Development of a New Mix Design Method and Specification Requirements for Asphalt Treated Bases

Research Report 0-6361-1

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Performed in cooperation with the
Texas Department of Transportation
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Center for Transportation Infrastructure Systems
The University of Texas at El Paso
El Paso, TX 79968
(915) 747-6925
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<tr><td colspan="5">16. Abstract
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To achieve the objective of this project, current TxDOT procedures such as Tex-126-E and Tex-204-F were evaluated and modified to propose new generically-named Tex-126-H and Tex-204-H specifications. A comprehensive parametric study comparing the results of the two proposed specifications with the existing specification was performed. The impact of the number of gyrations, curing temperature, binder grade, and asphalt content variation were evaluated using prepared laboratory specimens. Parameters including density, unconfined compressive strength, indirect tensile strength, and modulus using the existing and proposed specifications were compared. Based on these studies, a new method for determining the optimum asphalt content (OAC) for ATBs was developed. The recommendations were then evaluated at six actual construction projects for reasonableness.
The most practical setup for laboratory tests was achieved by using Tex-204-H specifications, which proposes preparation of 6 in. diameter and 4.5 in. high specimens using 75 gyrations of the SGC. Furthermore, it is recommended to cure specimens for 24 hrs at room temperature (77°F) before conducting the indirect tensile strength because the results from this procedure were more sensitive to asphalt content while reducing the mix design period of time. The appropriate asphalt content should satisfy a target indirect tensile strength, which is at least 85 psi, and a relative density of 97%.
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Hector Hernandez, MSCE
Jose Garibay, MSCE
Soheil Nazarian, Ph.D., PE (66495)

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by

Hector A. Hernandez, MSCE
Jose Garibay, MSCE
and
Soheil Nazarian, PhD, PE

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ABSTRACT

Asphalt treated bases (ATBs) in Texas are usually designed as per Tex-126-E, "Molding, Testing, and Evaluating Bituminous Black Base Materials," and constructed as per Item 292, "Asphalt Treatment (Plant-Mixed)," of the 2004 Standard Specification book. This specification is a hybrid of base and hot mix asphalt concrete procedures and requirements, which are sometimes incompatible. In addition, this Item uses a specific Texas Gyratory Base Compactor (TGBC) that is not readily available to all districts. Some districts use test method Tex-204-F, Part III, 'Mix Design for Large Stone Mixtures Using the Superpave Gyratory Compactor." However, this procedure was originally developed to design TxDOT Type A and Type B hot mix on 6 in. by 4.5 in. specimens. Under Item 292, the unconfined compressive strength of the mix (as per Tex-126-E) is used to assess the quality of the mix. Specimens prepared under Tex-204-F are not the appropriate size for this type of testing. As such, the quality of the mix is assessed with the indirect tensile strength. The objective of this project was to propose a new mix design procedure for asphalt treated bases that can use standard equipment such as the Superpave Gyratory Compactor (SGC) to mold the specimens for mix design.

To achieve the objective of this project, current TxDOT procedures such as Tex-126-E and Tex-204-F were evaluated and modified to propose new generically-named Tex-126-H and Tex-204-H specifications. A comprehensive parametric study comparing the results of the two proposed specifications with the existing specification was performed. The impact of the number of gyrations, curing temperature, binder grade, and asphalt content variation were evaluated using prepared laboratory specimens. Parameters including density, unconfined compressive strength, indirect tensile strength, and modulus using the existing and proposed specifications were compared. Based on these studies, a new method for determining the optimum asphalt content (OAC) for ATBs was developed. The recommendations were then evaluated at six actual construction projects for reasonableness.

The most practical setup for laboratory tests was achieved by using Tex-204-H specifications, which proposes preparation of 6 in. diameter and 4.5 in. high specimens using 75 gyrations of the SGC. Furthermore, it is recommended to cure specimens for 24 hrs at room temperature (77°F) before conducting the indirect tensile strength because the results from this procedure were more sensitive to asphalt content while reducing the mix design period of time. The appropriate asphalt content should satisfy a target indirect tensile strength, which is at least 85 psi, and a relative density of 97%. The current specifications for constructing ATB are adequate. The necessity of achieving the density should be reinforced

IMPLEMENTATION STATEMENT

The products of the proposed research include the guidelines for design and construction of asphalt treated bases. These guidelines and specification have been developed for TxDOT districts that are interested in constructing sections with asphalt treated bases. Recommendations for updating/modifying test procedures are documented. An implementation project to provide training to TxDOT personnel and assisting several districts in implementing this protocol is desirable.

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CHAPTER ONE – INTRODUCTION

One of the alternative stabilized bases that are available to TxDOT districts is the asphalt treated bases (ATB) that falls under current specification Item 292. ATB is a dense-graded HMA with a wide gradation band intended for use as a base course. ATB is perceived to cost less than typical HMA mixes because it can be produced with less expensive aggregates and lower percentages of asphalt binder. As an alternative to untreated base materials, ATB can also provide a reasonably watertight barrier that may prevent fines infiltration into the subgrade.

Based on the survey of 25 TxDOT Districts, about half a dozen districts place ATB's, with the Houston and Beaumont Districts being by far the most frequent users. However, most districts utilize Tex-204-F to achieve their mix designs primarily because the compactor specified in Tex-126-E is not available to all districts. As such, an updated mix design for ATB is needed.

To develop modern test protocols for designing ATB's, the first consideration is to determine whether the ATB should be designed and used as a high-quality base (similar to other stabilized bases) or as a low-quality hot mix (as compared to Types A and B asphalt mixes). The mix design requirements for these two alternatives are different, which in turn will impact the mix design process from compaction of specimens to their performance testing. No matter which alternative (high-quality base or low-quality hot mix) is pursued, for the ease of operation, the mix design should be compatible with current TxDOT practices to avoid the acquisition of new equipment and minimize the training time for the technicians.

Based on the discussion above, our goals in this project are to achieve the following items:

- Define criteria and procedures that are compatible with production and placement requirements of ATB,
- Develop a new simple, efficient, and consistent mix design method that uses commercially available equipment,
- Develop draft laboratory specification requirements for better quality control of asphalt treated base.

OBJECTIVES AND SCOPE

The main goal of this project was to develop a laboratory test protocol to help in selecting the optimum asphalt content and a guideline or draft specification for the construction of asphalt-treated bases. To achieve this goal, the following objectives were addressed:

1. Document different uses and establish the most appropriate uses of the ATB in Texas taking both the engineering and economical consideration into account.
2. Evaluate the reasonableness, strengths and weaknesses of current practices in terms of mix design (Tex-126-E, and Tex-204-F) and construction practices (Item 292).
3. Evaluate and establish the most appropriate performance indicators and ways of designing ATB's in the laboratory based on the intended use and identified performance indicators.
4. Evaluate the best method of compacting the specimens given the available equipment in TxDOT districts such as the Superpave Gyratory Compactor (SGC) instead of the Texas Gyratory Base Compactor (TGBC) specified in Item 292.
5. Develop the compaction criteria in terms of energy and/or number of gyrations that is more representative of this type of mix in the field.
6. Evaluate and modify the process of determining the optimum asphalt content for these mixes from the process enumerated in Tex-126-E or Tex-204-F.
7. Establish the minimum strength requirements for ATB and the best way to measure them so that the benefits of the binder added to the mix is best represented.
8. Incorporate tests (e.g. moisture susceptibility) to ensure long-term performance of the mix.
9. Evaluate and recommend the best construction practices with special attention to the reasonableness and accuracy of the current quality management process.
10. Verify the mix design and the results from laboratory testing by evaluating the field performance.
11. Monitor and record the initial performance of pavement sections with ATB.

ORGANIZATION OF REPORT

Chapter Two contains a thorough literature review of studies addressing current compaction methods; specifications used in Texas and many other states and countries; performance of Asphalt Treated Base (ATB), and cost benefit of the use of the ATBs.

Chapter Three presents the result of the district survey conducted at the beginning of this research. The districts that previously have used ATB were identified. Construction and laboratory specifications and compactors used by those districts were identified. The survey also collected the main uses of ATB, factor to motivate its use, binder grades and types of aggregates, and criteria and problems found during design or construction of ATB.

Chapter Four reflects the work done to compare current (Tex-126-E and Tex-204-F) and proposed (Tex-126-H, Tex-204-H) protocols. Materials were retrieved from different districts to prepare specimens using the Texas Gyratory Base Compactors and Superpave Gyratory Compactors; the results were analyzed and compared. The properties of each material obtained were also presented.

Chapter Five contains a detailed evaluation of the parameters that impact the performance of a mix for the proposed mix design protocols. The impact of the number of gyrations, curing temperature, binder grade, change in gradation, and asphalt content variation to the property of the mixes for the proposed procedures were measured. Chapter Five also describes the mix design protocol selected. The compactor type, specimen size, density calculation, number of gyrations determined to meet the new protocol requirements are presented. Strength parameter, curing and testing temperature, density and strength requirements and the new method for determining the optimum asphalt content are demonstrated.

Chapter Six contains the information obtained from field investigation conducted at several sites in order to evaluate the results of the proposed protocol. The laboratory results and properties of the materials acquired from every field site are also discussed.

Chapter Seven contains a complete analysis comparing the usage of ATB and Type A/B mixes. The differences in the performance parameters between the ATB and Type A/B are presented. A cost-benefit analysis for the use of ATB is presented as well.

Chapter Eight is the closure chapter containing summary, conclusions and recommendations based on the results obtained and discussion.

CHAPTER TWO – REVIEW OF LITERATURE

The performance of a pavement depends on many factors such as the properties of the materials used, structural capacity of the pavement, construction method, traffic loading, and climatic conditions. For flexible pavements, the quality of the base layer is one of the most important factors. Previous research has found that much of the distress that flexible pavements experience can be traced to problems encountered in the base (Saeed et al., 2001). The use of a cost efficient base layer, that would extend the pavement life, that would require less thickness, or that would use local materials, is highly desirable. Asphalt-treated bases (ATB) fit this category.

According to the National Asphalt Pavement Association (NAPA), (http://training.ce.washington.edu/wsdot/Modules/02_pavement_types/02-3_body.htm), ATB is a dense-graded hot mix asphalt (HMA) with a wide gradation band with a lower asphalt content that can be used as a base course. Among the features that make it different from HMA are (Wong et al., 2004):

1) HMA layer may receive direct impact from traffic and experience more serious weather conditions than those experienced by the ATB
2) Thickness of ATB is greater than the one of the HMA

One of the main problems with semi-rigid pavement structures is transverse cracking in the stabilized base and the related propagation of cracks to the surface, which diminishes the life of pavements. In these cases, the ATB may be more flexible and resistant to fatigue cracking as compared to cement stabilized bases (Dykman et al., 2003).

Besides new construction, ATB can be beneficial in rehabilitation projects as well. According to Dykman et al. (2003), the crucial factors in choosing ATB as a way of rehabilitation are:

- Quick construction time, therefore decreased delays and diminished traffic disturbance
- Low permeability to moderate pore water pressure effect (Cedergren, 1977)
- Minimal moisture sensitivity as a consequence of moisture ingress
- Quite flexible, consequently decrease the possibility of reflective cracking (Marks and Heisman, 1985.)

Research related to ATB has been limited even though ATB has been used as structural pavement layer for more than 40 years (Dykman et al., 2003). McDowell and Smith (1969) performed the first comprehensive study in the design and construction of ATB (also known as black base). An important objective of their study was to observe the effects of loading rate on the unconfined compressive strength (UCS) of ATB. McDowell and Smith used loading rates of 6, 8, 10 and 15 in./min, noticing that when testing at fast rates of loading a definite improvement in compressive strength of asphalt treated materials over untreated materials was obtained. They stated that a fast rate of loading test should become part of the analysis of asphalt mixtures.

McDowell and Smith (1969) also studied the effects of moisture absorption on strength and its relation to total percent voids. They used pressure pycnometer to obtain saturation in the least amount of time. They concluded that mixtures having less than 5.5% total voids will possibly not lose strength due to absorption of moisture. While McDowell and Smith investigation was taking place, the Texas Gyratory Compactor (TGC) was revised so that 6 in. in diameter by 8 in. in height specimens could be prepared.

Compaction Methods

An analysis of the specifications of all fifty highway agencies that are incorporated in the Federal Highway Administration (FHWA) National Highway Specifications indicates that most highway agencies either support designing the ATB using the HMA specifications (e.g., Illinois, Indiana, Washington), or utilizing emulsion rather than asphalt (e.g., Delaware, Maine, Maryland). However, several transportation agencies are upgrading their conventional compaction methods such as TGC or Marshall with SGC for routine mix design. According to Button et al. (2006) the advantages of using the SGC include the following items:

- Its ability to estimate the compatibility of mixes from density during the compaction process
- Its ability to identify weak aggregate structures that collapse very quickly to lower air voids
- Improved reproducibility of samples due to mostly mechanical control of compaction process
- Ability to simulate field compacted mixes relatively better than other compaction methods

Gyratory compaction was originally created in 1939 by the Texas Highway Department to help in the molding and design of asphalt mixtures (Harman et al., 2002). Gyratory compactors were designed to simulate the orientation of aggregate, degradation of aggregate, field compaction, and traffic degradation that occurs in HMA during production, compaction and traffic loading (Collins et al., 1997). Dykman et al. (2003) state that gyratory compaction can simulate the action of a roller in the field due to its capability to rotate the principal stresses. On the other hand, gyratory compaction can create totally different compaction characteristics. These characteristics depend on the adjustment and calibration of several parameters that affect the degree of compaction of laboratory HMA specimens (Mokwa et al., 2008).

According to Button et al. (2006), the lower angle of gyration of the SGC (1.25°) imparts significantly less mechanical energy into the specimen per gyration as compared to the TGBC (5.8° gyration angle). Different angles of gyration have different influence on the orientation of the aggregates, particularly the larger aggregates. The differences between specimens prepared using the TGBC and SGC, such as air void structure, aggregate orientation, voids in mineral aggregate (VMA) and density gradient, will not likely be consistent because these differences will depend on the shear resistance of the mixture.

Mokwa et al. (2008) used confining pressures ranging from 30 psi to 90 psi in preparing specimens with a SGC. They found that mixes with smaller particles sizes exhibited higher rates of densification as a result of higher confining pressures. The confining pressure applied to the specimen according to Tex-126-E varies from 20 psi to 60 psi for the TGBC.

Aguiar-Moya et al. (2007) indicate that the basis for the number of gyrations is that the compactive effort obtained in the laboratory should produce the same outcome on the asphalt mixtures (to increase density) as traffic loads for in-place asphalt mixes. As more weight is assigned to fatigue resistance, the optimum number of gyrations decreases, therefore producing mixes with higher binder contents. Similarly, as more significance is given to rutting, the optimal number of gyrations increases. Button et al. (2006) indicate that the design gyrations in SGC can be reduced below the initial recommendations without compromising rutting resistance of HMA mixtures.

Although the SGC can produce the same volume of air voids as the TGBC in a given mixture type, the resulting optimum asphalt contents and engineering properties of the compacted mixtures may be measurably different because of different aggregate orientations and different density gradients within the specimens (Button et al., 1994; Von Quintus et al., 1991).

According to NAPA (http://training.ce.washington.edu/wsdot/Modules/05_mix_design/05-3_body.htm) the Hveem method has been proven to produce quality HMA from which long-lasting pavements can be constructed. Hveem method has the following six main steps:

1. Aggregate selection
2. Asphalt binder selection
3. Sample preparation using the California Kneading Compactor (Figure 2.1)
4. Stability and cohesion determination using a Stabilometer and Cohesiometer (Figure 2.2)
5. Density and voids calculations, and
6. Optimum asphalt binder content selection.

The basic concept of the Marshall mix design method was originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army. The Marshall method is very popular because of its relatively simplicity, economical equipment and proven record. Similar to Hveem method, the Marshall method consists of the following six basic steps:

1. Aggregate selection
2. Asphalt binder selection
3. Sample preparation using the Marshall Hammer (Figure 2.3)
4. Stability and Flow Test using the Marshall Stability testing apparatus (Figure 2.4)
5. Density and voids calculations, and
6. Optimum asphalt binder content selection

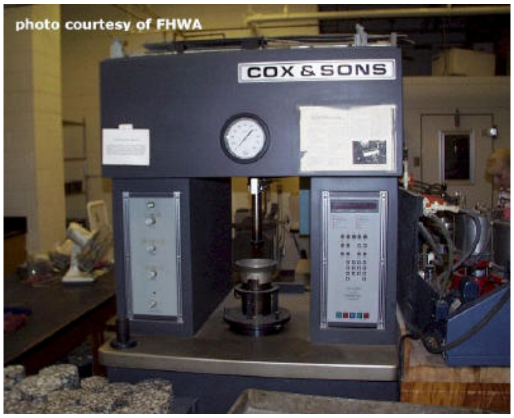
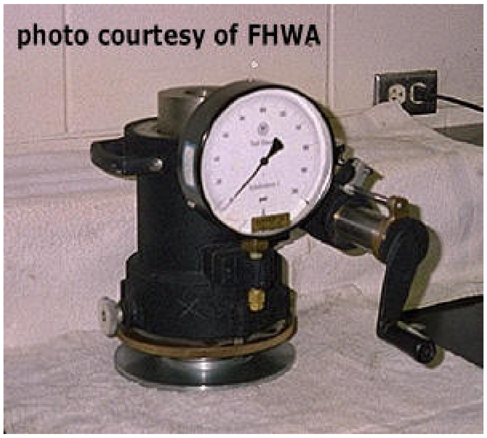


Figure 2.1 – Kneading Compactor



a) Stabilometer

b) Cohesiometer

Figure 2.2 – Hveem Machine used for Hveem Mix Design Method

According to Wong et al. (2004) conventional Marshall method is not appropriate for ATB mixture design because the maximum size of aggregate and the thickness of ATB may not be comparable to those of asphalt layer.

TxDOT Specifications

An evaluation of TxDOT construction activities pointed out that about six out of twenty-five districts place ATBs, with Houston and Beaumont Districts being the most recurrent users. In Texas, ATBs are traditionally designed and constructed as per Item 292 "Asphalt Treatment (Plant Mixed)," of the 2004 Standard Specification book. Since the compactor under Item 292 is not available to all districts, some districts have started using Tex-204-F, Part III 'Mix Design for Large Stone Mixtures Using the Superpave Gyratory Compactor."

Figure 2.3 – Marshall Hammer

Figure 2.4 – Marshall Stability

Item 292: Asphalt Treatment (Plant-Mixed)

Table 2.1 shows the mix requirements for Item 292. This specification is a hybrid of base and hot mix asphalt concrete procedures and requirements. Under Item 292, the aggregates basically have the same gradation and quality as Item 247 for untreated base, which is less rigorous than those utilized in Type A/B mixes under Item 341 or 344. Aggregate quality requirements for Item 292 are reflected in Table 2.2. Item 292 permits the use of crushed concrete in the mix, which is usually unacceptable in the Type A/B mixes. It seems that the main incentive for the utilization of Item 292, as stated by NAPA, may be to incorporate local materials (raw or recycled) in the local construction.

Under Item 292, 3% to 9% binder is suggested for the ATB; however, based on our review of several mix designs from several districts, the optimum binder content is about 4% to 5%. For Type A/B mixes the optimum binder content is typically 5% to 6%. The unconfined compressive strength of the mix (as per Tex-126-E) is used to assess the quality of the mix. Since the placement of the mixes under Item 292 and 341/344 is similar (with less strict field quality management for Item 292), it seems that ATB cost should be slightly less than Type A/B mixes.

Tex-126-E: Molding, Testing, and Evaluating Bituminous Black Base Materials

This method is used to mold an asphalt stabilized (black base) material, and to determine the relationship between asphalt content and density (a.k.a. asphalt-density curve) and similarly an unconfined compressive strength-density curve. The compacted black base specimens are made in duplicates and are tested for their unconfined compressive strengths at 140°F. The specimens are subjected to two types of deformation rates: a slow (0.15 in./min) and a fast deformation rate (10 in./min). Specimens tested at a slow deformation rate yield relatively lower strengths as compared to the fast deformation rate. From the strength-density relationship, the minimum density that would satisfy the unconfined strength requirements as per Item 292 is taken as the minimum allowable density.

Table 2.1 – Mix Requirements for ATB as per Item 292

Master Gradation Bands Tex-200-F, Part I, % Passing by Weight				
Sieve Size	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**
1-3/4"		100	100	As shown on the plans
1-1/2"	100	90-100		
1"	90-100			
3/8"	45-70			
#4	30-55	25-55		
#40	15-30	15-40	15-40	
Strength Requirements				
Slow strength, psi, min.[1]	50	40	30	30 [2]

1. At optimum asphalt content
2. Unless a higher minimum strength is shown on the plans

Table 2.2 – Aggregate Quality Requirements

Property	Test Method	Specification Requirement
Wet ball mill, % max	Tex-116-E	50
Max increase, % passing #40		20
Liquid Limit, max	Tex-104-E	40
Plasticity Index, max	Tex-106-E	10
Sand Equivalent, % min	Tex-203-F	40

Tex-204-F Part III: Mix Design for Large Stone Mixtures Using Superpave Gyratory Compactor (SGC)

This procedure was originally developed to design Type A and Type B hot mixes from a 6 in. by 4.5 in. specimen as per Table 2.3. Depending on the PG grade of the binder, the material, mixing, and compaction temperatures are according to Table 2.4. The specimens are molded to either 100 gyrations, or as shown on the plans, or as per Table 2.5.

The specimens prepared under Tex-204-F are not the appropriate sizes for unconfined compressive strength (as per Tex-126-E). As such, the strength of the mix is assessed with the indirect tensile strength at a deformation rate of 2 in./min. at a temperature of 77 ± 2°F according to Tex-226-F.

Table 2.3 – Minimum Size of Samples as per Tex 204 Part III

Nominal Maximum Size of Particles, Passing Sieve	Minimum Weight of Sample for Test, lb
Coarse Aggregate	
2"	8
1-1/2"	8
1"	6
3/4"	4
1/2"	3
3/8"	2
Fine Aggregate	
#4	1.1
#8	1.1

Table 2.4 – Material, Mixing, and Compacting Temperatures as per Tex 204 Part III

PG Grade	Asphalt Material Temperature, °F	Mixing Temperature, °F	Compaction Temperature, °F
64-22	290	290	250
64-28	300	300	275
70-22	300	300	275
70-28	325	325	300
76-16	325	325	300
76-22	325	325	300

Table 2.5 – Compaction Parameters as per Tex-241-F

Design ESALs[1] (million)	Compaction Parameters			Typical Roadway Application [2]
	$N_{initial}$	N_{des}	$N_{maximum}$	
<0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways is local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to <3	7	75	115	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of country roadways may be applicable to this level.
3 to <30	8	100	160	Applications may include many 2-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, US highways, and some rural interstates.
≥30	9	125	205	Applications include the vast majority of the US Interstate System, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on 2-lane roadways may also be applicable to this level.

[1] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-yr. period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 yr., and choose the appropriate N_{des} level

[2] Typical Roadway Applications as defined by *A Policy on Geometric Design of Highway and Streets*, AASHTO

Other DOTs Current Specifications

As mentioned before some agencies either support designing the ATBs using the HMA specifications, or utilizing emulsion rather than asphalt. Other agencies specify design processes for asphalt treated permeable bases, which are out of the scope of this project. However, few states have specifications for the ATB design.

Alaska

According to Alaska Department of Transportation (AKDOT) the ATBs are designed under Section 306 "Asphalt Treated Base Course." The selection of aggregate is mainly determined by AASHTO requirements presented on Table 2.6. In Alaska, the aggregate requirements shown on Table 2.7 are used. An important point mentioned in the Alaskan specification is the weather limitations, which states not to place the asphalt mixture on a wet or frozen surface, or when weather conditions will prevent proper handling, compacting or finishing of the mixture. It also states not to place the asphalt mixture unless the air temperature is above 40 °F, as measured in the shade and away from any heat sources.

Table 2.6 – Aggregate Mix Requirements

Property	Base Course	Test Method
L.A. Wear, %	50, max.	AASHTO T 96
Degradation Value	45, min.	ATM 313
Fracture, %	70, min.	WAQTC FOP for AASHTO TP 61
Liquid Limit	---	WAQTC FOP for AASHTO T 89
Plastic Index	6, max.	WAQTC FOP for AASHTO T 90
Sodium Sulfate Loss, %	9, max. (5 cycles)	AASHTO T 104

Table 2.7 – Aggregate Base Gradations in Alaska

Sieve	Gradation	
	C-1	D-1
1-1/2"	100	--
1"	70-100	100
3/4"	60-90	70-100
3/8"	45-75	50-80
#4	30-60	35-65
#8	22-52	20-50
#50	8-30	8-30
#200	0-6	0-6

Arkansas

Arkansas Department of Transportation's (ARDOT) design of ATB falls under Section 417 "Open Graded Asphalt Base Course." Besides the size of the aggregates requirements, there is a criterion for asphalt content for each grade type as shown on Table 2.8.

Washington

Washington Department of Transportation (WSDOT) has its own specification for ATB design. This design has two general requirements:

1. Los Angeles Wear, 500 Rev. → 30% max.
2. Degradation Factor → 15 min.

When the aggregates are mixed within the limits of Table 2.9 in the laboratory with the designated grade of asphalt, the mixture shall be capable of meeting the following test values:

- Stabilometer Value → 30 min.
- Cohesiometer Value → 50 min.
- Modified Lottman Stripping Test → 80% min.
- Sand Equivalent Value → 30 min.

Table 2.8 – Mix Requirements for ATB Design in Arkansas

Sieve Size	Type 1	Type 2	Type 3	Type 4
3"	100			
2 1/2"	95-100			
2"		100		
1-1/2"	30-70 [±7]	75-90 [±7]		
1"				100
3/4"	0-15 [±7]	50-70 [±7]	100	90-100
1/2"			90-100	
3/8"	0-2			20-55 [±5]
#4		8-20 [±5]	0-15 [±5]	0-10
#8			0-3	0-5
#100		0-5		
Asphalt Content	1.5 - 4.0	1.5 - 4.0	1.5 - 4.0	2.5 - 3.0

Note: The number in brackets is the allowable tolerance from the mix design value

Table 2.9 – Aggregate Requirements

Sieve Size	Percent Passing
2"	100
1/2"	56-100
1/4"	40-78
#10	22-57
#40	8-32
#200	2.0-9.0
Asphalt Content	2.5 - 4.5

International Review

Australia

A study in Queensland, Australia by Dykman et al. (2003) mentioned that due to the population growth, more emphasis is being placed on maintenance and rehabilitation processes. Due to the relatively thin granular base courses used, pavement rehabilitation techniques now prefer modification than stabilization. This involves using treatments that balance the materials' strength and ductility in order to produce strong but flexible granular layer so that fatigue cracking can be minimized. ATB is considered as an alternative for this purpose. Dykman et al. (2003) used Marshall and gyratory-compacted specimens. ATB mixes appeared to be fairly rut resistant and retained a high stiffness. This characteristic of ATB may improve the load distribution capacity of the pavement, leading to more effective protection of the underlying layers. Dykman et al. (2003) and Ullman and Nolan (1991) conclude that the following benefits can be obtained from ATB, if used properly:

- ATB can be placed with conventional equipment
- Fast construction
- Less cost than conventional hot-mix asphalt
- High stability
- Possibility of using marginal aggregates
- Potential for recycling

Singapore

Wong et al. (2004) stated that ATB has better strength, stability, flexibility and durability as compared to common macadam base. Using ATB in highways with high traffic volume and increasing axle loading has been beneficial with respect to pavement performance. According to Wong et al., the determination of asphalt content for best performance is through establishing a balance between friction and cohesion. They recommended a procedure that considered the variations of the maximum density, indirect tensile strength and unconfined compressive strength of a mix to obtain the optimum mix design. Through static creep and fatigue tests, they demonstrated that mixture using their design method had good resistance to permanent deformation and fatigue at the bottom of the base. They prepared their specimens using an SGC, with the number of gyrations being based on the locking point of the mix. As a conclusion from that study, Wong et al. (2004) recommended the use of compression test and indirect tensile test for ATB design since these tests are simple and convenient.

Performance of ATB

Some of the parameters that play an important role in the performance of the ATB as a system are the structural integrity of the section, the internal stability of the layer, the environmental conditions, and most importantly the quality of construction.

Structural Integrity

The structural integrity of a flexible pavement section is controlled by several parameters. In most classical structural design programs (such as FPS19), the design thickness of the layers is (directly or indirectly) estimated based on the criteria that the stresses at the interfaces of the hot mix and base, and the base and subgrade, are low enough so that the cracking and rutting will not be an issue. The traffic volume is also a major consideration. For a given traffic condition, the thicker the layers overlying the base is, the thicker the base layer and the stiffer the subgrade are, the lower the base layer stresses will be. This indicates that not only the quality of base should be considered, the stiffness of the subgrade, and the thickness of the hot mix should also be considered. The complex modulus or diameteral resilient modulus tests can be performed for this purpose.

Internal Stability

The internal stability is defined as the excessive deformation of the base under the load. This manifests as rutting primarily associated with the base layer. To address this issue, repeated load permanent deformation lab tests as advocated by the FHWA should be used in conjunction with the appropriate models that predicts the rutting of the hot-mix, base, and subgrade layers individually.

Environmental Conditions

The main environmental parameter of interest is the adverse effects of moisture and temperature on the strength and modulus of the base. Therefore, the importance of considering the impact of moisture on the performance of the material should not be neglected. Hamburg wheel tracking device, perhaps with some relaxed requirements, can be used for this purpose. Alternatively, two inter-related methods can be used to assess the impact of moisture on the performance of the base: Tube Suction Test (Tex-145) and the Free-Free Resonant Column (proposed Tex-147) or V-meter (proposed Tex-259). The Tube Suction Test (TST) qualitatively provides an estimate of the water-retention of the base material that can be correlated to the potential of damage to the base due to softening. The Free-Free Resonant Column (FFRC) or V-meter test is a quantitative nondestructive lab method that can be performed on a specimen for its modulus. In both methods, each specimen is oven-dried for two days and then allowed to soak moisture through capillary saturation. The modulus of the specimen is measured every day in conjunction with the tube suction test. The residual modulus corresponds to the modulus measured after the specimen soaked moisture for several days. Since the same specimen is used throughout for both TST and FFRC tests, the variation in moisture content with time can also be obtained by weighing the specimens daily. In that manner, the moisture retention properties of the material and its impact on modulus can be measured. Of course separate specimens should be prepared and tested for strength and modulus at optimum and after moisture conditioning to determine the retained strength and retained modulus for conventional design.

Quality of Construction

No matter how much attention is focused on the mix design, the performance of the mix is directly related to the quality of construction. The necessity to perform a thorough evaluation of the component materials, and a thorough testing regimen and an aggressive quality control/ quality assurance program is well understood by TxDOT and is incorporated in the appropriate specifications. One of the major quality management tool used is the density of the in-place mat. To successfully assess the density of the mat, two parameters are necessary: The theoretical maximum specific gravity of the mixture (Tex-227-F) and the bulk specific gravity of the cores obtained from the finished mat (or density with the NDG) as per Tex-207-F. Both of these methods have been the subject of numerous studies by the federal and state highway agencies.

There is some concern that the densities measured in those fashions may not be accurate or repeatable because of the nature of the base material (limited control on the gradation) used in ATBs. The most recent and comprehensive study of this matter has been carried out under a multi-year, multi-phase project (NCHRP 9-26) that was completed in 2007 by the AASHTO Materials Reference Laboratory (AMRL). The report from Phase 1 of the project included precision estimates of selected volumetric properties of HMA using non-absorptive aggregates (Spellberg and Savage, 2003). The report from Phase 2 discusses the results of an investigation into the cause of variations in HMA bulk specific gravity test results using non-absorptive aggregates by Spellberg and Savage (2004). The report from Phase 3 includes a robust technique developed by AMRL for analyzing proficiency sample data for the purpose of obtaining reliable single-operator and multi-laboratory estimates of precision (Holsinger et al., 2005). The report from Phase 4 includes the precision estimates of selected volumetric properties of HMA using absorptive aggregates, and the effect of aging period on the volumetric properties of the absorptive aggregates (Azari et al., 2006). The Phase 5 report includes the update precision estimates for AASHTO Standard Test Method T269, "Percent Air Voids in Compacted Dense and Open Asphalt Mixtures." Table 2.10 shows the precision estimates of this study based on the repeatability and reproducibility of the data.

Table 2.10 – Precision Estimates

Compaction Method	Specimen Diameter, in	Standard Deviation (1s)[a]	Acceptable Ranged of Two Test Results (d2s)[a]
Single Operator Precision:			
Marshall Apparatus[b]	4	0.48	1.36
California Kneading Compactor	4	0.52	1.47
Gyratory Shear Compactor	4	0.50	1.42
Superpave Gyratory Compactor	6	0.47	1.33
Multi-laboratory Precision:			
Marshall Apparatus[b]	4	1.08	3.06
California Kneading Compactor	4	1.39	3.94
Gyratory Shear Compactor	4	1.49	4.22
Superpave Gyratory Compactor	6	1.01	2.86

[a] These values represent the 1s and d2s limits described in ASTM Practice C670.
[b] The results reported for specimens compacted using T245 were determined as the average of three specimens.
Note: The precision estimates given in the table are based on the analysis of test results from three pairs of AMRL proficiency samples. The data analyzed consisted of results from 20 to 578 laboratories for each of the three pairs of samples. The analysis included three binder grades: PG 70-22, PG 64-10, and PG 64-22. Average results for air voids ranged from 2.37% to 7.95%. The details of this analysis are in NCHRP Final Report, NCHRP Project No. 9-26, Phase V.

Cost-Benefit

According to NAPA, (http://training.ce.washington.edu/wsdot/Modules/02_pavement_types/02-3_body.htm) ATB should cost less than typical HMA mixes since it can be produced with less expensive aggregates and lower percentages of asphalt binder. Among the advantages of ATB, as stated by NAPA, on a site that must export material (excess cut), an ATB pavement can save a considerable amount of excavation, hauling and disposal costs. Furthermore, on a site that must import material (excess fill), ATB can be used to build the pavement over more marginal subgrades. Another benefit from ATB is that it provides a water proof barrier to prevent fines infiltration into the subgrade and pavement structure. If water accumulates in the subgrade, the repetition of pavement loading may cause subgrade fines to migrate into the base and pavement structure. This can clog the base layer, which blocks drainage and create voids in the subgrade into which the pavement may settle. One additional valuable characteristic of ATB is the alternative to untreated base material. According to NAPA, ATB is structurally up to three times as strong as an untreated granular base. NAPA states that it may be feasible to use thinner layers for the same structural support.

In accordance with feedback from local authorities in Queensland, Australia, ATBs have performed very well over a period of ten years and in particular, its value for money when compared to other base stabilization treatments (Dykman et al., 2003). According to McDowell and Smith (1969) the economic benefit of ATB over other hot mixes is generally dependent on the use of local base materials, which do not have to be washed and sieved before batching.

CHAPTER THREE – DISTRICT SURVEY

A survey was conducted to identify the activities related to the use of Asphalt Treated Base (ATB) throughout Texas, and to identify possible sites to be incorporated in this study. The questionnaire is included in the appendix at the end of this report.

Survey responses were received from the following 18 districts: Abilene, Amarillo, Atlanta, Austin, Brownwood, Bryan, Childress, Dallas, Fort Worth, Houston, Laredo, Lufkin, Paris, Pharr, San Angelo, San Antonio, Wichita Falls, and Yoakum. The responses to the survey questions are summarized in this section.

Question 1: Have you used or are you using Asphalt Treated Base (ATB) in construction/ rehabilitation projects in your district?

Six districts (Abilene, Houston, Paris, Pharr, San Angelo, and Wichita Falls) reported they had used or were using ATB in their projects. Based on information from lettings in Site Manager, the districts that have recently used Item 292 are as per Table 3.1. The districts that have used Item 345 (similar but discontinued version of Item 292) are summarized in Table 3.2.

Table 3.1 – Districts that have used ATB in their construction based on Item 292

Year	Tons of Asphalt Treated Base Material							
	Abilene	Beaumont	Houston	Paris	San Angelo	San Antonio	Waco	Wichita Falls
2005		2,882	16,602					
2006		139,815	149,159		248	217		688
2007		106,890	87,341	49,530	1,222		318	
2008	9,273	59,872	430,632		13,430	3,123		

Table 3.2 – Districts that have used ATB in their construction based on Item 345

	Tons of Asphalt Treated Base Material					
Year	Beaumont	El Paso	Houston	San Angelo	San Antonio	Waco
2005	251,204		74,751	13,359	1,394	16,616
2006	122,402		220,980			133
2007	162,887	441	146,029	3,103		
2008	43,679		353,711			

Houston and Beaumont are the districts with the highest quantities of ATB. Personal contact with the Wichita Falls and San Antonio Districts indicated that they had changed ordered the ATBs reflected in the tables to Type A/B HMA mixes.

Question 2: If yes, how many such projects have been completed in the last 5 years or are scheduled to be constructed in the near future in your district?

The six districts that responded positively to the previous question had at least worked with one ATB project, with Houston being the leader with approximately 20 ATB projects.

Question 3: Which specification do you use for the design of ATB?

Of the districts that use ATB, 50% follow only Item 292 for the design of ATB. Abilene District uses only Tex-204-F for the design, and Pharr district applies both design procedures (Figure 3.1).

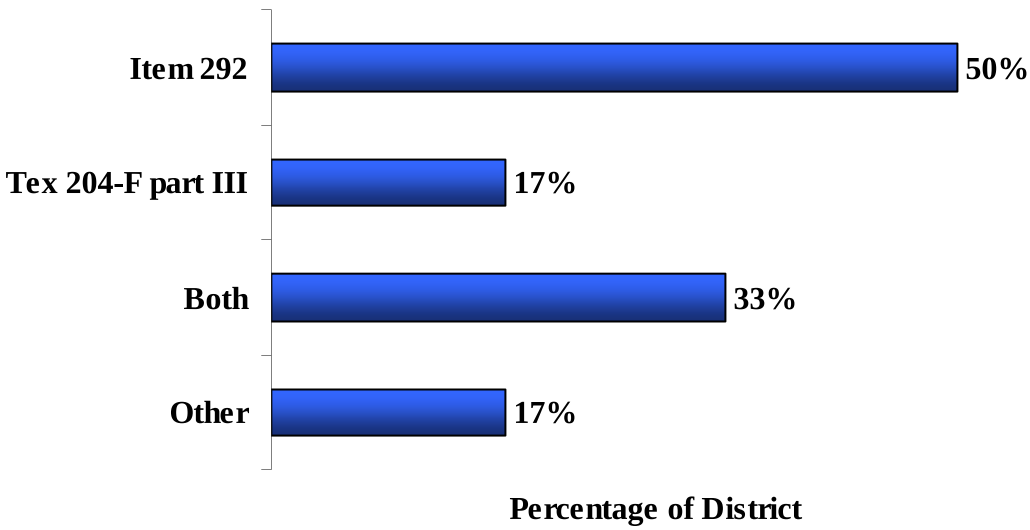


Figure 3.1 – Specifications Used for ATB Design

If you use Item 292 or Tex-204-Part III, do you waive any of the requirements?

Abilene waives Tex-242-F "Hamburg Wheel-Tracking Test", Tex-226-F "Indirect Tensile Strength", and if virgin base is used, it should meet triaxial requirements as per Tex 126-F "Molding, Testing, and Evaluating Bituminous Black Base Material". Houston and Pharr waive Tex-126-E and the strength requirements, respectively.

Question 4: Which compactor do you use for the design of ATB?

As shown in Figure 3.2, half of the districts that handle ATB use the Superpave Gyratory Compactor (SGC) for their design. Only San Angelo district uses the 6 in. gyratory press mentioned in Tex-126-E.

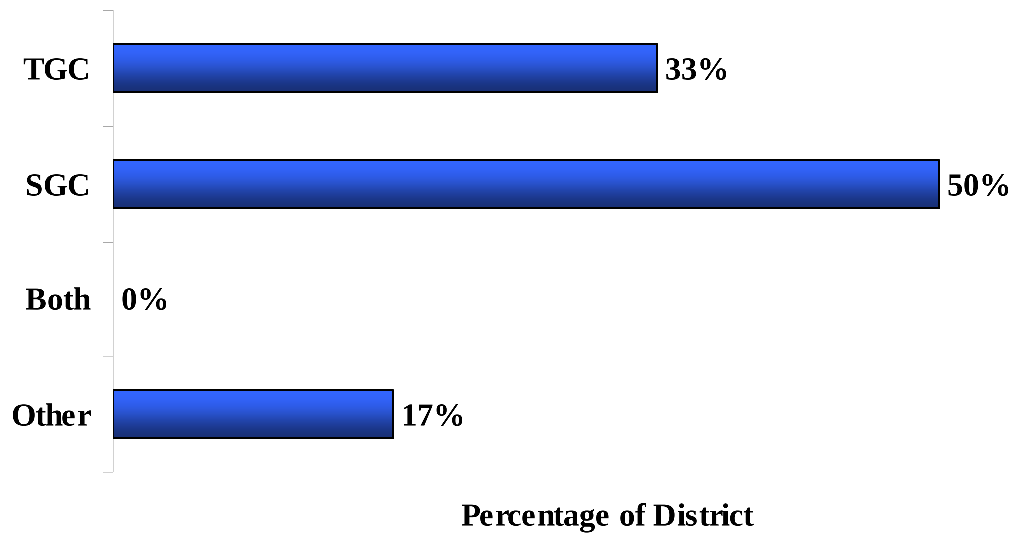


Figure 3.2 – Compactors used for ATB design

Question 5: What are the main uses of ATB in your district?

Most of the districts make use of ATB as an alternative to stabilized base and to Type A/B HMA (Figure 3.3.). Pharr District also applies ATB to reduce the pavement structure by eliminating the lime-treated subgrade at high volume intersection.

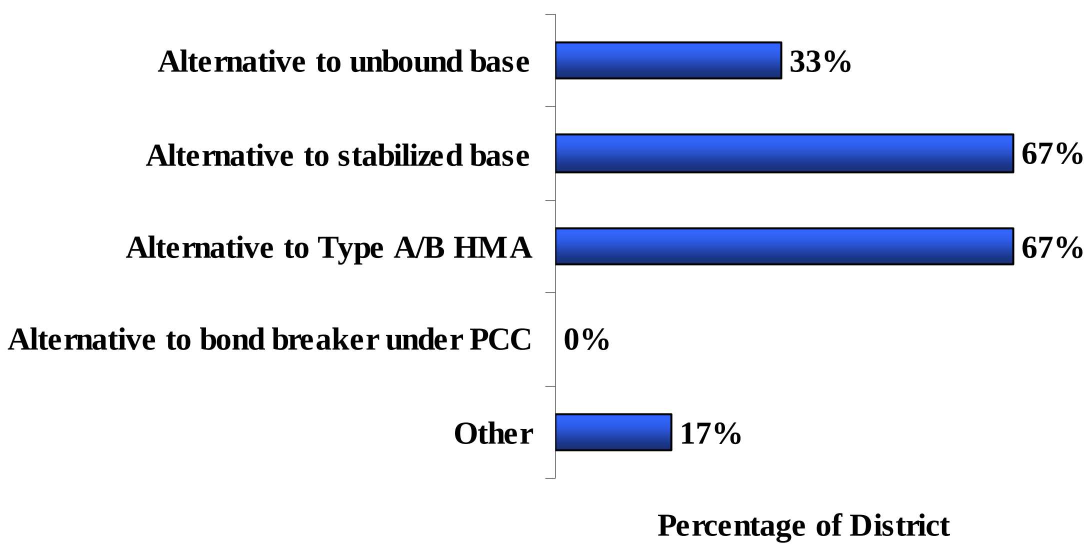


Figure 3.3 - Main Uses of ATB

Question 6: What factors motivate you to select ATB for projects in your district over other alternatives?

The respondents indicated their main reasons of using ATB are the following items: (1) more economical, (2) easier to construct, (3) short curing time, (4) stronger than stabilized bases, and (5) rut resistance (see Figure 3.4).

