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16. Abstract

Recent changes to the Texas hot mix asphalt (HMA) mix-design procedures such as adaption of the higher-stiffer PG asphalt-binder grades and the Hamburg test have ensured that the mixes that are routinely used on the Texas highways are not prone to rutting. However, performance concerns have been raised with these HMA mixes that are now drier, more difficult to compact, and more susceptible to premature cracking. This is particularly problematic with the dense-graded mixes (Type C and D) that are widely used throughout the state of Texas.

Therefore, there has been a great need to either: (1) modify the existing Texas HMA mix-design criteria and/or to include new simpler cracking test procedures; or (2) develop new mix-design methods that will optimize HMA field performance, particularly with respect to cracking. As a means toward addressing these issues, this report provides documentation of a 4-year research study that included the following major tasks: a) comparative evaluation of the Texas gyratory and balanced mix design (BMD) methods; b) development and evaluation of numerous HMA mix-designs including RAP and RAS mixes, c) extensive laboratory test including Hamburg rutting and Overlay Tester crack evaluations; d) accelerated pavement testing and performance evaluation; e) field testing and performance monitoring of in-service highway test sections.

Based on the study findings and as documented herein, recommendations for updates and modifications to the Texas HMA mix-design methods were made. Additionally, new guidelines and specifications were also developed for new generation HMA mix-design procedures. Overall, the BMD method that is rutting-cracking performance based exhibited superiority over the traditional Texas gyratory mix-design method, particularly in terms of HMA mix constructability and cracking performance.

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NEW GENERATION MIX-DESIGNS: LABORATORY-FIELD TESTING AND MODIFICATIONS TO TEXAS HMA MIX-DESIGN PROCEDURES

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DISCLAIMER

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LIST OF NOTATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
ADTT	Average daily truck traffic
ALF	Accelerated loading facility
APT	Accelerated pavement testing
AV	Air voids
BBR	Bending beam Rheometer
BMD	Balanced Mix Design
COV	Coefficient of variation
DC	Dry-cold climatic environment
DM	Dynamic modulus test
DSR	Dynamic shear Rheometer
DT	Direct-tension test
DW	Dry-wet climatic environment
ESAL	Equivalent single axle load
FWD	Falling weight deflectometer
GPR	Ground penetrating radar
HMA	Hot-mix asphalt
HMAC	Hot-mix asphalt concrete
HWTT	Hamburg wheel tracking test
IDT	Indirect-tension test
IR	Infrared
IRI	International roughness index
LTE	Load transfer efficiency
LTRC	Louisiana transportation research center
M	Moderate or mixed climatic environment
MTD	Material transfer device
MDD	Multi-depth deflectometer
NB	North bound
NDT	Non-destructive test (ing)

NMAS	Nominal maximum aggregate size
OT	Overlay Tester
PG	Performance grade
QA	Quality assurance
QC	Quality control
RLPD	Repeated load permanent deformation test
SB	Southbound
SCB	Semi-circular bending test
TG	Texas gyratory
TGC	Texas gyratory compactor
TxDOT	Texas Department of Transportation
WAC	Water absorption capacity
WC	Wet-cold climatic environment
WW	Wet-warm climatic environment
ε_t	Horizontal tensile strain measured in microns (με)
ε_v	Vertical compressive strain measured in microns (με)
ϕ	Symbol phi used to mean diameter

CHAPTER 1
INTRODUCTION

Recent changes to the Texas hot mix asphalt (HMA) mix design procedures such as adaption of the higher-stiffer PG asphalt-binder grades and the Hamburg test have ensured that the HMA mixes that are routinely used on the Texas highways are not prone to rutting. However, performance concerns have been raised about these HMA mixes that are now drier, more difficult to compact, and more susceptible to both reflective and fatigue cracking. This is particularly problematic with the dense-graded Type C and D mixes that are widely used throughout the state of Texas. Several new ideas are under consideration to either:

- Modify the existing HMA mix-design criteria and/or to include new and simpler cracking test procedures.
- Develop new HMA mix-design methods that have the potential to optimize the HMA field performance, particularly with respect to cracking.

RESEARCH OBJECTIVES AND SCOPE OF WORK

Based on the above background, this project developed new generation HMA mix-design procedures that optimize both rutting and cracking performance, without compromising the constructability aspects of the HMA mixes. As documented in this report, the scope of the work to accomplish this objective included the following key tasks:

1) Development of numerous HMA mix-designs for laboratory, APT, and field performance evaluation.
2) Comprehensive laboratory testing for HMA material property characterization and performance prediction.
3) Construction of APT test sections and ALF testing.
4) Construction of in-service highway field test sections and performance monitoring.
5) Make recommendations for updates and modifications to the current Texas HMA mix-design specification and procedures.

DESCRIPTION OF THE REPORT CONTENTS

This report consists of seven chapters including this chapter (Chapter 1) that provides the background, research objectives, methodology, and scope of work. Chapter 2 through 7 present and discuss the following aspects:

- Chapter 2 HMA mix-design methods.
- Chapter 3 Experimental design plan and HMA mixes evaluated.
- Chapter 4 Laboratory testing and HMA material property characterization.
- Chapter 5 APT performance evaluation.
- Chapter 6 In-service highway field performance evaluation.

Chapter 7 provides a summation of the report with a list of the major findings and recommendations. Some appendices are also included at the end of the report. Additionally, reference should also be made to the following reports that are an integral part of this research work:

1) Report 0-6132-1 (Walubita et al., 2010).
2) Report 0-6132-2 (Walubita and Scullion, 2012).
3) Product 0-6132 P1 (Scullion and Walubita, 2012).

SUMMARY

In this introductory chapter, the background and the research objectives were discussed. The research methodology and scope of work were then described; followed by a description of the report contents. Note in this report that as some of the laboratory tests such as the Hamburg and DSR use standard metric (SI) units, some of the test results (including some dimensions such as length, diameter, etc.) have consequently been reported in metric units.

CHAPTER 2
HMA MIX-DESIGN METHODS

Two HMA mix-design methods, namely the Texas gyratory (TG) and the proposed balanced mix design (BMD), were comparatively evaluated. These methods are discussed in this chapter and include a step-by-step description of the mix-design process up to selection of the optimum asphalt-binder content (OAC). A summary is then provided at the end of the chapter to highlight the key features and differences of the two mix-design methods.

THE TEXAS GYRATORY MIX-DESIGN METHOD

The TG is the mix-design method traditionally used in Texas for designing HMA mixes (TxDOT, 2004). It is a volumetric-density based method using the Texas gyratory compactor (TGC) and the "*design asphalt-binder content*" (OAC) is selected based on meeting the following two key aspects that are discussed in the subsequent text:

- Volumetric requirements (TGC lab density and voids in the mineral aggregate [VMA]).
- Laboratory performance requirements (Hamburg rutting and indirect-tensile strength).

Volumetric Requirements – TGC Lab Density and VMA

Assuming that material selection and the specific aggregate requirements are satisfactorily met, meeting the TGC lab density and VMA are the two critical volumetric requirements of this HMA mix-design method for any selected OAC. These volumetric properties are directly and/or indirectly related to the HMA mix stability, durability, and long-term performance of HMA pavements.

The specific volumetric requirements for most dense- and fine-graded Texas HMA mixes include the following (TxDOT, 2004; 2011):

- TGC lab density: $96\% \leq \rho_{TGC} \leq 98\%$
- VMA: $VMA \geq 13\%$

Typically, a minimum of three trial asphalt-binder contents are tried and the one meeting the above criteria is selected as the design asphalt-binder content. Laboratory sample molding and compaction at a minimum of three trial asphalt-binder contents is accomplished with the TGC; see Figure 2-1 (TxDOT 2004; 2010).

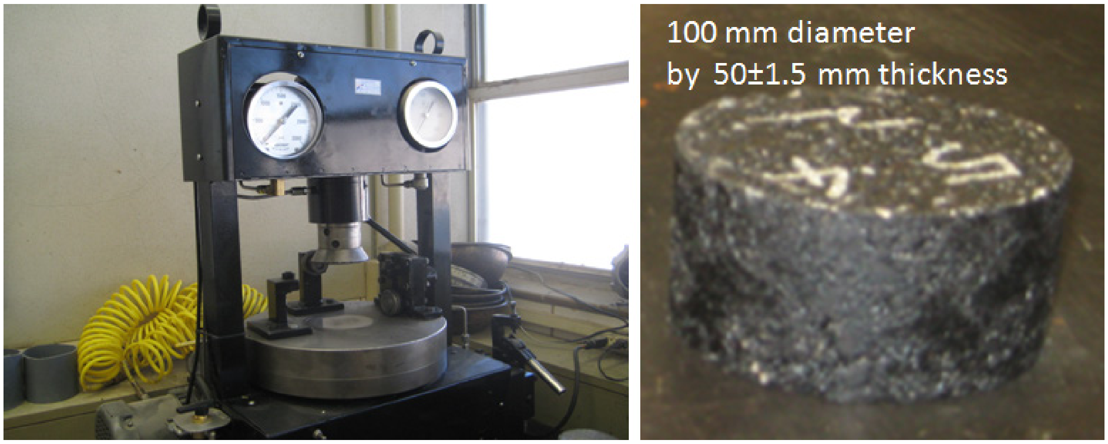

Figure 2-1. The Texas Gyratory Compactor.

Full operational details of the TGC are documented elsewhere (TxDOT, 2011). At each of the three trial asphalt-binder contents such as 4.5, 5.0, 5.5 percent, three replicate samples are typically molded to the dimensions shown in Figure 2-1. Densities and VMA are then measured on the replicate samples and then averaged for each respective set. The asphalt-binder content whose density and VMA meets the above requirements is tentatively selected as the design asphalt-binder content and then, subjected to laboratory performance evaluation that is discussed in the subsequent text.

Laboratory Performance Requirements – Tensile Strength and Rutting

HMA tensile strength and rutting resistance are the two performance properties evaluated in the laboratory under this mix-design method, with the HMA test samples molded at the OAC and 7±1 percent air void (AV) in the Superpave Gyratory Compactor (SGC) (TxDOT, 2004). Like for the TGC, molding and compaction temperatures vary depending on the asphalt-binder type (TxDOT, 2004). However, unlike the TGC, the SGC has the potential to mold samples up to dimensions of 6 inches (150 mm) diameter by 7 inches (175 mm) in height. Figure 2-2 illustrates the SGC together with some examples of molded samples.

Figure 2-2. The Superpave Gyratory Compactor.

Laboratory HMA mix performance evaluation (i.e., indirect tensile strength and rutting) at the OAC selected in Step 1 is based on the following two tests and the associated criterion:

- The indirect tensile strength (IDT) test: The current IDT criterion is a dry tensile strength range of 85 to 200 psi for the HMA mix at ambient temperature (TxDOT, 2004). This test basically provides an indirect measure of durability and cracking resistance potential of the mix.
- The Hamburg (HWTT) rutting test: The standard HWTT rutting criterion is a rut depth of less than 12.5 mm in a 50°C water bath, i.e., $Rut_{HWTT} \leq 12.5$ mm after 10,000, 15,000, or 20,000 load passes depending on the asphalt-binder type, i.e., 10,000 HWTT load passes for HMA mixes with asphalt-binder PG 64-XX, 15,000 HWTT load passes for HMA mixes with asphalt-binder PG 70-XX, and 20,000 HWTT load passes for HMA mixes with asphalt-binder PG 76-XX (TxDOT, 2011). Because the test is run under water, the Hamburg test also provides a measure of the moisture susceptibility (stripping potential) of the HMA mix in addition to the rutting resistance properties.

HMA mixes and/or asphalt-binder contents that simultaneously meet these IDT and HWTT criteria are considered as acceptable; otherwise the mix must be redesigned (TxDOT, 2011). For laboratory performance evaluation, Texas mandates the test samples to be molded at 7±1 percent AV or 93±1 percent density in the SGC (TxDOT, 2004; 2011). Like for the TGC, molding and compaction temperatures vary depending on the asphalt-binder type.

Selection of the Design Asphalt-Binder Content

HMA mixes and/or asphalt-binder contents that simultaneously meet the volumetric and laboratory performance requirements as discussed above will be selected as the final design OAC; otherwise, a redesign or modification may be warranted (TxDOT, 2011).

Basic Steps of the TG Mix-Design Method

Based on the preceding discussions and as summarized in Figure 2-3, the traditional Texas TG HMA mix-design method consists of the following basic steps:

- Step 1 – material selection.
- Step 2 – TGC lab molding and design AC determination.
- Step 3 – design AC verification and performance testing (Hamburg and IDT).
- Step 4 – selection of design OAC (or redesign).

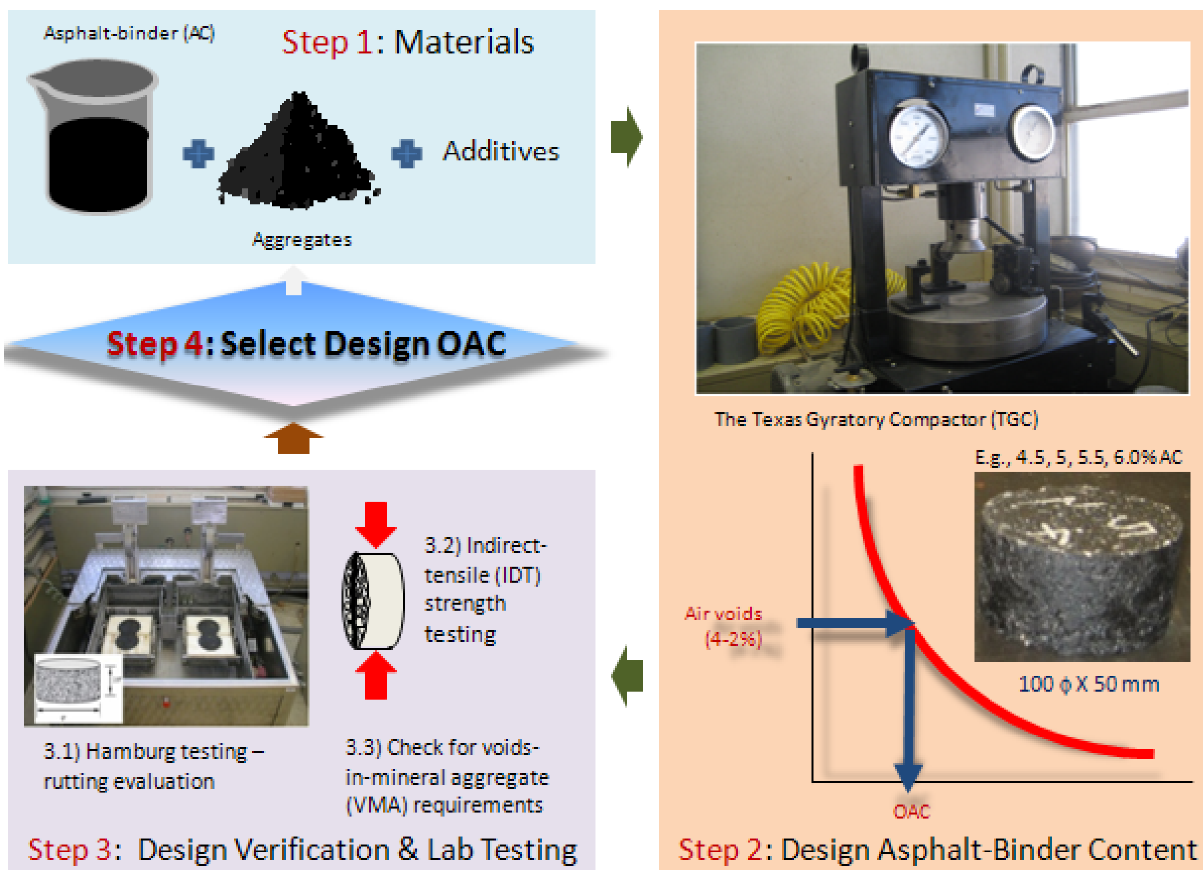

Figure 2-3. The Basic Steps of the Traditional Texas TGC HMA Mix-Design Process.

THE PROPOSED BALANCED MIX-DESIGN METHOD

The concept of the BMD method is fundamentally centered on designing HMA mixes that are not only rutting-and cracking-resistant but also not susceptible to moisture (Zhou et al., 2006). Rutting, cracking, and moisture damage are some of the key distresses associated with today's HMA pavements. Thus, it is important to address these distresses in the HMA mix-design process.

As shown in Figure 2-4, the mix-design philosophy is based on designing and selecting an OAC that simultaneously meets certain prescribed laboratory rutting (≤ 12.5 mm) and cracking requirements using the HWTT and Overlay (OT) tests, respectively, with a minimum of three trial asphalt-binder contents at 93±1 percent lab density (Zhou et al., 2006).

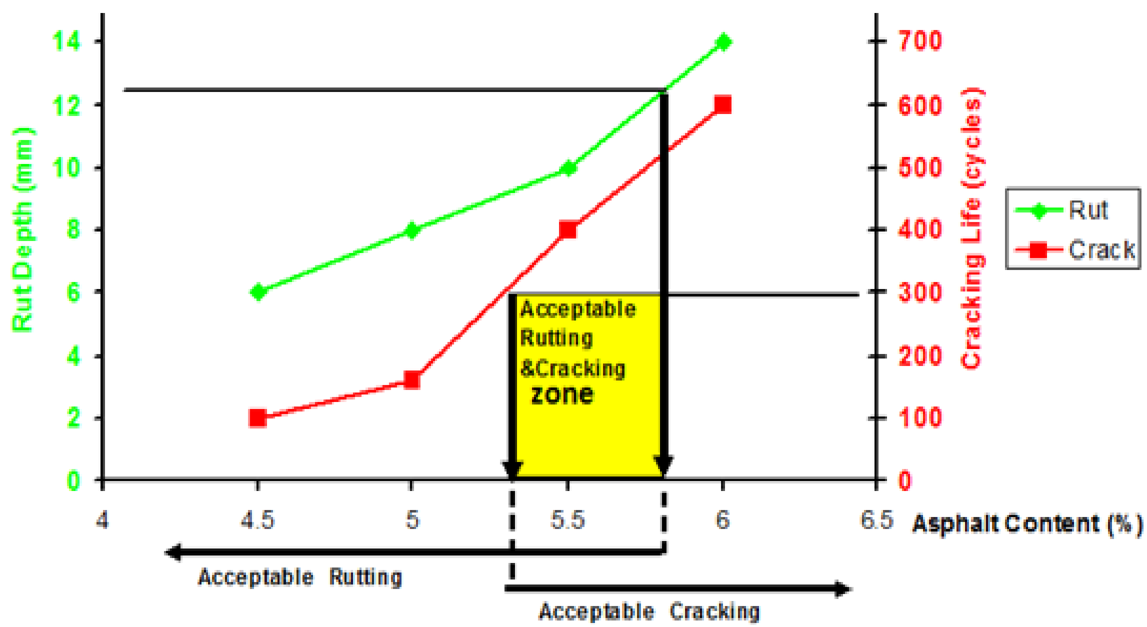

Figure 2-4. The BMD Concept (Zhou et al., 2006).

Rutting and Cracking Pass-Fail Screening Criteria

Based on Figure 2-4, rutting based on the Hamburg test is the limiting criterion for the maximum selectable design OAC, i.e., the upper limit of the design OAC. The standard HWTT rutting criterion is 12.5 mm (i.e., $Rut_{HWTT} \leq 12.5$ mm), and HMA mixes and/or asphalt-binder contents meeting this criterion are considered as acceptable with sufficient laboratory rutting resistance (TxDOT, 2004; 2011).

Cracking based on OT testing is the limiting criterion for the minimum selectable design OAC, i.e., the lower limit of the design OAC. Although no criteria are formally approved for the commonly used dense-graded mixes, research has shown that HMA mixes and/or asphalt-binder contents that last over 300 cycles (i.e., $N_{OT} \geq 300$) prior to crack failure at 93 percent load reduction have exhibited satisfactory field performance (Von Holdt and Scullion, 2005; Zhou et al., 2006; Walubita et al., 2010). As will be seen in the subsequent chapters of this report, 300 OT cycles was found to be too tight a threshold particularly for RAP and RAS mixes. Therefore, 200 OT cycles was used as a tentative screening criterion in this study.

Figure 2-4 clearly shows that as the asphalt-binder content increases, the rutting resistance decreases and vice versa for the cracking resistance. Conversely, the opposite result would be expected if the asphalt-binder content is decreased. A balanced OAC design includes an asphalt-binder content in which the HMA mix simultaneously passes both the laboratory HWTT rutting ($Rut_{HWTT} \leq 12.5$ mm) and OT cracking ($N_{OT} \geq 200$) requirements, respectively. Any asphalt-binder content selected as the design OAC within this zone is acceptable and is considered to be representative of a laboratory rut- and crack-resistant mix that is also not very prone to moisture damage (Zhou et al., 2006; Walubita and Scullion, 2008).

Hamburg Rutting and OT Crack Testing

The Hamburg is a standard test device used for characterizing the rutting resistance of HMA mixes in the laboratory including stripping susceptibility assessment (moisture damage potential). The OT on the other hand is a simple performance test used for characterizing the cracking potential of HMA mixes in the laboratory at an ambient (room) temperature of 25°C.

Figures 2-5 and 2-6 show photographical views of the HWTT and OT devices, respectively, and includes the test specimen setups for lab-molded samples. Details of the test loading configurations including the pass-fail criteria are summarized in Table 2-1 (Zhou et al., 2006; TxDOT, 2011). However, both the HWTT and OT test parameters can be optionally changed to meet the user specific needs. For the purpose of HMA mix-design and screening, both the Hamburg and OT test samples are gyratory molded to and tested at 93±1 percent density (TxDOT, 2004; 2011).

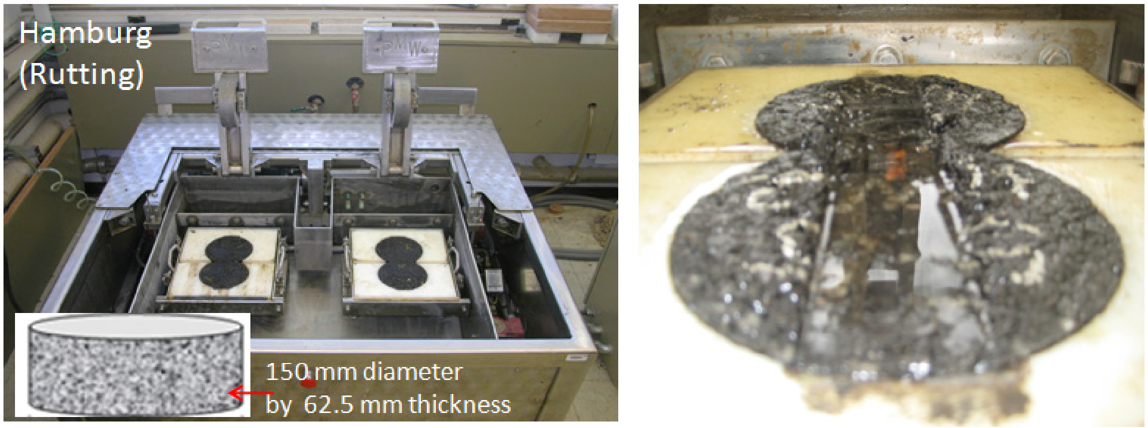

Figure 2-5. The Hamburg Wheel Tracking Test Device.

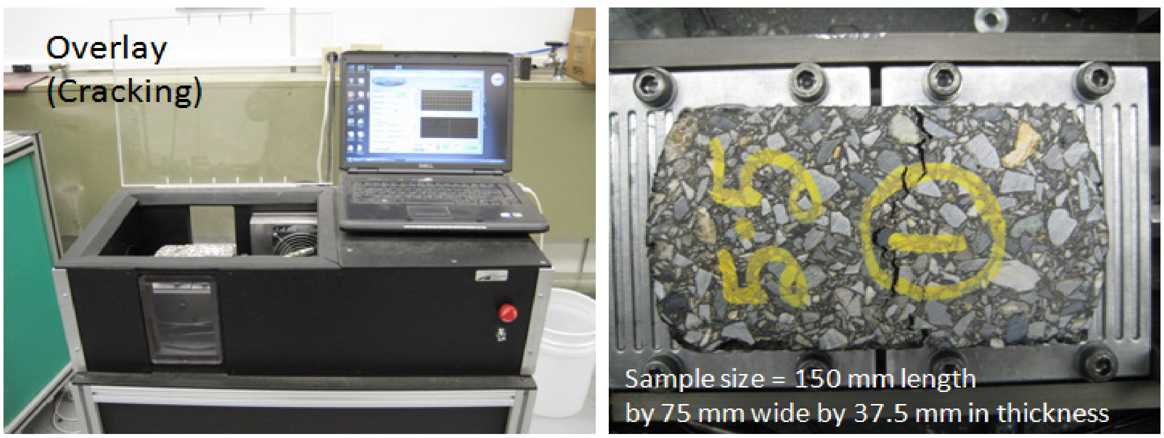

Figure 2-6. The Overlay Tester.

Table 2-1. Test Loading Configuration for the Hamburg and Overlay.

Item	Hamburg (HWTT)	Overlay (OT)
Test objective	Laboratory characterization of the rutting resistance and stripping potential of HMA mixes	Laboratory characterization of cracking potential of HMA mixes
Load magnitude	158 lbf	0.025 inches horizontal displacement
Loading mode	Repetitive passing	Cyclic triangular displacement-controlled waveform
Loading frequency	52 passes per minute	10 seconds per cycle (5 s loading and 5 s unloading)
Test temperature	122°F (50°F)	77°F (ambient ≈ 25°C)
Specimen dimensions	6 inches diameter by 2.5 inches thick	6 inches long by 3 inches wide by 1.5 inches thick
Pass-fail screening criteria	≤ 12.5 mm after 10,000 passes for PG 64-XX mixes ≤ 12.5 mm after 15,000 passes for PG 70-XX mixes ≤ 12.5 mm after 20,000 passes for PG 76-XX mixes	≥ 30, 100, 150, 300, & 750 cycles at 93% reduction in the initial peak load (tentative) – still under review.

Selection of the Design Asphalt-Binder Content

As stated previously, only AC levels simultaneously meeting the Hamburg rutting and OT cracking requirements should be selected as the balanced design OAC. HMA mixes and/or AC levels with Hamburg rut depth less than 12.5 mm are considered acceptably rut-resistant; otherwise the mix should discretionarily be redesigned, modified, or rejected.

HMA mixes and/or AC levels with OT cycles greater than 200 are considered to have acceptable lab crack-resistance while those with less than 30 cycles should discretionarily be redesigned, modified, or rejected. For crack attenuating mixes (i.e., CAM mixes), however, 750 cycles is specified as the standard OT pass-fail screening criterion (TxDOT, 2011).

Typical HMA mix-design modifications may include but not limited to the following considerations:

- Changing the aggregate gradation (i.e., blending proportions).
- Changing the material type and/or source (e.g., asphalt-binder and aggregate).
- Changing the asphalt-binder content.
- Adding and/or modifying the type and quantity of additives, etc.

Basic Steps of the BMD Method

Based on the preceding discussions and as summarized in Figure 2-7, the proposed balanced HMA mix-design method consists of the following basic steps:

- Step 1 – material selection.
- Step 2 – SGC lab molding of Hamburg and OT samples.
- Step 3 – performance testing (Hamburg and OT) and design AC determination.
- Step 4 – design AC selection and verification (density and VMA requirements).
- Step 5 – selection of design OAC (or redesign).

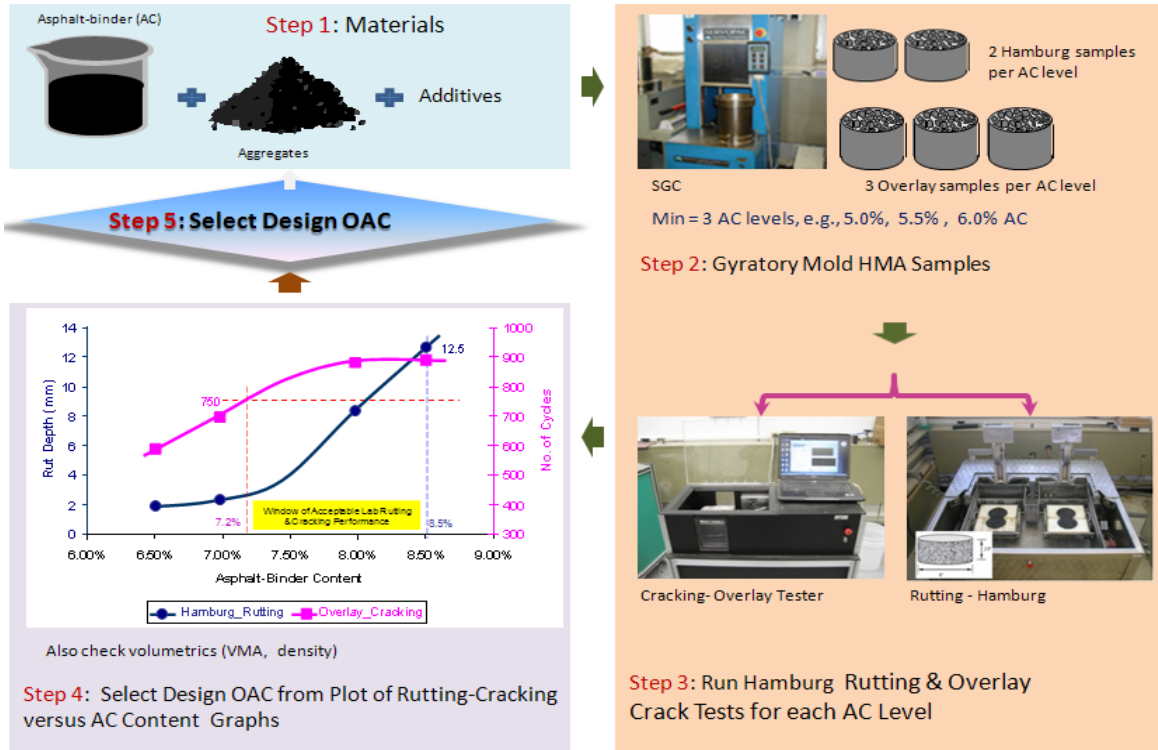

Figure 2-7. The Basic Steps of the BMD Process.

SUPPLEMENTARY LAB TESTS

In addition to the HWTT and OT, the lab tests listed in Table 2-2 were also conducted to supplement the results from the HWTT rutting and OT cracking tests.

