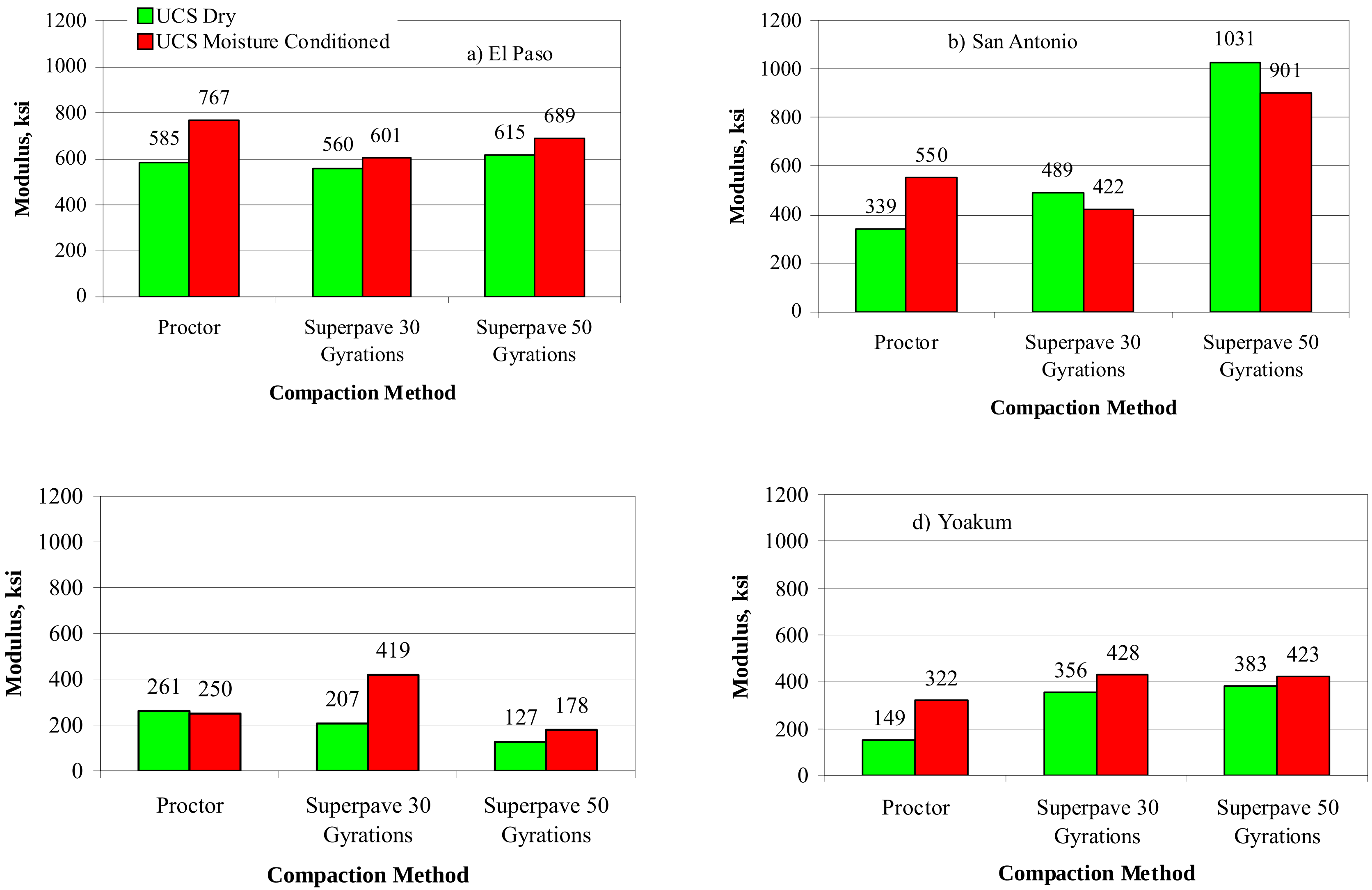


Figure 5.10 – Impact of Compaction Method on FFRC Modulus

Chapter 6 - Preliminary Guideline

6.1 INTRODUCTION

As part of this study, researchers at UTEP have developed and evaluated a preliminary protocol for mix design and required tests for emulsion-treated base materials. The preliminary guideline was based on the results from both phases of laboratory testing and can be viewed in its entirety in Appendix C. However, a description of how the guideline came about based on the findings of the research is given in this chapter. As a reference for understanding the basic steps given in this chapter, a mix design flow chart is given in Appendix D of this report.