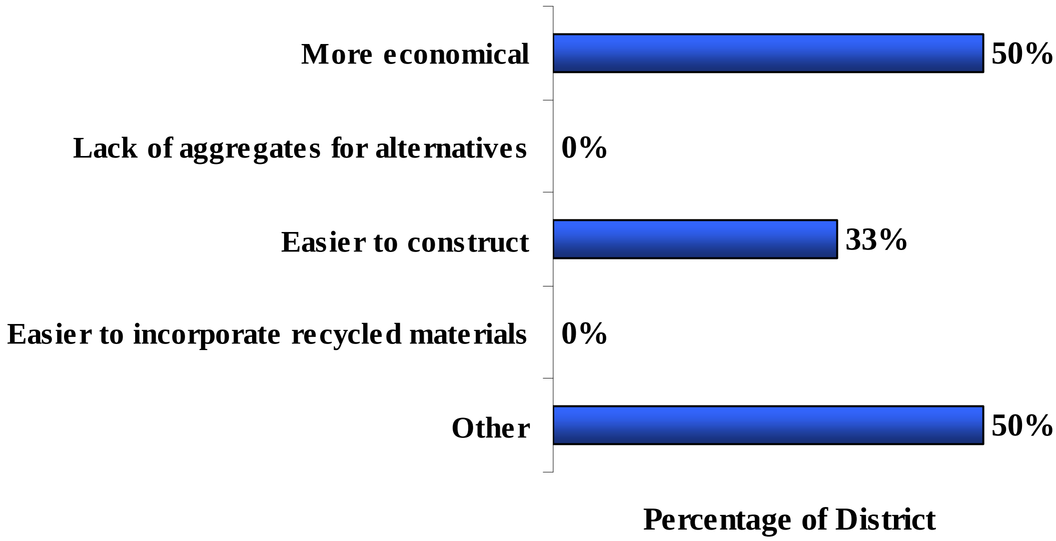


Figure 3.4 – Factors for Selection of ATB in Projects

Question 7: What typical aggregate types does your district use on ATB projects?

Based on the responses to the questionnaire, the majority of the districts use limestone as aggregate for ATB, just Paris district uses sandstone as aggregate.

Question 8: Do you add RAP or Crushed Concrete to your ATB?

50% of the districts using ATB add RAP to ATB, the other half do not add RAP or crushed concrete.

Question 9: As per Item 292, what are the major types and grades of the materials you use in your district?

Grade 1 as per Item 292 is the most used throughout the state, but Abilene and Houston Districts prefer to use Grade 2.

Question 10: What binder grades does your district use on ATB projects?

As shown in Figure 3.5, PG 64-22 is used for ATB by all districts in Texas. However, occasionally PG 70-22 and PG 76-22 are specified.

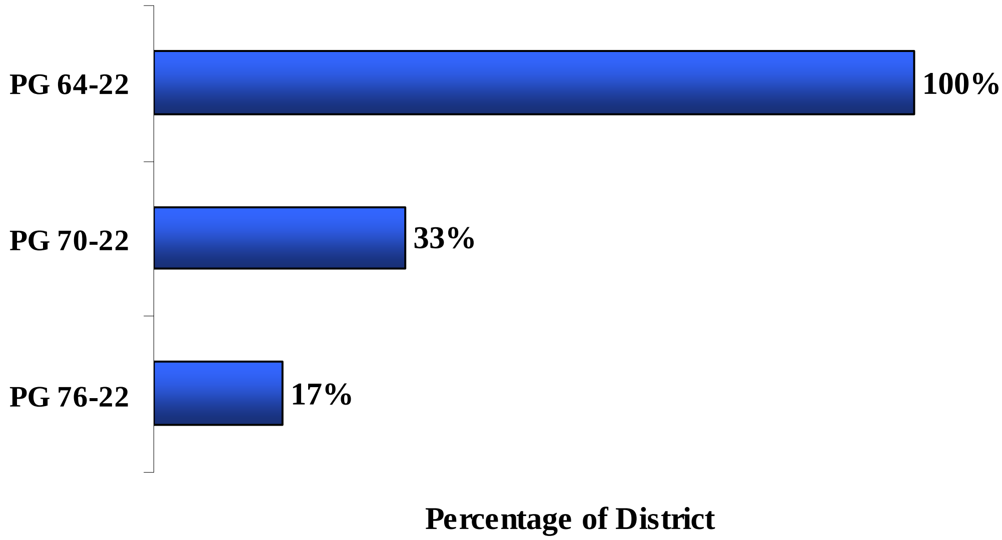


Figure 3.5 – Binder used for ATB projects

Question 11: What criteria are used to determine the amounts of binder?

Most of the districts that responded positively to the use of ATB in projects determine the amount of binder following TxDOT specifications, mainly density. San Angelo district bases the amount of binder on Area Engineer's preference and experience.

Question 12: What construction specifications do you use for your projects?

Half of the districts follow Item 292 for construction purposes. Pharr District states a lift thickness no greater than 4 in. Paris District requires 5% to 9% air voids calculated by the Theoretical Maximum Specific Gravity.

Question 13: What types of problems, if any, have you encountered with design or construction of ATB?

Based on the questionnaire, the districts were satisfied with the performance of their projects. However, segregation is mentioned as a more frequent problem presented in ATB than in HMA.

The Houston and Paris Districts staff was visited to obtain insight in their use of ATB, their current mix design processes and their concerns. The insight gained by the research staff from these two districts was quite evaluable.

Based on the questionnaire and interaction with the PMC, the candidate districts that were considered for this study are shown in Table 3.3.

Table 3.3 – Candidate Districts Considered for This Study

District	Aggregate Type
El Paso	Dolomite
Beaumont	Limestone
Paris	Sandstone
Wichita Falls	Limestone
Houston LP-610	Limestone
Houston SH-99	Limestone

CHAPTER FOUR – COMPREHENSIVE EVALUATION OF ALTERNATIVE PROTOCOLS

The current methods commonly used by the districts were described in Chapter 2. This section contain an explanation of those methods along with two alternative proposed methods that are more in line with the operational requirements of TxDOT. Table 4.1 shows a summary of the different mix design methods used in this study. The main differences between mix design methods are; how the optimum asphalt content (OAC) is calculated, the size of the specimens, curing temperature and the strength test. To set the criteria for each method and to select a preferred method, a comparative study of the properties of different mixes was carried out.

Table 4.1 – Summary of Mix Design Methods

Baseline Mix Design	Tex-126-E	Tex-204-F	Tex-126-H	Tex-204-H
Compactor	TGBC	SGC	SGC	SGC
Specimen Size, in.	6x8	6x4.5	6x8	6x4.5
OAC based on	Asphalt Density Curve	Volumetric Properties	Asphalt Density Curve	Asphalt Density Curve
Curing and Testing Temperature, °F	140	77	140	77
Strength Test	UCS	IDT	UCS	IDT

Tex-126-E

In this method, ATBs are molded using a Texas Gyratory Base Compactor (TGBC). Several specimens with different asphalt contents are prepared and tested to develop an asphalt content-density curve and an asphalt content-unconfined compressive strength (UCS) curve. The OAC is determined from the asphalt content-density curve. The ATB specimens are made in duplicates and are tested for their unconfined compressive strengths at 140°F. The specimens are subjected to two types of deformation rates: slow (0.15 in./min) and fast (10 in./min.) Specimens tested at a slow deformation rate yield relatively lower UCS's as compared to the fast deformation rate ones. From the UCS-density relationship, the minimum density that would satisfy the UCS requirements as per Item 292 is taken as the minimum allowable density.

Tex-204-F

This procedure was originally developed to design Type A and Type B hot mix at 97% density using 6 in. x 4½ in. specimens. Unless otherwise indicated, the specimens are molded to 100 gyrations using a SGC. The quality of the mix assessed with the indirect tensile strength at a deformation rate of 2 in./min and a nominal temperature of 77^{o}F.

Proposed Tex-126-H

The proposed Tex-126-H (hybrid) is similar to Tex-126-E, with one exception. While Tex-126-E uses a Texas Gyratory Base Compactor (TGBC), Tex-126-H advocates the use of a Superpave Gyratory Compactor (SGC) to produce the specimens. The other aspects of the protocol are the same as Tex-126-E, where the asphalt-density curve and UCS-density curve are developed to assess the OAC and field density.

Proposed Tex-204-H

The second proposed method, Tex-204-H (Hybrid), is similar to Tex-204-F. The only difference is the way the OAC is selected. For Tex-204-H, the requirements for volumetric properties such as VFA are waived because it is not possible to modify the gradation to achieve the required volumetric properties. In Tex-204-H protocol, attention is paid to asphalt-density curve, similar to Tex-126-H, and the IDT strength.

Comparison of Properties from Different Approaches

Mix designs were performed on six materials (see Table 3.3) following the four approaches indicated above to highlight their similarities and differences. To demonstrate different approaches a local material from El Paso is used as an example. Results from the other materials are then summarized.

Index Properties

The gradation curves of all materials as received are shown in Figure 4.1. To prepare the materials for mix design, the entire stock of the material was sieved first to develop a global gradation curve. This gradation curve was used throughout the study. The acceptable range as per Item 292 Grade 1 is also shown in the figure. Houston SH-99 and Paris materials do not fulfill those requirements.

Figure 4.2 illustrates the material constituents for all materials. Houston SH-99 and Paris have higher concentrations of gravel (72% and 70%, respectively) while El Paso material has the lowest gravel concentration (55%). Coarse sand contents range from 9% to 28%, with Houston SH-99 containing the lowest concentration and Wichita Falls the highest. The fine sand contents of all materials are similar, ranging from 12% to 18%. El Paso and Wichita Falls have the highest fines concentrations (5%) while other materials contain 1% to 2% fines.

Material classifications as per Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System, as well as the Atterberg limits are summarized in Table 4.2. Under the USCS, all materials classified as GP (poorly-graded gravel) except for Houston LP-610 and Wichita Falls which were categorized as GW (well-graded gravel). All materials are classified as A-1-a under the AASHTO system. All materials seem to be non-plastic except Wichita Falls.

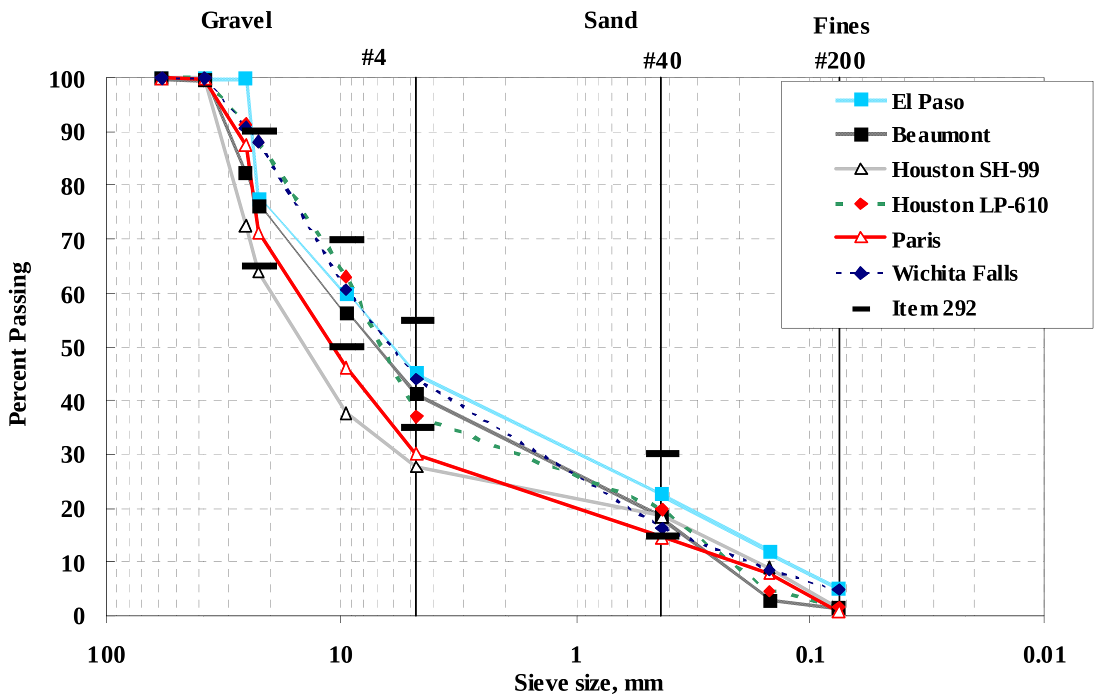


Figure 4.1 – Gradation Curves from Different Materials Used in This Study

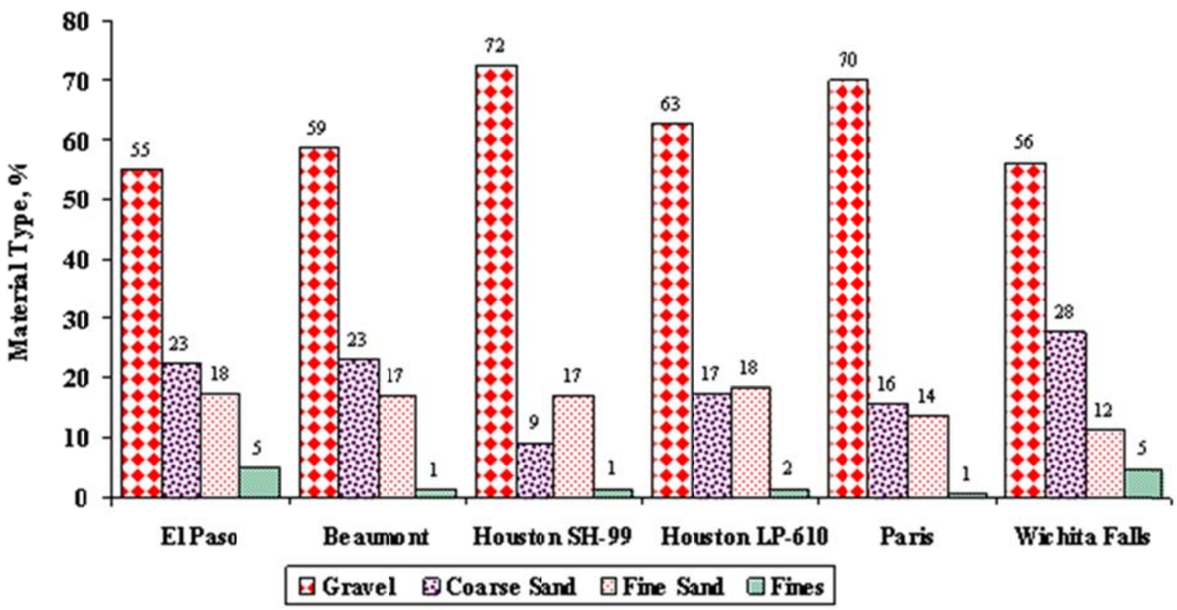


Figure 4.2 – Material Constituents for the Sites Being Studied

Table 4.2 – Soil Classification and Plasticity Index for Bases under Study

Material Source	Classification		Atterberg Limits	
	USCS	AASHTO	Liquid Limit	Plasticity Index
Beaumont	GP	A-1-a	Non Plastic	
El Paso	GP	A-1-a	Non Plastic	
Houston SH-99	GP	A-1-a	Non Plastic	
Houston LP-610	GW	A-1-a	Non Plastic	
Paris	GP	A-1-a	Non Plastic	
Wichita Falls	GW	A-1-a	21	4

The sand equivalency, wet ball mill and aggregates hardness for each material are presented in Table 4.3. The materials used in this study met the sand equivalency requirement except for Wichita Falls materials. All material met the wet ball mill requirements; Beaumont material was near to reach the maximum acceptable value. All materials exhibit Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) 30% or less.

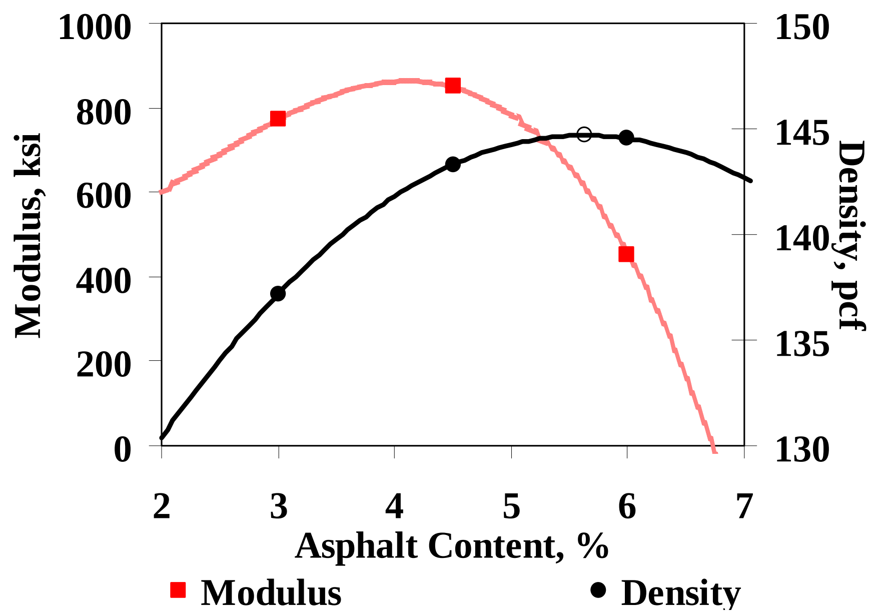
Table 4.3 – Sand Equivalency and Wet Ball Mill and Hardness for Bases under Study

Material Source	Sand Equivalency, %	Wet Ball Mill, %	Aggregate Crushing Value	Aggregate Impact Value
Beaumont	79	49	15	8
El Paso	53	28	16	9
Houston SH-99	82	11	25	16
Houston LP-610	80	16	29	18
Paris	52	12	24	14
Wichita Falls	26	31	30	20
Item 292 Limits	Min 40	Max 50	-	-

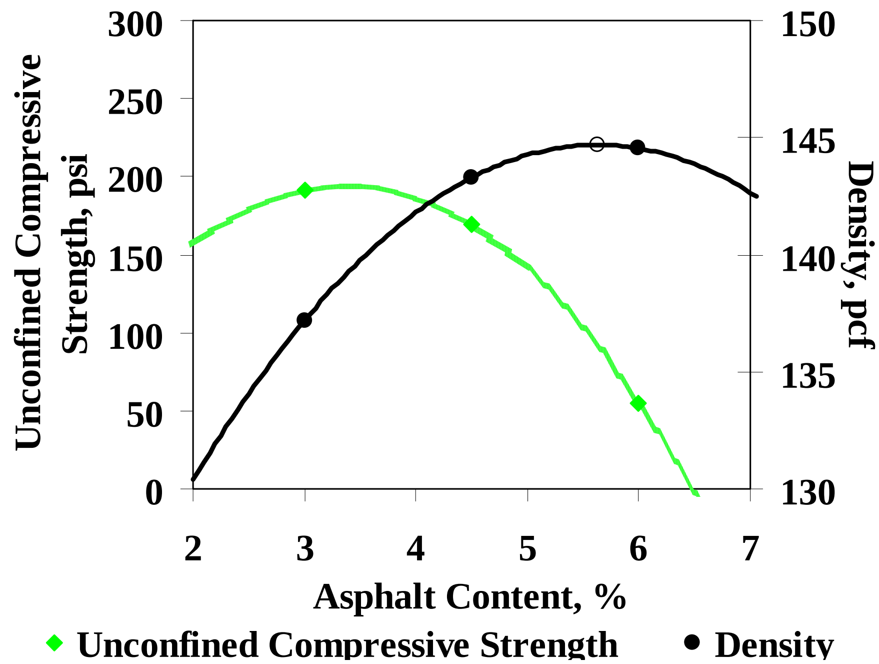
Results from Tex-126-E Protocol

Three sets of 6 in. by 8 in. specimens, prepared with the TGBC at nominal asphalt contents of 3%, 4.5% and 6%, were tested to determine the optimum asphalt content (OAC). Based on the consultation with the PMC, the maximum AC content was limited to 6% for economic reasons. A minimum AC content of 3% was selected for constructability.

The compacted specimens were weighed and their heights and diameters were measured to calculate their densities. After the specimens equilibrated to 140°F oven for 48 hrs, they were tested as quickly as possible to avoid any heat loss for their moduli using the Free-Free Resonant Column (FFRC) tests, followed by UCS. Figure 4.3 shows the results from the El Paso material.



a) Asphalt Content–Density/Modulus Curves



b) Asphalt Content-Density/Strength Curves

Figure 4.3 – Density/Modulus /Strength vs. Asphalt Content as per Tex-126-E

The OAC as per Tex-126-E is about 5.6%. The strength requirements for ATB as per Item 292 (50 psi) are met by all three AC contents used in this study.

Two alternative OACs can also be extracted from Figure 4.3, one being at the AC content when the modulus is maximum and the other when the UCS is maximum. The OACs based on modulus and UCS are 4.1% and 3.0%, respectively.

Table 4.4 shows the density, UCS and modulus for each sets of specimens tested at 3%, 4.5% and 6% asphalt contents for all materials. The variations in density with AC content are 6% or less for all materials. Almost all materials exhibited their lowest strengths and moduli at an AC content of 6%.

Table 4.4 – Density, Strength and Modulus at Different Asphalt Contents as per Tex-126-E

Parameter	Asphalt Content	Material Site					
		Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density, pcf	3%	137	138	138	140	129	128
	4.5%	140	143	144	141	129	132
	6%	141	145	141	140	130	136
UCS, psi	3%	161	192	206	76	214	227
	4.5%	126	169	95	160	141	354
	6%	119	55	69	85	128	236
Modulus, ksi	3%	609	526	865	560	650	653
	4.5%	558	871	690	1145	687	1443
	6%	271	436	481	623	426	962

The OAC values based on density are compared to those from modulus and strength in Table 4.5 for all materials. The OACs based on density are typically higher as compared to those based on modulus and strength. The OACs based on densities fall between 4.3% and 6%.

Table 4.5 – Optimum Asphalt Content based on Density, Strength or Modulus as per Tex-126-E

Optimum Asphalt Content Based on Maximum	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density	6.0	5.6	4.7	4.5	4.3	6.0
UCS	6.0	3.0	3.0	4.5	3.0	4.5
Modulus	3.4	4.1	3.0	4.7	4.0	4.8

Results from Tex-126-H Protocol

The same process followed to obtain the OACs using Tex-126-H specifications. A Pine SGC at 100 gyrations was used to prepare the specimens. Figure 4.4 shows the asphalt content-density, asphalt content-modulus and asphalt content-strength curves for El Paso material as per Tex-126-H. The specimens with 3% binder exhibited the highest modulus and strength. OAC from maximum density was obtained at 3.9% asphalt content. The density curve in Figure 4.4 is so flat that any asphalt content between 3% and 5% can easily be practically considered as the OAC from that curve given the uncertainties in obtaining the density of each specimen.

The density, UCS and modulus of every sets of specimens tested are summarized in Table 4.6. The variations in the densities with AC contents were less than 5% for all materials. The densities are generally the greatest at binder contents of 4.5%. Ignoring Wichita Falls materials,

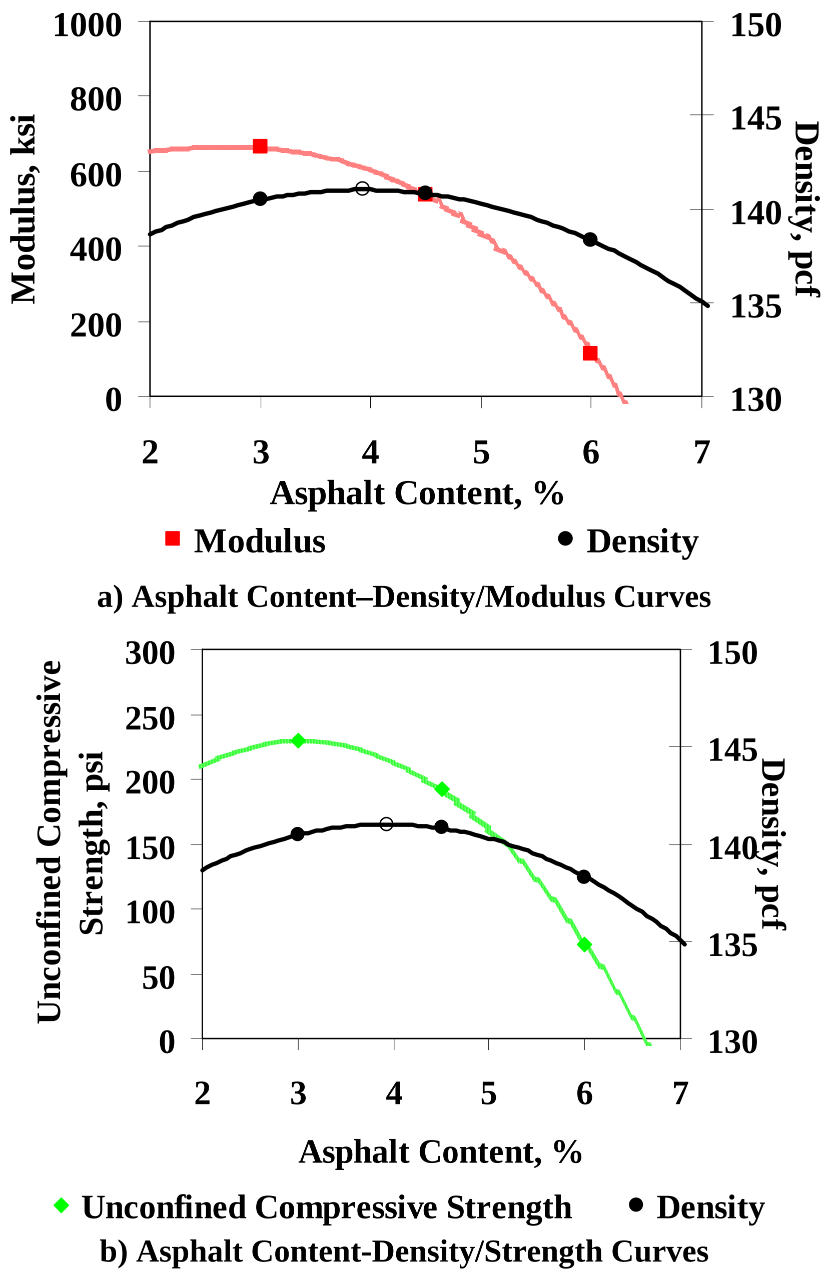


Figure 4.4 – Density/Modulus /Strength vs. Asphalt Content as per Tex-126-H

the maximum strengths and moduli were obtained at 3% AC contents. Once again, all specimens marginally or significantly passed the strength requirement of 50 psi for ATB as per

Item 292. As reflected in Table 4.7, once again the highest OACs are generally obtained based on density.

Table 4.6 – Density Strength and Modulus at Different Asphalt Contents as per Tex-126-H

Parameter	Asphalt Content	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density, pcf	3%	134	141	135	136	127	126
	4.5%	136	141	136	137	126	130
	6%	135	138	134	134	130	133
UCS, psi	3%	159	230	84	167	N/A*	207
	4.5%	180	192	55	121	163	410
	6%	105	73	48	70	125	301
Modulus, ksi	3%	948	664	1022	1422	N/A*	498
	4.5%	960	537	915	909	527	1423
	6%	462	115	369	534	600	1524

*** unable to retrieve an intact specimen after compaction and as such could not be tested.**

Table 4.7 – Optimum Asphalt Contents Based on Density, Strength or Modulus as per Tex-126-H

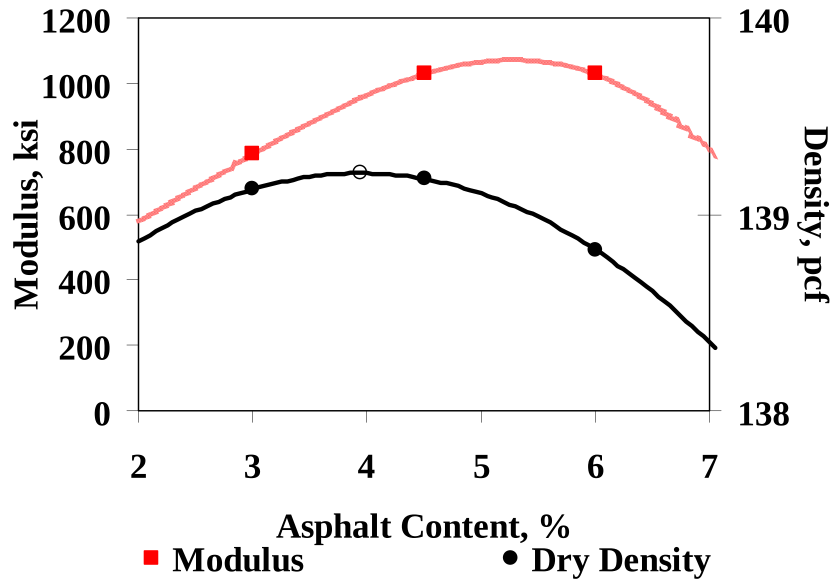
Optimum Asphalt Content Based on Maximum	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density	4.7	3.9	4.2	4.1	6.0	6.0
UCS	4.1	3.0	3.0	4.2	5.0	4.7
Modulus	3.6	3.0	3.4	3.0	5.5	5.4

Results from Tex-204-H Protocol

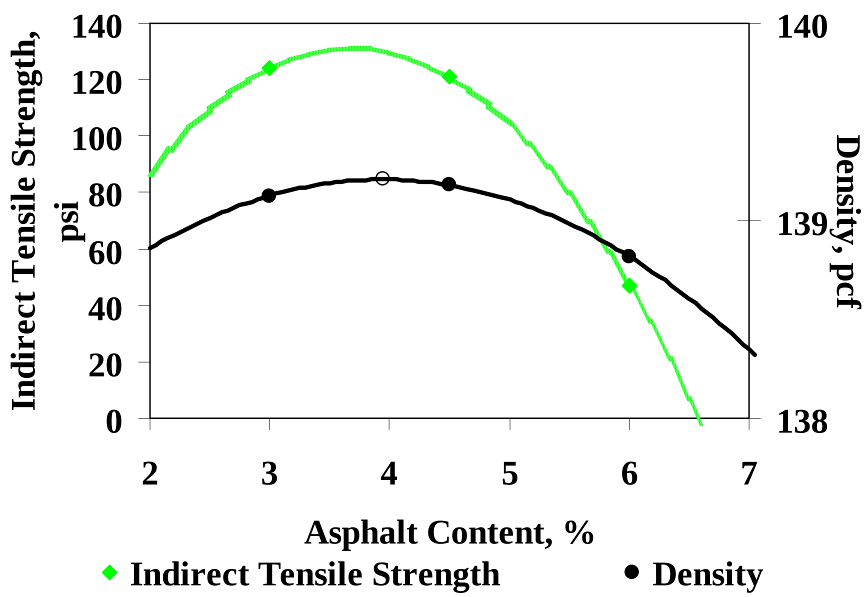
The asphalt-density curve for Tex-204-H for El Paso material is illustrated in Figure 4.5. The OAC based on density is 3.9% at a density of about 139 pcf. It is hard to judge the accuracy of this OAC, since the density changes by less than 1% with the change in the asphalt content. The OACs based on modulus and IDT occur at about 5.3% and 3.7%, respectively. Since the specimens' heights were only 4.5 in., a v-meter was used to measure the moduli.

The values obtained for density, indirect tensile strength (IDT) and modulus for all materials prepared under Tex-204-H are summarized in Table 4.8. For all materials the variations in the density with asphalt content are rather small. Most materials exhibit their highest IDT strengths between asphalt contents of 3 and 4.5%. Wichita Falls specimens with 3% asphalt content could not be tested because they broke after compaction but before testing. Moduli of the specimens tested do not vary much for most materials similar to the densities.

The OAC values based on maximum density, indirect tensile strength and modulus as per Tex-204-H for all materials are summarized in Table 4.9. As opposed to the Tex-126-E and Tex-126-H results, no clear pattern is apparent for this protocol.



a) Asphalt Content-Density/Modulus Curves



b) Asphalt Content-Density/Strength Curves

Figure 4.5 – Density/Modulus /Strength vs. Asphalt Content as per Tex-204-H

Table 4.8 – Density, Strength and Modulus at Different Asphalt Contents as per Tex-204-H

Parameter	Asphalt Content	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density, pcf	3%	133	139	138	137	126	129
	4.5%	136	139	138	138	130	132
	6%	135	139	135	134	130	134
IDT Strength, psi	3%	133	124	118	168	91	N/A
	4.5%	163	121	105	150	116	110
	6%	100	47	72	104	101	170
Modulus, ksi	3%	855	783	1007	538	617	N/A
	4.5%	862	1030	1103	553	622	790
	6%	880	1030	1055	547	688	857

Table 4.9 – Optimum Asphalt Contents Based on Density, Strength or Modulus as per Tex-204-H

Optimum Asphalt Content Based on Maximum	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Density	6.0	3.9	3.8	3.8	6.0	6.0
IDT Strength	4.2	3.7	4.7	3.0	6.0	6.0
Modulus	6.0	5.3	4.8	4.8	6.0	5.6

Tex-204-F

Figure 4.6 shows the gradation curves for the six materials and the acceptable limits for Item 344 type SP-A. El Paso, Houston LP-610 and Wichita Falls materials fit well between the gradation requirements for Item 344 Grade SP-A. Beaumont, Houston SH-99 and Paris materials do not fulfill those requirements, since they are coarser than Item 344 Grade SP-A requirements.

To check whether any of the mixes would meet the volumetric properties as per Tex-204-F Part III, the theoretical maximum specific gravity (G_{mm}) in accordance to Tex-227-F were determined. Triplicate samples were tested to assess the repeatability of this test method. The G_{mm} values are reported in Table 4.10. All samples tested exhibited coefficients of variation (COV's) of 1.2% or less. The bulk specific gravities (G_{mb}) for all specimens are presented in Table 4.11. The maximum G_{mb} values are obtained at binder contents between 4.5 and 6%.

Figure 4.7 shows an example of the volumetric properties for the El Paso material. For El Paso material, the OAC is 5.2% (see Figure 4.7a). Voids in mineral aggregates (VMA) for 5.2% asphalt content is about 15%, which is greater than a minimum value of 13 specified in Item 344 for SP-A mixes. The voids filled with asphalt (VFA) of about 74% at a binder content of 5.2% fell between the 65-75% as required by Item 344.

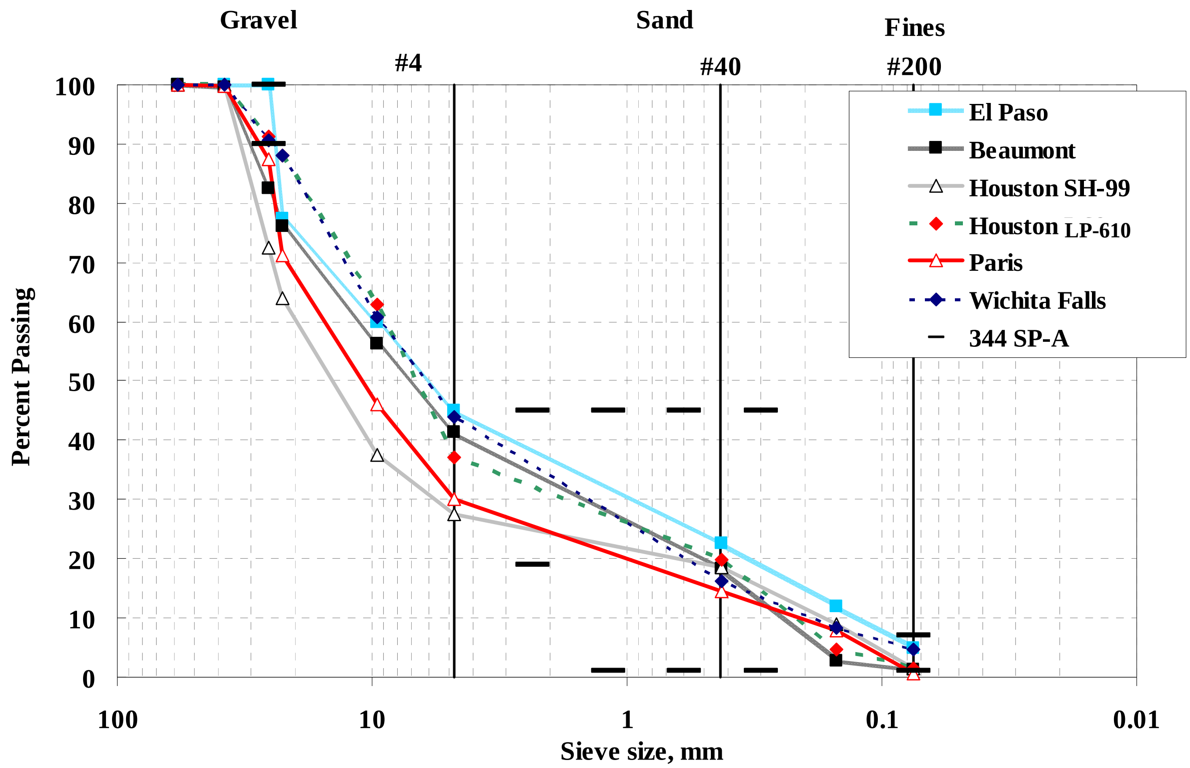


Figure 4.6 – Gradation Curves from Different Materials Compared to Item 344 Grade SP-A

Table 4.10 – Maximum Theoretical Specific Gravities for Tex-204-H Specimens

Asphalt Content	Parameter	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
3.0%	**Average**	2.45	2.62	2.51	2.47	2.37	2.55
	COV*	0.3%	0.5%	0.3%	0.4%	0.1%	0.4%
4.5%	**Average**	2.45	2.55	2.43	2.41	2.46	2.48
	COV	0.2%	0.7%	0.1%	0.1%	0.3%	0.1%
6.0%	**Average**	2.39	2.46	2.38	2.36	2.4	2.41
	COV	0.3%	1.2%	0.4%	0.2%	0.7%	1.1%

*** COV = coefficient of variation**

Table 4.11 – Bulk Specific Gravities for Tex-204-H Specimens

Asphalt Content	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
3.0%	2.33	2.41	2.39	2.30	2.25	2.28
4.5%	2.37	2.47	2.40	2.35	2.30	2.37
6.0%	2.41	2.40	2.41	2.30	2.34	2.41

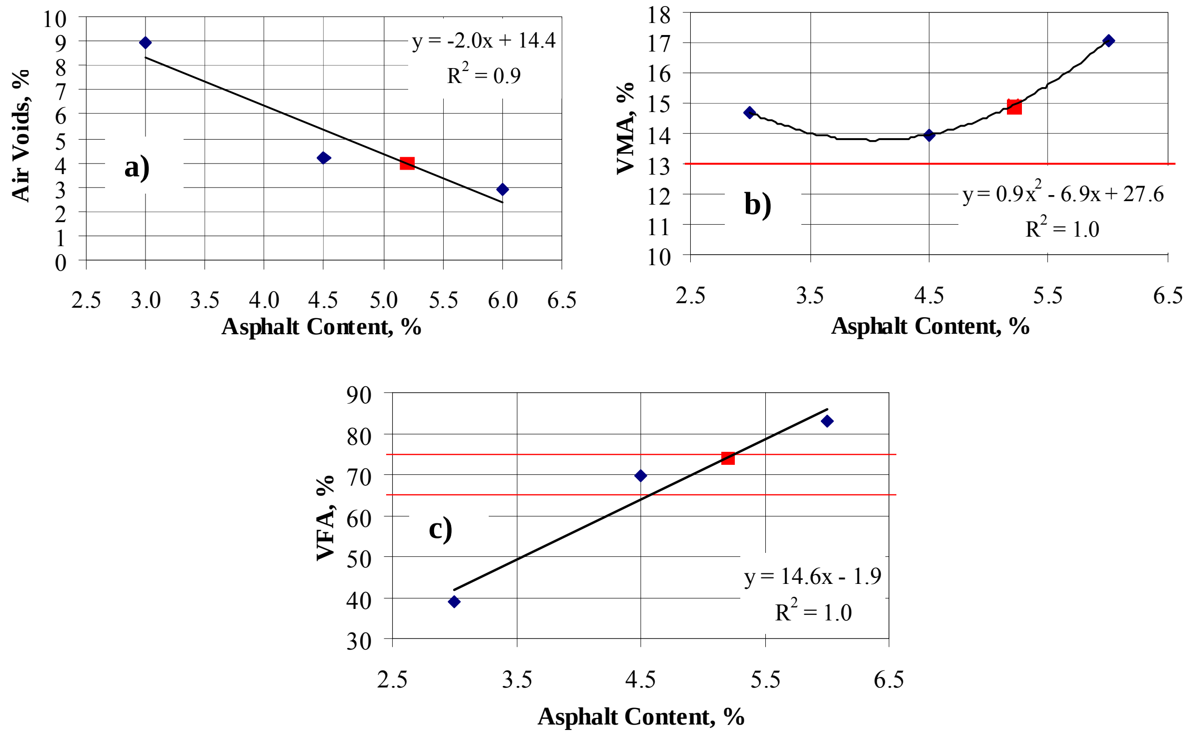


Figure 4.7 – Volumetric Properties for El Paso Material

Table 4.12 shows the volumetric properties for all specimens as well as the requirements to be met for Item 344 SP-A mixes. The majority of the materials successfully passed the requirements, except for the VFA value for Houston SH-99, Paris and Wichita Falls.

Table 4.12 – Volumetric Properties for Tex-204-H Specimens

Values at 4% Air Voids	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls	Item 344 Grade SP-A
AC, %	4.0	5.2	3.7	4.3	5.8	5.0	-
VMA, %	14.3	14.9	20.2	14.8	18.4	15.6	Min. 13
VFA, %	71.5	74.1	80.4	72.4	78	75.5	65-75

Moisture Susceptibility

One of the test methods used to quantify moisture susceptibility is Tex-242-F, Hamburg Wheel-Tracking Test (HWTD). This test was performed on specimens prepared at OAC's determined from Tex-126-H and Tex-204-H protocols based on density. The results for the HWTD are summarized in Table 4.13. Even though the minimum number of passes required for a PG 64-22 binder is 10,000, tests were continued up to 20,000 passes. All specimens tested exhibited acceptable rut depths at 10,000 cycles. All specimens were in the acceptable limits at 15,000 and

20,000 cycles except for Houston LP-610 which reached the 0.5 in. deformation at 15,300 cycles.

Table 4.13– Hamburg Wheel Test Results for All Materials

Test Method	Number of Passes	Rut Depth, mm					
		Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
Tex-126-H	OAC, %	**4.7**	**3.9**	**4.2**	**4.1**	**6.0**	**6.0**
	10,000	2.3	4.3	5.3	5.6	2.2	2.7
	15,000	2.4	5.4	7.9	11.4	2.3	2.9
	20,000	3.1	6.0	11.8	12.1	2.8	3.4
Tex-204-H	OAC, %	**6.0**	**3.9**	**3.8**	**3.8**	**6.0**	**6.0**
	10,000	0.2	3.8	2.6	6.7	2.2	2.7
	15,000	0.4	4.4	2.7	12.2	2.3	2.9
	20,000	0.6	4.7	3.6	*	2.8	3.4

*** Exceeded 12.5 mm rut after 15,300 passes.**

The second test used to quantify moisture susceptibility is Tex-144-E, the Tube Suction Test (TST). This test was also performed using the OAC based on density obtained in this study for Tex-126-H and Tex-204-H. Table 4.14 shows the strengths and moduli before and after the TST tests. The difference between before and after the TST is the asphalt curing time. Most of the materials demonstrated an increase in strength and moduli after the TST. Houston LP-610 was the only material that did not gain strength and modulus with curing.

Analysis of Results

The OAC values based on the three different criteria (density, strength and modulus) used for all materials are summarized in Figure 4.8. The variations in OACs based on density for Tex-126-H, Tex-204-H and Tex-204-F are compared with the OACs based on density for Tex-126-E in Figure 4.9. The alternative mix design methods typically yield lower OACs as compared to Tex-126-E. Paris material was the only one that had higher OAC's with Tex-126-H and Tex-204-H than OAC for Tex-126-E. This inconsistency is caused by the flatness of the density curves as discussed above. As such, the OAC obtained based on density should be reviewed to decide on the OAC of a mix.

Similarly, the OACs based on strength are compared in Figure 4.10. Most of the OACs are greater than those of the Tex-126-E OAC values based on strength. Two of the materials, Beaumont and Houston LP-610 were outliers; they had a lower OAC than Tex-126-E in all three different mix design methods.