SUMMARY

This chapter provided a comparative discussion of the traditional Texas TG and the BMD methods that were evaluated in this study. Key attributes associated with each mix-design method are listed below, and the basic HMA testing required for each method are summarized in Table 2-3:

1) The traditional TG method: HMA mix-design and OAC selection is based on meeting some prescribed laboratory TGC density and VMA requirements. HMA mix-design and OAC verification is based on meeting some specified Hamburg rutting and IDT performance testing at 93 percent density.
2) The new BMD method: HMA mix-design and OAC selection is based on meeting some prescribed laboratory Hamburg rutting (i.e., < 12.5 mm) and OT cracking (i.e., ≥ 200

cycles) requirements. HMA mix-design and OAC verification is based on meeting some specified density and VMA requirements.

Table 2-2. List of Supplementary Lab Tests.

#	Test	Test Objective
1	Troxler ignition oven	Asphalt-binder content &aggregate extractions.
2	DSR & BBR	Characterization of the asphalt-binder rheological properties & PG grade determination.
3	Dynamic modulus (DM)	HMA modulus properties at 14 to 130°F and 0.1 to 25 Hz.
4	Repeated load permanent deformation (RLPD)	HMA permanent deformation and visco-elastic properties at 77°F (25°C) and 104°F (40°C).
5	Direct-tension (DT), indirect-tension (IDT), & semi-circular bending (SCB)	Characterization of HMA fracture and crack-resistance properties at 77°F. (As a supplement to the OT test, the DT, IDT, and SCB tests were conducted as surrogate crack tests to provide additional data on the fracture and crack-resistance properties of the HMA mixes.)

Table 2-3. HMA Mix-Design Testing.

#	Mix-Design Method	Test	Replicates	Objective/Output Data	TxDOT Spec/Reference
1	TG	Texas Gyratory Compactor (TGC)	≥3 × at least 4 AC levels	Sample molding & OAC determination	Tex-206-F
		Hamburg	≥ 2	Rutting performance evaluation	Tex-242-F
		Indirect-Tension (IDT)	≥ 3	Tensile strength characterization	Tex-226-F
2	BMD	Superpave Gyratory Compactor (SGC)	≥2 per AC level	Sample molding	Tex-241-F
		Hamburg (HWTT)	≥ 2 per AC level (min 3 AC levels)	Rutting evaluation & OAC determination	Tex-242-F
		Overlay (OT)	≥ 4 per AC level (min 3 AC levels)	Cracking evaluation & OAC determination	Tex-248-F

CHAPTER 3
MATERIALS AND HMA MIX-DESIGN DEVELOPMENT

Four mix types (CAM, Type B, Type C, and Type D) with over 10 different mix-designs were evaluated in this study. The materials, HMA mix-designs, specimen fabrication, and AV measurement procedures are discussed in this chapter. A summary of key points is provided at the end of the chapter.

MATERIALS AND MIX-DESIGNS

Various aspects in terms of the materials and HMA mix-designs were considered in developing the experimental design plan. As a minimum, the intent of the experimental design for this study was as follows:

- Evaluate at least two commonly used Texas dense-graded mixes, with known poor and satisfactory field cracking performance, respectively; preferably a Type B (typically poor crack-resistant) and D (satisfactory crack-resistant) mix.
- Evaluate at least two asphalt-binder contents, OAC and OAC plus 5 percent.
- Evaluate at least two asphalt-binder types, with PG 64-22 and PG 76-22 included in the matrix.
- Evaluate at least two commonly used Texas aggregate types, typically limestone (marginal) and crushed gravel.
- Cover at minimum, all five Texas climatic regions (DC, DW, M, WC, and WW).
- Construct APT test sections and evaluate at least one mix type under ALF testing.
- Construct 1,000 ft test sections on in-service highways in various districts and evaluate their field performance under conventional tracking to validate the mix designs.

Table 3-1 lists these mixes and includes the material type, material sources, district, and climatic location. Where applicable, highway names the mix had recently been used and/or where TTI researchers have field test sections are also indicated in the table. In terms of the districts and climatic location, Figure 3-1 shows that the selected mixes cover a reasonable geographical and climatic span of Texas, which includes all the five climatic regions, namely DC, DW, M, WC, and WW.

Table 3-1. HMA Mixes and Material Characteristics.

#	Mix Type	District Source	Climatic Location	Asphalt-Binder	Aggregate	Hwy where Used
2	CAM	Bryan	Wet-warm (WW)	PG 76-22 (Jebro)	Capitol Limestone + Lime	FM 158 (6 TTI test sections)
3	Type B	Chico	-	PG 64-22 (Valero)	Limestone (Chico)	SH 114
3	Type D	Chico	-	PG 70-22 (Valero)	Limestone (Chico)	-
	Type C	Chico	-	PG 76-22 (Valero)	Limestone (Chico)	-
4	Type D	Atlanta	Wet-cold (WC)	PG 64-22 (Lion)	Quartzite (Jones Mill) + RAP (Fractionated)	US 59 (3 TTI test sections)
5	Type C	New Braunfels	Dry-warm (DW)	PG 70-22 (Valero)	Limestone (Hunter)	FM 2440
	Type C		-	PG 76-22 SBS (TFA)	Gravel (Jones [Martin Marietta])	IH 25
6	Type C	Laredo	DW	PG 64-22	Crushed Gravel + RAP + Lime	US 59, Spur 400, Loop 20, & US 83 (4 TTI test sections)
7	Type D	Childress	Dry-cold (DC)	PG 58-28 PG 64-22 (Valero)	Granite + RAP + Lime	US 287
8	Type C	Fort Worth	WC	PG 70-22	Granite + RAP + Anti-strip	
9	Type C	Odessa	DW	PG 70-22	Limestone	-
10	Type C	Waco	Moderate or Mixed (M)	PG 64-22 PG 70-22 PG 76-22	Gravel/Limestone/Dolomite + RAP + RAS + Lime	SH 31
	Type C & D	San Antonio	DW	PG 64-22 PG 70-22 PG 76-22	Limestone + RAP	-
	Type C	Beaumont	WW	PG 64-22 (Valero)	Limestone (Brownwood)	-
13	Type D	Amarillo	DC	PG 58-28, PG 64-22 PG 64-28, PG 70-28 (Holly)	Limestone/Dolomite + RAP (Fractionated) + RAS + Lime	US 54
12	Type C	Beaumont	WW	PG 76-22 (Valero)	Limestone (Brownwood)	APT by TTI (LA – LTRC) (8 TTI test sections)

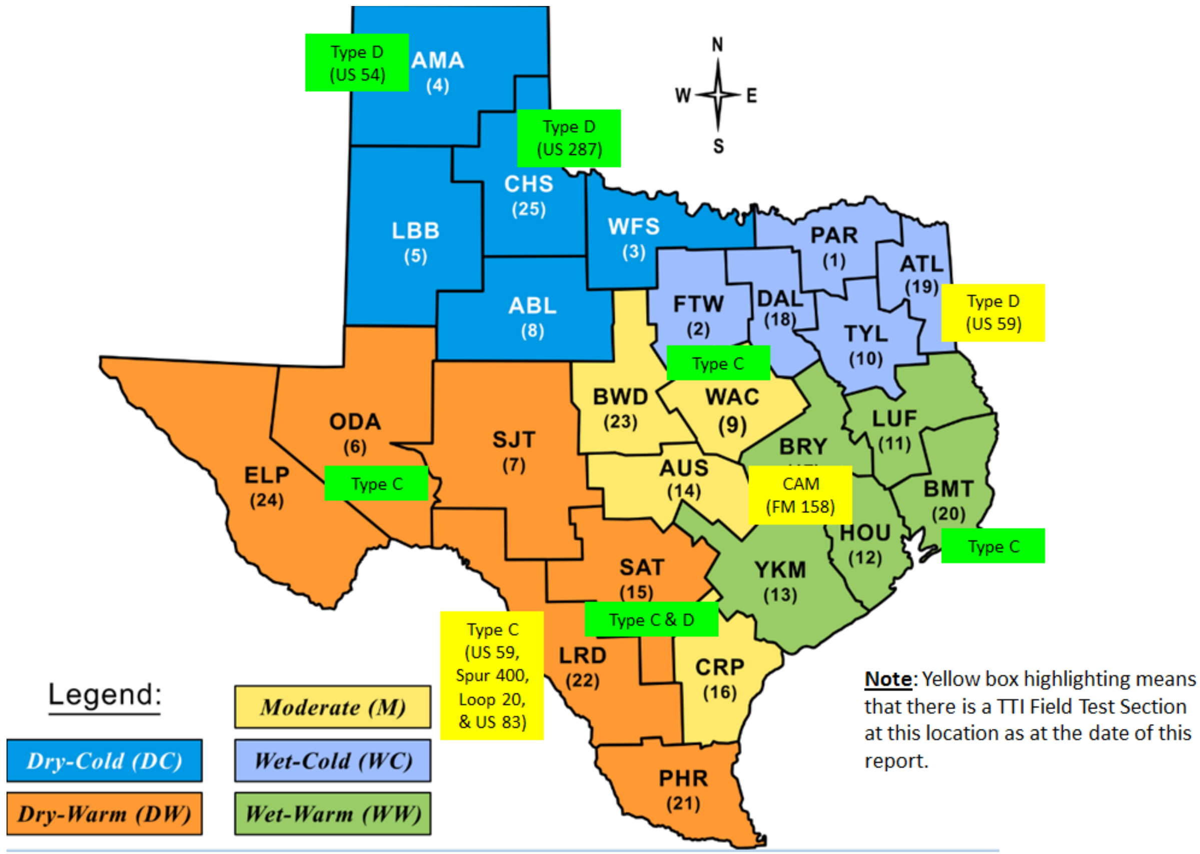

Figure 3-1. Geographical Location of Some of the HMA Mixes Used in This Study.

HMA MIX-DESIGN DEVELOPMENT AND MODIFICATIONS

As part of the research objectives and in order to meet the BMD requirements, numerous HMA mix-designs were developed and/or modified in the laboratory based on the original TGC designs. In general, the iterative mix-design steps undertaken to meet the BMD requirements so as to improve both the laboratory and field performance of the mixes included the following:

- Changing the TGC design density, e.g., vary between 96 and 98 percent, lab density, and/or AC level (4.8 to 5.3 percent).
- Changing the aggregate type and/or source, e.g., from limestone to quartzite.
- Changing the asphalt-binder type/grade and/or source, e.g., PG 70-22 to PG 64-22
- Changing the aggregate gradation and/or blend proportions, e.g., reducing the proportions of the fines or vice versa.
- Replacing the rock types in the aggregate blends.
- Changing the additives and/or the additive proportions, e.g., adding lime, anti-stripping agents.

- Modifying the quantity/proportion of cycled materials, e.g., RAP, RAS.
- Conducting additional lab tests such as aggregate absorption capacity and modifying/reducing the proportion of the most absorptive rock in the aggregate blend.
- Using a different aggregate gradation design specification, e.g., switching from a Type C to Type D mix.

Chapter 4 presents details of these mix-design development and/or modifications. Examples of mix-design modifications as implemented in this study are given in the subsequent subsection.

HMA Mix-Design Modification Examples

In order to improve laboratory performance in the Hamburg (rutting) and Overlay (cracking) tests, mix-design modifications were made to the original Type C (Hunter) and Type C (Beaumont) mixes. The Hamburg-rutting and Overlay-cracking performance on the original Type C (Hunter) mix, for instance, was not satisfactory (< 50 cycles). The measured Hamburg rut depth of 11.1 mm was very close to the 12.5 mm threshold after 15,000 HWTT load passes. Additionally, there was also visual evidence of stripping, suggesting moisture damage in the mix. Furthermore, the mix sustained only 34 load cycles in the OT test.

After aggregation gradation and blend modifications (i.e., removing the field sand and adding 1.0 percent lime) as shown in Table 3-2, the modified mix-design exhibited significant improvements in the Hamburg test, with the measured rut depth being 4.4 mm after 15,000 HWTT load passes. However, as evident in Table 3-2, no major improvements were observed in the OT in terms of laboratory cracking performance. In fact, the OT test indicated that the aggregate used in this mix was of relatively poor quality and probably absorptive. As a result, multiple cracks managed to cut through the aggregates during OT testing with this limestone mix.

Table 3-2. Example 1: Type C Mix (Hunter) – Original versus Modified Mix-Design.

Mix	Asphalt-Binder + Aggregate	OAC	Aggregate Blend	HWTT Rut Depth	OT Results
Type C (Hunter) Original	PG 70-22 + Limestone	4.7%	10% C-rock + 25% D-rock + 25% F-rock + 25% manufactured sand + 15% field sand	11.1 mm @ 15 k	34 cycles
Type C (Hunter) Modified	PG 70-22 + Limestone	4.9%	10% C-rock + *35% D-rock + 15% F-rock + 39% manufactured sand* + 1.0% lime	4.4 mm @ 15 k	38 cycles
Laboratory test benchmark utilized				≤ 12.5 mm	≥ 300 cycles

Like the Type C (Hunter) mix, the Type C (Beaumont) mix also performed unsatisfactorily in the Hamburg test, with the rut depth exceeding the 12.5 mm threshold after 10,000 HWTT load passes. The number of load cycles to crack failure in the OT test was also below 300. HMA mix-design modifications including switching to a higher PG asphalt-binder grade, i.e., PG 76-22, and changing the aggregate blend resulted in improved laboratory performance both in the Hamburg and the OT tests. Table 3-3 shows these modifications and the subsequent laboratory test results. Appendix A contains detailed mix-design sheets.

Table 3-3. Example 2: Type C Mix (Beaumont) – Original versus Modified Mix-Design.

Mix	Asphalt-Binder + Aggregate	OAC	Aggregate Gradation	HWTT Rut Depth	OT Results
Type C (Beaumont), Original	*PG 64-22* + Limestone	4.3%	20% C-rock + *40% Grade 5 + 25% Screenings + 15% washed sand*	12.8 mm @ 10 k	144 cycles
Type C (Beaumont - Modified)	*PG 76-22* + Limestone	5.2%	20% C-*rock + 40% Grade 5 + 30% Screenings + 10% washed sand*	7.0 mm @ 20 k	600 cycles
Laboratory test benchmark utilized				≤ 12.5 mm	≥ 300 cycles

Aggregate Gradations

Figure 3-2 shows an example plot of the aggregate gradations for some of the mixes listed in Table 3-1. As expected, the figure suggests that the Type B mix gradation is the coarsest. Similarly, the Type D mix exhibits the finest gradation. Appendix A includes detailed aggregate gradation tables and graphs for each respective mix.

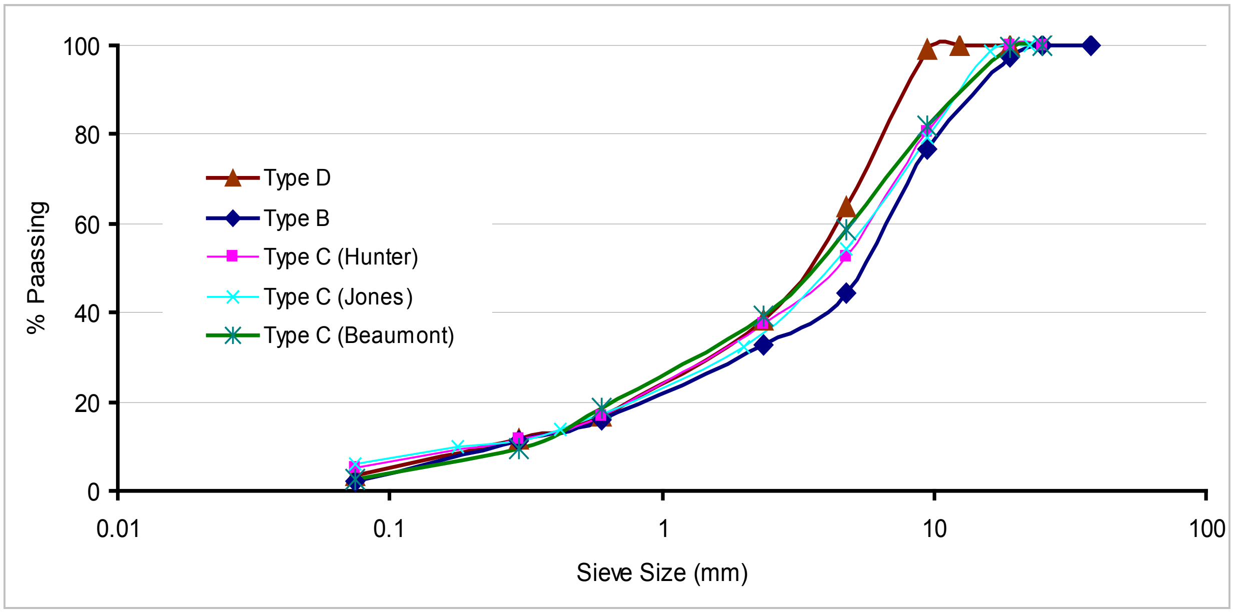

Figure 3-2. Example Aggregate Gradations for Type B, C, and D Mixes.

Aggregate Sieve Analysis

In order to accurately reflect the specified aggregate gradation for each mix type and account for the dust particles, adjustments were made to the original aggregate gradation based on the results of a wet sieve analysis. The wet sieve analysis is necessary to adjust the aggregate gradation because, quite often, dust particles and the aggregate fractions that pass the number 200 sieve size tend to cling to the surfaces of the particles that are larger than the number 200 sieve size. This phenomenon is often not well accounted for in a given gradation specification.

Wet sieve analysis is basically an iterative process of aggregate sieving, wetting/washing, and drying, followed by subsequent gradation adjustments based on the aggregate mass loss or gain on the individual sieve sizes. For this study, the wet sieve analysis was accomplished based on the TxDOT standard specification Tex-200-F (TxDOT, 2004). On average, three to four iterations were required prior to achieving the final adjustment. After the gradation adjustment, new maximum theoretical specific gravities (G_t) were determined using the ASTM standard D2041. A wet sieve adjustment does not change the fundamental properties of the gradation. Rather, it gives a more accurate representation of the specified gradation.

HMA SPECIMEN FABRICATION

For the lab-molded samples directly from raw materials, the HMA specimen preparation procedure was consistent with the TxDOT standard specifications Tex-205-F and Tex-241-F (TxDOT, 2011). The basic procedure involved the following steps: aggregate batching, wet sieve analysis, asphalt-aggregate mixing, short-term oven aging, compaction, cutting, and finally, volumetric analysis to determine the AV. Table 3-4 summarizes the HMA mixing and compaction temperatures, as a function of the asphalt-binder grade.

Table 3-4. HMA Mixing and Compaction Temperatures.

#	Asphalt Binder Performance Grade (PG)	Mixing Temperature	Compaction Temperature
1	PG 76-22	325°F (163°C)	300°F (149°C)
2	PG 70-22	300°F (149°C)	275°F (135°C)
3	PG 64-22	290°F (143°C)	250°F (121°C)

The temperatures in Table 3-4 are consistent with the TxDOT Tex-205-F and Tex-241-F test specifications for PG asphalt-binders (TxDOT, 2004, 2011). Prior to mixing, the aggregates were pre-heated at the mixing temperature for at least 8 hours to remove any moisture and facilitate easy mixing. The asphalt-binder was also pre-heated for approximately 1 hour prior to mixing to liquefy it.

Aggregate Batching

For fabricating the lab-molded samples directly from raw materials, the aggregates (including recycled materials, when applicable) were batched according to the mix-design sheets (Tex-204-F) based on the Tex-205-F test procedure (TxDOT, 2011). The procedure was carefully followed so that it was consistent with the TxDOT standard specification Tex-205-F. Calculated amounts of dry aggregates for each sieve size were added to the pan along with mineral filler and hydrated lime where applicable, then mixed thoroughly. The mixed aggregates were then heated in an oven at the appropriate mixing temperature.

Mixing and Sample Molding

Once the raw aggregates reached the required mixing temperature, they were removed and placed in the mixing bowl along with the heated RAP or RAS, etc. Required amounts of asphalt binder were added and were thoroughly mixed using a mechanical mixer. The mixture was placed into the oven at an appropriate compaction temperature for short-term aging.

HMA short-term oven aging for both lab-molded samples and plant mixes lasted for two hours at the compaction temperature consistent with the American Association of State Highway and Transportation Officials (AASHTO) PP2 aging procedure for Superpave mix performance testing. Short-term oven aging simulates the time between HMA mixing, transportation, and placement up to the time of in situ compaction in the field.

All of the HMA specimens (both from plant-mix materials and raw materials) were molded and gyratory compacted using the standard SGC according to Tex-241-F (TxDOT, 2011). All the HMA specimens for laboratory performance testing were compacted to a target AV content of 7±1 percent.

Cutting of Specimens and AV Measurements

DT, IDT, and SCB specimens were compacted in the SGC to a height of 6.9-inch in a 6-inch diameter mold. Based on the recent Tex-248-F modification recommendations, the OT specimens were compacted in the SGC to a height of 5.0-inch in the same mold (Walubita et al., 2012). The Tex-242-F standard specifications of 2.5-inch thick by 6.0-inch diameter molded samples was utilized (TxDOT, 2011). During molding, it was necessary to vary the AV of the 6.9-inch mold in order to achieve the target AV in each respective specimen type because of the differences in the geometry and AV distribution.

Based on the test specimen geometries and the required specimen dimensions shown in Table 3-5, two IDT specimens (typically cut from the middle zone) were obtainable from a one 6.9-inch long molded sample. Four SCB specimens were obtainable from the same molded sample configuration, while only one DT specimen could be obtained from the 6.9-inch long molded sample. Likewise, two OT specimens were obtainable from a 5.0-inch long molded OT sample. HWTT specimens were molded and fabricated to dimensions of 2.5-inch thick by 6.0-inch in diameter. These details are further listed in Table 3-5 for more clarity.

Table 3-5. HMA Specimen Molding, Cutting, and Coring.

Target Test Specimen	Test Specimen Geometry/ Dimensions	Sample Molding Configuration	No. of Obtainable Test Specimens	Comment
IDT	2.5-inch thick by 6-inch diameter	Cylindrically shaped = 6-inch diameter by 6.9-inch in height	2 from one molded sample	Typically cut from the middle zone, where density is considered more uniform
SCB	2.5-inch thick by 6-inch diameter		4 from one molded sample	
DT/DM/ RLPD	2.5-inch thick by 6-inch diameter by 3-ich tall		1 from one molded sample	
OT	1.5-inch thick by 3-inch wide by 6-inch width	Cylindrically shaped = 6-inch diameter by 5-inch in height	2 from one molded sample	
HWTT	2.5-inch thick by 6-inch diameter	Cylindrically shaped = 6-inch diameter by 2.5-inch in height	1 from one molded sample	

After the specimens were cut and cored, the volumetric analysis based on fundamental water displacement principles as specified in ASTM D2726 were completed to determine the exact AV content of each test specimen. HMA specimens that failed to meet AV specification (i.e., 7±1.0 percent) were discarded. The specimens that met the AV specification were stored at ambient temperature on flat shelves in a temperature-controlled facility prior to gluing and testing.

HMA Replicate Specimens and Lab Testing

For each variable (such as the AC level) and test type per mix type, a minimum of three replicate specimens were fabricated and tested. Thus, the results presented in this report represent an average of three replicate specimens/tests. All the performance lab testing (i.e., HWTT, OT, etc.) was conducted at 7±1 percent AV for the HMA specimens, with 30 percent COV as a guiding threshold for acceptable repeatability and variability in the test results.

SUMMARY

This chapter provided a presentation of the materials and mix designs used in this study. In total, four common Texas mix types (Type B, C, D, and CAM) with over 10 different mix designs were developed. Iterative steps utilized in the development and/or modification of the mix-designs was also presented and discussed. The experimental design plan including the HMA specimen fabrication, short-term oven aging, and specimen cutting were also discussed.

CHAPTER 4
HMA MIX-DESIGN DEVELOPMENT AND LAB TESTING

As stated in Chapters 1 and 2, one of the primary goals of this study was to develop numerous HMA mix-designs based on the BMD method alongside the traditional Texas TGC method, and thereafter, validate their field performance through APT testing and/or in-service highway test sections under conventional traffic loading. Following Table 3-1 and Figure 3-1 in Chapter 3, numerous HMA mix-designs were developed in various districts, covering all the five Texas climatic zones, namely:

1) Amarillo District (DC) - Type D mix
2) Atlanta District (WC) - Type D mix
3) Beaumont District (WW) - Type C mix
4) Bryan District (WW) - CAM mix
5) Childress District (DC) - Type D mix
6) Fort Worth District (WC) - Type C mix
7) Houston District (WW) - CAM and Type D mixes
8) Laredo District (DW) - Type C mix
9) Odessa District (DW) - Type C mix
10) San Antonio (DW) - Type C and D mixes
11) Waco District (M) - Type C mix

As will be demonstrated in this chapter, different mix design iterations and modifications were executed on different mixes to meet the BMD requirements and improve performance based, among others, on the material type and previous district mix-design problems. Accordingly, this chapter presents these mix-design developments, modifications, and laboratory test results (mainly the HWTT rutting and OT cracking tests). Results from other supplementary tests such as the DSR, BBR, IDT, SCB, water absorption, etc., are also discussed in this chapter. A summary of key findings and observations is then presented to conclude the chapter. Appendix A includes the typical HMA mix-design sheets for the mixes.

AMARILLO (AMA) DISTRICT

A Type D mix, with RAP and RAS, was iteratively evaluated to determine its optimal BMD performance through changing the asphalt-binder PG grade while maintaining the same aggregate gradation and blend proportions. The HMA mix details are listed below and the lab test results are shown in Figure 4-1; see Appendix A for the mix-design sheet.

- HMA mix: Type D (Item 341 – fine surface)
- Aggregate type: Dolomite/limestone/gravel (Miller)
- Aggregate blend: 49% Miller 7/16″ rock + 10.6% Miller washed coarse rock + 10% Miller gravel screenings + 10% river sand
- Recycled material: 15.2% fractionated RAP + 4.2% RAS
- Anti-strip agent: 1% hydrated lime (Chemical lime)
- Asphalt-binders evaluated: PG 58-28, PG 64-22, and PG 64-28 (Holly)
- AC levels evaluated: 5.7%, 6.2%, and 6.7%

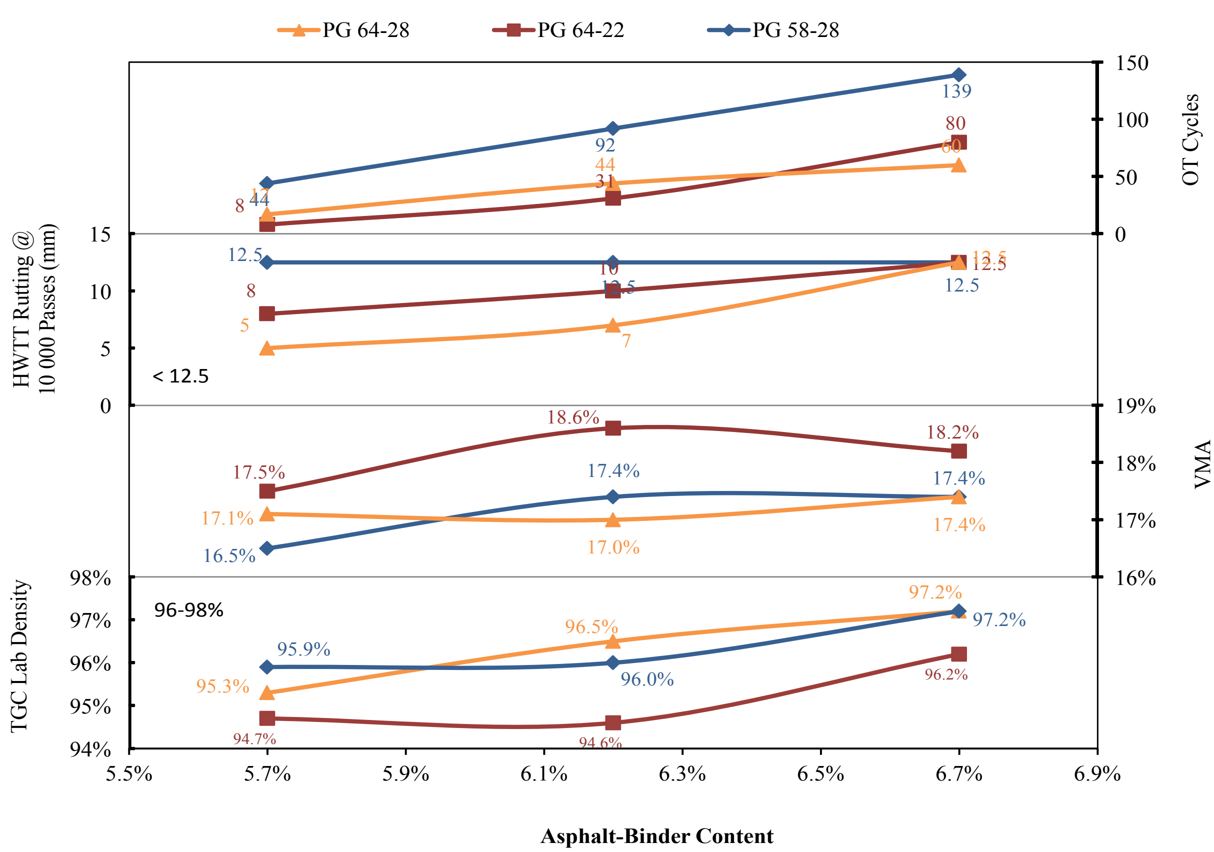

Figure 4-1. Lab Test Results for the Type D Mix (AMA).

For the materials and aggregate gradation/blends considered, Figure 4-1 shows that although exhibiting superior OT cracking performance, the PG 58-28 failed to meet the BMD HWTT rutting requirements for all of the AC levels that were evaluated. On the other hand, if 30 cycles is tentatively used as the OT cracking pass-fail screening criterion, the PG 64-28 would be considered satisfactory at 96.5 percent with an OAC of 6.2 percent. For the given aggregates and recycled materials, PG 64-22 would also be considered reasonable at 6.2 percent AC, but PG 64-28 would be the best choice as it gives a slightly superior BMD performance.

In general, the recommended options for future improvement of the HMA mix-design to optimize the material BMD performance include the following:

- Modify the aggregate blend proportions.
- Change the aggregate type and source. In particular, Texas limestone is often problematic.
- Change the proportion and/or source of the recycled materials.
- Blend with aggregates of superior quality from different sources.
- For the considered asphalt-binder source, the use of high temperature PG grades lower than 64 should be avoided as this could cause potential rutting problems under high summer pavement temperatures, especially considering that Amarillo is in the DC climatic environment.
- Evaluate other asphalt-binder sources.
- Conduct water absorption tests on the aggregates.
- Relaxing and modifying the BMD requirements, i.e., using 30 cycles for OT cracking requirements for RAP/RAS mixes.

