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16. Abstract

Recent studies show some mixes with softer binders used outside of Texas (e.g., Minnesota's Cold Weather Road Research Facility mixes) have both good rutting and cracking performance. However, the current binder performance grading (PG) system fails to justify/identify this phenomenon, particularly as it applies to softer but highly modified binders. Therefore, it is necessary to improve the current asphalt grading system and recommend associated specification limits, especially for modified binders.

The major objectives of this research project were to (a) identify/develop simple lab evaluation methods to characterize binder properties, (b) recommend potential binder specification changes, (c) track the field performance of pavements using different binders including softer but highly modified binders, and (e) develop a statewide catalogue of binder recommendations for each district based on cracking performance simulation and life cycling analysis results.

Since the binder lab evaluation methods and recommendations have been documented in Report 0-6647-1, this report mainly focuses on field test section performance predictions/simulations and the statewide catalogue of binder recommendations. Eleven test sections using different binder types and binder contents, with and without Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS), were built and monitored during this project. This report documents the construction information, plant mix lab testing results, and performance survey/prediction results. Through validated performance prediction models, the researchers conducted 2700 cracking performance simulations to cover different asphalt mixtures, climatic zones, overlay thicknesses, traffic levels, and existing pavement structures. The statewide catalogue of binder recommendations was developed based on the simulation results. The life cycling cost analysis was conducted in three typical climate-zone districts—Amarillo (cold), Austin (moderate), and Pharr (hot)—and further justified the potential use of softer but highly modified binders in Texas, especially in cold areas.

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TEXAS CRACKING PERFORMANCE PREDICTION, SIMULATION, AND BINDER RECOMMENDATION

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TABLE OF CONTENTS

List of Figures .... **viii**
List of Tables .... **x**
Chapter 1 Introduction **1**
Objectives 1
Organization of the Report 2
Chapter 2 Information on Constructed Field Test Sections **3**
Introduction 3
SH 15 Test Sections 3
US 62 Test Sections 10
Loop 820 Test Sections 14
Summary 21
Chapter 3 Performance Prediction of Field Test Sections **23**
Introduction 23
Background of TxACOL and TxME 23
Prediction of SH 15 Test Sections 25
Prediction of US 62 Test Sections 31
Prediction of Loop 820 Test Sections 36
Field Test Section Survey 39
Summary 41
Chapter 4 Cracking Performance Simulations and Statewide Binder Recommendations **43**
Introduction 43
Partial Factorial Design 43
Simulation Method and Results 47
Development of Statewide Binder Type Recommendation Catalogue 49
Summary 51
Chapter 5 Life Cycling Cost Analysis **53**
Introduction 53
Overview of FHWA RealCost 53
Inputs of FHWA RealCost 54
Life Cycling Cost Analysis Results 62
Summary 67
Chapter 6 Summary and Conclusions **69**
Laboratory Measured Engineering Properties for a Range of Different Binders and Mixes ... 70
Identification of the Strengths and Weaknesses of the New AASHTO/ASTM Binder Grading System 70
Candidate Test Methods for Binder and Adhesion Properties 70
Predicted Performance of Different Aggregate/Binder Combinations 71
Overlay Design Recommendations for the Different Parts of Texas 71
Recommended Binder Specification Changes 71
Cost-Benefit Analysis of Using Softer but Rut Resistant Binders in Texas 71
References **73**
Appendix Laboratory Measured Engineering Properties for Different Binders and Mixes **75**

LIST OF FIGURES

Figure 2-1. Location of SH 15 Test Sections. 3
Figure 2-2. Reference Object of the Start Point for SH 15 Test Section 1. 4
Figure 2-3. Existing Pavement Condition of SH 15 Test Sections. 5
Figure 2-4. Rollers on SH 15 Test Sections. 6
Figure 2-5. Tack Coating Photos of SH 15 Test Sections. 7
Figure 2-6. Paving Photos of SH 15 Test Sections. 8
Figure 2-7. Removing Big Lumps from Asphalt Mix. 9
Figure 2-8. Location of US 62 Test Sections. 10
Figure 2-9. Reference Object for US 62 Test Section 3 Start Point. 11
Figure 2-10. Existing Pavement Conditions of US 62 Test Sections. 12
Figure 2-11. Rollers on US 62 Test Sections. 13
Figure 2-12. US 62 Test Sections after Tack Coating. 13
Figure 2-13. US 62 Paving Photos. 14
Figure 2-14. Location of Loop 820 Test Sections. 15
Figure 2-15. Loop 820 Test Section Numbers. 15
Figure 2-16. Start Location of Loop 820 Test Sections. 16
Figure 2-17. End Location of Loop 820 Test Sections. 16
Figure 2-18. Existing Pavement Condition of Loop 820 Test Sections. 17
Figure 2-19. Overlay Mix Type for Each Test Section on Loop 820. 17
Figure 2-20. Rollers on Loop 820 Test Sections. 18
Figure 2-21. Edge Preparing Photos of Loop 820 Test Sections. 19
Figure 2-22. Tack Coating Photos of Loop 820 Test Sections. 20
Figure 2-23. Paving Photo of Loop 820 Test Sections. 21
Figure 3-1. Main Screen of TxACOL Program. 24
Figure 3-2. Main Screen of TxME Program. 25
Figure 3-3. Overview of SH 15 Test Sections Right after Construction. 26
Figure 3-4. Pavement Structure of SH 15 Test Sections. 26
Figure 3-5. Material Property Input Example for SH 15 Test Sections. 29
Figure 3-6. Cracking Performance of SH 15 Test Sections. 29
Figure 3-7. Rutting Performance of SH 15 Test Sections. 30
Figure 3-8. OT Cycles Ranking of SH 15 Test Sections. 31
Figure 3-9. Dynamic Modulus Ranking of SH 15 Test Sections. 31
Figure 3-10. Overview of US 62 Test Sections Right after Construction. 32
Figure 3-11. Pavement Structure of US 62 Test Sections. 33
Figure 3-12. Cracking Performance of US 62 Test Sections. 34
Figure 3-13. Rutting Performance of US 62 Test Sections. 35
Figure 3-14. Overview of Loop 820 Test Sections Right after Construction. 36
Figure 3-15. Pavement Structure of Loop 820 Test Sections. 37
Figure 3-16. Cracking Performance of Loop 820 Test Sections. 38
Figure 3-17. Rutting Performance of Loop 820 Test Sections. 39
Figure 3-18. Field Survey of SH 15 Test Sections. 40
Figure 3-19. Field Survey of US 62 Test Sections. 40
Figure 3-20. Field Survey of US 62 Test Sections. 41
Figure 4-1. Texas Environmental Zones. 44

Figure 4-2. TxACOL Traffic Input Screen. 45
Figure 4-3. OT Test Results of 15 Asphalt Mixes. 46
Figure 4-4. An Example of Simulation Results. 48
Figure 4-5. Sorted Simulation Results According to OT Cycles. 49
Figure 5-1. Interface of FHWA RealCost Software. 54
Figure 5-2. Example of Project Details Screen. 55
Figure 5-3. Example of Analysis Options Screen. 56
Figure 5-4. Example of Traffic Data Screen. 57
Figure 5-5. Example of Value of User Time Screen. 58
Figure 5-6. Example of Alternative and Activity Input Screen. 61
Figure 5-7. LCCA Results of Amarillo: Present Value of Agency and User Cost. 64
Figure 5-8. LCCA Results of Austin: Present Value of Agency and User Cost. 65
Figure 5-9. LCCA Results of Pharr: Present Value of Agency and User Cost. 67
Figure A-1. MSCR Test Results of Nine Asphalt Binders. 76
Figure A-2. OT Test Results of 15 Asphalt Mixes. 76
Figure A-3. Hamburg Wheel Tracking Test (HWTT) Results of Gravel Mixes with Five Binders. 77
Figure A-4. HWTT Results of Limestone Mixes with Five Binders. 77
Figure A-5. HWTT Results of Granite Mixes with Five Binders. 78

LIST OF TABLES

Table 2-1. GPS Coordinates of SH 15 Test Sections. 4
Table 2-2. GPS Coordinates of US 62 Test Sections. 11
Table 3-1. Dynamic Modulus of SH 15 Test Sections. 27
Table 3-2. Rutting Properties of SH 15 Test Sections. 28
Table 3-3. Cracking Properties of SH 15 Test Sections. 28
Table 3-4. Dynamic Modulus of US 62 Test Sections. 33
Table 3-5. Rutting Properties of US 62 Test Sections. 34
Table 3-6. Cracking Properties of US 62 Test Sections. 34
Table 3-7. Dynamic Modulus of Loop 820 Test Sections. 37
Table 3-8. Rutting Properties of Loop 820 Test Sections. 38
Table 3-9. Cracking Properties of Loop 820 Test Sections. 38
Table 4-1. Summary of Factorial Design. 47
Table 4-2. Required OT Cycles for Different Environmental Zones, Existing Pavement Structures, Overlay Thicknesses, and Traffic Levels. 49
Table 4-3. Statewide Binder Type Recommendation Catalogue. 50
Table 5-1. Initial Construction Agency Cost Calculation. 59
Table 5-2. Predicted Cracking Life for Different Alternatives. 59
Table 5-3. Activity Numbers and Activity Service Life. 62
Table 5-4. LCCA Results of Amarillo for Conventional Existing AC over GB. 63
Table 5-5. LCCA Results of Amarillo for Thinner Existing AC over CTB. 63
Table 5-6. LCCA Results of Austin for Conventional Existing AC over GB. 64
Table 5-7. LCCA Results of Austin for Thinner Existing AC over CTB. 65
Table 5-8. LCCA Results of Pharr for Conventional Existing AC over GB. 66
Table 5-9. LCCA Results of Pharr for Thinner Existing AC over CTB. 66
Table 5-10. Best Options for Each District per LCCA Results. 67
Table A-1. Test Results of the Five Asphalt Binders. 75
Table A-2. DMA Test Results at a Temperature of 86°F and a Strain of 0.25. 78