Table 4.14 – Impact of Tube Suction Tests on UCS and Seismic Modulus

Test Method	Parameter	Beaumont		El Paso		Houston SH-99		Houston LP-610		Paris		Wichita Falls	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Tex-126-H	OAC, %	4.7		3.9		4.2		4.1		6.0		6.0	
	UCS, psi	405	509	485	653	373	498	583	539	337	446	392	426
	Modulus, ksi	2411	2242	1739	3028	1279	2738	2494	2462	1720	2482	1940	2054
Tex-204-H	OAC, %	6.0		3.9		3.8		3.8		6.0		6.0	
	IDTS, psi	92	107	123	190	63	148	203	153	98	134	143	212
	Modulus, ksi	833	938	825	901	835	1123	910	834	872	919	882	834

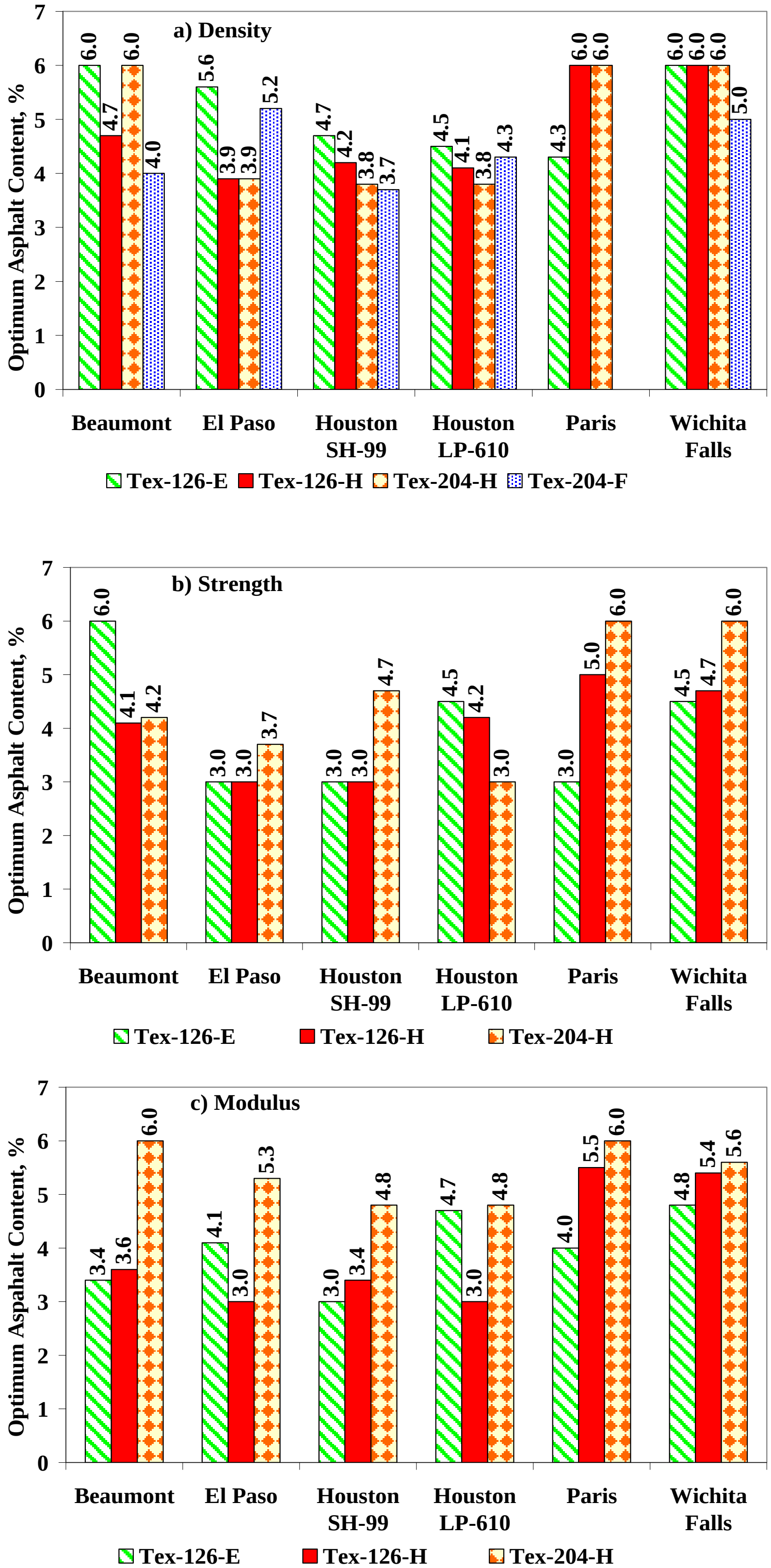


Figure 4.8 – Comparison of Optimum Asphalt Contents Based on Density, Strength, and Modulus

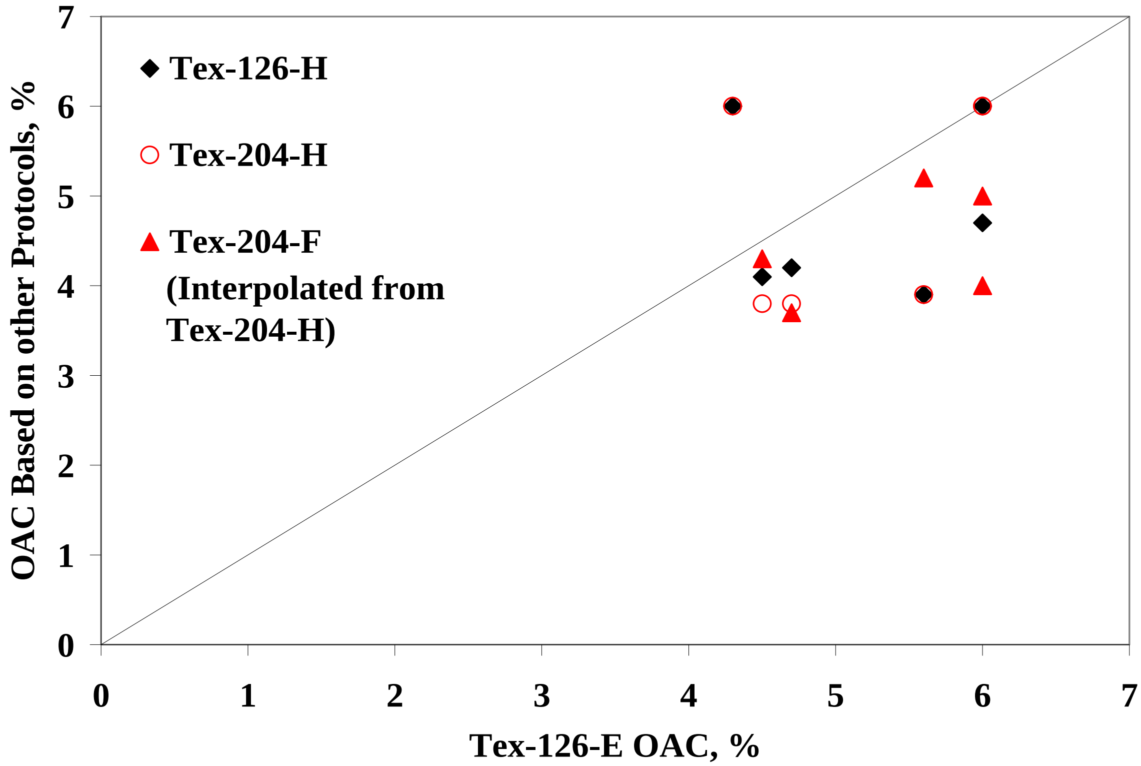


Figure 4.9 – Comparison of Tex-126-E OAC with other Methods Based on Density

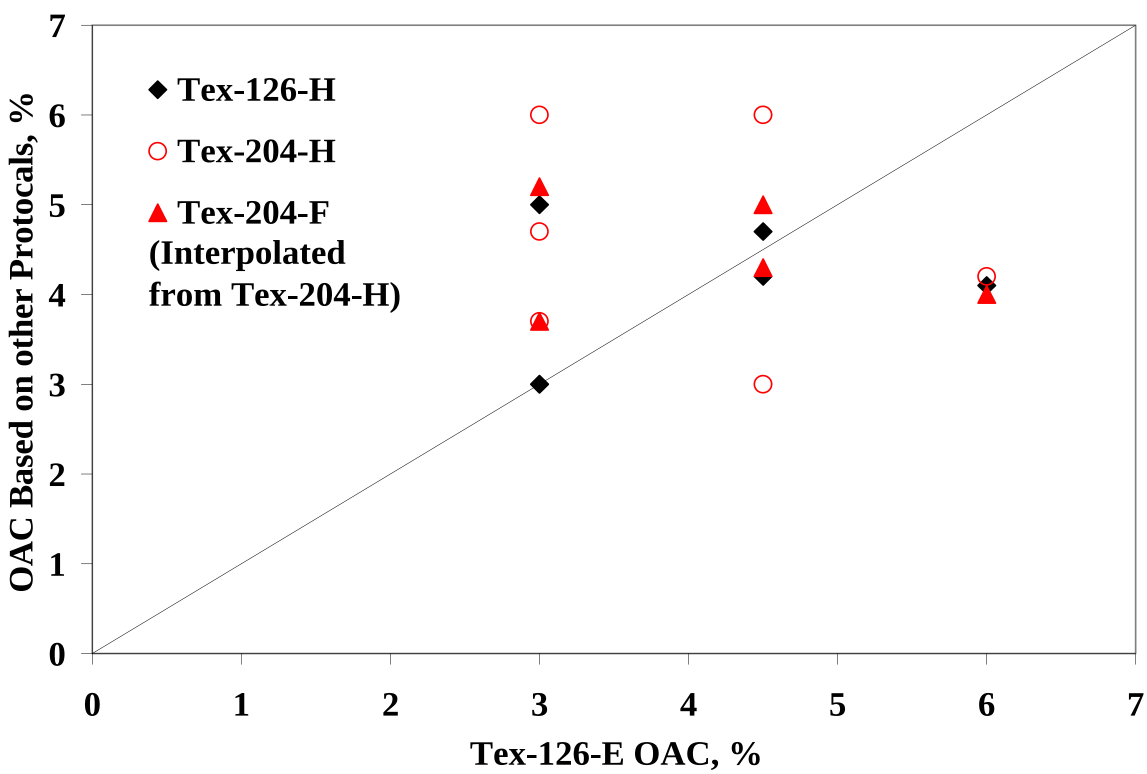


Figure 4. 10 – Comparison of Tex-126-E OAC with other Methods Based on Strength

The OAC values based on modulus are compared in Figure 4.11. Similarly most of the OACs are greater than that of Tex-126-E values based on modulus with three outliers Houston LP-610 (Tex-126-H and Tex-204-F) and El Paso (Tex-126-H).

Figure 4.12 shows the maximum densities for all materials and for all mix design methods. For a given mix, the densities are fairly close. The maximum density for most materials is generally reached when Tex-126-E is followed. The lowest densities are typically obtained from Tex-204-F by waiving some of the volumetric requirements.

For comparison purposes, UCS and IDT specimens were prepared based on OAC of each method and were tested for strength and modulus. The variations in the UCS values are shown in Figure 4.13. All materials reached the 50 psi strength requirement for ATB as per Item 292. The strongest material is Wichita Falls while the weakest material analyzed was Houston SH-99. The specimens prepared with the Superpave Gyratory Compactor usually exhibit similar or higher UCS as compared to those prepared with the Texas Gyratory Compactor.

The IDT strengths obtained from 6 x 4.5 in. specimens are shown in Figure 4.14. No obvious pattern could be found in the data. Given the uncertainty in the IDT tests, in most cases the strengths are similar from different methods of estimating OAC.

Finally, the moduli obtained from these specimens are shown in Figures 4.15 and 4.16. The variations in moduli are in line with the corresponding strengths shown in Figures 4.13 and 4.14.

So far this study shows that mix design using the SGC is feasible. Based on the results reported in this chapter, the adoption of either Tex-126-H or Tex-204-H will be discussed.

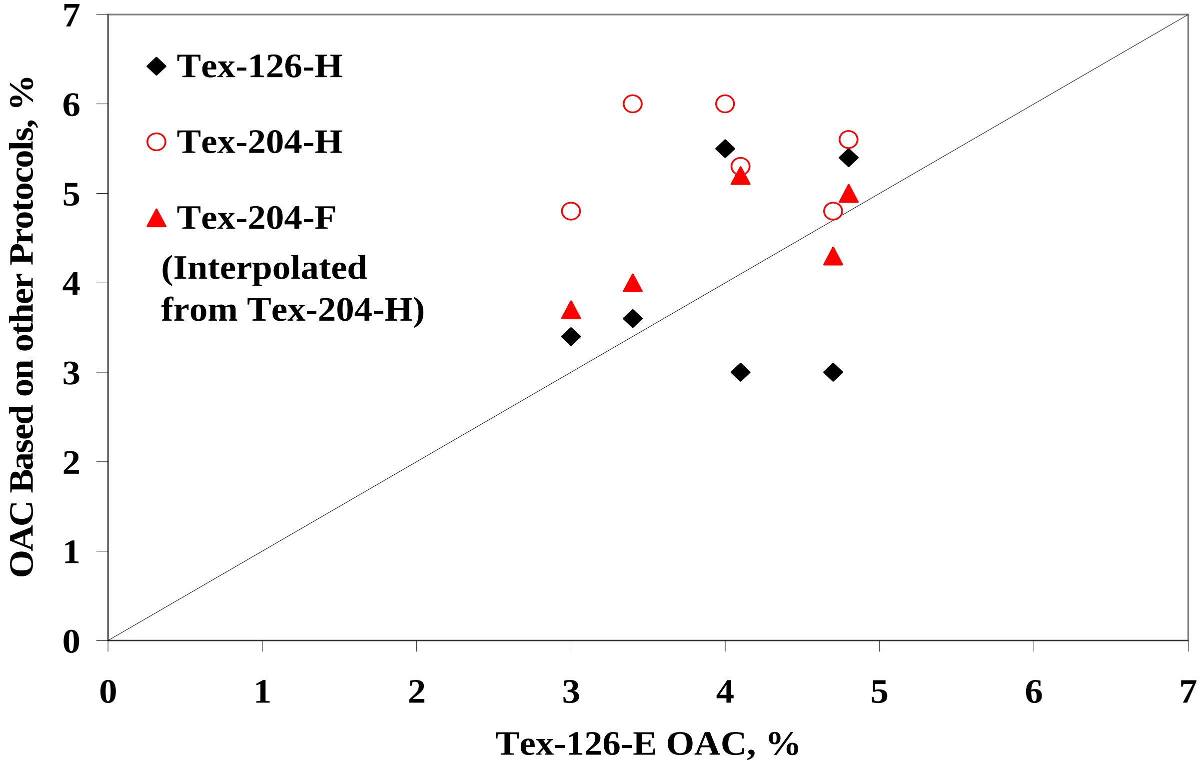


Figure 4.11 – Comparison of Tex-126-E OAC with other Methods Based on Modulus

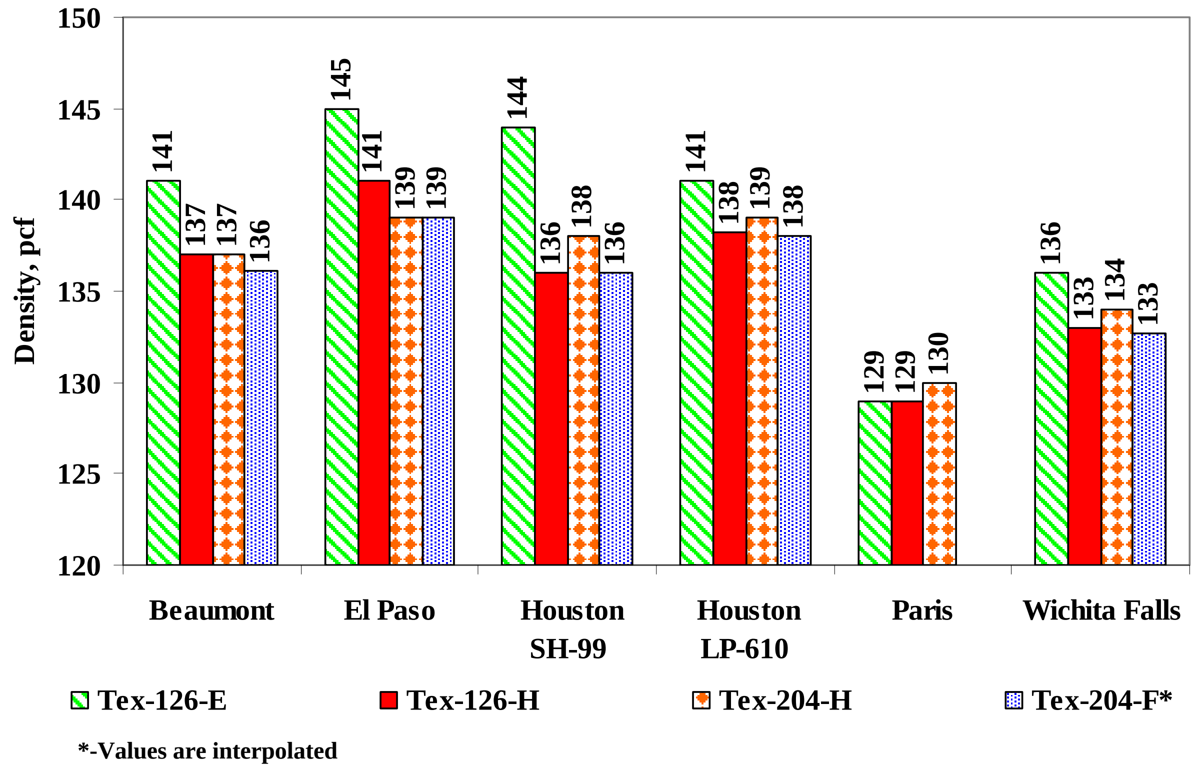


Figure 4.12 – Densities at OACs for Each Test Method

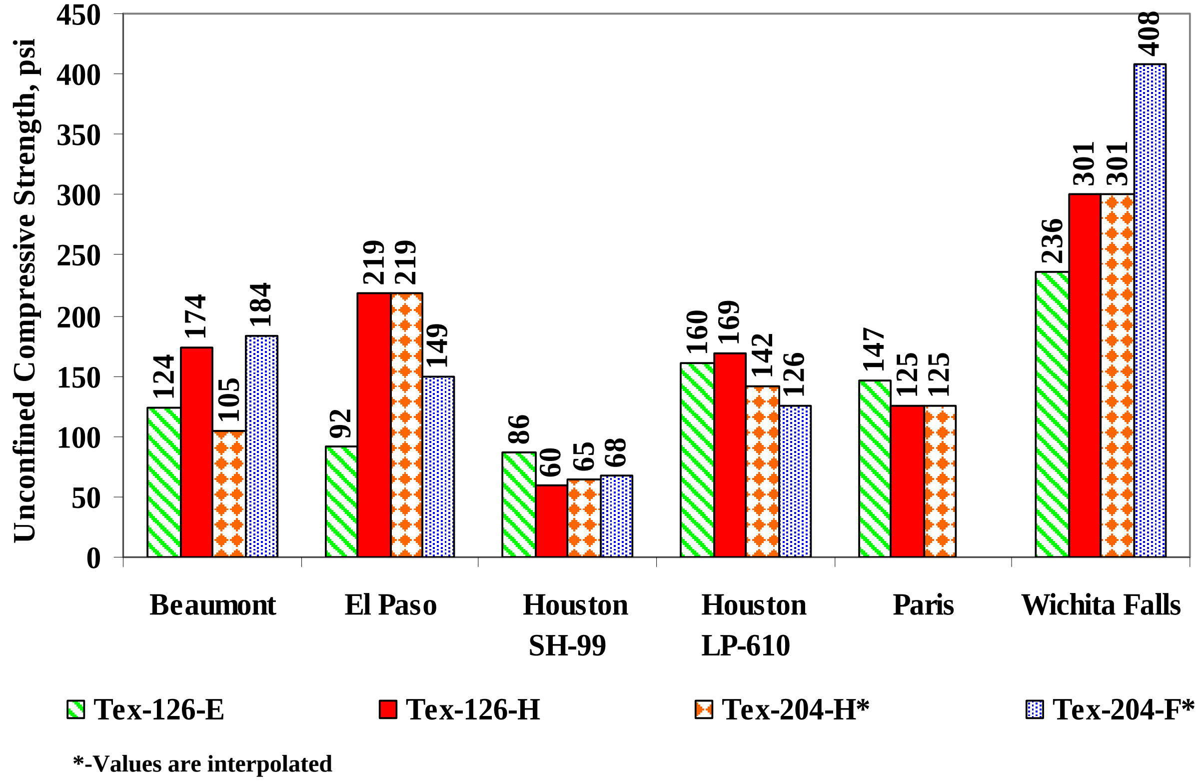


Figure 4.13 – UCS at OACs for Each Test Method

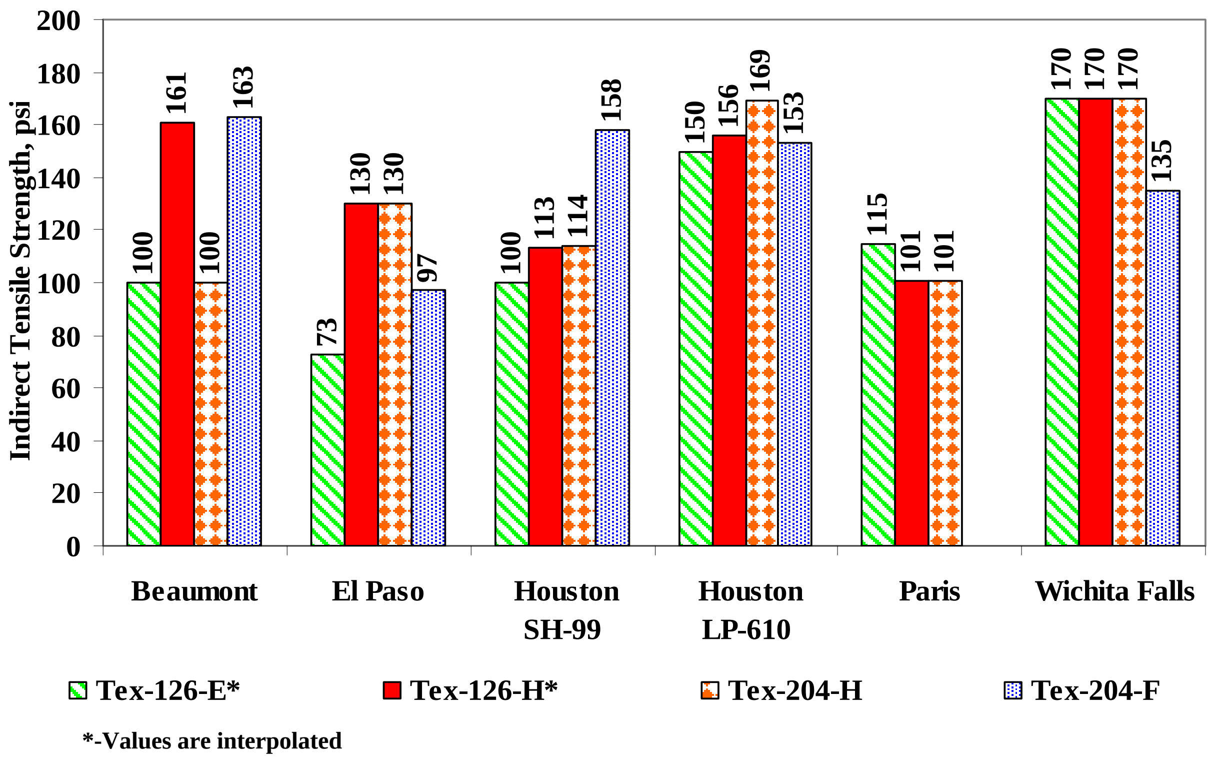
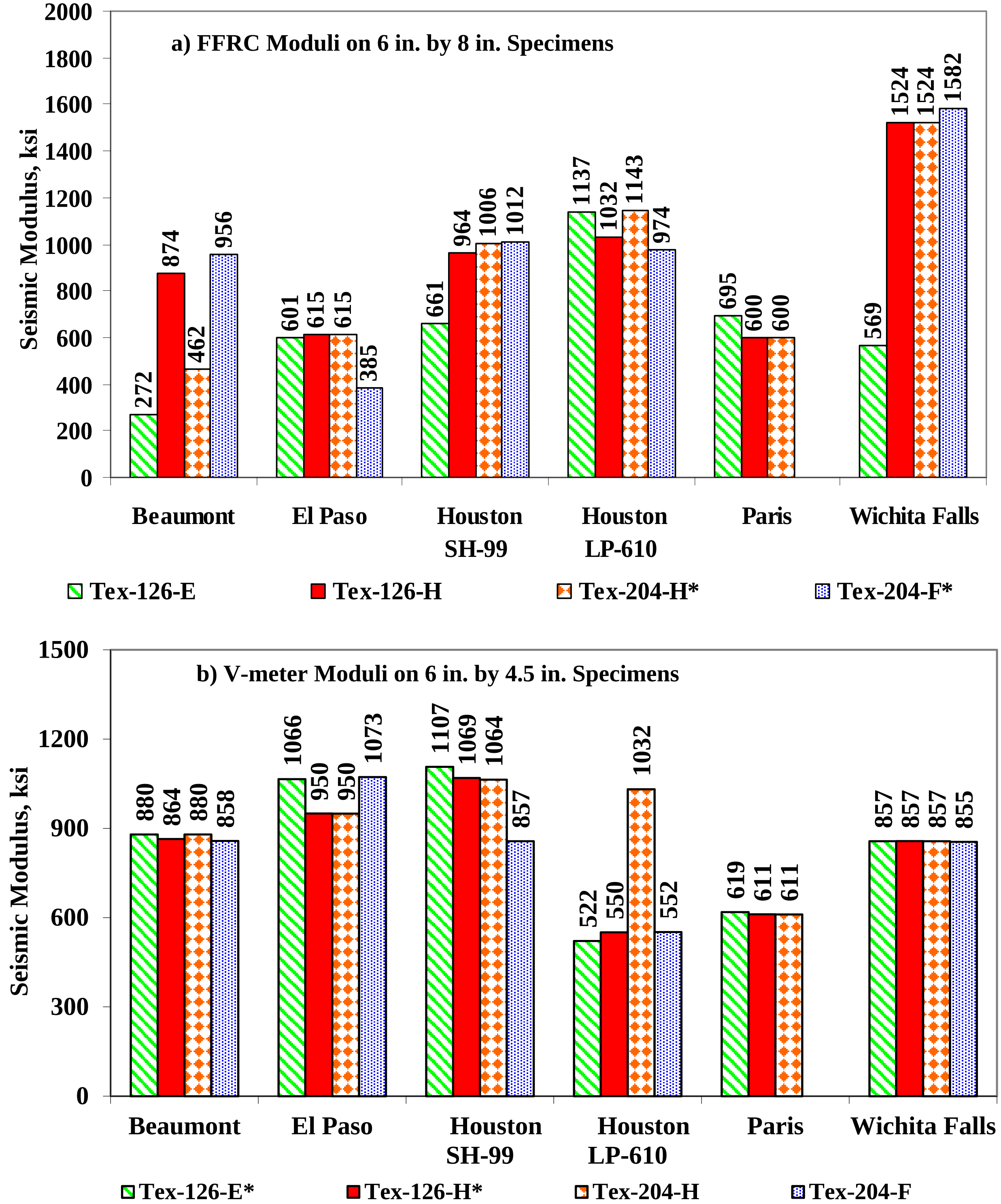


Figure 4.14 – IDT at OACs for Each Test Method



***-Values are interpolated**

Figure 4.15 – Seismic Modulus at OACs for Each Test Method

CHAPTER FIVE – EVALUATION OF PARAMETERS THAT IMPACT PERFORMANCE

The two alternative protocols deemed reasonable for fulfilling the objectives of this project are Tex-126-H and Tex-204-H. Many specimens were mixed, compacted and tested at different numbers of gyrations using the SGC to evaluate the impact of the number of gyrations on the properties of the mixes. Specimens were also mixed and compacted using the TGBC to try to match the densities of the SGC specimens with the ones compacted using the TGBC. The impact of curing temperature is also presented in this chapter in which specimens were tested after 24 or 48 hrs of curing at 77°F or 140°F. Two different grades of asphalt (PG 76-22 and PG 64-22) were evaluated as well. The differences in optimum asphalt content, density, strength and modulus between the two binders are presented. The impact of the change in gradation on optimum asphalt content, density, strength and modulus is summarized at the end of this chapter.

Impact of Number of Gyrations

Tex-126-H Protocol

The impact of the number of gyrations on the (OAC based on density as per Tex-126-H is summarized in Figure 5.1. The OAC's for Paris and Wichita Falls seem to be 6% (upper limit imposed on the asphalt content) or greater. Except for the Houston SH-99, the increase in the number of gyrations results in typically less than 1% change in the OAC. The OAC's as per Tex-126-E are also included in Figure 5.1. The OAC's for 60 to 80 gyrations are typically closer to the OAC's from Tex-126-E.

The densities at corresponding OAC's for different numbers of gyrations of SGC are compared with those from Tex-126-E in Figure 5.2. The impact of the number of gyrations of SGC on density is rather small (typically less than 3 pcf). In almost all cases, the highest densities are associated with Tex-126-E protocol.

The impact of the number of gyrations on UCS and modulus are shown in Figures 5.3 and 5.4, respectively. All specimens were prepared to the nominal dimensions of 6 in. by 8 in. The UCS and modulus values mostly follow the same pattern. As the UCS increases the modulus also increases. A clear pattern is not evident in these results primarily because of the complex interaction of the compaction energy with the asphalt content. The other complicating factor is the so-called locking point during the compaction with the SGC. Locking point is defined as the

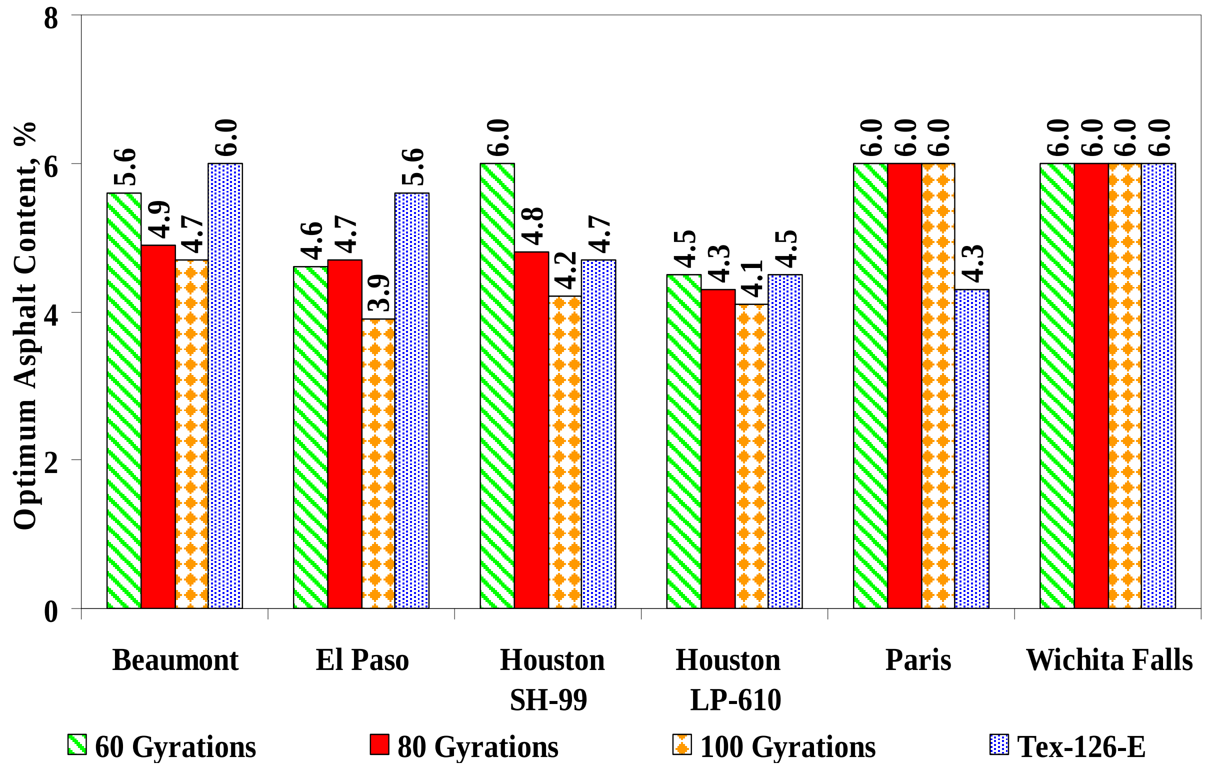


Figure 5.1– Impact of Number of Gyrations on OAC Based on Density for Tex-126 –H Protocol

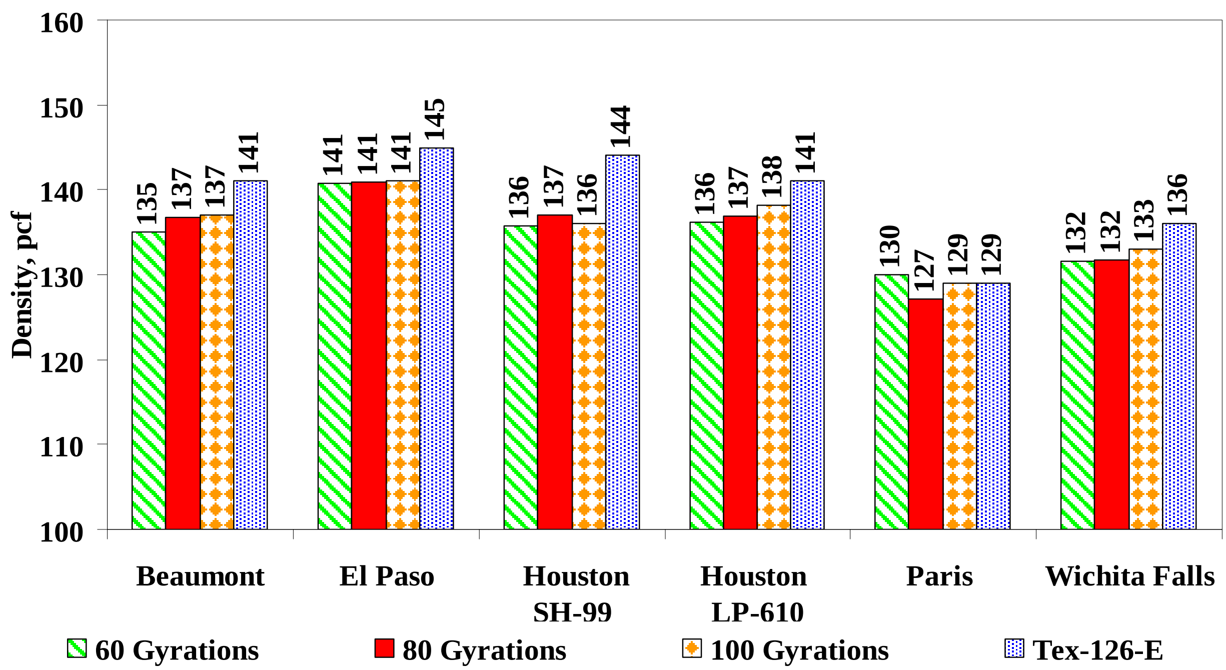


Figure 5.2 – Impact of Number of Gyrations on Density for Tex-126-H Protocol

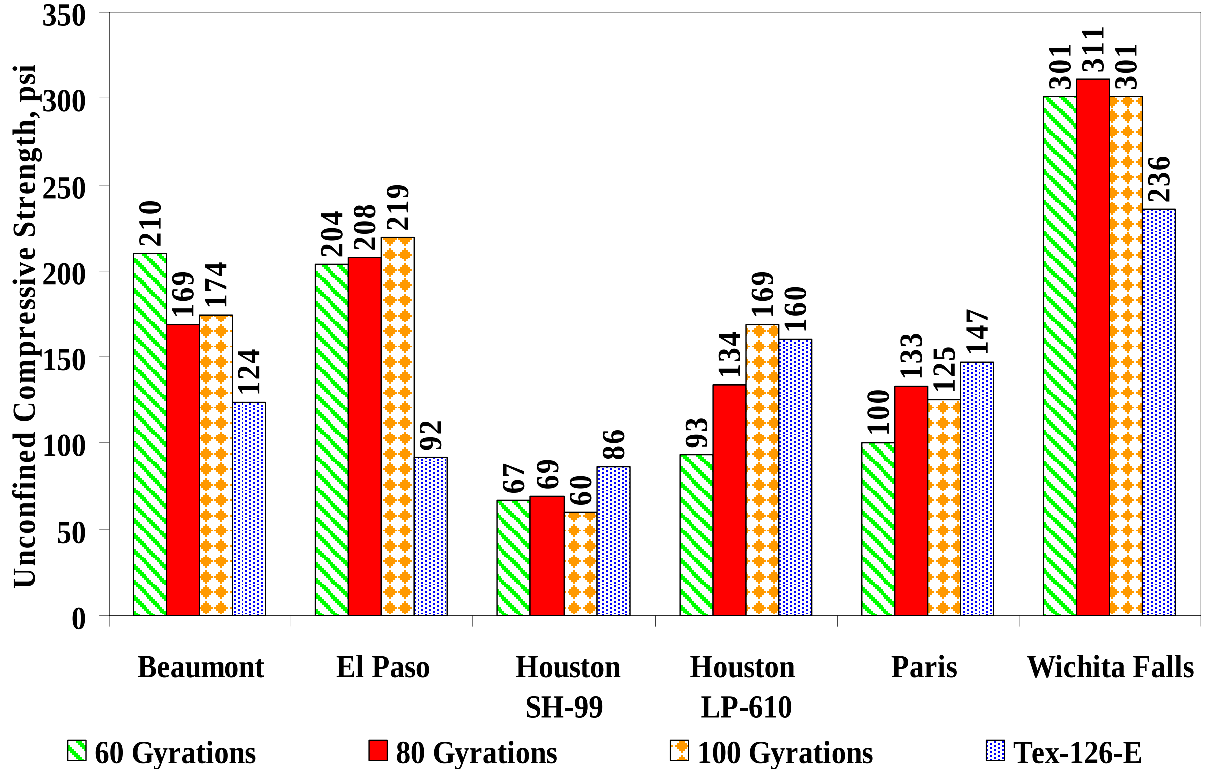


Figure 5.3 – Impact of Number of Gyrations on UCS for Tex-126-H Protocol

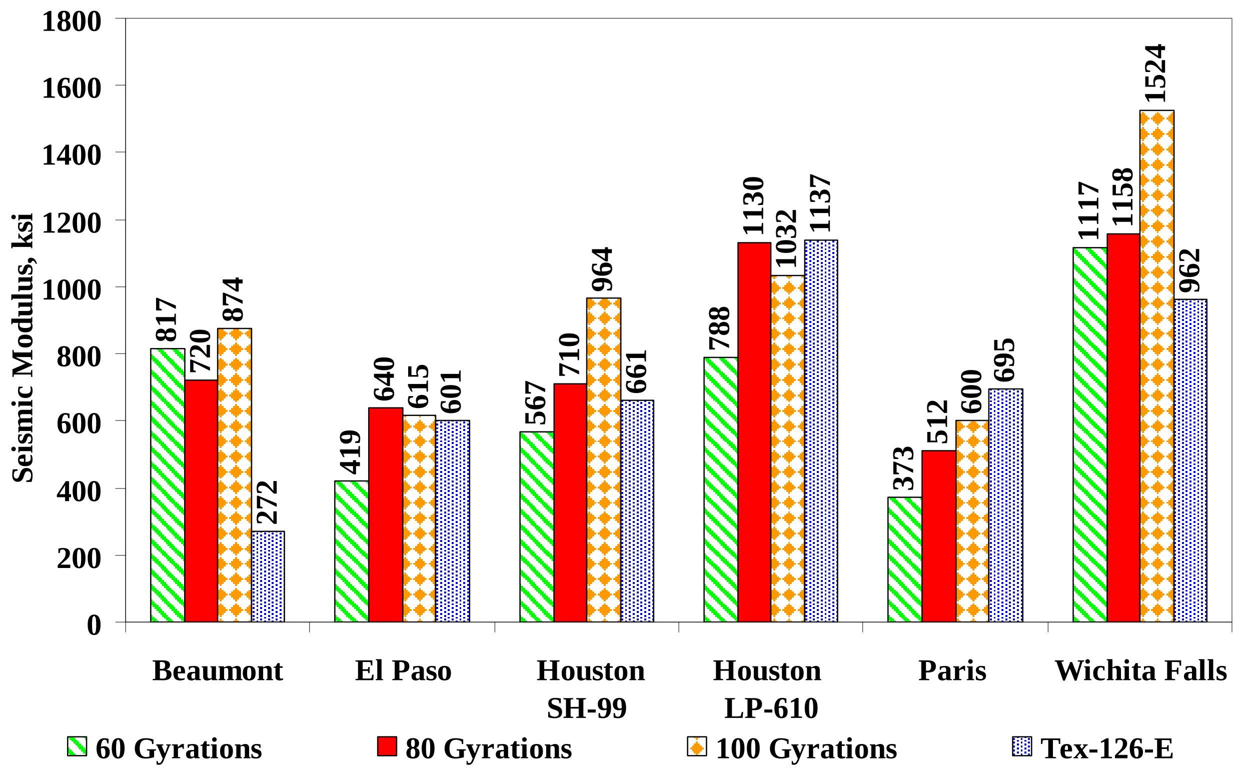


Figure 5.4 – Impact of Number of Gyrations on Modulus for Tex-126-H Protocol

first gyration in the first occurrence of three gyrations of the same height (Varvik and Carpenter, 1998). At the locking point aggregates lock together and additional gyrations may degrade the aggregates. The locking points for all mixes are presented in Figure 5.5. Except for Paris materials, the locking points are less than 100 gyrations. This indicates that the use of 100 gyrations may not be desirable for the ATB mixes.

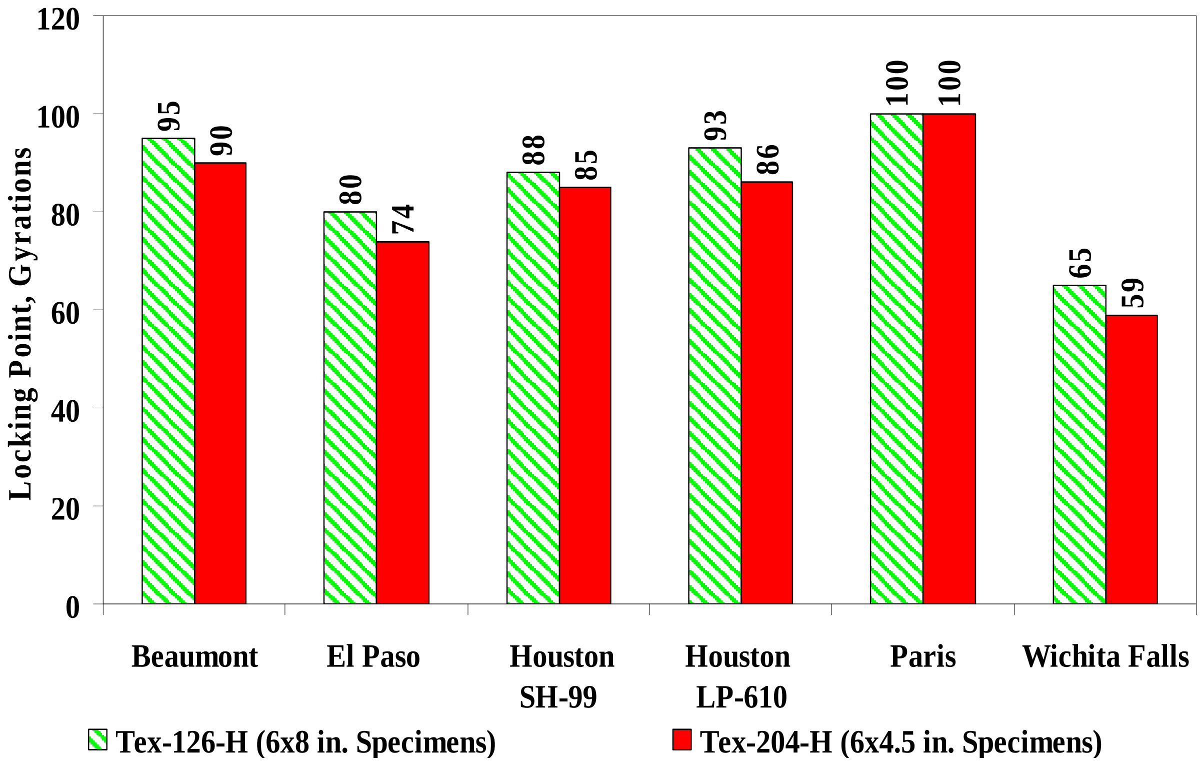


Figure 5.5 – Locking Points for Tex-126-H and Tex-126-E Specimens

A more systematic way of evaluating the impact of the number of gyrations on density is shown in Figure 5.6a. The densities from the SGC at different numbers of gyrations are compared with those from the TGBC for all asphalt contents tested (i.e., 3%, 4.5% or 6%). Overall, the densities obtained with the SGC for the three numbers of gyrations are 2 to 3% less than those from the TGBC. Naturally, the same trends hold for the maximum density as shown in Figure 5.6b. The numbers of gyrations greater than 60 do not seem to have an impact on the density of the mix.