ATLANTA (ATL) DISTRICT

A Type D mix earmarked for placement as an overlay on US 59 in Panola County was evaluated for the Atlanta District. This mix was composed of very high quality Quartzite aggregates and fractionated RAP materials; see Appendix A for the mix-design sheet. So, the only mix-design change was a slight increase in the design AC from the original 97 percent TGC lab design density (5.2 percent AC) to 98 percent density (5.5 percent AC) to improve the BMD cracking resistance potential of the mix under OT testing. As shown in Table 4-1 and Figure 4-2 through 4-6, this change in the AC from 5.2 percent to 5.5 percent significantly improved the HMA cracking resistance from 269 cycles to 506 cycles; almost doubling the OT crack life.

Table 4-1. HWTT- OT Results of the Type D Mix (ATL).

Item	Original TGC Design	The BMD Method
Mix Type	Type D – Fine Surface (Item 341)	
Aggregates	Quartzite (Jones Mill)	
Aggregate blend	40% ½″ CA quartzite + 13% 3/8″ CA quartzite + 20% RAP + 19% Screenings + 8% fine sand	
Recycled material	20% RAP = 10% coarse + 10% fine	
Asphalt-binder	PG 64-22 (Lion)	
Design AC	5.2%	5.5%
Corresponding TGC lab design density	97.0%	98.0%
VMA (≥ 14.0)	14.8	14.9
HWTT rutting @ 15,000 load passes	3.1 mm	4.1 mm
OT cracking	269 cycles	506 cycles
OT FE Index (Monotonic)	5.44	6.83
IDT strength (85–200 psi)	126 psi	104 psi
IDT FE Index		
SCB strength	124 psi	100 psi
SCB FE Index		
Balanced AC range (@ 96–98% density)		

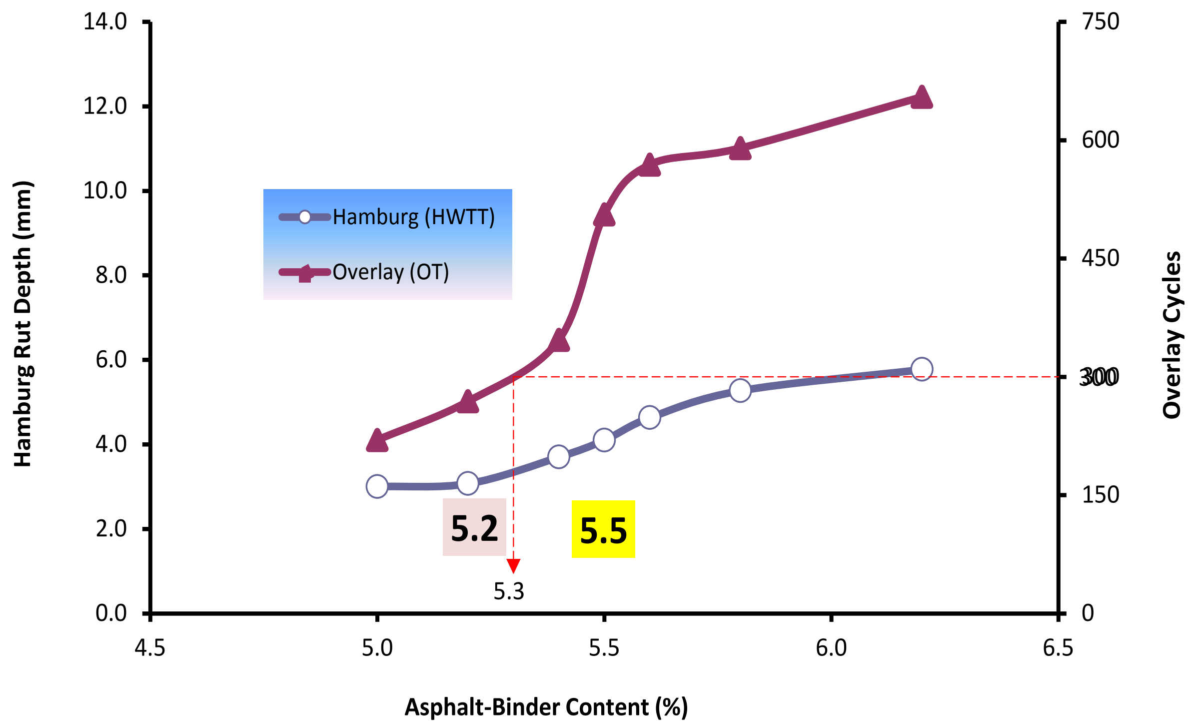

Figure 4-2. HWTT-OT Lab Results for Type D Mix (ATL).

Table 4-2. TGC Lab Density and VMA Results (ATL).

AC	5.2%	5.4%	5.5%	5.6%	5.8%	6.2%
Corresponding TGC Lab Density	97.0%	97.9%	98.0%	98.2%	98.5%	98.7%
VMA (≥ 14.0)	14.8%	14.9%	14.9%	15.0%	15.1%	15.2%

Figure 4-3. Type D 5.2% AC (3.1 mm) and 5.5% AC (4.1 mm) HWTT Specimens (ATL).

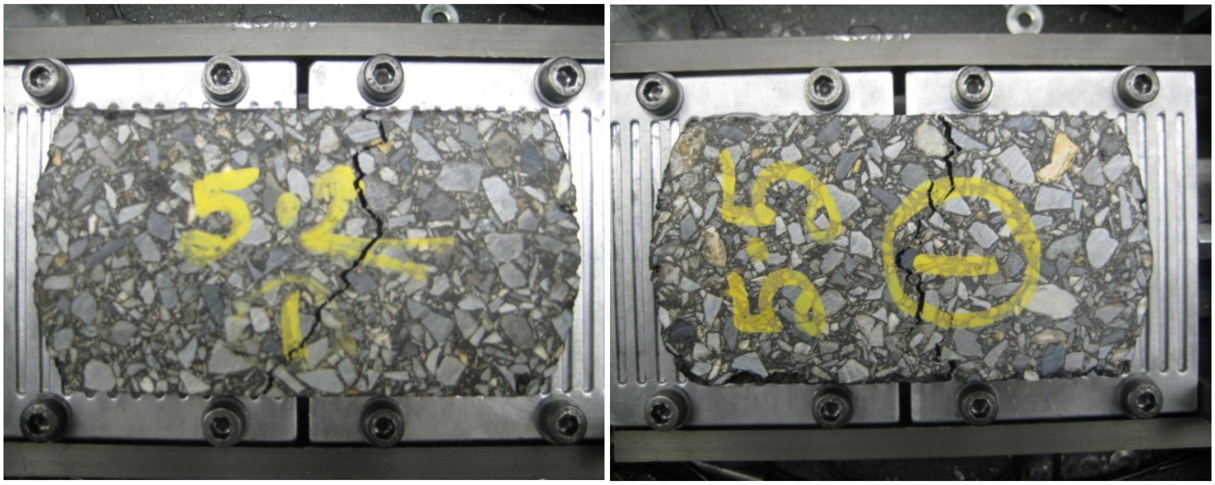

Figure 4-4. Type D 5.2% AC (269 Cycles) and 5.5% AC (506 Cycles) OT Specimens (ATL).

Figure 4-5. Type D 5.2% AC (126 psi) and 5.5% AC (104 psi) IDT Specimens (ATL).

Figure 4-6. Type D 5.2% AC (124 psi) and 5.5% AC (100 psi) SCB Specimens (ATL).

In addition to being satisfactory in terms of the BMD rutting and cracking requirements, Table 4-3 and Figure 4-5 also shows that the two AC levels (5.2 and 5.5 percent) satisfactorily met the density (96–98 percent), VMA (≥ 14.0 percent), and IDT strength (85–200 psi) requirements (TxDOT, 2004). As discussed in the subsequent chapters, field test sections were constructed and comparatively validated for field performance under conventional trafficking.

As noted in the preceding text, this mix and the selected AC levels were satisfactory and did not warrant the need for mix-design modifications and/or material change. Therefore, no BMD improvement modifications were suggested. However, if 150 cycles is tentatively assumed as the OT crack pass-fail screening criterion for Type D mixes, any AC level ranging from 4.8 to 5.5 percent corresponding to 96.5 to 98.0 percent TGC lab density would suffice as the BMD design AC for the given material combination.

BEAUMONT (BMT) DISTRICT

The mix evaluated from this district and discussed herein was a Type C, composed of PG 76-22 (Valero) and limestone (Brownwood); see Appendix A for the mix-design sheet. This is the same mix that was evaluated at the APT test in LA under ALF trafficking; refer to Report 0-6132-2 (Walubita et al., 2012) and the subsequent chapters of this report. As shown in Table 4-4, the design difference for this mix was mainly in the OAC level and the lab design density. The traditional TGC method yielded an OAC of 4.3 percent (96 percent lab design density) while the OAC for the BMD method was 5.2 percent (97.5 percent lab design density). Clearly Table 4-4 shows that the BMD method resulted in superior OT cracking resistance performance.

Table 4-3. Type C HWTT-OT Lab Test Results (BMT).

Item	TG Method	BMD Method
Mix designation	Control	Modified
Mix type	Type C (Item 341 – Coarse Surface)	
Materials	PG 76-22 (Valero) + Limestone (Brownwood)	
Aggregate blend	20% C-rock + 40% Grade 5 + 30% Screenings + 10% washed sand	
Design OAC	4.3%	5.2%
Corresponding TGC lab density (96% ≤ TGC < 98%	96.0%	97.5%
VMA (≥ 14%)	14.0	14.2%
HWTT rutting @ 20,000 load passes (≤ 12.5 mm)	4.7	7.0
OT crack cycles (≥ 300)	90	600
IDT (85 ≤ IDT ≤ 200 psi)	165 psi	130 psi
Balanced AC range (@ 96–98% density)	N/A	5.1–5.6%
APT placement	Control test sections	Modified test sections

As shown in Table 4-4, the BMD method yielded a superior crack resistant mix with OT crack life over six times more than the mix designed with the traditional TGC method. More details of these mix-designs along with other supplementary test results including the DM, RLPD, IDT, and SCB are documented in Report 0-6132-2 (Walubita et al., 2012). Additionally, Table 4-4 shows that if 100 cycles was tentatively used as the OT crack pass-fail screening criterion, the TGC mix-design with 4.3 percent AC would still have failed.

Comparing Tables 3-3 (Chapter 3) and 4-4, it is evidently clear that despite a slight difference in the aggregate blend proportions on the screenings and sand, the best asphalt-binder type for the given aggregates in terms of the BMD method is PG 76-22, with a balanced AC range of 5.1 to 5.6 percent. The PG 64-22 failed to meet the HWTT rutting requirements (Table 3-3). Future BMD design iterations should also explore the use of PG 70-22 (Valero) as well as other asphalt-binder sources.

BRYAN (BRY) DISTRICT

A CAM mix, earmarked for 1-inch thick overlay placement on FM 158, with Capitol limestone was evaluated using different PG 76-22 asphalt-binder sources. In this particular case study, TTI was requested by both the Contractor (Knife River Corporation) and the Bryan TxDOT District Office to assist with the mix design as the Contactor was initially having problems getting his proposed mix design to meet the Item 3131 CAM Hamburg rutting and OT cracking requirements. This was a concern as the Contractor had successfully designed and constructed an earlier project with an identical mix design. The Bryan District lab engineer asked TTI for an evaluation of the proposed mix to assess if lower asphalt-binder contents would meet the Item 3313 CAM requirements and potentially save the district money.

The Contractor was concerned because the initial proposed PG 76-22 (Martin), while having satisfactory HWTT rutting performance, could not meet the OT CAM cracking requirements of a minimum of 750 cycles. As shown in Table 4-5, this asphalt-binder (source) had less than 200 OT cycles for all of the AC levels that were evaluated, i.e., 6.5 to 7.1 percent with a corresponding TGC lab density range of 96.7 to 99.0 percent. However, the asphalt-binder source (Martin PG 76-22) successfully met the HWTT rutting requirement (i.e., less than 5.0 mm rutting).

Table 4-4. CAM HWTT-OT Lab Test Results (BRY).

	#	AC	Lab TGC Density	VMA (>17)	HWTT Rutting	OT Cracking	OT Peak Load (lbs)
Martin PG 76-22	1	6.5%	96.7%	18.4	2.9 mm	132	815
	2	6.7%	98.5%	17.2	3.6 mm	169	770
	3	6.9%	98.9%	17.4	4.1 mm	173	696
	4	7.1%	99.0%	17.6	4.4 mm	173	835
Valero PG 76-22	1	6.5%	96.5%	19.0	4.5 mm	736	580
	2	6.7%	97.5%	18.1	4.9 mm	951	630
	3	6.9%	98.0%	18.1	5.7 mm	956	553
	4	7.1%	98.4%	18.4	7.4 mm	1,000	563
Jebro PG 76-22	1	6.5%	96.5%	18.7	3.2 mm	861	600
	2	6.7%	97.0%	18.7	4.3 mm	1,000	774
	3	6.9%	97.5%	18.7	5.0 mm	938	640
	4	7.1%	98.0%	18.7	5.4 mm	1,000	612
Threshold Used			98.0%	≥ 17	≤ 12.5 mm @ 20,000 load passes	≥ 750 cycles	500-900 lbs

Two alternative PG 76-22 asphalt-binder sources were comparatively evaluated, Valero and Jebro, both of which successfully passed the Item 3131 (CAM) HWTT rutting and OT cracking requirements; see Table 4-5 and Appendices A and B. Based on TTI's results in Table 4-5 and Appendix B, the following course of action was undertaken:

- The Contractor elected to use the Jebro PG 76-22 asphalt-binder and the Bryan District's Special Specification Item 3131 with the volumetric design requirement of 98 percent density after 50 gyrations; the OAC was found to be 7.1 percent. At this OAC level, the HWTT rut depth was 5.4 mm after 20,000 passes and 1,000 OT cycles.
- TTI also conducted performance tests at a lower target density of 96.5 percent on both asphalt-binders (Valero and Jebro) and found that all the criteria were met while using approximately 0.5 percent less asphalt-binder, i.e., HWTT < 5.0 mm rutting after 20,000 passes and OT > 750 cycles for 6.5 percent PG 76-22 Jebro and 6.6 percent PG 76-22 Valero, respectively; see Table 4-6.
- The district elected to place the mix with a target AC of 6.7 percent (Jebro), which is allowable under the Item 3131 CAM specification, where the AC is paid for as a separate bid item. The 6.7 percent PG 76-22 Jebro asphalt-binder corresponded to 97 percent lab density with HWTT = 4.3 mm rutting after 20,000 load passes and OT = 1,000 cycles.

These results are summarized in Table 4-7. Detailed results can also be found in Appendix B.

- The modified CAM mix-design (6.7 percent PG 76-22 Jebro) was placed on the entire project length of about 1.6 miles long on FM 158 as a 1 inch thick overlay by Knife River Corporation late 2010 from December 10 to 31.
- Lab test were also conducted on plant-mix materials delivered to the project site. The extracted and measured AC based on the ignition oven test was close to the design value (6.55 percent versus 6.7 percent). The measured HWTT (4.4 mm rut depth) and OT (796 cycles) results also did not differ significantly from the lab design values and still met the Item 3131 CAM specification .

Asphalt-Binder DSR and BBR Tests

To investigate the cause of the poor laboratory performance of the Martin PG 76-22 in the OT cracking test, DSR and BBR tests were conducted to characterize the rheological properties of the asphalt-binders. The results of these tests are shown in Figure 4-7 and Table 4-8, respectively.

Table 4-5. CAM Mix-Design Recommendations (BRY).

Lab Density	Jebro PG 76-22				Valero PG 76-22			
	AC	**VMA**	**HWTT**	**OT**	**AC**	**VMA**	**HWTT**	**OT**
96.5%	6.5%	18.7	3.2 mm	861	6.6%	18.6	4.8 mm	951
97.0%	6.7%	18.7	4.3 mm	1,000	6.7%	18.1	4.9 mm	956
97.5%	6.9%	18.7	5.0 mm	938	6.9%	18.1	5.7 mm	1,000
98.0%	7.1%	18.7	5.4 mm	1,000	7.1%	18.4	7.4 mm	951
Threshold		≥ 17.0	≤ 12.5 mm	≥ 750		≥ 17.0	≤ 12.5 mm	≥ 750

Table 4-6. CAM HWTT-OT Lab Test Results at 97% and 98% TGC Densities (BRY).

Item	Martin PG 76-22	Valero PG 76-22	Jebro PG 76-22
Mix-design method	TTI BMD Method		
Mix type	CAM (Item 3131)		
Aggregates	Capital Limestone		
Aggregate blend	21% Gr5 (Delta pit) + 18% D-rock (Marble Falls pit) + 60% screenings (Marble Falls pit)		
Anti-strip	1% Lime (Austin White Lime)		
Gradation	Same		
Recycled material	None		
Design AC @ 97% TGC density	-	6.6%	6.7%
Design AC @ 98% TGC density	6.6%	6.9%	7.1%
OT for AC @ 97% TGC density (OT ≥ 750 cycles)	--	800	1 000+
OT for AC @ 98% TGC density (OT ≥ 750 cycles)	150	956	1,000+
Hamburg @ 20,000 load passes for AC @ 97% TGC density (< 12.5 mm)	-	4.7 mm	4.3 mm
Hamburg @ 20,000 load passes for AC @ 98% TGC density (< 12.5 mm)	3.9 mm	5.7 mm	5.4 mm

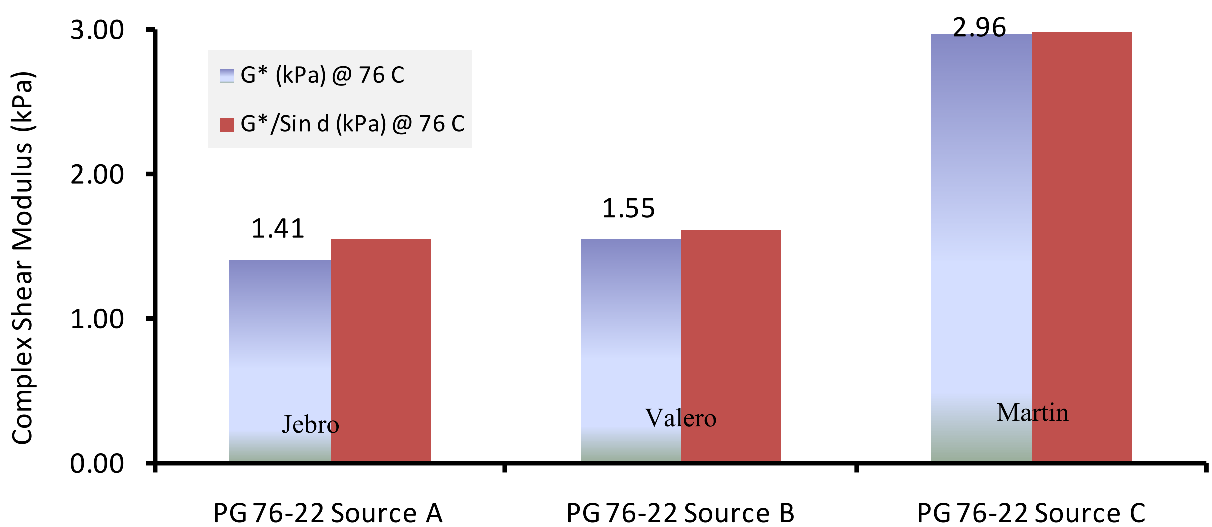

Figure 4-7. Comparison of Asphalt-Binder Shear Modulus at 76°C.

Table 4-7. Asphalt-Binder DSR and BBR Test Results.

Asphalt-Binder	DSR (Higher Temp)			BBR (Lower Temp)			True Grade Temp (°C)	Final PG Grade
	Temp (°C)	G* (kPa)	G*/Sin δ (kPa)	T (°C)	S (MPa)	m-value		
PG76-22 Jebro	76.03	1.41	1.54	-12	174	0.325	80.05-22	PG 76-22
PG76-22 Valero	76.03	1.55	1.61	-12	132	0.316	80.58-22	PG 76-22
PG76-22 Martin	*81.97*	1.03	1.05	-12	277	0.317	82.46-22	*PG 82-22*
Threshold			≥ 1.00 kPa		≤ 300	≥ 0.300	@ 1.00 kPa	

As shown in Figure 4-7 and Table 4-7, the Martin PG 76-22 was found to be a stiffer asphalt-binder that finally graded out as a PG 82-22, i.e., the true grade temperature range was 82.46-22°C (Table 4-7). It is evident from these results that not all PG 76-22 asphalt-binders are manufactured equally; it is apparent that material source has an influence and needs to be considered when selecting the appropriate material combinations during the mix-design stage.

Texas currently does not test the upper temperature limit. Therefore, an asphalt-binder can be a PG 82- but still be accepted as a PG 76-.As shown herein, this could be a potential issue in terms of both the asphalt-binder rheological properties and the overall mix performance. Nonetheless, this is not to discount the fact that the performance of the Martin PG 76-22 would have probably been different if a different aggregate type was explored.

Lessons Learned and Recommendations

From the results of this case study, the lessons learned along with the recommendations can be summarized as follows:

- Not all PG 76-22 asphalt-binders are manufactured equally; it is apparent that material source has an influence and caution should be exercised when selecting materials during the mix-design process. Texas currently does not test the upper temperature limit. Therefore, an asphalt-binder that is graded as PG 82- can still be accepted as a PG 76-. This could be a potential issue in terms of the overall mix performance. Nonetheless, this is not to discount the fact that the performance of the PG 76-22 Source C would have probably been different if a different aggregate type was explored.

- In addition to the standard 98 percent target laboratory density, performance tests on future CAM designs should also be run at asphalt-binder contents found at lower laboratory densities such as 96.5, 97, or 97.5 percent. As shown herein, this could lead to a potential cost saving while still satisfying the CAM lab performance requirements and being construct-able in the field.
- The Bryan District's usage of a PG 76-22 with 1 percent lime for CAM designs to be placed as surface layers in high traffic locations appears to be working well. Thus, considerations should be made to incorporate these requirements into the statewide specification Item 365.
- In situations where unsatisfactory BMD mix performance has been obtained, it is also strongly recommended to conduct asphalt-binder tests to characterize the rheological properties of the asphalt-binders. As noted in this study, the asphalt-binder itself could be a cause for poor lab performance.
- As observed from this case study, material type and source have a profound influence on the BMD mix-design process and HMA performance. Consequently, it is recommended to always use quality materials from reliable sources and to (where needed) conduct material verification and compatibility tests.

CHILDRESS (CHS) DISTRICT

A Type D RAP mix with PG 58-28 and granite/trap-rock aggregates, earmarked for use on US 287, was successfully evaluated and designed for Childress District. The original OAC design at 96 percent TGC lab density was 4.9 percent. The HMA mix-design details are listed below and the lab test results are summarized in Table 4-8 and Figure 4-8. The mix-design sheet details are in Appendix A.

- Mix type: Type D (Item 341 – fine surface)
- Asphalt-binder: PG 58-28 (Valero)
- Aggregate: Granite/trap-rock aggregates (G-T Fletcher)
- Aggregate-blend: 11% ½″-rock + 39% 5/16″-rock + 28% screenings
- Recycled material: 20% fractionated RAP = 13% coarse + 7% fine
- Anti-strip: Hydrated lime (2%)

Table 4-8. Type D HWTT-OT Lab Test Results (CHS).

AC	TGC Lab Density	VMA	HWTT Rutting	OT Cycles
4.9%	96.0%	15.3	5.1 mm	117
5.1%	96.5%	15.3	7.1 mm	366
5.4%	97.0%	15.5	9.3 mm	506
5.6%	97.5%	15.5	10.8 mm	620
5.8%	98.0%	15.6	12.5 mm	825
Threshold used	96-98%	≥ 14.0	≤ 12.5 mm @ 10,000 load passes	≥ 300

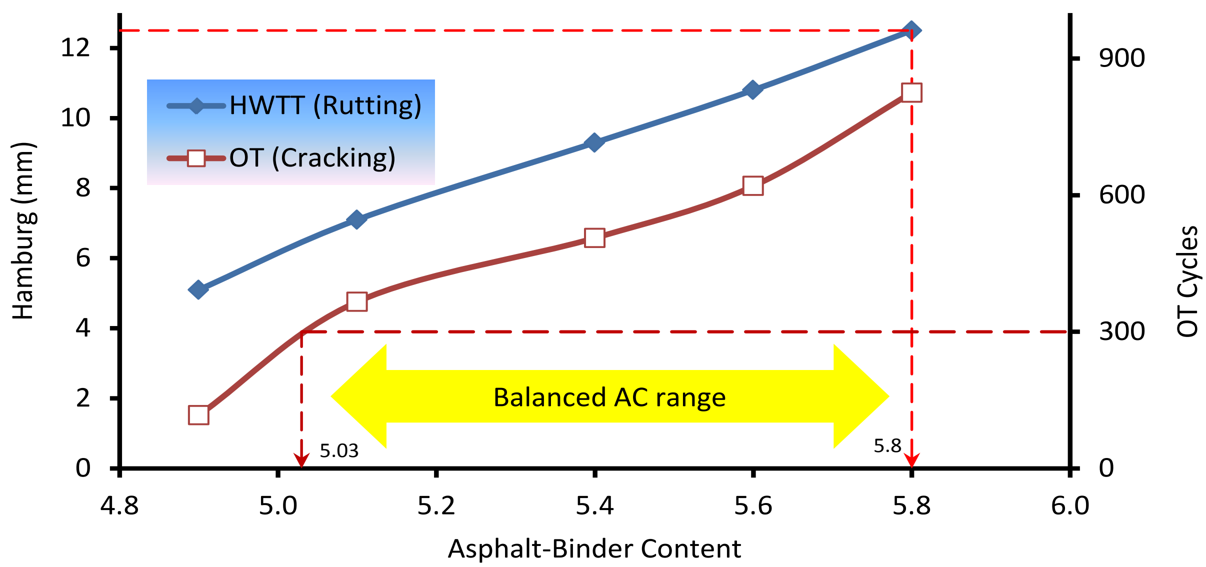

Figure 4-8. Type D HWTT-OT Lab Test Results (CHS).

As evident in Figure 4-8, this Type D mix consisted of good quality materials and satisfactorily met the BMD requirements with a balanced AC range of 5.1 to 5.8 percent, corresponding to 96.5 to 98.0 percent lab density. If 96.5 percent lab density is considered, the BMD AC would be 5.1 percent and 5.4 percent if 97.0 percent lab density is considered. Thus, the recommendation would be either 96.5 (5.1 percent AC) or 97.0 percent (5.4 percent AC) lab design density. For additional BMD mix improvements (if needed) the following options can be considered:

- Design at 96.5 or 97.0 percent lab TGC density.
- Explore the use of higher PG asphalt-binder grades such as other PG 64-22 or PG 64-28.
- Modify the aggregate gradations and blend proportions, i.e., increase the coarse RAP and the ½ inch-rock and/or reduce the screenings, fine RAP, and the 5/16 inch-rock.

FORT WORTH (FTW) DISTRICT

A Type C RAP with PG 70-22 and granite aggregates was evaluated for this district. The original OAC design at 96 percent TGC lab density was 4.6 percent. The HMA mix-design details are listed below, and the lab test results are summarized in Table 4-9 and Figure 4-9. The mix-design sheet details can be found in Appendix A.

- Mix type: Type C (Item 341 – coarse surface)
- Asphalt-binder: PG 70-22 (Jebro)
- Aggregates: Granite (Mill Creek)
- Aggregate-blend: 37% C-rock + 19% D-rock + 29% manufactured sand
- Recycled material: 15% RAP
- Anti-strip: Akzo Nobel 2912 (1%)
- Ignition oven test: 4.3% AC (−0.3% less; spec tolerance ±0.3%)

If 100 cycles is tentatively used as the OT crack pass-fail criterion for Type C mixes, the recommended BMD designs based on Figure 4-9 would be as follows:

1) 4.8 percent AC corresponding to 96.5 percent lab design density.
2) 5.0 percent AC corresponding to 97.0 percent lab design density.
3) 5.2 percent AC corresponding to 97.5 percent lab design density.

Table 4-9. Type C HWTT-OT Lab Test Results (FTW).

AC	TGC Lab Density	VMA	HWTT Rutting	OT Cracking	Comment
4.6%	96.0%	15.1	2.8 mm	048	Plant-mix
4.6%	96.0%	15.1	2.4 mm	084	Raw materials molded in TTI lab
5.0%	97.0%	15.0	3.8 mm	158	
5.2%	97.5%	15.0	4.1 mm	175	
5.4%	98.0%	15.0	4.2 mm	189	
Threshold used	(96% ≤ TGC ≤ 98%)	(≥ 14)	≤ 12.5 mm @ 20,000 load passes	≥ 100	

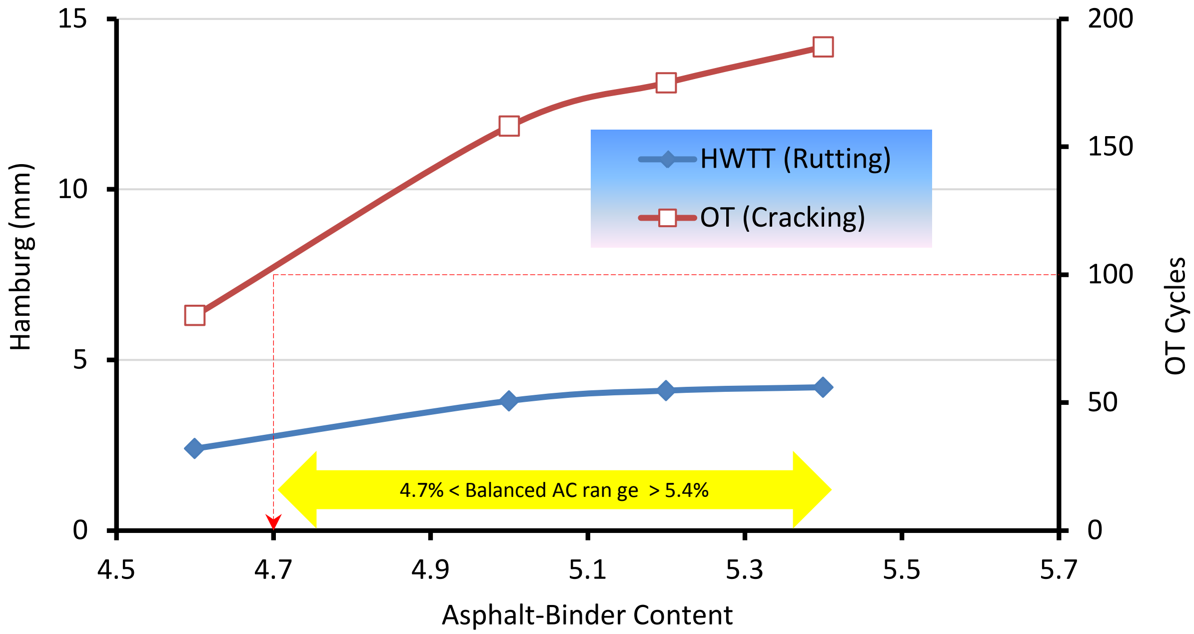

Figure 4-9. Type D HWTT-OT Lab Test Results (FTW).