CHAPTER 1
INTRODUCTION

Recent studies on mixes from out of state (Minnesota) found that mixes from Minnesota's Cold Weather Road Research Facility have substantially better cold weather cracking properties compared to mixes currently used in Texas. While Minnesota's mixes pass Hamburg rutting requirements, the binders are much softer than the ones normally used on Texas roads according to typical performance grade (PG) measurements. To address this discrepancy, several new binder tests and associated specifications were evaluated in this project. According to the findings documented in Research Report 0-6674-1 (Zhou et al. 2014), the linear amplitude sweep (LAS) test shows good correlation with the asphalt mixture overlay test (OT). Researchers believed that the multiple stress creep and recovery (MSCR) test, which directly measures the permanent deformation properties of asphalt binders and the new specifications, would show that softer but highly modified binders would be acceptable for use in Texas. However, these findings and claims needed further validations through tests of mixtures used in Texas pavements. Therefore, for this study, it was necessary to build field test sections in different Texas districts in order to evaluate the influence of binder type, binder content, and Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS) mixes.

OBJECTIVES

The major objectives of Research Project 0-6674 were to:

- Determine if the new America Association of State Highway and Transportation Officials (AASHTO) MSCR-based binder grading system is superior to the current Texas Department of Transportation (TxDOT) system.
- Identify/develop a simple test method or methods to characterize fracture and adhesive properties of modified and unmodified asphalt binders and associated tentative specification limits.
- Determine if asphalt binders not currently used in Texas would potentially improve overlay performance and conduct an associated cost-benefit analysis.
- Identify optimal asphalt binder/aggregate combinations for different environmental zones in Texas.
- Develop and initially populate a catalogue of all the measured (binder, binder/fine aggregate mastic, and asphalt mix) properties with relevant information that can be used to track the field performance of pavements constructed using these asphalt binders.

Since the first two objectives were discussed in Report 0-6674-1, this report (0-6674-2) mainly focuses on the last three objectives. To achieve these objectives, researchers built 11 test sections using some softer but highly modified binders in the Amarillo, Childress, and Fort Worth Districts for this project. This report documents the related construction information, plant mix lab testing results, and performance survey/prediction results. Field performance predictions were conducted for each test section and were used to validate the prediction programs and models. Through validated performance prediction models, the researchers conducted 2700 cracking performance simulations to cover different asphalt mixtures, climatic zones, overlay thicknesses, traffic levels, and existing pavement structures. A statewide catalogue of binder recommendations was then developed based on the simulation results. A life cycling cost analysis was conducted among three typical districts—Amarillo (cold), Austin (moderate), and Pharr (hot)—which further justified the potential use of softer but highly modified binders in Texas, especially in cold areas.

ORGANIZATION OF THE REPORT

This report is composed of six chapters. Following this introduction (Chapter 1), Chapter 2 presents the information on the constructed field test sections, such as location, pavement structure and condition, and mix types. Chapter 3 focuses on the project activities related to characterizing the mix property of each test section and conducting performance predictions such as rutting and cracking. Based on the validated performance prediction models, Chapter 4 describes the cracking performance simulation work and the development of the statewide binder recommendations for Texas based on the simulation results. Next, the life cycling cost analyses in terms of different binder types in some typical areas are discussed in Chapter 5. Finally, Chapter 6 provides a summary of findings and conclusions of this project.

CHAPTER 2
INFORMATION ON CONSTRUCTED FIELD TEST SECTIONS

INTRODUCTION

This chapter documents the construction and monitoring information of 11 test sections: four on SH 15 in north Amarillo, three on US 62 in Childress, and four on Loop 820 in Fort Worth. The information includes (a) the locations, including Global Positioning System (GPS) coordinates, of each test section; (b) the existing pavement structure and pavement conditions; (c) the asphalt mix type of each test section; and (d) the construction information, such as laying temperature and compaction pattern. This information combined with binder/mix properties provided a preliminary catalogue to track the field performance of test sections.

SH 15 TEST SECTIONS

The four SH 15 test sections are part of an overlay project constructed on October 7, 2013. The overlay is composed of 1.5 inches of Type D mix and 1 inch of Type F mix. The differences among the four test sections involve different binder type and/or binder content used in the Type D mix. The location of sections, existing pavement conditions, and construction information are described below.

Location of SH 15 Test Sections

The four test sections are located end to end on the eastbound side of SH 15, at the north end of Perryton in Amarillo. Figure 2-1 shows the start point of Section 1 (Point A) and the end point of Section 4 (Point B). The start point of Section 1 (Point A) is about 4.3 mi away from the US 83–SH 15 intersection. Each test section is about 1000 ft.

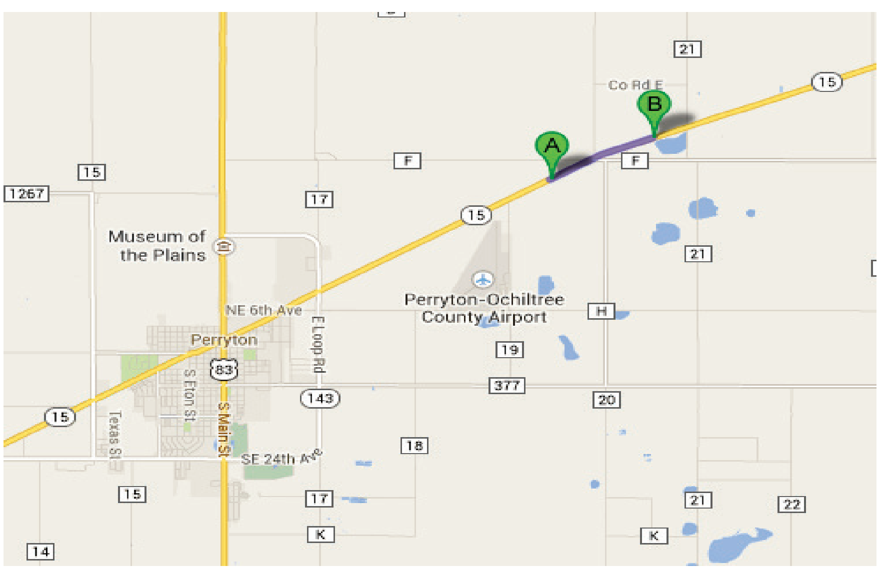


Figure 2-1. Location of SH 15 Test Sections.

The GPS coordinates for each test section are recorded in Table 2-1. Researchers also identified some permanent reference objects to help in locating the test sections for future performance monitoring.

Table 2-1. GPS Coordinates of SH 15 Test Sections.

Section ID	Begin		End		Length (ft)
	Latitude	Longitude	Latitude	Longitude	
S1	36°25.887′	-100°44.277′	36°26.006′	-100°44.033′	1390
S2	36°26.040′	-100°43.966′	36°26.154′	-100°43.705′	1450
S3	36°26.201′	-100°43.560′	36°26.293′	-100°43.268′	1530
S4	36°26.328′	-100°43.155′	36°26.395′	-100°42.956′	1050

Figure 2-2 shows an example of the start point reference object for Test Section 1—Milepost 368 at the road side.

Figure 2-2. Reference Object of the Start Point for SH 15 Test Section 1.

SH 15 Existing Pavement Conditions

The existing pavement was asphalt concrete pavement with some transverse and longitudinal cracking (see Figure 2-3). Ground Penetrating radar (GPR) data were collected before the milling work and showed that the existing Asphalt Concrete (AC) pavement thickness was about 2.5 inches. After that, researchers milled about 1 inch of the existing pavement and replaced it with 1 inch of Type F mix. No obvious transverse cracks were observed in the shoulder or the milled surface during construction.

Figure 2-3. Existing Pavement Condition of SH 15 Test Sections.

Asphalt Mix Types of SH 15 Test Sections

The Type D mixes of the four test sections are all warm mixes. The binder types and asphalt contents of the SH 15 test sections are:

- Section 1: PG 58-28, 5.5 percent.
- Section 2: PG 58-28, 5.8 percent.
- Section 3: PG 64-34, 5.8 percent.
- Section 4: PG 64-34, 5.5 percent.