As demonstrated in Chapter 4, the change in density with asphalt content is rather small for the ATB mixes, which may lead to uncertainty in determining the OAC. Another angle in recommending the number of gyrations is the sensitivity of the asphalt-content-density relationships as shown in Table 5.1. The sensitivity is defined as the difference between the maximum and minimum densities at 3%, 4.5% and 6% asphalt contents (used in defining the asphalt content density relationships) for a given compaction protocol, divided by the average density of the three measurements. The asphalt content density curve is defined better as the sensitivity increases In no case the sensitivity is greater than 7%, indicating that perhaps judgment should be used in estimating the OAC. However, the preliminary data from 80 gyrations seem to be the most promising.

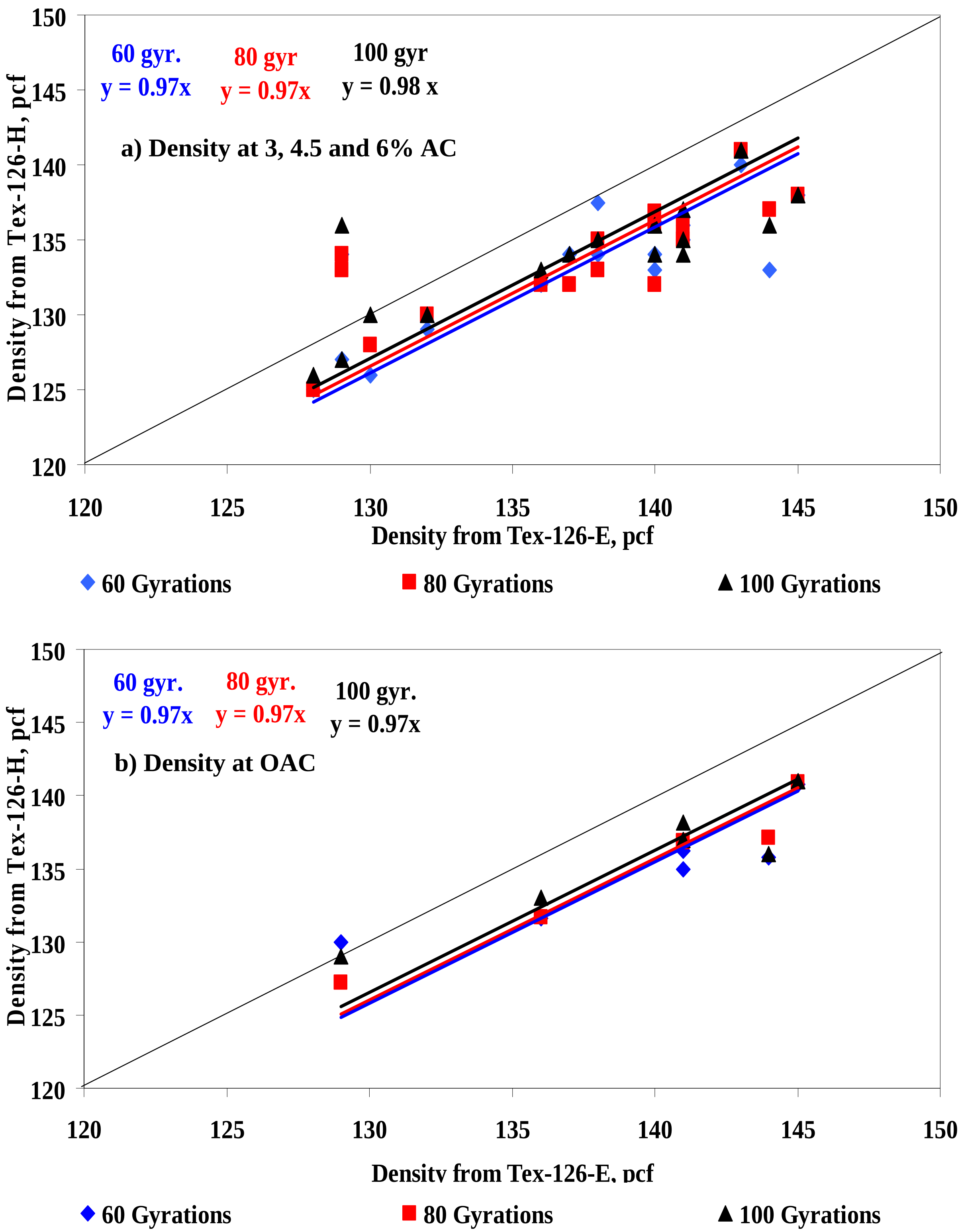


Figure 5.6 – Comparison of Density from Tex-126-E and Tex-126-H Protocols

Table 5.1 – Sensitivity of Density to Asphalt Content for Tex-126-H Protocol

Compaction Method	Sensitivity, (Max. Density – Min Density)/Avg. Density					
	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
SGC 60 Gyrations	1%	2%	3%	2%	6%	5%
SGC 80 Gyrations	3%	4%	3%	4%	5%	5%
SGC 100 Gyrations	1%	2%	1%	2%	7%	5%
TGBC	3%	5%	4%	1%	1%	6%

Tex-204-H Protocol

The impact of the number of gyrations on OAC, density, indirect tensile strength and modulus are summarized in Figures 5.7 to 5.10 for Tex-204-H protocol. As reflected in Figure 5.5, the locking points for this protocol are slightly lower than those for Tex-126-H, perhaps because of the smaller specimen heights 4.5 in. as opposed to 8 in. for Tex-126-H). The trends for the OAC's (Figure 5.7) are similar to those presented for Tex-126-H in Figure 5.1 except for the Beaumont material. The patterns for the densities (Figure 5.8) at the OAC's are also similar to those from Tex-126-H.

The number of gyrations does not seem to significantly impact the IDT strengths (Figure 5.9) and moduli (Figure 5.10), and the IDT strengths from the SGC and TGBC specimens are closer to one another than the corresponding UCS values from Tex-126-H and Tex-126-E.

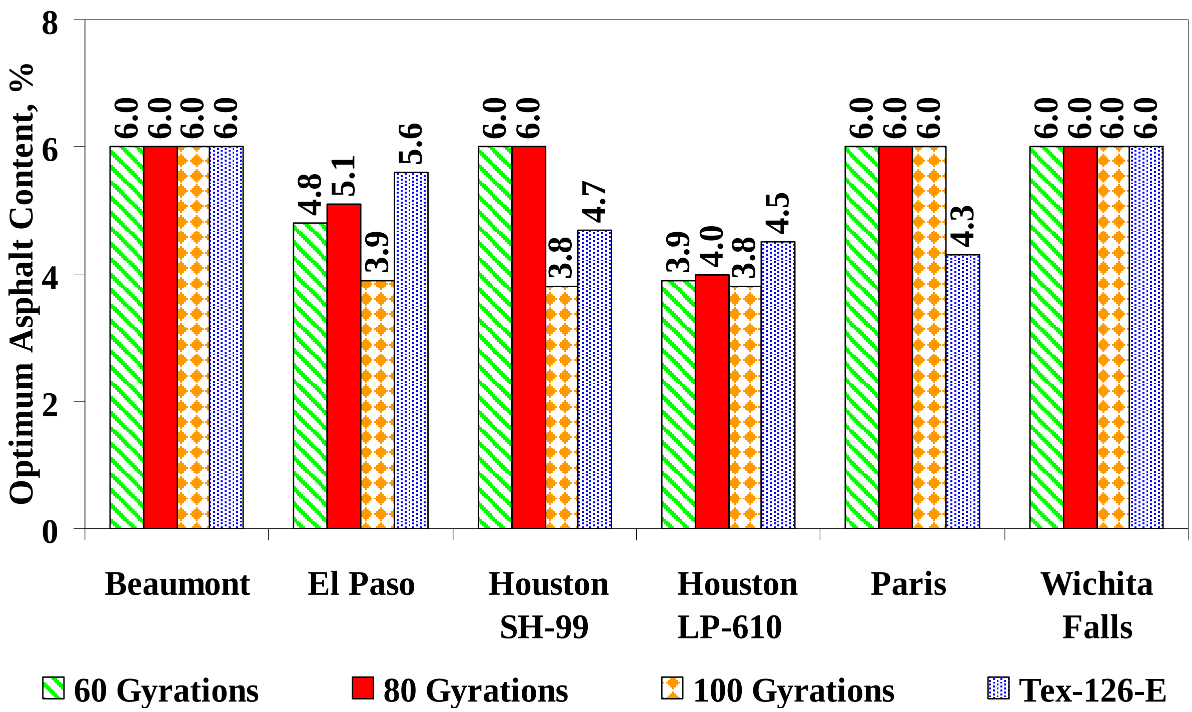


Figure 5.7 – Impact of Number of Gyrations on OAC for Tex-204-H Protocol

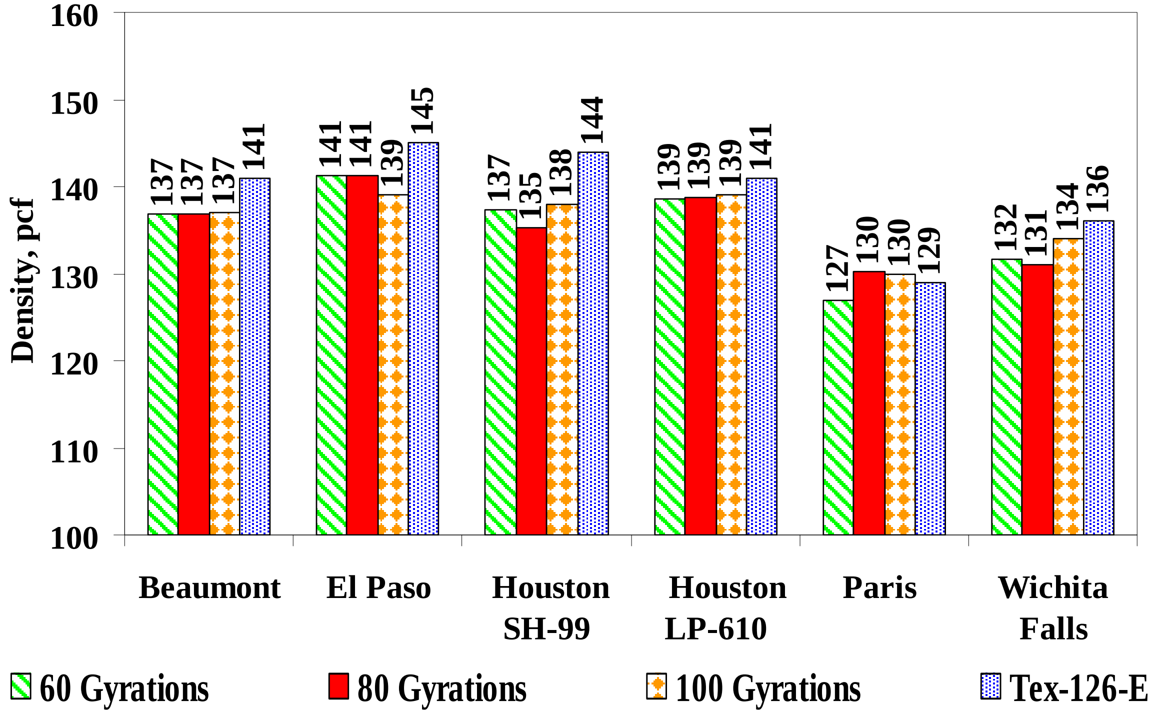


Figure 5.8 – Impact of Number of Gyrations on Density for Tex-204-H Protocol

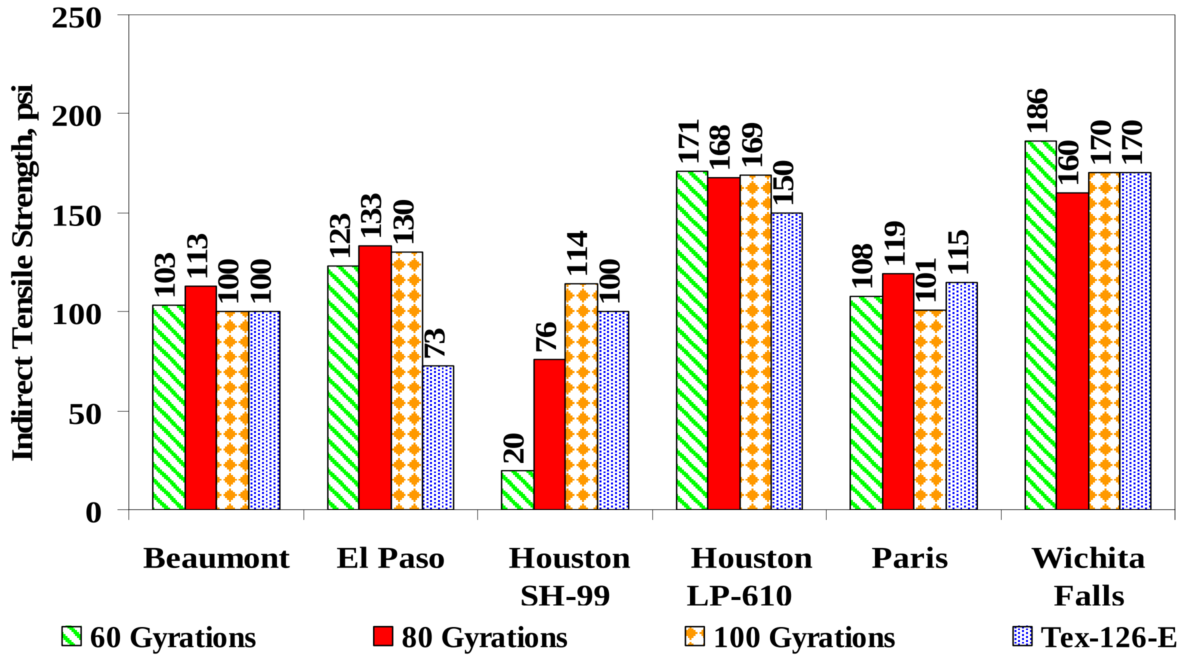


Figure 5.9 – Impact of Number of Gyrations on IDT Strength for Tex-204-H Protocol

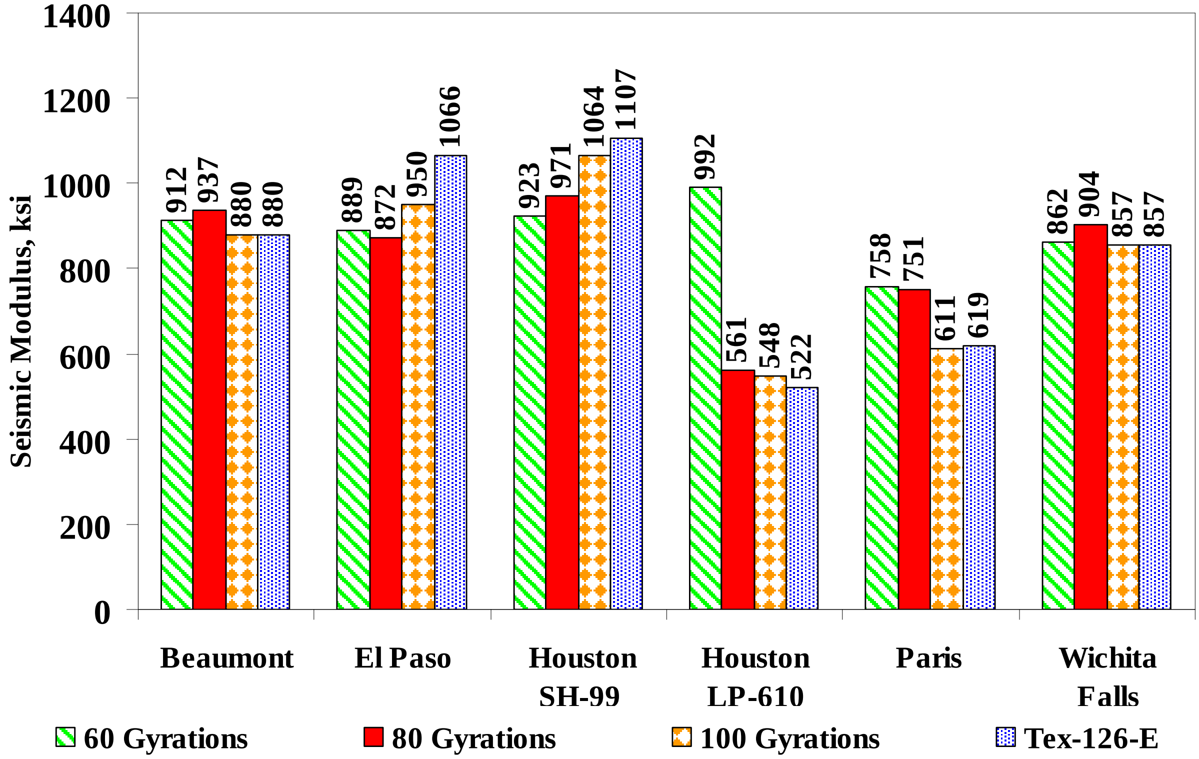


Figure 5.10 – Impact of Number of Gyrations on Modulus for Tex-204-H Protocol

The impact of the number of gyrations on density at respective OAC's of the mixes is shown in Figure 5.11. The densities obtained from SGC for the three numbers of gyrations are 2 to 3% less than those from the TGBC . This occurs because the TGBC exerts more compaction energy than the SGC because the angle of the TGBC's head is greater than the SGC. In general, the numbers of gyrations above 60 do not significantly or systematically impact the density. As reflected in Table 5.2, the densities of the specimens prepared at 60 or 80 gyrations exhibit higher sensitivity to the asphalt content. Based on this exercise, 60 to 80 gyrations may be more appropriate for preparing specimens.

Table 5.2 – Sensitivity of Density to Asphalt Content for Tex-204-H Protocol

Compaction Method	Sensitivity, (Max. Density – Min Density)/Avg. Density					
	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
SGC 60 Gyrations	6%	5%	1%	3%	4%	5%
SGC 80 Gyrations	3%	6%	1%	3%	9%	3%
SGC 100 Gyrations	3%	3%	2%	3%	6%	4%
TGBC	3%	5%	4%	1%	1%	6%

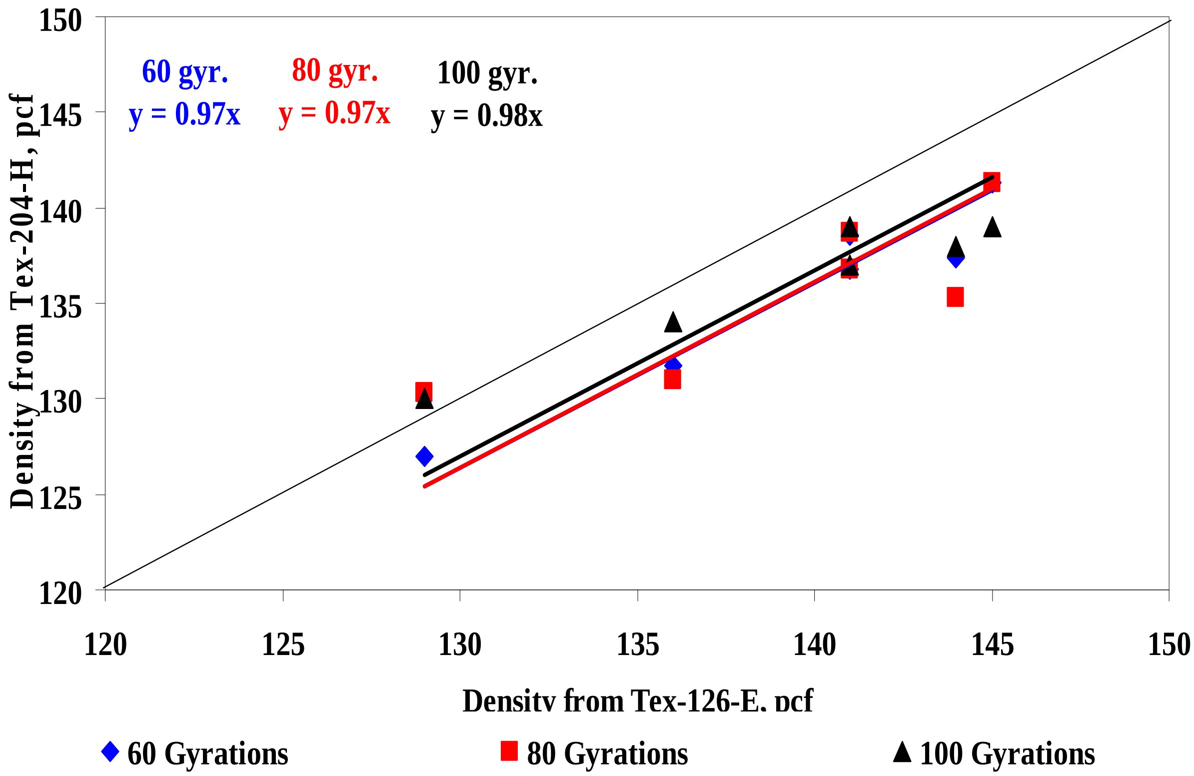


Figure 5.11 – Comparison of Density from Tex-126-E and Tex-204-H Protocols

Impact of Curing Temperature

Tex-126-H Protocol

The impacts of curing temperature on the UCS and modulus for specimens prepared as per Tex-126-H are shown in Figures 5.12 and 5.13, respectively. All specimens were prepared at their corresponding OAC's at 100 gyrations. The first series of specimens was cured for 24 hours at room temperature and tested also at room temperature. The second series of specimens was cured in an oven at 140°F for 48 hrs but tested at room temperature, while the third series of tests was carried out on specimens cured for 48 hrs at 140°F and tested at that temperature.

From the first two sets of data, the 48 hrs of curing in the oven does not seem to significantly impact the strength or modulus of the mixes. As such, instead of curing the specimens for 48 hrs, one can simply cure them for 24 hrs at room temperature to save time and complications with handling high-temperature specimens.

As expected, the impact of the temperature at the time of testing is more pronounced comparing the second and third sets of data. Perhaps the UCS and modulus testing can also be done at the room temperature to mainstream the testing and to improve the reliability of the results since the operator is not rushed to test the specimen in order to maintain the temperature of the specimen.

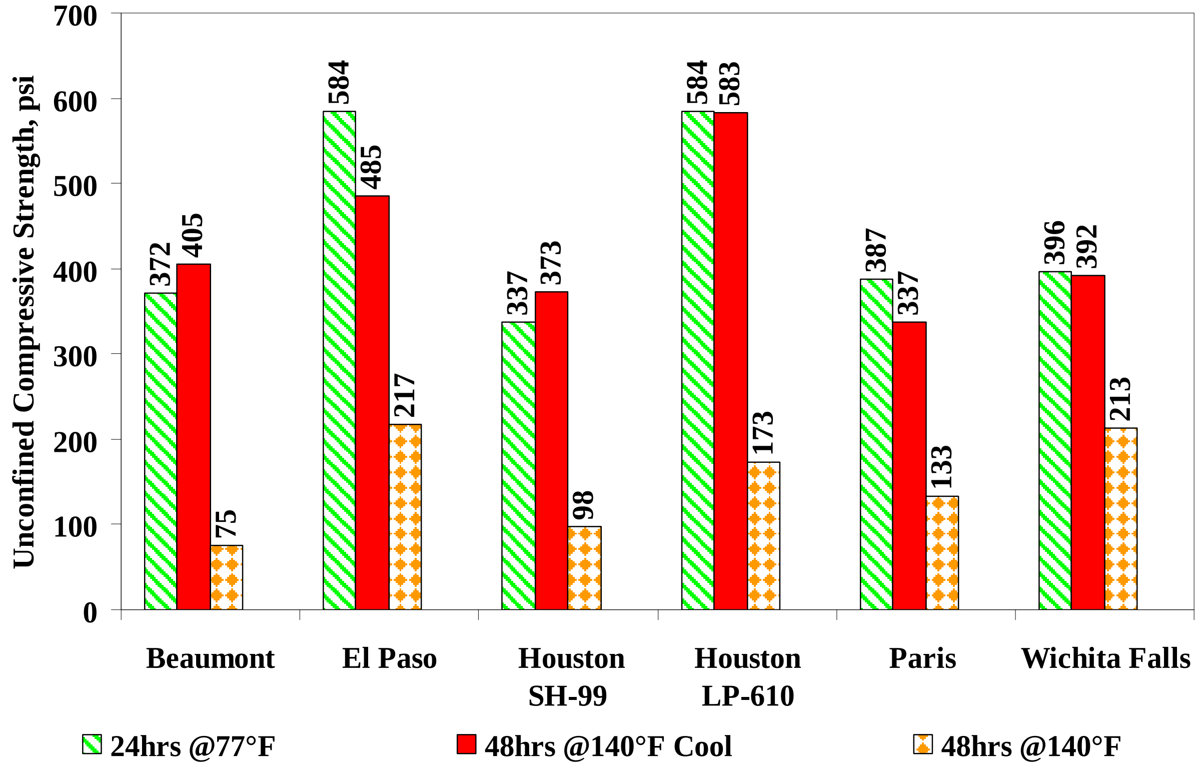


Figure 5.12 – Impact of Curing Temperature on UCS for Tex-126-H Protocol

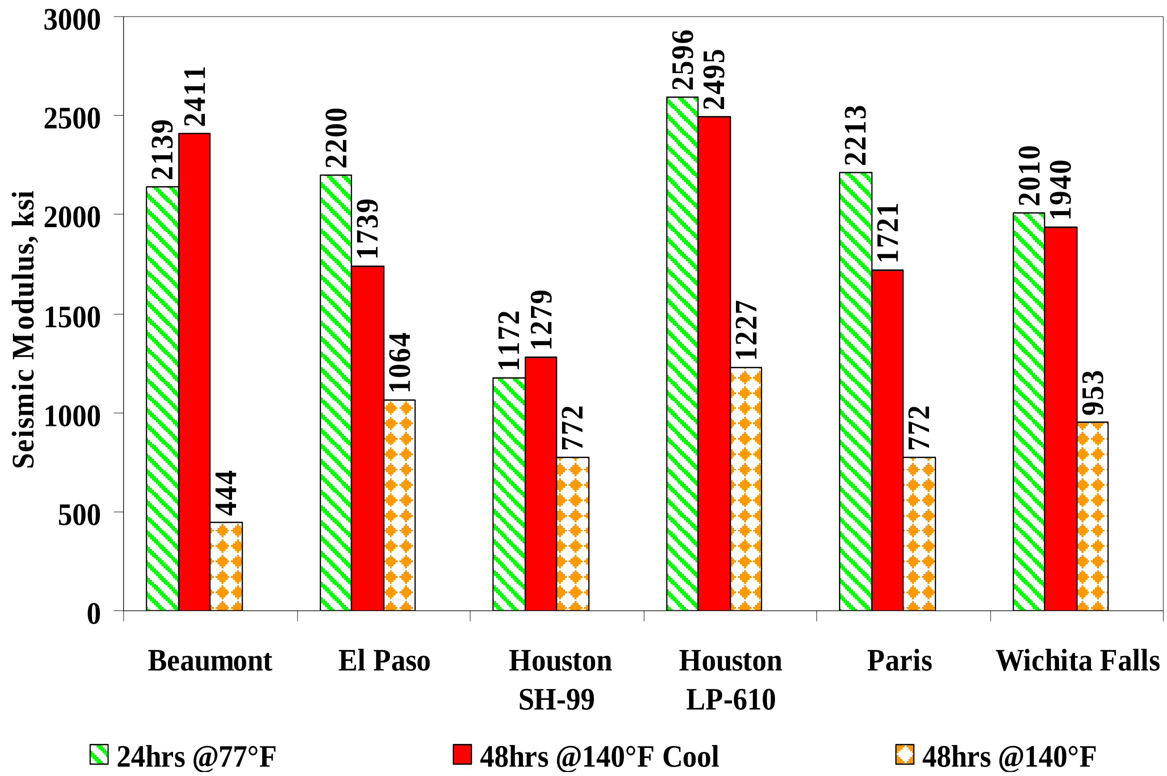


Figure 5.13 – Impact of Curing Temperature on Modulus for Tex-126-H Protocol

The strengths from the two alternative curing processes are compared with the standard ones (i.e. 48 hrs of curing at 140°F and testing at 140°F) in Figure 5.14. The strengths from the Tex-126-H specimens after subjecting them to standard curing were similar to those of Tex-126-E, indicating that the compactor used for sample preparation has little impact on the UCS strength. However, the Tex-126-H specimens tested at 77°F exhibit strengths that are about 3.4 times greater than those tested under Tex-126-E protocol, independent of the number of days (1 or 2 days) that the Tex-126-H specimens were cured.

To further verify this concept, the specimens prepared using Tex-126-E protocol were subjected to three curing regimes and tested. As shown in Figure 5.15, the trends are similar to those discussed above. There is more scatter in the data that can perhaps be attributed to the better quality of the specimens prepared by the SGC. The impact of the temperature is also less evident, perhaps due to the fact that the TGBC specimens are denser requiring more than 4 hrs to cool to room temperature.

Tex-204-H Protocol

The impacts of curing temperature on IDT and modulus for specimens prepared as per Tex-204-H are shown in Figures 5.16 and 5.17, respectively. Once again, the trends are similar to those from Tex-126-H. As reflected in Figure 5.18, specimens cured either one or two days at 140°F and tested at 77°F yielded similar results. However, when the specimens were tested at 140°F, the strengths were about 4 times less than those tested at 77°F.

Impact of Binder Grade

Tex-126-H Protocol

The OAC's for the specimens prepared as per Tex-126-H using PG 64-22 and PG 76-22 binders for all materials are shown in Figure 5.19. The OAC's are less for the PG 64-22 binder except for the Wichita Falls material. The Paris mixes were not tested because of the lack of raw materials.

The impact of the binder grade on the densities of the materials is rather small (less than 2 pcf) for most materials as depicted in Figure 5.20. Wichita Falls is the only material that is experiencing a significant increase in the density with the PG 76-22 binder. The reason for this pattern is unknown.

The UCS values for the Tex-126-H specimens mixed with different binder grades at their respective OAC's are shown in Figure 5.21. Because of the complex interaction of the AC content, a clear pattern cannot be observed. The specimens with the 76-22 binder seem to be stronger in compression for the Houston SH-99, Houston LP-610 and Wichita Falls materials. The Beaumont material showed no impact of the binder grade, and the El Paso material is the only material in which the PG 64-22 specimen showed a higher UCS value.

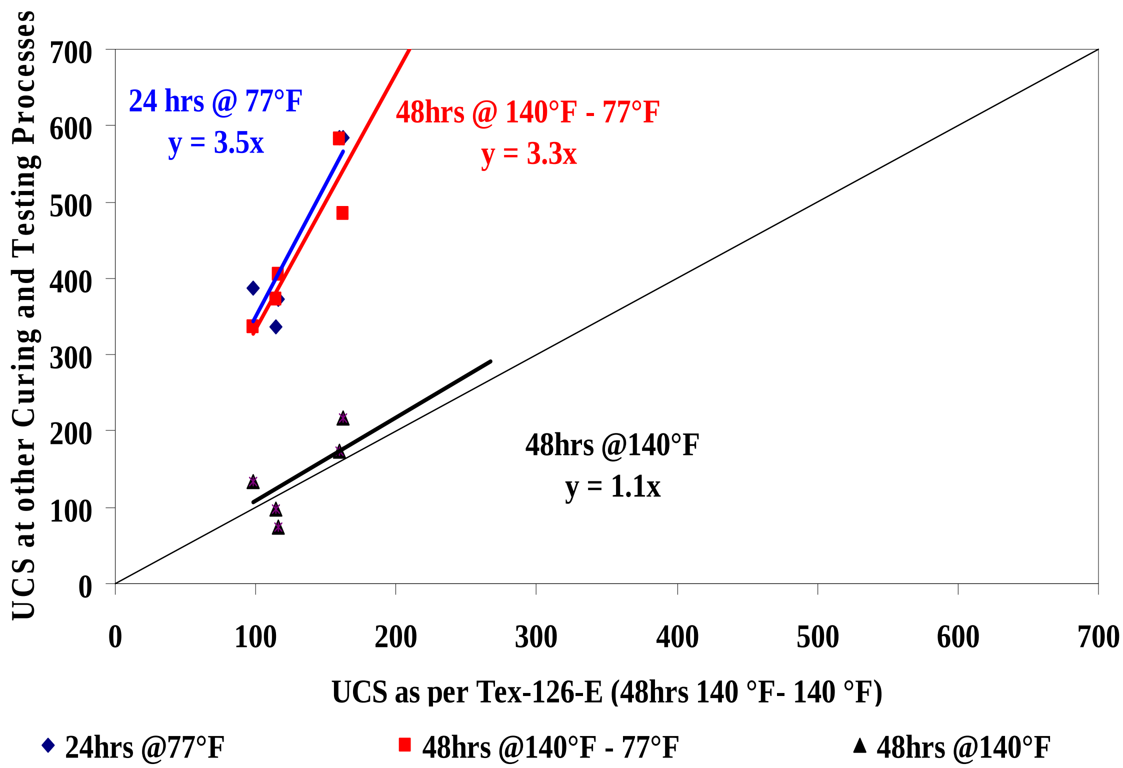


Figure 5.14 – Comparison of Strengths from Different Curing Regimes using Tex-126-H Specimens with Those from Tex-126-E

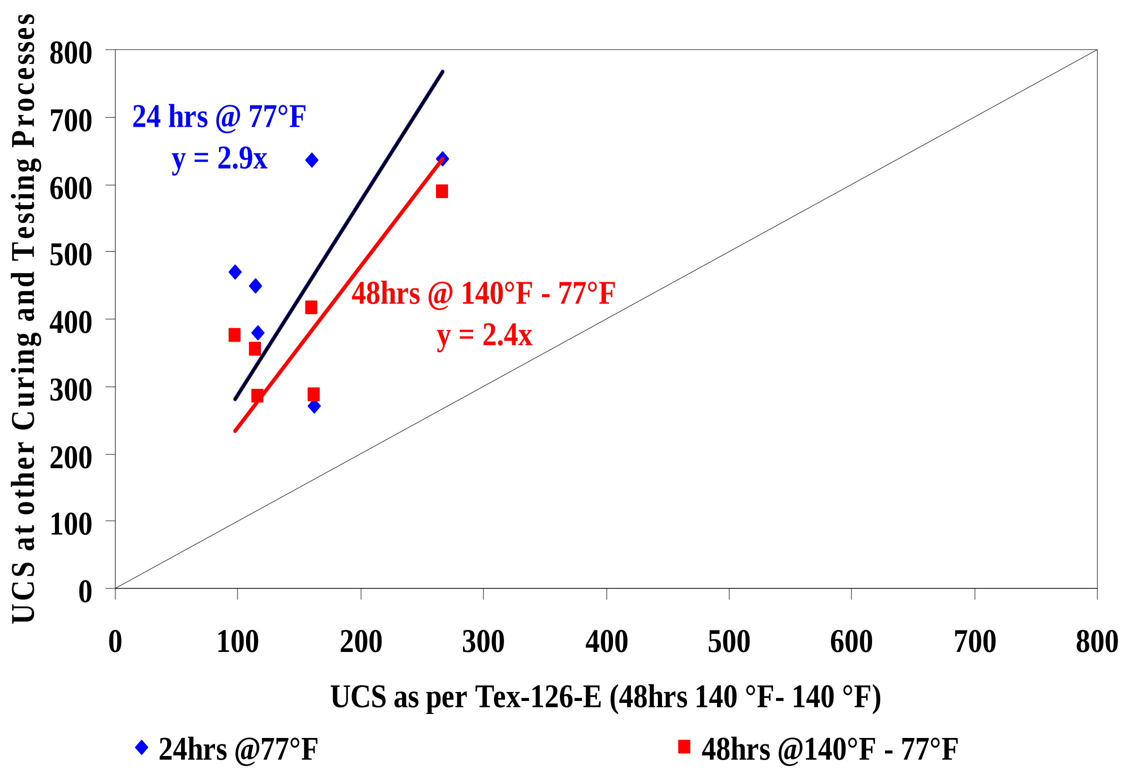


Figure 5.15 – Comparison of Strengths from Different Curing Regimes using Tex-126-E Specimens

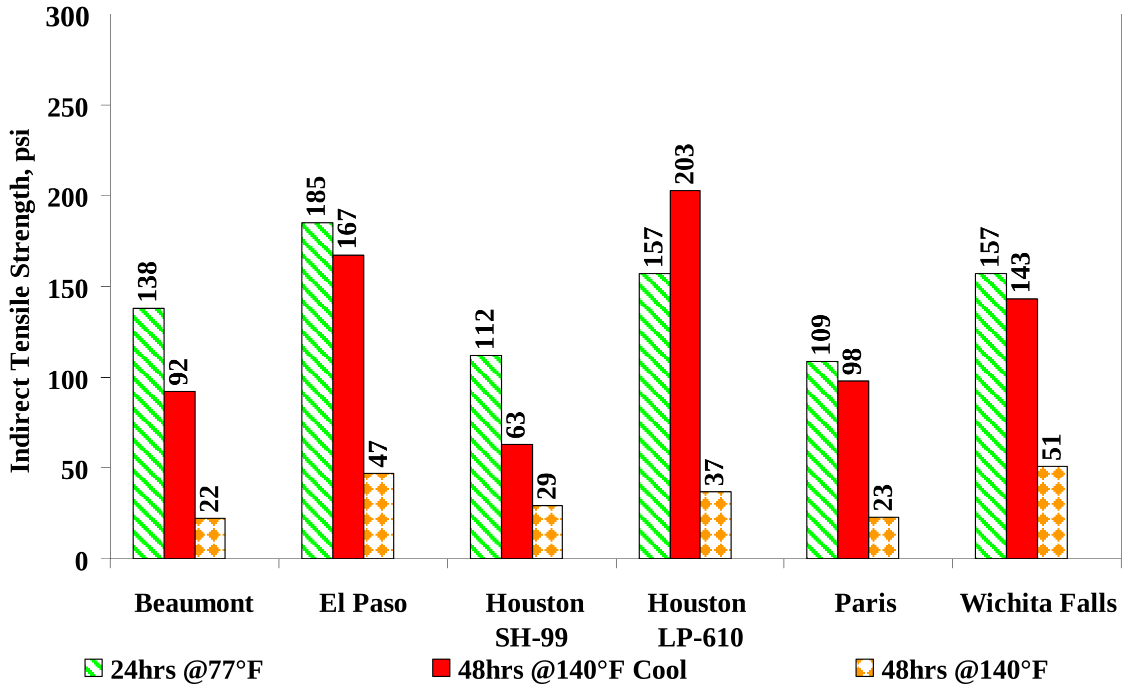


Figure 5.16 – Impact of Curing Temperature on IDT Strength for Tex-204-H Protocol

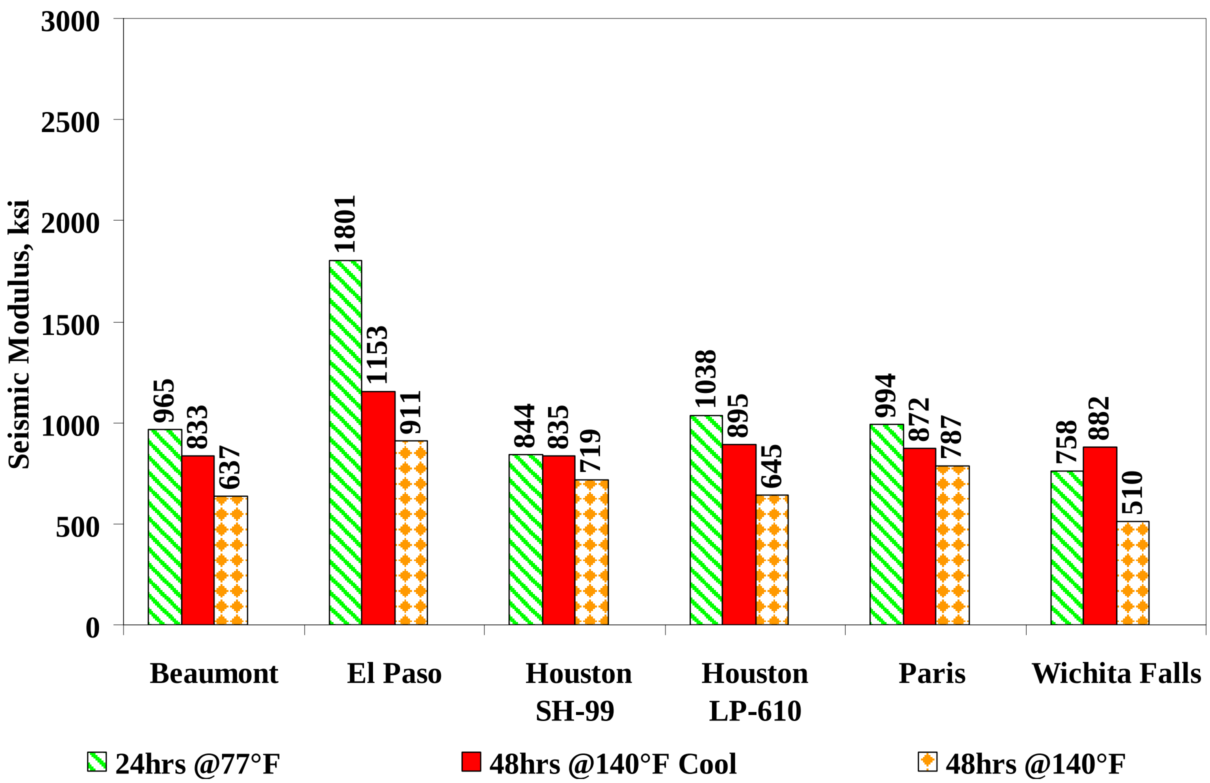


Figure 5.17 – Impact of Curing Temperature on Modulus for Tex-204-H Protocol

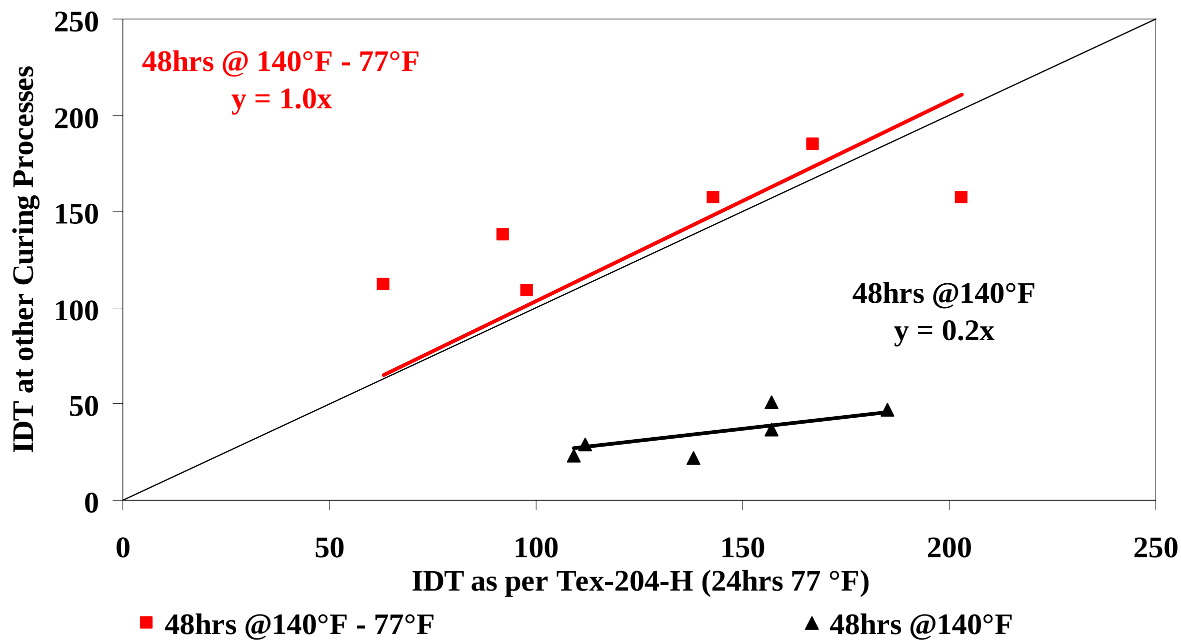


Figure 5.18 – Comparison of Strengths from Different Curing Regimes using Tex-204-H Specimens