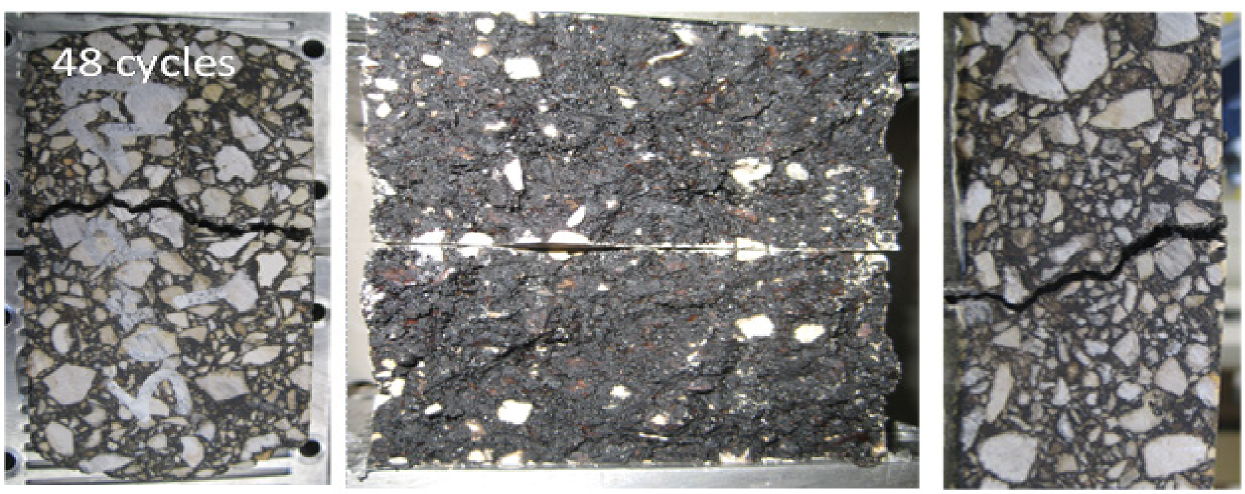

Figure 4-10. Type D OT Samples (4.6% AC) after Testing (FTW).

Recommendations for mix-design modifications and material changes to improve the BMD performance include the following options:

- Design at 96.5, 97.0, or 97.5 percent lab TGC density.
- Modify the aggregate blend proportions, i.e., reduce the C-rock and increase D-rock.
- Reduce the RAP proportion to 10 percent and increase the D-rock.
- Use better quality RAP materials and/or different sources.

- Explore lower PG asphalt-binder grades such as PG 58-28, PG 64-22, or PG 64-28.
- Relax and modify the BMD requirements, i.e., use 100 cycles for OT cracking requirements for Type C mixes.

HOUSTON (HOU) DISTRICT

A Type D mix earmarked for use on IH10 and FM 2920 (Harris County) was evaluated, and the lab test results are listed in Table 4-10 alongside the Atlanta Type D mix for comparison purposes as both mixes incorporated fractionated RAP.

Table 4-10. Type D HWTT-OT Lab Test Results (HOU).

Item	Houston (IH 10 and FM 2920)	Atlanta (US 59)
Mix type	Type D (Item 344 SP D [RBL])	Type D (Item 341- Fine Surface)
Asphalt-binder	PG 76-22 (Wright)	PG 64-22 (Lion)
Aggregate type	Limestone	Quartzite (Jones Mill)
Aggregate blend	15% Fractionated Fine RAP + 50% F-Rock + 35% Screenings	40% ½″ quartzite + 13% 3/8″ quartzite + 20% RAP + 19% screenings + 8% fine sand
Recycled material	15% fractionated fine RAP	20% fractionated RAP
AC in RAP	4.8%	4.3% in Coarse & 7.2% in Fine
Other additives	Anti-strip (Unichem No. 8162)	None
Rice	2.368	2.452 @ 5.2% AC & 2.440 @ 5.5% AC
TGC lab density	98.0 % @ 7.0% AC	97.5 % @ 5.2% AC & 98.0 % @ 5.5% AC
HWTT rutting (≤ 12.5 mm @ 20,000 load passes)	Load passes = 20,000 1) TTI lab @ 7.0% AC = 5.2 mm 2) Houston lab @ 7.0% AC = 8.9 mm	Load passes = 15,000 1)TTI lab @ 5.2% AC = 3.7 mm @ 5.5% AC = 4.4 mm 2)Atlanta lab @ 5.2% AC = 6.6 mm
OT cracking (≥ 150 cycles)	1) TTI lab = 68 cycles (COV = 70%) 2) Houston lab = 68 cycles (COV = 10%)	TTI lab @ 5.2% AC = 225 cycles @ 5.5% AC = 400 cycles
IDT (85–200 psi)	1) TTI lab @ 7.0% AC = 108 psi 2) Houston lab @ 7.0 % AC = 111 psi	1)TTI lab @ 5.2% AC = 149 psi @ 5.5% AC = 132 psi 2) Atlanta lab @ 5.2% AC = 144 psi
Hwy (County)	IH 10 & FM 2920 (Harris)	US 59 (Panola)

Clearly, Table 4-10 shows a significant difference in the effects of the material type, source, and quality on mix lab performance, particularly in terms of the OT cracking test. The Atlanta Type D mix consists of better quality aggregates and RAP materials than the Houston Type D mix with limestone. In fact, the Atlanta Type D mix exhibited a crack life over six times than that of the Houston Type D mix in terms of the OT cycles to failure. Inevitably, this comparison emphasizes the need to always use quality materials to optimize the mix performance as well as to meet the BMD requirements.

Considering the generally marginal limestone aggregates from Central Texas and if 30 cycles is tentatively used as the OT crack pass-fail screening criterion for RAP mixes, the Houston Type D mix would nonetheless be considered reasonable. However, for use as the RBL as indicated for IH 10, this Type D mix would be considered unsuitable. Suggested recommendations for improving the mix's BMD performance include the following:

- Explore other asphalt-binder PG grades and sources. As observed in the preceding section, similar asphalt-binder PG grades from different sources are not the same and have different rheological properties.
- Use quality RAP materials from different sources.
- Change the aggregate type and/or source.
- Modify the aggregate blend proportions, and/or replace them with different quality rock types/sources.
- Pre-coat the F-rock to minimize any propensity for asphalt-binder absorption. Central Texas limestone aggregates, in general, have historically exhibited these issues (marginal quality and absorption).
- Relax and modify the BMD requirements, such as using 30 cycles for OT cracking requirements for RAP/RAS mixes.

LAREDO (LRD) DISTRICT

For this district, it was desired to assess if the Type C RAP mix designed with PG 70-22 based on the traditional TGC method could be cost-effectively improved using the BMD method. As shown in Table 4-11, the initial 4.8 percent PG 70-22 design at 96.5 percent TGC lab density had performed very poorly in terms of the OT cracking test (only 38 cycles). Using the BMD method, researchers redesigned the mix with a lower asphalt-binder PG grade, namely a PG 64-22 from Valero. The corresponding BMD lab test results are shown in Tables 4-11 and 4-12.

Table 4-11. Type C HWTT-OT Lab Test Results (LRD).

Item	Original TGC Design	The BMD Method
Mix type	Type C (Item 341)	Type C (Item 341)
Asphalt-binder	PG 70-22 (Valero)	PG 64-22 (Valero)
Aggregate	Crushed gravel (A.C)	Crushed gravel (A.C)
Aggregate blend	21% Gr3 + 15% Gr4 + 27% Gr5 + 7% Gr6 + 9% Fine Sand	21% Gr3 + 15% Gr4 + 27% Gr5 + 7% Gr6 + 9% Fine Sand
Recycled material	20% fine RAP	20% fine RAP
Anti-strip	1% lime	1% lime
Design OAC	*4.8% PG 70-22*	*5.0% PG 64-22*
Design lab TGC density	96.5%	96.5%
Rice	2.432	2.414
VMA (≥ 13%)	14.4%	14.8%
Hamburg rutting (≤ 12.5 mm @ 20,000 load passes)	*2.9 mm*	*6.0 mm*
OT cracking (≥ 100)	*38 cycles*	*200 cycles*
IDT (85–200 psi)	140.5 psi	122.3 psi
SCB	156.0 psi	148.0 psi
Test section designation	Control	Modified
Hwy here placed		*1) Loop 20(≅ 1mile long) ,* *2) US 59 (≅ 3 miles long), &* *3) Spur 400 (≅ 1mile long)*

Table 4-12. Type C HWTT-OT Lab Test Results for PG 64-22 and PG 70-22 (LRD).

	AC	Corresponding TGC Lab Density	VMA	HWTT Rutting	OT Cracking (Cycles)
PG 70-22 (Valero)	4.7%	96.0%	14.6	2.04 mm	24
	4.8%	**96.5%**	**14.4**	**2.9 mm**	**38**
	5.0%	97.0%	14.3	2.7 mm	46
	5.2%	97.5%	14.4	2.9 mm	60
	5.5%	98.0%	14.5	3.2 mm	73
PG 64-22 (Valero)	4.8%	96.0%	14.7	5.4 mm	180
	5.0%	**96.5%**	**14.8**	**6.0 mm**	**200**
	5.2%	97.0%	14.8	6.5 mm	219
	5.4%	97.5%	14.7	8.0 mm	311
	5.6%	98.0%	14.7	9.7 mm	380
Threshold Used		(96% ≤ TGC ≤ 98%)	(≥ 13)	≤ 12.5 mm @ 20,000 load passes	≥ 100

At equivalent TGC lab densities, the results show that lowering the asphalt-binder PG grade from PG 70-22 to PG 64-22 improved the OT crack life of the mix by over five times in terms of the OT cycles. Considering the pass-fail screening criteria assumed in Tables 4-11 and 4-12, Figure 4-11 shows that an AC range of 4.8 to 5.6 percent corresponding to a lab density of

96 to 98 percent would be sufficient with the PG 64-22 asphalt-binder. Appendix A includes mix-design sheet details.

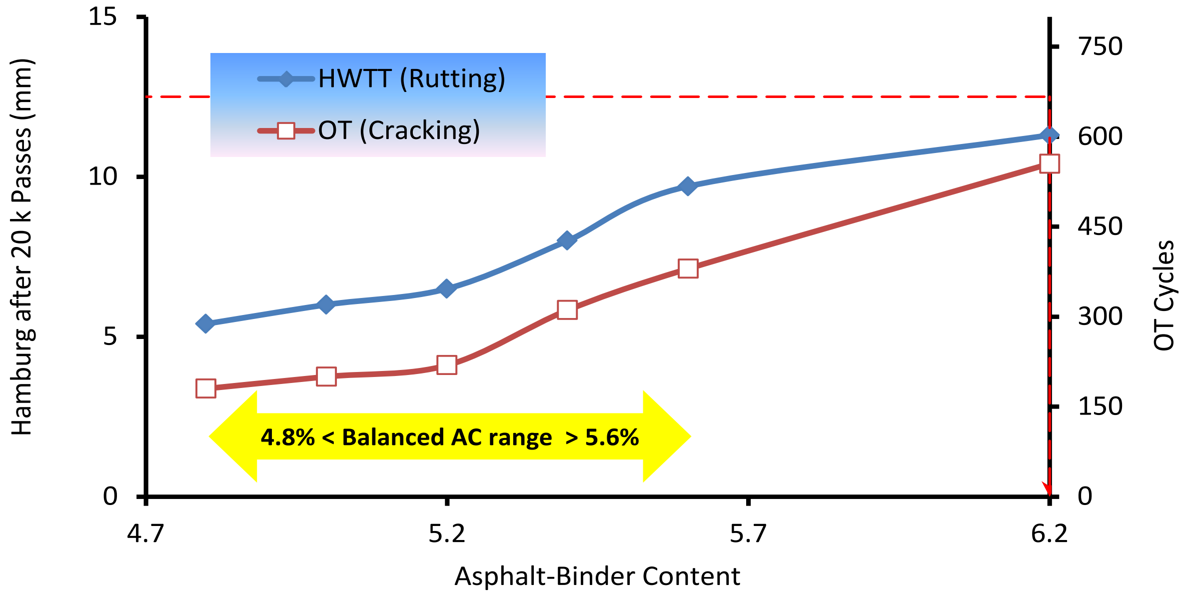

Figure 4-11. Type C HWTT-OT Lab Test Results (LRD).

For consistency with the initial PG 70-22 design density, an AC of 5.0 percent (PG 64-22) at 96.5 percent lab density was selected and has since been placed as 2-inch thick overlay on various highways in the district; refer to the subsequent chapters of this report. An important observation from this case study is that the OT cracking performance for RAP mixes is improved by changing to a lower asphalt binder PG, provided quality materials are used. The challenge would be to simultaneously balance the rutting performance when such a modification has occurred.

Besides the need to review the BMD requirements for the OT cracking pass-fail screening criteria (i.e., tentatively using100 cycles for Type C mixes), the overall results did not warrant any modification recommendations for these materials.

SAN ANTONIO (SAT) DISTRICT

Two mix types, Type C and D, all with PG 70-22 (Valero) and limestone aggregates (Hunter-Colorado Materials) were evaluated. Appendix A lists the original HMA mix-design sheets based on the TGC method. As shown in Table 4-13, laboratory performance of the original TGC mix designs was unsatisfactory, either in terms of the OT cracking testing or HWTT rutting testing or both.

Table 4-13. HWTT- OT Results of the Type C and D Original Mix-Designs (SAT).

Item	Type C - Original TGC Design	Type D - Original TGC Design
HMA mix	Type C Item 340 (Coarse Surface)	Type D Item 340 (Fine Surface)
Materials	PG 70-22 (Valero) + Limestone	PG 70-22 (Valero) + Limestone
Aggregate-blend	10% D-rock +25% F-rock + 20% Man. Sand + 20% Field Sand	23% D-rock + 37% F-rock + 25% Man. Sand + 15% Field Sand
Recycled material	15% RAP	None
OAC	4.7% @ @ 96.5% TGC lab density	5.1% @ 96.5% TGC lab density
HWTT rutting (≤ 12.5 mm)	5.6 mm @ 20,000 load passes	Failed @ 12,300 load passes
OT cracking (≥ 30 cycles)	22 cycles	67 cycles

Additionally, both mixes exhibited stripping problems under HWTT testing in a water bath at 50°C. During OT testing, cracking also occurred directly through large limestone rocks; see Figure 4-12. This is an indication of undesirably poor quality rocks. More pictures are also included in Appendix B.

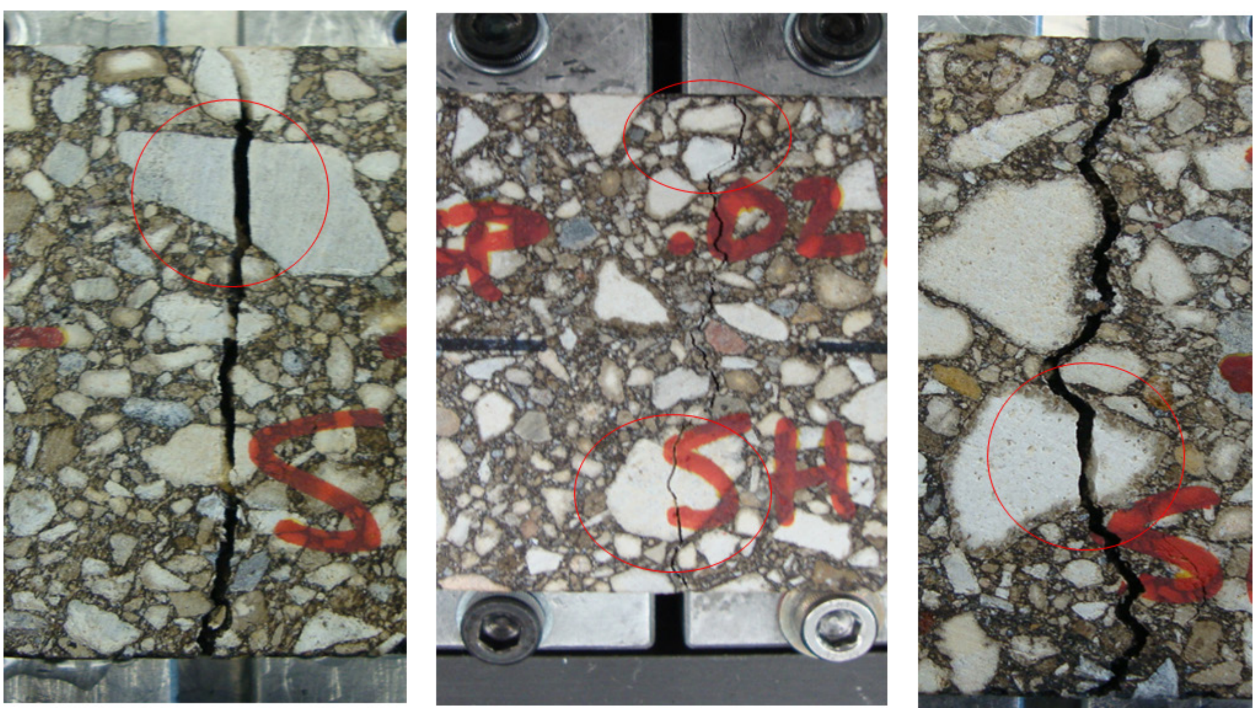

Figure 4-12. Cracking Cutting through a Limestone Rock during OT Testing.

Given the historical quality issues of the limestone aggregates from Central Texas as well as the results shown in Table 4-13, the focus of the mix-design iterations in an attempt to meet the BMD requirements and improve these mixes' performance included the following:

- Changing the aggregate blend proportions (i.e., reduce the fines content).
- Removing or modifying the most absorptive rock from the aggregate blend, e.g., F-rock.
- Adding hydrated lime as an anti-stripping agent to minimize moisture damage and stripping.
- Change the design lab density (TGC) and AC level.
- Add and/or modify the RAP and/or RAS content.
- Change the asphalt-binder PG grade.

The results in Table 4-14 shows that only Modification #02 with 10 percent RAP at 5.1 percent OAC (97 percent TGC density) would be considered reasonable if 30 cycles is tentatively taken as the pass-fail screening criterion for the OT cracking test for RAP mixes. All other mix-design modifications were unsatisfactory.

Table 4-14. SAT - HMA Mix Modification and HWTT-OT Results.

Item	Original TGC Design	Modification# 01	Modification# 02	Modification# 03
HMA mix	Type D Item 340 (Fine Surface)	Type D Item 340 (Fine Surface)	Type D Item 340 (Fine Surface)	Type D Item 340 (Fine Surface)
Materials	PG 70-22 (Valero) + Limestone	PG 70-22 (Valero) + Limestone	PG 70-22 (Valero) + Limestone	PG 70-22 (Valero) + Limestone
Aggregate-blend	23% D-rock + 37% F-rock + 25% Man. Sand + 15% Field Sand	50% D-rock + 10% F-rock + 25% Man. Sand + 15% Field Sand	25% D-rock + 35% F-rock + 25% Man. Sand + 5% Field Sand	25% D-rock + 35% F-rock + 25% Man. Sand + 5% Field Sand
Recycled material	None	None	10% RAP	10% RAP
Anti-strip	0.00%	0.00%	0.00%	0.00%
OAC	5.1% @ 96.5% TGC lab density	4.6% @ 97% TGC lab density	5.1% @ 97% TGC lab density	5.4% @ 97.5% TGC lab density
HWTT rutting (≤ 12.5 mm @ 15,000 Passes)	Failed @ 12,300 load passes	Failed @ 14,700 load passes	7.6 mm @ 15,000 load passes	Failed @ 12,900 load passes
OT cracking (≥ 30 cycles)	67 cycles	44 cycles	54 cycles	105 cycles
Comment	Redesign	Redesign	**OK**	Redesign

As shown in Table 4-15, water absorption tests were also conducted on the aggregates. The results indicate that the rocks (limestone aggregates) are highly absorptive with WAC greater than 2.0 percent. This effectively means that the rocks absorb some of the asphalt-binders and reduce the net effective asphalt-binder content needed for bonding and/or durability performance.

Table 4-15. Water Absorption Results for the Aggregates.

#	Aggregate	WAC	Comment
1	C-rock	2.4%	High absorptive potential
2	D-rock	2.4%	High absorptive potential
3	F-rock	2.6%	High absorptive potential
4	RAP (coarse)	1.2%	Intermediate absorptive potential

Threshold: (1) High absorption = WAC > 2%; (2) Intermediate absorption = 1.0% ≤ WAC ≤ 2.0%; (3)Low absorption = WAC < 1.0%

Overall, future recommendation options for optimizing the material performance to meet the BMD requirements include the following:

- Pre-coat the aggregates so as to minimize moisture damage and stripping potential.
- Minimize the amount of the fines and other smaller NMAS aggregates such as the highly absorptive Type F-rock.
- Add quality RAP (fractionated) and/or RAS materials from reliably quality sources.
- Blend with aggregates of superior quality from different sources.
- Design the AC at around 97 percent TGC lab density.
- Relax and modify the BMD requirements for RAP/RAS mixes (i.e., OT ≥ 30 cycles).

WACO (WAC) DISTRICT

A Type C RAP/RAS mix, earmarked for use on SH 31, was evaluated to assess if redesigning the mix-design using the BMD method could lead to improved performance, particularly in terms of cracking. In general, laboratory experience has shown that RAP and RAS mixes have satisfactory HWTT rutting performance but often very poor OT cracking performance. This Type C mix with an original OAC design of 5.0 percent PG 70-22 corresponds to 97.0 percent TGC lab density, and HWTT rutting of 3.1 mm after 20,000 loads passes, was no exception. The OT crack life was only 48 cycles.

Given the preceding scenario, these researchers' design iterations were focused on improving the BMD cracking performance of the mix starting with trying other asphalt-binder PG grades, namely PG 64-22 and PG 76-22. The OT results of these mix-design iterations are shown in Figure 4-13. The HMA mix details are listed below while the mix-design sheet details are included in Appendix A.

- Mix type: Type C (Item 340 – coarse surface)
- Asphalt-binder: PG 64-22, PG 70-22 (original design), and PG 76-22 (all Jebro)
- Aggregate: Gravel and limestone/dolomite aggregates (Pit 365 - Naruna)
- Aggregate-blend: 25% C-rock + 15 percent D/Frock + 12.3% F-rock + 22% screenings + 6 % sand
- Recycled material: 16.2% fractionated (fine) RAP + 2.5% RAS
- Anti-strip: Hydrated lime (1%)

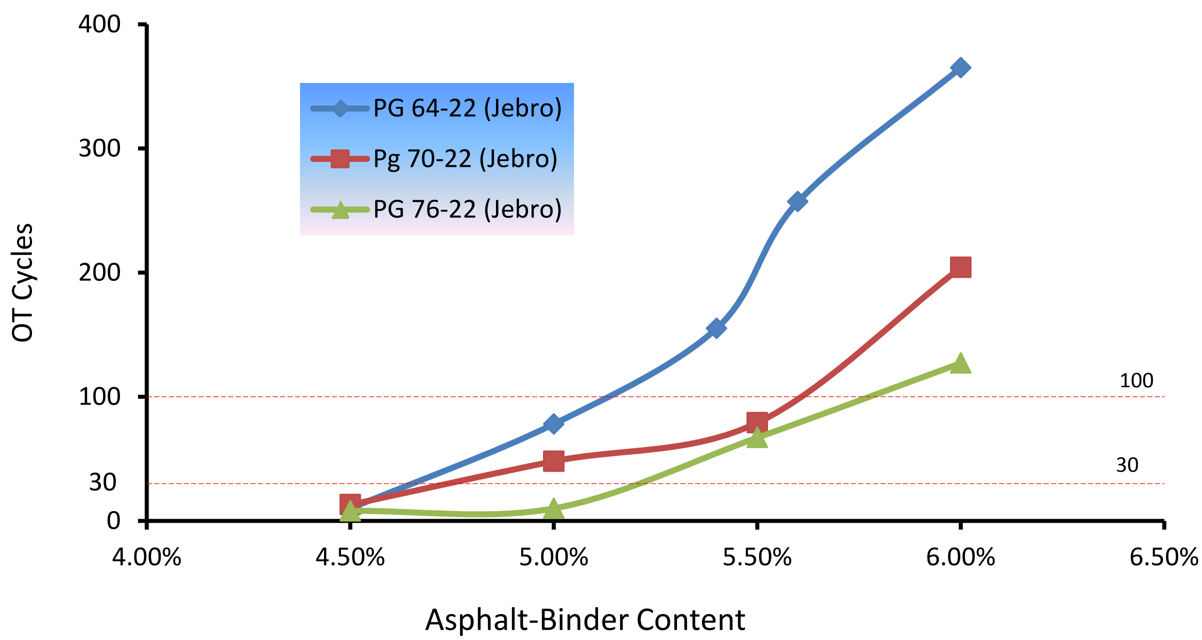

Figure 4-13. Type C OT Lab Test Results (WAC).

While all the asphalt-binder PG grades exhibited satisfactory HWTT rutting performance of less than 11 mm (after 20,000 load passes) for the evaluated AC range (i.e., 4.5 to 6.0 percent), Figure 4-13 shows that going to a lower PG grade improves the OT cracking performance for this Type C RAP/RAS mix. Therefore, the BMD recommendation would be to use the cheaper PG 64-22 asphalt-binder. If 100 cycles is tentatively used as the OT crack pass-fail screening criterion, the best BMD choice would be 5.4 percent PG 64-22, corresponding to a TGC lab design density of 96.5 percent and HWTT rutting of 10.9 mm after 20,000 load passes.

Overall, the key conclusions and recommendations drawn from these results include the following:

- The use of lower asphalt-binder PG grades, such as PG 64-XX, tends to improve the OT cracking performance of RAP/RAS mixes. The challenge is simultaneously balancing the HWTT rutting performance when shifting to a lower PG grade.
- Blending marginal limestone with quality aggregates such as crushed gravel and/or use of quality recycled materials has a positive impact on improving the BMD performance of a mix.
- The BMD pass-fail screening criteria, particularly for the OT cracking, should be reviewed or at least be material (or mix type) dependent.

SUMMARY

In this chapter, over 10 different mixes (composed of different materials including RAP and RAS) from 11 Texas districts were evaluated in the laboratory, both in terms of the traditional TGC method and the new BMD method. The key findings, lessons learned, and recommendations drawn from this chapter are summarized as follows:

- Compared to cracking, RAP and RAS mixes generally have superior HWTT rutting performance. The use of lower asphalt-binder PG grades tends to improve their OT cracking performance to meet the minimum BMD requirements.
- Like the RAP and RAS mixes, it was a challenge to get the mixes with limestone aggregates (particularly from Central Texas) to pass the BMD requirements. Viable options to improve the BMD performance of limestone mixes include precoating the absorptive rock or blending the limestone with other quality aggregates such as crushed gravel.
- Not all asphalt-binders are manufactured equally. Material source has an influence on the quality of the asphalt-binder, and caution should be taken when selecting materials during the HMA mix-design process. Contractors are recommended to routinely perform material verification tests instead of simply relying on the suppliers' data.

- It is imperative that quality materials from reliable sources are used in order to meet the minimum BMD requirements. In general, it was observed in this chapter that most of the mixes meet the BMD requirements within a TGC lab design density range of 96.5 to 97.5 percent, with the majority at 96.5 percent.
- The BMD requirements, in particular the OT crack pass-fail screening criteria, need to be material specific in order to sufficiently accommodate the RAP/RAS mixes. In this regard, the following are tentatively proposed:
    1) CAM mixes: OT ≥ 750 cycles
    2) SMA/RBL mixes: OT ≥ 300 cycles
    3) Type D and F mixes: OT ≥ 150 cycles
    4) Type C mixes: OT ≥ 100 cycles
    5) Engineer's decision or redesign: OT < 30 cycles

CHAPTER 5
ACCELERATED PAVEMENT TESTING AND PERFORMANCE EVALUATION

As means to provide a preliminary field validation of the BMD method, accelerated pavement testing (APT) was conducted on the Type C mix from BMT District (Table 4-4 in Chapter 4). This was done under ALF trafficking in LA at LSU-LTRC. Both the TGC and BMD mix designs, denoted as Control and Modified, respectively, were evaluated under ALF trafficking in terms of:

- Rutting performance under ALF trafficking.
- Reflective and fatigue cracking under ALF trafficking.

The scope of work to accomplish this APT task includes lab testing, constructing of eight APT test sections, accelerated testing with the ALF, and performance testing in terms of rutting, cracking, FWD, densities, etc. Full details of this APT work including construction, ALF loading parameters, and field test results are documented in Reports 0-6132-1 and 0-6132-2 (Walubita et al., 2010; 2012). This chapter simply provides an overview of the key findings in terms of the laboratory and field APT test results. Additional data related to this APT can also be found in Appendix C of this report.

HMA MIX-DESIGNS AND LAB TEST RESULTS

Table 5-1 shows that while the HWTT test results were marginally different, the Modified mix (with 5.2 percent OAC) exhibited better OT lab crack resistance than the Control mix (with 4.3 percent OAC), as expected. As evident in Table 4-2, the Modified mix lasted over 300 OT cycles for all of the sample types that were tested including the plant-mix material that was sampled from the APT site. Theoretically and as will be shown in the subsequent sections of this chapter, these results suggest that the Modified mix based on the BMD method would be more crack resistant under ALF trafficking than the Control mix (TGC method).

Table 5-1. Type C HWTT-OT Lab Test Results (BMT).