Section 1 uses the control mix, Section 2 uses the mix with the same binder but a higher asphalt content, and Section 3 and Section 4 use the softer but highly modified binder PG 64-34 with different asphalt contents, respectively. The mix designs follow the TxDOT specification.

Construction Information of SH 15

The average paving temperature was 245°F, measured from the material in the paver. Figure 2-4 shows the rollers used on SH 15 test sections. The compaction pattern was four vibrating compactions (CB64), plus six static compactions (Dynapac CP274 or CP271), plus one static compaction (CB64). The same compaction pattern was employed for all the test sections.

a. CB64—Tandem Vibratory Roller.

b. Dynapac CP274 or CP271—Pneumatic Roller.

Figure 2-4. Rollers on SH 15 Test Sections.

Figures 2-5 and 2-6 show the tack coating and paving photos, respectively.

a. Tack Coat Spraying Machine.


b. Test Sections after Tack Coating.

Figure 2-5. Tack Coating Photos of SH 15 Test Sections.

a. Roadtec Shuttle Buggy Vehicle Transferring Material.

b. Paver Placing the Asphalt Mix.

Figure 2-6. Paving Photos of SH 15 Test Sections.

During construction, some big lumps were found in the unloaded mix from one truck and were picked up and removed (see Figure 2-7).

a. Big Lumps in the Asphalt Mix.

b. Getting Rid of the Big Lumps.

Figure 2-7. Removing Big Lumps from Asphalt Mix.

Generally, the test sections were completed in an orderly way. For each test section, seven buckets of mixes were sampled and taken back to the Texas A&M Transportation Institute (TTI) for lab tests, such as dynamic modulus, repeated load, Hamburg, and OT tests. About 10 field cores per section were also taken to TTI for corresponding lab tests.

US 62 TEST SECTIONS

The three US 62 test sections were constructed on October 3, 2013. The overlay is composed of 2 inches of Type D mix and 3 inches of Type B mix. The location of sections, existing pavement conditions, and construction information are described below.

Location of US 62 Test Sections

The three test sections are located on the eastbound side of US 62, close to Childress. Figure 2-8 shows the start point of Section 1 (Point A) and the end point of Section 3 (Point B). Each test section is about 1500 ft.

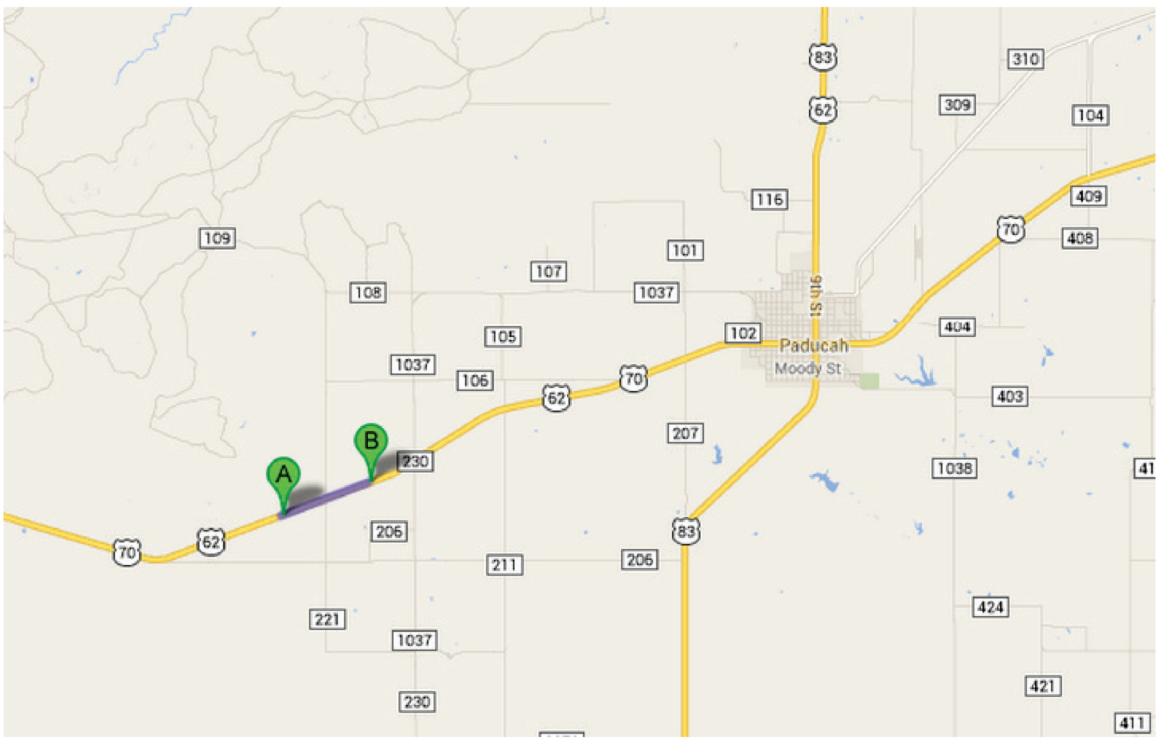


Figure 2-8. Location of US 62 Test Sections.

The GPS coordinates for each test section are recorded in Table 2-2. Researchers also identified some permanent reference objects to help with locating the test sections for future performance monitoring.

Table 2-2. GPS Coordinates of US 62 Test Sections.

Section ID	Begin		End		Length (ft)
	Latitude	Longitude	Latitude	Longitude	
S1	36°25.887′	-100°44.277′	36°26.006′	-100°44.033′	1390
S2	36°26.040′	-100°43.966′	36°26.154′	-100°43.705′	1450
S3	36°26.201′	-100°43.560′	36°26.293′	-100°43.268′	1530

Figure 2-9 shows an example of the Section 3 start point reference object—Milepost 442 on the road side.

Figure 2-9. Reference Object for US 62 Test Section 3 Start Point.

US 62 Existing Pavement Conditions

Figure 2-10 shows the existing pavement conditions of test sections on US 62. The previous pavement structure was 8 inches of asphalt pavement plus 11 inches of flexible base. The 8 inches of pavement were fully milled down and replaced with 2 inches of Type D mix and 3 inches of Type B mix. The paving of the 2 inches of Type D mix of these test sections was conducted on October 3, 2013.

Figure 2-10. Existing Pavement Conditions of US 62 Test Sections.

Asphalt Mix Types of US 62 Test Sections

The differences among the three test sections involve the use of different binder types and the inclusion or absence of RAP/RAS in the Type D mix. The Type D mixes of each test section of US 62 are:

- Section 1: PG 64-34, with RAP/RAS.
- Section 2: PG 70-28, virgin mix.
- Section 3: PG 70-28, with RAP/RAS.

Construction Information of US 62

The average paving temperature was 320°F, measured from the material in the paver. Figure 2-11 shows the rollers used on US 62 test sections. The compaction pattern was two vibrating compactions (Dynapac CC722), plus four static compactions (Dynapac RR602), plus one static compaction (Dynapac RS607). The same compaction pattern was employed for all the test sections.

Figure 2-11. Rollers on US 62 Test Sections.

Figures 2-12 and 2-13 show the tack coating and paving photos, respectively.

Figure 2-12. US 62 Test Sections after Tack Coating.

Figure 2-13. US 62 Paving Photos.

Researchers observed no abnormity during the construction of the US 62 test sections. For each test section, seven buckets of mixes were sampled and taken back to TTI for lab tests, such as dynamic modulus, repeated load, Hamburg, and OT tests. Cores from these test sections were also taken the day after construction for parallel tests.

LOOP 820 TEST SECTIONS

Four test sections on Loop 820 were constructed on July 20, 2012, and were monitored as non-planned experimental test sections for Project 0-6674. The location of sections, existing pavement conditions, and construction information are described below.

Location of Loop 820 Test Sections

The four test sections are side by side on four lanes of the westbound side of Loop 820 in Fort Worth. Figure 2-14 shows the start point, Point A (GPS coordinate 32°48.239′, -97°25.887′), and the end point, Point B (GPS coordinate 32°48.162′, -97°25.761′) of the test sections. The test sections (lanes) are numbered 0, 1, 2, and 3 in Figure 2-15. The length of the test sections is 992 ft.