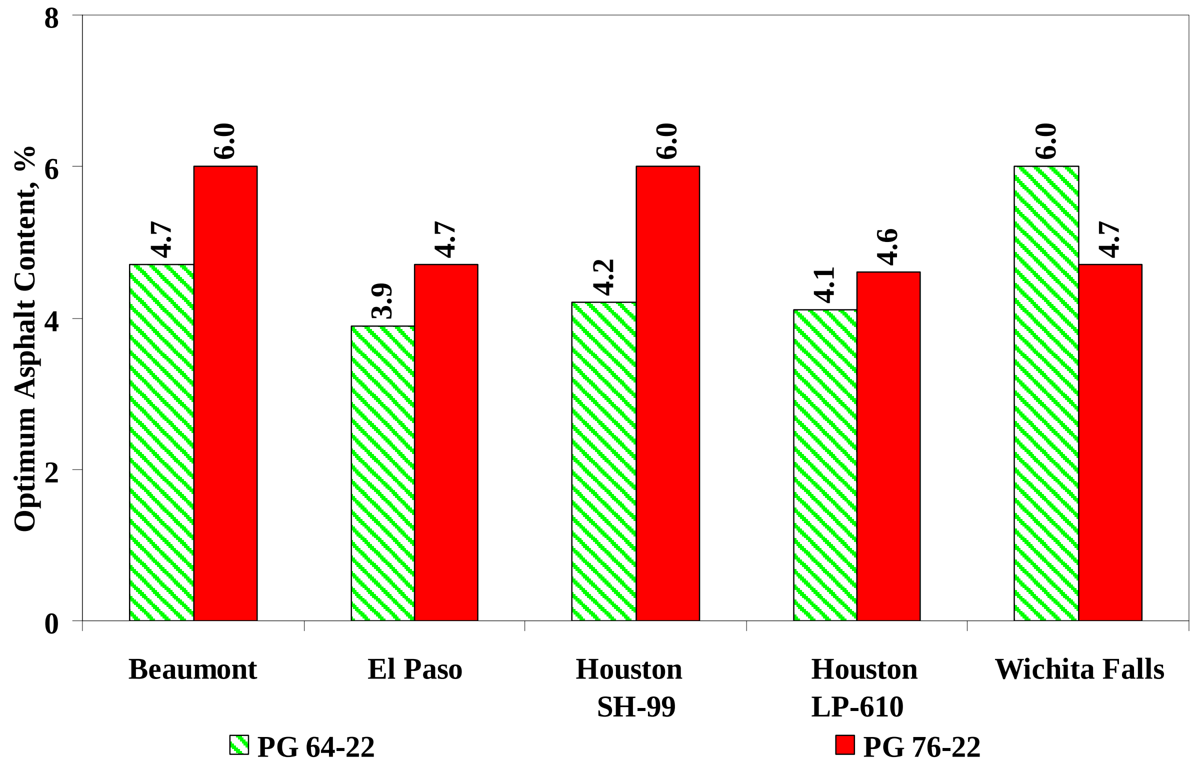


Figure 5.19 – Impact of Binder Grade on OAC based on Density for Tex-126-H Protocol

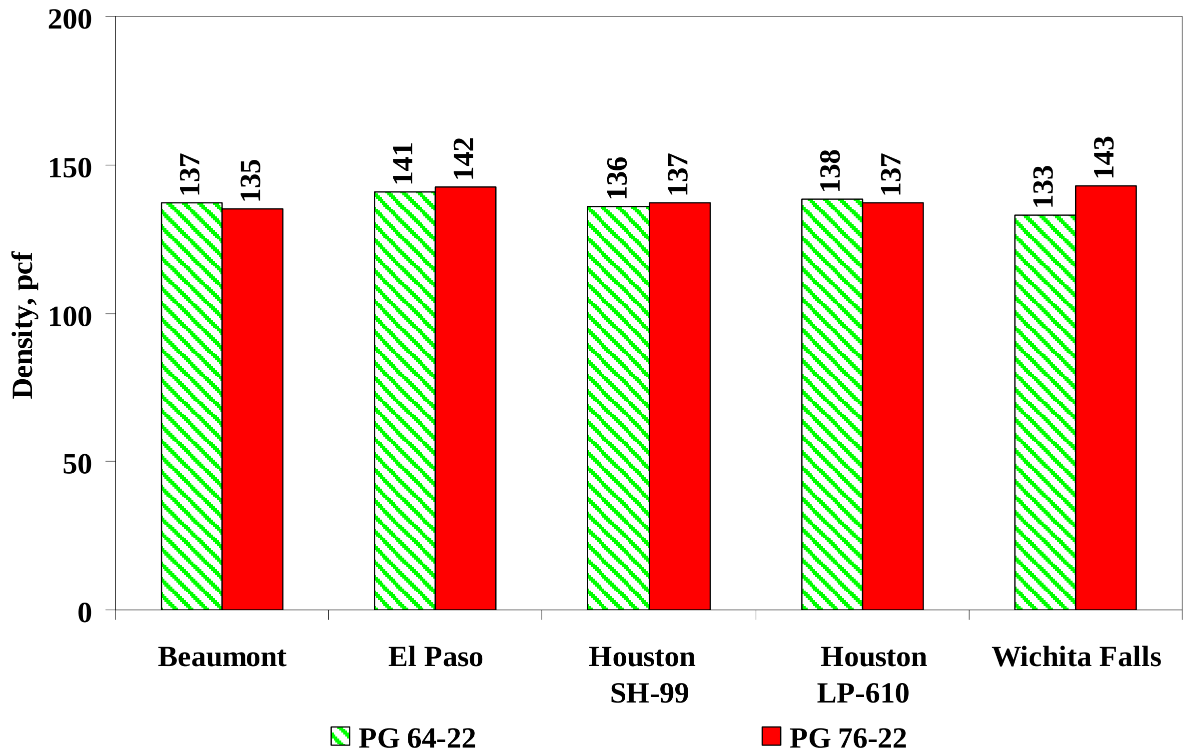


Figure 5.20 – Impact of Binder Grade on Density for Tex-126-H Protocol

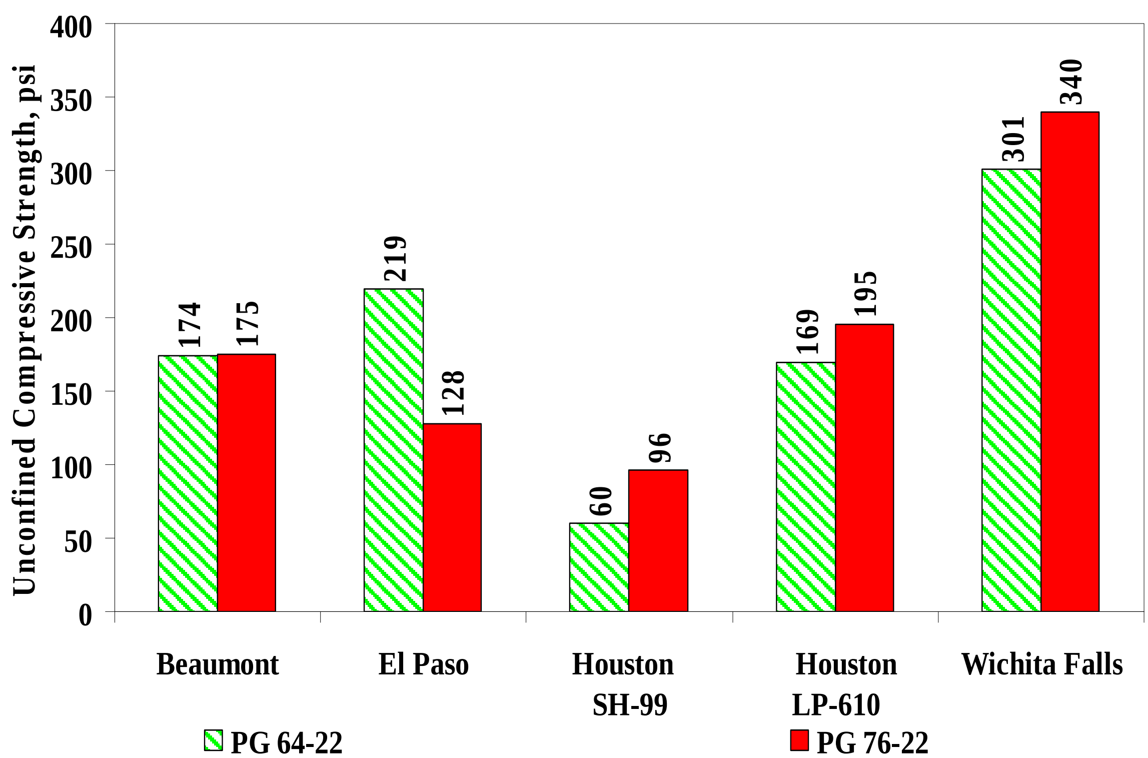


Figure 5.21 – Impact of Binder Grade on UCS for Tex-126-H Protocol

Tex- 204-H Protocol

The OAC's based on density obtained from the two binders from the Tex-204-H protocol are compared in Figure 5.22. In this case, the OAC's from the two binders are closer to one another. As shown in Figure 5.23, the densities were not impacted significantly by the binder grade. They are generally within 3 pcf of one another.

The impact of the binder grade on the IDT strengths is shown in Figure 5.24. Unlike the UCS trends in Figure 5.21, the PG 76-22 specimens seem to be stronger under tension as compared to the PG 64-22 specimens for almost all materials. The trends for seismic moduli, as shown in Figure 5.25, are different. The reason for this contradiction is that the modulus is more indicative of the compressive strength than the tensile strength.

Impact of AC Content

Each material was tested at its OAC and ±1 of its OAC to observe how the change in binder content will impact the behavior of the mix. The specimens were cured for 24 hrs and tested at 77°F. The variations in the UCS with asphalt content for Tex-126-H specimens are shown in Figure 5.26. Most materials are stronger either at the OAC or 1% less than OAC. A clear pattern is not obvious because as indicated in Chapter 4 the selection of OAC based on the density is rather uncertain. The modulus pattern is not that different as shown in Figure 5.27.

The IDT strengths and seismic moduli for the Tex-204-H specimens are shown in Figures 5.28 and 5.29, respectively. In most cases, the change in AC content does not seem to impact the IDT strength and modulus much.

Impact of Gradation

Up to this point, all the specimens were molded using the in place gradation of the materials as delivered to UTEP. As indicated in Chapter 4, those gradations met the Item 344 gradations. A second gradation that was compatible with Item 292 was developed for each material by increasing the fine contents in order to quantify the importance of the gradation in a mix. As reflected in Table 5.3, the modified gradations (values in parenthesis) were obtained by modifying only the materials finer than No. 40 Sieve so that 15% of the materials passed the number 200 sieve (while the original gradation contained less than 5%). This experiment was carried out on four materials.

Tex-126-H Protocol

Figure 5.30 compares the OACs for the Tex-126-H protocol from the two different gradations used. The quantities of the asphalt needed to achieve the maximum density for the Item 292 gradations are higher or close to those from the Item 344 gradations. The changes in maximum densities are not significant as the fines content increases, but the high fines content specimens' densities were found equal or slightly higher than the densities of the original gradations (see Figure 5.31).

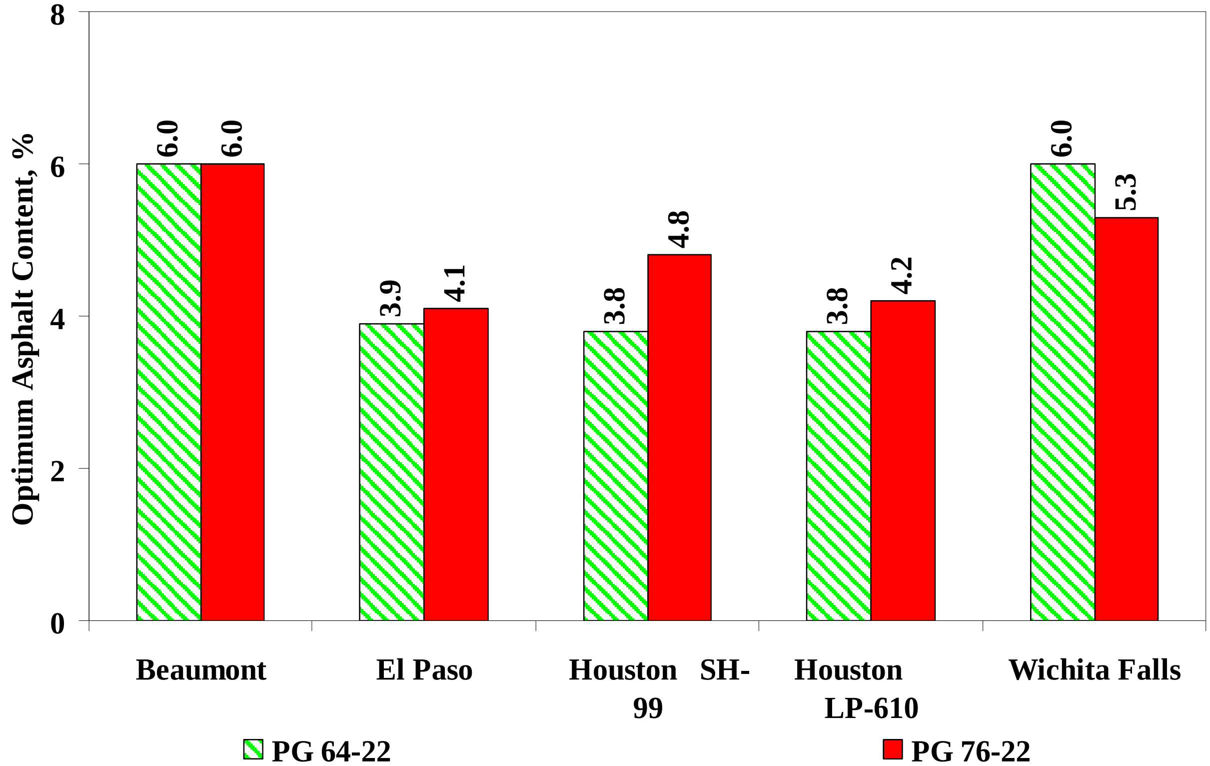


Figure 5.22 – Impact of Binder Grade on OAC for Tex-204-H Protocol

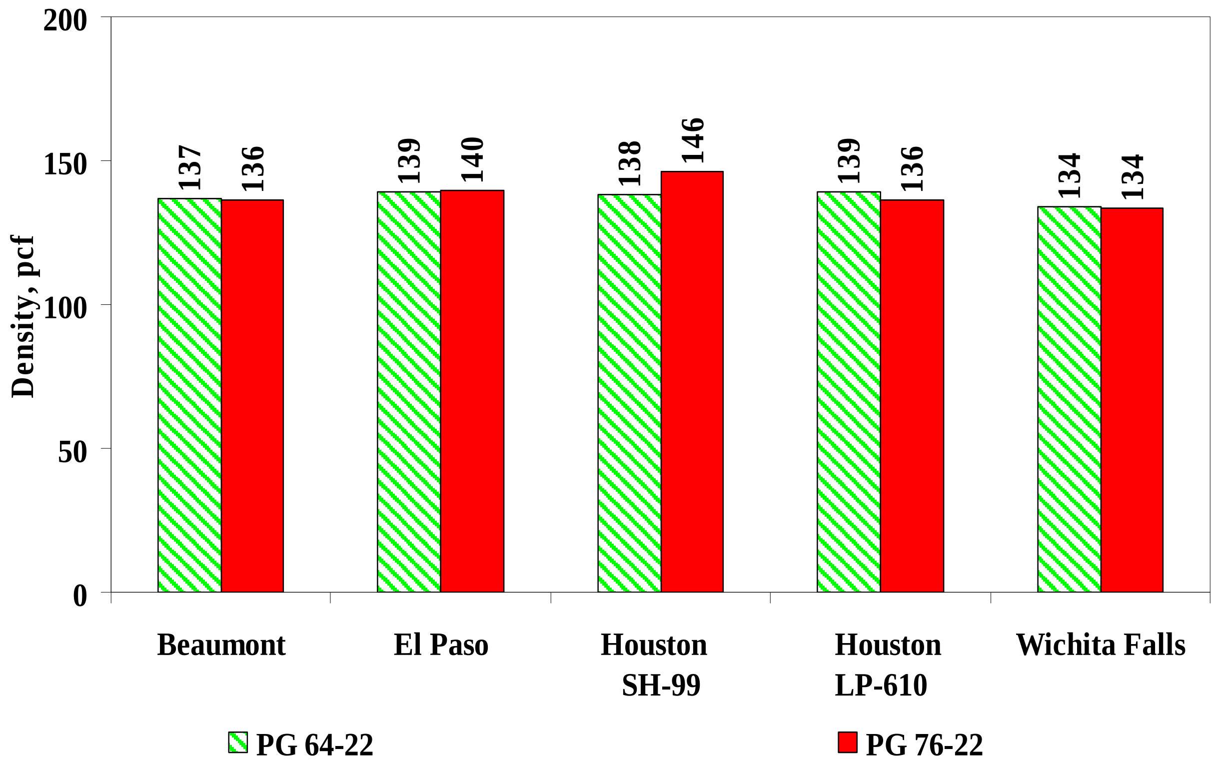


Figure 5.23 – Impact of Binder Grade on Density for Tex-204-H Protocol

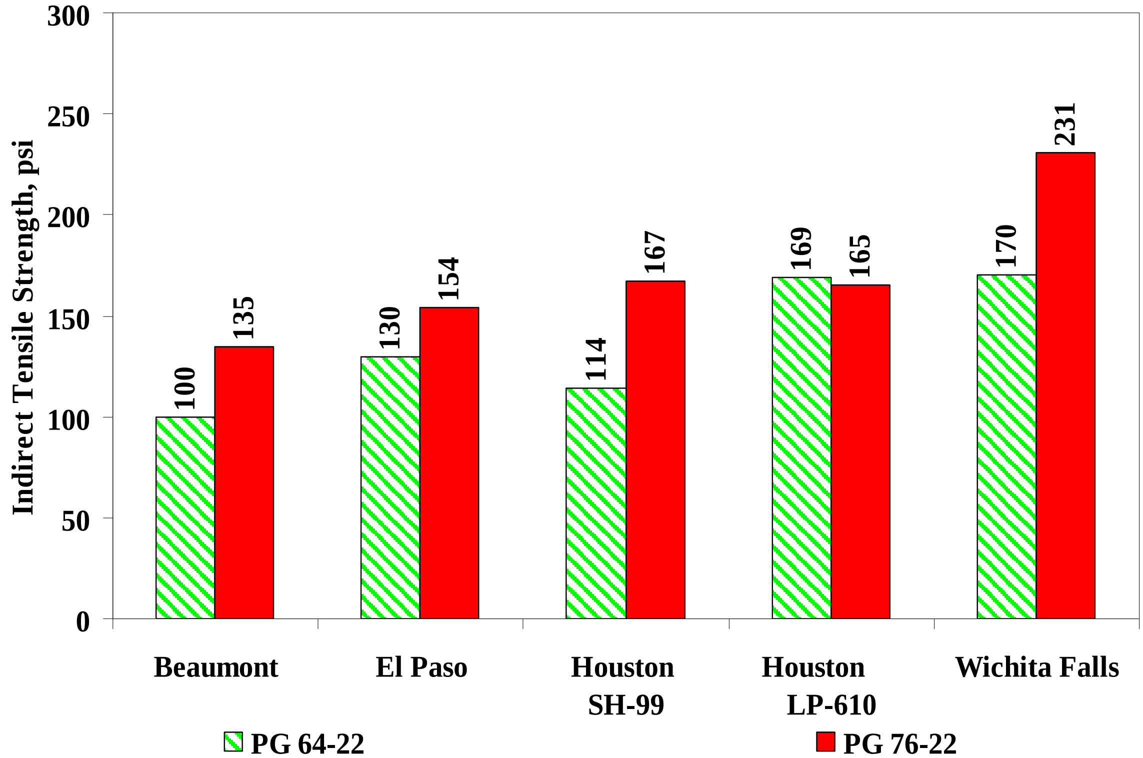


Figure 5.24 – Impact of Binder Grade on IDT Strength for Tex-204-H Protocol

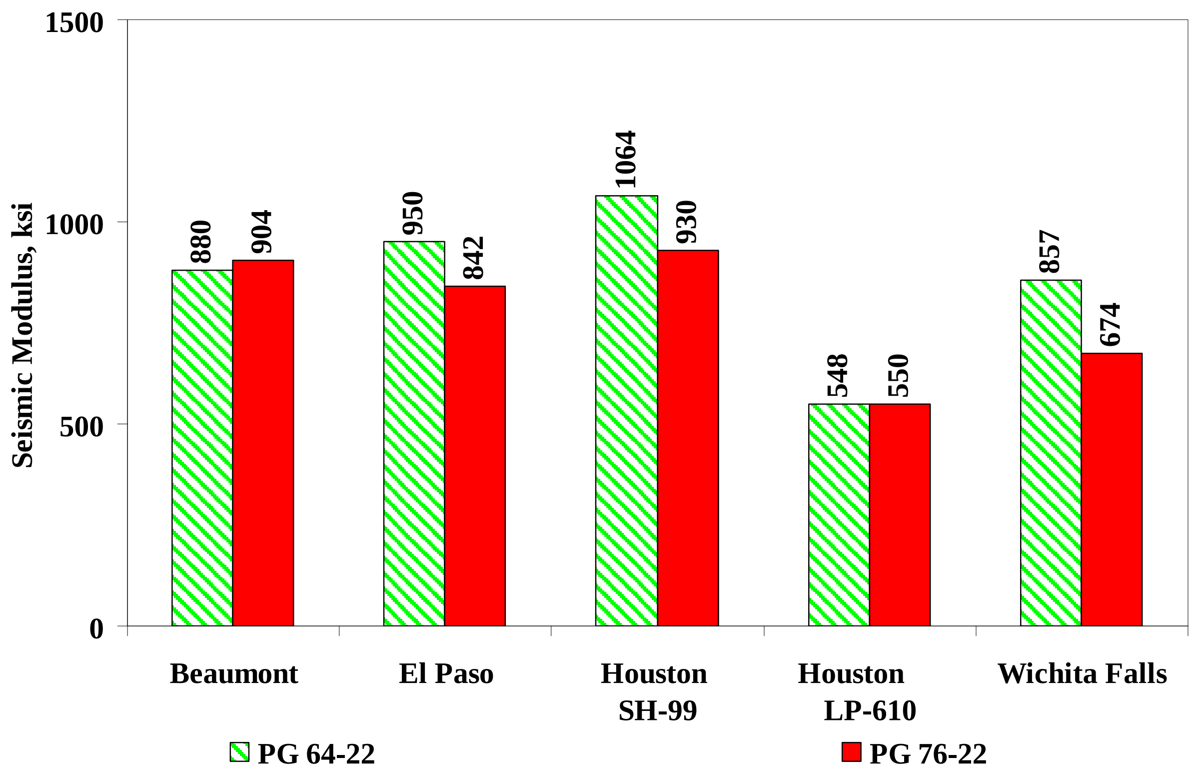


Figure 5.25 – Impact of Binder Grade on Modulus for Tex-204-H Protocol

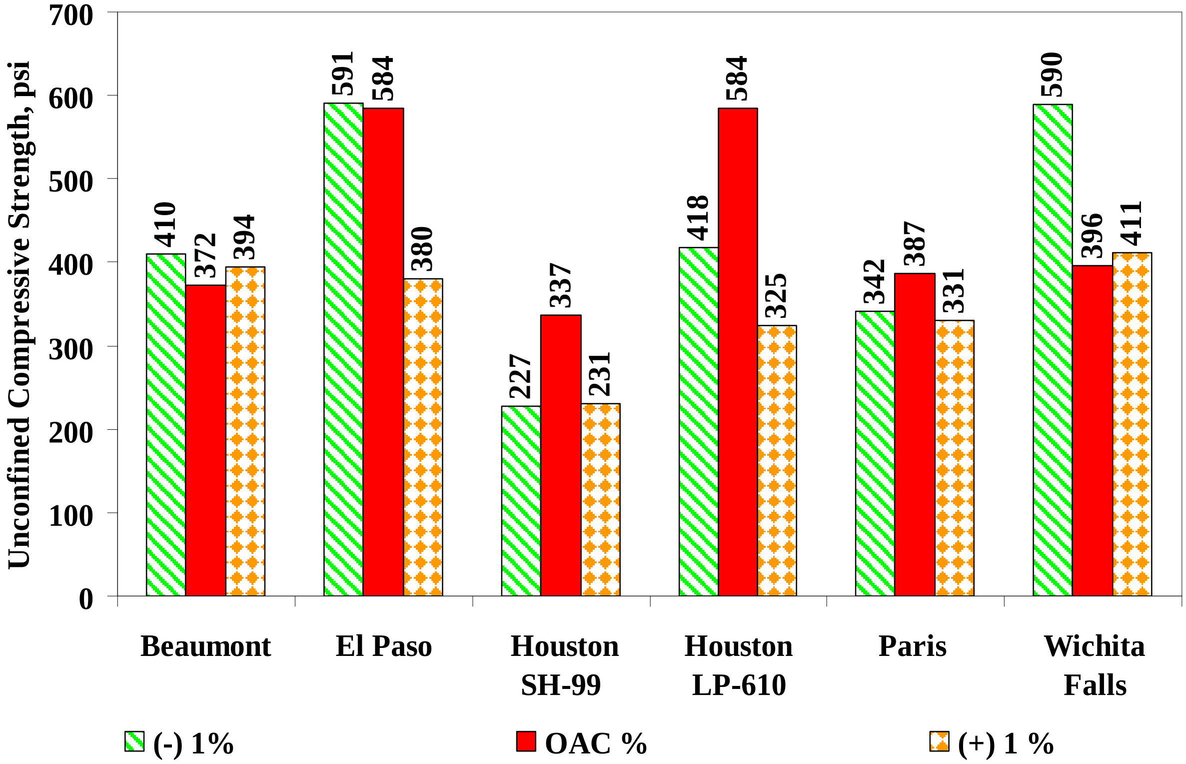


Figure 5.26 – Impact of Asphalt Content Variation on UCS for Tex-126-H Protocol

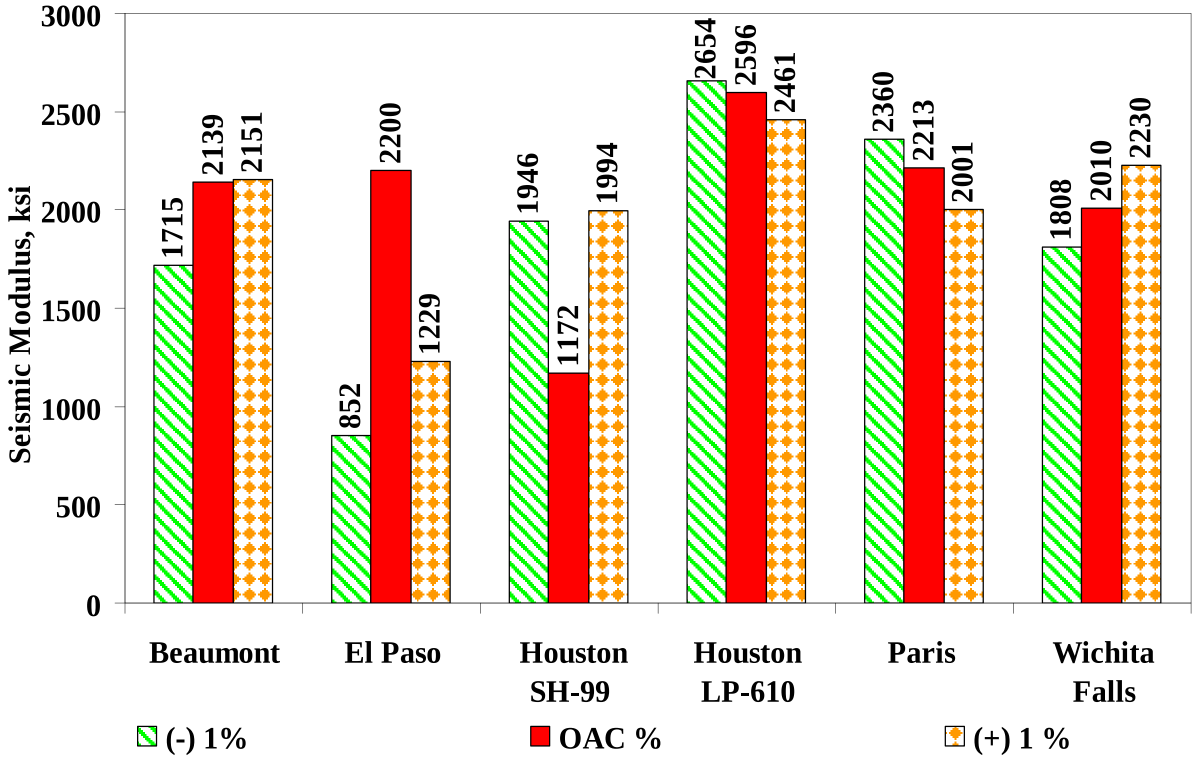


Figure 5.27 – Impact of Asphalt Content Variation on Modulus for Tex-126-H Protocol

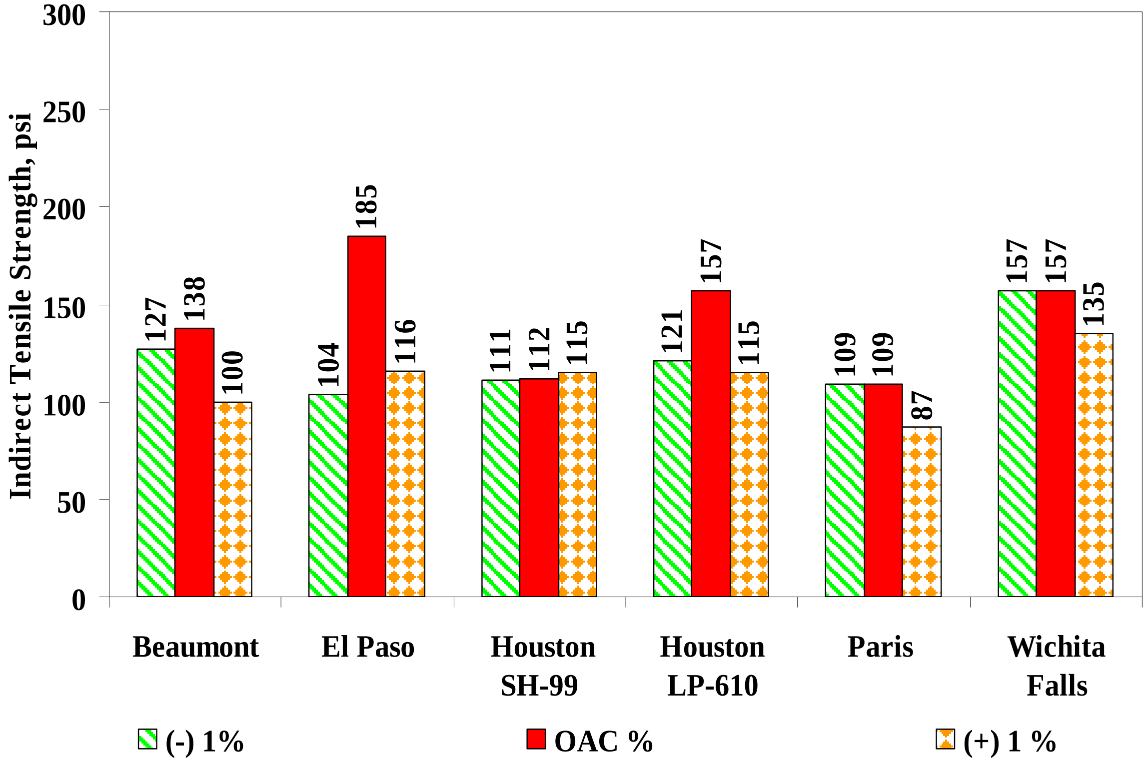


Figure 5.28 – Impact of Asphalt Content Variation on IDT for Tex-204-H Protocol

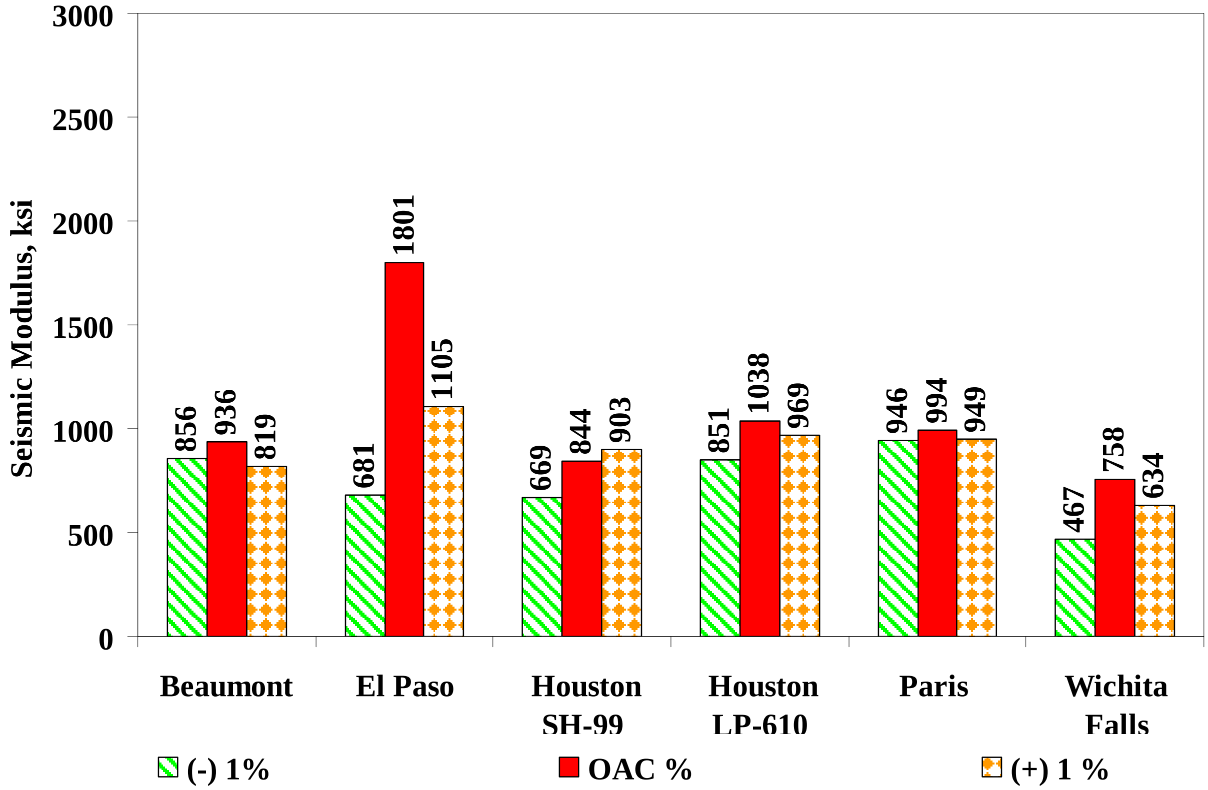


Figure 5.29 – Impact of Asphalt Content Variation on Modulus for Tex-204-H Protocol

Table 5.3 – Original and Modified Gradation

Sieve Size	Particle Diameter (mm)	Beaumont	El Paso	Houston SH-99	Houston LP-610	Paris	Wichita Falls
2”	58	100	100	100	100	100	100
1.5”	38.1	100	100	100	100	100	100
1"	25.4	83	100	73	91	87	91
7/8"	22.4	76	78	64	88	71	88
3/8"	9.52	56	60	38	63	46	61
#4	4.75	41	45	28	37	30	44
#40	0.425	18 (26)*	23 (26)	19 (22)	20 (26)	14 (22)	16 (25)
#100	0.15	3 (19)	12 (18)	9 (19)	5 (19)	8 (18)	8 (18)
#200	0.075	1 (15)	5 (15)	1 (15)	2 (15)	1 (15)	5 (15)

* Numbers in parentheses corresponds to modified gradations that would meet Item 292 requirements.

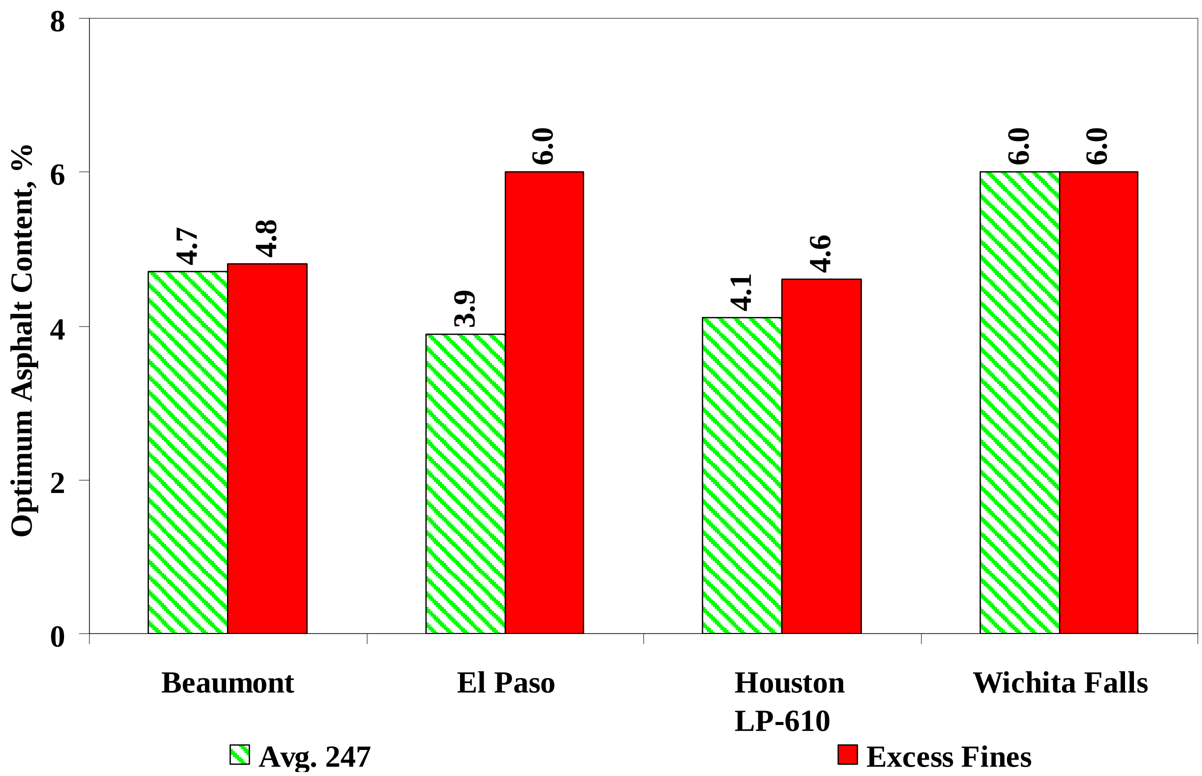


Figure 5.30 – Impact of Fines Content Variation on OAC Tex-204-H Protocol.

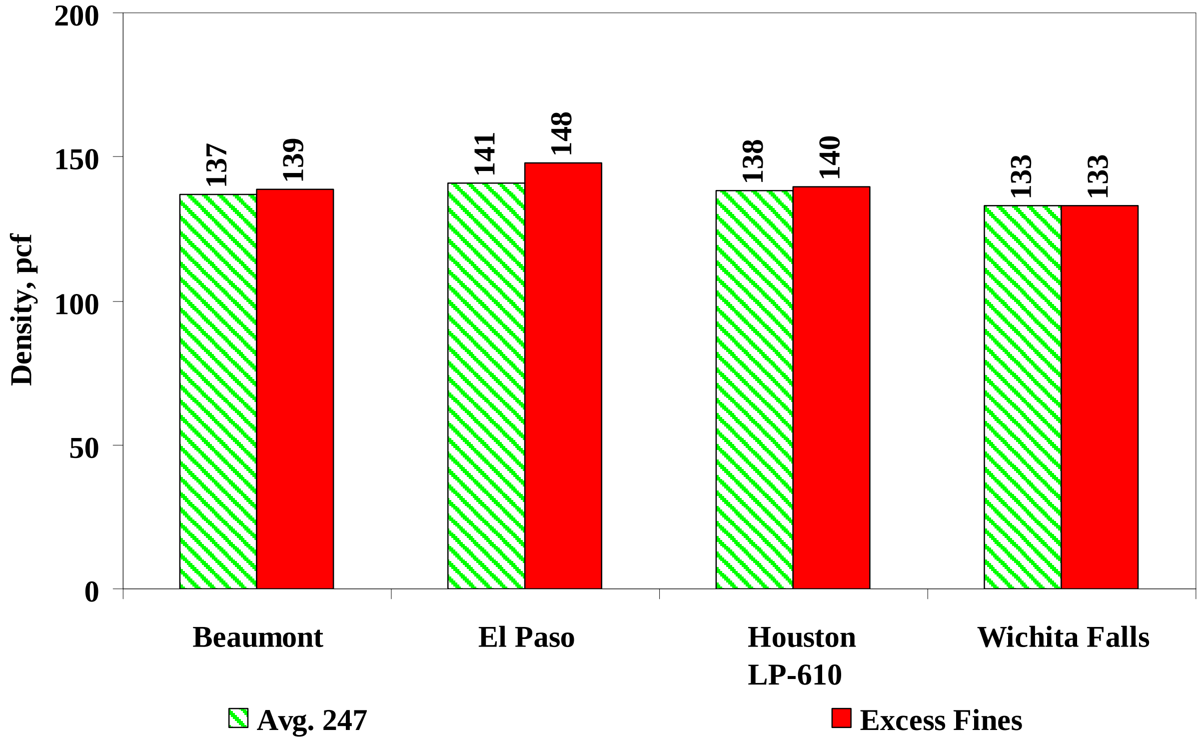


Figure 5.31 – Impact of Fines Content Variation on Density Tex-204-H Protocol.

As reflected in Figures 5.32 and 5.33, the addition of fines negatively or positively impacts the UCS and modulus depending on the original gradations of the materials as retrieved from the field.

Tex-204-H Protocol

The OACs for Item 292 and Item 344 gradations for Tex-204-H specimens are compared in Figure 5.34. The changes in the OACs as a result of changes in gradations seem to be more pronounced for this protocol as opposed to Tex-126-H. The changes in densities, however, are again rather small except for the Wichita Falls material (see Figure 5.35).

As reflected in Figure 5.36, the IDT strengths from the finer gradations are typically similar or higher than those from the original, coarser gradations. In Figure 5.37 the moduli show somewhat different trend. As indicated before, the modulus is more an indication of the compressive behavior of a mix than tensile behavior.

