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16. Abstract

Very thin overlays 1-inch thick or less were placed as surface layers on five major highways in Texas. These mixes were designed in the laboratory to have a balance of good rut resistance as measured by TxDOT's Hamburg Wheel Tracking test and good reflection cracking resistance as measured by TTI's Overlay Tester. These Crack Attenuating Mixes (CAM) were designed and constructed based on a new special specification SS 3109. In the design phase the optimal asphalt content was initially determined using the Superpave Gyratory Compactor selecting the asphalt content that achieved 98% density after 50 gyrations. This approach worked well with stiff binders and top quality granite aggregates. However design problems were encountered with the transition to softer binders and locally available materials. The researchers proposed an alternative design procedure where the performance tests are run first at a range of asphalt contents and a window defined where both rutting and crack resistance requirements are met. The CAM mixes designed have 100% passing the 3/8-inch sieve and binder contents ranging from 7 to 8.3% asphalt. Few construction problems were identified; these fine mixes are easy to compact and finish. However, on one project thermal segregation problems were identified which caused low density pockets and areas of raveling. Initial performance even over jointed concrete has been good, and skid resistance measurements looked very reasonable.

The CAM mixes cost approximately 25% per ton more than the traditional mixes, but as they are placed as 1-inch thick mats rather than 2-inch thick, there is a clear economic advantage of using these high quality materials. TxDOT is in the process of updating SS 3109, and a statewide specification is scheduled for release in early 2009.

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DESIGN AND PERFORMANCE EVALUATION OF VERY THIN OVERLAYS IN TEXAS

by

Tom Scullion
Senior Research Engineer
Texas Transportation Institute

Fujie Zhou
Assistant Research Engineer
Texas Transportation Institute

Lubinda Walubita
Assistant Transportation Researcher
Texas Transportation Institute

and

Stephen Sebesta
Assistant Research Scientist
Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

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CHAPTER 1
INTRODUCTION

BACKGROUND

The most commonly used surface mixes in Texas are the Item 340 Type C and D. For these mixes the common placement depth is 2 inches. Project 0-5598 research was conducted to design and construct thin overlays that could be placed at a thickness of 1 inch or less. Several propriety thin mixes are currently available such as micro-surfacing or Nova-chip, but these have limitations. The micro-surfacing are typically stiff mixes, which are used for filling rutted areas; they contain cement they are often stiff and therefore perform poorly on cracked sections. The Nova-chip is a propriety system that has potential but is thought to not be competitively priced.

The challenges of developing a high performance thin overlay revolve around balancing the following competing and sometimes conflicting requirements:

- provide adequate rut resistance,
- provide adequate crack resistance,
- provide adequate skid resistance,
- provide construction specifications for placement and compaction, and
- provide a mix that is economical.

In Project 0-5598 attempts were made to develop a very thin overlay mix that meets these requirements. For thin overlays the engineering properties that are considered in the design phase are rut resistance and reflection cracking resistance. In Texas these are measured by the Hamburg Wheel tracking test (HWTT), and reflection cracking is measured by TTI's overlay tester (OT) as described below.

Rut Resistance (Hamburg Test)

The Hamburg test (Tex Method 242 F) is the approved test for measuring the moisture susceptibility and rutting potential of HMA layers in Texas. During the test two 2.5- inch high by 6-inch diameter HMA specimens are loaded at 122 °F to characterize their rutting properties. The samples are submerged in a water bath and loaded with steel wheels. Figure 1 shows a schematic illustration of the Hamburg test device.

Figure 1. The Hamburg Test Device.

The test loading parameters for the Hamburg test were as follows:

- Load: 705 N (158-lb force)
- Number of passes: 20,000
- Test condition/temperature: Under water at 50 °C (122 °F)
- Terminal rutting failure criterion: 0.5 inch (12.5 mm)
- HMAC specimen size: 6-inch diameter by 2.5-inch high

Crack Resistance (Overlay Tester)

The upgraded TTI Overlay tester shown in Figure 2 is the standard test for measuring the reflection cracking potential of HMA surface layers in Texas (Tex Method 248-F). This new version of the device has been implemented within TxDOT (Cedar Park). Three TxDOT districts have been given this equipment (Atlanta, Childress, and Houston).

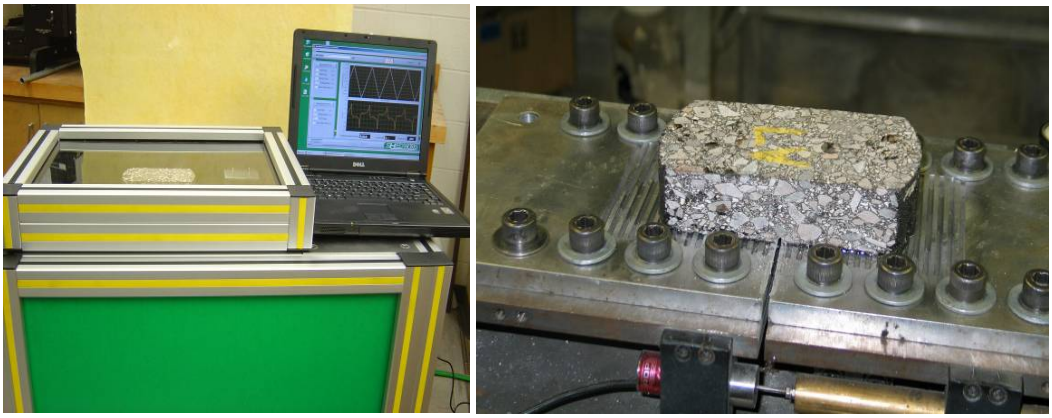


Figure 2. Overlay Tester Equipment and Sample.

The test loading parameters for the Overlay Tester are as follows:

- Loading: cyclic triangular displacement-controlled waveform at 0.025 in (0.63 mm)
- Loading rate: 10 seconds per cycle
- Test temperature: 25 °C (77 °F)
- Tentative cracking failure criterion: 300 load cycles (for surface mixes), higher for crack attenuating layers
- Specimen size: 6-inch total length by 3-inch width by 1.5-inch

The overlay tester was developed to evaluate a mix's resistance to thermally induced reflection cracking. However mixes that pass this test will also have good fatigue resistance. This was demonstrated by TTI with testing of the performance of mixes under accelerated pavement testing conditions (Zhou, 2007).

The concept of a balanced mix design is shown in Figure 3. The green line represents the Hamburg rut depth for different binder contents; rut depths below 12.5 mm (0.5 inches) are acceptable. The red line shows the performance in the overlay tester; in this case samples that last over 300 cycles to failure are judged as acceptable. This figure clearly shows the concept of a balanced design. As the percent asphalt increases the rutting resistance decreases, but the cracking resistance increases. The balanced design is the zone of asphalt contents that passes both rutting and cracking requirements. Studies at TTI (Zhou 2006) have shown that the window of acceptable asphalt contents is narrow for the lower PG grades. For PG 64-22 binders adding additional binder often get the mixes to rut excessively. The window for PG 76-22 has been found to be substantially wider as these binders are not highly rut susceptible. Zhou's studies also showed that for some combinations of aggregate and binder, it is impossible to meet both requirements.

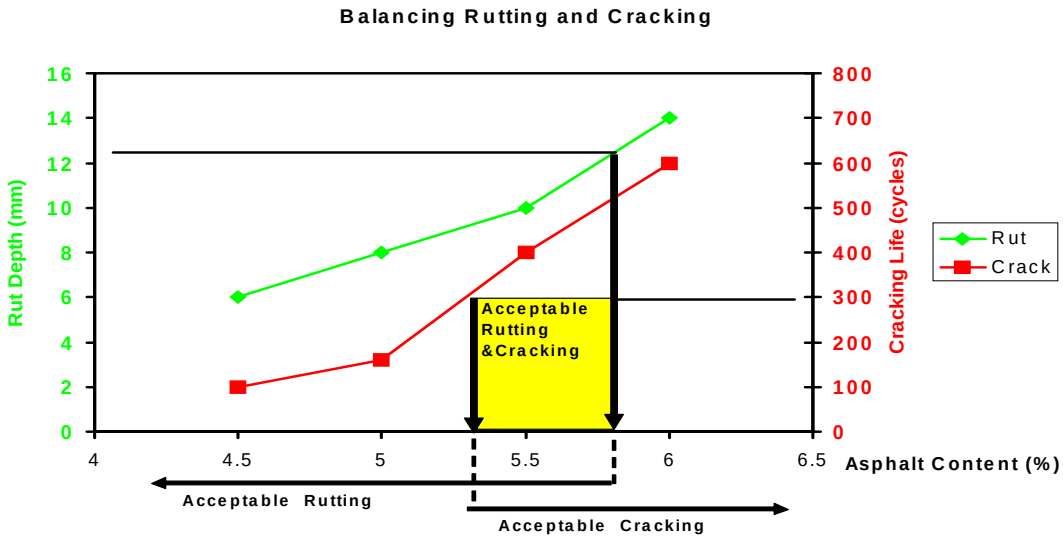


Figure 3. Determining the Binder Content to Meet Rutting and Cracking Requirements.

CURRENT SPECIFICATIONS

In this project based partially on the recommendations from early work, the Bryan District (TxDOT, 2007 Darlene Goehl and Pat Williams) developed a one-time use Special Specification for ultra thin overlays (SS 3109). The proposed mix was called the "Crack Attenuating Mix" (CAM). Several innovative features were included in the specification, namely:

1) The optimum asphalt content was selected based on volumetric principles to provide 98% of maximum theoretical density with 50 gyrations in the Superpave Gyratory Compactor.
2) To validate the engineering properties of the mix, samples would be compacted to 93% of maximum theoretical density. These samples then had to meet the Hamburg requirements shown below in Table 1 and last a minimum of 750 cycles in the Overlay Tester.

Table 1. Standard HWTT Terminal Rutting Failure Criteria.

Rut_{HWTT}	Number of Passes	Mix with Binder Type
≤ 12.5 mm (0.5")	10,000	PG 64-XX
≤ 12.5 mm (0.5")	15,000	PG 70-XX
≤ 12.5 mm (0.5")	20,000	PG 76-XX

3) The asphalt and aggregates would be paid for separately, which allows districts to vary the amount of binder required without the need for change orders or redesigns.
4) The specification mandates the use of 1% lime and an antistrip agent (this is somewhat controversial and some districts prefer liquid antistrip whereas others are more interested in meeting the performance requirements and using lime as an option).
5) The aggregate quality requirements were high (similar to that of TxDOT's performance mixes).
6) No recycled asphalt or river sand are permitted. Table 2 shows the proposed gradation for the CAM mix.
7) Tight requirements were placed on temperature at placement.

Table 2. CAM Gradation Band.

Sieve Size	Fine Mixture (% Passing by Weight or Volume)
1/2"	–
3/8"	98.0–100.0
#4	70.0-90.0
#8	40.0–65.0
#16	20.0-45.0
#30	10.0–30.0
#50	10.0–20.0
#200	2.0–10.0

PROJECT 0-5598 YEAR 1 REPORT

In the year 1 report for this project (Walubita and Scullion, 2008) details were provided on the background to this specification and on the attempts by TTI and the TxDOT districts to design mixes according to this specification. A total of eight different CAM designs were proposed and evaluated in the laboratory. Many of these mixes were made with the PG 76-22 binder and generally very good quality aggregates, typically granites and sandstones. Most of the designs passed the SS 3109 requirements; however, some problems were reported with mixes that attempted to use limestone aggregates. The year 1 report also provided some preliminary performance data on the very thin overlay mixes placed around the state. Several short test sections had been placed, and the initial performance was reported to be very good.

OBJECTIVES OF THIS REPORT

1) Several of the mixes designed in the year 1 research were placed on highways around Texas. This report will provide construction histories of the various projects and provide performance data collected to date. A list of several of the major projects is provided in Chapter 2 of this report.
2) Problems were encountered in designing balanced mixes when binders other than PG 76-22 were used and when lower quality aggregates were proposed. Major problems were encountered with the proposed volumetric design procedure on a project in San Antonio. This lead TTI to evaluate alternatives to the existing volumetric design approach. A description of the three alternatives mix design approached is provided in Chapter 3 of this report
3) Based on the findings from Chapter 3, TTI has proposed a revised mix design procedure for the CAM mixes described in Chapter 4 of this report.

CHAPTER 2
VERY THIN OVERLAY SECTIONS IN TEXAS

INTRODUCTION

In the year 1 report from this project (Walubita, 2008), the lab results from numerous thin overlay designs were reported. These overlays were most notably designed for the Beaumont and Houston Districts. In each case high quality granite aggregates were used and PG 76-22 binder. These materials were used not as surface layers but primarily as a level up course on cracked concrete pavements. No problems have been reported with either the design or construction of these mixes.

During year 2 of this project very thin overlay mixes were placed as surface layers on the following five sections in Texas:

- US 59 (Timberland Drive) in Lufkin,
- Pumphrey Drive in Fort Worth,
- Loop 20 at International Drive in Laredo,
- US 281 in Marble Falls, Austin, and
- US 90 San Antonio.

In all cases the mix designs were made using the volumetric design procedure proposed in SS3109. The results of the lab designs are shown in Table 3. Only one of these mixes (US 59 Lufkin) used the PG 76-22 binder and granite aggregates. No problems were reported in arriving at a design that meets the performance tests for the US 59 project. However, during the course of this project as a result of the large increases in asphalt prices, efforts were made to make the CAM mixes more economical. This resulted in changes to a lower PG graded binder typically PG 70 or modified PG 64, with sometimes a change to locally available aggregates. With all of the other mixes problems were encountered using the SS 3109 design recommendations. The criteria which the mix failed the requirements are highlighted in red in Table 3.

The problems encountered and the adjustments made by the districts will be described in the remainder of this section. In chapters 3 and 4 recommendations will be described on how to more effectively arrive at an optimal asphalt content to meet the balanced mix design requirements. In one case (US 90) it was not found impossible to achieve a balanced mix

design, and in others the performance requirements were waived or the binder contents were modified in production.

Table 3. Mix-Design Volumetrics and Lab Test Results.

Item Mix Type	Mix-Design Characteristics						
	Materials	**Rice**	**VMA (≥ 16%)**	**AV (≅ 7±0.5%)**	**T_F (≥ 10 µm)**	**HWTT (≤ 12.5 mm)**	**OT (≥ 750)**
US 59 – Lufkin TxDOT CAM	8.3% PG 76-22S + Granite	2.302	20.4%	7.0%	15.05	7.81	900+
FW – Pumphrey Drive 01 TxDOT F – Crumb Rubber	6.6% 64-22 + 7% Crumb Rubber + 1% Akzo + Granite	2.398	-	*7.6%*	21.8	*13.78* (*after 3063 passes*)	900+
FW – Pumphrey Drive 02 TxDOT F – Latex	7.2% PG 64-22 + 3% Latex + Granite	2.394	-	7.5%	21.7	*13.89* (*after 4075 passes*)	900+
Loop 20 Laredo TxDOT CAM	7.0% PG 70-22 50% gravel, 48.5% screenings + 1.5% lime	2.370	17.7%	6.7%		6.2mm (after 20000 passes)	*678*
US 281 Marble Falls TxDOT CAM	7.4% PG 70-22S 45% Sandstone + 55% limestone	2.379	18.9	6.9%		12.5 (after 17,400)	1200 +
# US 90 San Antonio TxDOT CAM	7.6% PG 70-22 + 22% Grade5 78% Man Sand	2.639	22.5%	6.5%		*12.8mm* (after 9,000 passes)	1000 +

Balanced mix design not possible this design was based on 96% density not 98%

Legend: VMA = voids in mineral aggregate; AV = air voids; T_F = asphalt-binder film thickness; HWTT= Hamburg wheel tracking test for rutting resistance characterization (failure criterion ≤ 12.5 mm rut depth); OT = Overlay tester for cracking resistance characterization (failure criterion ≥ 750 load cycles at 93 percent stress reduction.

US 59 – LUFKIN: TxDOT CAM DESIGN

As evident in Table 3, this mix (8.3% PG 76-22S + granite) met all the balanced mix-design requirements. The aggregates used are shown below in Figure 4.

	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:	Martin Marietta		Granite Mountain		Texas hydraded																	
Aggregate Number:	Jones Mill 3/8's		Hotmix Scr.		Lime																	
Sample ID:	Malvern, Ar.		Sweethome, Ar.		Cleburne, Tx.										Combined Gradation							
Rap?, Asphalt%:															Total Bin							
Individual Bin (%):	30.0	Percent	69.0	Percent	1.0	Percent		Percent		Percent		Percent		Percent	100.0%	Lower & Upper Specification Limits		Within Spec's	*Restricted Zone*		*Within Spec's*	Individual % Retained
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							
1"	100.0	30.0	100.0	69.0	100.0	1.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes				0.0
3/4"	100.0	30.0	100.0	69.0	100.0	1.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes				0.0
1/2"	100.0	30.0	100.0	69.0	100.0	1.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes				0.0
3/8"	100.0	30.0	100.0	69.0	100.0	1.0		0.0		0.0		0.0		0.0	100.0	98.0	100.0	Yes				0.0
No. 4	56.7	17.0	88.9	61.3	100.0	1.0		0.0		0.0		0.0		0.0	79.4	70.0	90.0	Yes				20.6
No. 8	16.7	5.0	60.3	41.6	100.0	1.0		0.0		0.0		0.0		0.0	47.6	40.0	65.0	Yes				31.7
No. 16	7.6	2.3	40.2	27.7	100.0	1.0		0.0		0.0		0.0		0.0	31.0	20.0	45.0	Yes				16.6
No. 30	4.9	1.5	25.6	17.7	100.0	1.0		0.0		0.0		0.0		0.0	20.1	10.0	30.0	Yes				10.9
No. 50	3.7	1.1	14.6	10.1	100.0	1.0		0.0		0.0		0.0		0.0	12.2	10.0	20.0	Yes				8.0
No. 200	2.4	0.7	3.6	2.5	100.0	1.0		0.0		0.0		0.0		0.0	4.2	2.0	10.0	Yes				8.0
# Not within specifications # Not cumulative																						
Asphalt Source & Grade:	PG 70-22 0r PG76-22						Binder Percent, (%):		8.3		Asphalt Spec. Grav.:		1.025									
Antistripping Agent:	Texas Hydraded Lime						Percent, (%):		1													

Figure 4. Lufkin's CAM Mix.

The mix was placed in the summer of 2007 as a 1-inch overlay to resurface an existing pavement in downtown Lufkin on business highway US 59. The existing underlying pavement structure was jointed concrete with approximately 2 to 3 inch of existing Hot Mix Asphalt (HMA). Rolling Dynamic Deflectometer (RDD) and Ground Penetrating Radar (GPR) data were collected along this project. The complete RDD for the entire project 4500 feet is shown in Figure 5.