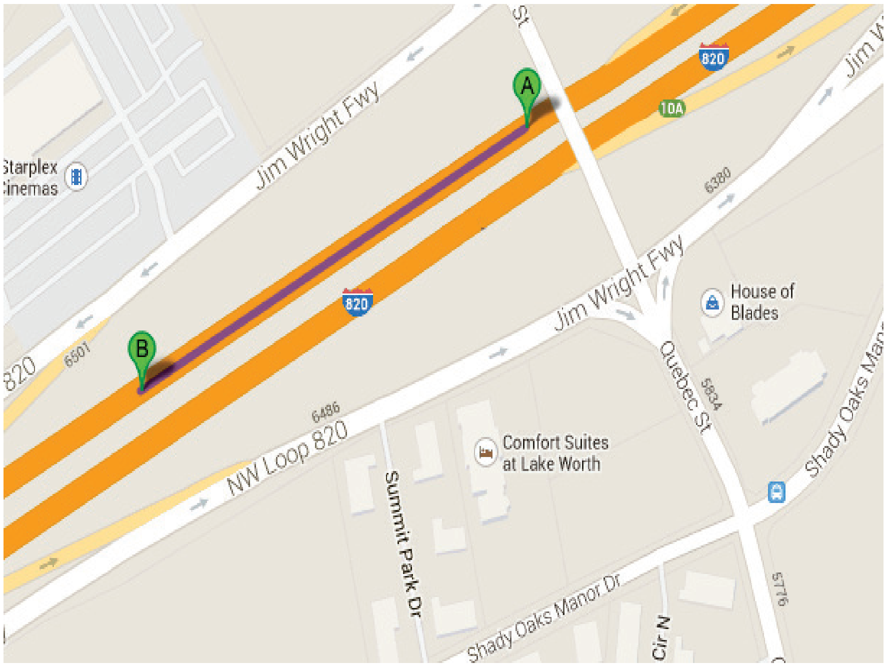


Figure 2-14. Location of Loop 820 Test Sections.

Figure 2-15. Loop 820 Test Section Numbers.

The reference object for the test section start location is the pole just past the Quebec bridge; the test sections start 61 ft away from the first pole (see Figure 2-16). The end location of the test sections is close to Milepost 9; see Figure 2-17.

Figure 2-16. Start Location of Loop 820 Test Sections.

Figure 2-17. End Location of Loop 820 Test Sections.

Loop 820 Existing Pavement Conditions

The existing pavement of Loop 820 was continuously reinforced concrete pavement (CRCP) with many fine cracks; the estimated cracking gap was around 5–6 feet (see Figure 2-18).

Figure 2-18. Existing Pavement Condition of Loop 820 Test Sections.

Asphalt Mix Types of Loop 820 Test Sections

The overlay mix for each test section is illustrated in Figure 2-19, from the inside lane to the outside lane. The thickness of all test sections is 2 inches.

Traffic Direction →	
	Section 0: control-PG64-22 13%RAP/5%RAS+Advera additive
	Section 1: APAC-PG64-22 13%RAP/5%RAS blended with Advera
	Section 2: PG64-28 13%RAP/5%RAS+Advera additive
	Section 3: PG64-22+0.4% more+13%RAP/5%RAS+Advera

Figure 2-19. Overlay Mix Type for Each Test Section on Loop 820.

Construction Information of Loop 820

TTI researchers monitored the construction of Test Sections 1, 2, and 3, which occurred on the night of July 19, 2012. The average paving temperatures measured with the TTI temperature gun were 262°F, 268°F, and 272°F for Test Section 1, 2, and 3, respectively. The TTI temperature gun is, on average, 6°F higher than the construction company's gun. Overall, researchers felt that Test Section 3 had the highest paving temperature.

Figure 2-20 shows the rollers used on the Loop 820 test sections. The compaction pattern was three vibrating compactions (Dynapac CC624 steel roller, high frequency), plus eight static compactions (Dynapac CP271 pneumatic roller), plus one or two static compactions (Ingersoll-Rand DD70). The same compaction pattern was employed for all test sections.

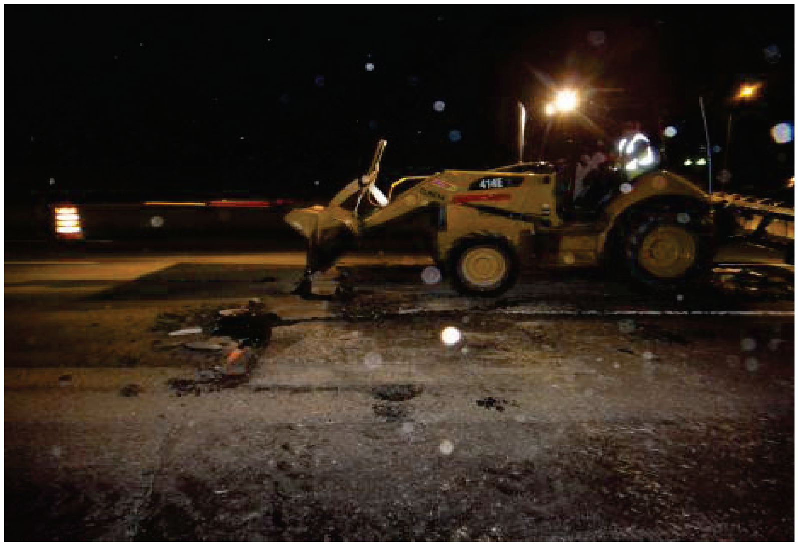
a. Dynacpac CC624 Steel Roller.

b. Dynapac CP271 Pneumatic Roller.

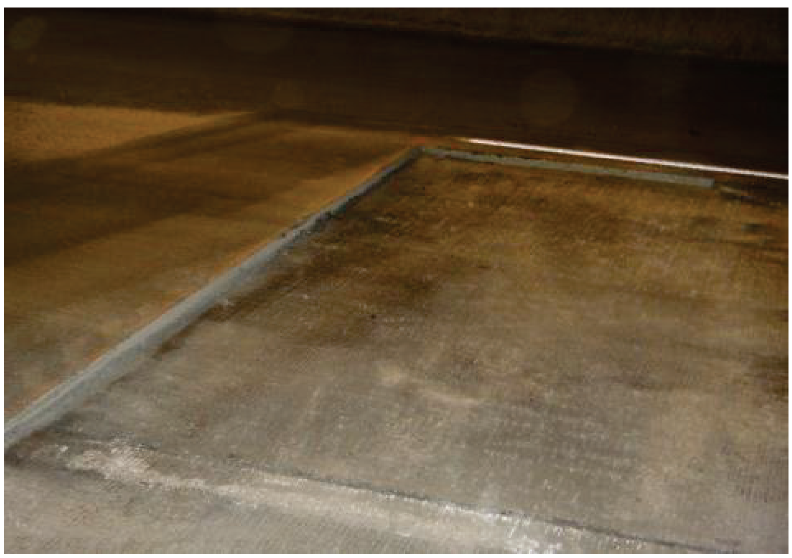
c. Ingersoll-Rand DD70 Roller.

Figure 2-20. Rollers on Loop 820 Test Sections.

Figures 2-21, 2-22, and 2-23 show the edge preparing, tack coating, and paving photos, respectively. Note that some tack coating areas show uneven spraying, as seen in Figure 2-22b.



a. Edge Preparing Machine.



b. The Well-Prepared Edge.

Figure 2-21. Edge Preparing Photos of Loop 820 Test Sections.

a. Tack Coat Spraying Machine.

b. Pavement after Tack Coating.

Figure 2-22. Tack Coating Photos of Loop 820 Test Sections.

Figure 2-23. Paving Photo of Loop 820 Test Sections.

Ten buckets of plant mix for each test section (Sections 1, 2, and 3) were taken, and researchers sampled 13 barrels of raw material (five barrels of Type D rock, three barrels of screenings, two barrels of RAP, one barrel of pure RAS, one barrel of RAS blended with Advera, and one barrel of sand), and two buckets of PG 64-22 binder. For each test section, 10 cores were taken one day after the construction.

SUMMARY

The research team oversaw the construction of and then monitored and analyzed 11 test sections: four on SH 15 in north Amarillo, three on US 62 in Childress, and four on Loop 820 in Fort Worth. Generally, test section construction was well organized. All test section start and end points were carefully identified and marked. For each test section, seven buckets of mixes were sampled and taken back to TTI to conduct dynamic modulus, repeated load, Hamburg, and OT tests. Field cores were also taken from each test section and were used for parallel lab tests. Researchers then used these test results for performance predictions, as described in the next chapter.

Researchers documented all relevant information on the constructed field test sections, including (a) the locations, such as GPS coordinates, of each test section; (b) the existing pavement structures and pavement conditions; (c) the asphalt mix type of each test section; and (d) the construction information, such as laying temperature and compaction pattern. This information combined with binder/mix properties provided a preliminary catalogue to track the field performance of test sections.

CHAPTER 3
PERFORMANCE PREDICTION OF FIELD TEST SECTIONS

INTRODUCTION

As documented in previous chapters, the research team oversaw the construction of and then monitored 11 test sections using different binders (especially some softer but highly modified binders) and different asphalt contents. Tracking and comparing the field performance of these test sections was intended to provide valuable information and experience to pavement engineers. Researchers documented all the relevant information, such as plant mix property, pavement structure information, and weather information, in order to inform performance predication of the test sections using current TxDOT flexible pavement design and analysis programs, such as Texas Asphalt Concrete Overlay Design and Analysis System (TxACOL; Zhou et al. 2010; Hu et al. 2010) and Texas Mechanistic-Empirical Flexible Pavement Design System (TxME; Hu et al. 2012; Hu et al. 2014). The purpose of the field performance prediction was two-fold: (a) to validate/verify these programs and models, and (b) to justify why some sections may perform better than others.