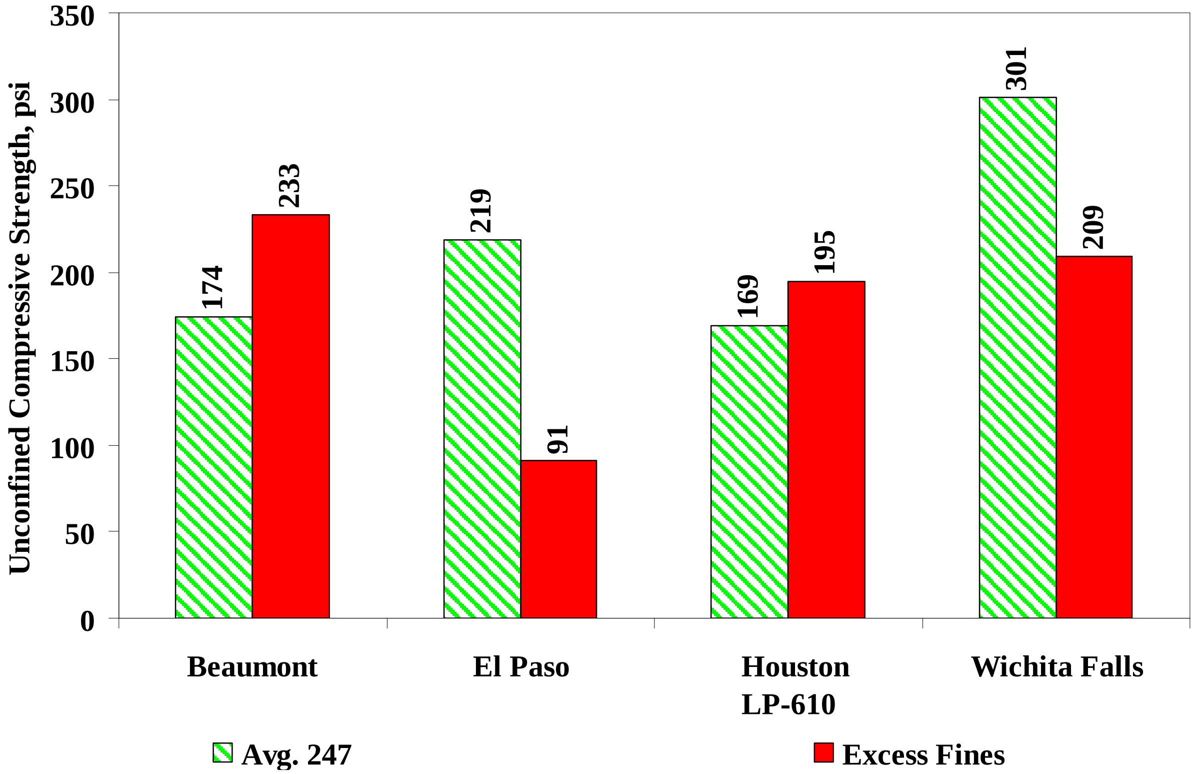


Figure 5.32 – Impact of Fines Content Variation on UCS Tex-126-H Protocol.

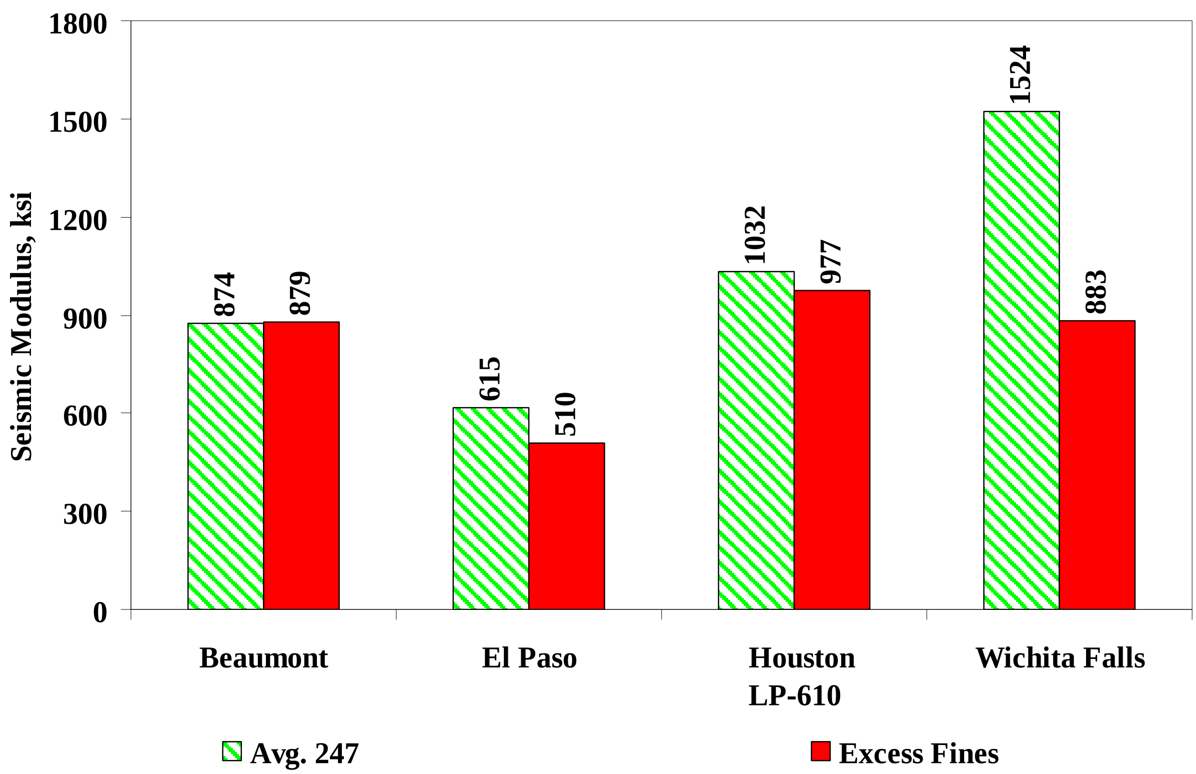


Figure 5.33 – Impact of Fines Content Variation on Modulus for Tex-126-H Protocol.

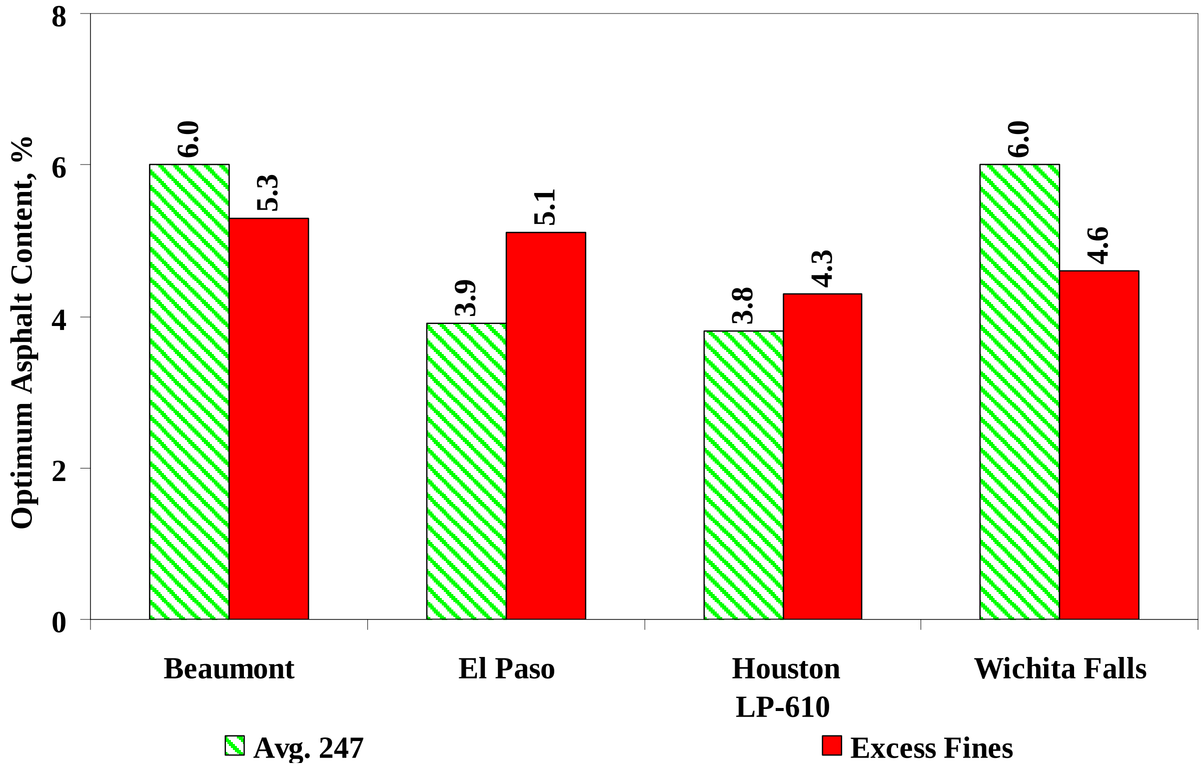


Figure 5.34 – Impact of Fines Content Variation on OAC for Tex-204-H.

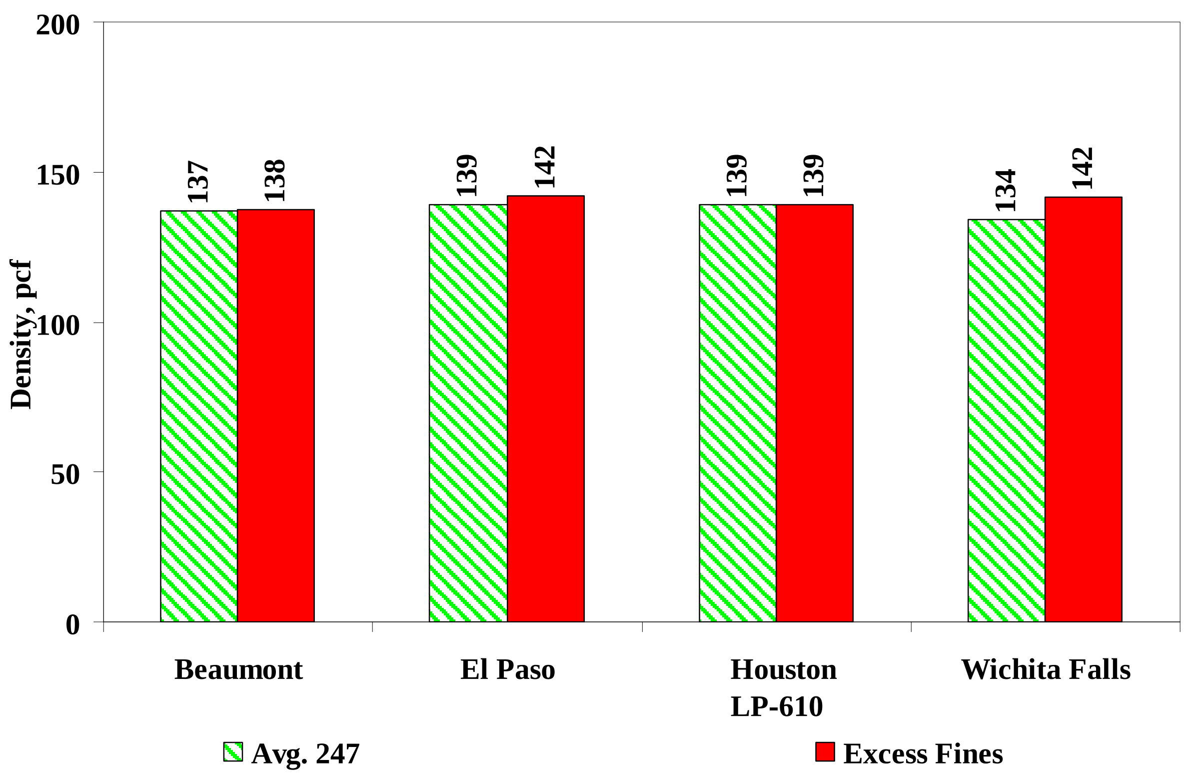


Figure 5.35 – Impact of Fines Content Variation on Density for Tex-204-H.

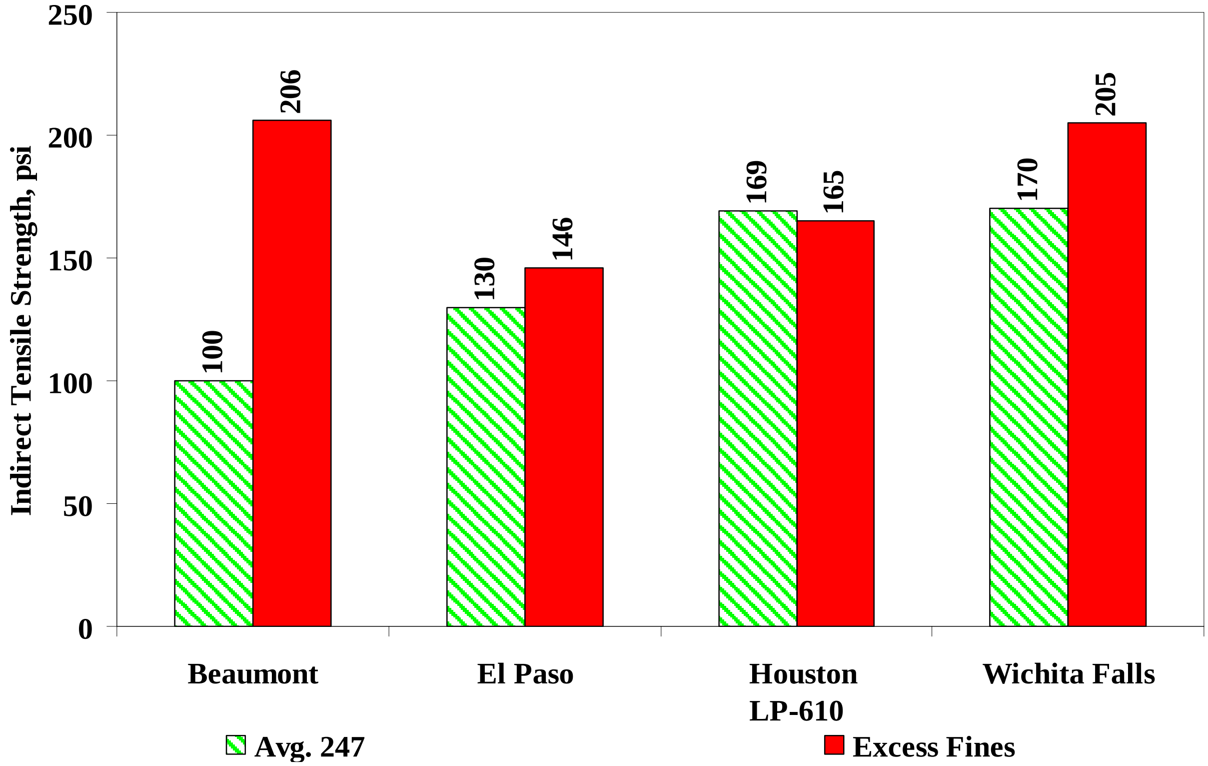


Figure 5.36 – Impact of Fines Content Variation on IDT for Tex-204-H.

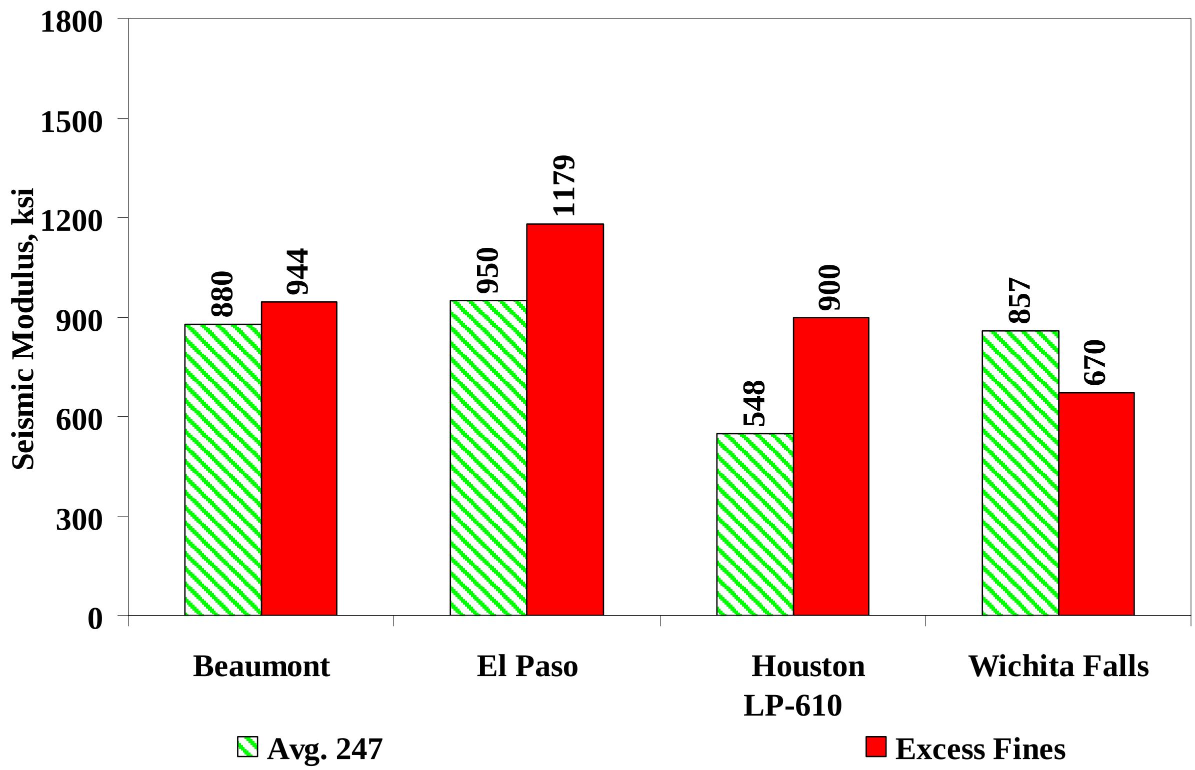


Figure 5.37 – Impact of Fines Content Variation on Modulus for Tex-204-H.

Proposed Mix Design Protocol

As discussed before, two alternative mix design protocols were considered. The salient features of these two protocols are compared with those from the existing Tex-126-E and Tex-204-F in Table 5.4. Other practical factors, such as the availability of equipment and ease in specimen preparation and curing were also considered. To minimize the training required for TxDOT staff, an attempt was made to adapt the existing test procedures as much as possible.

The protocol called Tex-204-H is recommended for the mix design of the ATB. A draft protocol for implementing Tex-204-H is included in Appendix B. The justification for selecting this protocol is provided in the remainder of this chapter.

Table 5.4 – Summary of Mix Design Methods Studied

Mix Design Protocol	Tex-126-E	Tex-204-F	Tex-126-H	Tex-204-H
Compactor	TGBC	SGC	SGC	SGC
Specimen Size, in.	6x8	6x4.5	6x8	6x4.5
OAC based on	Asphalt Density Curve	Volumetric Properties	Asphalt Density Curve	Asphalt Density Curve
Curing Duration and Temperature	48 hrs @140°F	48 hrs @77°F	24 hrs @140°F	24 hrs @ 77°F
Curing/Testing Temperatures, °F	140	77	77	77
Strength Test	UCS	IDT	UCS	IDT

- **Compaction Device:** Because of the availability of the Superpave Gyratory Compactors (SGC) in all districts and scarcity of the Texas Gyratory Compactors (TGBC), the SGC was selected. This will save funds to refurbish or acquire TGBC devices and minimizes the training of the district technicians.
- **Specimen Size:** Standard 6 in. x 4.5 in. specimens are recommended because of ease in preparation, requiring less material for mix design and more uniformity in specimens.
- **Density Calculation**: The density is calculated by dividing the weight of the molded specimen over its volume as done in Item 247, "Flexible Base".
- **Number of Gyrations:** Tentatively, a number of gyrations of 75 is proposed. As shown in Table 5.5, density is not very sensitive to the changes in the asphalt content for the ATB mixes, which may lead to uncertainty in determining the OAC. The greater this value is, the better the asphalt content density curve is defined. The highest sensitivity is obtained for the number of gyrations of about 80. Since the 75 gyrations are already included in Tex-204-F, that number was selected. Such a number of gyrations is recommended because of the sensitivity of the asphalt content to strength and modulus. Table 6.2 shows the average sensitivity of these parameters for Tex-126-H and Tex-204-H protocols for the six different types of materials used in this study. Again, the highest sensitivities for strength and modulus are obtained at around 80 gyrations.

Table 5.5 – MD Curve Sensitivity Results

Gyrations	Density		Strength		Modulus	
	UCS	IDT	UCS	IDT	UCS	IDT
60 Gyrations	2%	4%	43%	61%	50%	33%
80 Gyrations	4%	5%	64%	61%	75%	47%
100 Gyrations	2%	3%	48%	45%	55%	22%
TGBC	3%	NF	68%	NF	80%	NF*

*** NF – Not Feasible to Compact**

- **Strength Parameter:** Indirect tensile strength tests (IDT) was selected as the surrogate strength test because of the size of the specimen prepared (6 in. diameter and 4.5 in. height) and sensitivity of IDT to asphalt content.
- **Curing and Testing temperature.** Curing temperature of 77^{o}F for 24 hrs and testing at 77^{o}F are recommended. This will reduce the mix design time and eliminates the need for additional equipment for high-temperature curing of specimens (see Chapter 5 for more detail).
- **Strength Requirement:** A minimum strength of 85 psi as per TxDOT Item 344 is recommended.
- **Moisture Susceptibility:** Even though there are some concerns about the moisture susceptibility of ATB. None of the specimens tested as part of this research exhibited any signs of stripping or moisture susceptibility. As such, such a requirement has not been added to the specification.
- **Maximum Asphalt Content:** The maximum asphalt content is limited to 6% for economic reasons. If more than 6% binder is required for a given mix, either an alternative source or alternative gradation is recommended. Alternatively, a Type A or B mix can be explored.

Determination of OAC

In order to determine the OAC the following steps are recommended:

1. Develop IDT-density-asphalt content curves such as the one shown in Figure 5.38.
2. Estimate the maximum density, MD.
3. Convert the density to relative density by dividing the measured densities by the maximum density as shown in Figure 5.39.
4. Report the minimum asphalt content, AC_{mim}, at the asphalt content where the maximum density is archived (i.e., relative density equal 100%) as marked in Figure 5.39.
5. Determine the maximum asphalt content (not to exceed 6%), where the relative density is equal to 97%, $AC_{max,d}$, as marked in Figure 5.39.
6. Determine the maximum asphalt content (not to exceed 6%) where the IDT strength is equal to 85 psi, $AC_{max,s}$ (see Figure 5.39).
7. Report the maximum asphalt content, AC_{max}, as the minimum value of $AC_{max,d}$ and $AC_{max,s.}$

8. Select the average of the AC_{min} and AC_{max} as the OAC. This value is a compromise between the desired strength and the constructability of the mix.
9. The target field density should be equal to the density at the OAC, with the caveat that no test point should yield a relative density less than 97% during field quality management.

For the example for the mix shown in Figures 5.38 and 5.39, AC_{min} is 4.4% , AC_{max} is 5.4% and the OAC is 4.9% (say 5%). The target field density should be 142 pcf.

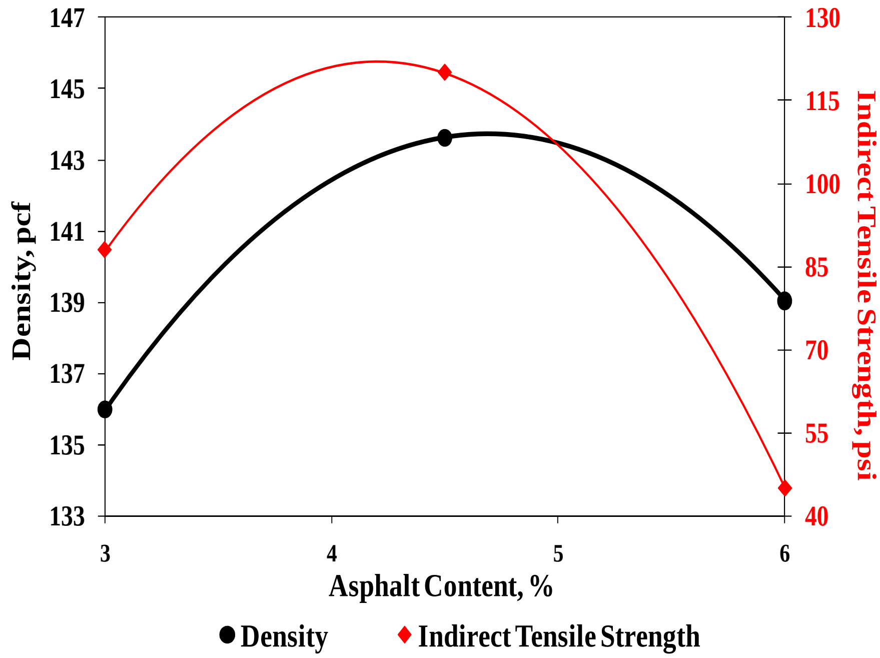


Figure 5.38 – Density/IDT Asphalt Content Combined Curves

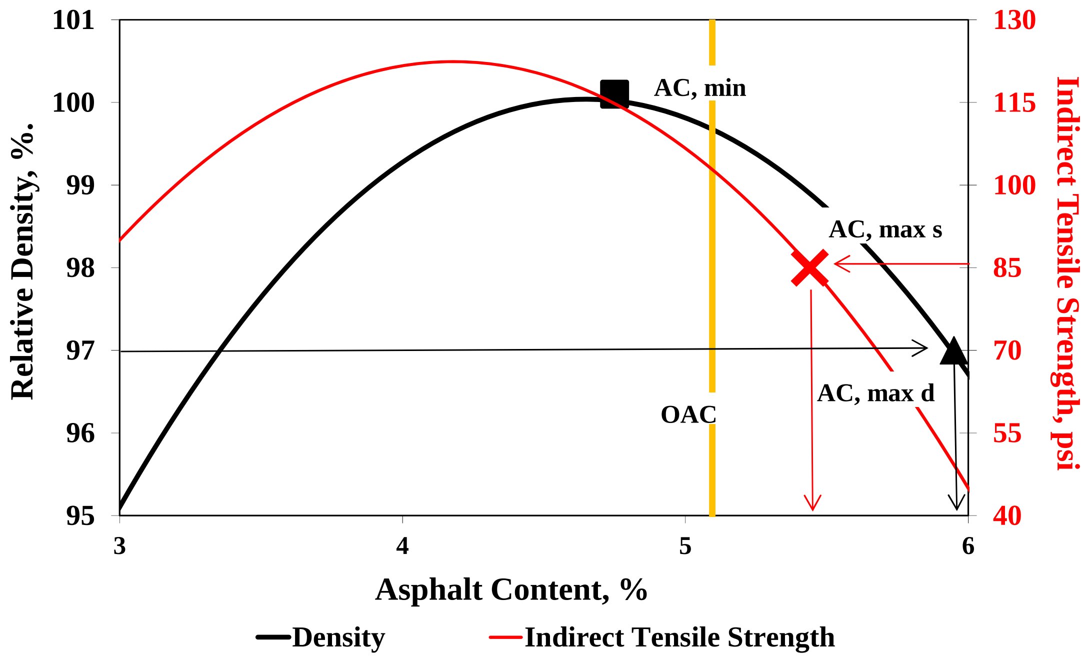


Figure 5.39 – Relative Density/IDT Asphalt Content Combined Curves

CHAPTER SIX – FIELD PERFORMANCE MONITORING

In this chapter the information obtained from field investigation conducted before, during and after construction at five sites is presented. Figure 6.1 shows the locations of the five sites that were monitored. These sites were located in Alpine in El Paso District, Beltway 8 and FM 526 (Federal Rd) in Houston District, and FM 943 and FM 2798 in Beaumont District.

The pavement profile of each site is shown in Figure 6.2. The ATB layers varied in thickness between 8 in. and 10 in. All sites were covered with surface treatment, expect for Alpine that the ATB was covered with a concrete slab, and Houston Beltway 8 that the ATB was not covered at all.

Materials used to produce the mixture were collected from the plants for laboratory tests. During construction, plant-produced mixtures were also collected and taken to the laboratory for index and strength tests. A Portable Seismic Property Analyzer (PSPA) was used about 24 hrs, 6 months and 12 months after field compaction at selected stations. Falling Weight Deflectometer (FWD) tests were performed approximately 6 and 12 months after construction. Cores were also extracted from most sites at selected stations. The laboratory and field properties were compared with the materials and information gathered at each site. The results and conclusions of this activity are presented in this chapter.

Laboratory Results

Raw Materials

The gradation curves of the combined blend from materials collected at the quarries are shown in Figure 6.3. Since the same quarry materials were used for both projects in Houston and Beaumont, only one mix design was used for each district. To prepare the mix design from each source, the entire stock was sieved first to develop a global gradation curve. That gradation curve was used throughout the study. The acceptable tolerances as per Item 292 Grade 1 are also shown in the figure. All gradation curves met the requirements of Item 292.

As shown in Table 6.1, the Alpine materials had a Plasticity Index (PI) of 4 while Beaumont and Houston materials were non-plastic. The sand equivalency and aggregate hardness for each material are also presented in Table 6.1. The Houston and Beaumont materials met the sand

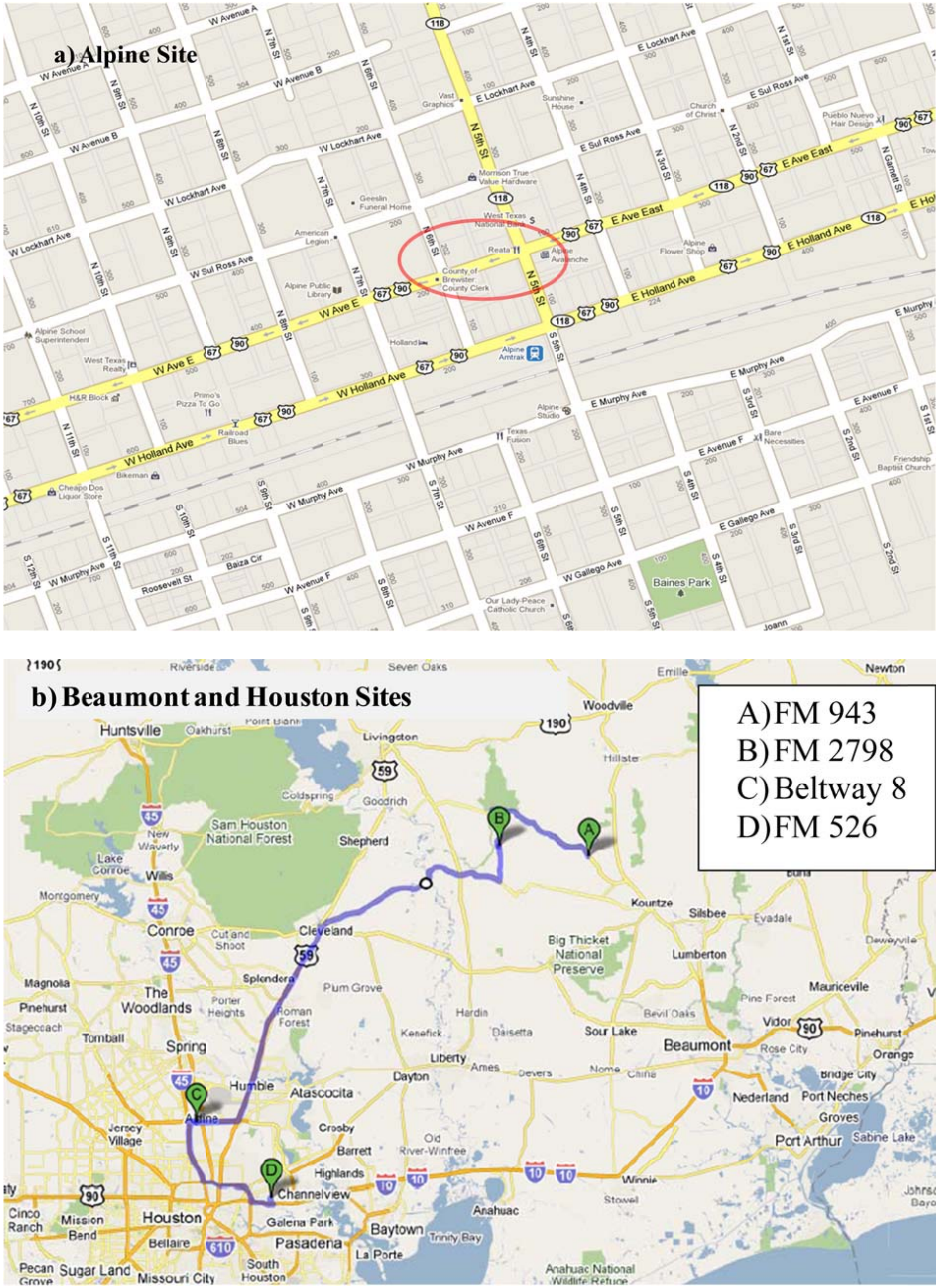


Figure 6.1 – Locations of Sites Visited used in this Study

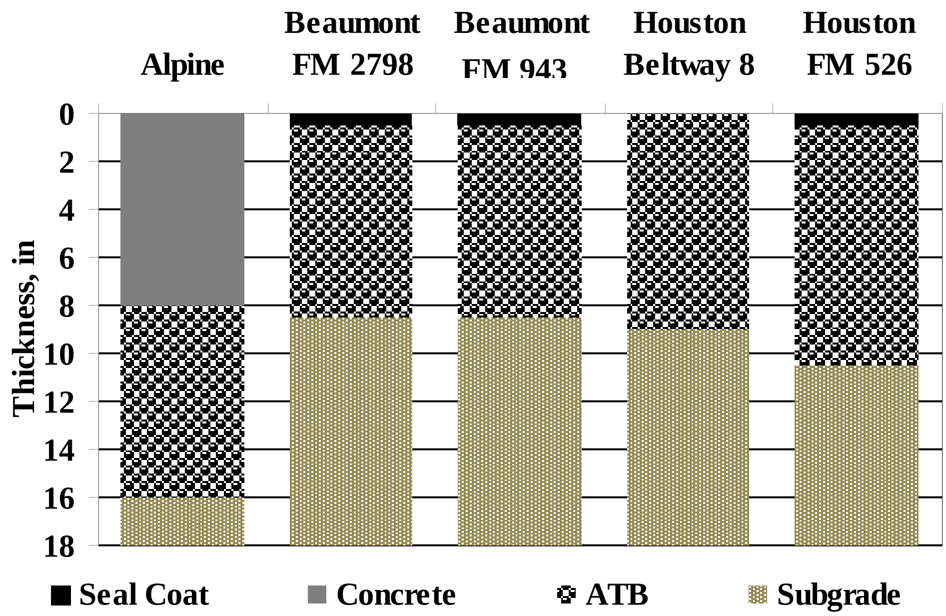


Figure 6.2 – Pavement Profiles for Sites Visited in this Study

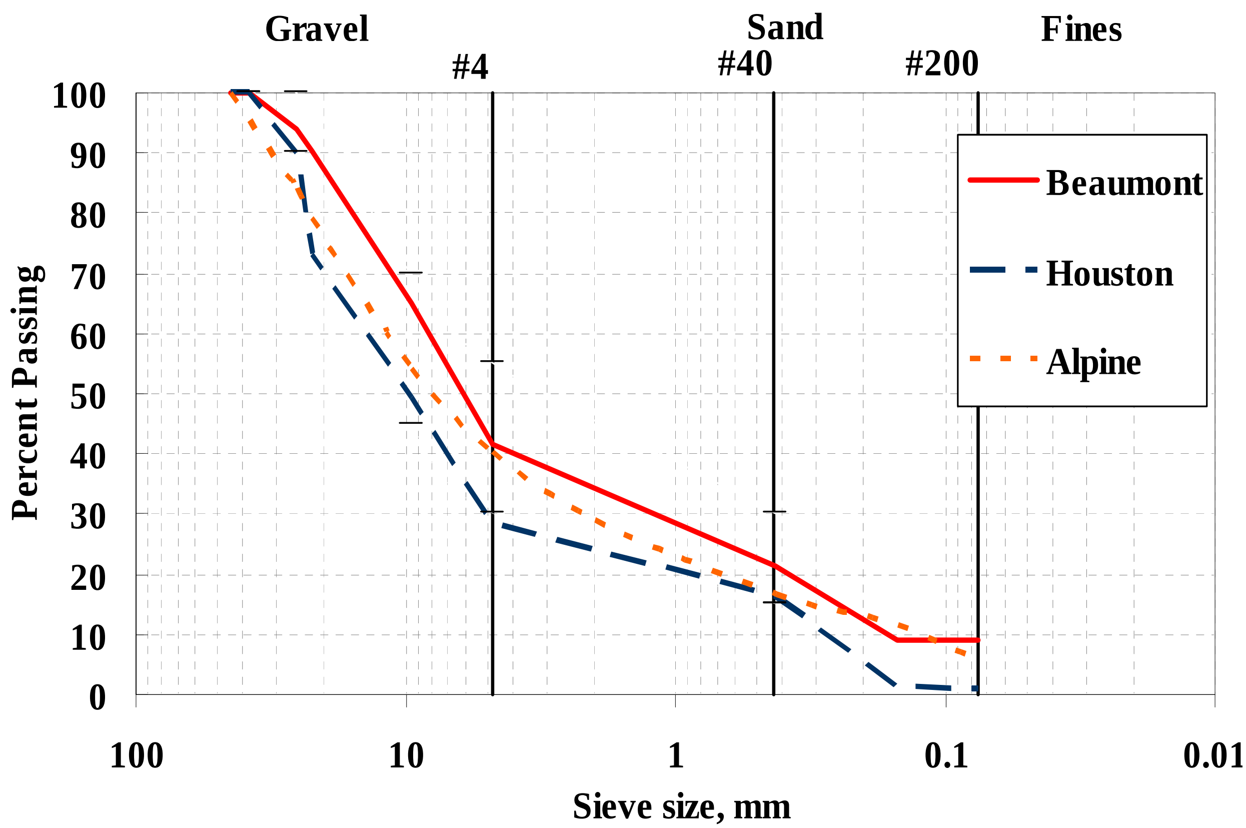


Figure 6.3 – Laboratory Gradation Curves for Alpine, Beaumont and Houston Materials

equivalency requirements while the Alpine material did not. The Wet Ball Mill test results are within acceptable range for all sites.

Table 6.1 – Sand Equivalency, Wet Ball Mill and Hardness for Materials Used

Parameter	Alpine	Beaumont	Houston	Specification Requirement
Plasticity Index	4	Non Plastic	Non Plastic	10 max
Sand Equivalency, %	34	86	63	40 min
Wet Ball Mill, %	27	31	26	50% max
				20% Max increase

Figures 6.4 through 6.6 show the test results for determining the OAC for the Alpine, Beaumont and Houston materials, respectively. The AC_{min} varied between 4% and 4.5%. Since the variations in the density with asphalt content were rather small and the IDT strengths in all cases were greater than 85 psi, an AC_{max} of 6% was assigned to all mixes. As such, the proposed OAC's for all mixes varied between 5% and 5.2%.

V-Meter moduli from laboratory specimens prepared for each site at different asphalt contents (AC) are shown in Table 6.2. The greatest moduli were recorded for the Houston material and the smallest for the Beaumont material. The Alpine material with 3% AC exhibited a low modulus because of difficulties in obtaining stable specimens perhaps because of the lack of fines. Since the moduli of the specimens with 4.5% and 6% AC were similar, the averages of these two moduli were used for comparison with field values.

Table 6.2 – Variations in Modulus with Asphalt Content for Alpine, Beaumont and Houston Materials

Sites	Alpine	Beaumont	Houston
AC, %	**Modulus, ksi**		
3.0	399	964	1062
4.5	1103	852	1215
6.0	1203	814	1286

Plant-Mixed Materials

The binder content of the plant-mixed material at each particular site and station was measured using an ignition oven. The averages and coefficients of variation (COV) of binder content are reported in Table 6.3. The design OAC of each site as provided by the District is also included in Table 6.3 as well. As per current TxDOT specifications, the asphalt content should not vary by more than 0.5% from the design OAC. All sites met this requirement except for the Beaumont FM 943 that had 0.7% more asphalt than target. All mixes contained more asphalt than their respective design OACs except for Alpine. Considering 5% to 5.2% target OAC recommended by this study, all mixes but the Beaumont FM 2798 meet or marginally meet the specification.

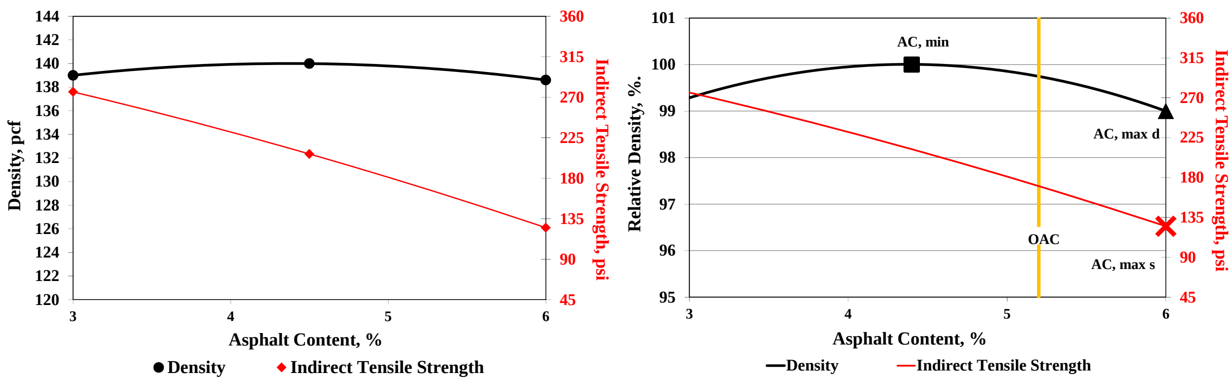


Figure 6.4 – Density/ Strength vs. Asphalt Content for Alpine Material

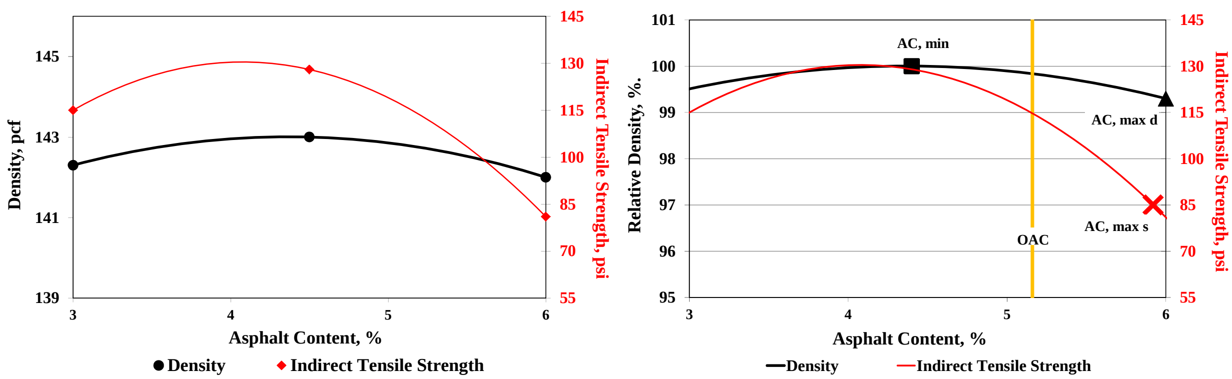


Figure 6.5 – Density/ Strength vs. Asphalt Content for Houston Material

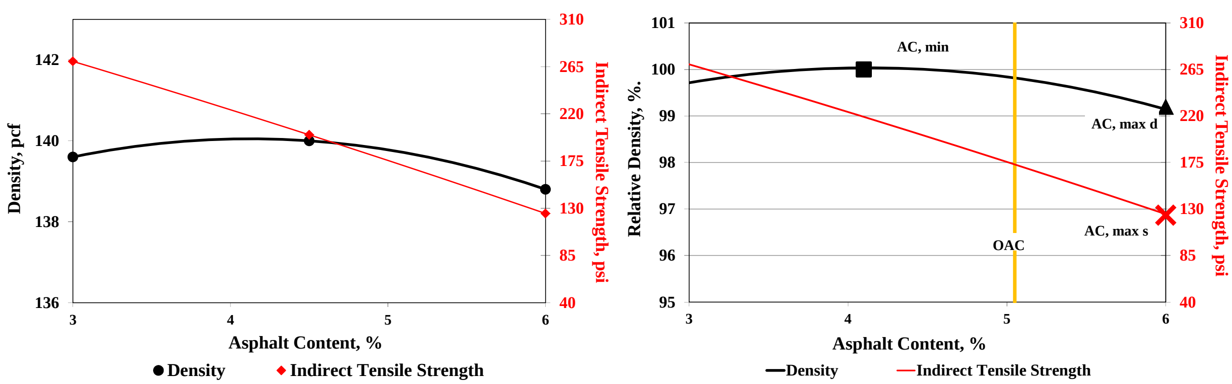


Figure 6.6 – Density/ Strength vs. Asphalt Content for Beaumont Material

Table 6.3 – Asphalt Contents of Plant-Mixed Materials

Site	Binder Content		
	As Designed by District, %	Average Field, %	COV Field, %
Alpine	6.0	5.5	4.3
Beaumont FM 2798	4.1	4.3	5.9
Beaumont FM 943	4.1	4.8	3.2
Houston Beltway 8	4.5	4.6	6.2
Houston FM 526	4.5	4.6	9.2

Average gradation curves for materials subjected to the ignition oven are presented in Figure 6.7 without correction factors. The original and the plant-mixed gradations of Alpine aggregates met the Item 292 requirements. Even though the Beaumont FM 943 and Houston FM 526 gradations obtained from the plant-mixed materials did not exactly follow their original design gradations, they still met the Item 292 requirements. The Houston Beltway 8 and Beaumont FM 2798 plant-mixed materials contained higher sand contents as compared to their respective original design gradations which mainly consisted of gravel. These two plant-mixed materials do not meet the Item 292 gradation requirements.