Item	TGC Method	BMD Method
Mix designation	Control	Modified
Mix type	Type C (Item 341 – coarse surface)	
Materials	PG 76-22 (Valero) + Limestone (Brownwood)	
Aggregate blend	20% C-rock + 40% Grade 5 + 30% Screenings + 10% washed sand	
Design OAC	4.3%	5.2%
Corresponding TGC lab density (96% ≤ TGC < 98%	96.0%	97.5%
VMA (≥ 14%)	14.0	14.2%
HWTT rutting @ 20,000 load passes (≤ 12.5 mm) ⇒ TTI design	4.7 mm	7.0 mm
HWTT rutting @ 20,000 load passes (≤ 12.5 mm) ⇒ plant-mix from APT site	2.3 mm	4.1 mm
HWTT rutting @ 20,000 load passes (≤ 12.5 mm) ⇒ field cores at zero ALF trafficking	3.0 mm	4.7 mm
HWTT rutting @ 20,000 load passes (≤ 12.5 mm) ⇒ raw materials from Contractor's plant	3.0 mm	7.7 mm
OT crack cycles (≥ 300) ⇒ TTI design	90	600
OT crack cycles (≥ 300) ⇒ plant-mix	41	446
OT crack cycles (≥ 300) ⇒ raw materials directly from Contractor's plant	32	306
IDT (85 ≤ IDT ≤ 200 psi)	165 psi	130 psi
Balanced AC range (@ 96–98% density)	N/A	5.1–5.6%
APT placement	Control test sections	Modified test sections

APT TEST SECTIONS AND ALF LOADING PARAMETERS

As shown in Figure 5-1, eight APT test sections were constructed, namely two for rutting, two for fatigue cracking, and four for reflective crack evaluation. Thereafter, these test sections were subjected to ALF trafficking. Details of the test sections including the pavement structures, construction, and ALF loading parameters are included in Appendix C of this report. More details can be found in Reports 0-6132-1 and 0-6132-2 (Walubita et al., 2011; 2012).

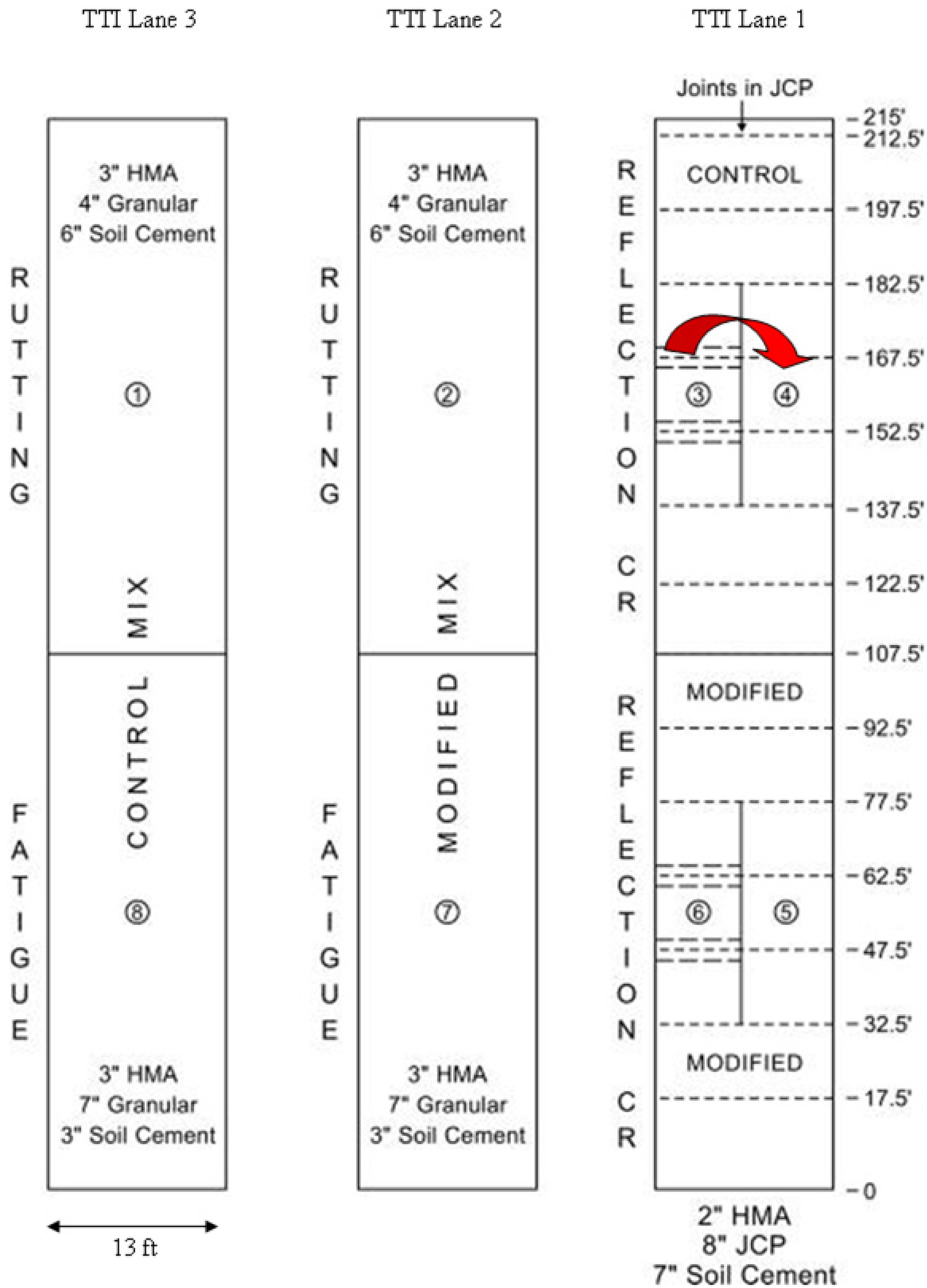

Figure 5-1. Layout of the Eight APT Test Sections at LTRC (LSU, LA).

APT TEST RESULTS – ALF TRAFFICKING

ALF trafficking of the test sections started in 2009 and concluded in 2011. The rutting tests occurred during the summer months under hot weather conditions. The cracking tests took place during the winter months under cold weather conditions. The TGC and BMD comparative results of these field APT tests are summarized in this section. Full details can be found in Report 0-6132-2 (Walubita et al., 2012).

ALF RUTTING RESULTS

Consistent with the laboratory test predictions based on the BMD method and as theoretically expected, the Modified mix with more asphalt-binder rutted more than the Control mix under ALF trafficking. After 100,000 ALF load passes under equivalent test temperatures, the rut depth measured on Section 2 with the Modified mix (at 5.2 percent AC) was almost 50 percent more than that accumulated on Section 1 with the Control mix (at 4.3 percent AC), i.e., 15 mm versus 8 mm. These results are shown graphically and pictorially in Figures 5-2 and 5-3, respectively.

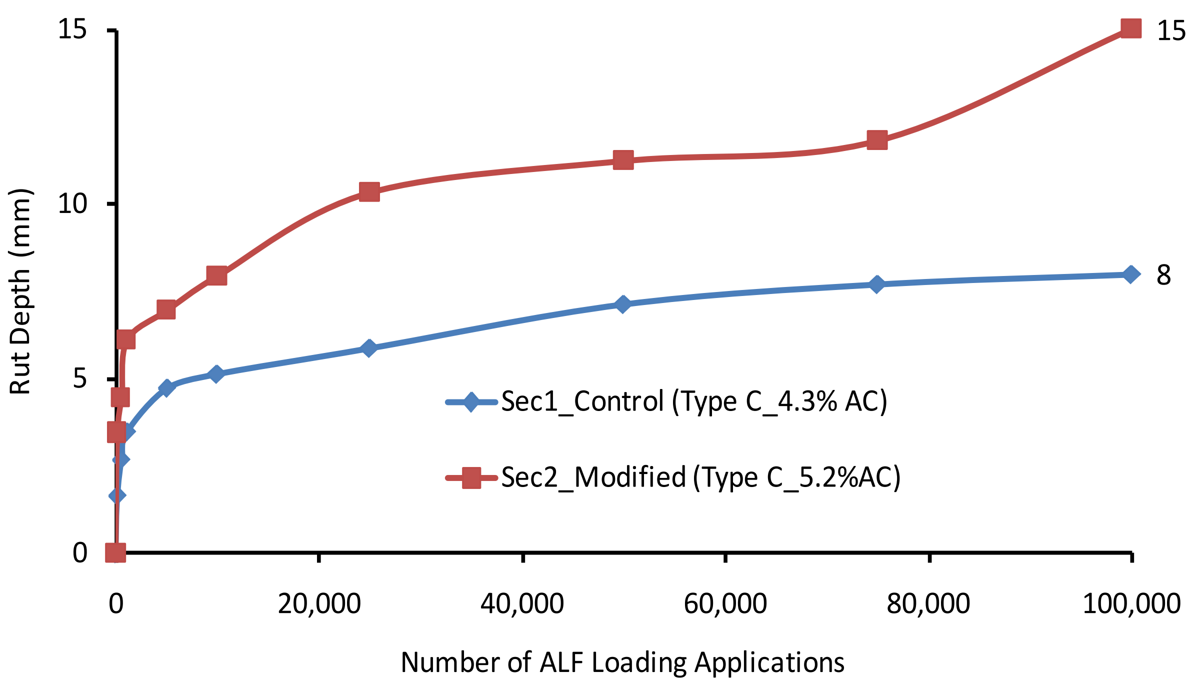

Figure 5-2. Rutting under ALF Load Trafficking.

Figure 5-3. Surface Rutting on Sections 1 (Control) and 2 (Modified).

As shown in Figure 5-4, subsequent trenching of the test sections indicated that all of the deformation was coming from the top HMA layer. Deformation in the base and subgrade was marginal.

Figure 5-4. Trenching and Pictorial Comparison of Rutting on Test Sections 1 and 2.

In general, the APT performance of these rutting test sections was consistent with the laboratory test predictions (Chapter 4) and was as theoretically expected, i.e., the Control (low AC) performed better in terms of rutting resistance compared to the Modified mix (BMD method).

ALF REFLECTIVE CRACKING TEST RESULTS

Under similar ALF trafficking conditions, reflective cracking appeared on the Control Section 4 with poor LTE (i.e., 50 percent) just after 75,000 ALF load passes; see Figure 5-5 below. In the case of the Control Section 3 with good LTE (> 90 percent), reflective cracking was only visible after 175,000 ALF load passes, thus further substantiating that LTE has an influence on the rate of reflective crack propagation.

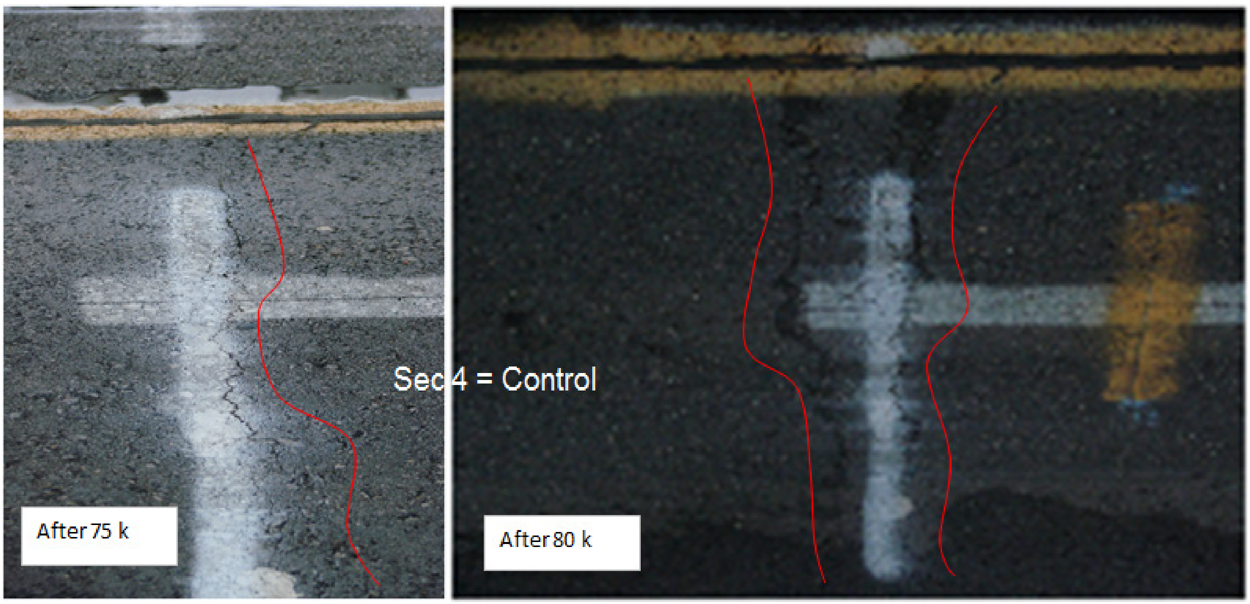

Figure 5-5. Reflective Cracking on Control Section 4 (LTE = 50 Percent).

By contrast and in line with the BMD mix-design expectations, no cracking was observed on the Modified Section 6 (poor LTE = 50 percent) even after applying 100,000 ALF load passes and increasing the tire load (from 9.8 kips to 14.6 kips); see Figure 5-6 and Appendix C. For the Modified Section 5 with good LTE (i.e., LTE > 90 percent), no cracking was observed within the trafficked test sections. Cracking manifested only around the joints after 143,000 ALF load passes.

Figure 5-6. Reflective Cracking Comparison of Section 4 (Control, LTE = 50 Percent) and Section 6 (Modified, LTE = 50 Percent) after 75,000 ALF Load Passes.

ALF FATIGUE CRACKING TEST RESULTS

As documented in Report 0-6132-2 (Walubita et al., 2012), the fatigue crack test sections performed unexpectedly under ALF trafficking; the Modified (high AC) section cracked while there was no cracking on the Control section (low AC = 4.3 percent). Also, both sections unexpectedly accumulated substantially high rutting. As detailed in Report 0-6132-2 (Walubita et al., 2012), forensic evaluations including trenching of these fatigue crack test sections revealed the following:

- The Control Section 8 (4 inches) was thicker than the Modified Section 7 (3 inches) in terms of the surfacing HMA layer. This was considered to be due to construction-related issues.
- The distresses (particularly rutting) were found to be related to the base and construction problems.
- Coring indicated micro-damage and micro-cracking on the Modified Section 7.
- ALF trafficking on these sections was done in the summer during high temperatures. As a result, high rutting was observed, particularly on the Control Section 8.

SUMMARY

In general, the APT work discussed in this chapter was very helpful to these researchers. As a starting point, it provided an invaluable platform for preliminarily validating the BMD method relative to the traditional TGC method. To summarize the chapter, the key findings and recommendations drawn from the APT testing with ALF trafficking are as follows:

- The rutting sections performed as expected. The Control mix (4.3 percent AC) performed relatively better in terms of rutting resistance than the Modified mix (5.2 percent AC) and correlated with the laboratory test predictions.
- The reflective cracking sections performed as expected and correlated with the laboratory test predictions. The Control sections with 4.3 percent AC (TGC method) cracked earlier than the Modified with 5.2 percent AC (BMD method), and the poor LTE (50 percent) sections cracked earlier than the good LTE (> 90 percent) sections.

Based on these promising APT test results (particularly for rutting and reflective cracking) that correlated well with the laboratory BMD test predictions, incorporating both the HWTT and OT tests in future HMA mix-design methods should be considered. Evidently, there is a need to consider standardizing the BMD method as one of the new generation HMA mix-design methods, particularly in terms of minimizing the premature cracking of HMA pavements.

As documented in Report 0-6132-2 (Walubita et al., 2012), the Modified mix-design based on the BMD method also exhibited superior constructability characteristics in terms of workability and compactability. At a target placement density of 96±3 percent, the Modified mix (BMD) had a measured QC density of 93.7 percent versus 92.6 percent for the Control mix (TGC). This is partly due to the relatively high AC that aids in lubrication during compaction to attain a better uniform density. Uniform density attainment translates into uniform mat thickness, which is what is desired. Furthermore, high AC may also translate into better durability in the long term.

CHAPTER 6
IN-SERVICE HWY FIELD TESTING AND PERFORMANCE EVALUATION

Where resources and circumstances permit, the best approach to evaluate and validate new road materials, design methods, test methods, etc., is through field testing of in-service highway sections under conventional traffic loading. Researchers undertook this approach using the BMD method and the associated lab tests. Toward this goal and in order to preliminarily validate the BMD method relative to the traditional TGC method, these researchers undertook the following actions:

1) Liaised with the TxDOT districts and Contractors and requested to construct 1,000 ft test sections (outside lanes) using the BMD designed mixes alongside the traditional TGC mix-designs on in-service highway projects that were under construction or rehabilitation. Incidentally, these all happened to be overlay projects.
2) Conducted pre-construction field evaluations to document and record the existing pavement conditions and distresses prior to overlay placement. These field evaluations included visual walking crack surveys, FWD testing, GPR, coring, pictures/videos, etc.
3) Monitored and recorded the construction process including the rolling pattern, number of passes, MTD, mat temperatures, QC nuclear density measurements, pictures/videos, etc.
4) Conducted post-construction tests including GPR, profiles, coring, pictures/videos, etc.
5) Performed periodic performance evaluation of the test sections twice per year; namely toward end of winter to evaluate the cold weather distresses and toward end of summer to evaluate the hot weather distresses. The field tests included visual walking crack surveys, FWD, rut measurements, profiles, pictures/videos, coring as needed, etc.

Following the above mentioned aspects, this chapter presents and discusses some examples of the field evaluation and validation of the BMD method in comparison to the traditional TGC method. Field test sections constructed on in-service highways in two districts, Atlanta and Laredo, are presented herein as demonstration examples. A summary of key observations, experiences, and findings is presented at the end of the chapter.

FIELD TEST SECTIONS IN THE ATLANTA DISTRICT

There are three in-service field test sections (1¾ inch thick overlays) in the Atlanta District on highway US 59 in Panola County: two Control (traditional TGC design) and one Modified (BMD design) (Table 4-1). The location, construction, and performance evaluation details of these sections are discussed in the subsequent text of this section.

Project Location

As noted in Figure 6-1 below, the test sections are located between FM 999 and the Shelby County line in the SB direction in Panola County. The controlling CSJ# for this project is 0063-05-033 with an entire project length of 6.0 miles.

Figure 6-1. Geographical Location of the Test Sections in Atlanta District.

Traffic Data

The ADT on this highway as of fall 2011 was approximately 3,711 with about 40.4 percent trucks (i.e., ADTT of 1501). While the posted speed limit is 70 mph, the average vehicle speed is 72.6 mph. The projected 20-year design 18-kips ESALs is 21.4 million.

Pre-Construction Field Tests

Prior to overlay construction, pre-construction surveys were conducted to record and document the existing pavement condition and distresses. As part of these pre-construction surveys, a detailed mapping (visual-walking) of the existing cracks was undertaken and included recording the number, size, severity, GPS location, etc., of the cracks. An example is shown in Table 6-1 and Figure 6-2 through Figure 6-4; see Appendix D for more details.

Table 6-1. Existing Transverse Cracks on Control Section 01 (ATL).

Crack#	Location from Crack#1	GPS Location	Remark	Severity
1	0 ft	N 32° 02. 660'; W 094° 17. 286'	Right side - Driveway/ Left side - Turnaround	High
2	133 ft	N 32° 02. 642' W 094° 17. 269'		
3	655 ft	N 32° 02. 577' W 094° 17. 206'		Low
4	833 ft	N 32° 02. 552' W 094° 17. 182'		High
5	1197 ft	N 32° 02. 506' W 094° 17. 135'	Driveway/Gated property on opposite side (US 59 N. bound)	
6	1306 ft	N 32° 02. 494' W 094° 17. 122'		Moderate
7	1393 ft	N 32° 02. 483' W 094° 17. 111'		

Figure 6-2. Example of Pre-Existing Cracks on Control Section 01 (ATL).

Figure 6-3. Example of Pre-Existing Cracks on the Modified Section (ATL).

Figure 6-4. Example of Pre-Existing Cracks on Control Section 02 (ATL).

From Figure 6-2 through Figure 6-4, the US 59 pavement had a combination of transverse, fatigue, and longitudinal cracks. As part of the study, the cracks were documented to contribute to the evaluation and validation of the BMD method. The intent was for the subsequent performance monitoring to evaluate the rate of these crack propagations through the HMA overlay in the TGC and BMD designs. More details of the crack mapping surveys are included in Appendix D.

Other tests such as GPR, FWD, and coring were also conducted, and the results are summarized in Appendix D. As shown in Figure 6-5, the existing pavement structure consisted of approximately 10 inches of existing HMA and 12 inches of base based on the GPR measurements taken prior to overlay placement.

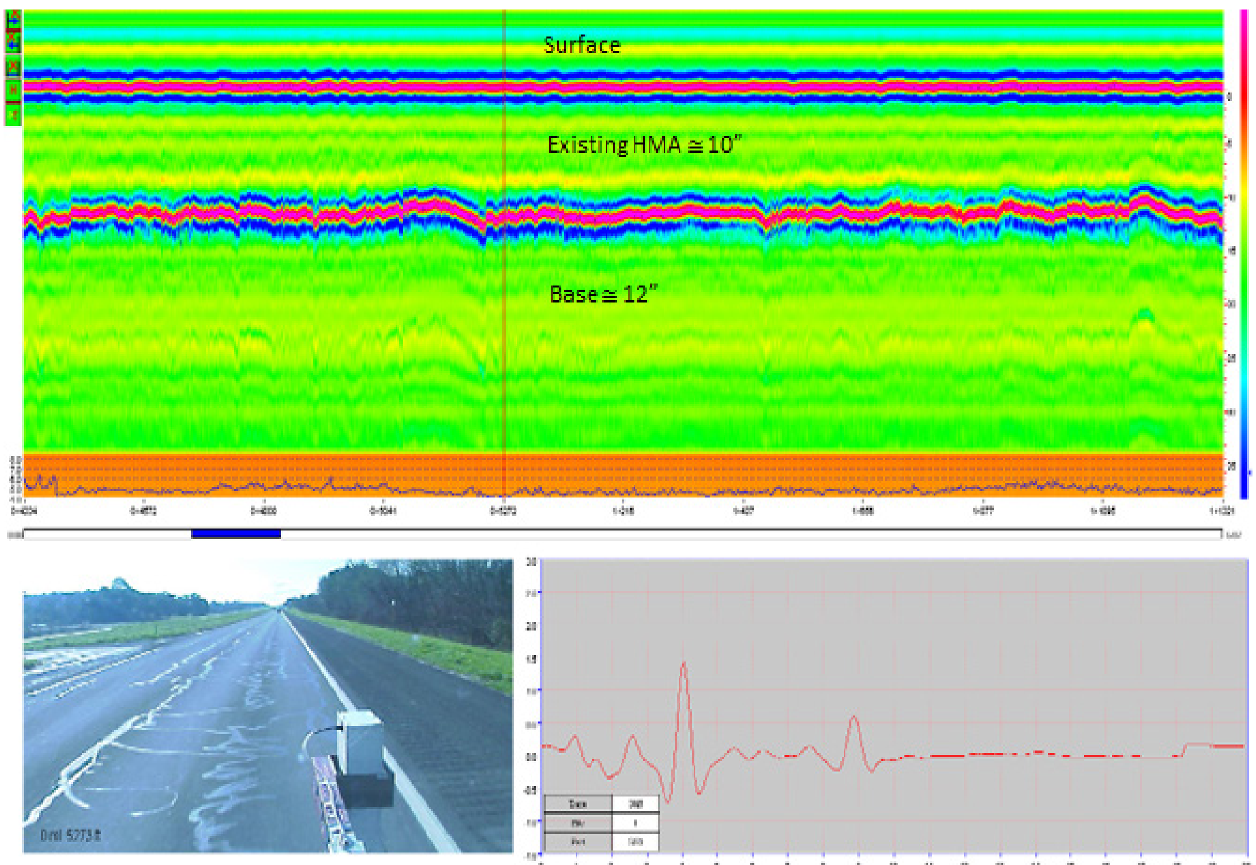

Figure 6-5. Pre-Construction GPR Measurements (ATL).

Construction Monitoring – HMA Placement

TTI researchers monitored and recorded the construction of test sections. Details of the construction process are documented in Appendix E. In a nutshell, the basic construction details are bullet-listed as follows:

- Contractor: Madden
- Date of construction: March 2010
- Mix type: Type D (Item 341)
- AC (Control – TGC design): 5.2% PG 64-22 (Lion)
- AC (Modified – BMD design): 5.5% PG 64-22 (Lion)
- Aggregates: Quartzite (Jones Mill)
- Target HMA mat (overlay) thickness: 1¾ inch
- Mat temperature: 300°F
- MTD: Roadtec
- Compaction – breakdown steel roller (vibro): 20 ton (6 passes)
- Compaction – finishing steel roller (vibro): 5 ton (4 passes)

The specific construction data for each test section are summarized in Table 6-2. Pictures of the completed HMA mat are shown in Figures 6-6 and 6-7. The contractor used a MTD (Roadtec) as well as infra-red thermal imaging to monitor the paving mat temperature. Milling (1 to 2 inches deep) was also intermittently conducted where cracking was very severe.

Table 6-2. Construction Details (ATL).

Item	Control Section 01	Modified Section	Control Section 02
Length (ft)	1,479	1,848	1,000
HMA mix-design method	TGC	BMD	TGC
AC (%)	5.2	5.5	5.2
Air temperature (°F)	54	68	69
PVMNT surface temperature (°F)	76	80	80
HMA mat temperature (°F)	300	300	300
Target HMA mat density (%)			
HMA mat density (Nuclear gauge)	142.0	144.0	142.8
HAM mat (Overlay) thickness (inches)	1¾	1¾	1¾

Figure 6-6. Example of Finished HMA Mat on Control Section 01 (ATL).

Figure 6-7. Example of Finished HMA Mat on Control Section 01 (ATL).

Post-Construction Field Tests

Post-construction QC tests including the GPR, high-speed profiles, and coring were conducted just a few days after overlay placement. As summarized in Appendix F, these QC tests indicated that the construction quality was satisfactory and within the specification. However, the test data indicated the Modified section at 5.5 percent AC attained a relatively high density (144 pfc versus 142 pfc) and better surface finish (QC IRI of 36.2 in/mi versus 43.0 in/mi).

Routine Performance Evaluation of the Test Sections

As stated in introductory section, periodic performance evaluations were conducted twice per year: namely toward end of winter to evaluate the cold weather distresses and toward end of summer to evaluate the hot weather distresses. These field performance tests included visual/walking crack surveys, taking of photographs, surface rut measurements with a straightedge, FWD tests, and high-speed profiles. As summarized in Table 6-3 and Figure 6-8 through 6-10, performance of all the tests is satisfactory with no serious distresses; see Appendix G for more details.

Table 6-3. Field Performance Evaluation (ATL).

Item	TTI Section 1	TTI Section 2	TTI Section 3
Designation	Control# 1	***Modified***	Control# 2
Section length	1,479 ft	*1,848 ft*	1,000 ft
HMA Mix-Design Details			
Mix Type	Type D – Fine Surface (Item 341) - PG 64-22 + Quartzite + 20% RAP		
Design target AC	5.2%	*5.5%*	5.2%
Lab design TGC density	97.0%	*98.0%*	97.0%
Overlay (OT) crack testing	269 cycles	*506 cycles*	269cycles
Hamburg @ 15,000 passes	3.1 mm	*4.1 mm*	314 mm
Construction Details			
HMA overlay thickness	1¾ inch	*1¾ inch*	1¾ inch
Date of HMA placement	March 26, 2010	*March 26, 2010*	March 26, 2010
Avg. QA IRI (in/mi)	43.3	*36.2*	42.7
Performance to Date (Oct 2012)			
Cracking	None	*None*	None
Avg. surface rutting (inches)	0.14	*0.20*	0.13
Avg. IRI (in/mi)	44	*39*	43
Avg. FWD surface deflection	7.6 mils	*8.0 mils*	8.7 mils
Avg. PVMNT surface temperature	97°F	*97°F*	97°F
Other distresses	None observed!	*None observed!*	None observed!

Figure 6-8. Field Performance – Control Test Section 1 (Oct 2012) – No Distresses (ATL).

Figure 6-9. Field Performance – Modified Test Section (Oct 2012) – No Distresses (ATL).

Figure 6-10. Field Performance – Control Test Section 2 (Oct 2012) – No Distresses (ATL).

Test Section Performance to Date

As shown in Figure 6-8 through 6-10, field performance is to date (October 2012), after over 2 years of service, still satisfactory on all the test sections with no distresses whatsoever, both Control (TGC design) and Modified (BMD design). In general, this mix-design was composed of very high quality materials, and therefore, satisfactory performance was expected on all sections. However, some construction benefits were realized with the BMD designed mix (Modified) in terms of the following:

- High mat density attainment, i.e., 144.0 pfc versus 142.4 pfc for the TGC design.
- Smooth mat surface finish, i.e., IRI of 36.2 in/mi versus 43.0 in/mi for the TGC design.

FIELD TEST SECTIONS IN THE LAREDO DISTRICT

There are three in-service field test sections (2 inch thick overlays) in the Laredo District on three highways, namely Loop 20, Spur 400, and US 59 in Webb County, all consisting of the BMD designed mix (Table 4-11). The location, construction, and performance evaluation details of these sections are discussed in the subsequent text of this section.

Project Location

Figure 6-11 shows the geographical location of the highway projects. The project limits, length, and test section location are listed in Table 6-4.

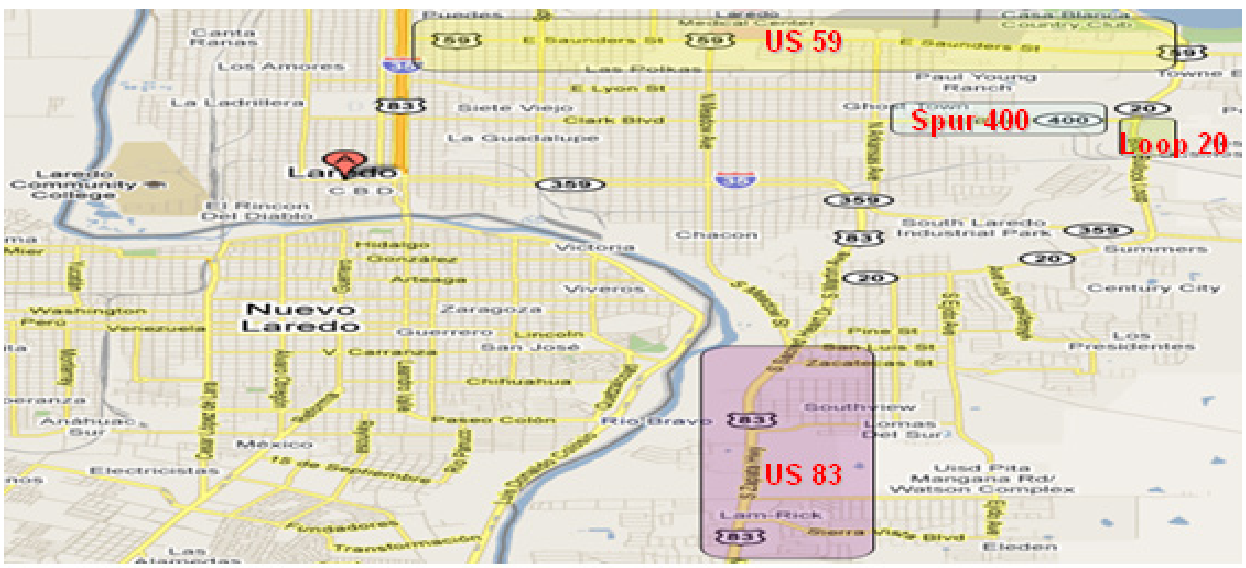

Figure 6-11. Geographical Location of the Test Sections in Laredo District.