This chapter provides the detailed information of pavement performance prediction for these 11 test sections, organized/categorized by the road name. For each road—SH 15 (four test sections), US 62 (three test sections), and Loop 820 (four test sections)—the general information, the pavement structure information, and the material property information are illustrated. Finally, this chapter shows the final predictions for the test sections of each road in graph format for comparison purposes.

BACKGROUND OF TXACOL AND TXME

TxACOL

TxACOL is an asphalt concrete overlay design and analysis program that was developed during TxDOT Project 0-5123, "Integrated Asphalt (Overlay) Mixture Design, Balancing Rutting and Cracking Requirements," and was calibrated and implemented in TxDOT Project 5-5123-03, "Pilot Implementation of the New Asphalt Overlay Design System." One of the main features of this program is that it incorporates fracture mechanics to predict the asphalt cracking performance based on incremental methods. The models in this program adopt asphalt mixture material properties, such as dynamic modulus, fracture property, and rutting property, to perform the calculation of monthly rut depth and cracking rate. Like Mechanistic-Empirical Pavement Design Guide (MEPDG), this program also integrates the Enhanced Integrated Climatic Model (EICM) model to determine pavement hourly temperature and determine pavement response based on the pavement temperature profile and traffic load information. Figure 3-1 shows the main screen of TxACOL.

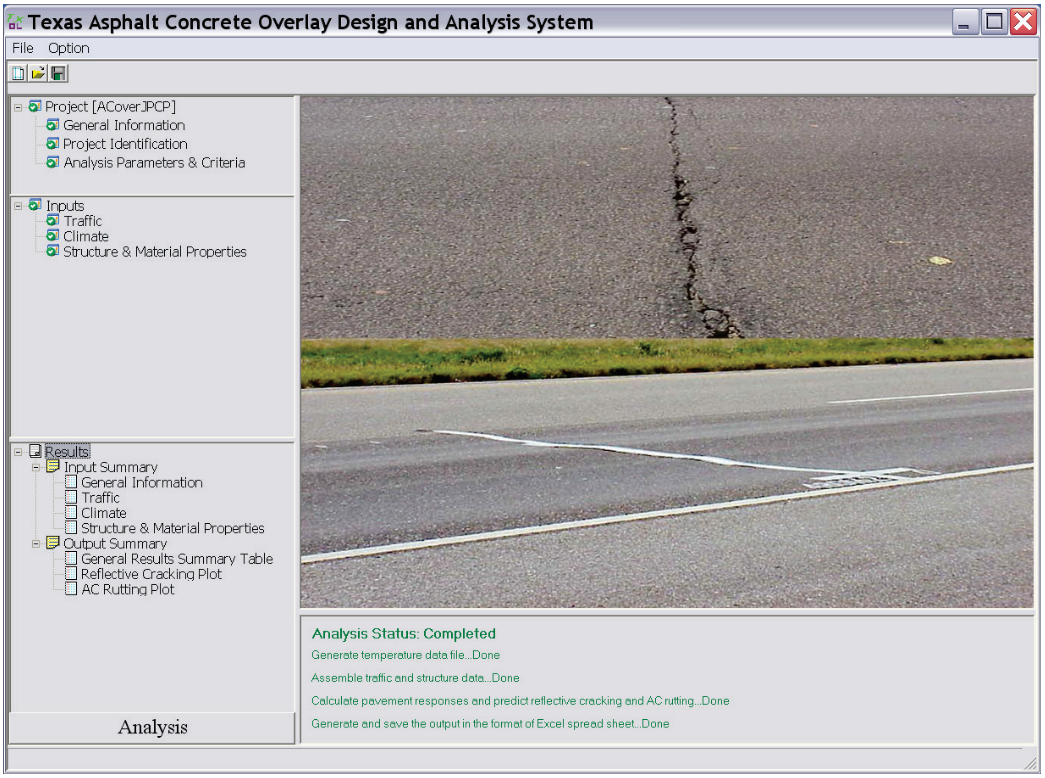


Figure 3-1. Main Screen of TxACOL Program.

TxME

TxME is a mechanistic-empirical flexible pavement design and analysis program that aims to enable TxDOT designers to take full advantage of new materials and to make more economical and reliable designs. The main features of TxME include:

- Mechanistic-empirical modeling.
- Performance-based material characterization.
- Traffic load spectrum incorporation.
- Design input variability-based reliability methodology.
- Incremental distress prediction.
- Fast running speed.
- User-friendly interface.
- Convenient connection with current flexible pavement design system FPS 21.

Figure 3-2 shows the main screen of TxME.

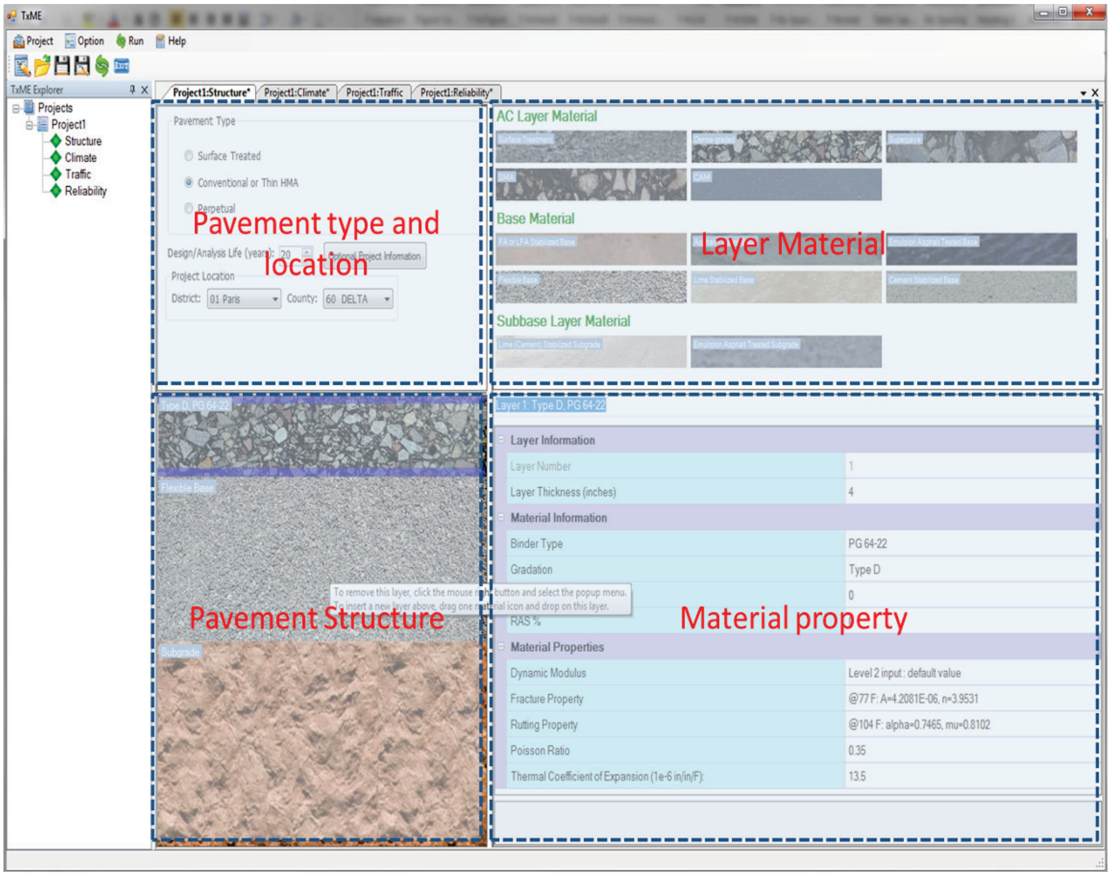


Figure 3-2. Main Screen of TxME Program.

PREDICTION OF SH 15 TEST SECTIONS

There are four test sections on SH 15, and their general information, pavement structure, material properties, and prediction results are presented below.

General Information

The four test sections on SH 15 are located end to end and are numbered Section 1, 2, 3, and 4. As Chapter 2 documented, the difference between the test section overlay materials is the binder type and binder content, as shown below:

- Section 1 PG 58-28 @ 5.5 percent AC.
- Section 2 PG 58-28 @ 5.8 percent AC.
- Section 3: PG 64-34 @ 5.8 percent AC.
- Section 4: PG 64-34 @ 5.5 percent AC.

PG 64-34 is the softer but highly modified binder. Figure 3-3 shows the overview of the SH 15 test sections right after construction.

Figure 3-3. Overview of SH 15 Test Sections Right after Construction.

Pavement Structure

GPR data were collected before the milling work and showed that the existing AC pavement thickness was about 2.5 inches. After that, about 1 inch of the existing pavement was milled. The overlay was 1.5 inches of Type D plus 1 inch of Type F mixes. The base layer was assumed to be 10 inches for all test sections. Figure 3-4 shows the pavement structure that researchers analyzed for SH 15 test sections.