6.2 SAMPLING AND PREPARATION OF MATERIAL

The existing base material and add-rock are to be oven-dried. Once these materials reach a constant moisture content, sieve analysis and index tests are performed on them. RAP materials should be dried outside under direct sunlight since even a relatively low oven temperature may lead to clumping of what little fines that may be present in the RAP. After drying, the RAP it should be freezer before crushing to facilitate the breaking of the material. A sieve analysis is then performed on the RAP. For all sieve analyses, a No. 200 sieve should be included in the sieve stack. After obtaining the gradations of the individual materials being used in the mixture, they are to be combined into a "batch mix" according to their proportions identified from the field data. This global gradation is then used for preparing all specimens required for testing.

6.3 DETERMINATION OF OMC AND TLC

The steps outlined in Tex-113-E are to be followed to obtain the 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 air 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 material. 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% (i.e., 10% to 20% of the volume of the voids *-liquid plus air-* in the mix is 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 (Wwet), drying it in a 230ºF oven for 24 hours, and measuring the weight of the dried specimen (Wdry). 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, Wwet is equal the weight of aggregates (Waggregates) and water (Wwater), and Wdry is the weight of the dry aggregates only. 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 (Wasphalt) becomes part of the weight of solids (aggregate plus asphalt) since the water in the emulsion (Wwater in emulsion) evaporates during curing. As such, the measured total liquid content (TLCmeasured) 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 (TLCassumed), which is calculated from:

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

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 (γtotal)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 TLCmeasured (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 content 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 TLCmax, and the assumed mixing moisture content (MMC), the maximum allowable emulsion content (ECmax), can be determined from:

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

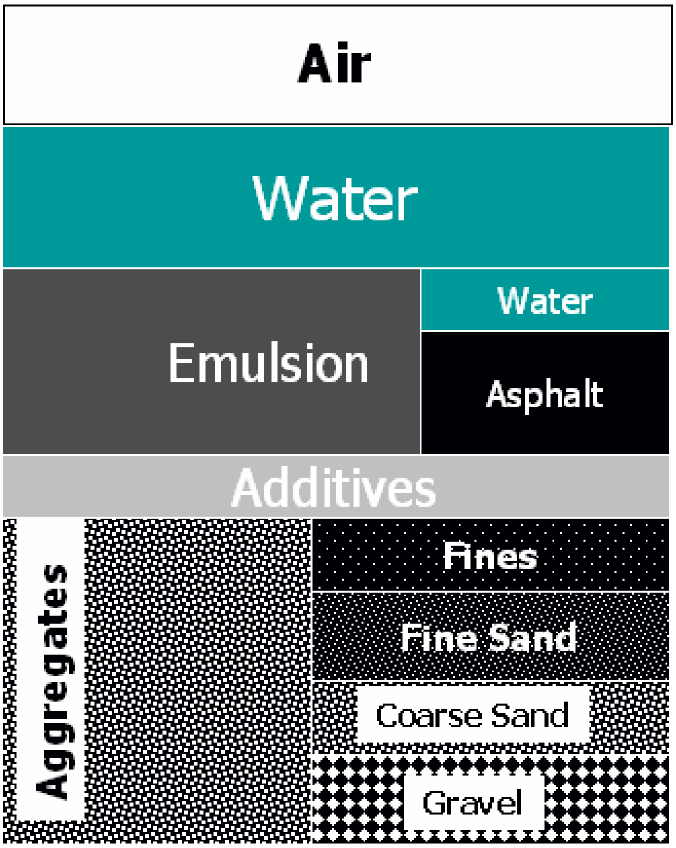


Figure 6.1 –Constituents of an Emulsion Treated Base

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 E. 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 are2.8% and 7.7%, respectively.