Table 6-4. Hwy Project and Test Section Location Details.

#	Hwy	Project TRM Limits		Length (miles)	TTI Test Section Location (1,000 ft)		
		Start	End		Start GPS	End GPS	Comment
1	US 59	826 + 1.843	828 + 1.495	≅ 3	N 27° 31’ 49.8” W 099° 28’ 47.7”	N 27° 31’ 49.9” W 099° 28’ 37.0”	EB outside lane; opposite Laredo Hospital
2	Spur 400	432 + 0.014	432 + 1.140	≅ 1	N 27° 31’ 00.9” W 099° 27’ 07.7”	N 27° 31’ 00.9” W 099° 27’ 18.8”	WB outside lane; starting by Wal Mart
3	Loop 20	430 + 0.894	430 + 1.569	≅ 1	N 27° 30’ 58.0” W 099° 26’ 56.7”	N 27° 30’ 48.2” W 099° 26’ 56.8”	SB outside lane, opposite TxDOT offices!

The controlling CSJ# for all the above projects is 0038-01-066; with a total project length of 4.0 miles. As per Table 4-11, the BMD based mix (5.0 percent PG 64-22 + crushed gravel + 20 percent RAP + 1 percent lime) was placed on the entire project lengths of 4.0 miles, in both directions. Note that because of superior HWTT rutting and OT cracking performance, the TxDOT District Office and the Contractor opted to use the BMD design on all their projects. As indicated in Table 6-4, TTI have 1,000 ft long test sections, in the outside lane, in on each of the three highways; so in total three test sections.

Traffic Data

Loop 20, Spur 400, and US 59 are busy urban roads with very highway traffic volume, either standing traffic or travelling at an average speed of less than 20 mph. The approximate ADT on these highways is 42 800 with 15 percent trucks. The projected 20-year design 18-kips ESALs is 21.8 million.

Pre-Construction Field Tests

Like for the sections in ATL, TTI researchers had conducted a comprehensive crack survey and marked out the three test sections prior to construction; one on each highway. Details of these crack mapping surveys are included in Appendix D of this report. Examples of transverse crack mapping details including pictures are shown in Table 6-5 and Figures 6-12 through 6-14. GPR tests were also conducted prior to overlay placement and indicated the existing pavement structure to be in the order of 15 inches HMA plus 19 inches flex base (Type A Grade 1) on US 59. On Loop 20, the existing pavement structure appeared to be composed of

8 inches HMA and 19 inches flex base (Type A Grade 1) based on the GPR. Spur 400 consists of 5 inch existing HMA over 19 inches flex base (Type A Grade 1).

Table 6-5. Crack Mapping on Existing Pavement prior to HMA Overlay (LRD).

Hwy/Section	Lane	Location	Elevation	Severity?	Comment
US 59	Outside EB	N 27° 31.826' ; W 099° 28.342	502ft	High	Five severe transverse cracks were counted around this location averaging 18″ long
US 59	Outside WB	TRM 827+0.000	-	Medium	Eight transverse cracks counted around this location averaging 15″ long
US 59	Outside & Inside EB	TRM 826+2.600	-	High	Transverse and longitudinal cracks around this TRM
US 59	Outside EB (Wheel path)	TRM 826+2.000	-	Medium	Fatigue cracking in wheel path
Spur 400	Outside EB	TRM 432 + 0.500	-	Medium	One transverse crack about 10″ long
Loop 20	Outside SB	TRM 430 + 1.000	-	Low	One transverse crack about 7.5″ long

Figure 6-12. Example of Cracking on US 59 prior to 2 inch HMA Overlay.

Figure 6-13. Example of Cracking on Spur 400 prior to 2 inch HMA Overlay.

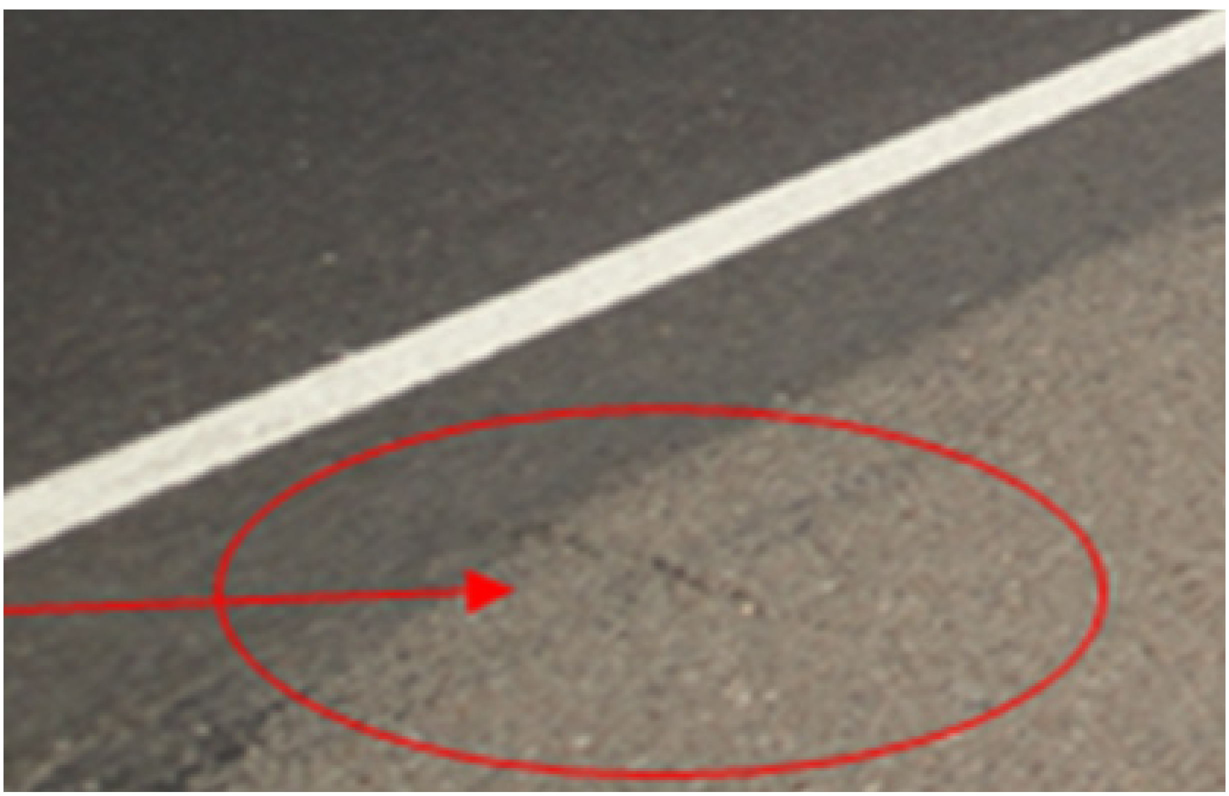

Figure 6-14. Example of Cracking on Loop 20 prior to 2 inch HMA Overlay.

Construction Monitoring – HMA Placement

TTI researchers monitored and record the construction of all the three highway projects and test sections. Details of the construction process are documented in Appendix E. In a nutshell, the basic construction details are listed as follows:

- Contractor: Anderson Colombia Co.
- Date of construction: Summer 2010 (June – August)
- Mix type: Type C (Item 341)
- AC (Modified – BMD design): 5.0% PG 64-22(Valero)
- Aggregates: Crushed gravel
- Target HMA mat (overlay) thickness: 2 inch
- Mat temperature: 300°F
- MTD: None
- Compaction – breakdown steel roller (vibro): 20 ton (6 passes)
- Compaction – finishing steel roller (vibro): 5 ton (4 passes)

The construction operation, which was carried out at night due to heavy daytime traffic, consisted of mill (2 to 4 inches deep) and inlay on some sections; see Figure 6-15. The specific construction QC test results for each highway project are summarized in Table 6-6, and the completed 2 inches thick HMA mats are pictorially shown in Figure 6-16.

Figure 6-15. Example of Mill and Inlay Operation on US 59 (LRd).

Table 6-6. QC Results on Plant-Mix, Cores, and In-Situ HMA Mat.

#	Item	US 59	Spur 400	Loop 20
1	Design AC=	5.0%	5.0%	5.0%
	Avg. Ignition Oven AC (TxDOT) =	5.2%	5.1%	5.2%
	Avg. Ignition Oven AC (TTI) =	5.1%	5.1%	5.3%
	(Tolerance = ±0.3%)			
2	Lab design density=	96.5%	96.5%	96.5%
	Avg. QC core density (TxDOT) =	96.4%	96.8%	96.5%
	Avg. core density (TTI) =	96.3%	96.5%	96.4%
3	Avg. QA IRI (30-90)=	88	-	67
	Avg. QA PSI=	3.9	-	4.2
4	TTI Hamburg on plant-mix =	4.4 mm	-	4.8 mm
	TTI OT on plant-mix =	136	-	186
	TTI OT on core =	-	-	297
5	Compaction rolling pattern	Breakdown: 3 passes vibratory (steel wheel roller) Finisher: 2 to 4 passes static (steel wheel roller)		
6	Total HMA tonnage	5,263	3,371	3,003

Figure 6-16. Example Completed 2 inch Thick HMA Mats on Loop 20 and US 59.
(5.0%PG 64-22 + Crushed Gravel + 20% RAP + 1% Lime)

Post-Construction Field Tests

Post-construction QC tests including the GPR, high-speed profiles, and coring were conducted just a few days after overlay placement. As summarized in Table 6-6 and Appendix F, these QC tests indicated that the construction quality was satisfactory and with the specification. In fact, the Contractor received a total bonus of about US $8 253 for Loop 20 and US 59. The bid price for this job was US $58.00 per ton of HMA.

Routine Performance Evaluation of the Test Sections

Periodic performance evaluations were conducted twice per year: namely toward end of winter to evaluate the cold weather distresses and toward end of summer to evaluate the hot weather distresses. These field performance tests included visual/walking crack surveys, taking of photographs, surface rut measurements with a straightedge, FWD tests, and high-speed profiles. As summarized in Table 6-7 and Figure 6-17 through 6-19, performance of all the tests is satisfactory with no serious distresses; see Appendix F for more details.

Table 6-7. Field Performance Evaluation (LRD).

Item	Loop 20	Spur 400	US 59
HMA overlay thickness	2 inch	2 inch	2 inch
Section length (ft)	1,000	1,000	1,000
Date of HMA placement	June - August, 2010	June - August, 2010	June - August, 2010
Mix type	Type C (Item 341) = 5.0% PG 64-22 + Crushed gravel + 20% RAP + 1% Lime		
Lab design density (%)	96.5	96.5	96.5
Performance To Date (Oct 2012)			
Cracking	None	None	None
Avg. surface rutting in wheel path (inches)	0.07	0.06	0.10
Avg. IRI (in/mi)	83	89	78
Other distresses	-	≅ 0.38 inch rut depth @ HMA-bridge transition point on WB outside lane	-

Figure 6-17. Field Performance – Loop 20 (Oct 2012) – No Distresses (LRD).

Figure 6-18. Field Performance – Spur 400 (Oct 2012) – No Distresses (LRD).

Figure 6-19. Field Performance – US 59 (Oct 2012) – No Distresses (LRD).

Test Section Performance to Date

As shown in Figure 6-17 through 6-19, field performance is to date (October 2012), after over two years of service, still satisfactory on all the test sections with no distresses whatsoever. There is no cracking or rutting all the three test sections. Only problem noted was rutting on the HMA-bridge transition on the traffic approach side, which is predominantly a construction issue attributed to insufficient compaction; see Appendix F. Overall, the following can be inferred:

- The TxDOT District Office is very happy with the BMD design. The sections have performed satisfactory for over two years of service with no distresses. This has saved the district maintenance money as well as the unnecessary traffic closures during maintenance and/or rehab activities.
- The Contractor is very happy with the BMD design. He saved about US $5.00 per ton of HMA due to change in the asphalt-binder from PG 70-22 to PG 64-22 (BMD design). Currently, the Contractor is using the same BMD design on most of his projects in the Laredo District, notably Loop 480.

SUMMARY

As documented in this chapter, the performance of the BMD designed mixes was satisfactory and correlated with the laboratory test predictions in Chapter 4, providing a preliminary validation of the BMD method. On the basis of the field results discussed in this chapter, these researchers recommend the following:

- The BMD method along with HWTT and OT testing should be incorporated in Texas' new generation HMA mix-design procedures.
- Given that the test sections have just been in service for at most two and half years, long-term performance of the test sections is strongly recommended to further validate the BMD method and establish appropriate BMD pass-fail screening criteria.

CHAPTER 7
SUMMARY AND RECOMMENDATIONS

As documented in this report (Chapter 1 through 6), these TTI researchers developed and promoted the implementation of the BMD method for selecting the OAC for all of TxDOT's HMA mixes, including dense graded mixes (Item 341). In this BMD method, the HMA engineering properties are measured in both the laboratory design and the trial batch with both the HWTT (Tex-242-F) and the OT (Tex-248-F). To support the proposed BMD method, the researchers undertook the following actions:

1) Developed and evaluated numerous HMA mix-designs in various districts around the State; using the BMD method and then, comparing with traditional TGC designs.
2) Conducted numerous laboratory tests to characterize the HMA material properties and predict performance. Laboratory tests included the HWTT for rutting and OT for cracking evaluation. Other supplementary tests included the DM, RLPD, IDT, SCB, DSR, BBR, etc.
3) Constructed APT test sections at the LTRC (Chapter 5) and trafficked the test sections under accelerated loads using the ALF machine. Testing was designed to evaluate both the rutting and reflection cracking potential of a control mix (TGC design) compared to a modified mix (BMD design) to meet the balance mix design criteria.
4) Researchers also worked with the TxDOT districts to design and construct field test sections on in-service highways under ongoing construction and/or rehab project around Texas. As discussed in Chapter 4, TTI researchers used the BMD method to design these HMA mixes relative to the traditional TGC method.
5) Several full scale 1000 ft long test sections were constructed around the state. The most notable success was in the Laredo District, where using the BMD method resulted in a savings of over $5 per ton of HMA by moving to a less expensive asphalt-binder (i.e., PG 64-22 from PG 70-22) while improving the HMA's overall engineering properties. No problems were encountered with constructing any of the section and the field performance to date has been excellent.
6) The researchers conducted periodic field performance evaluation of both the APT and in-service field test sections. These field tests included rut measurements, crack mapping surveys, GPR, FWD, high speed profiles, pictures/videos, and coring where needed.

KEY FINDINGS

In the accelerated pavement testing conducted at the LTRC, the mixes performed as predicted by the BMD method. The original Control Item 341 Type D mix was designed using the TGC method and the OAC was found to be 4.3 percent with a HWTT rut depth of 4.7 mm after 20,000 passes and an OT life of 90 cycles. The modified mix designed with the Superpave gyratory and the BMD method recommended 5.2 percent OAC with a HWTT rut of 7.0 mm and an OT life of 600 cycles. The control mix was predicted to be more rut resistant than the modified mix and that was shown to be the case with the measured average wheel path ruts after 75,000 ALF load applications of 7.7 and 11.8 mm, respectively. However, the modified mix (BMD design) did substantially better than the control mix with regard to retarding reflection cracking. When placed over a jointed concrete pavement, the control mix (TGC design) had cracks in less than 75,000 ALF load applications, whereas the Modified mix (BMD design) had no reflection cracks after over 200,000 load applications.

In the field testing of in-service highway projects in Texas, the BMD method was able to optimize the design of typical dense graded mixes. Table 7-1 shows an example of results from the Laredo District; see also Chapter 4 Table 4-12.

Table 7-1. Type C HWTT-OT Lab Test Results for PG 64-22 and PG 70-22 (LRD).

	AC	Corresponding TGC Lab Density	VMA	HWTT Rutting	OT Cracking (Cycles)
Original TGC Design = PG 70-22 (Valero)	4.7%	96.0%	14.6	2.04 mm	24
	4.8%	**96.5%**	**14.4**	**2.9 mm**	**38**
	5.0%	97.0%	14.3	2.7 mm	46
	5.2%	97.5%	14.4	2.9 mm	60
	5.5%	98.0%	14.5	3.2 mm	73
Modified BMB Design = PG 64-22 (Valero)	4.8%	96.0%	14.7	5.4 mm	180
	5.0%	**96.5%**	**14.8**	**6.0 mm**	**200**
	5.2%	97.0%	14.8	6.5 mm	219
	5.4%	97.5%	14.7	8.0 mm	311
	5.6%	98.0%	14.7	9.7 mm	380
Threshold Used		(96% ≤ TGC ≤ 98%)	(≥ 13)	≤ 12.5 mm @ 20,000 load passes	≥ 100

The Contractor’s proposed mix is shown in the upper table, with a PG 70-22. The concern in this case was the OT performance at the OAC with only 38 cycles. The switch to the PG 64-22 based on the BMD method with an increase in AC by 0.2 percent saw the OT cycles increase to 200. This modified mix (BMD design) was placed on three major projects (US 59, Loop 20, and Spur 400) in the Laredo Districts in 2010 and the performance to date under very heavy traffic have been very good with no distresses.

RECOMMENDATIONS

This research recommended modifications to the existing TxDOT specifications for dense graded mixes, which includes the following:

- Require the HWTT and OT performance testing for every HMA mix to be performed at a minimum of two different AC levels. As a guideline, refer to the tentative BMD pass-fail screening criteria proposed in Chapter 4.
- Compute for every project the required (minimum) OT cycles based on the pavement type, current conditions, traffic level, and environment. To make these OT estimates, Dr. Fujie Zhou has developed a user friendly computer program that can be used to estimate the reflection cracking life of any proposed overlay/pavement combination.
- It will be critical to modify the specifications for all mixes so that the aggregates and asphalt-binder are paid for under separate bid items
- If the BMD method is adapted, it will be possible to remove some of the restrictions on RAP and RAS usage. The results from the performance tests will dictate the maximum level of usage.
- With the expanding use of warm mixes and other technologies, which are not accounted for in the current mix-design testing, it will also be critical to run both performance tests (HWTT and OT) in the acceptance testing of the trial batch.

Researchers propose that these recommendations be considered for evaluation in an "implementation project" and that the proposed BMD method should be incorporated into the upcoming Item 341 projects, to be run in parallel with the current mix-design approach.

REFERENCES

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Walubita LF and T. Scullion (2012). New Generation Mix Designs: Accelerated Pavement Testing of a Type C Mix with the ALF Machine. Draft Technical Report# 0-6132-2. TTI-The Texas A&M University System, TX, USA.

Zhou, F., S. Hu, and T. Scullion (2006). Integrated Asphalt (Overlay) Mix Design with Balancing Both Rutting and Cracking Requirements. Technical Report 5123-1, Texas Transportation Institute, College Station, Texas.

	BIN FRACTIONS						
	Bin No.1	Bin No.2	Bin No.3	Bin No.4	Bin No.5	Bin No.6	Bin No.7
Aggregate Source:	1/2" C.A.	3/8" C.A.	COARSE RAP	SCREENINGS	FINE RAP	FIELD SAND	
Aggregate Pit:	M / MARIETTA	M / MARIETTA	TXDOT	M / MARIETTA	TXDOT	GLOVER PIT	
Aggregate Number:	JONES MILL	JONES MILL	59 & 2625	JONES MILL	59 & 2625	LOCAL SOURCE	
Sample ID:							
Recycled Material?:			Yes		Yes		
Asphalt%:			4.3		7.2		

Combined Gradation

Individual Bin (%):	40.0	Percent	13.0	Percent	10.0	Percent	19.0	Percent	10.0	Percent	8.0	Percent		Percent	Total Bin 100.0%	Lower & Upper Specification Limits			Restricted Zone			
Sieve Size:	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum. % Passing	Lower	Upper	Within Spec's	*Lower*	*Upper*	*Within Spec's*	Individual % Retained
3/4"	100.0	40.0	100.0	13.0	100.0	10.0	100.0	19.0	100.0	10.0	100.0	8.0			100.0	100.0	100.0	Yes				0.0
1/2"	98.0	39.2	100.0	13.0	97.7	9.8	100.0	19.0	100.0	10.0	100.0	8.0			99.0	98.0	100.0	Yes				1.0
3/8"	82.7	33.1	100.0	13.0	87.6	8.8	100.0	19.0	100.0	10.0	100.0	8.0			91.8	85.0	100.0	Yes				7.1
No. 4	31.3	12.5	35.5	4.6	38.2	3.8	96.0	18.2	92.8	9.3	100.0	8.0			56.5	50.0	70.0	Yes				35.4
No. 8	10.6	4.2	8.3	1.1	25.5	2.6	76.8	14.6	71.6	7.2	100.0	8.0			37.6	35.0	46.0	Yes				18.9
No. 30	3.0	1.2	3.3	0.4	19.8	2.0	30.5	5.8	41.1	4.1	98.7	7.9			21.4	15.0	29.0	Yes				16.2
No. 50	2.4	1.0	2.9	0.4	17.9	1.8	22.3	4.2	33.2	3.3	94.9	7.6			18.3	7.0	20.0	Yes				3.1
No. 200	1.8	0.7	2.2	0.3	7.7	0.8	11.1	2.1	11.6	1.2	10.9	0.9			5.9	2.0	7.0	Yes				12.4

\# Not within specifications \# Not cumulative

Lift Thickness, in:					
Asphalt Source & Grade:	LION PG 64-22	Binder Percent, (%):	5.2	Asphalt Spec. Grav.:	1.030
Antistripping Agent:	N/A	Percent, (%):			

Remarks:

DESIGNED BY MARK DEAN @ LAI PLANS CALLED FOR PG 70-22 ASPHALT .
L.A.I. SUBSTITUTED LION PG 64-22 (HAMBURG RESULTS PASSED)

Figure A-1. ATL Original TGC Design – Combined Gradation.

Target Density, %:	**97.0**
Number of Gyrations:	

TEST SPECIMENS							**Mixture Evaluation @ Optimum Asphalt Content**			
								Hamburg Wheel Tracking Test		
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Indirect Tensile Strength (psi)	Number of cycles	Rut depth (mm)	*Overlay Tester Min. Number of Cycles*
4.0	2.371	2.506	2.665	2.517	94.2	15.0	144.4	15,000	6.6	
4.5	2.380	2.490	2.668	2.499	95.2	15.1				
5.0	2.390	2.480	2.678	2.480	96.4	15.2				
5.5	2.405	2.470	2.689	2.462	97.7	15.2				
6.0	2.409	2.455	2.693	2.444	98.6	15.5				

Effective Specific Gravity:	2.679

Estimated Percent of Stripping, %:	**0**

Optimum Asphalt Content :	**5.2**
VMA @ Optimum AC:	**15.2**

Interpolated Values	
Specific Gravity (Ga):	2.397
Max. Specific Gravity (Gr):	2.475
Theo. Max. Specific Gravity (Gt):	2.471

Remarks:

TXDOT VMA = 15.1 OK

Figure A-2. ATL Original TGC Design – Summary Sheet.

	BIN FRACTIONS						
	Bin No.1	Bin No.2	Bin No.3	Bin No.4	Bin No.5	Bin No.6	Bin No.7
Aggregate Source:	1/2" C.A.	3/8" C.A.	COARSE RAP	SCREENINGS	FINE RAP	FIELD SAND	
Aggregate Pit:	M / MARIETTA	M / MARIETTA	TXDOT	M / MARIETTA	TXDOT	GLOVER PIT	
Aggregate Number:	JONES MILL	JONES MILL	59 & 2625	JONES MILL	59 & 2625	LOCAL SOURCE	
Sample ID:							
Recycled Material?:			Yes		Yes		
Asphalt%:			4.3		7.2		
Individual Bin (%):	40.0 Percent	13.0 Percent	10.0 Percent	19.0 Percent	10.0 Percent	8.0 Percent	Percent

Total Bin: 100.0%

Combined Gradation

Sieve Size:	Bin No.1 Cum.% Passing	Bin No.1 *Wtd Cum. %*	Bin No.2 Cum.% Passing	Bin No.2 *Wtd Cum. %*	Bin No.3 Cum.% Passing	Bin No.3 *Wtd Cum. %*	Bin No.4 Cum.% Passing	Bin No.4 *Wtd Cum. %*	Bin No.5 Cum.% Passing	Bin No.5 *Wtd Cum. %*	Bin No.6 Cum.% Passing	Bin No.6 *Wtd Cum. %*	Bin No.7 Cum.% Passing	Bin No.7 *Wtd Cum. %*	Total Bin Cum. % Passing	Lower & Upper Specification Limits: Lower	Upper	Within Spec's	*Restricted Zone: Lower*	*Upper*	*Within Spec's*	Individual % Retained
3/4"	100.0	40.0	100.0	13.0	100.0	10.0	100.0	19.0	100.0	10.0	100.0	8.0			100.0	100.0	100.0	Yes				0.0
1/2"	98.0	39.2	100.0	13.0	97.7	9.8	100.0	19.0	100.0	10.0	100.0	8.0			99.0	98.0	100.0	Yes				1.0
3/8"	82.7	33.1	100.0	13.0	87.6	8.8	100.0	19.0	100.0	10.0	100.0	8.0			91.8	85.0	100.0	Yes				7.1
No. 4	31.3	12.5	35.5	4.6	38.2	3.8	96.0	18.2	92.8	9.3	100.0	8.0			56.5	50.0	70.0	Yes				35.4
No. 8	10.6	4.2	8.3	1.1	25.5	2.6	76.8	14.6	71.6	7.2	100.0	8.0			37.6	35.0	46.0	Yes				18.9
No. 30	3.0	1.2	3.3	0.4	19.8	2.0	30.5	5.8	41.1	4.1	98.7	7.9			21.4	15.0	29.0	Yes				16.2
No. 50	2.4	1.0	2.9	0.4	17.9	1.8	22.3	4.2	33.2	3.3	94.9	7.6			18.3	7.0	20.0	Yes				3.1
No. 200	1.8	0.7	2.2	0.3	7.7	0.8	11.1	2.1	11.6	1.2	10.9	0.9			5.9	2.0	7.0	Yes				12.4

\# Not within specifications \# Not cumulative

Lift Thickness, in:					
Asphalt Source & Grade:	LION PG 64-22	Binder Percent, (%):	5.5	Asphalt Spec. Grav.:	1.030
Antistripping Agent:	N/A	Percent, (%):			

Remarks:

DESIGNED BY MARK DEAN @ LAI PLANS CALLED FOR PG 70-22 ASPHALT .
L.A.I. SUBSTITUTED LION PG 64-22 (HAMBURG RESULTS PASSED)

Figure A-3. ATL BMD Design – Combined Gradation.

Target Density, %:	**98.0**
Number of Gyrations:	

CRM Content

TEST SPECIMENS							Mixture Evaluation @ Optimum Asphalt Content			
								Hamburg Wheel Tracking Test		
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Indirect Tensile Strength (psi)	Number of cycles	Rut depth (mm)	*Overlay Tester Min. Number of Cycles*
5.0	2.400	2.470	2.666	2.474	97.0	14.7	144.4	15,000	6.6	
5.4	2.404	2.454	2.664	2.460	97.7	14.9				
5.8	2.409	2.444	2.670	2.446	98.5	15.1				
6.2	2.415	2.443	2.687	2.431	99.3	15.2				

Effective Specific Gravity:	2.672

Estimated Percent of Stripping, %:	**0**

Optimum Asphalt Content :	**5.5**
VMA @ Optimum AC:	**14.9**

Interpolated Values	
Specific Gravity (Ga):	2.406
Max. Specific Gravity (Gr):	2.450
Theo. Max. Specific Gravity (Gt):	2.455

Figure A-4. ATL BMD Design – Summary Sheet.

MATERIAL CODE:		MIX TYPE:	ITEM341_C_Coarse_Surface
MATERIAL NAME:	TYPE C PG70-22 RAP		
PRODUCER:	Anderson Colombia		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:		CONTRACTOR DESIGN # :	

	BIN FRACTIONS						
	Bin No.1	**Bin No.2**	**Bin No.3**	**Bin No.4**	**Bin No.5**	**Bin No.6**	**Bin No.7**
Aggregate Source:	IH-35	A.C.	A.C.	A.C.	A.C.	A.C.	
Aggregate Pit:	Fractionated	La Perla	La Perla	La Perla	La Perla	Fine Sand	
Aggregate Number:	Fine RAP	Gr 3	Gr 4	Gr 5	Gr 6		Lime
Sample ID:							
Rap?:	Yes						
Asphalt%:	4.6						

Combined Gradation

Individual Bin (%):	20.0	Percent	21.0	Percent	15.0	Percent	27.0	Percent	7.0	Percent	9.0	Percent	1.0	Percent	Total Bin 100.0%	Lower & Upper Specification Limits		
Sieve Size:	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum.% Passing	*Wtd* Cum. %	Cum. % Passing	Lower	Upper	Within Spec's
1"	100.0	20.0	100.0	21.0	100.0	15.0	100.0	27.0	100.0	7.0	100.0	9.0	100.0	1.0	100.0	100.0	100.0	Yes
3/4"	100.0	20.0	100.0	21.0	100.0	15.0	100.0	27.0	100.0	7.0	100.0	9.0	100.0	1.0	100.0	95.0	100.0	Yes
3/8"	99.2	19.8	7.0	1.5	79.1	11.9	100.0	27.0	98.4	6.9	100.0	9.0	100.0	1.0	77.1	70.0	85.0	Yes
No. 4	87.9	17.6	0.3	0.1	0.4	0.1	70.6	19.1	65.9	4.6	99.9	9.0	100.0	1.0	51.4	43.0	63.0	Yes
No. 8	67.1	13.4	0.3	0.1	0.3	0.0	33.7	9.1	4.0	0.3	98.4	8.9	100.0	1.0	32.8	32.0	44.0	Yes
No. 30	37.3	7.5	0.3	0.1	0.3	0.0	11.8	3.2	2.1	0.1	98.2	8.8	100.0	1.0	20.7	14.0	28.0	Yes
No. 50	21.3	4.3	0.2	0.0	0.2	0.0	8.2	2.2	1.2	0.1	96.0	8.6	100.0	1.0	16.3	7.0	21.0	Yes
No. 200	6.1	1.2	0.2	0.0	0.2	0.0	3.8	1.0	1.1	0.1	21.4	1.9	100.0	1.0	5.3	2.0	7.0	Yes

\# Not within specifications \# Not cumulative

Lift Thickness, in:					
Asphalt Source & Grade:	Valero PG 70-22	Binder Percent, (%):	4.8	Asphalt Spec. Grav.:	1.033
Antistripping Agent:	Lime	Percent, (%):	1%		

Remarks:

Design prepared by : Maghsoud Tahmoressi, PE TxDOT Level II Certificate # 169

Figure A-5. LRD Original TGC Design – Combined Gradation.