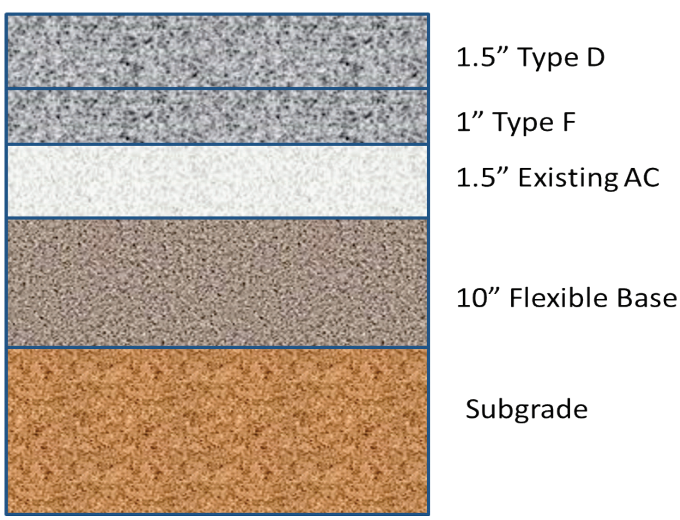


Figure 3-4. Pavement Structure of SH 15 Test Sections.

Material Properties

To conduct performance prediction, researchers used the following main inputs of material property: dynamic modulus, rutting properties, and cracking properties.

Dynamic Modulus

Table 3-1 lists the dynamic modulus values for each SH 15 test section. The test specimens were fabricated from the plant mix sampled at the construction site. Researchers conducted the tests using the asphalt mixture performance tester machine.

Table 3-1. Dynamic Modulus of SH 15 Test Sections.

Test Temp. (°C)	Test Frequency (Hz)	Modulus (ksi)			
		Section 1 PG 58-28 @ 5.5 AC	Section 2 PG 58-28 @ 5.8 AC	Section 3 PG 64-34 @ 5.8 AC	Section 4 PG 64-34 @ 5.5 AC
4	25	1799.6	1903.0	1728.4	1894.3
4	10	1567.7	1668.2	1480.7	1638.6
4	5	1394.9	1495.4	1301.5	1453.9
4	1	1023.8	1116.9	925.8	1059.4
4	0.5	882.9	970.7	786.4	910.1
4	0.1	602.2	673.2	511.4	611.0
20	25	806.3	845.4	685.6	784.7
20	10	631.3	665.3	520.6	605.5
20	5	521.2	551.0	418.5	494.0
20	1	309.8	333.4	230.1	282.1
20	0.5	246.5	267.1	177.9	221.1
20	0.1	132.3	147.3	90.7	116.3
40	25	176.3	184.3	142.3	165.7
40	10	117.1	124.2	91.7	109.5
40	5	83.1	89.5	65.6	78.8
40	1	35.0	38.8	29.6	34.9
40	0.5	25.4	28.5	23.5	27.1
40	0.1	12.7	14.5	14.0	15.3
40	0.01	6.3	7.2	8.5	7.5

Rutting Properties

A repeated load test is required to determine the rutting properties, α and μ. The test equipment and the specimen can be the same as in the dynamic modulus test. Two replicates are recommended. The maximum load repetition number is 10,000, and each load repetition time is 0.1 second of loading plus 0.9 second of rest. The rutting properties are determined based on the permanent strain curve (Hu et al. 2011). Table 3-2 lists the rutting properties for each test SH 15 section.

Table 3-2. Rutting Properties of SH 15 Test Sections.

Rutting Properties	Section 1 PG 58-28 @ 5.5 AC	Section 2 PG 58-28 @ 5.8 AC	Section 3 PG 64-34 @ 5.8 AC	Section 4 PG 64-34 @ 5.5 AC
α	0.6437	0.6697	0.7685	0.7694
μ	0.634	0.7035	0.539	0.44

Fracture Properties

The fracture properties, A and n, are determined by an OT-related approach (Zhou et al. 2007). Table 3-3 lists the OT cycles and corresponding cracking properties for each SH 15 test section.

Table 3-3. Cracking Properties of SH 15 Test Sections.

Cracking Properties	Section 1 PG 58-28 @ 5.5 AC	Section 2 PG 58-28 @ 5.8 AC	Section 3 PG 64-34 @ 5.8 AC	Section 4 PG 64-34 @ 5.5 AC
OT cycles	912	1590	9001	6549
A	9.7044E-9	3.3559E-9	1.2234E-10	2.2459E-10
n	5.6184	5.9097	6.8181	6.6514

SH 15 Test Section Prediction Results

TxACOL was used to predict the performance of the SH 15 test sections. The traffic volume was assumed to be 3 million Equivalent Single Axle Loads (ESALs) during 20 years. The climatic data from the Amarillo weather station was selected to determine the pavement temperature. Figure 3-5 shows an example of material input windows for one of the SH 15 test sections (Section 1).

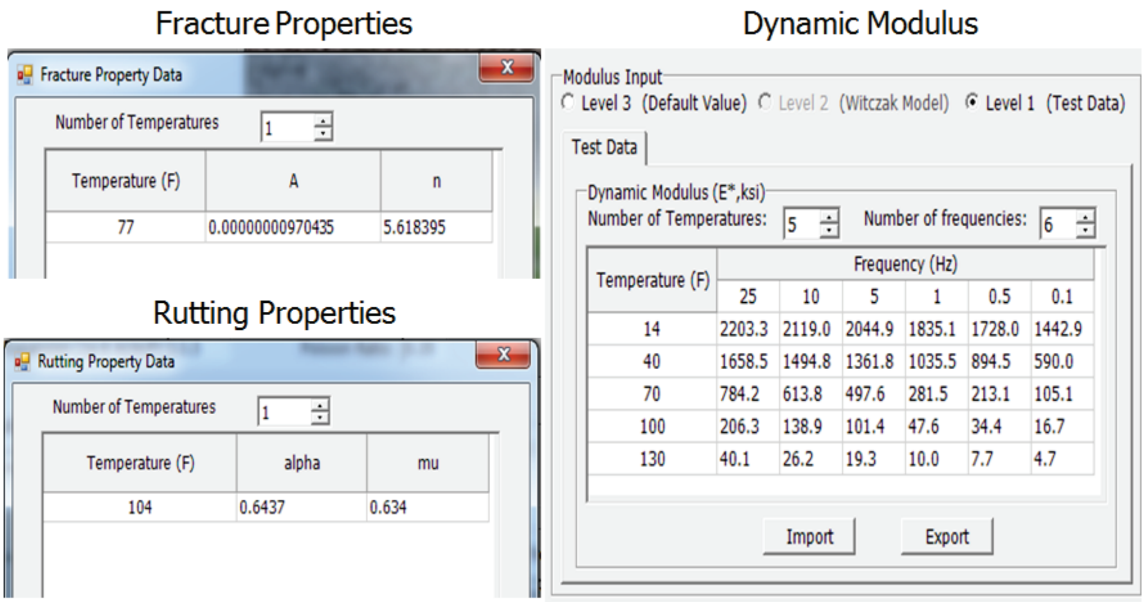


Figure 3-5. Material Property Input Example for SH 15 Test Sections.

Figures 3-6 and 3-7 show the prediction results in terms of monthly reflective cracking and rut development, respectively.

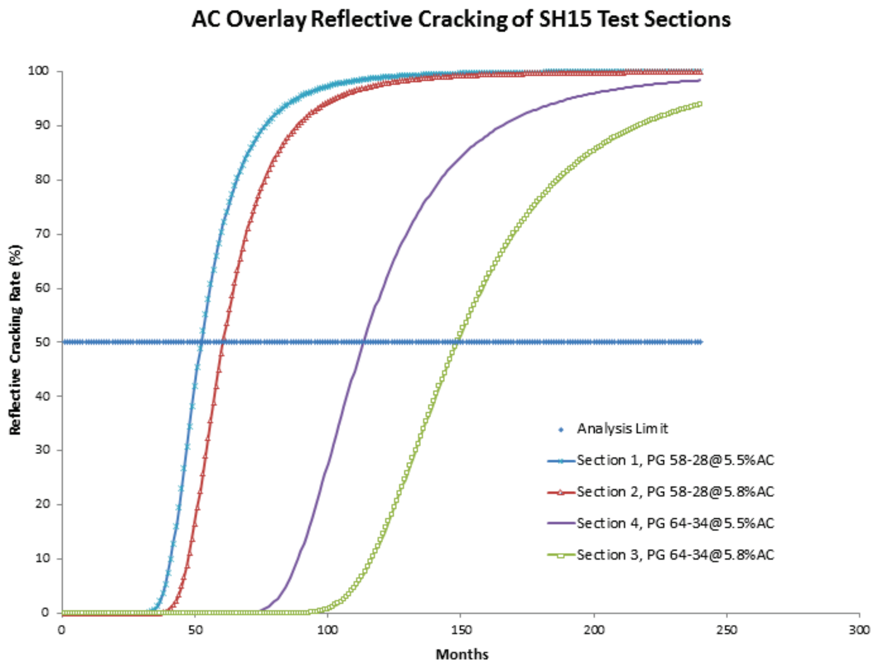


Figure 3-6. Cracking Performance of SH 15 Test Sections.