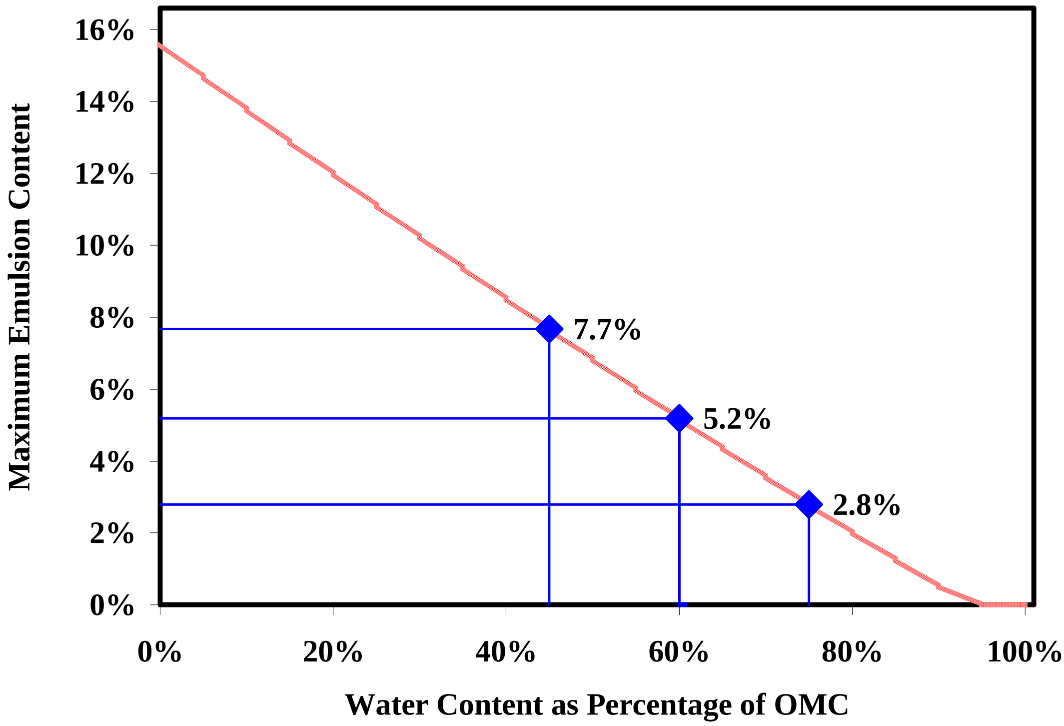


Figure 6.2 – Example Variation in Mixing Moisture Content with Maximum Allowable Emulsion Content

6.4 OPTIMUM EMULSION CONTENT FOR STRENGTH

Based on this criteria, the optimum emulsion content is determined by preparing specimens at different emulsion contents and subjecting them to IDT testing. The minimum emulsion content is 0% (no emulsion) and the maximum emulsion content is obtained from an excel sheet which incorporates the previous equations. Two intermediate emulsion contents are also proposed. After being subjected to IDT 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 IDT 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) should be considered.

6.5 ADDITION OF CALCIUM-BASED ADDITIVE

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

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

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 IDT testing to ensure that the minimum strength requirement is met. If the requirement is met, this becomes 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 IDT 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.

Chapter 7 - Observations and Recommendations

7.1 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.

7.2 MIX DESIGN SELECTION BASED ON RESULTS FROM IDT TESTING

The TxDOT Trial Specification specifies the UCS value 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 added. 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 can not 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. Additionally, using IDT as the first line of testing will inherently require less material.