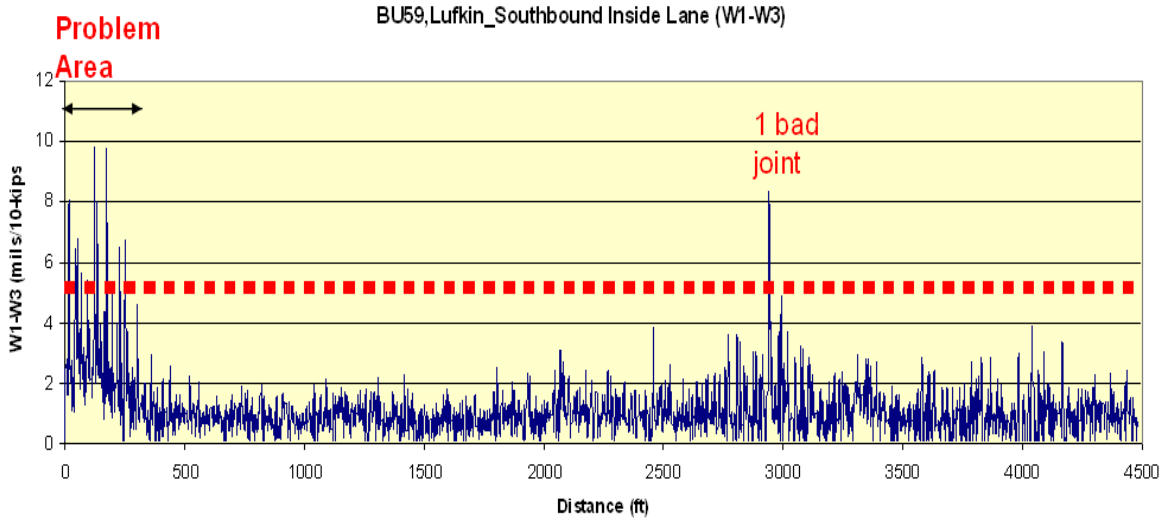


Figure 5. RDD Data (W1 – W3) for the CAM Project in Lufkin.

The data shown in Figure 5 is the difference in deflections between two sensors under the RDD. Sensor W1 is directly between the loading wheels and W3, which is 38 inches away. As the RDD rolls over a joint or crack the value of W1-W3 is an indication of the vertical movement or load transfer efficiency (LTE). Studies have found that if this value is greater than 5 mils then there will be a potential for a reflection cracking problem with that joint (Zhou and Scullion 2007). The 5 mils level is marked with the red line in Figure 5. The load transfer efficiency for this highway looks good. There is one small area at the beginning of the project about 250 feet long where the deflections are high, and there is one bad joint near 3000 feet from the beginning. The remainder of the section looks very good. This indicates that the section is a very good candidate for a thin overlay and that the design should be based on cracking caused by thermal movements of the underlying slabs. This is exactly the failure mode that is modeled in the overlay tester.

The problem area at the start of this project is expanded below in Figure 6. The large peaks in this data are recorded when the RDD runs over joints with poor load transfer. This plot shows that the eight problem joints are located in the first 250 feet of the project. It is anticipated that overlays placed over these joints would be prone to reflection cracking because of the high vertical movement occurring at these joints.

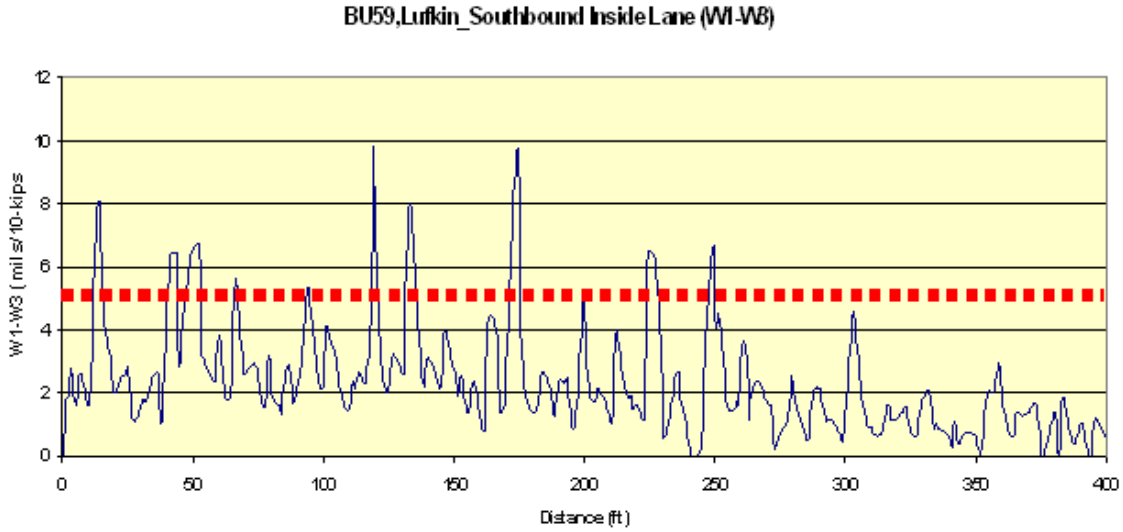


Figure 6. Problem Area Identified by the RDD on US 59.

Figure 7 shows the problem area. At this location it was proposed that the contractor perform joint repair before the placement of the CAM mix. The areas requiring repair where identified before the project was let and incorporated into the plan sheets for this project.

Figure 7. Location of Poor LTE on US 59 Prior to CAM Placement.

COMPARISON ON CAM WITH LUFKIN'S TRADITIONAL MAINTENANCE MIX

As shown in the photo on the right in Figure 7, this section of US 59 is continually receiving maintenance patches. This work was underway in a preliminary visit to the project, and samples of the widely used maintenance mix were obtained for testing at TTI. The existing limestone maintenance mix and the proposed CAM mix are shown side by side in Figure 8, prior to overlay testing.

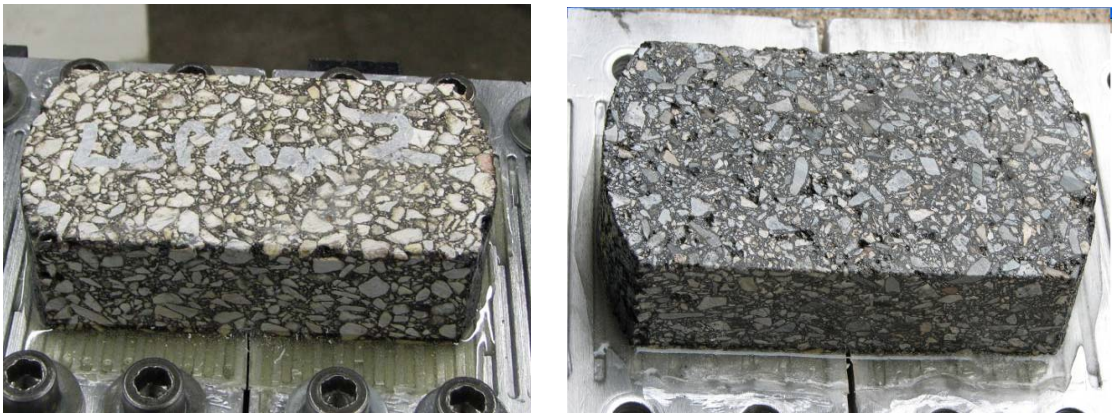


Figure 8. Lufkin's Traditional Maintenance Type D Mix (Left) CAM Mix (Right).

In both cases the samples were molded to 7% air voids for the performance tests. The results are shown below in Table 4. Both Hamburg and Overlay tester results for the CAM mix are markedly superior to traditional Type D material.

Table 4. Comparison of CAM with Lufkin's Type D Mix.

Mix Type	Binder	Hamburg	Overlay Tester
Limestone Type D	4.4% PG 64-22	12.5 mm after 5,800 passes	38 cycles
Granite CAM	8.3% PG 76-22	7.8 mm after 20,000 passes	1510 cycles

PLACEMENT OF CAM MIX

Prior to placement of the mix trail batch samples were obtained from the plant and subjected to Hamburg and Overlay testing. The trial batch samples passed both tests 8.7 mm in Hamburg after 20,000 passes and over 1100 cycles in the overlay tester.

On July 31 and August 1, 2008, researchers from the Texas Transportation Institute (TTI) conducted an infra-red thermal survey and observed construction of the Crack Attenuating Mixture placed at night on Business 59 in the Lufkin District. The results showed the following:

- The thermal profiles show good uniformity within truckloads. The temperature anomalies that occur are due to truck ends, with thermal differentials between 30 and 60 °F, and changes in the arrival temperature of trucks, which tended to result in mean placement temperatures of individual truckloads varying between approximately 275 and 300 °F.
- Of the core results that were available at the time of TTI's visit, the contractor achieved between 91.8 and 93.6 percent density using a CAT CB-634D breakdown and IR DD130 finish roller.
- Some locations of transverse cracking in the existing pavement seemed to be visible in the CAM at the time of placement. However, the defects seemed to be only temporary, likely resulting from a temporary swelling of the crack seal in the existing transverse cracks. The swells were not found the day after placement.

Paving Conditions

The contractor used belly-dump trucks to place the mix in windrows. A Lincoln 660 windrow elevator and a Blaw Knox PF-3200 paving machine then placed the CAM. Figure 9 shows the paving operation. Figure 10 shows the contractor's primary compaction roller was a CAT CB-634D. The contractor used an Ingersoll Rand DD130 for the finish roller.

Figure 9. CAM Paving Operation on Business 59.

Figure 10. CAT CB-634D on CAM.

Thermal Profile

To collect the thermal profile, TTI used a Pave-IR system attached to the paver footplate as Figure 11 shows. This system uses 10 infrared sensors spaced approximately 13

inches apart to profile the HMA placement temperatures. TTI used a sampling rate of 2 inches, i.e., a temperature scan was collected for every 2 inches of forward travel.

Figure 11. Pave-IR Collecting Thermal Profile on Business 59.

TTI performed two thermal surveys. The first survey collected the thermal profile of the turn lane that the contractor paved heading southbound. IR data were collected from approximately station 12+05 to 53+90. The second thermal profile was collected on the southbound inside lane, beginning at the northern project limit and continuing to station 45+09.

Thermal Profile Results from Turning Lane

Figure 12 shows excerpts from the thermal profile of the turning lane. The profiles show good uniformity within truckloads. The temperature anomalies that occur are due to truck ends, with thermal differentials between 30 and 60 °F, and changes in the arrival temperature of trucks, which tended to result in mean placement temperatures of individual truckloads varying between approximately 275 and 300 °F. The cold location shown by sensor 1 in the thermal profile resulted because that sensor was off the mat.

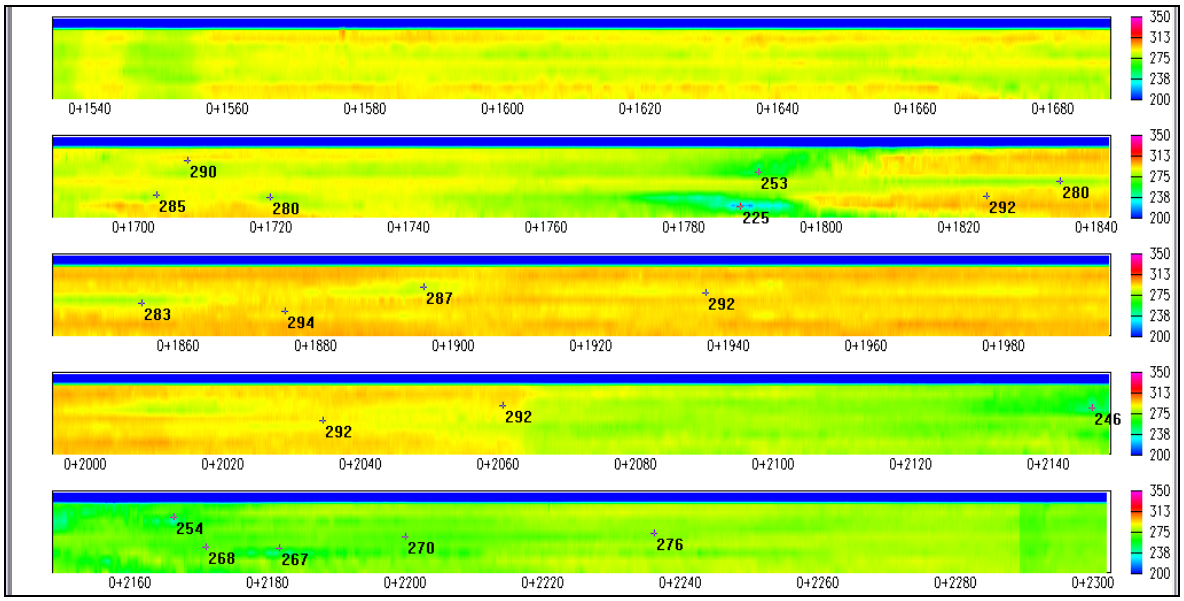


Figure 12. Thermal Profile at Start of US 75 Paving on 12-3-08.

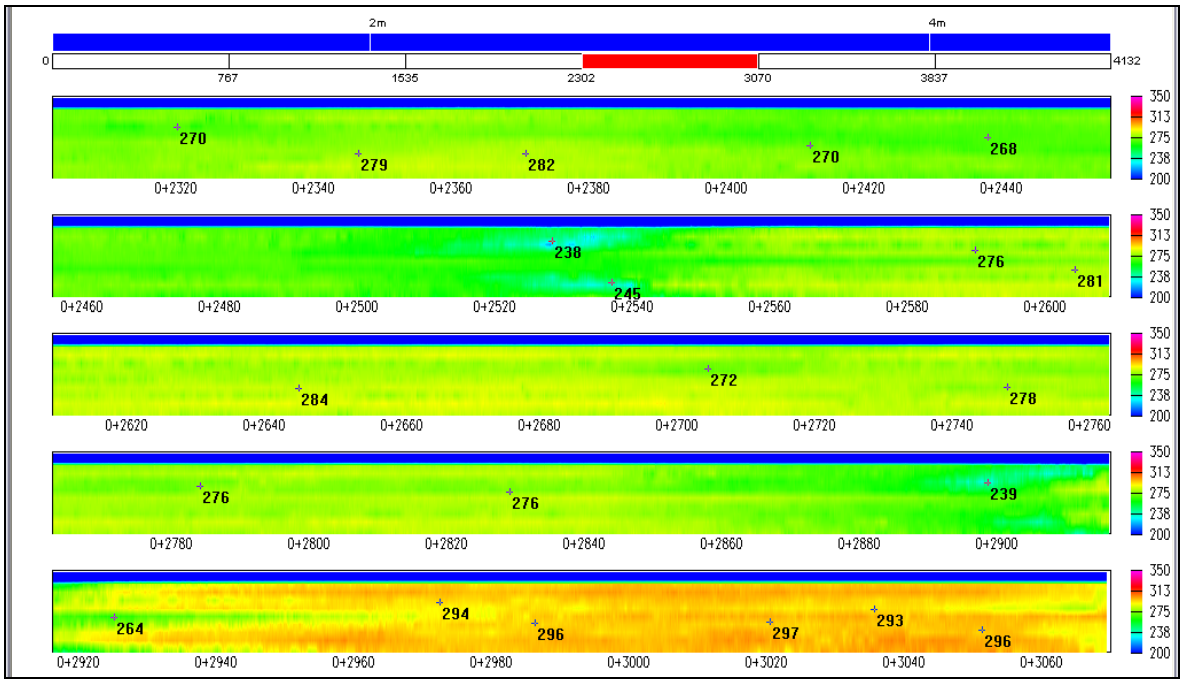


Figure 12. Thermal Profile at Start of US 75 Paving on 12-3-08. (Continued)

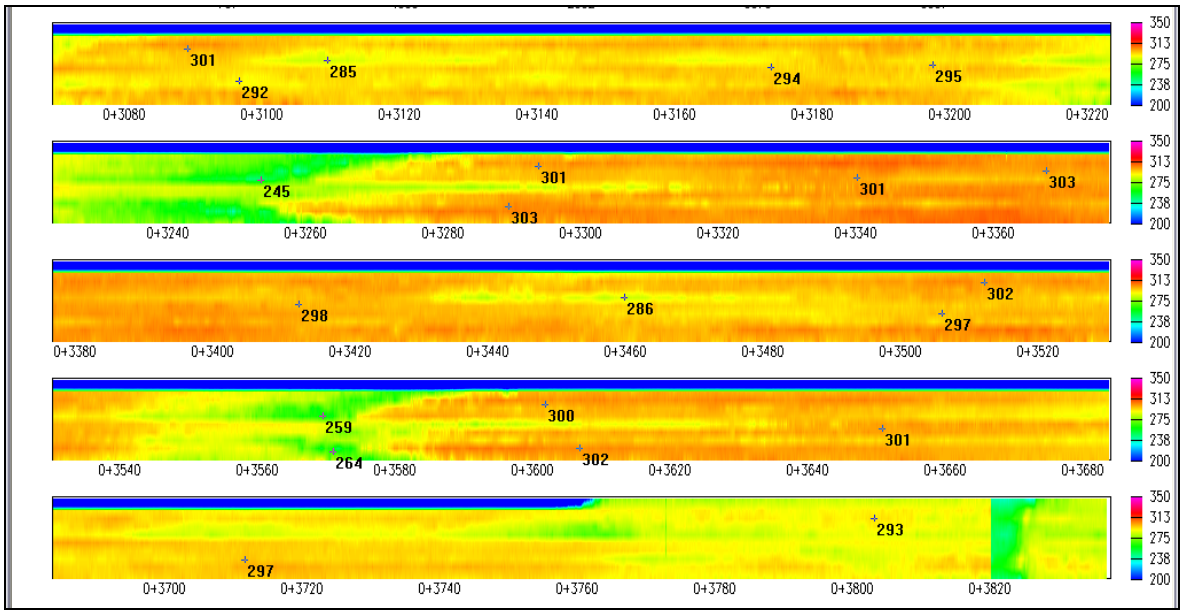


Figure 12. Thermal Profile at Start of US 75 Paving on 12-3-08. (Continued)

Figure 13 shows a histogram of the measured placement temperatures on the turning lane. The temperatures less than 200 °F resulted from sensor 1 being off the mat and should be ignored. The histogram shows approximately 97.5 percent of the placement temperatures fall within a 50 °F range from 260 to 310 °F.

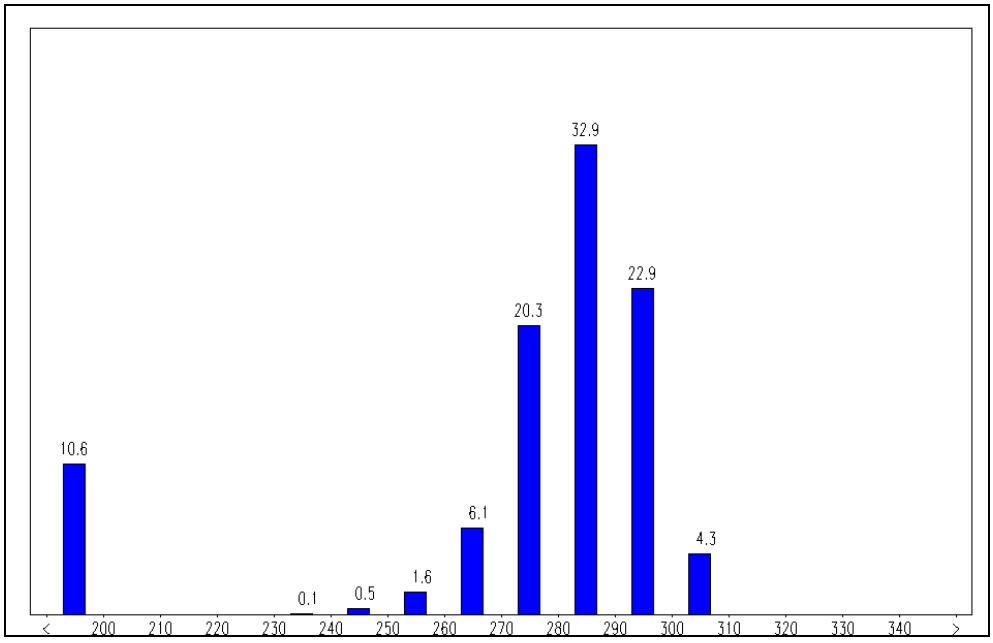


Figure 13. Temperature Histogram from CAM Turn Lane.

Thermal Profile Results from Southbound Inside Lane

Figure 14 shows excerpts from the thermal profile of the southbound inside lane. As before, the profile shows good uniformity within truckloads, some variations in the mean placement temperature from individual trucks, and some truck-end thermal differentials. The histogram from the temperatures recorded in the thermal profile, shown in Figure 15, reveals that approximately 95 percent of the placement temperatures fell within the 50 °F range from 260 to 310 °F.