Target Density, %:	**96.5**
Number of Gyrations:	**TxDOT**

CRM Content	

TEST SPECIMENS							Mixture
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Indirect Tensile Strength (psi)
4.0	2.310			2.461	93.9	15.1	
4.5	2.333	2.455	2.625	2.443	95.5	14.7	
5.0	2.355	2.432	2.619	2.426	97.1	14.3	120
5.5	2.361	2.391	2.589	2.409	98.0	14.5	
6.0	2.366			2.392	98.9	14.8	

Effective Specific Gravity:	2.611

Estimated Percent of Stripping, %:	**0**

Optimum Asphalt Content :	**4.8**
VMA @ Optimum AC:	**14.4**

Interpolated Values	
Specific Gravity (Ga):	2.347
Max. Specific Gravity (Gr):	2.440
Theo. Max. Specific Gravity (Gt):	2.432

Figure A-6. LRD Original TGC Design – Summary Sheet.

MATERIAL CODE:		MIX TYPE:	ITEM341_C_Coarse_Surface
MATERIAL NAME:	TYPE C PG 64-22 RAP		
PRODUCER:	Anderson Colombia		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:		CONTRACTOR DESIGN # :	

BIN FRACTIONS

	Bin No.1	Bin No.2	Bin No.3	Bin No.4	Bin No.5	Bin No.6	Bin No.7
Aggregate Source:	IH-35	A.C.	A.C.	A.C.	A.C.	A.C.	
Aggregate Pit:	Fractionated	La Perla	La Perla	La Perla	La Perla	Fine Sand	
Aggregate Number:	Fine RAP	Gr 3	Gr 4	Gr 5	Gr 6		Lime
Sample ID:							
Rap?:	Yes						
Asphalt%:	4.6						

Combined Gradation

Individual Bin (%):	20.0	Percent	21.0	Percent	15.0	Percent	27.0	Percent	7.0	Percent	9.0	Percent	1.0	Percent	Total Bin 100.0%	Lower & Upper Specification Limits			Restricted Zone					
Sieve Size:	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum.% Passing	Wtd Cum. %	Cum. % Passing	Lower	Upper	Within Spec's	Lower	Upper	Within Spec's	Individual % Retained	Cumulative % Retained	Sieve Size
1"	100.0	20.0	100.0	21.0	100.0	15.0	100.0	27.0	100.0	7.0	100.0	9.0	100.0	1.0	100.0	100.0	100.0	Yes				0.0	0.0	1"
3/4"	100.0	20.0	100.0	21.0	100.0	15.0	100.0	27.0	100.0	7.0	100.0	9.0	100.0	1.0	100.0	95.0	100.0	Yes				0.0	0.0	3/4"
3/8"	99.2	19.8	7.0	1.5	79.1	11.9	100.0	27.0	98.4	6.9	100.0	9.0	100.0	1.0	77.1	70.0	85.0	Yes				22.9	22.9	3/8"
No. 4	87.9	17.6	0.3	0.1	0.4	0.1	70.6	19.1	65.9	4.6	99.9	9.0	100.0	1.0	51.4	43.0	63.0	Yes				25.7	48.6	No. 4
No. 8	67.1	13.4	0.3	0.1	0.3	0.0	33.7	9.1	4.0	0.3	98.4	8.9	100.0	1.0	32.8	32.0	44.0	Yes				18.6	67.2	No. 8
No. 30	37.3	7.5	0.3	0.1	0.3	0.0	11.8	3.2	2.1	0.1	98.2	8.8	100.0	1.0	20.7	14.0	28.0	Yes				12.0	79.3	No. 30
No. 50	21.3	4.3	0.2	0.0	0.2	0.0	8.2	2.2	1.2	0.1	96.0	8.6	100.0	1.0	16.3	7.0	21.0	Yes				4.5	83.7	No. 50
No. 200	6.1	1.2	0.2	0.0	0.2	0.0	3.8	1.0	1.1	0.1	21.4	1.9	100.0	1.0	5.3	2.0	7.0	Yes				10.9	94.7	No. 200

\# Not within specifications \# Not cumulative

Lift Thickness, in:					
Asphalt Source & Grade:	Valero PG 64-22	Binder Percent, (%):	5.0	Asphalt Spec. Grav.:	1.033
Antistripping Agent:	Lime	Percent, (%):	1%		

Figure A-7. LRD BMD Design – Combined Gradation.

Target Density, %:	**96.5**
Number of Gyrations:	**TxDOT**

TEST SPECIMENS							Mixture Evaluation @ Optimum Asphalt Content			
								Hamburg Wheel Tracking Test		
Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Indirect Tensile Strength (psi)	Number of cycles	Rut depth (mm)	*Overlay Numbe*
4.2	2.311	2.425	2.577	2.441	94.7	14.7				
4.7	2.323	2.428	2.601	2.424	95.8	14.7				
5.2	2.334	2.409	2.599	2.407	97.0	14.8		20 000	6.0	
5.7	2.350	2.395	2.602	2.390	98.3	14.6				
6.2	2.359	2.377	2.601	2.373	99.4	14.8				

Effective Specific Gravity:	2.596

Estimated Percent of Stripping, %:	**0**

Optimum Asphalt Content :	**5.0**
VMA @ Optimum AC:	**14.8**

Interpolated Values	
Specific Gravity (Ga):	2.329
Max. Specific Gravity (Gr):	2.417
Theo. Max. Specific Gravity (Gt):	2.414

Figure A-8. LRD BMD Design – Summary Sheet.

APPENDIX B: LAB TEST RESULTS

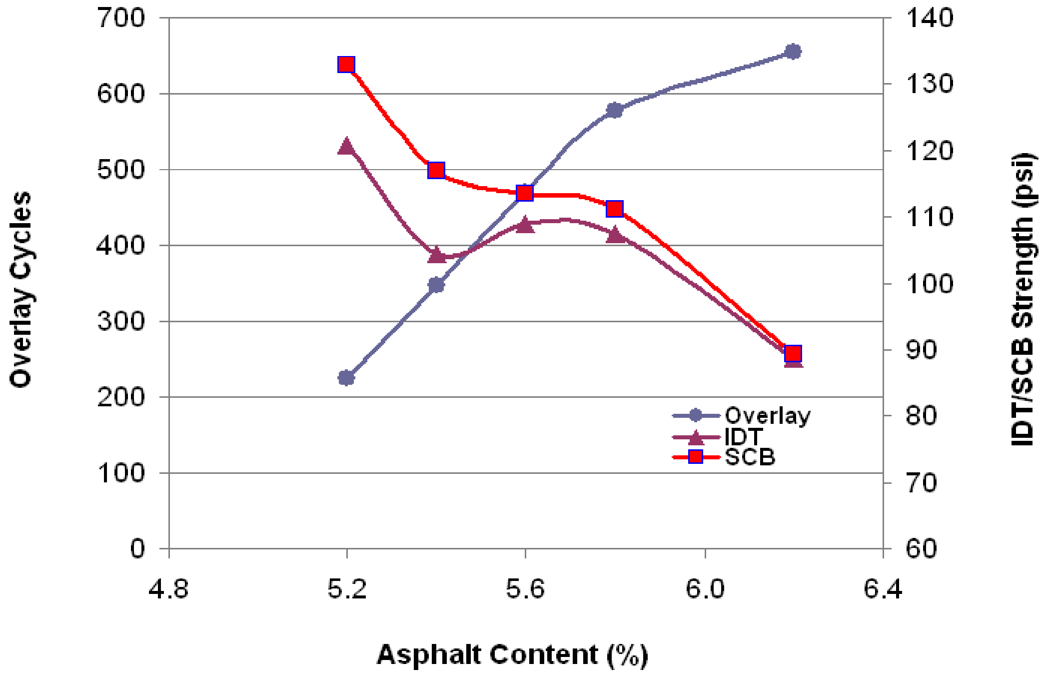

Figure B-1. OT (Cycles), IDT, and SCB (Strength) Results - ATL.

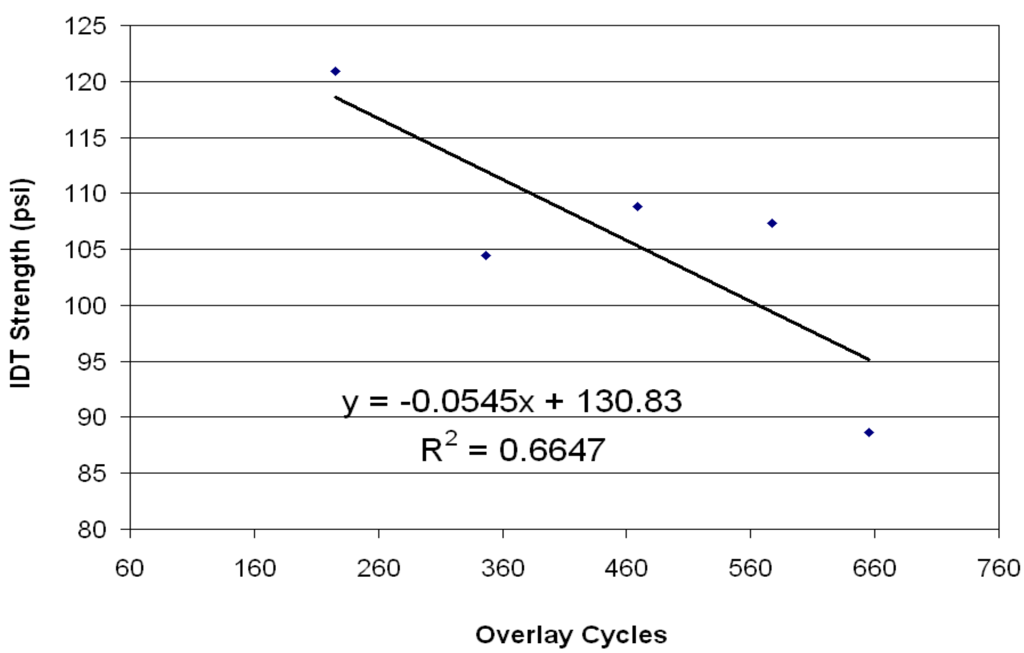

Figure B-2. IDT Strength vs OT Cycles - ATL.

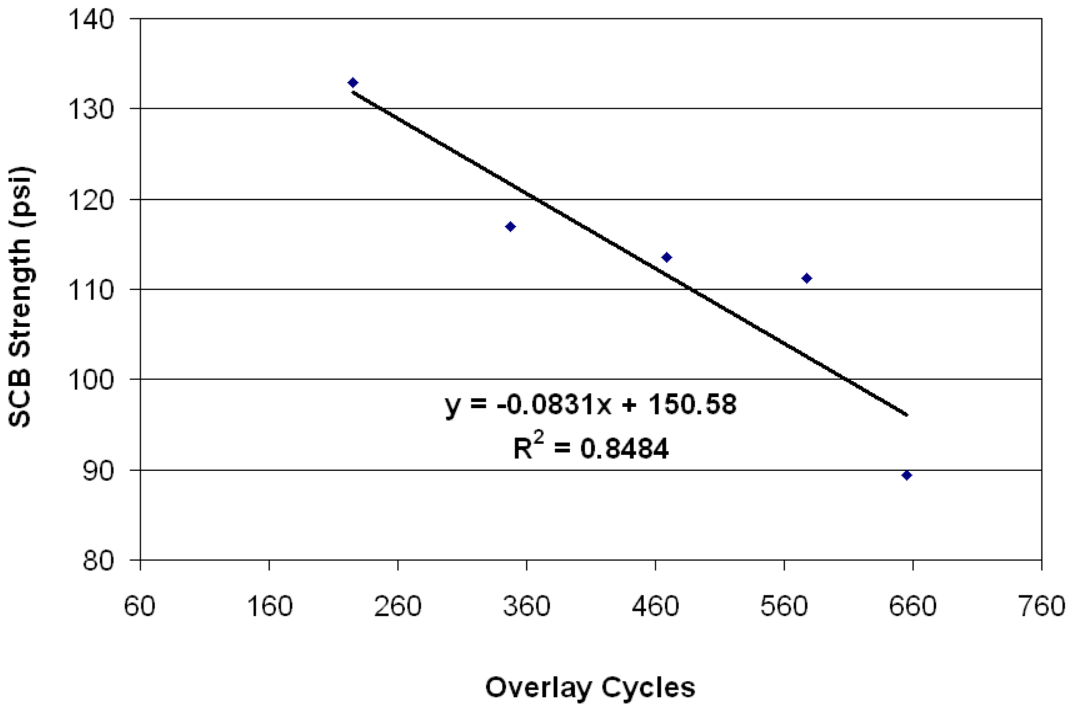

Figure B-3. SCB Strength vs OT Cycles – ATL.

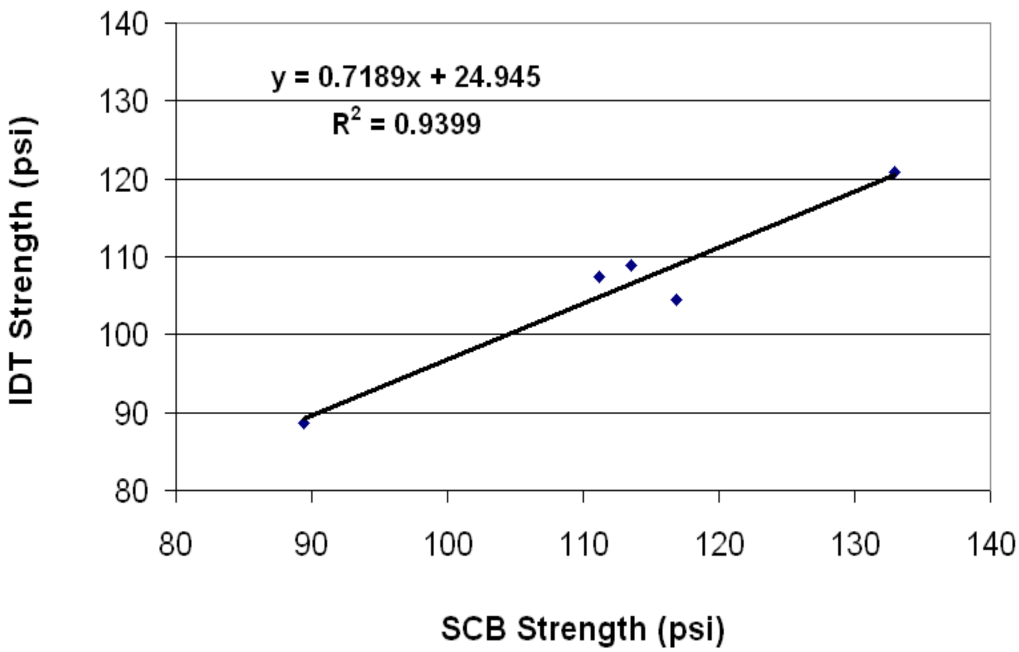

Figure B-4. IDT Strength vs SCB Strength - ATL.

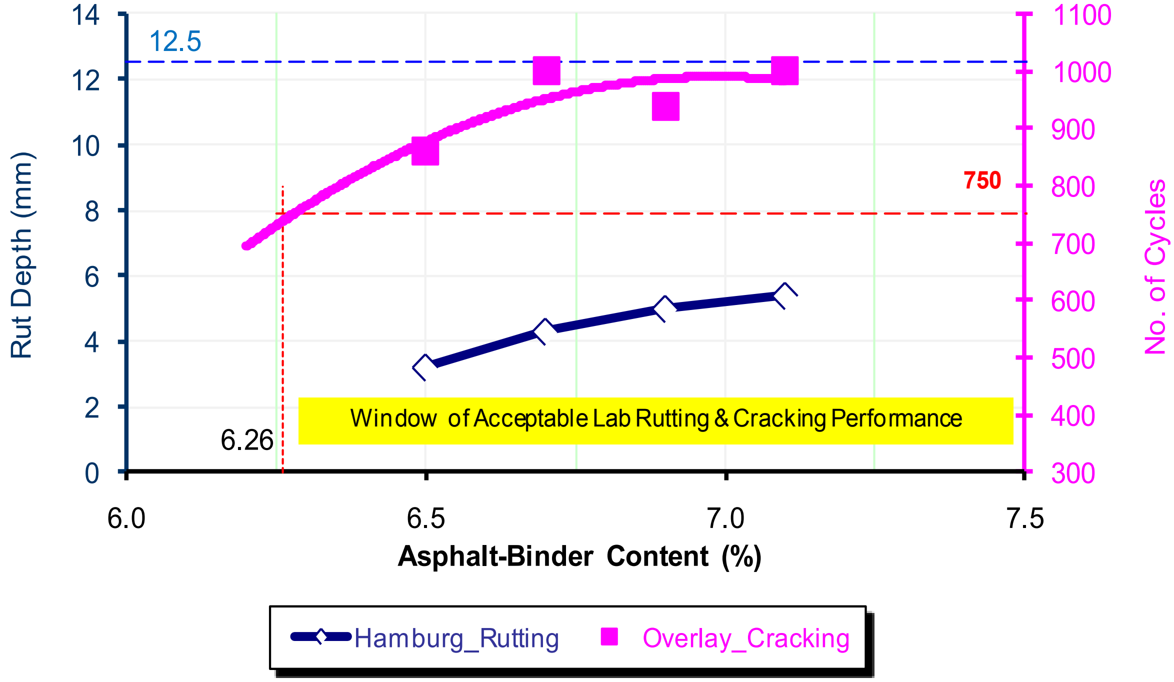

Figure B-5. HWTT and OT Results for Jebro PG 76-22 - BRY.

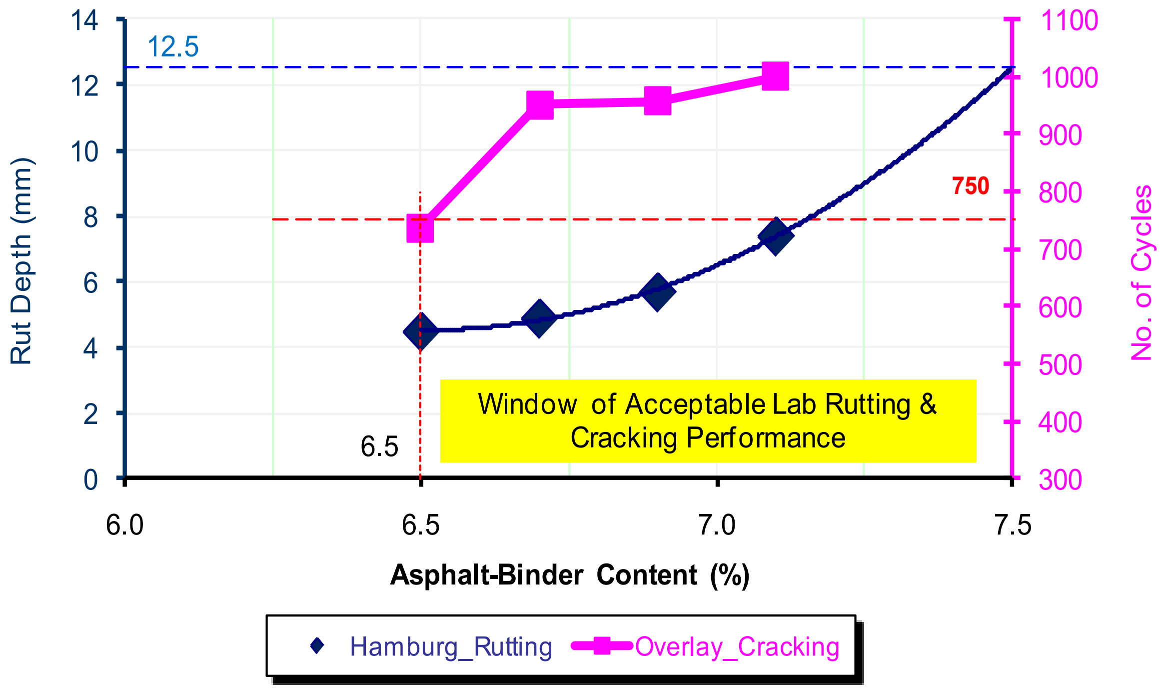

Figure B-6. HWTT and OT Results for Valero PG 76-22 - BRY.

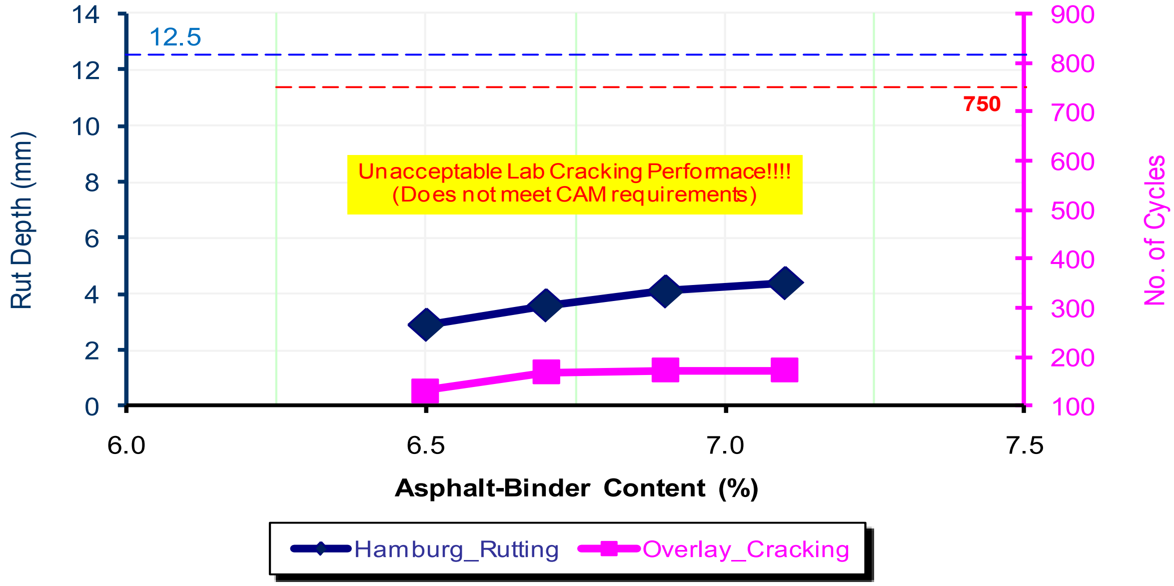

Figure B-7. HWTT and OT Results for Martin PG 76-22 - BRY.

Table C-1. ALF Test Loading Parameters and Test Results.

Sec#	Test Period	ALF Load Passes (K= 1 000)	Total ALF Load Passes	Tire Load (lbs)	Lateral Wander	AvgAir Temp. During Trafficking (°F)	HMA Mix	Purpose	Distress Observed
1	Sept – Nov 2009	100K	100,000	9 750	None	74.5	Control	Rut evaluation	8 mm rutting
2	Sept – Nov 2009	100K	100,000	9 750	None	74.5	Modified	Rut evaluation	15 mm rutting
3	Dec 09 – Feb 2010	0-75K	75,000	9 750	None	48.0	Control	Reflection crack evaluation	Cracking was only visible after 175 k load passes
		75-175k	100,000	14 600					
4	Dec 09 – Feb 2010	0-75k	75,000	9 750	None	48.0	Control	Reflection crack evaluation (50% LTE)	Cracking started after 75 k ALF load passes
		75-131 k	56,000	14 600					
5	Dec 10 - Feb 2011	0-75 K	75,000	9 750	None	-	Modified	Reflection crack evaluation	Cracking started after 143 k ALF load passes @ joint location Station +47.5
		75-175 K	100,000	14600	None	-			
6	Dec 10 - Jan 2011	0-75 k	75,000	9 750	None	-	Modified	Reflection crack evaluation (50% LTE)	None
		75-100 k	25,000	14600	None	-			
7	Mar – Jun 2010	0-125K	125,000	9 750	None	73.0	Modified	Fatigue crack evaluation	Cracked @ 150 k; 11 mm rutting after 100k
		125-150K	25,000	14 350	YES	73.0			
8	Mar – Jun 2010	0-125K	125,000	9 750	None	73.0	Control	Fatigue crack evaluation	No cracking; 8 mm rutting after 100 k
		125-150K	25,000	14 350	YES	73.0			
Total			**1,081,000**						

Note: ALF tire pressure = 105 psi (on all test sections); Wheel speed = 10.5 mph (on all test sections); Tire print width = 9 inches (on all test sections)

APPENDIX D: PRECONSTRUCTION FIELD TESTS FOR IN-SERVICE HWY TEST SECTIONS

Table D-1. Existing Transverse Cracks on Modified Section (BMD) – ATL.

Crack#	Location from Crack#1 (Section 1)	GPS Location	Remark	Severity
1	0 ft	N 32° 02. 078'; W 094° 16. 709'	Left side (US 59 N bound) – Fresh Water Pond and Turnaround	
2	365 ft	N 32° 02. 032'; W 094° 16. 664'		
3	383 ft	N 32° 02. 029'; W 094° 16. 658'		
4	553 ft	N 32° 02. 009'; W 094° 16. 638'		
5	567 ft	N 32° 02. 007'; W 094° 16. 634'		
6	655 ft	N 32° 01. 995'; W 094° 16. 628'		
7	727 ft	N 32° 01. 985'; W 094° 16. 618'		
8	807 ft	N 32° 01. 976'; W 094° 16. 606'		
9	918 ft	N 32° 01. 962'; W 094° 16. 623'		
10	1266 ft	N 32° 01. 918'; W 094° 16. 551'		
11	1350 ft	N 32° 01. 907'; W 094° 16. 551'		Very
12	1434 ft	N 32° 01. 897'; W 094° 16. 530'		
13	1700 ft	N 32° 01. 864'; W 094° 16. 496'		
14	1780 ft	N 32° 01. 854'; W 094° 16. 486'		
15	1813 ft	N 32° 01. 849'; W 094° 16. 483'		

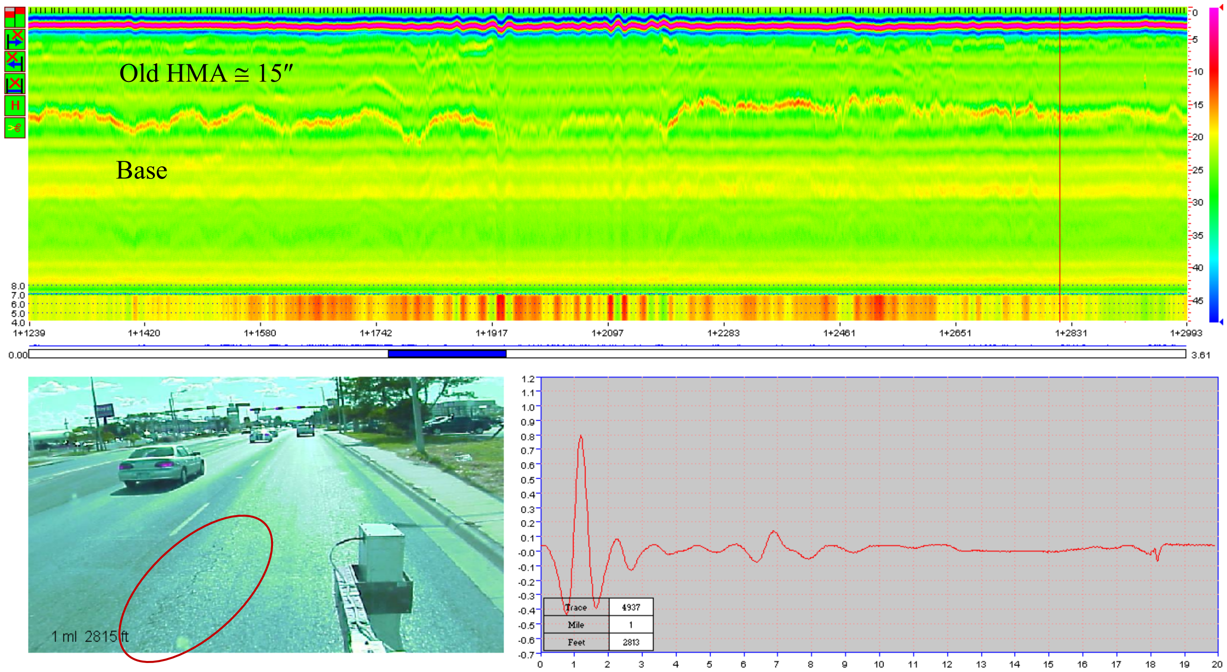

Figure D-1. GPR Test Runs on US 59 prior to 2″ HMA Overlay Placement, WB - LRD. (Existing HMA Layer Thickness → Variable). Existing HMA on this Highway Had Transverse, Longitudinal, and Fatigue Cracking.

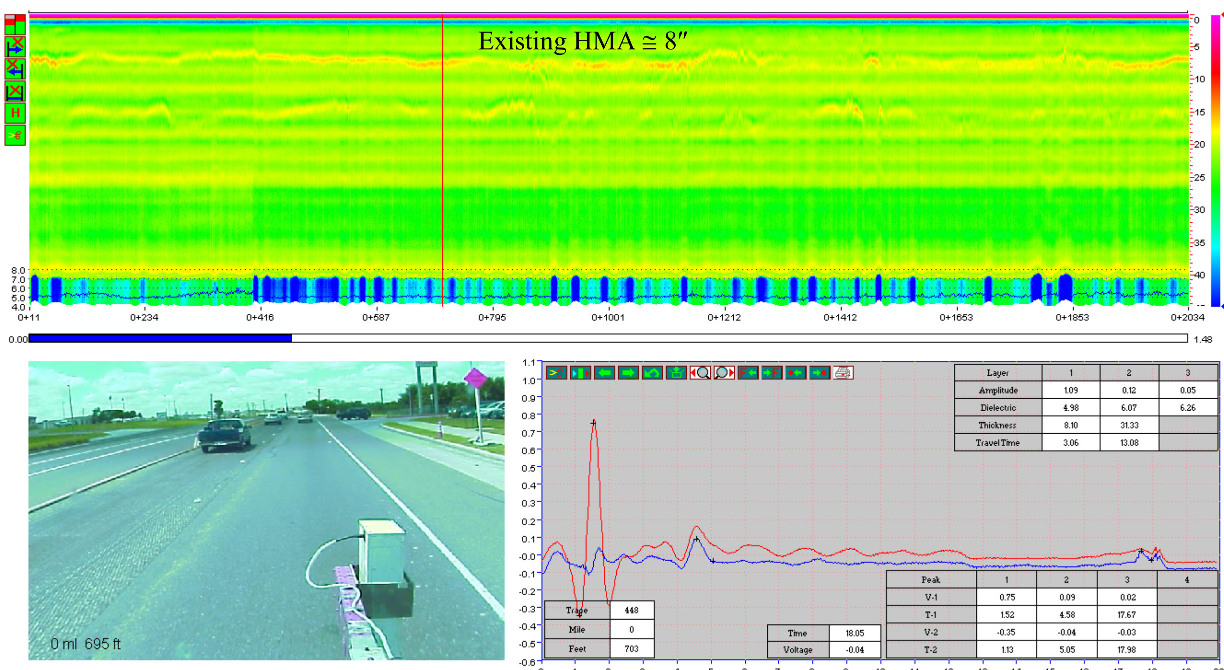

Figure D-2. GPR Test Runs on Loop 20 prior to 2″ HMA Overlay Placement, SB - LRD. (Existing HMA Layer Thickness → More Consistent than US 59); Very Little Distress on this Highway.