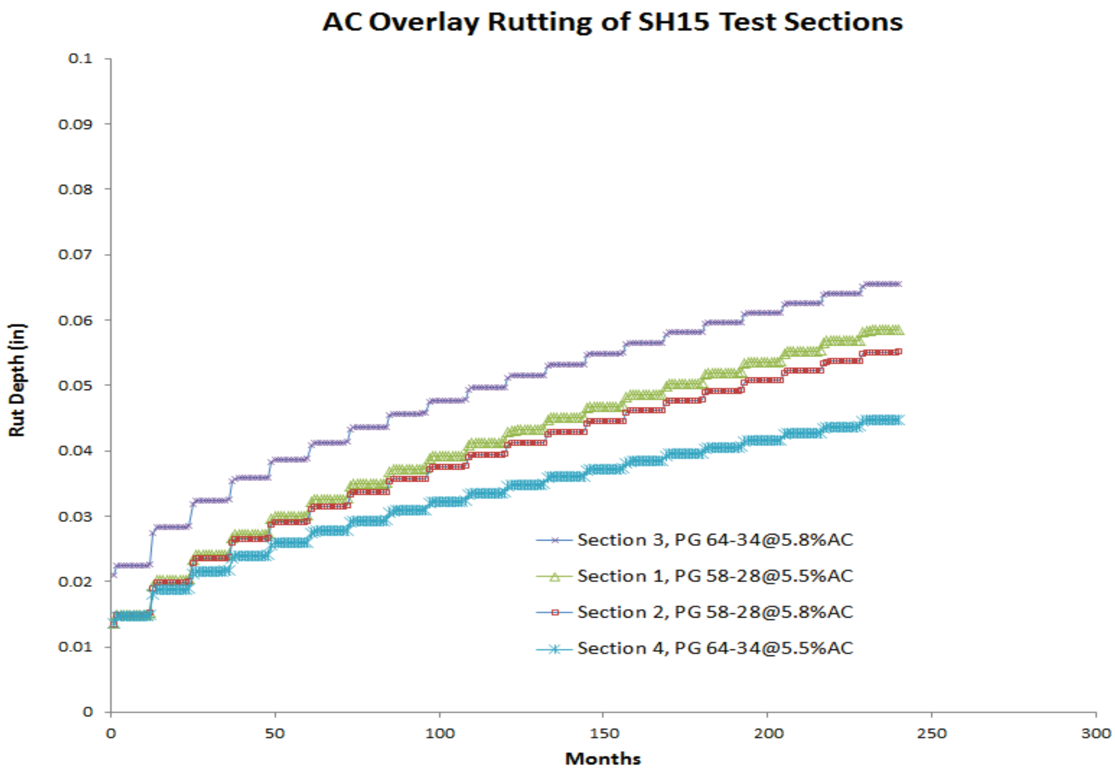


Figure 3-7. Rutting Performance of SH 15 Test Sections.

Figure 3-6 shows that the test sections (Section 3 and Section 4) using PG 64-34 binder have much better cracking resistance than the test sections using PG 58-28 binder (Section 1 and Section 2). Section 3 and Section 4 also perform well in terms of rutting resistance; the accumulated rut depths are less than 0.08 inches after 20 years.

According to Figures 3-6 and 3-7, the overlay cracking resistance and rutting resistance of SH 15 test sections can be ranked below:

- Reflective cracking resistance ranking: Section 3 > Section 4 > Section 2 > Section 1.
- Rutting resistance ranking: Section 4 > Section 2 > Section 1 > Section 3.

Researchers found that the rut resistance ranking is not exactly the opposite of the reflective cracking resistance ranking. Further observation showed that the reflective cracking resistance ranking is consistent with the OT cycles ranking (see Figure 3-8). In addition, either the rutting or the reflective cracking resistance ranking is consistent with the dynamic modulus ranking (see Figure 3-9), which indicates that modulus itself cannot differentiate the pavement performances.

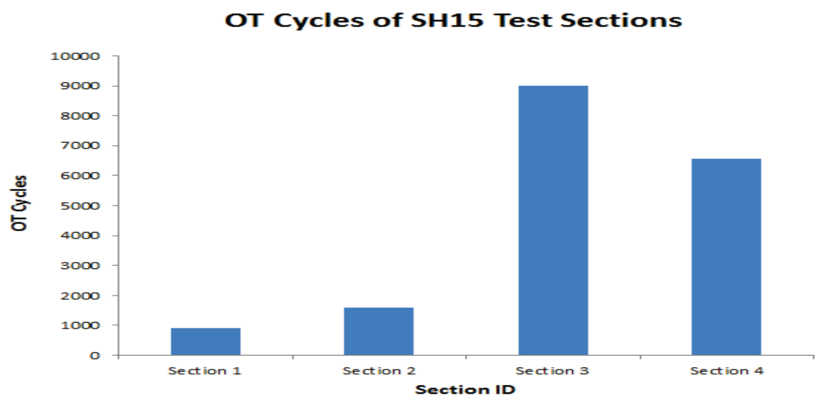


Figure 3-8. OT Cycles Ranking of SH 15 Test Sections.

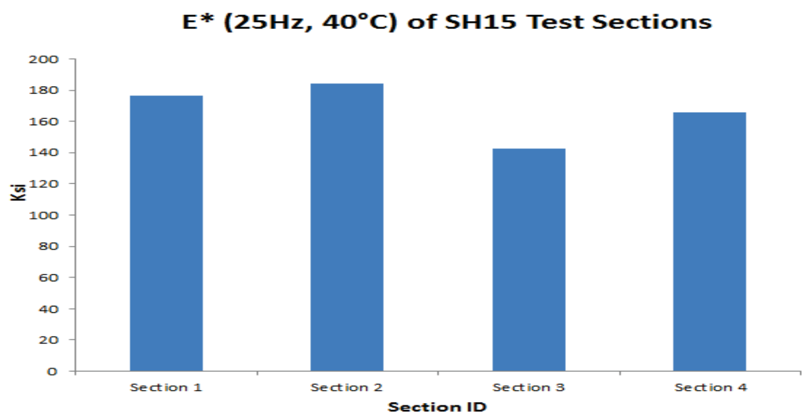


Figure 3-9. Dynamic Modulus Ranking of SH 15 Test Sections.

PREDICTION OF US 62 TEST SECTIONS

There are three test sections on US 62, and their general information, pavement structure, material properties, and prediction results are presented below.

General Information

The three end-to-end test sections on US 62 are named:

- Section 1: PG 64-34, with RAP/RAS.
- Section 2: PG 70-28, virgin mix.
- Section 3: PG 70-28, with RAP/RAS.

Figure 3-10 shows the overview of the US 62 test sections right after construction.

Figure 3-10. Overview of US 62 Test Sections Right after Construction.

Pavement Structure

The US 62 existing AC pavement thickness was about 8 inches. All existing pavement was milled and was replaced by 2 inches of Type D mix plus 3 inches of Type B mix. The base layer was 11 inches for all test sections. Figure 3-11 shows the pavement structure that researchers analyzed for the US 62 test sections.

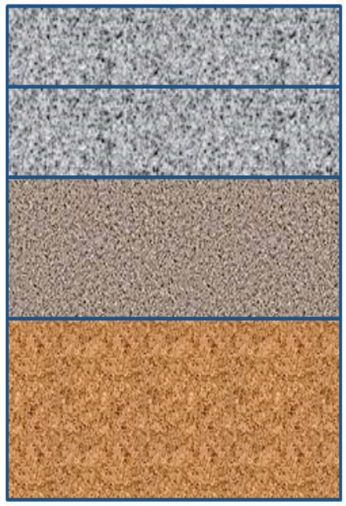


Figure 3-11. Pavement Structure of US 62 Test Sections.

Material Properties

Tables 3-4, 3-5, and 3-6 list the dynamic modulus, rutting properties, and cracking properties, respectively, for each test section on US 62.

Table 3-4. Dynamic Modulus of US 62 Test Sections.

Test Temp. (°C)	Test Frequency (Hz)	Modulus (ksi)		
		Section 1 PG 64-34, RAP/RAS	Section 2 PG 70-28, Virgin Mix	Section 3 PG 70-28, RAP/RAS
4	25	1479.8	1488.6	1826.0
4	10	1265.2	1283.2	1608.1
4	5	1108.0	1135.1	1453.8
4	1	782.5	821.7	1120.8
4	0.5	665.0	702.8	989.5
4	0.1	432.9	470.8	718.9
20	25	631.4	599.0	850.3
20	10	481.5	459.7	685.0
20	5	390.2	377.2	578.7
20	1	220.2	219.7	375.0
20	0.5	174.2	175.6	309.4
20	0.1	93.4	96.9	189.0
40	25	128.5	130.7	215.7
40	10	86.1	88.3	156.2
40	5	63.4	65.4	122.0
40	1	29.6	31.0	64.7
40	0.5	24.0	24.8	52.4
40	0.1	14.1	14.4	30.1
40	0.01	8.5	8.4	15.8

Table 3-5. Rutting Properties of US 62 Test Sections.