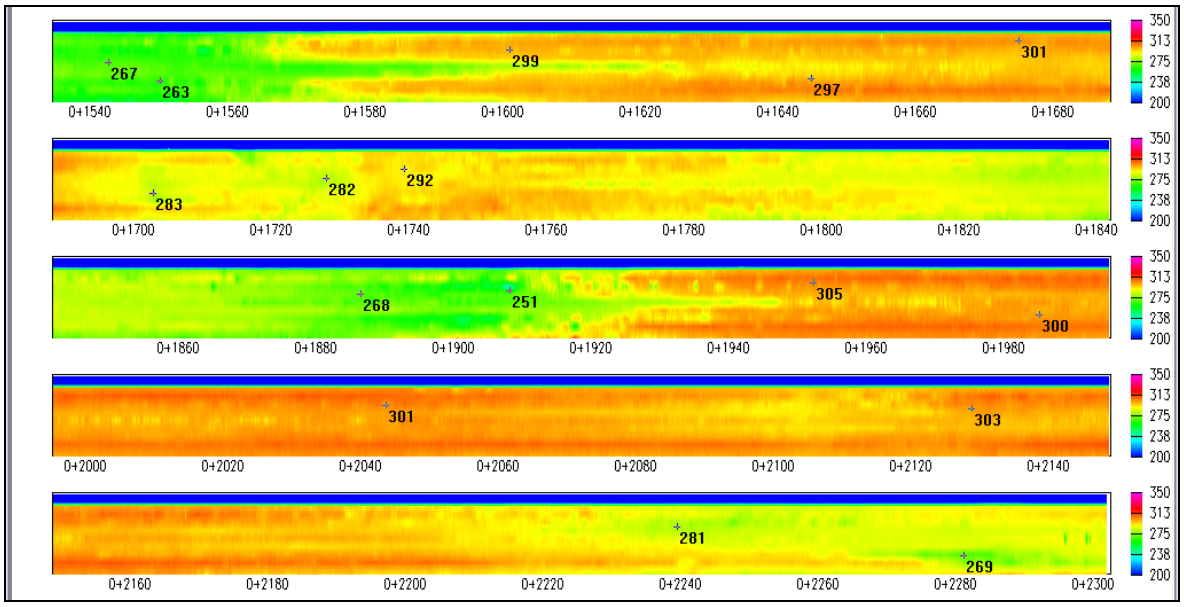


Figure 14. Thermal Profile of CAM Southbound Inside Lane.

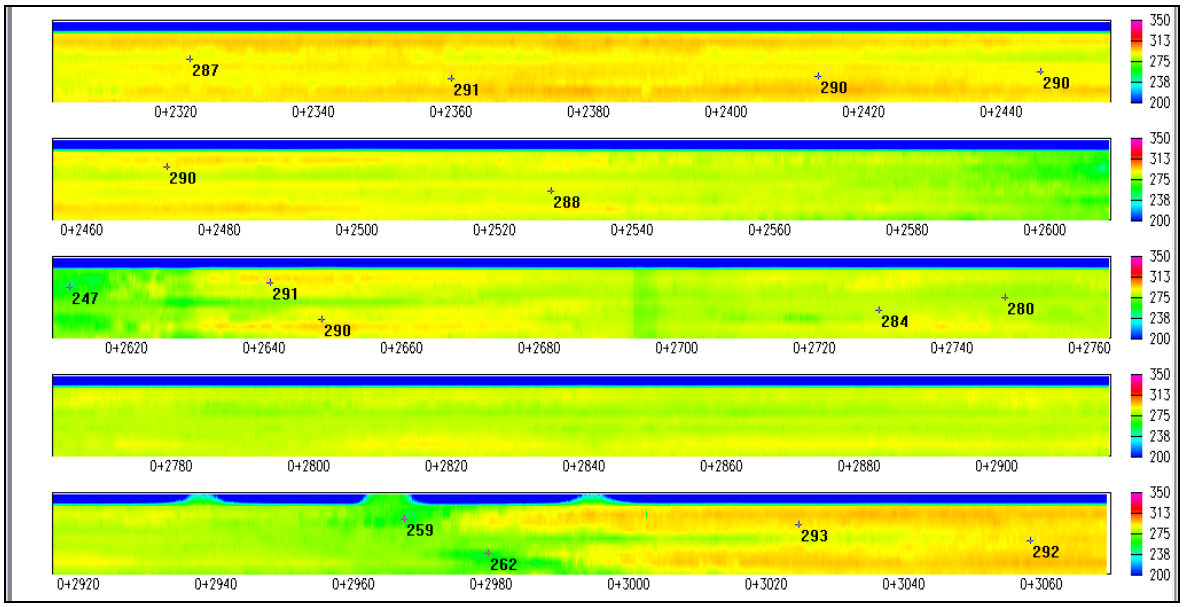


Figure 14. Thermal Profile of CAM Southbound Inside Lane. (Continued)

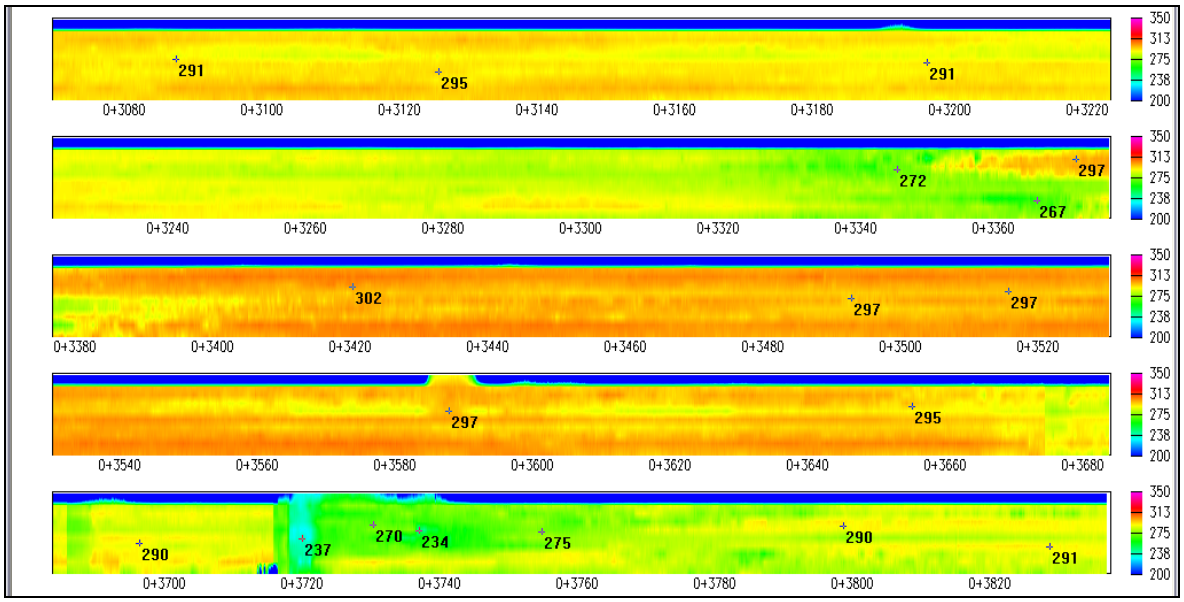


Figure 14. Thermal Profile of CAM Southbound Inside Lane. (Continued)

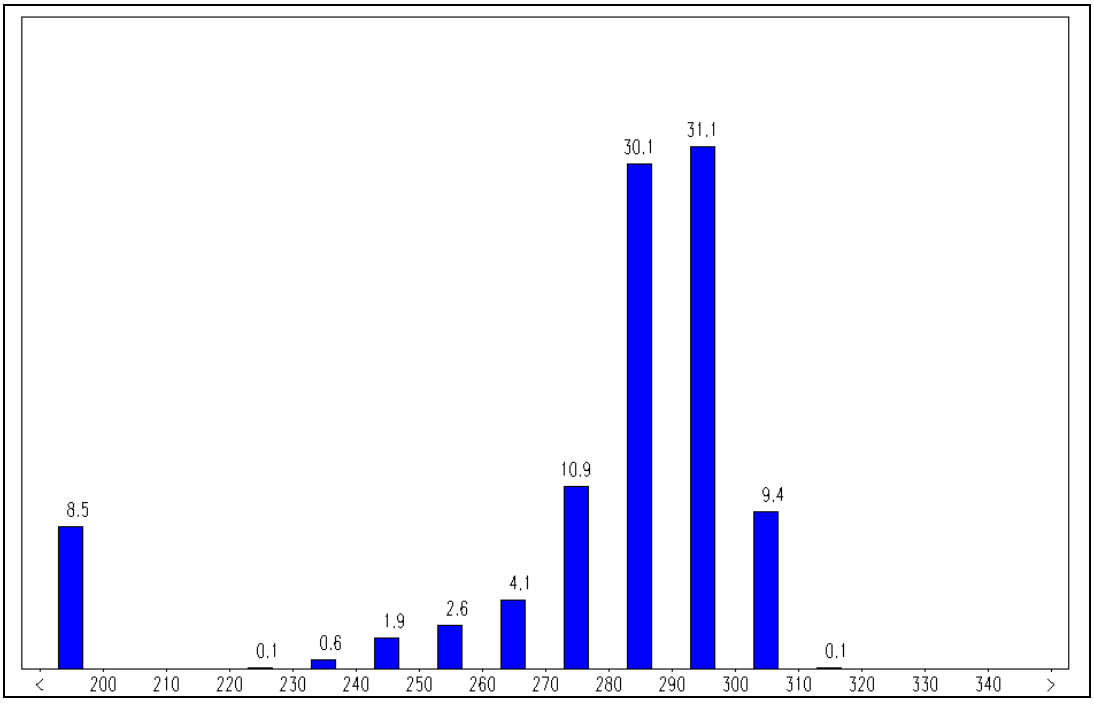


Figure 15. Temperature Histogram from CAM Southbound Inside Lane.

Core Density Results

During TTI's visit the contractor obtained density results for two cores. These core densities were 93.6 and 91.8 percent. Figure 16 shows the cores.

Figure 16. CAM Cores 1 and 2 (L to R).

Other Construction Considerations

At the time of paving, in some locations the CAM appeared to be heaved directly over existing transverse cracks that had been crack sealed. However, when driving the section the next day, nothing unusual was noticed in the appearance or ride of the pavement. This observation indicates the heaves observed the night of construction probably resulted from a temporary swelling of the crack seal in the existing transverse cracks.

TTI was not present during the final day of paving on this project. But temperature problems were reported by Mr. Kip Smith from the Lufkin lab. These were related to mechanical problems with the breakdown roller. The mix was placed at the correct temperature, but no compaction was performed for more than 1 hour. This 1000 ft section was replaced.

Performance To Date

After three months in service, a visual inspection and skid data were collected on this project. A photo of the CAM mix is shown in Figure 17.

Figure 17. CAM Mix on US 59 Three Months after Placement.

No performance problems were reported, and no reflection cracks were found. This inspection will be repeated in the spring of 2009. TxDOT also performed skid testing on this section, and the results are shown in Figure 18. This is with a bald tire locked wheel trailer traveling at 40 mph. The average value is reasonable at 23.5, but this section does have some low values with three values below 20. There are no standards for acceptable skid numbers, but values for new pavements are normally above 20. The cause for these low numbers is not known at this time. These measurements will be repeated on a semi-annual basis. The CAM mix has a high asphalt content, and the surface rocks are coated in asphalt. With trafficking perhaps the surface aggregates will become exposed and the skid numbers increase.

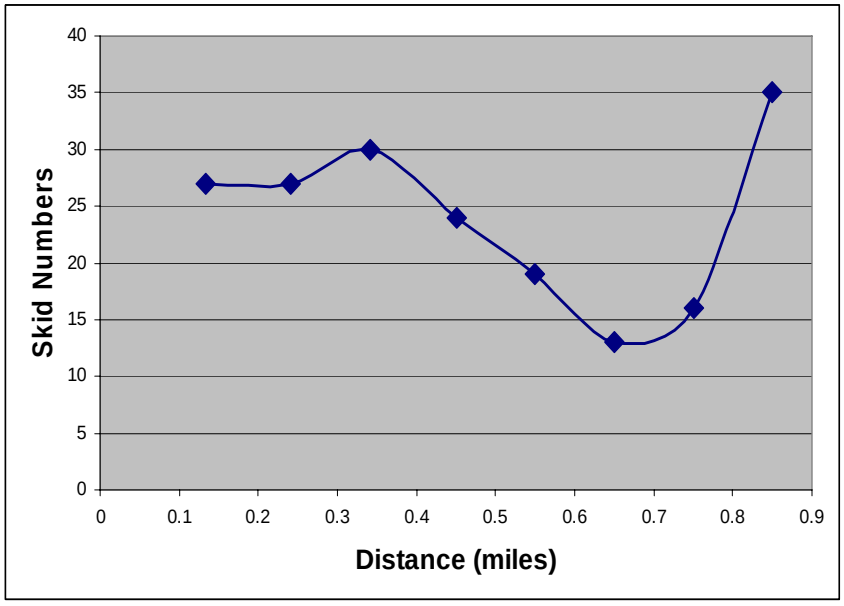


Figure 18. Skid Numbers from US 59 Three Months after Placement.

Mix Design Revisited

The mix design used on US 59 was based on the earlier mixes that had been successfully placed in Houston as rich bottom layers. This was the first time this mix has been used as a surface mix. As a final step in the evaluation a redesign was undertaken to use a lower PG graded binder with the same aggregates. The results of moving to a PG 70-22 is shown below in Table 5. All samples were molded to 7% + 1% air voids.

Table 5. Redesign of Lufkin CAM Mix with a PG 70-22 Binder.

Binder type	Hamburg results	Overlay tester results
8.3% PG 76-22	**7.81 mm after 20,000 passes**	**900+**
7.0% PG 70-22	**12.6 mm after 18,900 passes**	**900+**

The results in Table 5 are very interesting. The rutting performance with the PG 70-22 is worse than the PG 76, but they are still acceptable by TxDOT's current standards. The Hamburg requirement for a PG 70 binder is less than 12.5 mm rut in 15,000 passes. This design met that requirement and also did equally well in the overlay tester. The main issue here is that an acceptable design was also obtained with this mix with 1.3% less asphalt, which would be a substantial cost saving.

PUMPHREY DRIVE, FORT WORTH

Very Thin Overlay

A thin (1 inch–1.5 inch) hot-mix asphalt (HMA) overlay was placed on Pumphrey Drive in Fort Worth (FTW) from July 30, 2007, to August 3, 2007. Two mixes were designed for this project following the new proposed balanced mix design procedure using the Hamburg and Overlay Tester test methods. These two mixes had the same original PG64-22 binder, aggregates, and gradation but different binder modifiers. One mix was modified with 7 percent crumb rubber and the other modified with 3 percent SBR latex. After construction, three visual site inspections on this thin overlay project were conducted on December 14, 2007, April 2, 2008, and July 30, 2008. The overall performance of this thin HMA overlay project is very good.

This section summarizes the mix design, construction, visual observations, laboratory characterization of the plant mixes, and final recommendations. Figure 19 shows a plan view of the overlay project on Pumphrey Drive in Fort Worth. The underlying pavement structure is an old jointed concrete pavement with transverse joints at 15-foot spacing. All subsequent presentations and discussions in this report should be reviewed in conjunction with Figure 19.

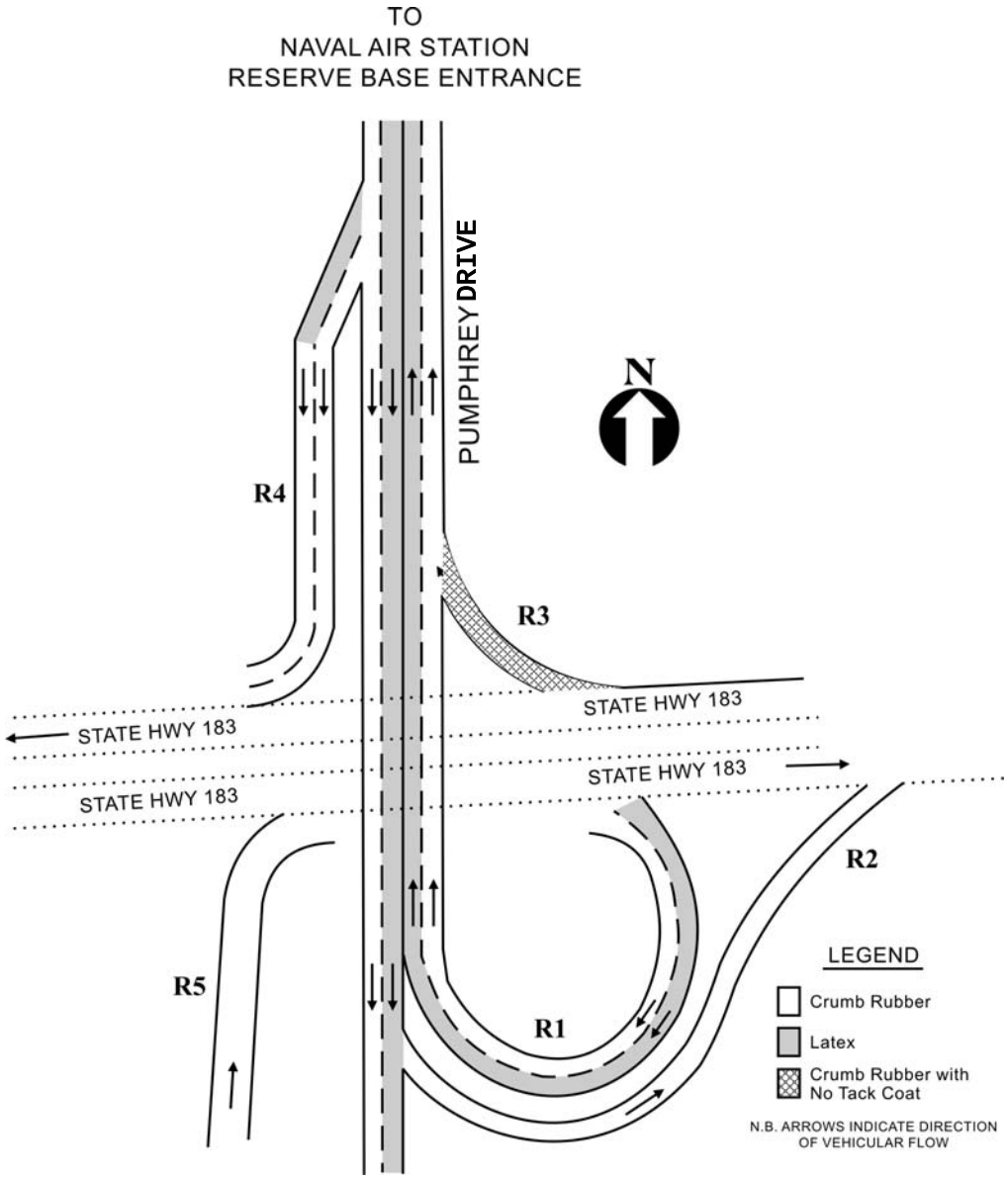
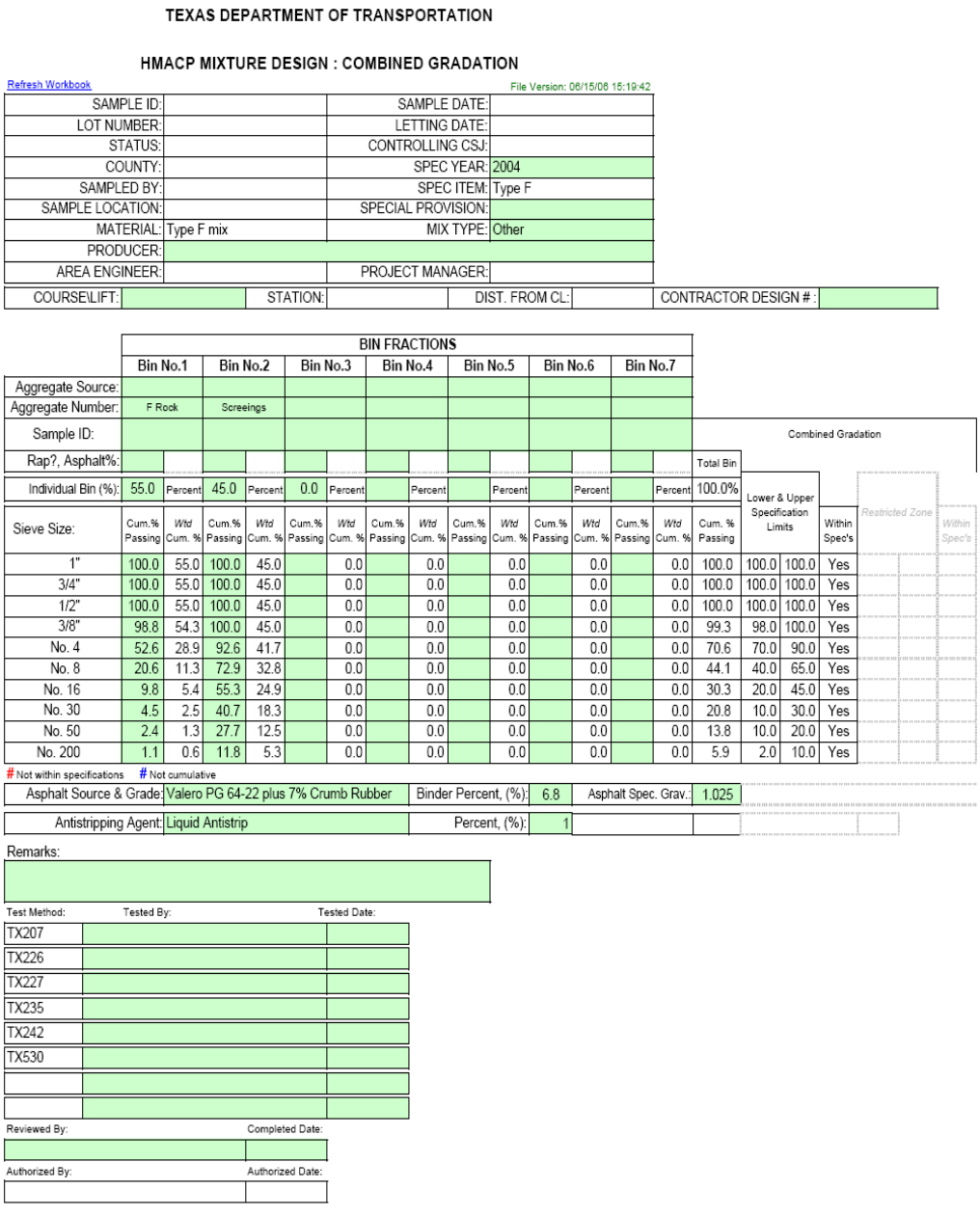