7.3 MOISTURE SUSCEPTIBILITY TESTING

Under the current specification, the retained strength in compression 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 strength in compression was typically acceptable for almost all mixes

in tension. This is partly because of the lack of penetration of moisture into the specimen during moisture conditioning. The lack of penetration of moisture also caused reasonably small values of dielectric constant. However, in several cases, the retained IDT strengths were less than 80%. This could be due to the method of compaction; using a gyratory compactor instead of the kneading method as is the case for UCS specimens. Specimen height may have played a role as well. The UCS specimens are generally larger and require more time for moisture to fully penetrate them. As such, it is recommended that the retained IDT be considered as the main criterion for moisture susceptibility.

7.4 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. 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. These could be topics for further research.

7.5 Misleading Modulus Results

As noted during the course of testing, materials which contained higher RAP contents and no emulsion what so ever generally reported high FFRC Modulus values. However, the retained strength values of these specimens after undergoing mechanical testing did not follow the same trend. Non-emulsion stabilized bases showed very low retained strength values. This modulus phenomenon could be a direct result of the temperature at which the specimens are initially cured (140ºF). At this high temperature it may be that the asphalt in the RAP is being "melted" and then cooled again before testing; allowing for the re-cementation of the asphalt particles in the mix. Hence, the specimens show higher stiffness values yet do not achieve the strength required.

7.6 Parametric Study Results

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

- Changes in gradation of the material have a minimal effect on the strength and stiffness of the specimens but do 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. 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 strength.

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Appendix A: Special Specification Emulsion Treatment Road Mixed (by TxDOT)

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: Mix design Procedure – Emulsion Treatment Road Mixed (By Sem Materials)

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.

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[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.

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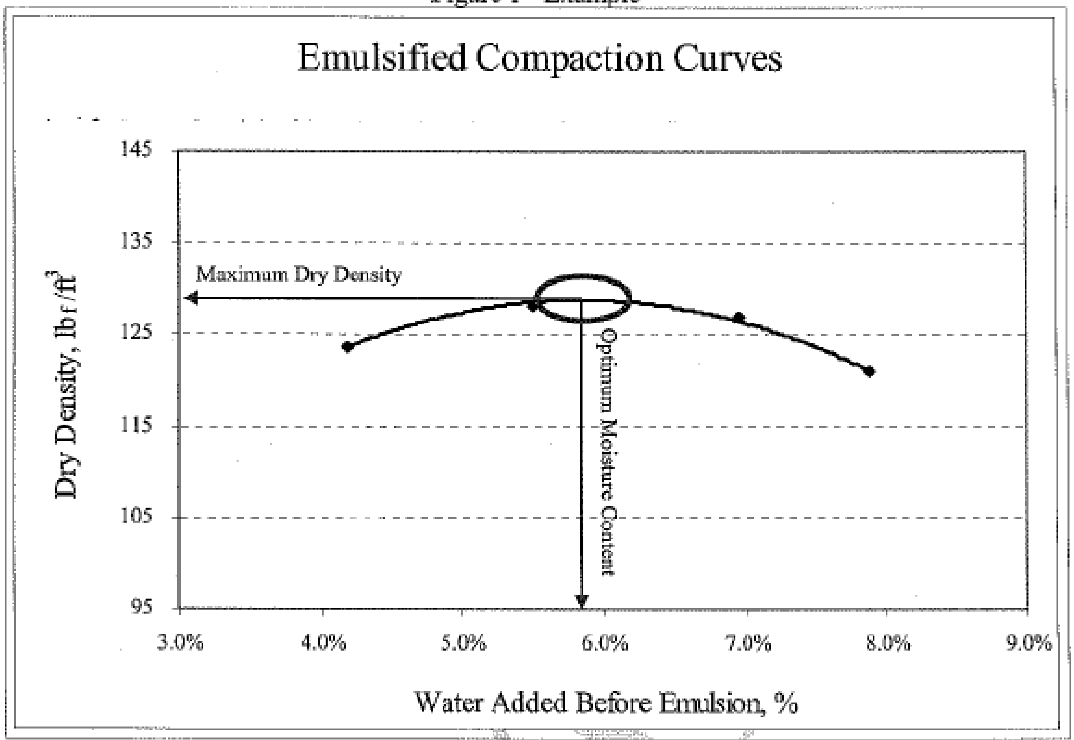
[2] Tex-113-E, Section 7, Step 5 & 6

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 ¾"" 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/m³ (0.1 lb/ft³)

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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 ϵ
- $UCS_{retained}$ on TST specimens to the nearest 1 psi

Appendix C: Preliminary Guideline for Mix Design and Lab Testing of Dual Stabilized Bases

1) Scope

This guideline provides the lab 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 old 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

Determine the OMC and MDD of the blended material 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 from the excel spreadsheet).