Bulk and theoretical maximum specific gravities (G_{mb} and G_{mm}, respectively) were obtained in accordance with Tex-227-F and Tex-207-F. The average and COV of each parameter, performed on ten specimens for G_{mm} and six specimens for G_{mb}, are shown in Table 6.4. The variability in the specific gravities as judged from COVs is rather small, and the air voids are all less than 4% (relative density is greater than 96%) which are close or exceed the 97% relative density proposed by the new protocol.

Table 6.4 – Bulk and Maximum Theoretical Specific Gravities for Plant-Mixed Materials Molded at 75 Gyrations

Site	G_{mm}		G_{mb}		Average Air Voids
	Average	COV, %	Average	COV, %	
Alpine	2.432	0.1	2.427	0.5	1.0%
Beaumont FM 2798	2.441	1.3	2.353	0.3	3.6%
Beaumont FM 943	2.465	0.8	2.377	0.3	3.6%
Houston Beltway 8	2.436	1.3	2.365	0.2	2.9%
Houston FM 526	2.477	1.1	2.404	0.3	3.0%

Three plant-mixed specimens were compacted to nominal dimensions of 6 in. x 4.5 in. using 75 gyrations of the SGC. These specimens were tested in the same fashion as those prepared for the proposed mix design (cured at 77°F for 24 hrs). The properties of these plant mixed specimens are shown in Table 6.5. The Alpine specimens are the densest but exhibited the lowest IDT strengths and the highest moduli as expected from a material with low fines content. Even though, the Beaumont FM 943 and Houston Beltway 8 specimens exhibited similar densities (142 pcf), the Beaumont specimens showed higher IDT but similar modulus values as compared to the Houston materials. This may be explained by the differences in gradations and sand equivalencies.

Field Observations and Activities

Six cores were extracted from the Alpine site, both Beaumont sites and Houston Beltway 8 site about 24 hrs after compaction. Coring at the Houston FM 526 was not permitted due to the criticality of the project. The average delivery and compaction temperatures of the mixes at the approximate locations of the cores are summarized in Table 6.6. The temperatures at delivery and compaction for the Alpine site were not recorded. According to Item 292, the delivery temperature must not exceed 350°F and compaction must be completed before temperature drops below 175°F. In this case, all the temperature readings met those requirements.

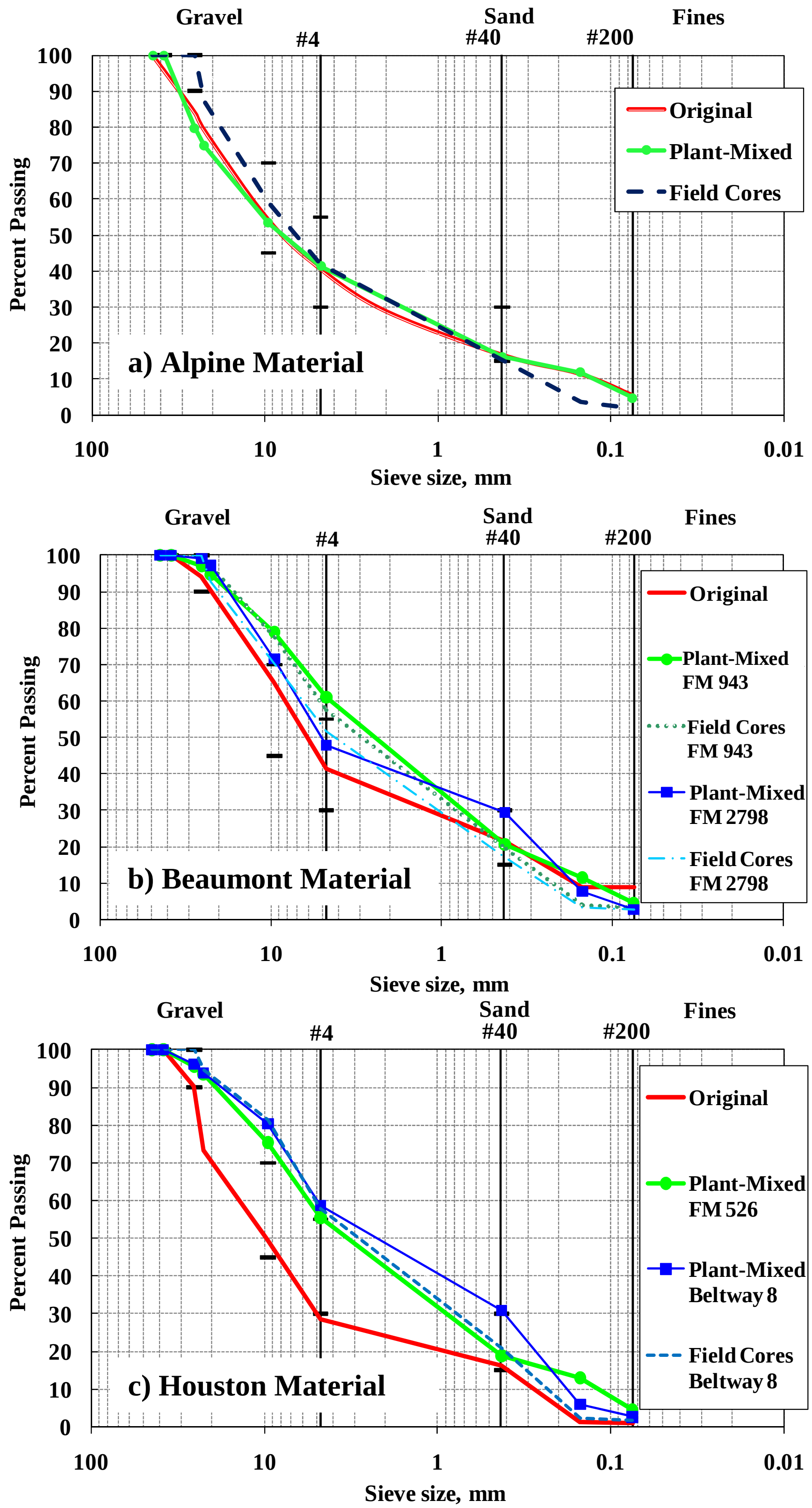


Figure 6.1 – Gradation Curves from Plant-Mixed Materials as Delivered

Table 6.5 – Properties of Plant-Mixed Molded using 75 Gyrations of SGC

	Density		IDT		Seismic Modulus	
	Average, pcf	COV, %	Average, psi	COV, %	Average, ksi	COV, %
Alpine	147	0.7	150	14.1	1189	1.1
Beaumont FM 2798	140	0.4	214	6.1	886	3.4
Beaumont FM 943	142	0.3	305	2.8	955	3.1
Houston Beltway 8	142	0.4	224	8.7	905	1.1
Houston FM 526	143	0.6	315	4.5	918	4.5

Table 6.6 – Delivery and Compaction Temperatures of Asphalt Material at the Sites

Material		Temperature	
		Average, °F	COV, %
Beaumont FM 2798	**Delivery**	289	3.5
	Compaction	228	3.0
Beaumont FM 943	**Delivery**	300	5.0
	Compaction	217	7.4
Houston Beltway 8	**Delivery**	273	6.6
	Compaction	209	2.7
Houston FM 526	**Delivery**	220	1.4
	Compaction	202	2.1

The G_{mb} based on the weight, volume and air voids of every core were measured in the laboratory as summarized in Table 6.7. Comparing the results listed in Tables 6.4 and 6.5 with Table 6.7, the cores' air voids are significantly higher and their densities are significantly lower than those of the plant-mixed materials molded by the SGC at 75 gyrations.

The average modulus and IDT strength of five random cores at each site are shown in Table 6.8. The Alpine and Houston Beltway 8 field cores showed higher IDT strengths and moduli.

Table 6.7 – Volumetric Properties of Field Cores

Sites	Density, pcf		G_{mb}		Air Voids, %*
	Average	COV, %	Average	COV, %	
Alpine	145	3.7	2.377	2.3	2.3
Beaumont FM 2798	129	3.9	2.143	4.0	12.2
Beaumont FM 943	124	3.7	2.094	5.2	15.1
Houston Beltway 8	136	4.3	2.288	2.3	6.1

*** G_{mm}'s in Table 6.4 was used to calculate air voids**

Table 6.8 – Strength and Modulus obtained from Field Cores

Site	IDT Strength		Modulus	
	Average, psi	COV, %	Average, ksi	COV, %
Alpine	145	16.6	891	8.8
Beaumont FM 2798	91	58.0	463	35.9
Beaumont FM 943	86	13.7	380	20.3
Houston Beltway 8	159	29.4	770	18.8

Field Results

The available PSPA moduli obtained after 24 hrs and approximately 6 and 12 months after construction of the ATB are shown in Figure 6.8. The PSPA tests could not be performed six and twelve months after construction at the Alpine site because it was covered with a concrete slab. We were unable to collect PSPA and FWD data for Houston Beltway 8 after 12 months because of the closure of the lane was not possible. These tests could not be performed on the Houston Beltway 8 after 12 months either. PSPA moduli increased in the first 6-month for all sites tested except for Houston Beltway 8 where the ATB was exposed to the environmental elements and was trafficked lightly. Further increases in the moduli are observed at all sites 12 months after construction.

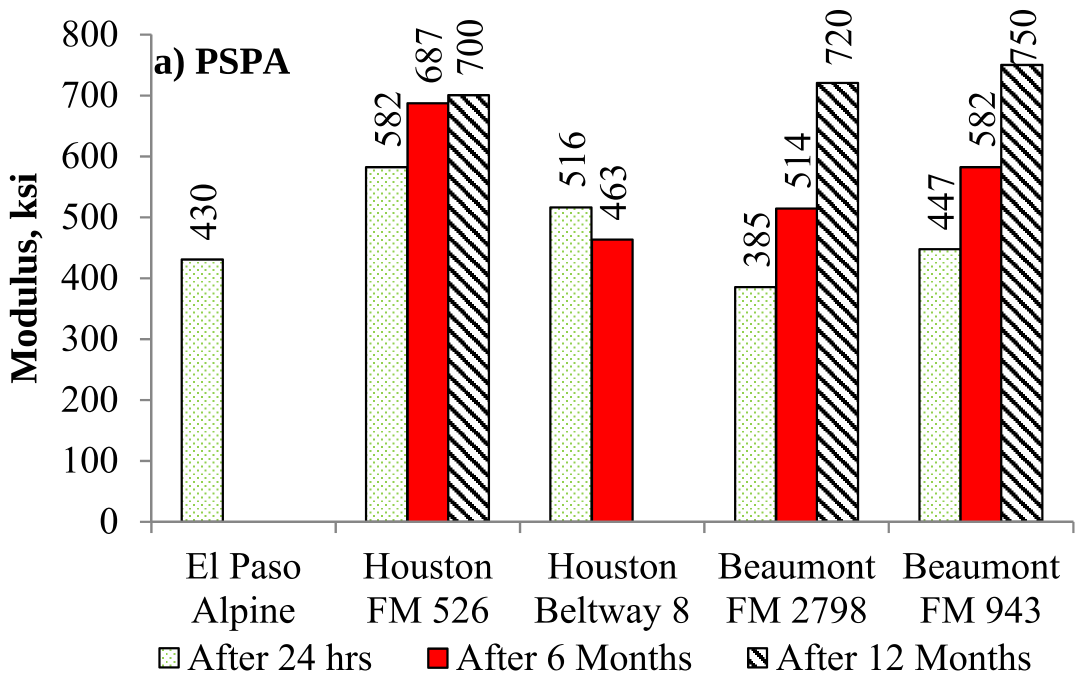
The backcalculated FWD moduli for all sites are also shown in Figure 6.8. The Alpine FWD results are questionable because deciphering the moduli of the ATB under a concrete layer is rather difficult. For the other sites, the moduli after 6 and 12 months are similar.

Comparison of Laboratory and Field Results

The air voids from the plant-mixed materials molded at 75 gyrations using the SGC are compared with the air voids of the field cores in Figure 6.9. The air voids of the field cores are considerably higher for all sites as compared to the lab-molded specimens. Similarly, the densities for the plant-mixed materials molded at 75 gyrations are substantially different than those from field cores as reflected in Figure 6.10.

A study was carried out to observe the number of gyrations required to match the field densities in the lab specimens. It was impossible to simulate the Beaumont FM 943 field densities in the lab. The lowest density that could be obtained with the SGC was 128 pcf by just applying the weight of the ram. Beaumont FM 2798 and Houston Beltway 8 materials reached their corresponding field densities after 3 and 15 SGC gyrations, respectively. About 66 gyrations were needed to reach the average field density for the Alpine material.

As shown in Figure 6.11, the IDTs of specimens molded at 75 gyrations are naturally higher at all sites as compared to those from cores extracted from the field. In addition, the IDTs of the lab specimens compacted to field densities are also marginally to significantly higher than the cores. The same trend is also observed for the seismic moduli of the specimens as shown in Figure 6.12.



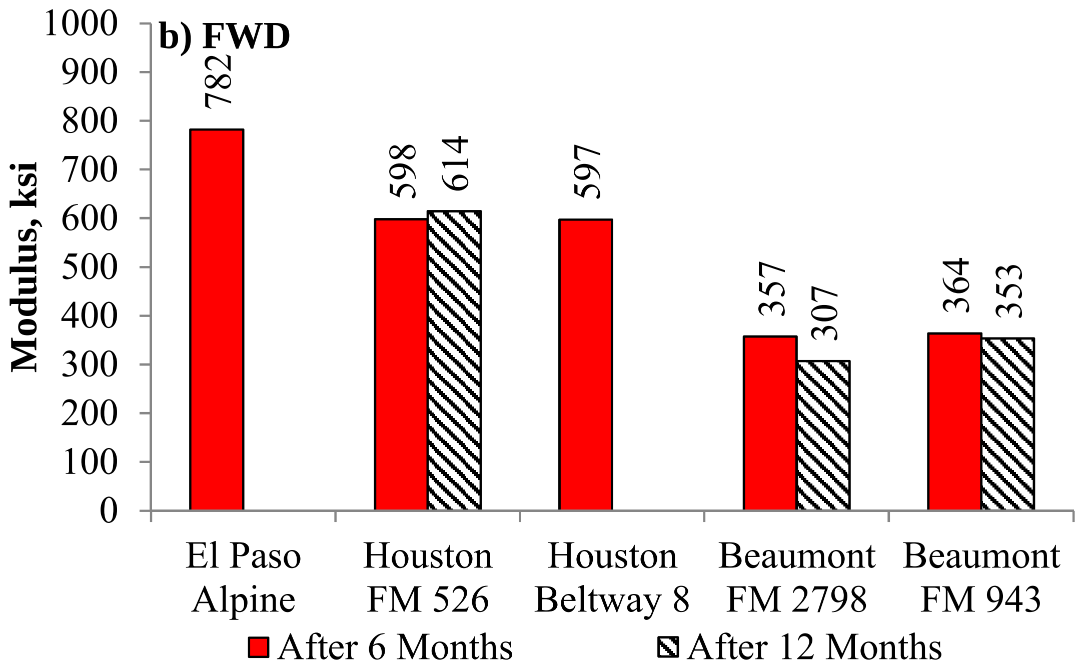


Figure 6.8 - PSPA and FWD from ATB Sites.

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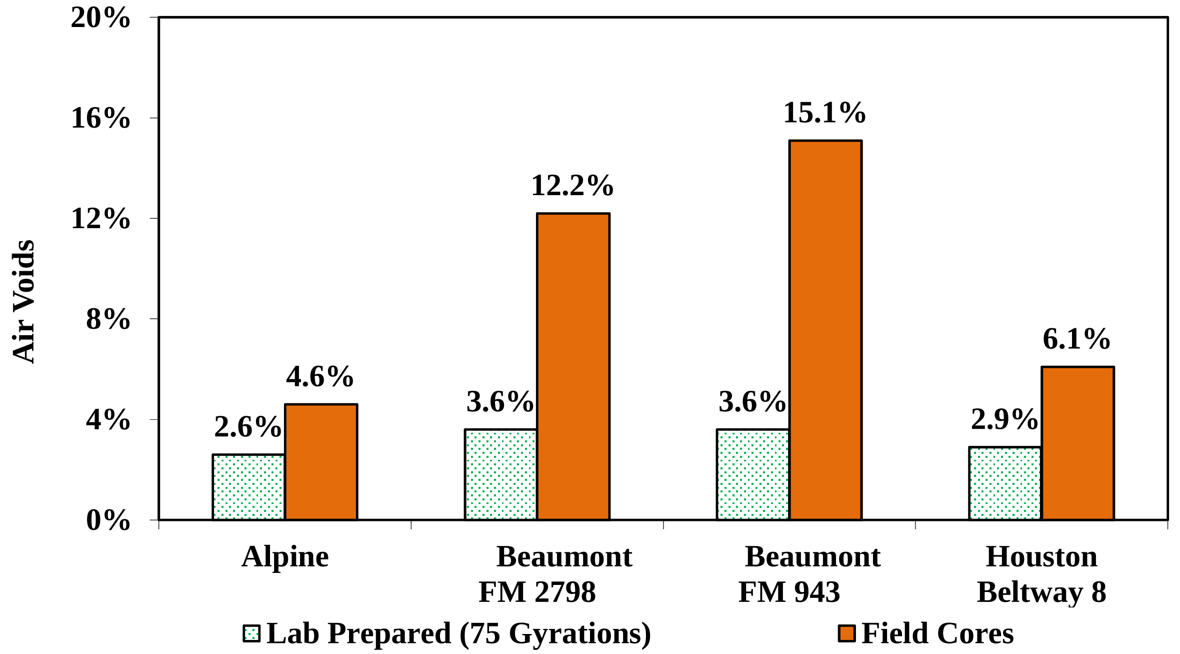

Figure 6.9 - Comparison between Air Voids of Laboratory Specimens and Field Cores

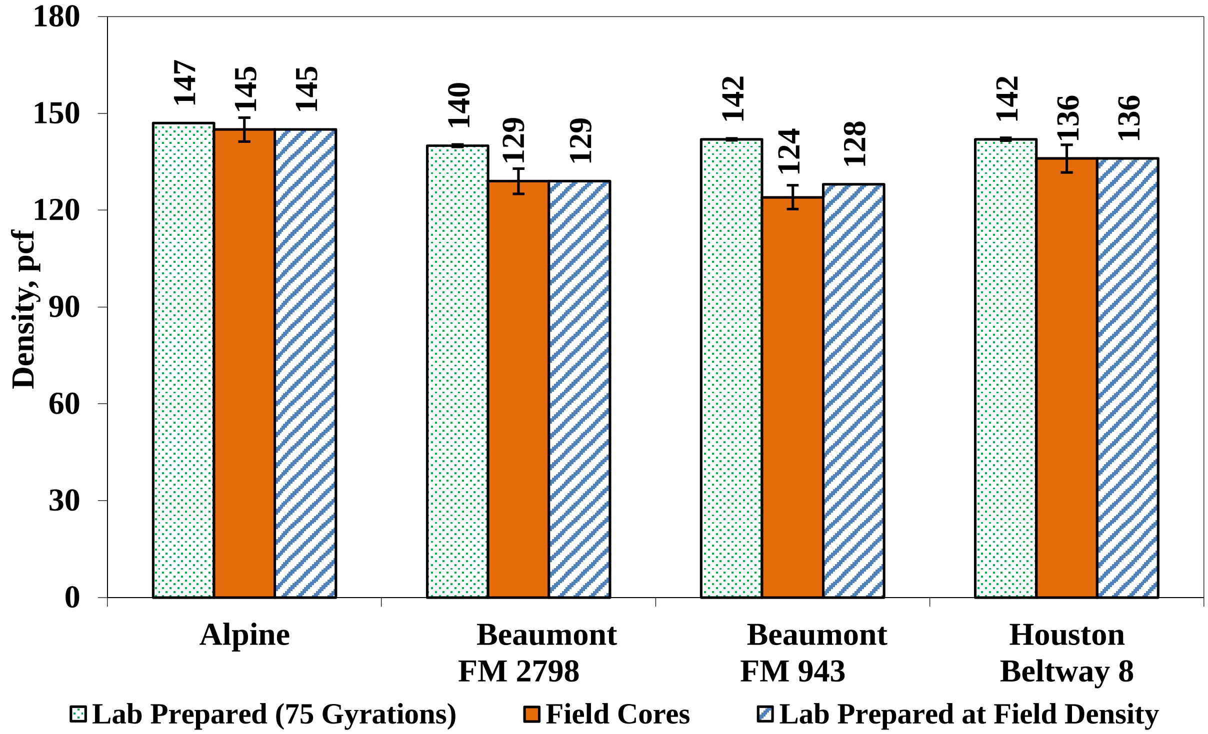

Figure 6.10 - Comparison between Densities of Laboratory Specimens and Field Cores.

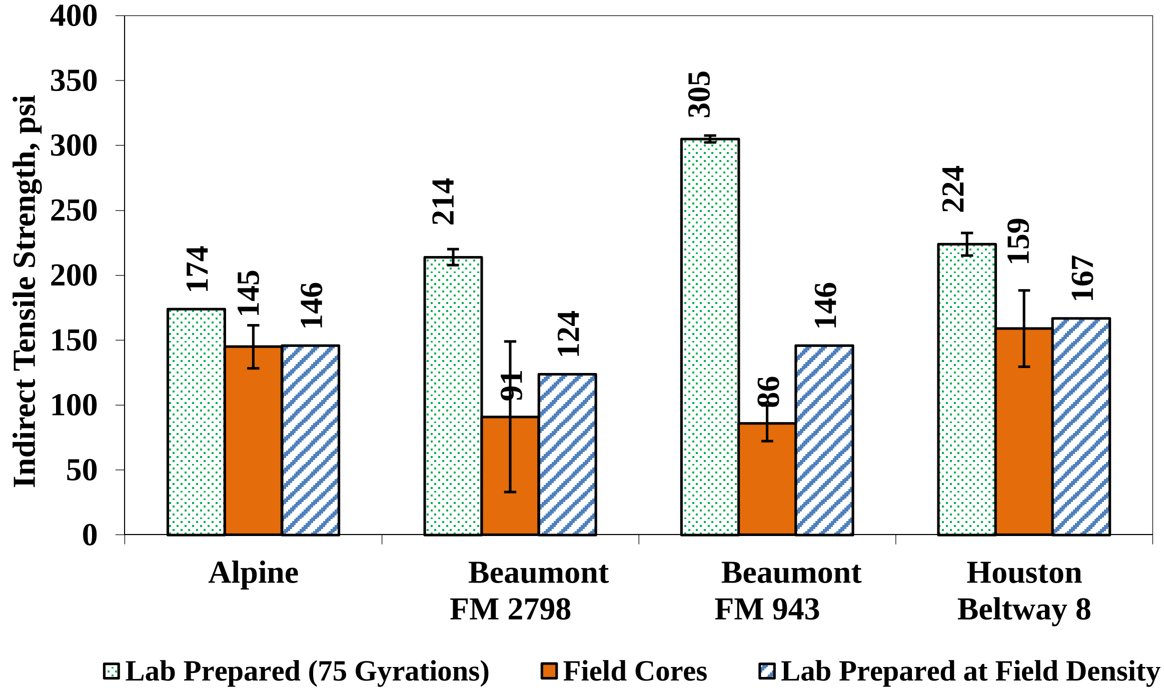

Figure 6.11 - IDT Comparison between Laboratory and Field Specimens.

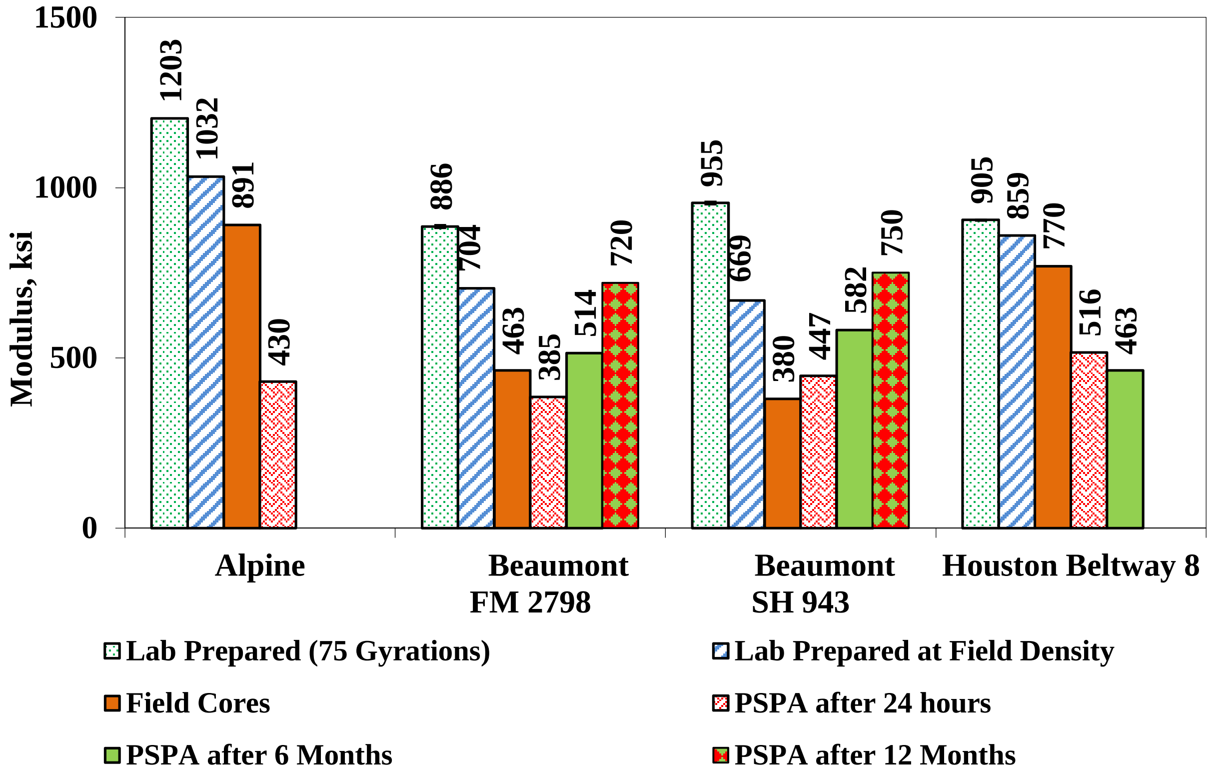

Figure 6.12 - Modulus Comparison between Laboratory and Field Specimens

The moduli obtained from the PSPA are also included in Figure 6.12 for comparison. Only six cores were tested with the v-meter whereas the PSPA values correspond to a much larger number of data points. The moduli obtained from specimens compacted to the field densities are typically comparable to the PSPA moduli 6 to 12 months after construction except for the Houston Beltway 8 site. As indicated before, this site was exposed to environment and was not trafficked.

The dynamic modulus test results at a frequency of 10 Hz and a temperature f 77°F for all mixes are shown in Figures 6.13. The specimens for these tests were prepared from plant-mixed materials using 75 gyrations of SGC as opposed to the 7% nominal air voids typically recommended for HMA specimens. For that reason, the dynamic moduli are higher than those observed for HMA specimens. All mixes seem to provide adequate modulus for a stabilized material with Beaumont FM943 providing the highest modulus.

The results from flow time tests are shown in Figure 6.14 as a means to evaluate the rutting potential of these materials. None of the materials exhibited a tertiary behavior. The permanent strains after 10,000 seconds of loading have a invers correlation to the dynamic modulus. Beaumont FM 943 which has the highest dynamic modulus exhibited the lowest maximum strain. In general, these materials exhibit good potential for not rutting under traffic load.

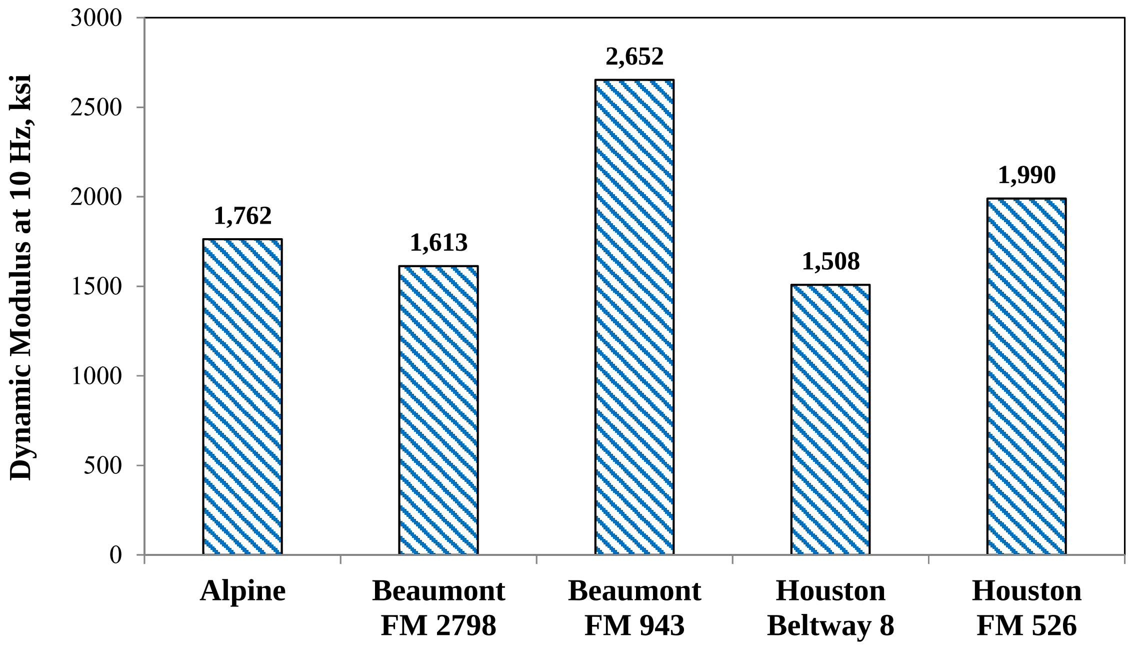

Figure 6.13 - Dynamic Modulus Results

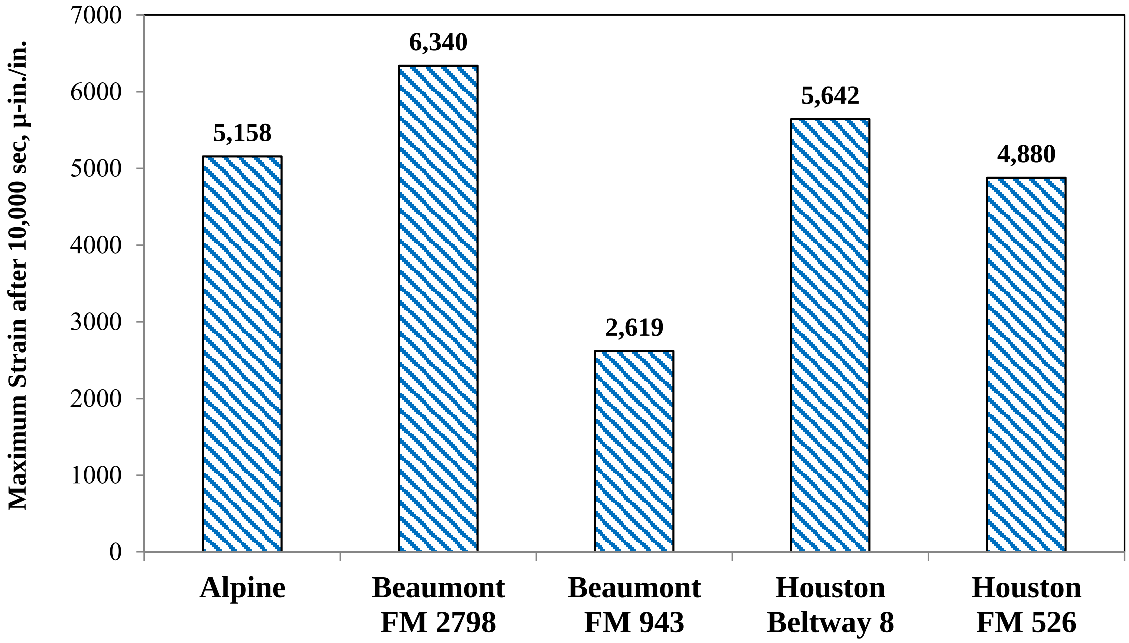

Figure 6.14 - Flow Time Results

Recommendation on Construction Specifications

Based on extensive field observations during construction and the field results documented above, the current TxDOT construction specifications seem adequate as long as they are enforced. Better process control on the gradation and binder content is recommended. Also, the criticality of achieving at least 97% relative density should be emphasized perhaps through training. Unlike thin layers of HMA that are usually placed with higher air voids (lower relative densities), the usually 8 in. to 10 in. thick ATB layers should be compacted as close as possible to the maximum density and in multiple lifts to achieve the desired density and to minimize the moisture damage to that layer.

CHAPTER SEVEN – COST BENEFIT ANALYSIS

A comparative study of local ATB and Type B mixes from El Paso and Houston Districts is presented in this chapter. Two mixes from two different plants in Houston District (called Houston 1 and Houston 2) were studied. Since Type B mixes used in Beaumont District are typically provided by similar plants in the Houston District, the results from Houston Type B mixes were also compared with those from Beaumont ATBs. The Type B plant-mixed materials were collected and transported to the laboratory for further testing. The PSPA and FWD field tests were performed at two sites where these materials were placed. As part of laboratory tests, prepared specimens from plant-mixed materials and cores were also evaluated. A comparison of relevant performance parameters from ATB and Type B was carried out. Finally, a cost benefit analysis between ATB and Type B mixes was performed.

Laboratory Results for Type B Materials

Plant-Mixed Materials

The El Paso and Houston 1 mixes were designed as per Item 340, whereas the Houston 2 mix was designed as per Item 341. All mixes utilized PG 64-22 binder. The average and coefficient of variation (COV) of binder content at each site from three samples placed in ignition oven are reported in Table 7.1. The Houston 1 and Houston 2 materials contained average asphalt contents that were about 1% greater than the design values.

Table 7.1 – Asphalt Contents of Plant-Mixed Materials

Mix	Mix Type Designation	As-Designed Binder Content,%	Mix Binder Content	
			Average, %	COV, %
El Paso	340	4.6	4.9	9
Houston 1	340	4.5	5.5	8
Houston 2	341	4.5	5.4	8

Average gradation curves for the three materials are presented in Figure 7.1. The corresponding specified ranges are also shown in the figure. The gradations obtained from the plant-mixed materials do not meet the Item 340/341 gradation requirements. The gradations of the field cores subjected to the ignition oven are also plotted in Figure 7.1. These gradations are finer than Item 340/341 requirements.

The average and COV of G_{mm} and G_{mb} performed on three specimens from each mix are shown in Table 7.2. For comparison purposes with the ATBs, the specimens were prepared with 75 gyrations of SGC. The variability in the specific gravities as judged from COVs is rather small, and the air voids are all less than 4%.

Table 7.2 – Bulk and Maximum Theoretical Specific Gravities for Plant-Mixed Materials Molded at 75 Gyrations

Mix	G_{mm}		G_{mb}		Average Air Voids, %
	Average	COV, %	Average	COV, %	
El Paso	2.421	0.3	2.358	0.3	2.6
Houston 1	2.428	0.8	2.342	0.7	3.5
Houston 2	2.408	0.3	2.365	0.5	1.8

IDT strengths and seismic moduli from triplicate specimens of plant-mixed materials compacted to nominal dimensions of 6 in. x 4.5 in. using 75 gyrations of the SGC are shown in Table 7.3. These specimens were cured at 77°F for 24 hrs and tested at 77°F for comparison with the ATB specimens.

Table 7.3 –IDT and Seismic Modulus Results for Plant-Mixed Material Molded at 75 Gyrations

Mix	IDT		Seismic Modulus	
	Average, psi	COV, %	Average, ksi	COV, %
El Paso	144	0.7	844	2.2
Houston 1	184	12.4	984	3.3
Houston 2	271	8.2	979	3.3

Field Cores

Two cores were extracted from the El Paso site and six from the Houston 1 site about 24 hrs after compaction. Measured air voids are summarized in Table 7.4. The moduli and IDT strengths of the cores are shown in Table 7.4. Some variations in IDT strengths are observed. The average IDT strength for Houston 1 site is higher than the El Paso site, while the moduli are comparable.

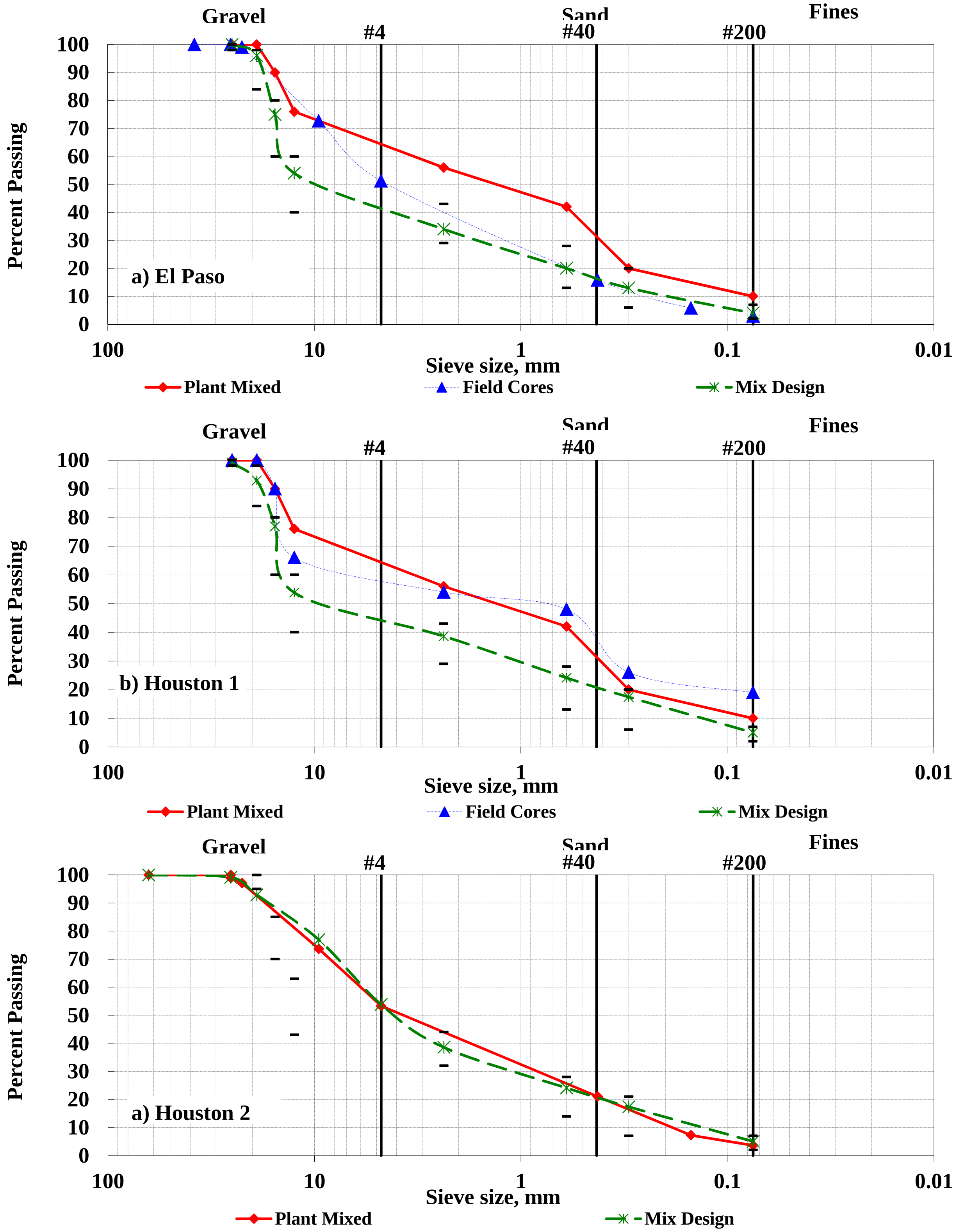

Figure 7.1 –Gradation Curves from Type B Materials

Table 7.4 – Air Voids, IDT and Modulus Results for Type B Field Cores

Site	Parameter	Air Voids	IDT, psi	Modulus, ksi
El Paso	Average	7.5%	117	876
	COV	13%	5%	6%
Houston 1	Average	7.5%	187	872
	COV	15%	35%	12%

Field Results

At this point in time no evidence of distress was observed at any of the ATB or Type B sites. PSPA and FWD tests were conducted at selected stations at the two sites. The average PSPA and the backcalculated FWD moduli are shown in Table 7.5. The average PSPA modulus for Houston 1 site is higher than the El Paso site. The FWD tests for the El Paso site were only performed 24 hrs after compaction since this site was near an intersection and the road could not be closed to perform the test after 6 months. For Houston 1 site, the seismic modulus increased with time.

Table 7.5 – PSPA and FWD Results for Type B Sites

Parameter	Time	Site	El Paso	Houston 1
PSPA Modulus	24 hr	Average, ksi	489	677
		COV, %	9	10
	6 Months	Average, ksi	N/A	800
		COV, %	N/A	13
FWD Modulus		Average, ksi	393*	772
		COV, %	32	37

* performed 24 hrs after compaction

Performance of ATB and Type B Mix Materials

An important parameter that controls the cost and performance of the ATB and HMA mixtures is the asphalt content. As shown in Figures 7.2, the asphalt content of the El Paso Type B HMA was less than the asphalt content of the ATB mix; whereas the Houston Type B HMA mixes contained similar or slightly higher asphalt contents than the ATB mixes from Houston and Beaumont.

The densities from the HMA mixes are compared with the densities of the ATB mixes in Figure 7.3. The lab densities of the specimens prepared with 75 gyrations of SGC are higher for the El Paso ATB as compared to the HMA but it is similar for the Houston and Beaumont mixes. However, the densities from the ATB or HMA field cores for the Houston and Beaumont mixes are less than the lab values. This indicates that perhaps the ATB mixes from Houston and Beaumont should be compacted with heavier equipment to achieve higher densities. The densities for the HMA mixes are reasonable given the current TxDOT specification requiring approximately 8% air voids.