Figure 19. Plan View of the Pumphrey Drive Project (Drawing Not to Scale).

Mix Design

As shown in Table 3 both mixes initially had problems passing the Hamburg test. With the rubber mix it was found impossible to pass the Hamburg at 98% density. Further details can be found in reference Zhou and Scullion (2008). For that mix the optimum was found by changing the density required after 50 gyrations to 96%. The mix-design characteristics of the crumb rubber and SBR latex materials are as follows with the detailed aggregate gradation sheets presented in Figure 20.



TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : COMBINED GRADATION

Refresh Workbook — File Version: 06/15/06 15:19:42

SAMPLE ID:		SAMPLE DATE:	
LOT NUMBER:		LETTING DATE:	
STATUS:		CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:		SPEC ITEM:	Type F
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL:	Type F mix	MIX TYPE:	Other
PRODUCER:			
AREA ENGINEER:		PROJECT MANAGER:	

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

	BIN FRACTIONS														Combined Gradation				
	Bin No.1		Bin No.2		Bin No.3		Bin No.4		Bin No.5		Bin No.6		Bin No.7						
Aggregate Source:																			
Aggregate Number:	F Rock		Screenings																
Sample ID:																			
Rap?, Asphalt%:															Total Bin				
Individual Bin (%):	55.0	Percent	45.0	Percent	0.0	Percent		Percent		Percent		Percent		Percent	100.0%	Lower & Upper Specification Limits		Within Spec's	Restricted Zone / Within Spec's
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				
1"	100.0	55.0	100.0	45.0		0.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes	
3/4"	100.0	55.0	100.0	45.0		0.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes	
1/2"	100.0	55.0	100.0	45.0		0.0		0.0		0.0		0.0		0.0	100.0	100.0	100.0	Yes	
3/8"	98.8	54.3	100.0	45.0		0.0		0.0		0.0		0.0		0.0	99.3	98.0	100.0	Yes	
No. 4	52.6	28.9	92.6	41.7		0.0		0.0		0.0		0.0		0.0	70.6	70.0	90.0	Yes	
No. 8	20.6	11.3	72.9	32.8		0.0		0.0		0.0		0.0		0.0	44.1	40.0	65.0	Yes	
No. 16	9.8	5.4	55.3	24.9		0.0		0.0		0.0		0.0		0.0	30.3	20.0	45.0	Yes	
No. 30	4.5	2.5	40.7	18.3		0.0		0.0		0.0		0.0		0.0	20.8	10.0	30.0	Yes	
No. 50	2.4	1.3	27.7	12.5		0.0		0.0		0.0		0.0		0.0	13.8	10.0	20.0	Yes	
No. 200	1.1	0.6	11.8	5.3		0.0		0.0		0.0		0.0		0.0	5.9	2.0	10.0	Yes	

Not within specifications # Not cumulative

Asphalt Source & Grade:	Valero PG 64-22 plus 7% Crumb Rubber	Binder Percent, (%):	6.8	Asphalt Spec. Grav.:	1.025
Antistripping Agent:	Liquid Antistrip	Percent, (%):	1		

Remarks:

Test Method:	Tested By:	Tested Date:
TX207		
TX226		
TX227		
TX235		
TX242		
TX530		

Reviewed By:	Completed Date:

Authorized By:	Authorized Date:

Figure 20. Aggregate Gradation Used in Both Mixes on Pumphrey Drive.

Details of the mixes used are as follows:

- **Type F mix with crumb rubber**

Mixture Type:	Type F Granite
Aggregates:	Martin Marietta Materials, Mill Creek, OK
	Producer Code 0050433
	Surface Aggregate Class (SAC) – A
Stockpiles:	F-Rock 55 %
Screenings:	45 %
Asphalt:	Valero PG64-22 plus 7 % Crumb Rubber from Bridges Pavement Solutions Inc.
Antistripping agent:	N/A
Optimum asphalt content:	6.8 % based on Overlay Tester and Hamburg test results

Mix properties at optimum asphalt content are:

VMA:	19.0 %
Bulk specific gravity:	2.316
Max. specific gravity:	2.398
Boil test, Tex-530-C:	No visual stripping
Overlay test, Tex-248F:	>1200 cycles
Hamburg test, Tex-242F:	<12.5 mm at 20,000 passes (meets PG76-22 requirement)

Special note: Special instruction for mix design has been provided by Bridges Pavement Solutions Inc., and this instruction should be followed during mix production in the plant. Otherwise, the performance of this mix may change.

- **Type F mix with SBR latex**

Mixture Type:	Type F Granite
Aggregates:	Martin Marietta Materials, Mill Creek, OK
	Producer Code 0050433
	Surface Aggregate Class (SAC) – A
Stockpiles:	F-Rock 55 %
Screenings:	45 %

Asphalt:	Valero PG64-22 plus 3 % UP7814 Anionic SBR Polymer (70 % min. Solid)
Antistripping agent:	1% Akzo Nobel, Kling-Beta 2550
Optimum asphalt content:	6.8 % based on Overlay Tester and Hamburg test results
Mixture properties at optimum asphalt content are:	
VMA:	18.8 %
Bulk specific gravity:	2.317
Max. specific gravity:	2.399
Boil test, Tex-530-C:	No visual stripping
Overlay test, Tex-248F:	>1200 cycles
Hamburg test, Tex-242F:	10.5 mm at 20,000 passes (meets PG76-22 requirement)

Existing PCC Pavement Condition and Repairs

Both Richard Williammee, P.E., Fort Worth District Materials Engineer and the TTI researchers evaluated the existing PCC pavement conditions on June 14, 2007, and made recommendations on the areas that needed to be repaired before placement of the thin HMA overlay. The main distress observed was spalling at the joints. The overall conditions of the main traffic lanes were acceptable except in two large areas with longitudinal cracks, settlements, and block cracking. Figure 21 shows examples of the existing conditions of the main traffic lanes before the HMA overlay. The general conditions of the PCC pavement on the ramps were substantially worse than those of the main traffic lanes as shown in Figure 22. Figure 23 presents some areas after repairs were made.

Figure 21. Observed Distresses on the Main Traffic Lanes, Pumphrey Drive, FTW.

Figure 22. Observed Distresses on the Ramps, Pumphrey Drive, FTW.

Figure 23. Repairs of Existing Distresses Before the HMA Overlay.

The load transfer efficiency of the joints in the main lanes was judged as good. Limited measurements were made with the FWD and all joints were in the 90 to 100% LTE range. None of the main lane joints exhibited any faulting and the main distress was spalling around the joint. The joints on the exit and entrance ramps were in poorer condition; the ramps themselves were badly cracked, and several of the joints were faulted.

CONSTRUCTION OPERATIONS

Pavement Surface Preparation

Typical pavement surface preparatory practices were followed. The pavement surface was swept and tack coated prior to the HMA placement. However, as shown by the cross hatching in Figure 19, one off-ramp was intentionally not tack coated as an experimental section. This was an experiment requested by the crumb rubber modifier supplier to assess the claim that the crumb rubber would hold onto the existing pavement surface without any tack coat.

HMA Placement and the Paving Process

The pavement surface temperature was about 106 °F, which meets the CAM SS 3109 recommendations (TxDOT, 2007). According to the Tarrant County construction crew, the air temperature should at least be 42 °F and rising for lay-down operations such as the Pumphrey Drive project. The air temperature was about 78 °F at the start of the construction operation which satisfied the ≥ 42 °F recommendation. No material transfer device was engaged in this lay-down operation. The trucks dumped the hot mix directly into the paver. This operation is shown in Figure 24.

It is worth noting that two overlay mat thicknesses were used in this overlay project due to different traffic levels. The HMA overlay was 1.5-inch thick starting from the Naval Air Base entrance to the middle of the overlay project where the traffic volume is much higher than the rest of the project in which only 1-inch thick mat was used.

Figure 24. Paver Operation on the Pumphrey Drive, FTW.

Visual Observation December 14, 2007

The visual inspection that was conducted on the overlay is presented in this section. This includes photos of the main lanes, on/off ramps, and the surface distresses observed. Figure 25 gives an overview of the main lanes and indicates satisfactory performance.

Figure 25. Overview on the Main Lanes between SH 183 and the Naval Base Entrance.

There were some indicative spots of minor bleeding/flushing in the wheel path, in particular on the latex surface. This observation is consistent with the higher than design asphalt-binder content used in the latex mix, i.e., the contractor applied more asphalt-binder than the design recommendations. The extracted asphalt-binder content was found to be 7.2% as opposed to the design value of 6.8%. Figure 26 shows some spots of potential for wheel path bleeding. None of these were considered serious defects.

Figure 26. Potential Spots for Flushing/Bleeding (Mostly on the Latex Surface).

Transverse Cracking

Transverse cracking reflecting through the thin overlay from the underlying jointed concrete pavement structure was the predominant surface distress that was visually observed, in particular on the on/off ramps. These transverse cracks occurred periodically at regular interspaced distances, consistent with the underlying concrete joints. The transverse cracks were mostly on the on/off ramps with none on the main lanes. However, the southbound on-ramp merging into SH 183 on the extreme eastern side was not as transverse cracked as the other ramps, especially toward the end section with SH 183. Figure 27 displays a photographical illustration of some of these transverse cracks.

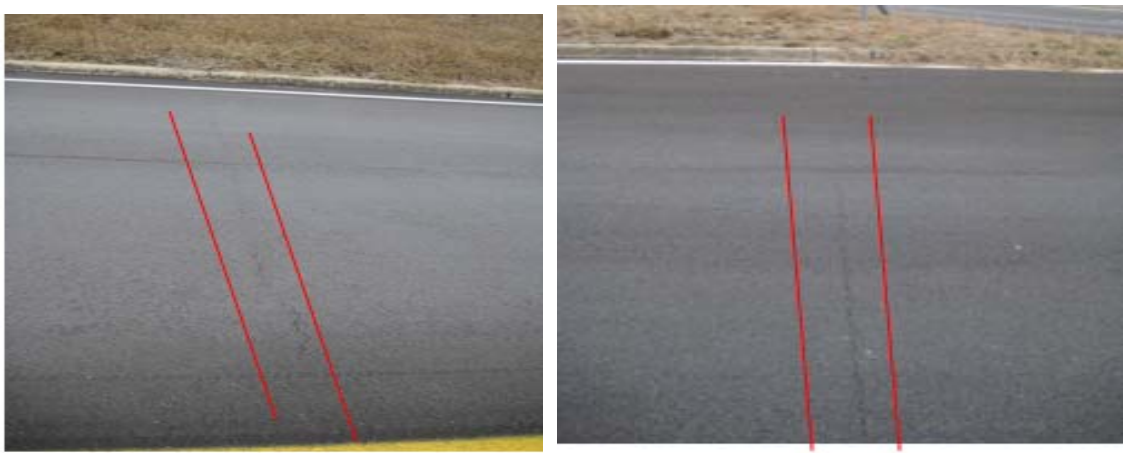


Figure 27a. Example of Transverse Cracks on Ramp R1 (see Figure 1).

Figure 27b. Reflected Transverse Cracking through Concrete Joints (Ramp R1).

Longitudinal Cracking

There was visual evidence of longitudinal cracking in the outside northbound lane on two locations of the section towards the Naval Base entrance between the SH 183 overpass and the bridge. These longitudinal cracks are shown in Figure 28 and are considered to be caused by differential settlement of the foundation, which was also suspected prior to overlay placement. Inevitably, this distress will require a structural rehab in the foreseeable future.

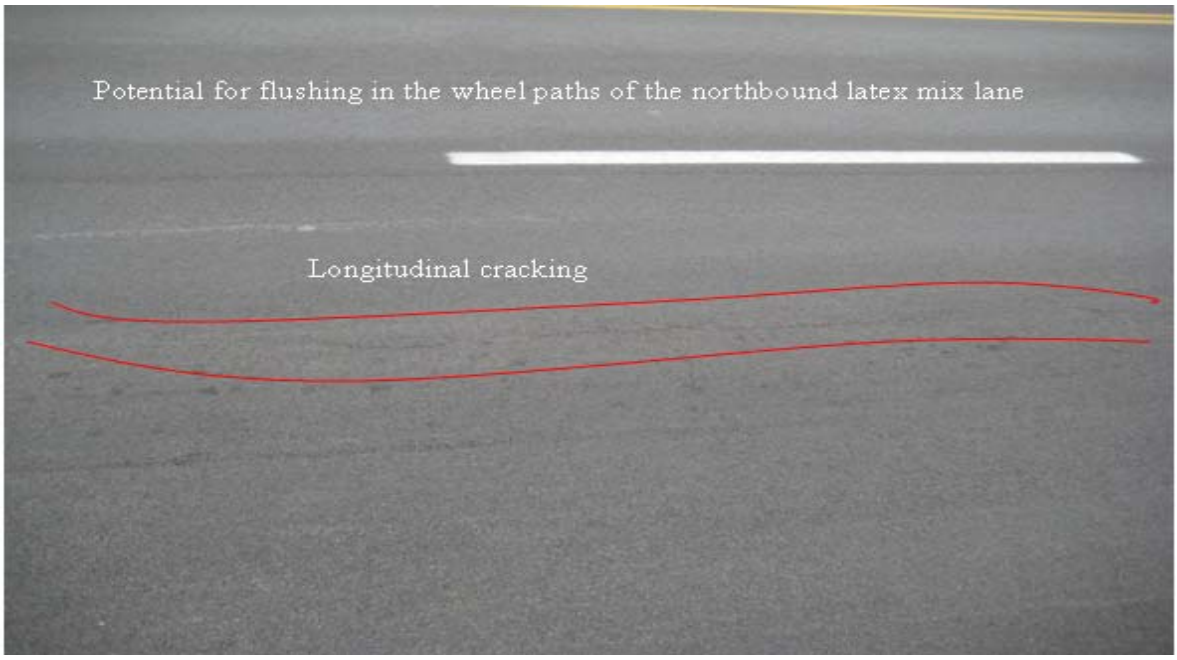


Figure 28. Longitudinal Cracking in the Outside NB Main Lane toward the Bridge.

Bumps/Humps due to Crack Sealant Material

In addition to transverse cracking, bumps/humps were found along the underlying concrete joints on the off-ramp R3, which was not tack coated at the time of the crumb rubber mix placement. In total, up to five regularly interspaced bump/humps, consistent with the concrete joints, were visually counted. These bumps/humps are considered to have been caused by the expansion of the crack sealant material at the time of overlay placement. In fact, the construction crew had also reported some compaction problems on this section, citing expansion of the crack sealant under the hot-mix as well as the crumb rubber itself as the probable cause. Incidentally, ramp R3 is the only section manifesting this problem. Figure 29 pictures an example of these bumps/humps on ramp R3.

Figure 29. Example of Humps on Off-Ramp R3.

Other Visual Observations and Plan View of All Distresses

In general, there was no visual evidence of serious rutting or traffic related fatigue cracking in the wheel paths on both the main lanes and ramps. Also, the bonding between the HMA overlay and the underlying concrete structure appeared satisfactory on all the sections, without any visual evidence of delaminating. Even the crumb rubber mix that was placed directly on the broomed concrete surface without any tack coat was holding satisfactorily, without any indication of debonding. However, there was visual evidence of localized shoving and minor material loss at the start of the off-ramp R1. This was attributed to insufficient HMA material/mat thickness at the time of construction. All plan view of all the distresses discussed in this update report is graphically illustrated in Figure 30.