C) Prepare and test four specimens for 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.

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 the material of approximately 12 lbs for each specimen of 6 in. in diameter and 4.5 in. in length.

b) Thoroughly add mixing water (preliminarily 60% of the OMC) 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 with a diameter of no more than 6 in. 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".

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 104°F for 72 hours, depending on the requirement by individual mix designs.

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" by 4.5" specimens following the procedure described in "***Preparation of IDTS Specimens***": one with 1% cement and another with 1% lime. Each of them contains the emulsion content predetermined.

Note: The addition of calcium-based additive may not always yield positive results. In that case, the final mix design is the minimum amount of emulsion which yields the closest results in accordance with the TxDOT Special Specification.

6) Verification by UCS Testing

A) Prepare two 6" by 8" 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 testing 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 manner similar to that as described for UCS testing.

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

C) Perform UCS testing on one specimen as per procedure Tex-117-E after the specimen is cooled down to ambient temperature (about 77°F).

D) Put the rest specimen under 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).

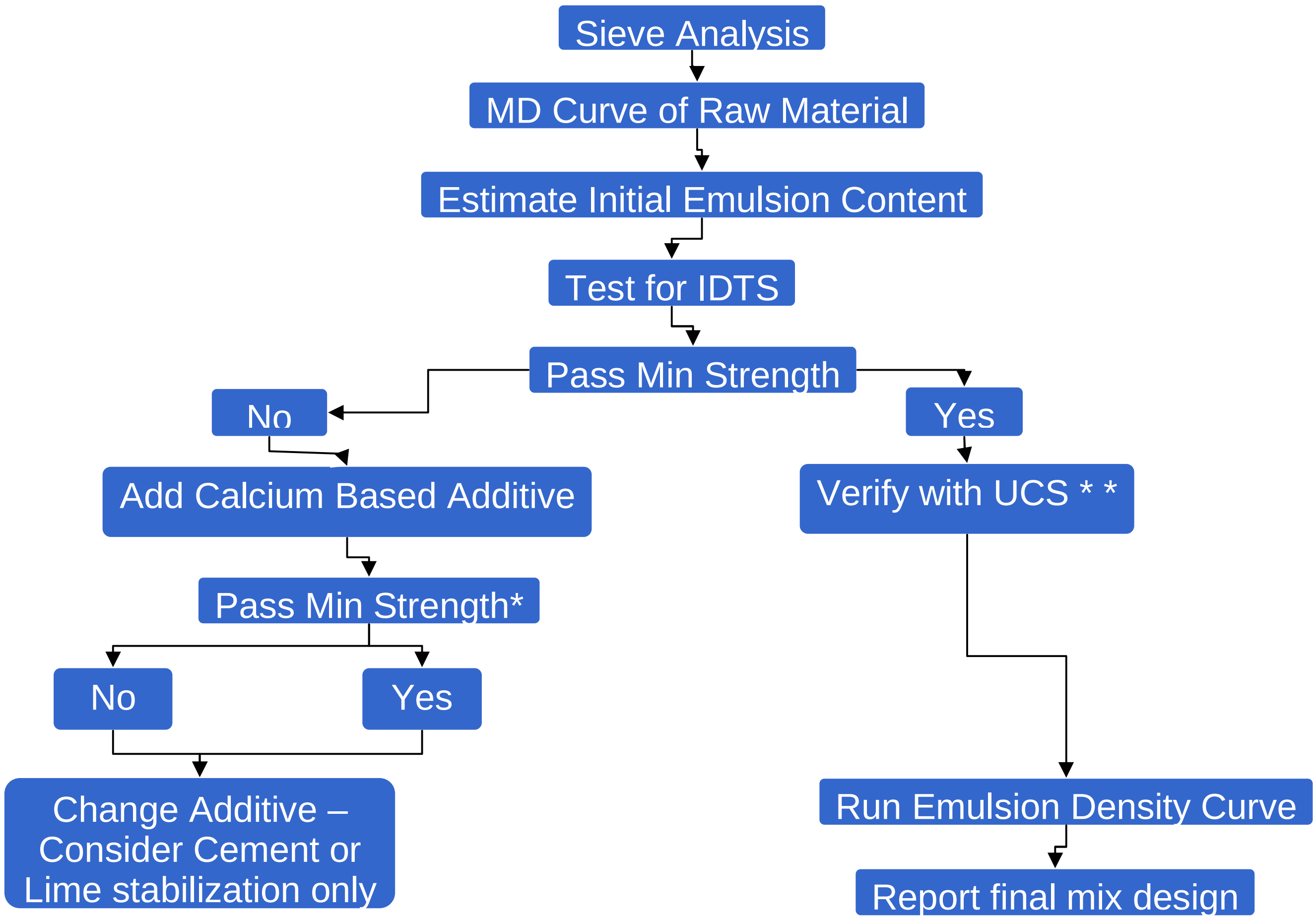
E) After final readings for modulus and dielectric constant, perform UCS testing on the specimen after eight-day moisture conditioning using the procedure described in Tex-117-E.