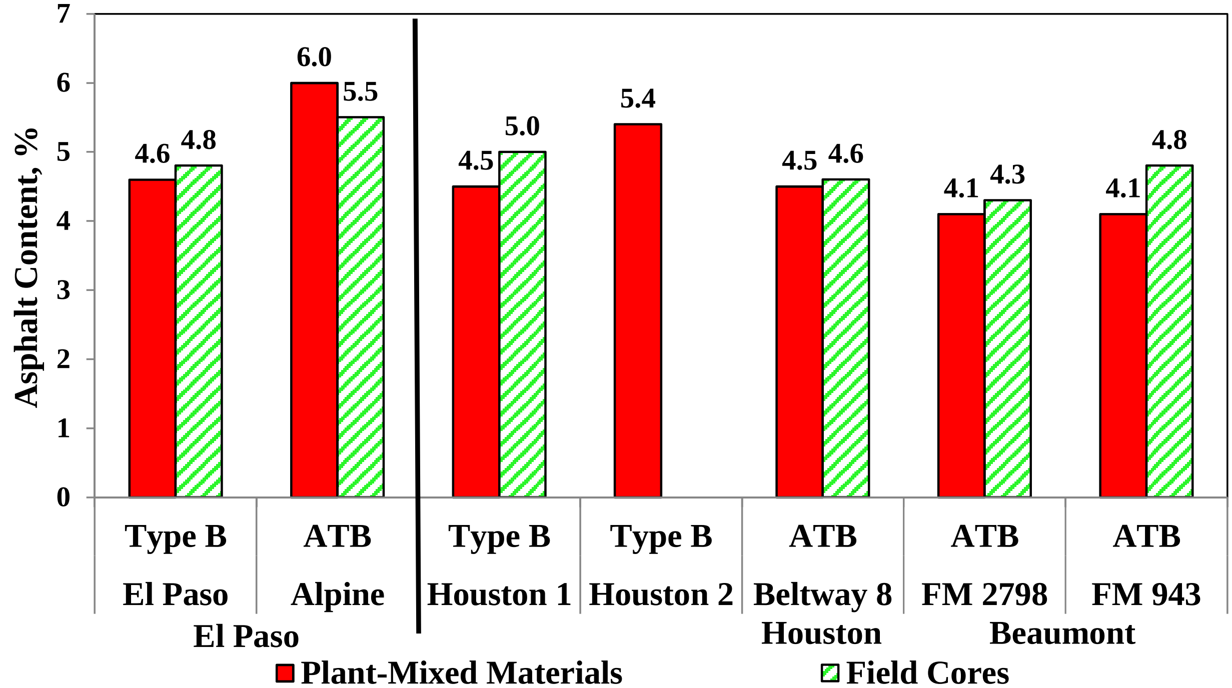

Figure 7.2 – Comparison of Asphalt Content for ATB and Type B Specimens

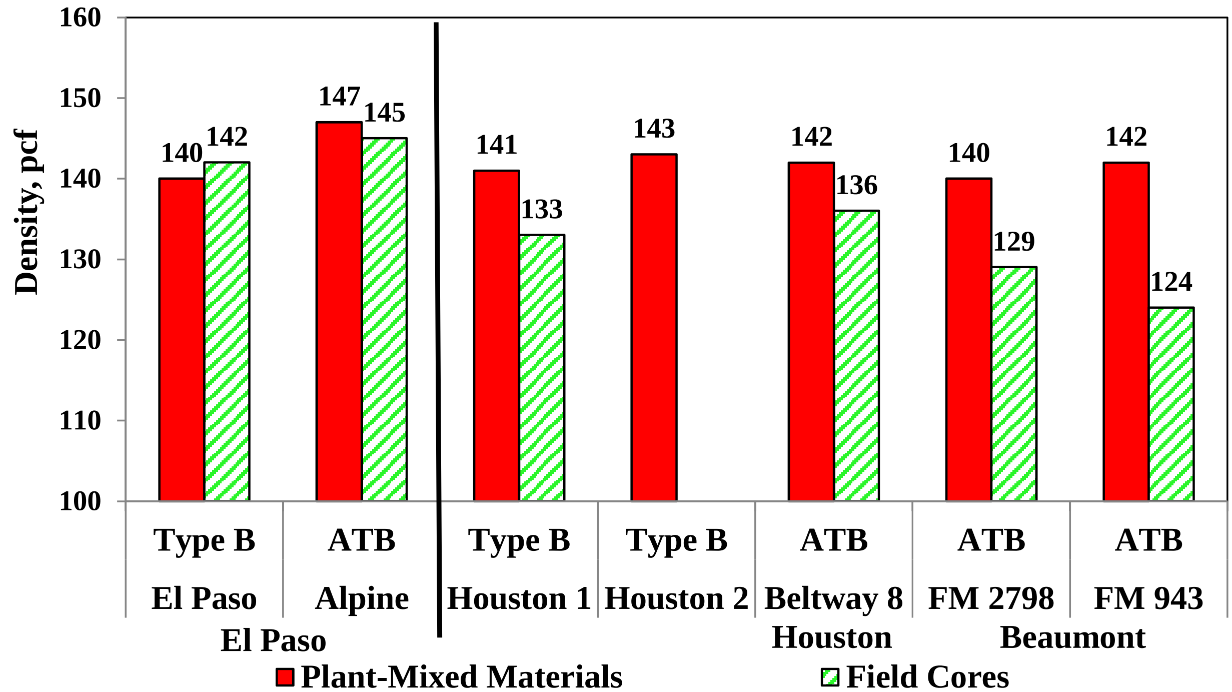

Figure 7.3 – Comparison of Density for ATB and Type B Specimens

Figure 7.4 shows the IDT strengths for all materials and mix types. For El Paso materials; the lab-prepared Type B and ATB specimens exhibited similar IDT strengths but the field cores are stronger for the ATB mix as compared to the Type B mix. The trends of the IDT strengths of the lab-prepared specimens for Type B and ATB mixes from Houston/Beaumont are mixed. However, the IDT strengths of the cores from Type B are greater than those from the ATB's for the Houston/Beaumont mixes.

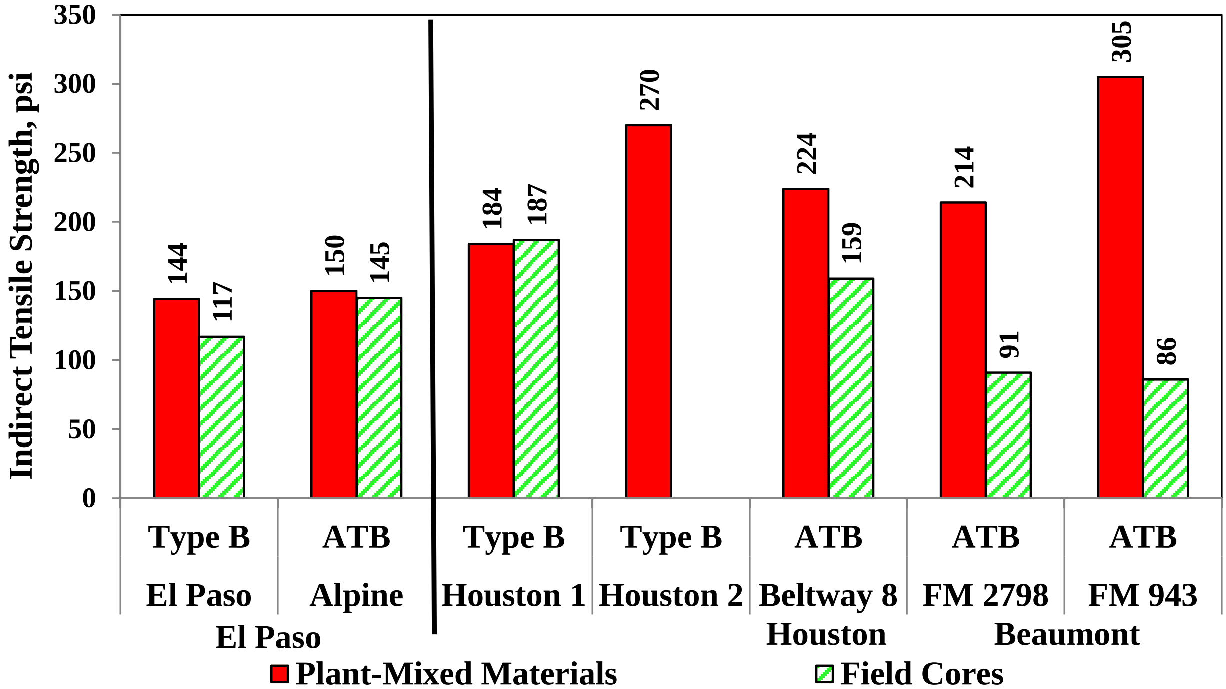

Figure 7.4 – Comparison of Indirect Tensile Strength for ATB and Type B Specimens

The stiffness properties of the mixes were assessed using the dynamic modulus and flow time tests. The results between these two mixes are compared in Figures 7.5 and 7.6. The Type B and ATB mixes for El Paso exhibited similar values for both tests. However, the two Type B mixes from Houston seem to perform better than the ATB mixes except in one case.

To quantify moisture susceptibility of mixes, tests were conducted using the Hamburg Wheel-Tracking device (HWTD) according to Tex-242-F. Testing was performed on plant-mixed specimens using 75 gyrations of the SGC. The results from the HWTD are summarized in Table 7.6. Even though the minimum number of passes required for a PG 64-22 binder is 10,000, tests were conducted to 20,000 passes. All materials tested exhibited acceptable rut depths at all cycles.

The variations in the field moduli measured with the PSPA and FWD are shown in Figure 7.7. The moduli of the Type B mixes 24 hrs after construction are greater than the ATBs perhaps because of better quality control and the fact that the HMAs were placed in thinner lifts. The PSPA moduli increase with time for most ATB sites except one site that was exposed to elements. Similar trends are observed from the FWD results.

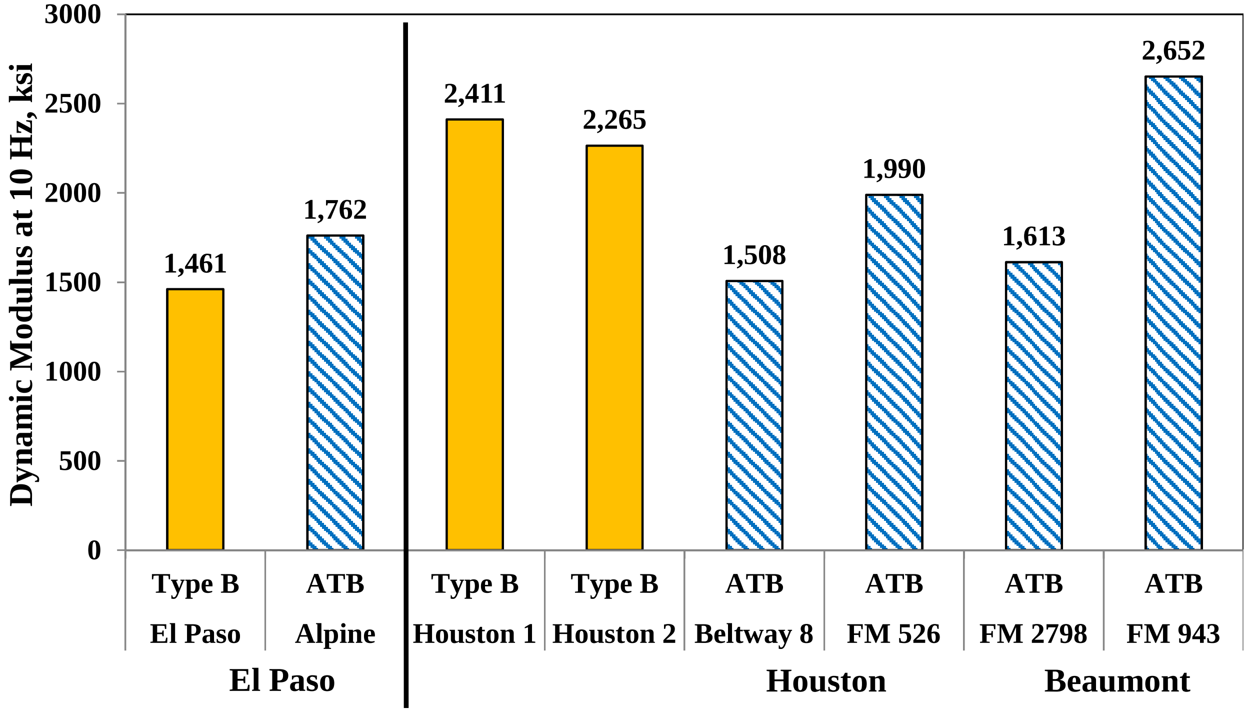

Figure 7.5 – Comparison of Dynamic Modulus for ATB and Type B Specimens

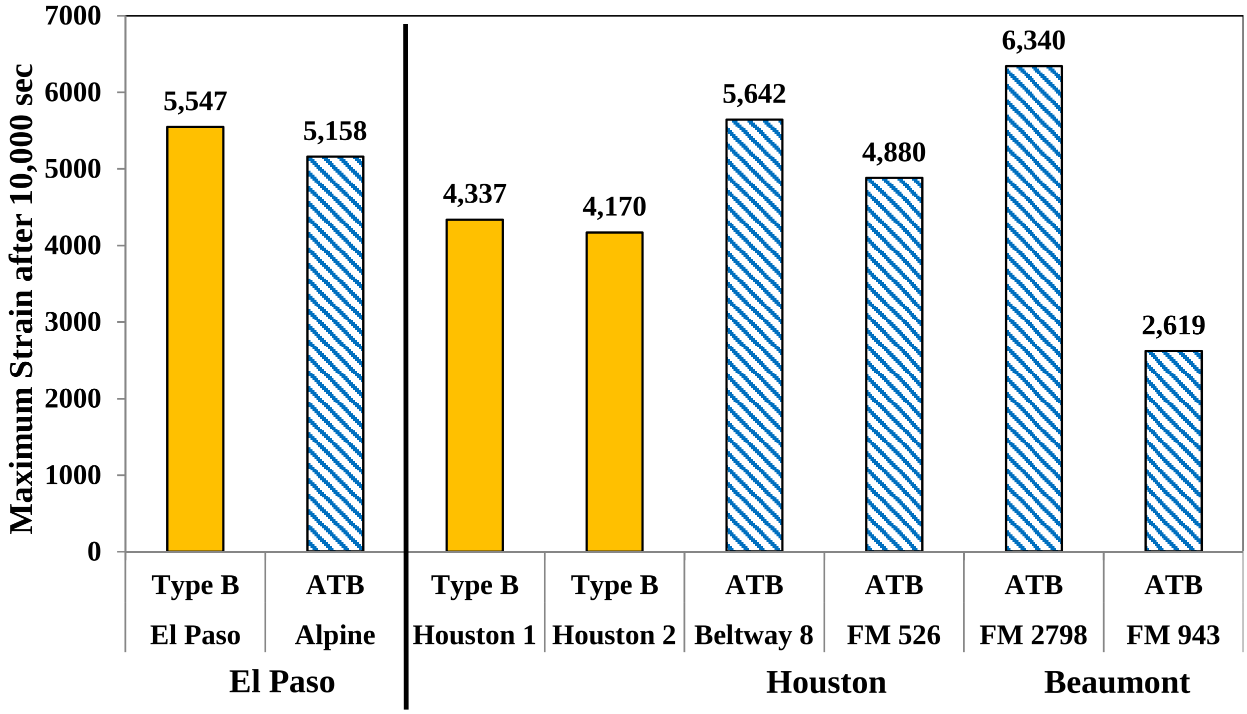

Figure 7.6 – Comparison of Flow Time Tests for ATB and Type B Specimens

Table 7.6 – Hamburg Wheel Test Results for ATB and Type B Materials

Number of Passes	Rut Depth, mm							
	El Paso		Type B		ATB			
	Type B	ATB	Houston 1	Houston 2	Houston Beltway 8	Houston FM 526	Beaumont FM 2798	Beaumont FM 943
5,000	1.9	3.1	2.4	2.2	2.1	2.5	1.4	2.1
10,000	2.7	4.6	3.0	2.6	2.5	2.7	1.8	2.5
15,000	3.1	5.4	3.7	2.9	2.8	4.8	1.8	2.5
20,000	3.9	6.3	5.5	4.7	3.0	5.5	1.8	2.5

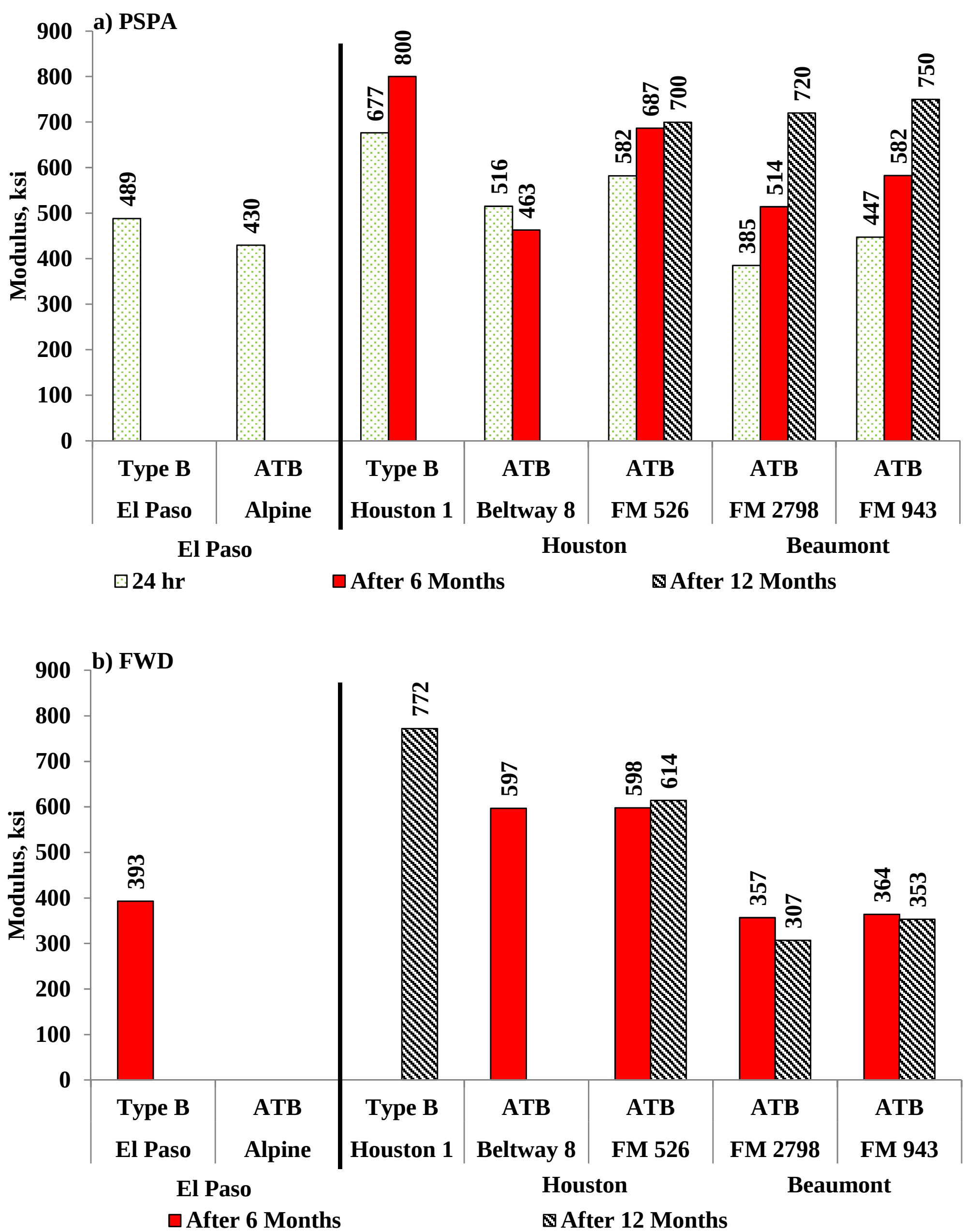

Figure 7.7 – Comparison of PSPA and FWD Modulus for ATB and Type B Specimens

Cost Comparison

A cost comparison was performed using TxDOT program Letting V9. This program reflects what TxDOT pays for each material including the cost of the raw material, asphalt binder, transportation from plant to the site and construction. Figure 7.8 compares on a yearly basis the usage and price per ton of Type B and ATB in Beaumont/Houston area. The study was focused on these two districts because they place more than 90% of the ATB's in Texas. For these two districts, the average unit price of the ATB is less than the Type B mixes. However, as reflected in Figure 7.8a, Type B mixes are not very popular in that region. For a more equitable cost analysis, the state-wide weighted average cost per ton of Type B mixes is also included in Figure 7.8b. The state-wide unit costs of Type B mixes are comparable with the unit costs of ATBs from Houston/Beaumont area. These trends indicate that the cost of the ATB mix will be comparable to the Type B mixes, should other districts in Texas decide to place higher quantities of ATB.

Figure 7.9 compares the costs of the specific ATB and Type B mixes studied in this chapter. Since El Paso District hardly ever uses the ATB mixes, its unit cost is significantly greater than the comparable Type B mix. This trend reverses for the Houston/Beaumont area where the ATB is used substantially more frequently than the Type B.

This case study demonstrates that the unit cost of the ATB will be comparable or less expensive than the Type B mixes, if the districts decide to use the ATB based on the perceived more reasonable and convenient new mix design process.

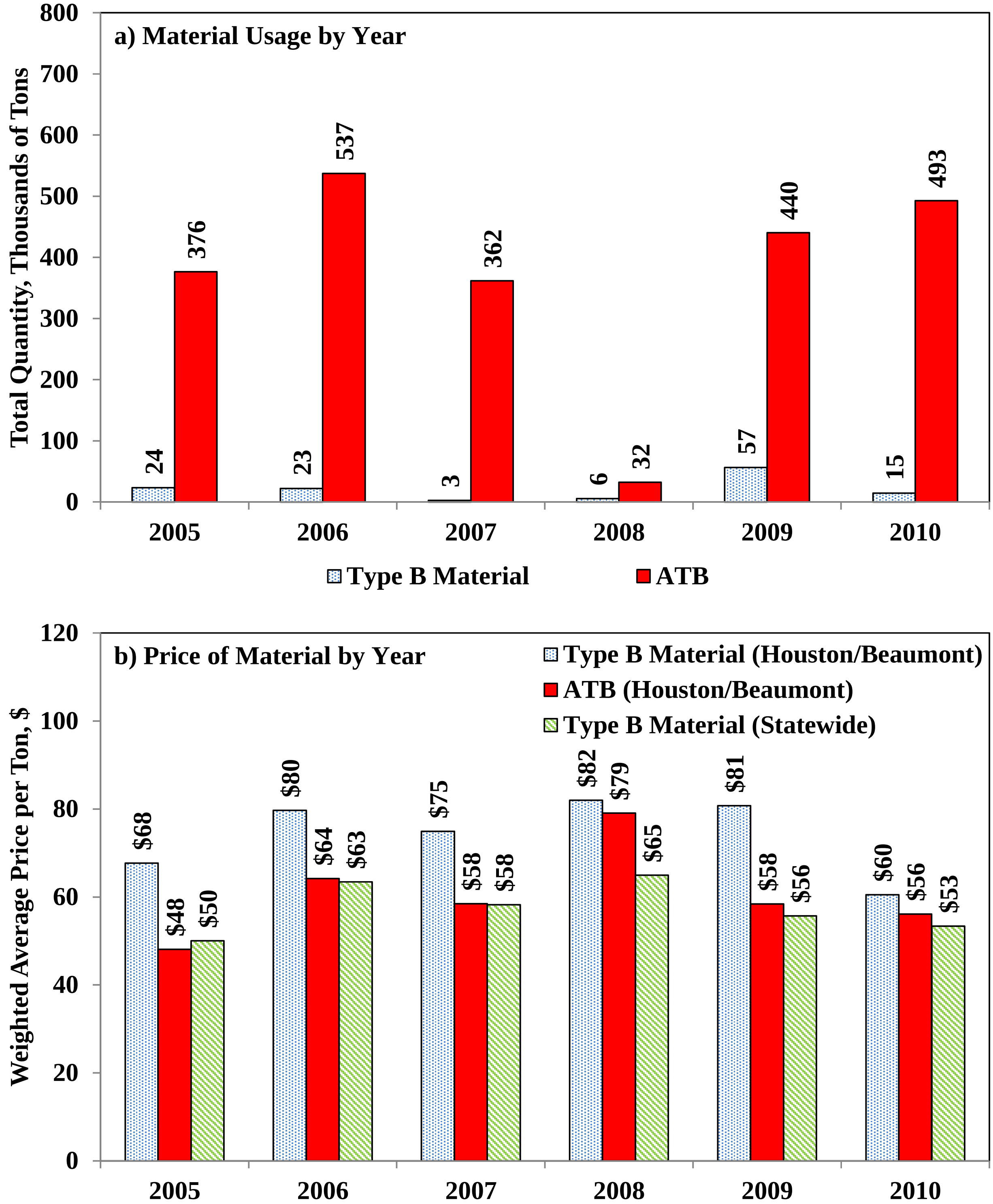

Figure 7.8 – Yearly Comparison of the Quantity Used and Price per Ton of ATB and Type B

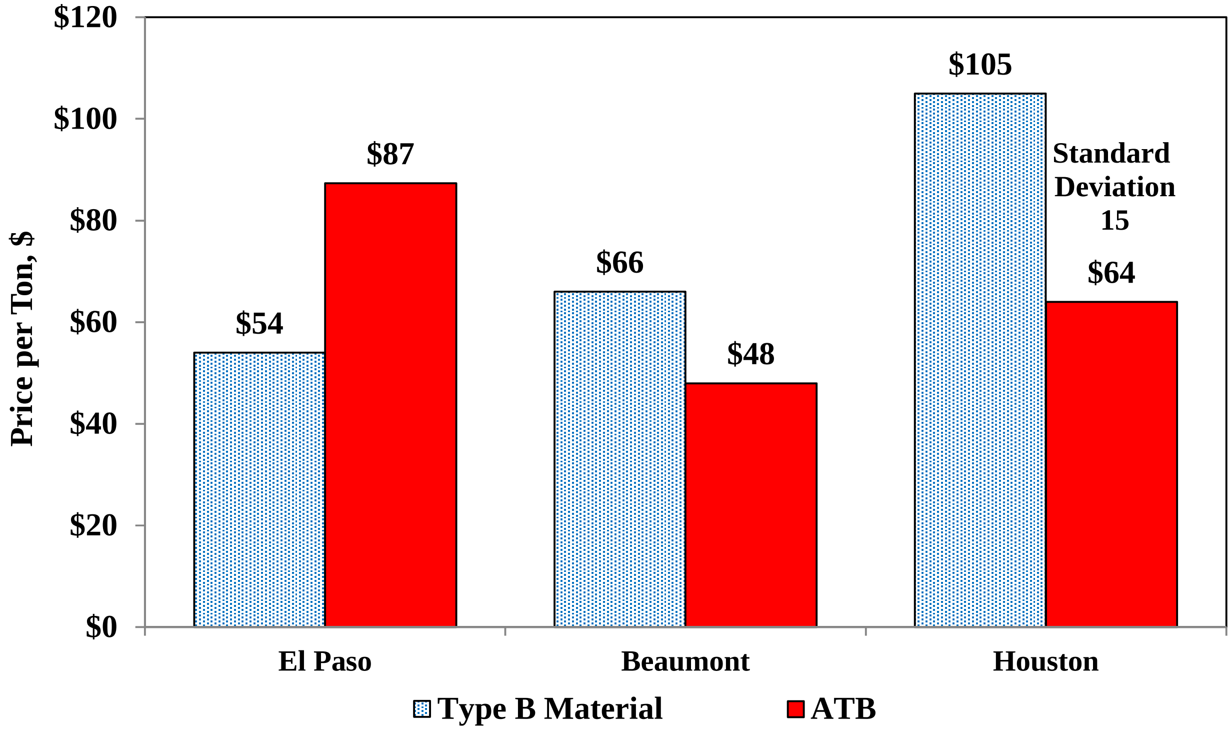

Figure 7.9 – Comparison of Price per Ton of ATB and Type B by Site

CHAPTER EIGHT – CLOSURE

Asphalt treated bases (ATBs) in Texas are usually designed and constructed as per Item 292, "Asphalt Treatment (Plant Mixed)," of the 2004 Standard Specification book. This specification is a hybrid of base and hot mix asphalt concrete procedures and requirements, which are sometimes incompatible. In addition, this Item uses a specific Texas Gyratory Base Compactor that is not readily available to all districts. The objective of this project was to propose a new mix design procedure for asphalt-treated bases that can use standard equipment such as the Superpave Gyratory Compactor (SGC) to mold the specimens for mix design.

To achieve the objective of this project, current TxDOT procedures such as Tex-126-E and Tex-204-F were evaluated and modified to propose new generically-named Tex-126-H and Tex-204-H test. A comprehensive parametric study comparing the results of the two proposed procedures with the existing procedures was performed. The most practical setup for laboratory tests was achieved by using Tex-204-H procedures, which proposes preparation of 6 in. diameter and 4.5 in. high specimens using 75 gyrations with the SGC. Furthermore, it is recommended to cure specimens for 24 hrs at room temperature (77°F) before conducting the indirect tensile strength because the results from this procedure were more sensitive to asphalt content while reducing the mix design period. The appropriate asphalt content should satisfy a target indirect tensile strength of at least 85 psi, and a relative density of 97%.

A cost-benefit analysis was also carried out between the ATB and Type B HMA. It seems that in most cases, the performance of the ATB mixes is comparable or slightly inferior to the Type B mixes. The main benefits of the ATB over HMA are that the local materials can be potentially used and that the ATB mixes are less permeable than the Type B mixes. The cost seems to be dictated by the popularity of mixes in given districts. The average unit cost of the ATB is less than Type B in the Houston/Beaumont area because the ATB is used more extensively than Type B. However, the average state-wide unit costs of the Type B are comparable to the ATB.

Based on the overall results of this study, the following conclusions can be outlined:

- The Superpave Gyratory Compactor results were found to be more uniform and consistent compared to the Texas Gyratory Base Compactor.
- Specimens prepared with the Superpave Gyratory Compactor usually exhibit similar or higher unconfined compressive strength and indirect tensile strengths as compared to those prepared with the Texas Gyratory Base Compactor.
- The indirect tensile strength was found to be more sensitive to the asphalt content, so it was selected to be as a parameter to estimate the optimum moisture content for a mix design.

- Curing of specimens at 77°F (room temperature) for 24 hrs after compaction did not yield strengths that were statistically different than curing the specimens at higher temperatures longer duration provided the specimens are tested at a temperature of 77°F.
- The optimum asphalt content obtained following the newly-proposed protocol is higher than those from traditional Item 292.
- Specimens molded with 80 gyrations were found to have the highest sensitivity to asphalt content as compared to the specimens molded at 60 and 100 gyrations. Since the 75 gyrations are already included in some of the procedures in Tex-204-F, 75 was selected as the number of gyrations.
- Unlike the traditional HMA mixes that are placed at air voids of about 8%, the ATB should be compacted to a relative density of 97% or greater to realize its benefits. Since the ATBs are placed in thicker lifts, heavier compactors may be necessary.

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Appendix A

Questionnaire

Questionnaire for TxDOT Research Project 0-6361

<u>Development of a New Mix Design Method and Specification Requirements for Asphalt Treated Base (Item 292)</u>

The asphalt stabilized bases in Texas are traditionally designed and constructed as per Item 292, "Asphalt Treatment (Plant Mixed)," of the 2004 Standard Specification book. Due to scarcity of the appropriate compactor specified in Item 292, some districts have started using Tex-204-F, Part III, 'Mix Design for Large Stone Mixtures Using the Superpave Gyratory Compactor." A new mix design procedure is needed for this type of material that can use standard equipment such as the Superpave Gyratory Compactor (SGC) to mold the mix design specimens.

UTEP has been granted a research project to evaluate Item 292 and to improve the laboratory design protocols for this type of base. The research team will also concentrate on the practical issues of the construction including the quality control and quality assurance and what test should be used to control the quality in the field.

This questionnaire is the first step toward documenting the current practices of TxDOT in using ATB. Your response to this questionnaire will help the research team to focus their efforts to provide a more practical and useful final product.

Questionnaire for TxDOT Research Project 0-6361

District: ________________ Contact Person(s): ________________________________

Telephone numbers and e-mails of contact persons:

____

(1) Have you used or are you using asphalt treated base (ATB) in construction/rehabilitation projects in your district?

Yes No

(2) If yes, how many such projects have been completed in the last 5 years or are scheduled to be constructed in the near future in your district?

______ projects

(3) Which specification do you use for the design of ATB?

Item 292 Tex-204-F Part III Both Others (specify) _________

If you use Item 292 or Tex-204-F Part III, do you waive any of the requirements? (If yes, please indicate them below)

(4) Which compactor do you use for the design of ATB?

Texas Gyratory Superpave Gyratory Both Others (specify) _____________

(5) What are the main uses of the ATB in your district? (check as many as apply to your district)

Alternative to unbound base Alternative to stabilized base
Alternative to Type A/B HMA Alternative to bond breaker layer under PCC
Others (please specify) __________________________________

(6) What factors motivate you to select ATB for projects in your district over other alternatives named in Question 3? (Please check as many as apply and comment in front of each line).

more economical____

lack of appropriate aggregates for alternatives_____________________________

easier to construct ____

easier to incorporate recycled materials ______________________________

Others (please specify) ____

____

(7) What typical aggregate types does your district use on ATB projects?

Limestone   Sandstone   Granite   Others (specify) ____________________

(8) Do you add RAP or Crushed Concrete to your ATB?

RAP   Crushed Concrete   Both   Neither

(9) As per Item 292, what are the major types and grades of the materials you use in your district? Please fill out the table below (assign a 1 for the ones you most use, a 2 for the ones you sometime use, and a 3 for those that you rarely use).

Grade	Type A	Type B
1		
2		
3		

(10) What binder grades does your district use on ATB projects?

____

(11) What criteria are used to determine the amounts of binder?

Based on district experience
Based on existing or special TxDOT specifications (please specify) ___________
Based on vendor's specifications (please specify) ________________________

(12) What construction specifications do you use for your projects?

____

(13) What types of problems, if any, you have encountered with deign or construction of ATB?

____
____
____
____
____

(14) Could you please comment on any area that this research should address to help you?

____
____
____
____
____

Do you mind if we contact you for more information?

Yes   No

Appendix B

Tex-204-H Test Procedure

Test Procedure for

MOLDING, TESTING, AND EVALUATING BITUMINOUS BLACK BASE MATERIALS

TxDOT Designation: TBD

Effective Date: Draft

1. SCOPE

1.1 Use this method to mold an asphalt stabilized (black base) material, and determine the relationship between the percent compacted density and percent asphalt in the material. The method is also the means to test specimens in indirect tensile strengths as Tex-226-F.

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

2. DEFINITIONS

2.1 *Maximum Density*—Maximum density is the highest density calculated based on dry weight of material per cubic foot.

2.2 *Optimum Asphalt Content*—Optimum asphalt content is the recommended percent asphalt taken as the percent asphalt that will produce the optimal density under a fixed compacted effort, and a minimum specified indirect tensile strength.

3. APPARATUS

3.1 *Superpave gyratory compactor (SGC).*

3.1.1 The compactor is an electro-hydraulic or electromechanical compactor with a ram and ram heads that are restrained from revolving during compaction.

3.1.2 The axis of the ram is perpendicular to the platen of the compactor.

3.1.3 The compactor tilts the specimen molds at an angle of 1.25 ±0.02° and gyrates specimen molds at a rate or 30.0 ±0.5 gyrations per minute throughout compaction.

3.1.4 The compactor is designed to permit the specimen mold to revolve freely on its tilted axis during gyration.

3.1.5 The ram applies and maintains a pressure of 87 ±2 psi (600 ±18 kPa) to the cylindrical axis of the specimen during compaction.

Note 1—This stress calculates to 2,383-±70 lbf (10,600 ±310 N) total force for 5.912 in. (150 mm) specimens.

3.2 *Specimen height measurement and recording device.*

3.2.1 When monitoring specimen density during compaction, provide a means to continuously measure and record the height of the specimen to the nearest 0.1 mm during compaction, once per gyration.

3.2.2 The system may include a printer connected to an RS232C port capable of printing test information, such as specimen height per gyration. In addition to a printer, the system may include a computer and suitable software for data acquisition and reporting.

3.3 *Specimen molds.*

3.3.1 Specimen molds must have steel walls that are at least 0.3 in. (7.5 mm) thick and are hardened to at least Rockwell C48.

3.3.2 Molds must have an inside diameter of 5.9 to 5.912 in. (149.90 to 150.00 mm) and be at least 10 in. (250 mm) high.

3.4 *Ram heads and mold bottoms.*

3.4.1 Ram heads and mold bottoms must be fabricated from steel with a minimum Rockwell hardness of C48.

3.4.2 The ram heads must be perpendicular to its axis.

3.4.3 The platen side of each mold bottom must be flat and parallel to its face.

3.4.4 All ram and base plate faces (the sides presented to the specimen) must be ground flat to meet smoothness requirement according to ANSI B 46.1 and must have a diameter of 5.885 to 5.896 in. (149.5 to 149.75 mm).

3.5 *Mercury thermometer*, marked in 5 °F (3°C) divisions or less, or a digital thermometer, capable of measuring the temperature specified in this test procedure.

3.6 *Balance*, Class G2 in accordance with Tex-901K, with a minimum capacity of 10,000 g.

3.7 *Heating oven*, capable of maintaining a temperature of at least 325 ±5°F (163 ±3°C).

3.8 Pans, metal, with flat bottom.

3.9 Scoop, spatula, trowel.

3.10 Paper disks.

3.11 Insulating gloves.

3.12 Lubricating materials.

3.13 Mechanical Mixer

4. CALIBRATION

4.1 Items requiring periodic verification of calibration include:

- Ram pressure
- Angle of gyration
- Gyration frequency
- LVDT (or other means used to continuously record the specimen height)
- Oven temperature

4.2 Verification of the mold and platen dimensions and the inside finish of the mold are also required.

4.3 When the computer and software options are used, periodically verify the data processing system output using a procedure designed for such purposes.

4.4 The manufacturer, other agencies providing such services, or in-house personnel may perform the verification of the calibration system standardization and quality checks. Frequency of verification must follow manufacturer's recommendations.

5. TEST REPORT FORMS

5.1 Tex 216-H Black Base Testing Data Worksheet

6. PROCEDURE

6.1 *Selecting Materials:*

6.1.1 Select the necessary type and source for each aggregate. Obtain representative samples consisting of a minimum of 50 lb (25 kg) of each aggregate. Take a representative sample for each source in accordance with Tex-400-A.

6.1.2 Obtain an adequate quantity of the asphalt and additives. Take samples in accordance with Tex-500-C.

6.1.3 Dry the aggregate to constant weight at a temperature of 140°F (60°C). Dry the recycled asphalt pavement (RAP), when applicable, at a temperature of 140°F (60°C).

6.1.4 If the stockpile gradation is unknown, obtain the gradation of each proposed aggregate stockpile in accordance with Tex-200-F, Part I. Use the construction stockpile gradation when it is available. Extract asphalt from RAP, when applicable, in accordance with Tex-210-F or Tex-236-F before performing a sieve analysis.

6.1.5 When applicable, estimate the asphalt content of the RAP (RAP only) in accordance with Tex-236-F. The RAP must be heated at 140°F (60°C), broken apart until friable, and quartered to obtain representative samples.

6.1.6 Calculate the bin percentages with the proposed aggregate so that the blended combination will fall within the specified gradation ranges for Item 292 (asphalt treated base). When applicable, use lime as an aggregate type when determining the bin percentages for the combined aggregate blend. The combined gradation will include the lime.

6.1.7 Check asphalt and additives for compliance with Item 292.

6.2 Weigh batching materials to be mixed:

6.2.1 Estimate the material weight to result in a compacted specimen having dimensions of 6 in. (150 mm) in diameter and 4.5± 0.2 in. (115 ± 5 mm) in height at 75 gyrations.

Note 2—It may be necessary to produce a trial specimen to achieve this height requirement. Generally, 4,700 to 4,800 g of aggregate are required to achieve this height.

6.2.2 Using the estimated weight from Section 6.2.1 and the percentages of the various sizes of particles obtained in preparation of the large sample, calculate the cumulative weights of each size to combine to make a specimen.

6.2.3 Separate the virgin aggregate material larger than the No. 4 (4.75 mm) sieve. Keep the RAP material separate from the virgin material.

6.2.4 Place the plus No. 4 (4.75 mm) fraction of the virgin aggregate in a tared mixing pan and the passing No. 4 (4.75 mm) portion of the virgin aggregate in a smaller tared pan. Place both pans in the oven for heating. Heat the virgin material and RAP to 290 ± 5°F (140 ± 3°C).

6.3 *Mixing*

6.3.1 Place a supply of asphalt to be used in the oven and set temperature in accordance with Tex-205-F depending on binder grade.

6.3.2 Remove the pans of material from the oven and weigh them after the material reaches the temperature determined in Item 6.3.1. Subtract the sum of the tares of the pans and obtain the dry weight of aggregates.

6.3.3 Place the pan containing the virgin passing No. 4 (4.75 mm) portion back in the hot oven, and place the mixing pan and its contents on the preheated hot plate for temperature retention.

6.3.4 Calculate the weight of asphalt required in the specimen, then place the mixing pan back on the scales and accurately weigh in the hot asphalt from the oven.

6.3.5 Place the material of the mixing pan in the mechanical mixer until the materials are well-coated. This may require several minutes.

6.3.6 When the mixing of the aggregate particles is complete, add in the passing No. 4 (4.75 mm) portion from the oven and continue mixing.

6.3.7 If applicable, add the RAP last and complete the mixing.

6.3.8 Put the mixed materials in a large pan and place it in the oven at set temperature in accordance with Tex-205-F depending on binder grade for two hours prior to molding.

6.4 *Molding Black Base Specimens:*

6.4.1 Preheat the mold and base plate in the oven as per Tex-205-F to help retain the heat of the mixture during loading and gyration.

6.4.2 After the two-hour curing, separate the larger aggregates equally, as judged by eye, at each side of the pan.

Note 3—Do not remove the mold and base plate from the oven when separating the large aggregate.

6.4.3 Remove the heated mold and base plate from the oven and place a paper disk on the bottom of the mold.

6.4.4 Place the mixture into the mold in one lift. Take appropriate care to avoid segregation in the mold.

6.4.5 After all the mix is in the mold, level the mix with a spatula and place another paper disk and the top plate on the leveled material.

Note 4—The intent of this technique is to mold each time at the maximum density. This produces more uniform and repeatable specimens.

6.4.6 After all the mix is in the mold, level the mix with a spatula and place another paper disk and the top plate on the leveled material.

6.5 Load the specimen mold with paving mix into the compactor and center the mold under the loading ram. The platen must have a generous coat of good lubricant to minimize damage to the platen and base plate.

6.5.1 Load the specimen mold with paving mix into the compactor and center the mold under the loading ram.

6.5.2 Lower the ram until the pressure on the specimen reached 87±2 psi (600±18 kPa).and begin the gyratory compaction in accordance with Tex-241-F..

6.6 Allow compaction to proceed until 75 gyrations.

6.7 When monitoring the specimen height, record the specimen height to the nearest 0.004 in. (0.1 mm) after each revolution.

6.8 Remove the angle from the mold assembly, raise the loading ram, remove the mold from the compactor, and extrude the specimen from the mold.

Note 5—Do not immediately extrude the specimen from the mold for lean, rich, and tender mixtures. Allow the mold to cool for approximately 10 min. or more in front of a fan.

6.9 Remove the paper disks from the top and bottom of the specimens.

Note 6—Before reusing the mold, place it in the oven for at least 5 min. The use of multiple molds will speed up the compaction process.

6.10 Store the fresh, hot molded specimen at room temperature 77°F (25°C) for further testing. Very rich specimens must be spaced about 2 in. (50 mm) away from other specimens to prevent damage in the case of slumping.

7. TESTING BLACK BASE SPECIMENS INDIRECT TENSILE STRENGTH

7.1 Perform indirect tensile strength (IDT) test on the compacted black base specimens after 24 hours in accordance with Tex-226-F.

7.2 *Develop IDT-Density-Asphalt Content Curves:*

7.2.1 Plot the laboratory molded density and IDT results as a function of asphalt content. Determine the maximum density from the plot, the asphalt content at this density is the traditional optimum asphalt content. See Figure 1a.

7.2.2 Convert the density to relative density by dividing the measured densities by the maximum density and plot with IDT strength. See Figure 1b.

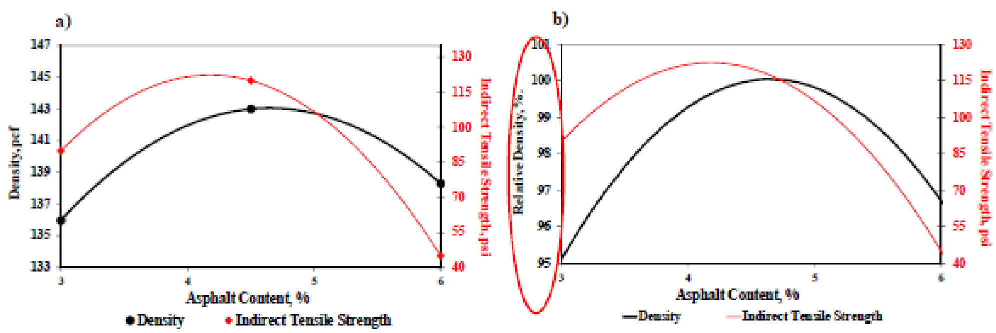

Figure 1 – Asphalt Content/Density/IDT Curve

7.2.3 Report the minimum asphalt content, AC_{mim}, where the maximum density is achieved. See Figure 2.

7.2.4 Determine the maximum asphalt content (not to exceed 6%), where the relative density is equal to 97%, $AC_{max,d}$.

$$Percent\,Actual\,Density\,in\,Field = \frac{Density\,of\,Core}{Target\ Density} \times 100$$

or

$$Percent\,Actual\,Density\,in\,Field = \frac{Nuclear\,Density}{Target\ Density} \times 100$$