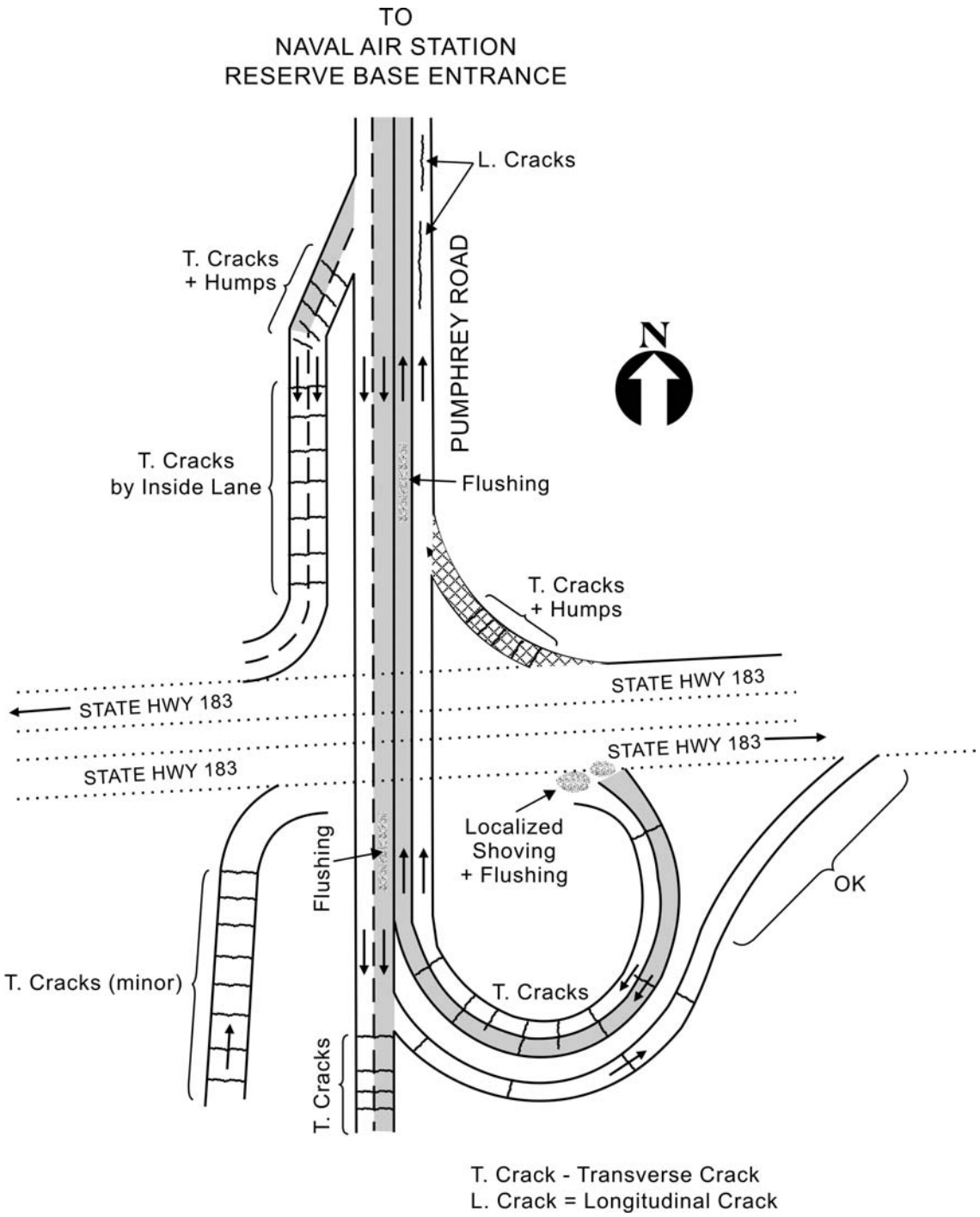


Figure 30. Plan View of All Visually Observed Distresses.

Skid Data

Skid data were collected on both mixes; the average vales for the latex and crumb rubber mixes respectively were 30 (range 26 – 34) and 37 (range 19 to 47). Skid numbers were good for both mixes with the crumb rubber being higher.

LOOP 20 LAREDO DISTRICT CAM DESIGN

The Laredo District designed and placed a short section of CAM mix for a heavily trafficked intersection (International Drive) on Loop 20. The two jobs described used granite aggregates from outside Texas. The Laredo project was the first to place a CAM with locally available gravel aggregates. The aggregates and the gradation used are shown in Figure 31 below.

	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:	Kiewit		MM																					
Aggregate Number:	Grave		Dry Scrng		Gravel Scrng		Lime																	
Sample ID:															Combined Gradation									
Rap?, Asphalt%:															Total Bin									
Individual Bin (%):	50.0	Percent	32.0	Percent	16.5	Percent	1.5	Percent		Percent		Percent		Percent	100.0%	Lower & Upper Specification Limits		Within Spec's	*Restricted Zone*		*Within Spec's*			
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									
1"	100.0	50.0	100.0	32.0	100.0	16.5	100.0	1.5		0.0		0.0		0.0	100.0	100.0	100.0	Yes						
3/4"	100.0	50.0	100.0	32.0	100.0	16.5	100.0	1.5		0.0		0.0		0.0	100.0	100.0	100.0	Yes						
1/2"	100.0	50.0	100.0	32.0	100.0	16.5	100.0	1.5		0.0		0.0		0.0	100.0	100.0	100.0	Yes						
3/8"	99.6	49.8	100.0	32.0	100.0	16.5	100.0	1.5		0.0		0.0		0.0	99.8	98.0	100.0	Yes						
No. 4	47.7	23.9	100.0	32.0	99.7	16.5	100.0	1.5		0.0		0.0		0.0	73.9	70.0	90.0	Yes						
No. 8	2.7	1.4	91.8	29.4	93.1	15.4	100.0	1.5		0.0		0.0		0.0	47.7	40.0	65.0	Yes						
No. 16	0.9	0.5	65.4	20.9	56.7	9.4	100.0	1.5		0.0		0.0		0.0	32.3	20.0	45.0	Yes						
No. 30	0.7	0.4	48.4	15.5	32.2	5.3	100.0	1.5		0.0		0.0		0.0	22.7	10.0	30.0	Yes						
No. 50	0.6	0.3	36.8	11.8	16.1	2.7	100.0	1.5		0.0		0.0		0.0	16.3	10.0	20.0	Yes						
No. 200	0.3	0.2	24.5	7.8	2.5	0.4	100.0	1.5		0.0		0.0		0.0	9.9	2.0	10.0	Yes						

Not within specifications # Not cumulative

Asphalt Source & Grade:	Valero PG70-22	Binder Percent, (%):	7.0	Asphalt Spec. Grav.:	1.020
Antistripping Agent:		Percent, (%):			

Figure 31. CAM Mix Used in Laredo.

This design used the recommended design procedure from SS 3109. The only problem found with the mix was that it did not meet the Overlay Tester requirement of 750 cycles (lasted 678). In this case the district decided to waiver the 750 requirement. The mix was placed after the traffic light in both the EB and WB directions for a distance of approximately 1200 feet. The district reported that most of the application was placed at a thickness of 0.75 inches. No problems were reported during construction. A photo of the location six months after construction is shown in Figure 32. On the other side of the intersection the district used the traditional Type C mix, and in the initial visual evaluation the CAM mix was thought to look more uniform than the dense graded material.

Figure 32. CAM Mix on Loop 20 in Laredo – Six Months after Placement.

Locked wheel skid measurements were made on lanes of the CAM mix. Figure 33 graphs the results. The skid numbers for this gravel mix are outstanding with an average value of 42.9.

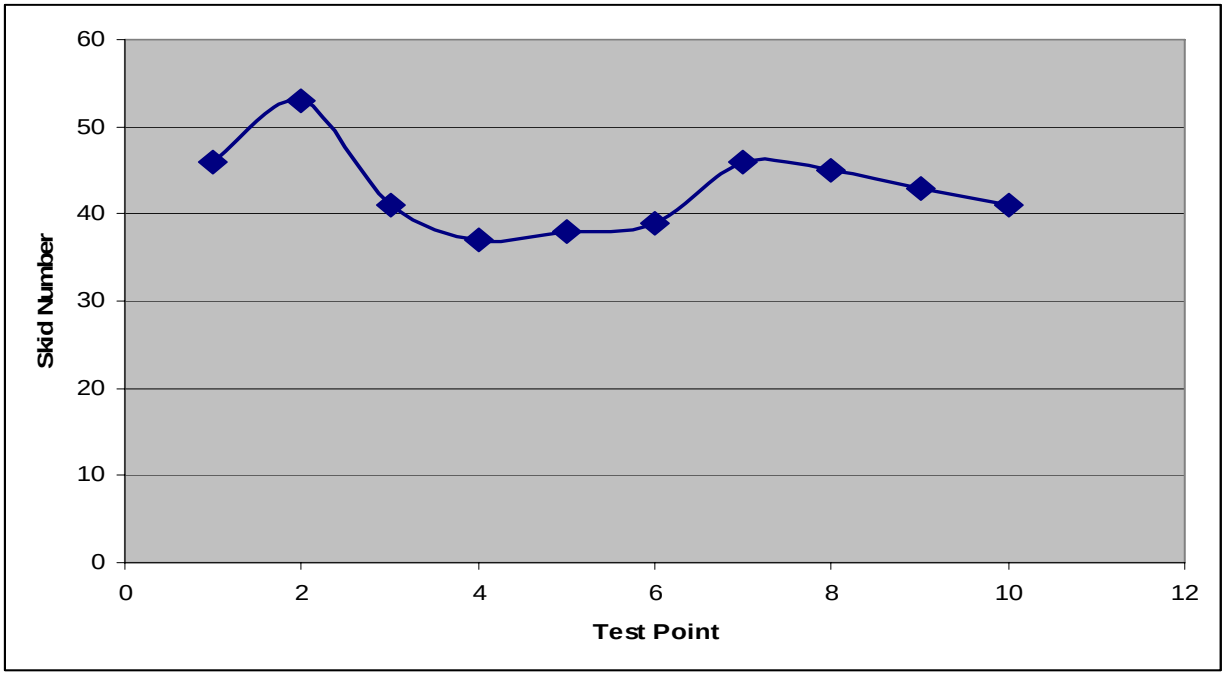


Figure 33. Skid Numbers from Loop 20 in Laredo.

The Laredo District continues to be very happy with the visual and skid performance of this section. They are planning several more application of the CAM mix in their district, including a 4-mile section of IH 35 where the surface cracking was found to be limited to the last overlay. This construction is scheduled for early 2009.

US 281 MARBLE FALLS, AUSTIN DISTRICT

The Austin District developed the design for US 281 using the requirements of SS3109. The aggregates and the gradations used are shown in Figure 34. The optimal asphalt content was found to be 7.4%, and in the design phase as shown in Table 3, this passed both the Hamburg and Overlay tester requirements.

	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:	Capitol		Spicewood																									
Aggregate Pit:																												
Aggregate Number:																												
Sample ID:	Sandstone Grade 5		Screenings												Combined Gradation													
Rap?:															Total Bin													
Individual Bin (%):	45.0	Percent	55.0	Percent		Percent		Percent		Percent		Percent		Percent	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						
3/8"	100.0	45.0	100.0	55.0											100.0	98.0	100.0	Yes				0.0						
No. 4	33.4	15.0	100.0	55.0											70.0	70.0	90.0	Yes				30.0						
No. 8	3.9	1.8	85.0	46.8											48.5	40.0	65.0	Yes				21.5						
No. 16	2.5	1.1	49.4	27.2											28.3	20.0	45.0	Yes				20.2						
No. 30	2.2	1.0	30.5	16.8											17.8	10.0	30.0	Yes				10.5						
No. 50	2.1	0.9	21.2	11.7											12.6	10.0	20.0	Yes				5.2						
No. 200	1.7	0.8	11.0	6.1											6.8	2.0	10.0	Yes				5.8						

Not within specifications # Not cumulative

Asphalt Source & Grade:	Pelican 70-22S	Binder Percent, (%):	7.4	Asphalt Spec. Grav.:	1.025
Antistripping Agent:		Percent, (%):			

Figure 34. CAM Design Proposed for US 281 in Marble Falls.

Problems were found in production where the TxDOT lab engineer sampled the first day's production. Based on his assessment the mix being placed failed the Hamburg test in less than 4000 passes, well less than the 15,000 specified. The mix was subject to a redesign and based on a revised design, the contractor reduced the asphalt content to 6.8% (from 7.4%). The revised mix design did substantially better in the Hamburg test.

Placement of the CAM mix was completed in mid-September 2008. US 281 will be a severe test of the ability of this mix to with stand heavy traffic loads over a badly deteriorated pavement section. GPR and FWD were collected prior to placement of the CAM mix. The existing pavement was very thin with 3 to 4 inches of HMA over a thin granular base. However, the subgrade in this area is very good. As shown below in Figure 35 the existing pavement condition was very poor. Areas of extensive alligator cracking were replaced with full depth patches. Figure 35 shows a before and after photo for the same section of US 281 (looking different directions).

Figure 35. CAM Job Marble Falls (Before and After Photos).

The initial skid data from this project looks very promising. The average skid value for all four lanes was 35.2, which is rated as very good (Figure 36).

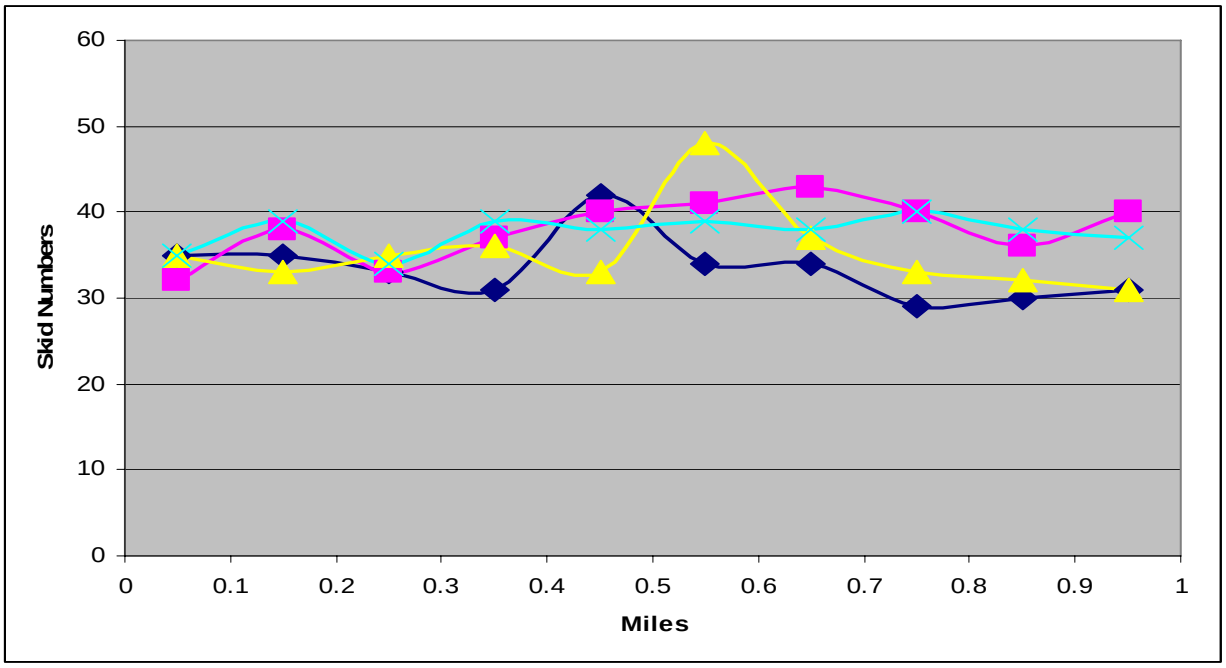


Figure 36. Skid Data from US 281 (Values for All Four Lanes).

US 90 UVALDE, SAN ANTONIO DISTRICT

Major problems were encountered by the contractor in arriving at an acceptable CAM design for this project. As shown in Table 3 the contractor's design has a major problem passing the Hamburg test at the optimum asphalt content (7.6%) estimated using 50 gyrations to achieve 98% density. TTI assisted the district to arrive at an acceptable design, and these efforts will be described in Chapters 3 and 4 of this report. The materials and gradations eventually used for the San Antonio project are shown below in Figure 37. In the lab design at an asphalt content of 6.8% PG 70-22 binder with 1% lime, this design lasted more than 1000 cycles in the overlay tester and rutted 6.4 mm after 15,000 passes of the Hamburg. Samples were also taken by TTI researchers during placement; these samples were returned to TTI and found also to pass the performance tests.

	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:	Knippa		Knippa		EE Hood													
Aggregate Pit:																		
Aggregate Number:																		
Sample ID:	Grade 5		Man Sand		Limestone Screenings								Hydrated Lime					Combined Gradat
Rap?:															Total Bin			
Individual Bin (%):	38.0	Percent	42.0	Percent	19.0	Percent		Percent		Percent		Percent	1.0	Percent	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
3/8"	97.1	36.9	100.0	42.0	100.0	19.0							100.0	1.0	98.9	98.0	100.0	Yes
No. 4	26.6	10.1	99.6	41.8	99.9	19.0							100.0	1.0	71.9	70.0	90.0	Yes
No. 8	0.9	0.3	81.1	34.1	96.6	18.4							100.0	1.0	53.8	40.0	65.0	Yes
No. 16	0.6	0.2	40.9	17.2	69.6	13.2							100.0	1.0	31.6	20.0	45.0	Yes
No. 30	0.6	0.2	20.5	8.6	49.0	9.3							100.0	1.0	19.1	10.0	30.0	Yes
No. 50	0.6	0.2	9.5	4.0	37.2	7.1							100.0	1.0	12.3	10.0	20.0	Yes
No. 200	0.5	0.2	1.3	0.5	25.4	4.8							100.0	1.0	6.6	2.0	10.0	Yes

Figure 37. Mix Design Used in San Antonio's CAM Job.

The lab design and test on both trial batch and field materials found this to be a good CAM design. This material was placed on US 90 in September 2008 and problems were encountered during construction of this thin mat. Because of scheduling issues TTI could only monitor the last day of placement of this mat. The infra-red bar was placed on the paver as shown in Figure 38, and typical temperature data are shown in Figure 39.

Figure 38. Infra-Red Monitoring of CAM Placement on US 90.

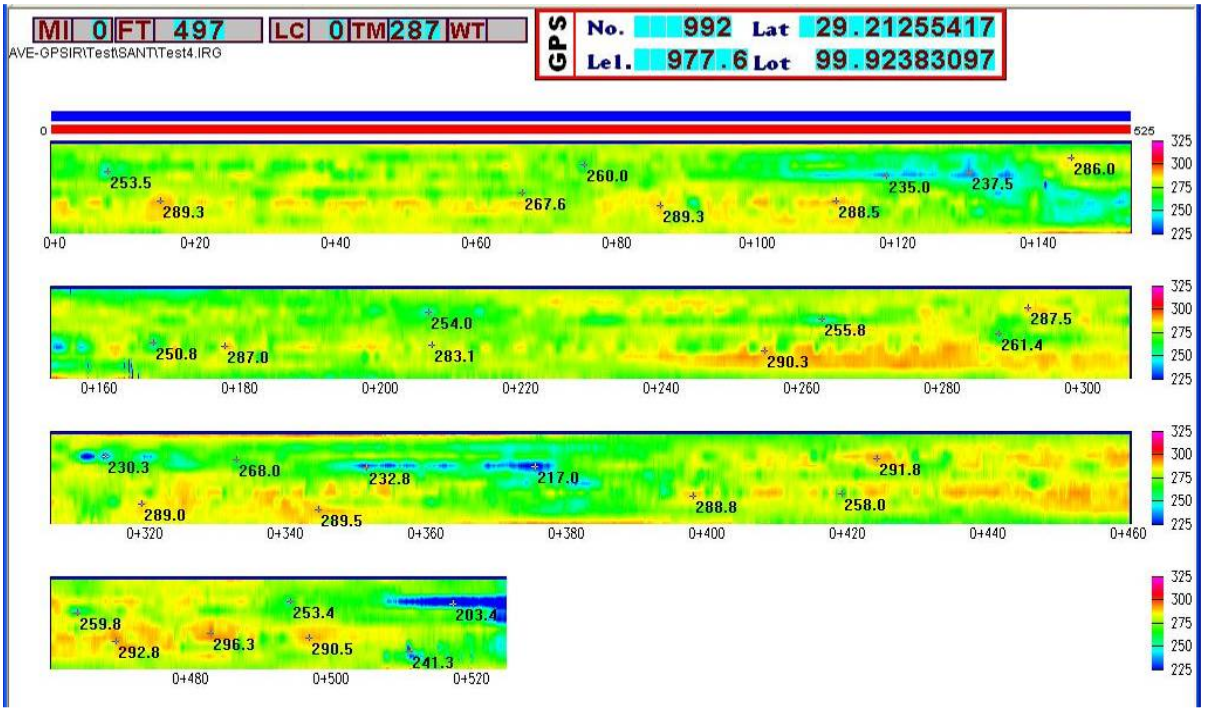


Figure 39. Infra-Red Results from a Typical Section of US 90 (525 ft by 12 ft Wide Section).