F) Calculate 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) Report

1. Blend percentages used and percent passing of material
2. Max 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. FFRC Modulus to nearest 1 ksi
9. Retained UCS and modulus to nearest 1%

Appendix D: Mix Design Flowchart


Sieve Analysis
MD Curve of Raw Material
Estimate Initial Emulsion Content
Test for IDTS
Pass Min Strength
No
Yes
Add Calcium Based Additive
Verify with UCS * *
Pass Min Strength*
No
Yes
Change Additive – Consider Cement or Lime stabilization only
Run Emulsion Density Curve
Report final mix design

Appendix E: Emulsion Analysis Tool Manual

This spreadsheet was designed to give TxDOT personnel a more precise starting point for emulsion selection when deciding the initial amount to be added to stabilized base materials. With some basic knowledge of the material in question, the engineer can make an educated decision as far as the quantity of emulsion to be used in their initial mix design considerations; in turn saving time going through a costly trial and error process. The analysis can also be run for dual stabilized materials.

Note: This is a multi-part spreadsheet, only those sections which pertain to emulsion stabilized materials are included in this text.

Material Specific Gravity

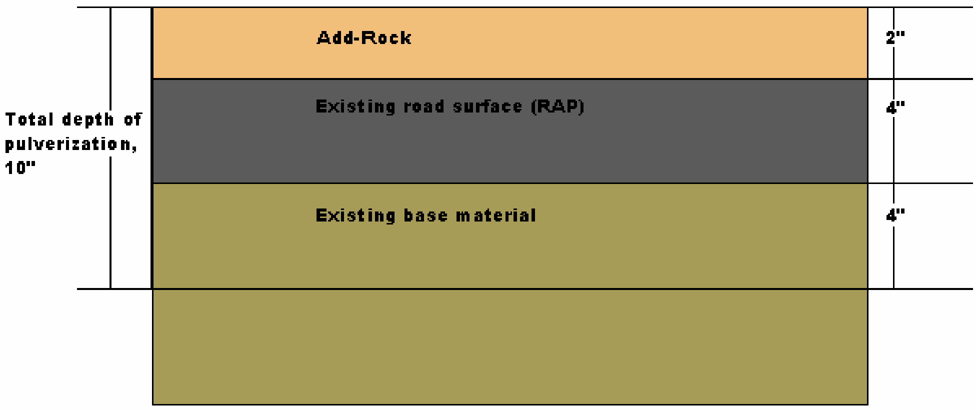
This section of the sheet requires the user to input mixture specific information. The specific gravity of the material is to be determined for each separately and then entered into their corresponding cells. The value for "Percentage used in Mixture" should be calculated based on the volumes to be used during construction. A brief description of how to do so is shown in the following figure.