APPENDIX E: CONSTRUCTION DETAILS FOR IN-SERVICE HWY TEST SECTIONS

Figure E-1. Roadtec Shuttle Buggy MTV.

Figure E-2. Roadtec Mixer/Paver.

Figure E-3. IR (Temp.) Bar Setup.

Figure E-4. Caterpillar Vibratory Compactor

Figure E-5.TTI Nuclear Density Measurements.

Figure E-6. Example of Finished HMA Mat.

Table E-1. Summary IR Thermal Results – ATL.

Profile ID:	U.S.59 SOUTH BOUND OUTSIDE LN	Profile Date:	3/26/2010 6:58:38 AM
Profile Number:	3	Letting Date:	
Status:	NH 2010(414)	Controlling CSJ:	0063-05-033
County:	PANOLA	Spec Year:	2010
Tested By:	MADDEN CONTRACTING	Spec Item:	341
Test Location:	43360	Special Provision:	204
Material Code:		Mix Type:	TYPE "D" RAP
Material Name:			
Producer:	LAI		
Area Engeneer:	STEVE JUNEAU	Project Manager:	

Course/Lift:	1	Temperature Differential Threshold:	25.0
Segment Length (ft):	150	Sensors Ignored:	1, 2, 10, 11, 12

Thermal Profile Results Summary				
Number of Profiles	Moderate 25.0°F < differential <= 50.0°F		Severe differential > 50.0°F	
130	Number	Percent	Number	Percent
	47	36	0	0

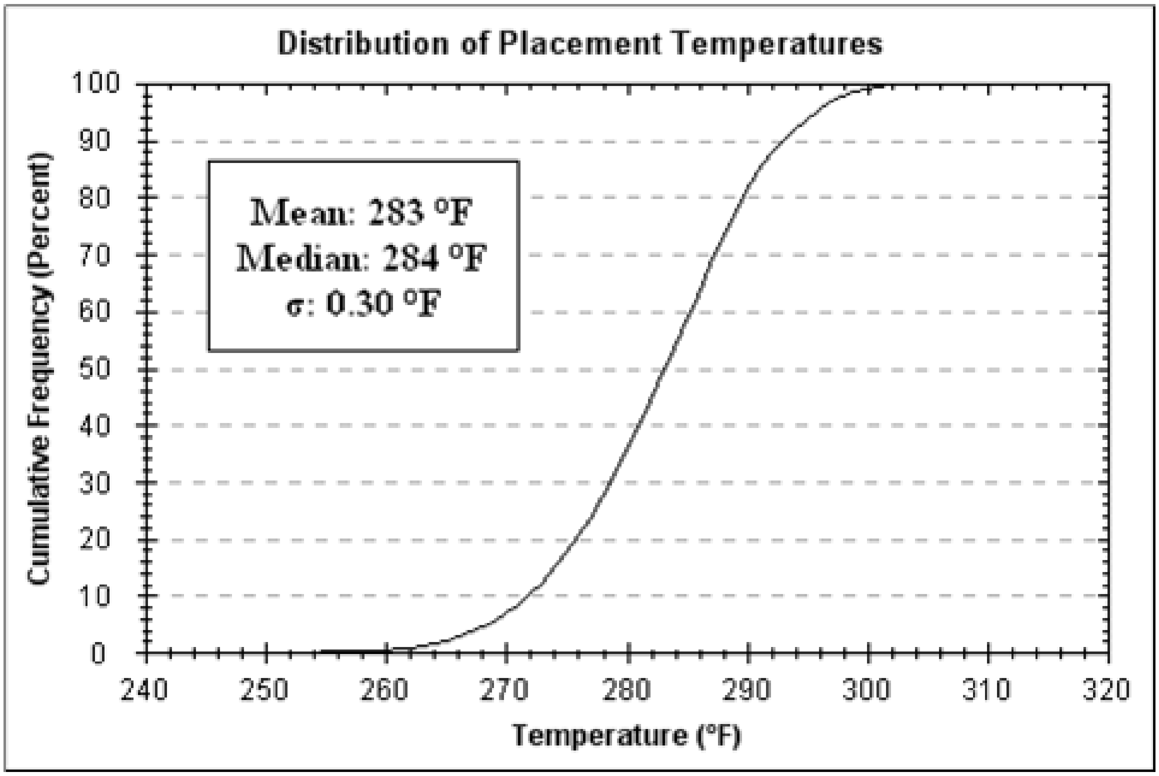

Figure E-7. Cumulative-Frequency IR Thermal Plots – ATL.

APPENDIX F: POST CONSTRUCTION QC FIELD TESTS

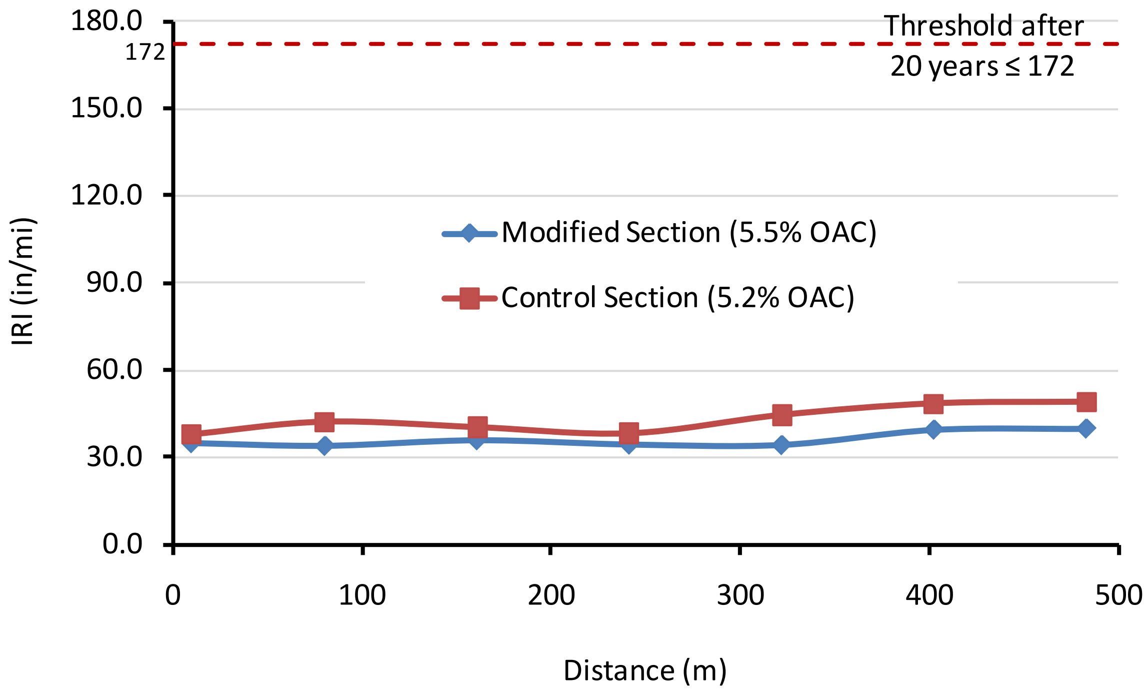

Figure F-1. International Roughness Index (IRI) Plot - ATL.

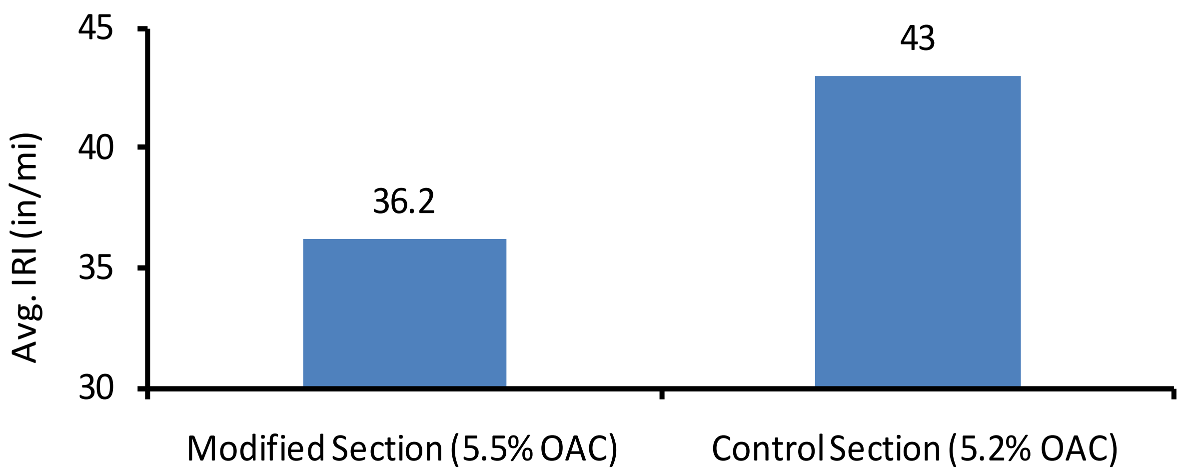

Figure F-2. Overall Average IRI Plots - ATL.

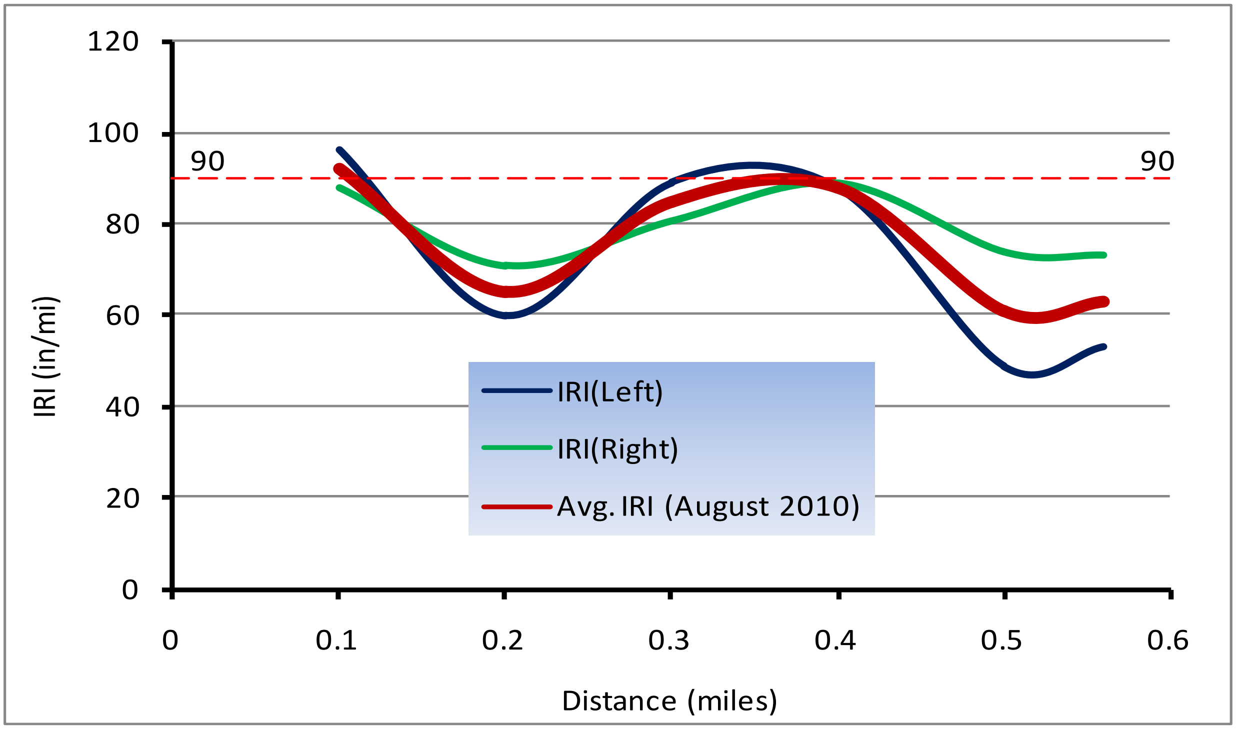

Figure F-3. Example IRI (QA) Plot for Loop 20 (August 2010) – LRD.

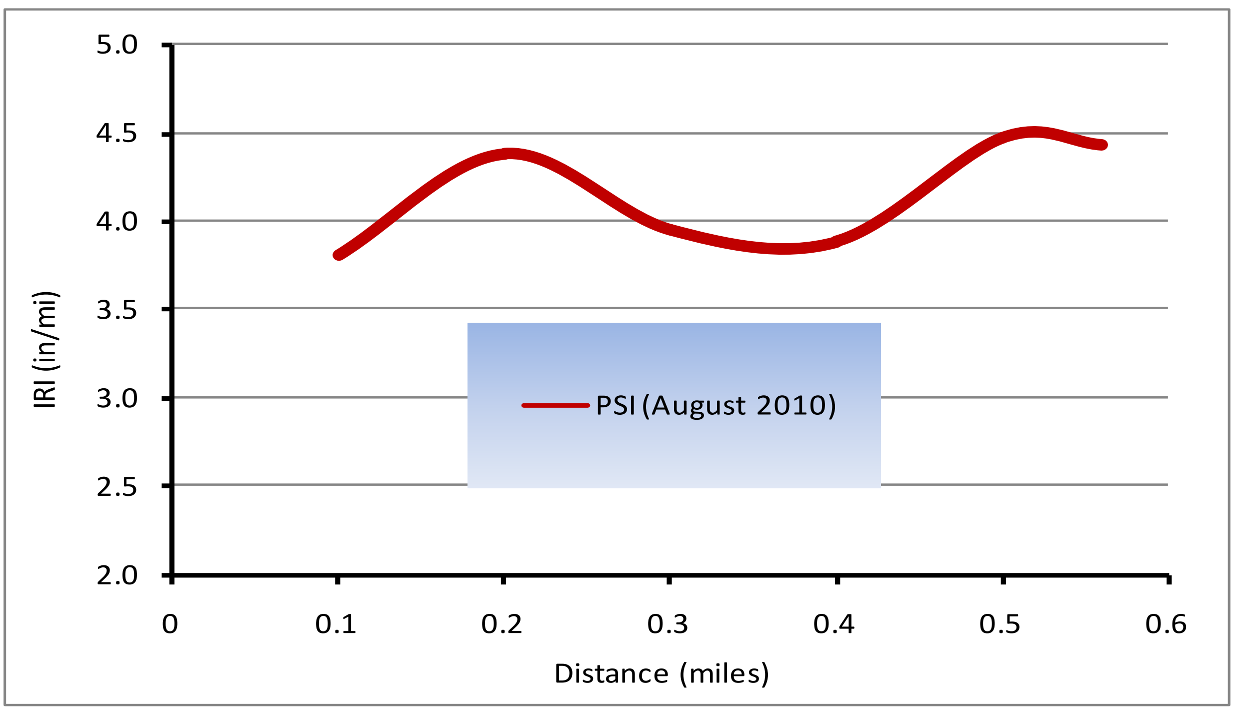

Figure F-4. Example PSI (QA) Plot for Loop 20 (August 2010) - LRD.

APPENDIX G: FIELD PERFORMANCE TESTING OF IN-SERVICE HWY TEST SECTIONS

Figure G-1. View of the Test Sections – No Visible Surface Rutting or Cracking – ATL. (After 5 Months; Oct 2010).

Figure G-2. View of the Test Sections – No Visible Surface Rutting or Cracking – ATL (After 2 Years; April 2012).

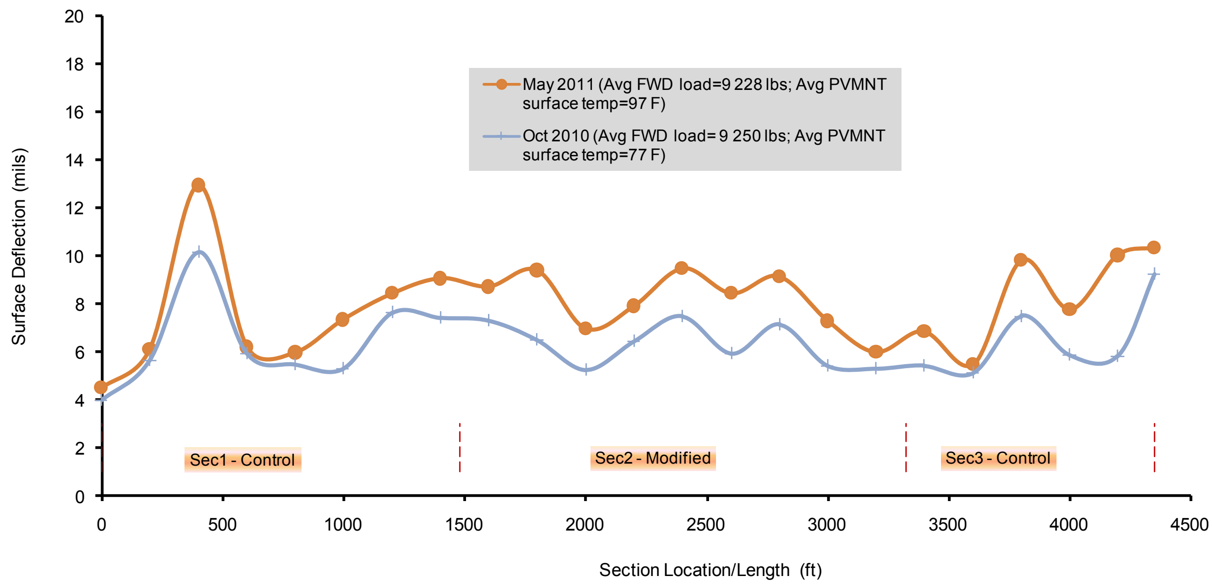

Figure G-3. Plot of FWD Surface Deflections - ATL.

Figure G-4. Loop 20 SB Direction – No Cracking or Rutting Observed - LRD.

Figure G-5. Spur 400 WB Direction – No Cracking or Rutting Observed - LRD.

Figure G-6. US 59 EB Direction – No Cracking or Rutting Observed - LRD.

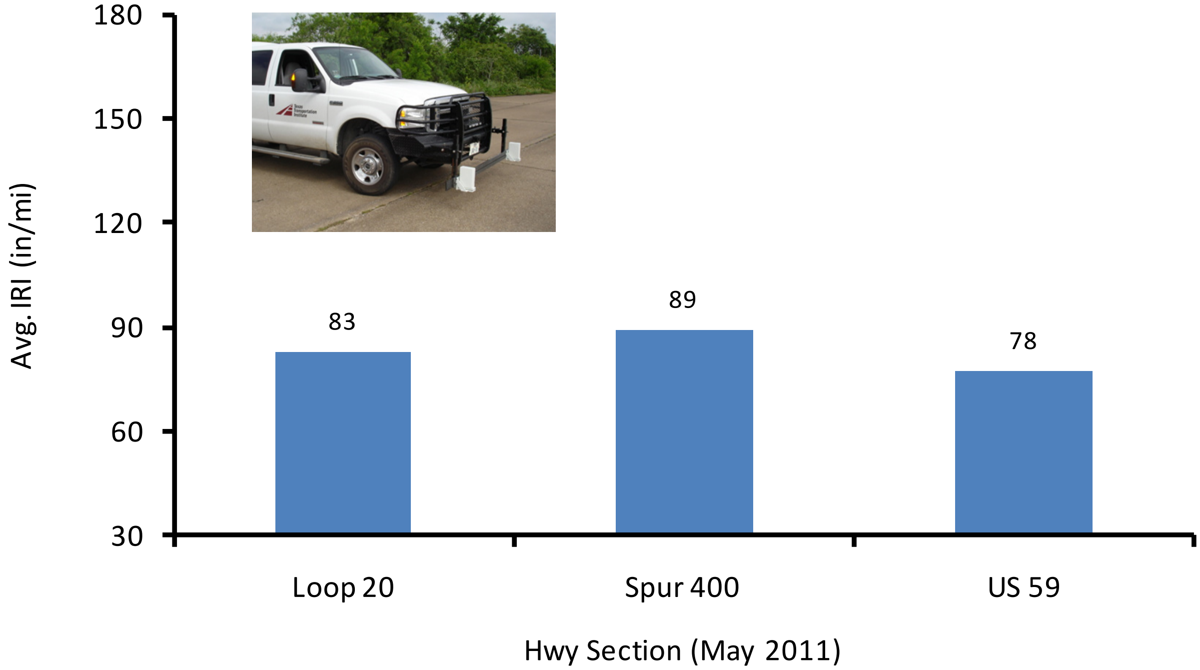

Figure G-7. Example Surface Profiles (Outside Lane) – Avg IRI as of May 2011 - LRD.

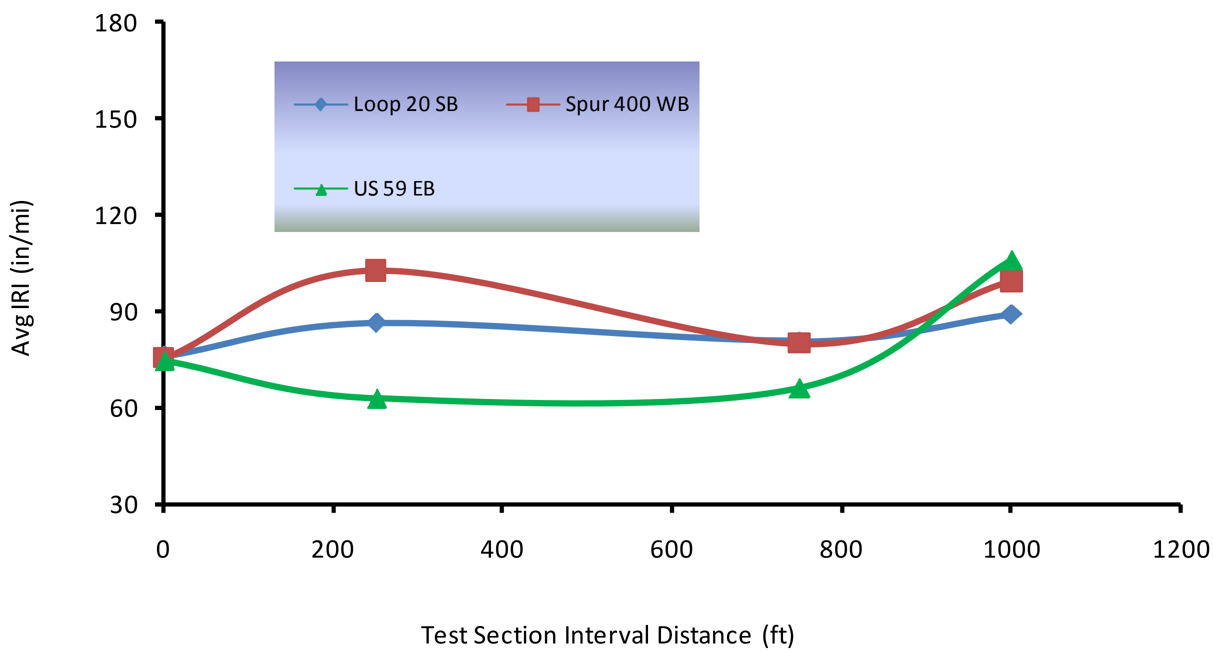

Figure G-8. Example Surface Profiles (Outside Lane) – Avg IRI (May 2011) - LRD.

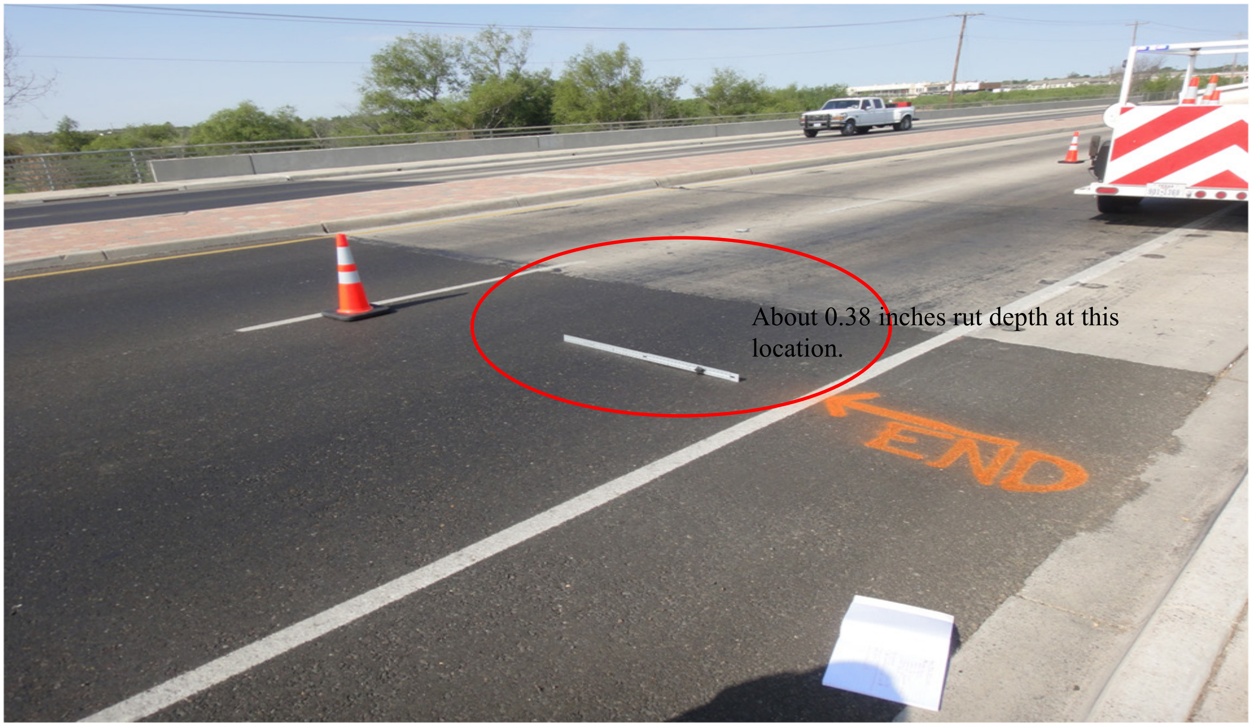

Figure G-9. HMA to Bridge Concrete Deck Transition ≅ 0.38 Inches Rut Depth (Spur 400) - LRD.

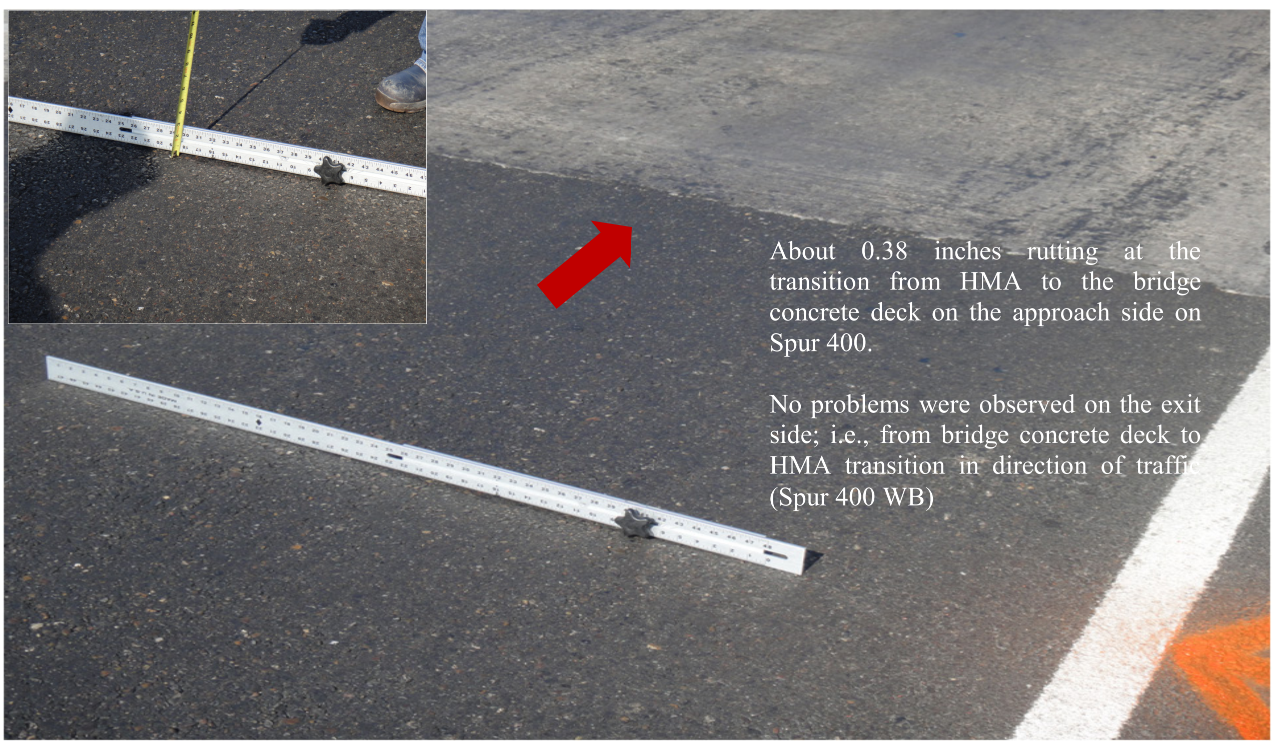

Figure G-10. Rut Measurements at the HMA-Bridge Transition on Spur 400 on the Traffic Approach Side; No Problems Were Observed on the Traffic Exit Side - LRD.