The CAM mix on US 90 was placed at a relatively low temperature, and more significantly there were major cold spots in the mat. As shown in Figure 39 streaks with temperatures at placement of 203 °F were found. The recommended temperature at placement should have been close to 280 °F. Figure 40 shows the consequences of the low placement temperature, where there is clear indication of thermal segregation, low density, and the resulting surface raveling.

Figure 40. Placement Problems with the CAM on US 90.

Skid data were collected approximately one month after placement, and the results from this mix were low as shown below in Figure 41.

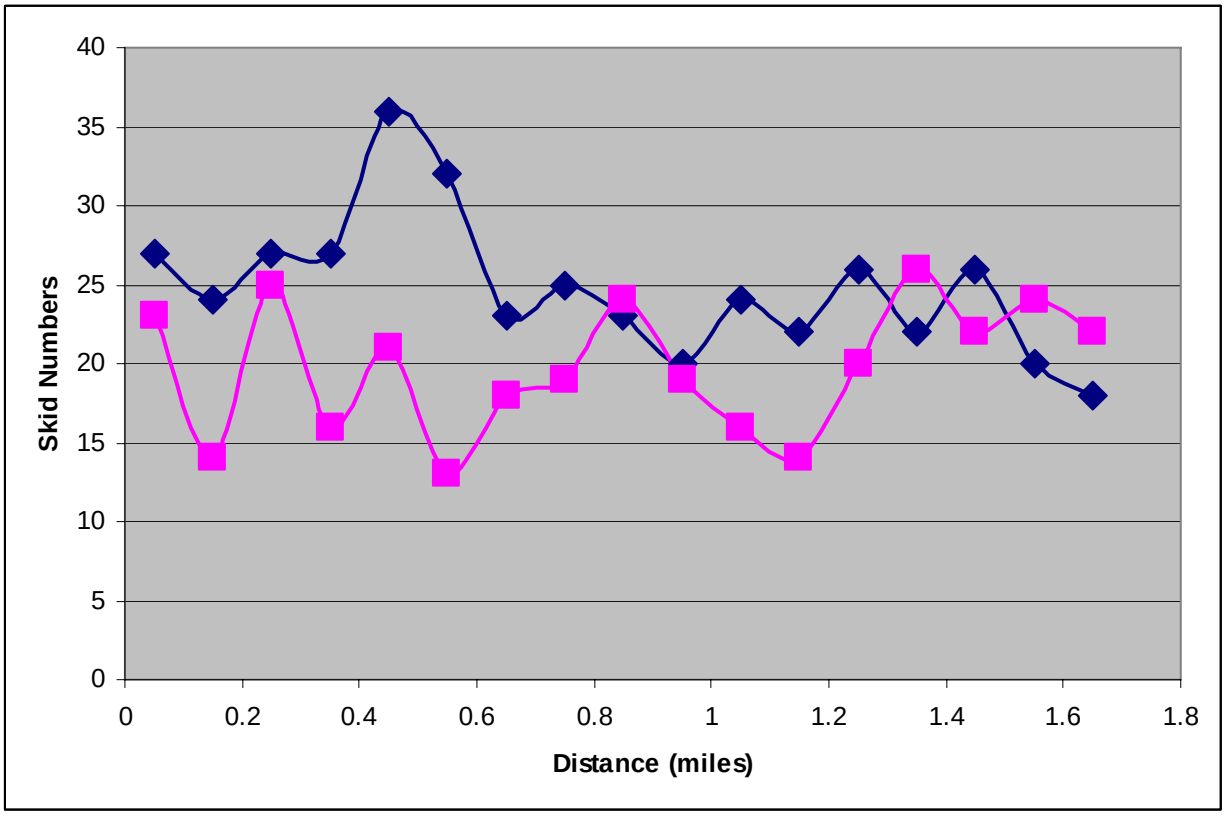


Figure 41. Skid Data from US 90 (Blue WB, Pink EB).

The average values are 24.8 WB and 19.8 EB. These are substantially less than the values found on earlier projects. The US 90 project is the only CAM project placed to date where performance problems have been observed. The poor visual appearance of the mat is primarily related to the low placement temperatures. The reason for the low skid numbers are not known at this time.

CHAPTER 3
EVALUATION OF DESIGN PROCEDURES FOR CAM MIXES

As documented in research Report 0-5598-1 (Walubita and Scullion, 2008), CAM mixes have been successfully designed following the TxDOT CAM SS 3109 specification (TxDOT, 2007). Two main features of these CAM mixes are the use of 1) high quality aggregates and 2) PG76-22 binder. As described in Chapter 2 problems have been recently encountered with using the SS3109 approach with current designs, especially the job in the San Antonio District. The main differences in the current cases are 1) the use of local aggregates and 2) the switch to a lower cost PG70-22 binder.

To address these design issues and develop a more general CAM mix design approach, the researchers reviewed the balanced mix design concept and experimented with three alternative approaches for determining optimal asphalt content to arrive at a mix design that passes both performance tests. These three different approaches are described in the next section of this report. This is followed by a description of how these approaches performed with the material from San Antonio.

THREE CAM MIX DESIGN APPROACHES: REVIEW AND COMPARISON

The following reviews each approach separately and then makes comparison for all three approaches.

Design Approach 1. SS 3109 Recommended Volumetric Procedure

The SS3109 approach is the only official CAM mix design procedure. This design process is illustrated in Figure 42. This approach follows the general TxDOT process of designing Superpave performance hot-mix asphalt (HMA) mixes(Item 344). The only difference is to determine the optimum asphalt content (OAC) based on N_{design}=50 and 98 percent instead of 96 percent design density. Also for the CAM both the minimum rutting and cracking resistance is specified at optimum asphalt content using Hamburg Wheel Tracking Test (HWTT) and the Overlay Test (OT) criteria. If both rutting and cracking criteria are met, the design is finished; otherwise, start over again. The total number of specimens required is 13; eight specimens for volumetric design and five specimens for performance check, as shown in Figure 42. The main

advantages of this approach are simplicity, it requires minor changes to current HMA mix design system, and consequently, it would be easy to implement. Meanwhile, its serious disadvantage is that this approach checks only one asphalt content (N_{design}=50 and 98 percent density). Consequently, this approach may not select the optimum asphalt content (OAC). This will be described later when discussing the case study of San Antonito CAM mix design. Additionally, the OAC based on N_{design}=50 and 98 percent density may be too high potentially there could still be room to further reduce the asphalt content to get a more economic CAM mix.

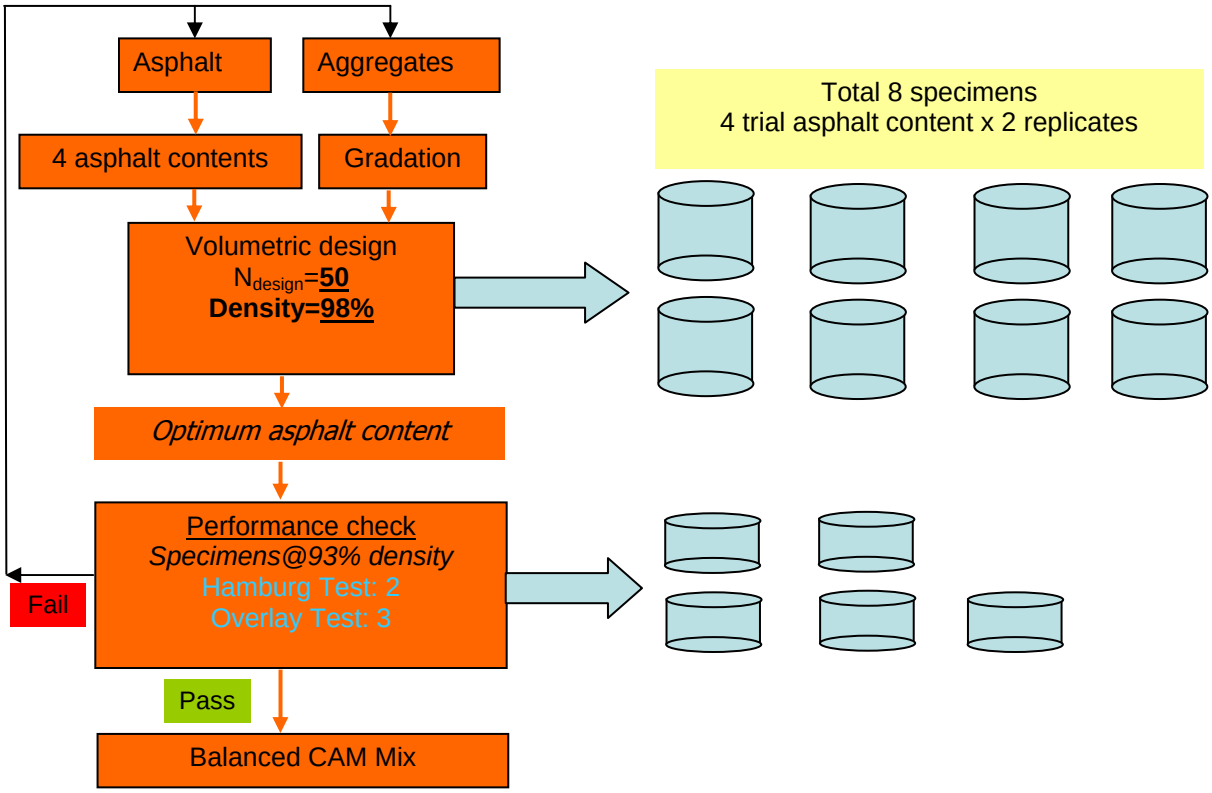


Figure 42. TxDOT's SS3109 Approach.

Design Approach 2. 0-5598-1 Approach

This approach proposed by Walubita and Scullion is well described in Report 0-5598-1. Its main components are presented below.

Step 1: Aggregate Sourcing and Material-Property Characteristics

- Review locally available aggregate sources. Typically, only fine-graded Type F rock (98 – 100 percent passing the ⅜" sieve) and screenings materials will be used.
- Recommend Class A aggregate (e.g., granite or crushed gravel for Texas materials) or Class B aggregates with low soundness value.

Step 2: Mold HMA Specimens at 50 Gyrations and 98 Percent Target Density to determine the OAC

- Use at least four trial asphalt contents (6.5, 7.0, 7.5, 8.0, and 8.5 percent in the example given below).
- For each trial asphalt content, mold at least two HMA specimens of 6-inch diameter by 5 inch in height.
- Measure the HMA specimen density and determine the OAC at 98 percent density.
- Cut the molded samples (Figure 43) to test in HWTT and OT tests for rutting and cracking resistance characterization.

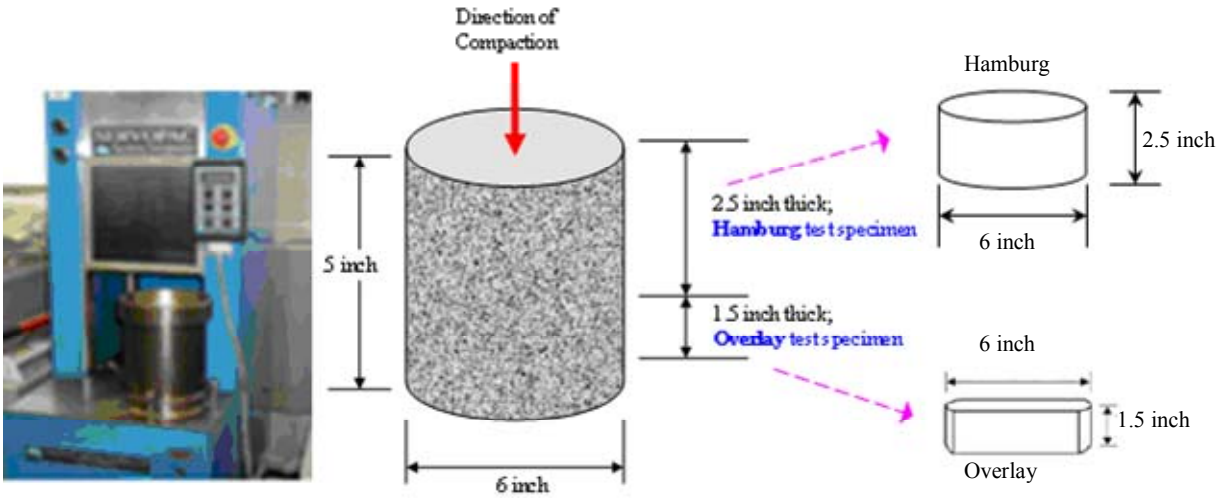


Figure 43. Gyratory Molding and Sawing of the HWTT and OT Specimens.

- Select the OAC as the asphalt content simultaneously meeting both the Hamburg rutting and overlay cracking criteria. A window of acceptable OAC will usually be determined, as shown in Figure 44. In this case the Hamburg requirement is met at all

binder contents below 7.8%, and the overlay tester requirement is met at all asphalt contents above 6.9%. Therefore the window of acceptable asphalt contents ranges from 6.9% to 7.8%. The binder content in the middle of the range would be selected for validation testing.

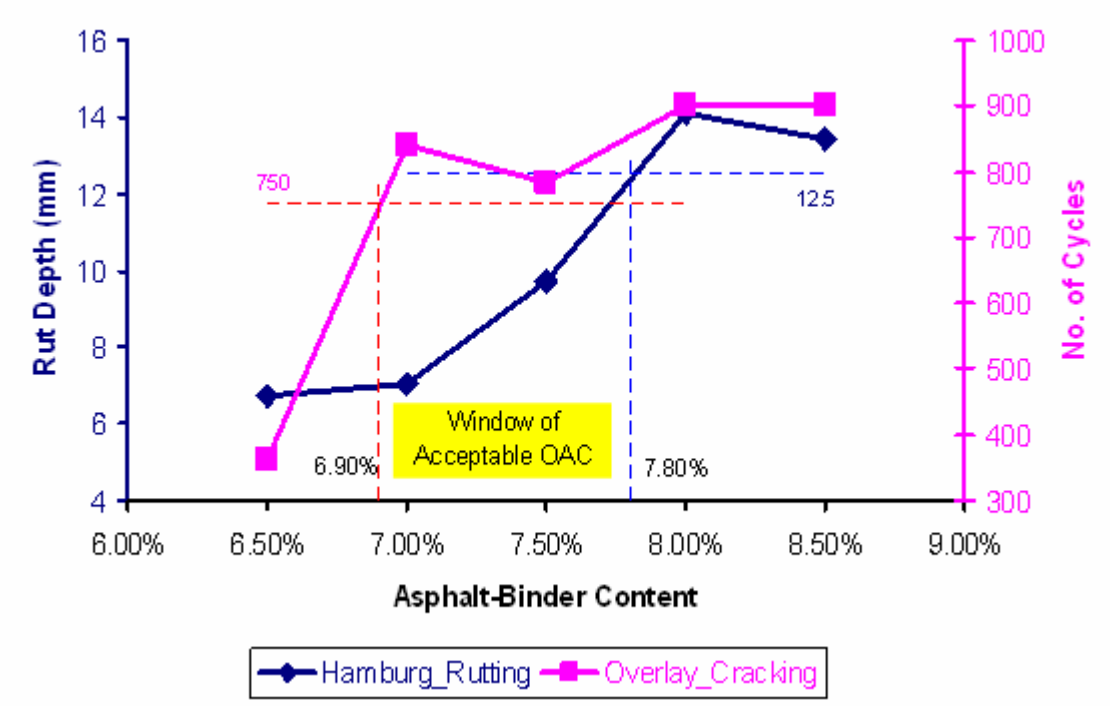


Figure 44. Lab Test Results and OAC Selection from Approach 2.

Step 3: OAC Verification (as per TxDOT-Recommended Mix Verification Procedures)

- Gyratory mold at least two separate HMA specimens at the balanced OAC and 93 percent density (as per TxDOT-recommended mix verification procedures).
- Run the HWTT and OT tests to verify the balanced OAC.
- Select the balanced OAC as the design OAC, or otherwise select a different OAC within the window of the acceptable balanced OAC determined from Step 2 till the balanced OAC is verified at 93 percent density.

Overall, the major difference between this approach and the SS3109 approach is in Step 2. The 0-5598-1 approach requires cutting and testing the specimens molded for volumetric design with both HWTT and OT, which significantly increases the amount of mix design work and makes the 0-5598-1 approach too complicated. Another question on this approach is that the

asphalt content within the window of acceptable OAC determined in Step 2 (Figure 3) may not be acceptable in Step 3, because of different specimen density in Steps 2 and 3. Note that the density of specimen in Step 2 is not 93 percent density. To enhance both the SS3109 and 0-5598-1 approaches, a simplified CAM mix design approach is proposed and presented next.

Design Approach 3. 0-5123 Balanced Mix Design Approach

The balanced mix design concept was well discussed and demonstrated under TxDOT research Project 0-5123 (Zhou et al., 2006). A simplified version of the balanced mix design approach proposed by Zhou et al. (2006) is shown in Figure 45. Comparing with the SS3109 and 0-5598-1 approaches, this simplified approach has several features:

1) Makes unnecessary the volumetric design approach for selecting OAC;
2) Mix performance evaluation:
    - Three trial asphalt contents are used instead of one in the SS3109 approach , and
    - All samples are molded to 93 percent density instead of varying density in the 0-5598-1 approach at Step 2.

The proposed approach is simple, straight forward, and easy to follow. However, the major problem with this approach is unknown N_{design} for quality control (QC) and quality assurance (QA) during the production.

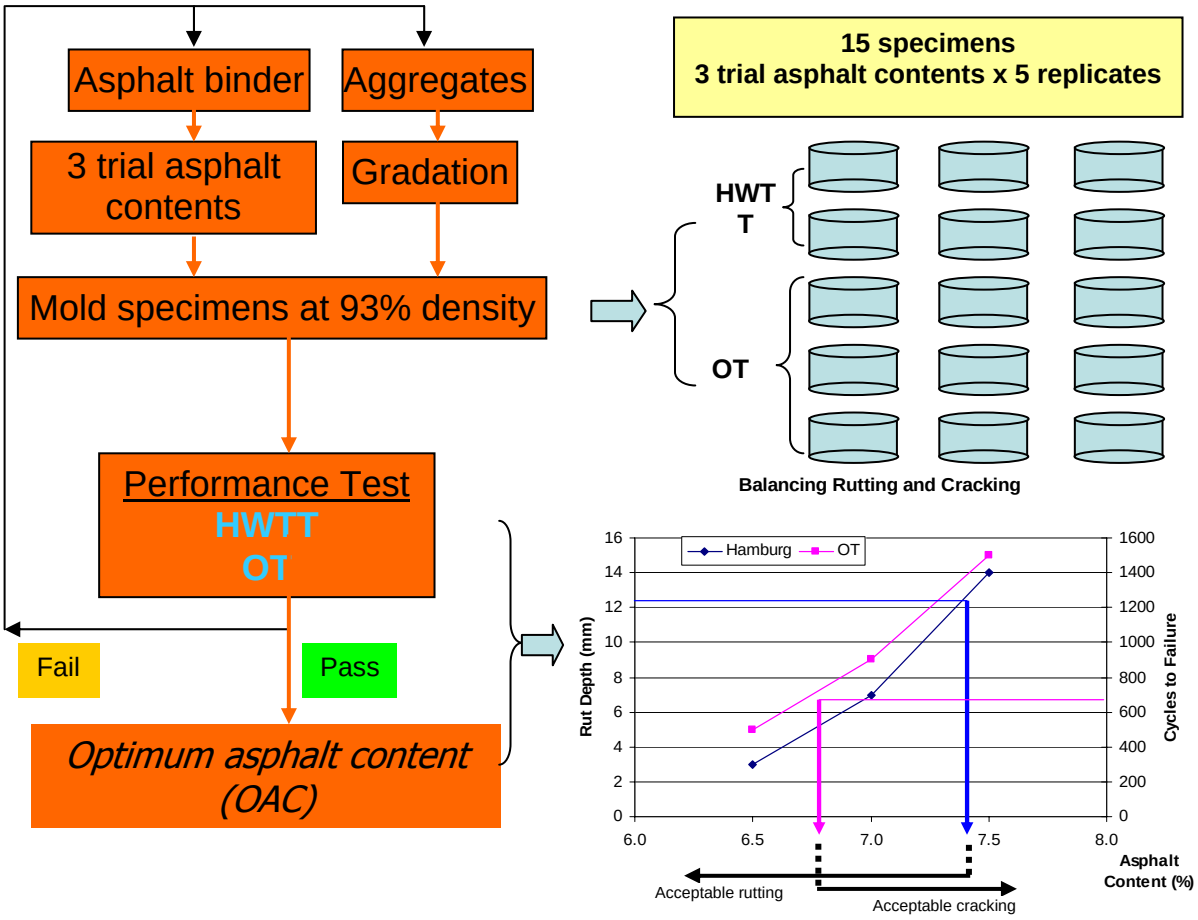


Figure 45. Simplified Version of Balanced Mix Design Approach (Zhou et al., 2006).