Depth of Add-Rock = **2"**, Thickness of existing road surface = **4"**
Total depth of pulverization = **10"**

Therefore the total thickness of the base layer to be pulverized, **10"-2"-4" = 4"**

Percentages required for accurate representation of pulverized material:

Add-Rock,	2"/10" = 20%
RAP,	4"/10" = 40%
Existing base,	4"/10" = 40%



Example calculations for material proportioning if not being used in combination with Blending Analysis Tool

Emulsion Information

A basic knowledge of the emulsion to be used during actual construction is required for this section of the sheet. The user is asked 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.

Note: Although the user is free to assign a value for specific gravity of the emulsion, the recommended value is 1.02.

Cementitious Additive

For this section of the sheet the user is asked to choose between two different types of cementitious additives to used (cement or lime). It is recommended that the user first run 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.

Desired Degree of Saturation

The user can vary the degree of saturation in order to compare results of moisture within the mixture. It is recommended however that the analysis be run with a value of 90% saturation in order to optimize compaction of the material.

Moisture Density Curve Data

In order to ensure accurate analysis of the mixture properties, the user must first perform moisture-density testing on the material in question. It is important that this testing is performed on the material according to the gradation percentages previously found so as to accurately represent field conditions. The moisture content of the material is to be entered in integer form and not as a percentage.

Run Emulsion Analysis

After entering all of the values required, the user is then ready to run the analysis. The emulsion analysis will run automatically. Afterwards, a graph of the maximum possible emulsion content vs. initial mixing water content will be generated. This graph gives the user a general idea of what emulsion content to start off with during the initial mix design. The initial moisture contents are expressed as percentages of the optimum moisture content for the material.

Note: It is important to state that the percentage of emulsion required as shown on the spreadsheet is based on the maximum amount of emulsion that can be introduced into the mixture in order to optimize compaction for a given degree of saturation. These values are calculated based on the optimum total liquid content of the emulsion stabilized base.

What if analysis (Maximum Recommended Emulsion)