In summary, each approach discussed above has its own advantages and disadvantages. Among these three approaches, the simplified version of balanced mix design approach is the most effective way to design a CAM mix passing both rutting and cracking requirements. But additional volumetric information, such as design density and design gyrations, still needs to be determined. Therefore, an enhanced version of balanced mix design approach is developed for the CAM mix design and can be used for other mix design as well.

Recommended CAM Mix Design Procedure

Figure 46 shows the recommended CAM mix design procedure. This procedure is composed of three steps: 1) material selection, 2) determination of balanced OAC, and 3) backcalculation of N_{design} at pre-selected design density.

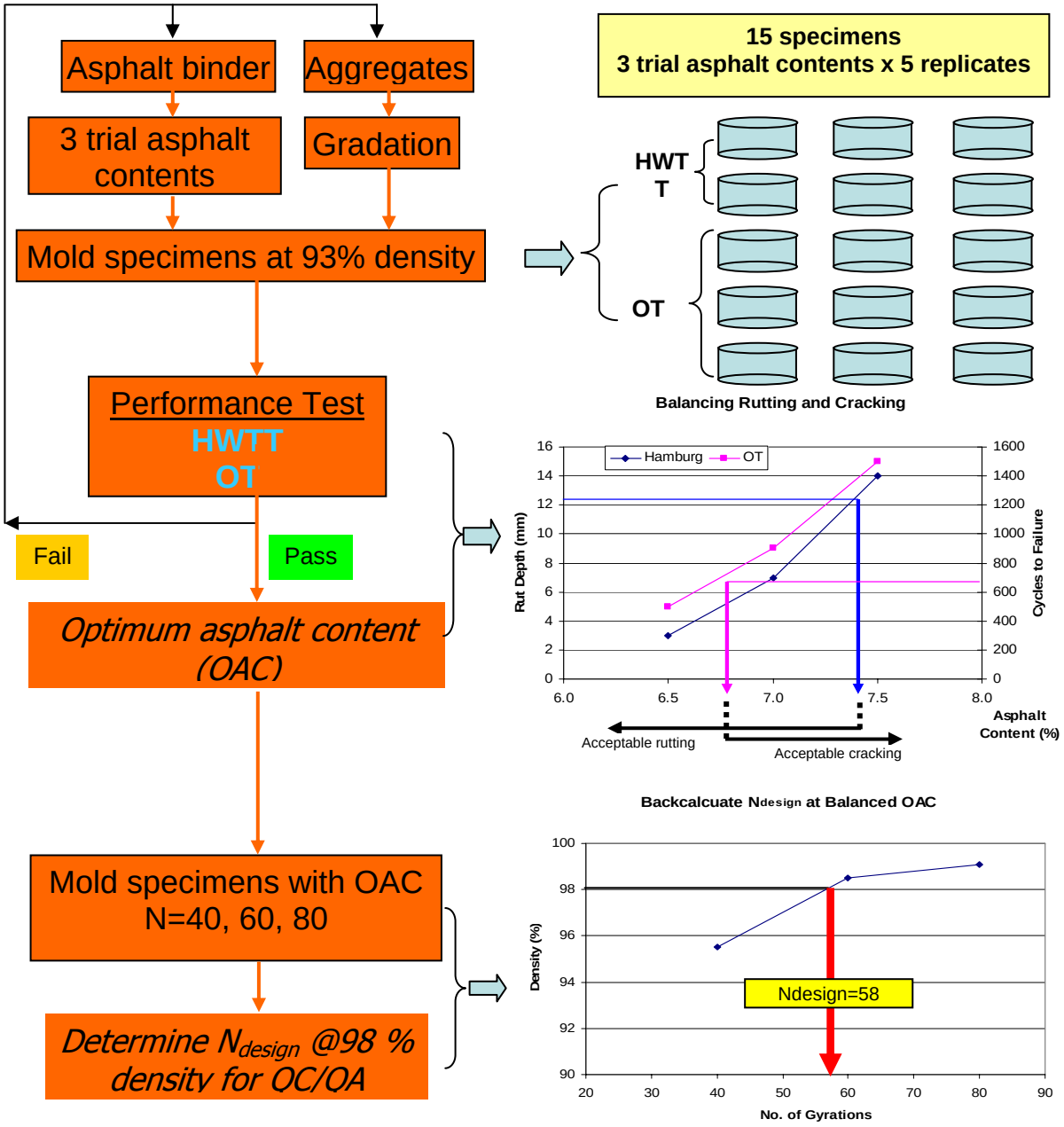


Figure 46. Recommended CAM Mix Design Procedure.

Detailed information is presented below:

- Step 1: Material selection
  - Asphalt binder and trail asphalt binder content

  Currently, both PG70-22 and PG76-22 binders have been used for the CAM mix design. Depending on traffic level, climate conditions, and available budget

resources, either PG70-22 or PG76-22 binder can be selected. Generally, three trail asphalt contents, 6.5, 7.0, and 7.5 percent, are enough for the CAM mix design. In the case where the gradation has lots of fines (such as high percentage of passing No. 200 sieve size), either try 4 asphalt content by adding 8.0 percent asphalt content or simply replace the 6.5 percent with 8.0 percent asphalt content.

- Aggregates and gradation

Review locally available aggregate sources. Typically, only fine-graded Type F rock (98 – 100 percent passing the ⅜" sieve) and screenings materials will be used. Recommend Class A aggregate (e.g., granite or crushed gravel for Texas materials) or Class B aggregates with a low soundness value. After selecting the aggregates, combine them together with different percentages to make sure the combined aggregates are within the CAM mix gradation limits.

- Step 2: Determination of the balanced OAC
  - For each trial asphalt content, determine the Rice density.
  - For each trial asphalt content, mold five Hamburg size specimens at 93 percent density, two for the Hamburg test and three for the Overlay test. (The latest specification calls for the overlay test specimens to be molded to a height of 4.5 inches and the required sample cut from the middle)
  - For each trial asphalt content, run both the Hamburg and Overlay tests.
  - Select the balanced OAC simultaneously meeting both the Hamburg rutting and overlay cracking criteria. A window of acceptable OAC will usually be determined, as shown in Figure 46.
- Step 3: Determination of N_{design} at pre-selected design density (i.e., 98 percent)
  - Select three gyration numbers: 40, 60, and 80.
  - For each selected gyration number, mold two specimens at the balanced OAC determined at Step 2 with 4500 gm material. A total of six specimens should be molded.
  - For each molded specimen, measure its air voids.
  - Draw the graph of density versus gyration number, and determine the N_{design} corresponding to the pre-selected design density, as shown in Figure 46.

Case Study: San Antonio CAM Mix Design

An example CAM design from a San Antonio project is presented below to demonstrate all the approaches discussed above. This case uses a PG70-22 binder and local aggregates. Figure 37 presented earlier shows the aggregates and the gradation for this CAM mix.

The simplified version of balanced mix design approach was employed. The three trial asphalt contents used are 6.4, 6.8, and 7.2 percent. The results are presented in Table 6, and especially, the Hamburg test results are shown in Figure 47. The acceptable asphalt content meeting both Hamburg-rutting and Overlay-cracking requirement ranges from 6.4 to 7.1 percent. Beyond 7.1 percent asphalt binder, the mix will have rutting problem. Based on this approach the optimal asphalt content for this mix would be 6.8% (as opposed to the 7.6% obtained from the SS 3109 specification).

In production the contractor tried the first trial batch with 6.5 percent asphalt content, but the density at 50 gyrations was only 92.1 percent, which is too low to be acceptable. Then the contractor had the second trial batch with 7.0 percent asphalt content, and the measured density was 97.2 percent. At this asphalt content the mix had 9 mm rut depth after 15,000 passes in the Hamburg test and also passed the Overlay test requirement. All this information indicates the importance of Step 3 in Figure 46 – determination of the N_{design}. Without this Step 3, it is difficult to conduct the QC/QA.

Table 6. Summary of the Hamburg and Overlay Test Results.

Trial Asphalt Content	Hamburg Test		Overlay Test	
	Rutting Depth (mm)	Pass/Fail	No. of Cycles	Pass
6.4%	5.2@15,000	**Pass >750 Pass**		
6.8%	6.4@15,000	**Pass >750 Pass**		
7.2%	12.7@15,000	**Fail**	**>750**	**Pass**

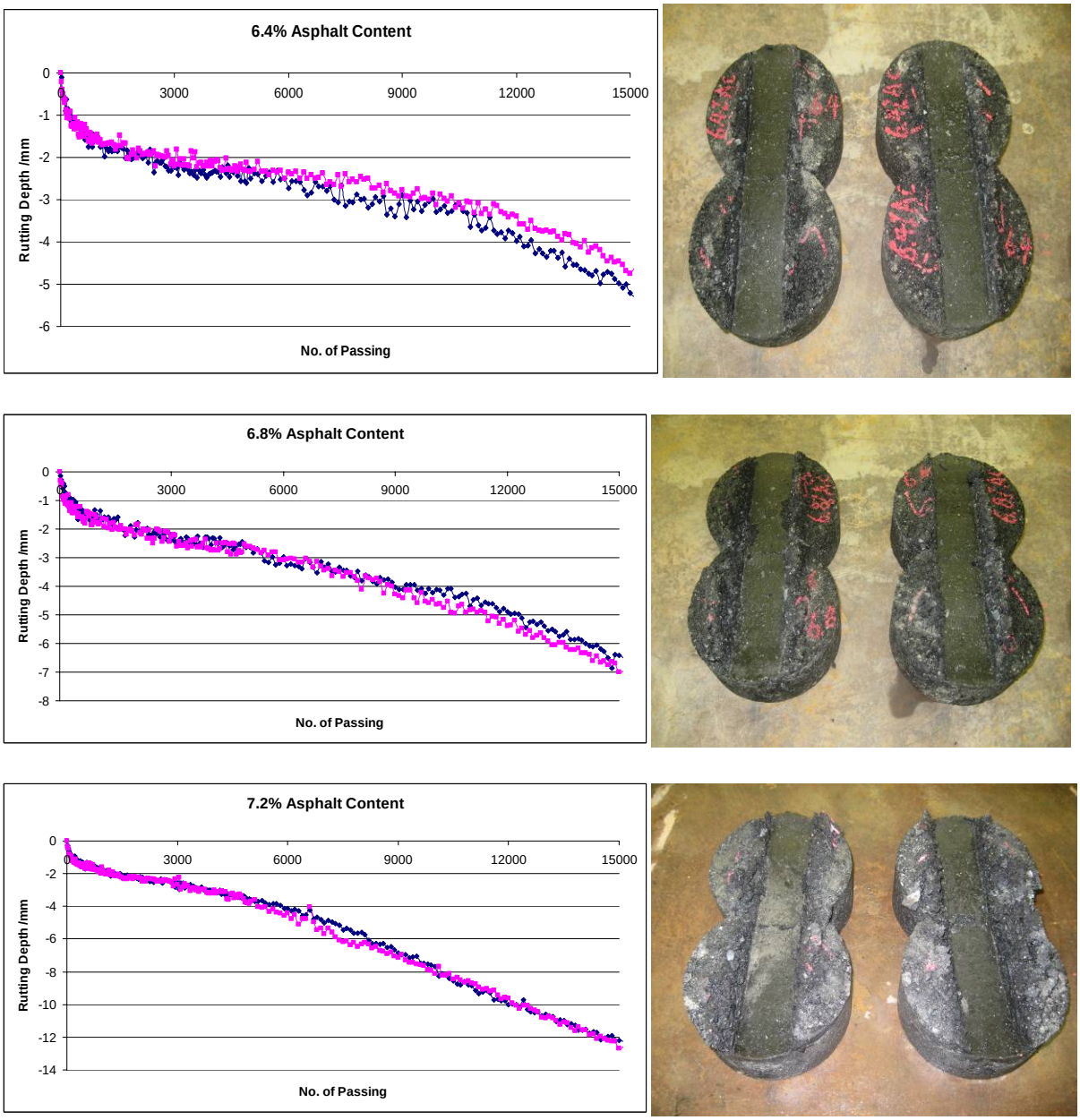


Figure 47. Hamburg Test Results.

Additionally, TTI researchers also tried the SS3109 approach with 50 gyrations and 98 density. Figure 48 presents the volumetric results. Apparently, the OAC with the 50 gyrations and 98 density is beyond 7.5 percent. As shown in Table 6 and Figure 47, the CAM mix will fail the Hamburg-rutting requirement when the asphalt content is more than 7.2 percent. This further demonstrates the limitation of current SS3109 volumetric approach.

TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 10/24/07 10:53:08

SAMPLE ID:		SAMPLE DATE:	8/05/08
LOT NUMBER:		LETTING DATE:	
SAMPLE STATUS:		CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	2004
SAMPLED BY:		SPEC ITEM:	3311
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL CODE:		MIX TYPE:	SS3111_CA_Mix
MATERIAL NAME:	Crack Attenuating Mixture (CAM)		
PRODUCER:	EE Hood		
AREA ENGINEER:	John Bohosluv, PE	PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:		CONTRACTOR DE

Target Density, %:	**98.0**
Number of Gyrations:	**50**

CRM* Content

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)
6.5	2.510	2.644	2.966	2.652	94.6	21.2
7.0	2.542	2.631	2.978	2.630	96.6	20.6
7.5	2.549	2.616	2.987	2.609	97.7	20.8

Figure 48. SS3109 CAM Mix Volumetric Design Results.

SUMMARY

In summary, this chapter recommends a general CAM mix design approach shown in Figure 46, which is applicable to both PG76-22 and PG70-22 binders and selected aggregates and local aggregates. The limitation of this approach is that the contractor will need to do an additional step to arrive at the final N_{design}. In the next chapter of this report the final recommendations on how to develop future CAM designs will be presented.

CHAPTER 4
DESIGN OF CRACK ATTENUATING MIXES (CAM)

In Chapter 3, a review was made of the different approaches to arrive at an optimal asphalt content for future CAM mixes. In this chapter these results are synthesized, and final recommendations are presented on how future designs should be performed. The advantages of this approach are:

1. It will quickly identify aggregate and binders combinations where a balanced mix design is not possible.
2. It will provide a more economic design; the researchers feel that the SS 3109 approach may result in too much asphalt in the mix.
3. It will provide the district with an operational window that will show when a decrease in performance will be anticipated for this mix. This is useful in evaluating the consequences of variations that occur in production.

INTRODUCTION

The Crack Attenuating Mix is proposed as a thin, durable, long-lasting, cost effective surface mix for pavement maintenance and preservation. Developed under TxDOT research 0-5598 this very fine mix is designed to pass both the current Hamburg Wheel Tracking Test (HWTT) to ensure moisture susceptibility and good rut resistance and strict Overlay Tester (OT) requirements to ensure good crack resistance. It is typically placed as a 1-inch thick mat. This mix has been evaluated in several districts around Texas, and the performance to date has been very good.

A new statewide specification is under preparation and will be available in 2009. This comprehensive specification includes all aspects of material selection, mix design, and construction. The design of the mix relies on the traditional volumetric approach, wherein the optimal asphalt content is designed based on achieving 98% lab molded density with 50 gyrations of a Superpave gyratory compactor. Once the OAC is determined, then samples are molded to 93% of maximum theoretical density and required to pass TxDOT's current Hamburg requirement and also last more than 750 cycles in the overlay tester. These volumetric

requirements were established early within the research project and are known to work well for PG 76-22 binders with good quality Class A aggregates. However in several recent projects, major problems were identified in attempting to establish an OAC which meets the performance test requirements. These problems included:

- TxDOT is encouraging districts to move away from the PG 76-22 binders because of cost and availability issues. The most recent CAM projects have used a PG 70-22 binder, and there is even consideration to move to a PG 64-22. The 50 gyration/98% density does not appear reasonable for the lower PG graded binder as it appears to recommend too much asphalt, which gives problems passing the HWTT.
- The high quality granite and sandstone aggregates are not available statewide. The districts want to use locally available materials.
- If the current volumetric design fails one of the performance tests then there is little guidance on what to do next. The new spec has options to increase the number of gyrations up to 100 and also waive either of the performance tests. This could lead to major confusion and potentially lower quality mixes.
- Mixes designed with the current volumetric method are resulting in too much binder in the mix. This is costly and could possibly introduce skid problems.

In this chapter, a new mix design procedure is proposed that builds on the fact that in the CAM design, the aggregates and asphalt are paid for separately. The proposed procedure attempts to define a window of asphalt contents where both cracking and rutting requirements are satisfied, based on performance tests. The OAC content is defined as the middle of the acceptable range. The volumetrics are then checked after the performance tests are satisfied. This procedure has several advantages; first, it will identify aggregate/asphalt combinations that will not work very early so that costly re-runs of the volumetric designs will be avoided. In one recent project at least 10 redesigns of a CAM mix were performed before it was concluded that the proposed mix would not work. It will also save money by identifying a window of OAC contents which will provide satisfactory performance.

The design procedure proposed is shown below in Figure 49. TxDOT is encouraged to evaluate this approach in upcoming projects; it should be run in parallel with the current

volumetric procedure. Meeting both an HWTT and OT test criteria is a new concept in Texas, and this will create many challenges for the TxDOT and the hot-mix industry. The new procedure will help minimize these challenges. This proposed mix design procedure is shown schematically in Figure 49.

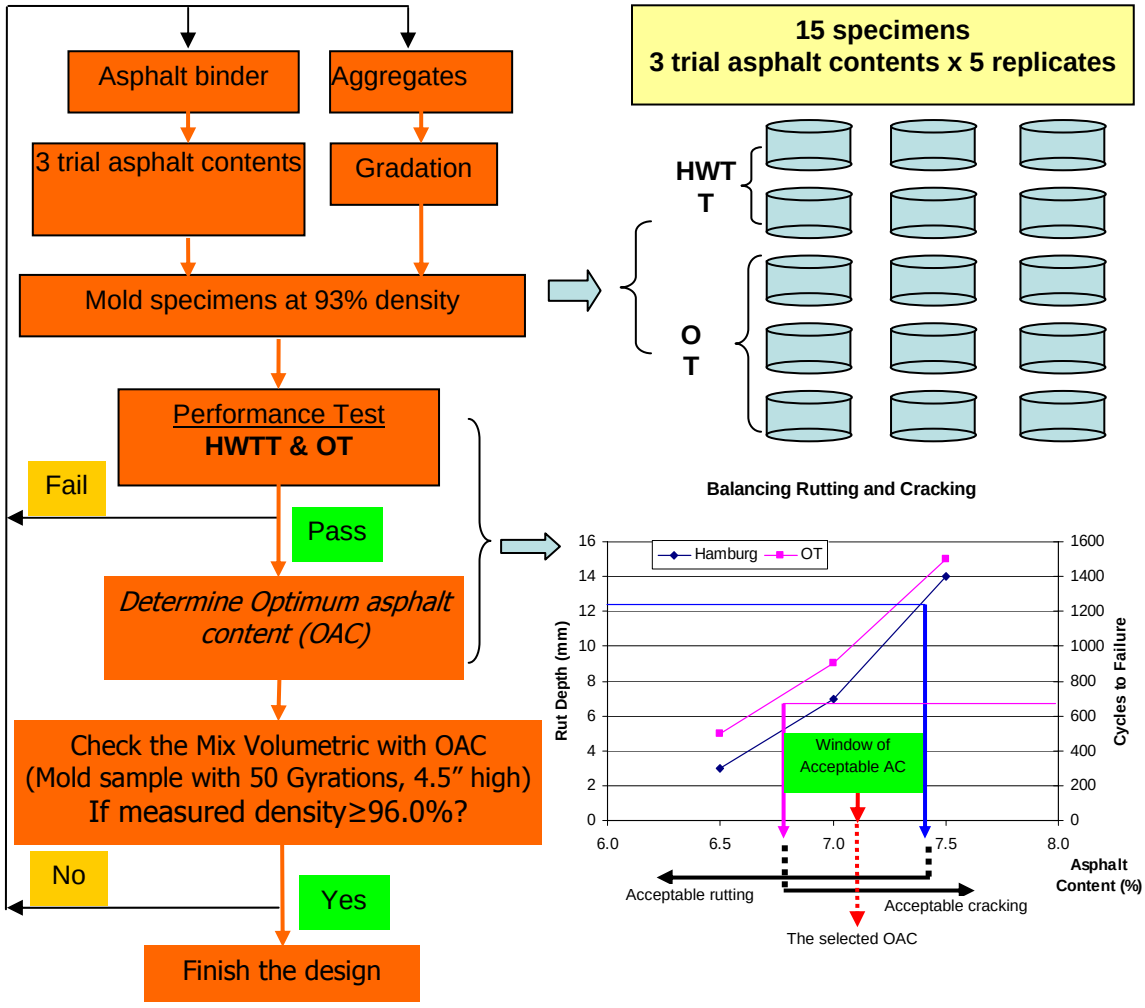


Figure 49. The Flow Chart for Design of CAM Overlay.

MINIMUM AGGREGATE PROPERTIES

The first step in the process is to identify locally available aggregates that meet the quality and gradation requirements of Tables 7 and 8 below. If at all possible 100% Class A aggregates should be used, but recent projects have used a blend of Class A materials with high quality limestone screenings. Successful designs have been placed with granite, sandstone, and crushed gravel aggregates. All materials used in the CAM should be crushed high quality materials preferably (but not necessarily) from the same source. Softer limestone materials should be avoided. Also currently RAP is not permitted in the CAM mixes. River sands are also not permitted as they typically have problems passing the HWTT.

Table 7. Aggregate Quality Requirements.

Property Test	**Method R**	**equirement**
Coarse Aggregate		
SAC	AQMP	As shown on plans
Deleterious material, %, max	Tex-217-F, Part I	1.0
Decantation, %, max	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %, max	Tex-461-A	Note 1
Los Angeles abrasion, %, max	Tex-410-A	30
Magnesium sulfate soundness, 5 cycles, %, max	Tex-411-A	20
Coarse aggregate angularity, 2 crushed faces, %, min	Tex-460-A, Part I	95[2]
Flat and elongated particles @ 5:1, %, max	Tex-280-F	10
Fine Aggregate		
Linear shrinkage, %, max	Tex-107-E	3
Combined Aggregate[3]		
Sand equivalent, %, min	Tex-203-F	45

1. Not used for acceptance purposes. Used by the Engineer as an indicator of the need for further investigation.
2. Only applies to crushed gravel.
3. Aggregates, without mineral filler, or additives, combined as used in the job-mix formula (JMF).

Table 8. CAM Gradation Band Shown.

Sieve Size	Fine Mixture (% Passing by Weight or Volume)
1/2"	–
3/8"	98.0–100.0
#4	70.0-90.0
#8	40.0–65.0
#16	20.0-45.0
#30	10.0–30.0
#50	10.0–20.0
#200	2.0–10.0

The new specification mandates the use of 1% lime as an antistripping agent in all mixes. However successful CAM mixes have been placed without the lime. The lime will definitely help with the mixes containing the lower PG binders. The need for lime should be based on the outcome of the performance tests. If problems are observed with passing the Hamburg, then lime should be considered.

MIX DESIGN PROCEDURE

In accordance with the flow chart shown in Figure 49, this mix design procedure is composed of six steps: 1) select trial asphalt contents; 2) run maximum theoretical density (RICE); 3) mold samples to 93 percent density; 4) run Overlay and Hamburg tests; 5) select optimal asphalt content; and 6) check mixture volumetrics. Detailed information is presented below.

Step 1: Select Trial Asphalt Contents

Depending on the traffic level, climate conditions, and available budget resources, PG64-22, PG70-22, PG70-28 or PG76-22 asphalt binder can be selected for the CAM. Table 9 proposes three trial asphalt contents for each binder.

Table 9. Recommended Asphalt Content.

Asphalt type	Asphalt Content		
	Low	Middle	High
PG 76-22	6.8	7.4	8.0
PG 70-22	6.4	6.8	7.2
PG 70-28	6.4	6.8	7.2
PG 64-22	6.0	6.3	6.6

The only designs that have currently been placed used either the PG 76-22 or PG 70-22.

Step 2: Run the Maximum Theoretical Density (RICE) at each AC Content

Before molding tested samples, for each trial asphalt content, determine the RICE maximum theoretical density. The standard methods for determining the Rice should be used including using the Metal Vacuum Pycnometer shown in Figure 50.

Figure 50. RICE Testing using Metal Vacuum Pycnometer.

Step 3: Mold Samples to 93% Density

Following TxDOT recommendation (Tex Method 242 HWTT and 248 OT), mold five samples at each asphalt content, two of them for Hamburg testing and three of them for Overlay testing. In total, 15 samples with three trial asphalt content are prepared for testing. Based on

the Rice values obtained in step 2, all samples are molded to the specified density of 93 ± 1% (after cutting for Overlay specimen). Figure 51 shows the scheme of preparing samples.

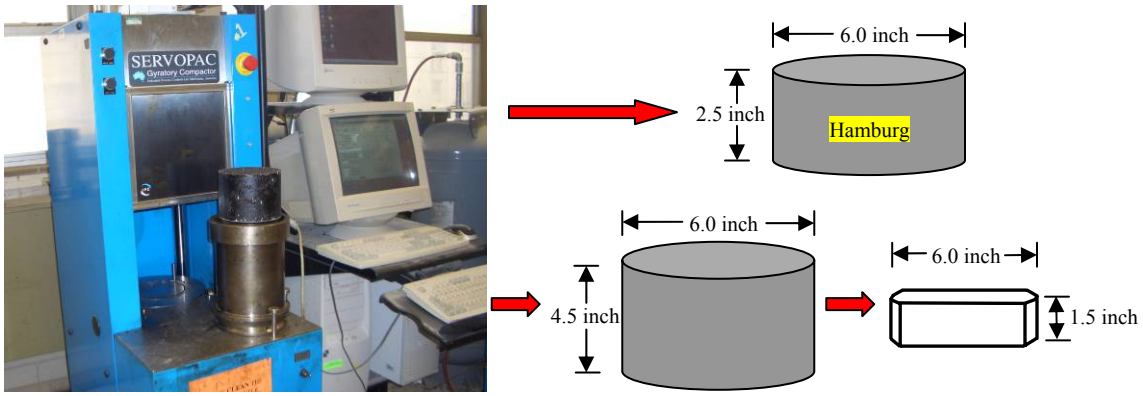
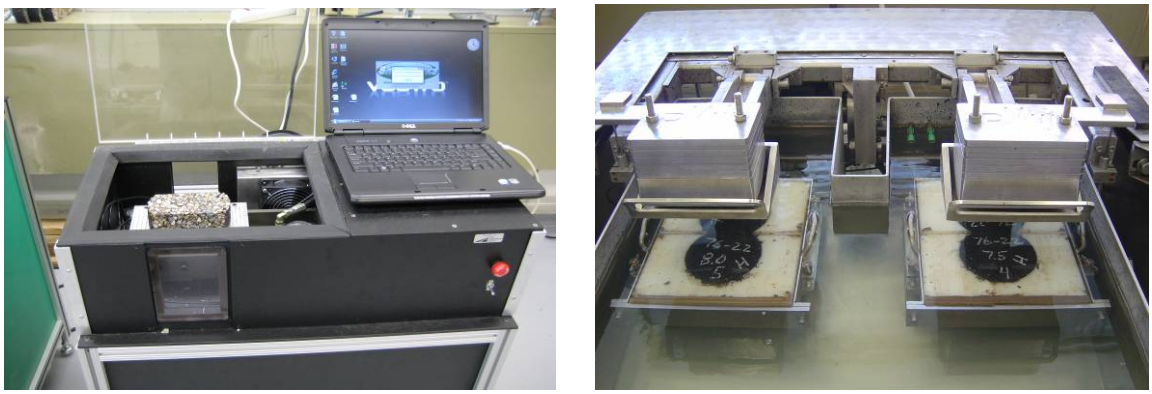


Figure 51. Molding Samples.

Step 4: Run Overlay Testing and Hamburg Testing

In accordance with Tex-248-F, run the Overlay test and in accordance with Tex-242-F, run the Hamburg test; see Figure 52 (a) and (b), respectively. Record the test results.



(a) Overlay Testing (b) Hamburg Testing

Figure 52. Overlay Testing and Hamburg Testing.

Step 5: Select Optimal Asphalt Content (OAC)

Select the OAC as the asphalt content simultaneously meeting both the Hamburg rutting and overlay cracking criteria. A window of acceptable asphalt content (AC) will usually be determined, as shown in Figure 53. The Hamburg results use the scale on the left and the overlay tester, the scale on the right. The failure criteria for the HWTT is 12.5 mm (i.e., rut depth$_{HWTT}$ ≤ 12.5 mm) and the OT is 750 cycles (N_{OT} ≥ 750 cycles). The middle value of the window of acceptable asphalt contents is selected as the initial OAC.

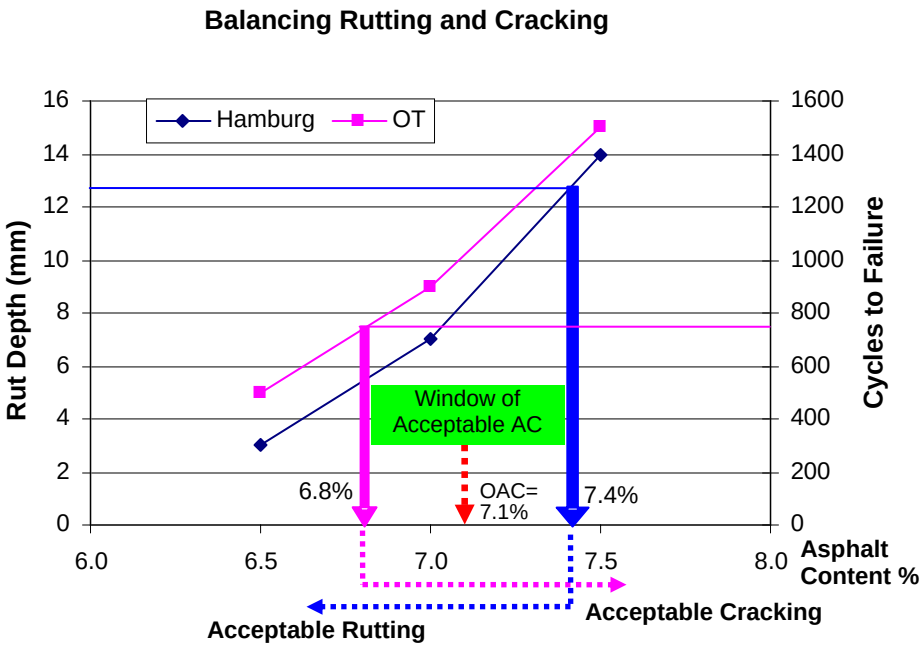


Figure 53. Selecting Optimal Asphalt Content.

Several different graphs have been found in practice. These include:

a) All samples pass the OT at all design AC contents. In that case, use the minimum asphalt content as the lower limit (or do a redesign; for example from Table 9 if the mix passes the HWTT test and OT at 6.8% PG 76-22 asphalt, then consider a redesign at 6.4% asphalt).

b) No asphalt content passes both tests (in that case a new combination of asphalt and aggregates must be used).

c) All samples pass the Hamburg but not the overlay tester. Do a rerun at a higher AC content than that specified in Table 9.

Step 6: Check Mixture Volumetrics

In order to meet the quality control (QC) and quality assurance (QA), it is necessary to check the sample's mix volumetric properties at the selected OAC. This will ensure that the mix will not have compaction problems and will provide a target density for the trial and production batch material.

Mold two 4.5-inch high samples with 50 gyrations at the initial selected OAC (i.e., 7.1% in Figure 5). If the measured density is between 96.0% and 98%, then the mix design of the thin overlay is complete. If the measured density is less than 96%, then increase the OAC by 0.2 % provided this is within the acceptable window. If it is more than 98% then reduce the OAC by 0.2%, provided this is within the acceptable window. Recheck the density at 50 gyrations.

EXAMPLE CAM MIX DESIGN

The need for procedure described above was found on a recent design project in San Antonio. The contractor was challenged with using locally available aggregates and PG 70-22 binder. The local aggregates are trap rock, which historically have been good. After many tries at passing the volumetric procedure, TxDOT and the contractor were about to give up on the design. The main problem was that all of the proposed mixes could not pass the HWTT criteria. A review was made of the proposed mix and three problems were found:

1) The proposed aggregate was out of specifications on the flat and elongated test. This rock was replaced with a Grade 5 rock that was more cubical.
2) Even with the proposed mix design and the use of 1% lime, the optimal asphalt content was selected using the volumetric procure to be 7.2%. This AC content failed the Hamburg test.
3) A redesign with the procedure described above was performed and an AC content of 6.8% was found to pass the performance tests; at this AC content, the mix achieved a density of 96.8 % of optimum at 50 gyrations.

According to Table 9, three trial asphalt contents 6.4, 6.8, and 7.2 percent, were selected. After RICE testing, the maximum specific gravity, 2.652, 2.629, and 2.608 g/cm^3 were obtained, respectively.

Table 10 presents mold 93±1% density samples for Hamburg and Overlay testing. The results are presented in Table 10. It is apparent that the acceptable asphalt content meeting both Hamburg-rutting and Overlay-cracking requirement ranges from 6.4 to 7.1 percent. Beyond 7.1 percent asphalt binder, the mixture will have rutting problems. The initial selected OAC was 6.8%.

Table 10. Summary of the Hamburg and Overlay Test Results.

Trial Asphalt Content	Hamburg Test		Overlay Test	
	Rutting Depth (mm)	Pass/Fail	No. of Cycles[1]	Pass/Fail
6.4%	5.2@15,000	Pass	>750	Pass
6.8%	6.4@15,000	Pass	>750	Pass
7.2%	12.7@15,000	Fail	>750	Pass

[1] average of three samples testing

CONSTRUCTION ISSUES

Few major construction problems have been reported with the CAM mixes manufactured and placed to date. The problems reported on US 90 were thought primarily to be related to the low placement temperature of the mix. The CAM material is placed with conventional asphalt pavers. The new statewide specification has a comprehensive set of requirements for this mix. However because of the thickness of the mat, particular attention should be placed to the temperature of the mat and the need for adequate rolling. Table 11 was taken from the new specification.

The use of Infra-red techniques to check thermal uniformity should also be encouraged. It is also critical for the rollers to be bumping the paver. One project ran into compaction problems when the initial steel wheel breakdown roller had problems. The mat was placed at the correct temperature, but compaction was delayed because of the roller problems.

The number and type of rollers is the choice of the contractor. The initial recommendation is that no vibratory rollers or pneumatic tired rollers be permitted. Compaction normally can be achieved by static steel wheel rollers. However, based on experience with the mix and prevailing weather conditions, these recommendations can be changed in order to achieve the required in-place densities (2% to 6%).

Table 11. Minimum Pavement Surface Temperatures.

	Minimum Pavement Surface Temperatures in Degrees Fahrenheit	
High Temperature Binder Grade	Subsurface Layers or Night Paving Operations	Surface Layers Placed in Daylight Operations
PG 64	45	50
PG 70	55[1]	60[1]
PG 76	60[1]	60[1]

[1]Contractors may pave at temperatures 10°F lower than the values shown in Table 6 when utilizing a paving process or equipment that eliminates thermal segregation. In such cases, the contractor must use either an infrared bar attached to the paver, a hand-held thermal camera, or a hand-held infrared thermometer operated in accordance with Tex-244-F to demonstrate to the satisfaction of the Engineer that the uncompacted mat has no more than 10°F of thermal segregation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Very thin high performance overlays are not new to Texas. They have been used very successfully in the Houston District since 2000 as level up layers on top of concrete prior to placing the final wearing surface. The difference with the CAM mixes described in this report is that these very thin overlays are used as surface layers. Based on the research conducted in this project the following conclusions are presented.

- The combination of the Hamburg and Overlay tester is highly recommended to produce a balance mix design for these overlays.
- The current volumetric procedure where an "optimal" asphalt content is defined in terms of an assigned number of gyrations and target density is difficult to implement when both performance tests must be passed. This procedure may work well for a single binder type and class of aggregate, but it runs into problems when variations occur.
- The design procedure proposed in Chapter 4 of this report recommends running the rutting and reflection cracking performance tests at a range of binder contents prior to checking volumetrics. This approach has several advantages over the volumetric approach as it a) provides districts with a working range of binder contents where acceptable performance can be anticipated (this range can be used to set tolerance levels during production); b) it quickly identifies asphalt and aggregate combinations where both performance requirements cannot be met; and c) can provide more economic mixes as it is thought the current volumetric procedure often results in too high an asphalt content.
- The CAM mix performance to date has been very good. The performance of the one inch overlay over jointed concrete pavement on Pumphrey Drive in Fort Worth has been very encouraging although more monitoring must be performed.
- Upfront testing must be performed on any project (especially jointed concrete) to ensure that it is a good candidate for a thin overlay. TxDOT has all of the nondestructive testing tools in house including GPR, FWD, and RDD to ensure that any project is a good candidate for these very thin overlays.

- Excellent skid resistance results were obtained on most of these projects.
- Problems will occur if the temperature at the time of compaction (not placement) is not carefully controlled. These very thin mats will not be readily compacted if the temperature is not controlled. The use of the Infra-red bar or thermal camera inspection should be encouraged on future jobs.
- As demonstrated in Laredo, successful CAM designs can be achieved with local aggregates (crushed gravel) and softer binders (PG 70-22).

The following recommendations are presented:

- On future designs it is proposed that the two proposed mix design procedures be run in parallel. The new volumetric procedure to be included in the statewide specification (SS3109) should be compared with the final balanced mix design approach proposed in Chapter 4 of this report.
- Districts wishing to gain experience with the CAM mix for the first time should be encouraged to design the first mix in-house with the assistance of CST and/or TTI. Several contractors are struggling to arrive at an acceptable mix design. Balancing both rutting and cracking requirements can be very challenging.
- The existing projects need to be monitored for a longer period.

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