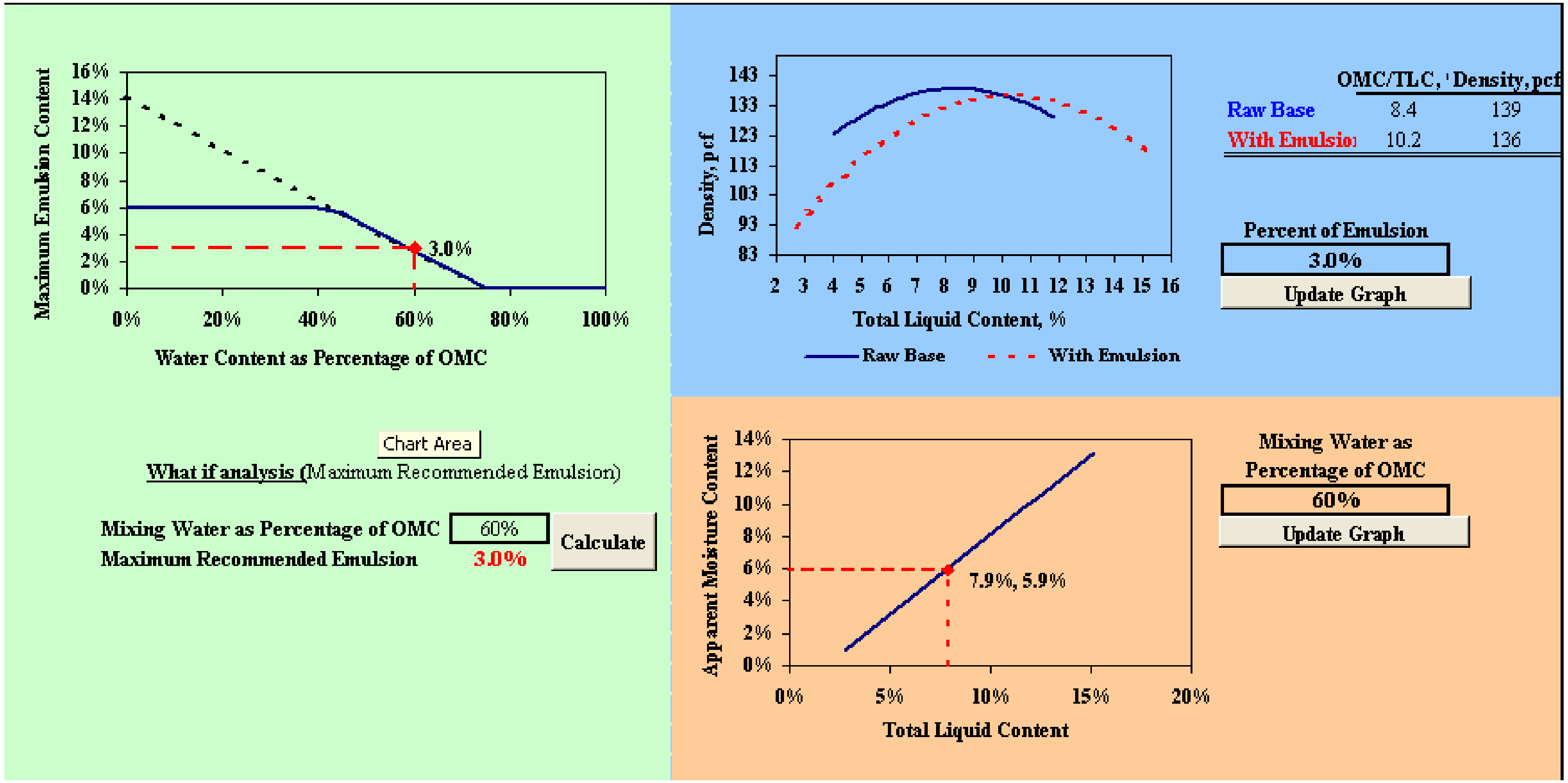
After performing the analysis, the user can vary the initial percentage of OMC in order to compare its effect on the maximum recommended emulsion content. Once a desired emulsion content has been entered into the required field, the analysis is performed by clicking on the button labeled "Calculate" (see Figure 16). The black 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 values, however is limited to a value of 6% emulsion.

MD Characteristics

This portion of the analysis is intended for use after the final mix design has been decided upon by the user. The percentage of emulsion is entered in the required field and the top button labeled "Update Graph" (see Figure 16) is then clicked. After which a graph of TLC vs Dry Density will be generated (red line on top graph in blue section). The two curves can then be compared against each other in order to evaluate the effects of emulsion on the density of the material.

The bottom graph in the orange section illustrates the total liquid content for the material based on varying initial moisture contents. This graph is generated by clicking on the bottom button labeled "Update Graph" (see Figure 16) after 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.

Note: This section of the analysis is intended for reference use only.



Example of Report Sheet

Curriculum Vita

Samuel Franco is a native of Clint, Texas but was born in El Paso on March 26th 1980. He attended Clint public schools all of his life and graduated from Clint High School in 1998. After graduating from The University of Texas at El Paso in December of 2006 with a Bachelors of Science in Civil Engineering he stayed at UTEP to fulfill his goal of attaining a Masters degree in the same subject area. For the past three years has called Austin his home. He currently works for Ferrovial-Agroman US Corp. as a Project Engineer in their infrastructure and highway construction division. The company is a world leader in public-private partnerships and design-build projects. Samuel served in the United States Air Force Reserves as a C-130 engine mechanic from the years of 2001 to 2007. Mr. Franco is an active member of the Austin community as well as many local organizations in the central Texas area.

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