Rutting Properties	Section 1 PG 64-34, RAP/RAS	Section 2 PG 70-28, Virgin Mix	Section 3 PG 70-28, RAP/RAS
α	0.7285	0.7581	0.7424
μ	0.5345	0.629	0.4905

Table 3-6. Cracking Properties of US 62 Test Sections.

Cracking Properties	Section 1 PG 64-34, RAP/RAS	Section 2 PG 70-28, Virgin Mix	Section 3 PG 70-28, RAP/RAS
OT cycles	5426	33192	417
A	3.2171E-10	1.0113E-11	4.3272E-8
n	6.5529	7.5019	5.2083

US 62 Test Section Prediction Results

Since all the existing AC layers of the US 62 test sections were removed and replaced, researchers treated the pavement type as a new conventional pavement. Thus, TxME was used to predict the AC fatigue cracking and rutting performance of the US 62 test sections. The traffic volume was assumed to be 3 million ESALs during 20 years. The climatic data from the Childress weather station were selected to determine the pavement temperature. The prediction results in terms of monthly fatigue cracking and rut development are shown in Figures 3-12 and 3-13, respectively.

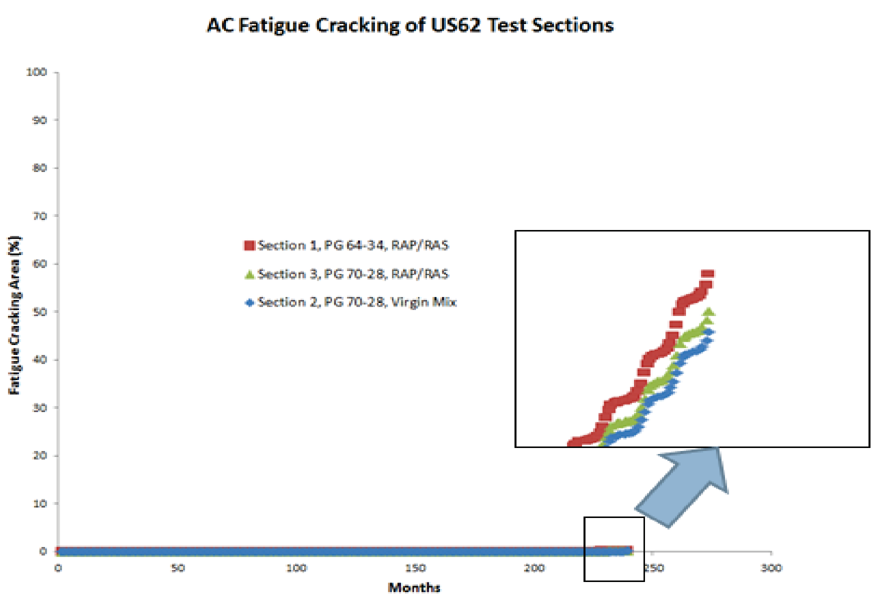


Figure 3-12. Cracking Performance of US 62 Test Sections.

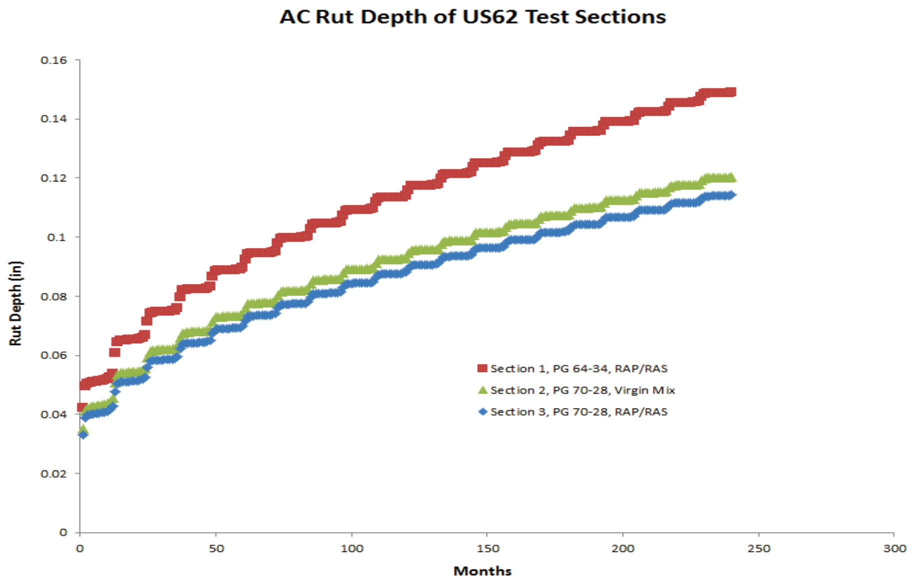


Figure 3-13. Rutting Performance of US 62 Test Sections.

Figure 3-12 shows that all test sections have very little fatigue cracking (less than 1 percent after 20 years). According to Figures 3-12 and 3-13, the fatigue cracking resistance and AC rutting resistance of US 62 test sections can be ranked:

- Fatigue cracking resistance ranking: Section 2 > Section 3 > Section 1.
- AC rutting resistance ranking: Section 3 > Section 2 > Section 1.

Generally, these rankings are reasonable since the rut resistance ranking is not exactly the opposite of the fatigue cracking resistance ranking. Further observation shows that the dynamic modulus ranking and the OT cycles/fracture properties ranking (see Tables 3-4 and 3-6) are:

- Dynamic modulus ranking: Section 3 > Section 2 ≥ Section 1.
- OT cycles ranking: Section 2 > Section 1 > Section 3.

Note that the fatigue cracking resistance ranking is not consistent with either the OT cycles ranking or the dynamic modulus ranking. This is because the AC fatigue cracking life depends on both the crack initiation life (controlled by AC bottom stress, influenced by dynamic modulus) and crack propagation life (influenced by fracture property A). Stiff AC materials may have shorter crack propagation life (A is larger) but longer crack initiation life (bottom stress is smaller). The two competitive effects depend on many other parameters, such as climate condition, overlay thickness, base modulus, or base thickness. This scenario is consistent with the MEPDG finding (El-Basyouny and Witczak 2005), which points out, "It is observed that for very thick AC sections, fatigue damage (cracking) is increased for low stiffness AC mixtures. This is 180 degrees opposite to the findings of mix stiffness-fatigue damage for very thin AC layers. The influence of AC mix stiffness is more significant as the foundation support decreases. In general, for a very large AC thickness, low E* mixtures would tend to show more damage (cracking)."

PREDICTION OF LOOP 820 TEST SECTIONS

There are four test sections located on the westbound side of Loop 820, side by side on four lanes. The general information, pavement structure, material properties, and prediction results of the Loop 820 test sections are presented below.

General Information

The four test sections on Loop 820 are numbered Section 0, 1, 2, and 3. All the test section overlay mixes contain 13 percent RAP and 5 percent RAS. The differences between the mixes involve the binder type and binder content, and the sections are named:

- Section 0: PG 64-22, Control mix.
- Section 1: PG 64-22, Advera blended with RAP/RAS.
- Section 2: PG 64-28.
- Section 3: PG 64-22 with 0.4 percent more binder.

Figure 3-14 shows the overview of the Loop 820 test sections right after construction.

Figure 3-14. Overview of Loop 820 Test Sections Right after Construction.

Pavement Structure

The existing pavement on Loop 820 was CRCP. Figure 3-15 shows the pavement structure that researchers analyzed for the Loop 820 test sections.

Figure 3-15. Pavement Structure of Loop 820 Test Sections.

Material Properties

Tables 3-7, 3-8, and 3-9 summarize the dynamic modulus, rutting properties, and cracking properties, respectively, for each test section on Loop 820.

Table 3-7. Dynamic Modulus of Loop 820 Test Sections.

Test Temp. (°C)	Test Frequency (Hz)	Modulus (ksi)			
		Section 0 PG 64-22, control mix	Section 1 PG 6422, blended with Advera	Section 2 PG 64-28	Section 3 PG 64-22 with 0.4% more binder
4	25	2393.7	2033.0	2011.2	2309.5
4	10	2220.5	1845.6	1826.3	2117.5
4	5	2088.4	1700.5	1685.5	1971.6
4	1	1781.6	1381.1	1362.6	1639.8
4	0.5	1647.0	1243.6	1226.0	1494.0
4	0.1	1341.7	935.6	928.7	1178.2
20	25	1458.7	1119.8	1046.6	1242.6
20	10	1264.9	940.9	866.0	1052.0
20	5	1120.6	820.1	747.5	922.5
20	1	825.7	570.5	511.5	658.3
20	0.5	713.8	485.4	432.8	566.8
20	0.1	489.6	314.8	280.3	381.5
40	25	468.2	384.5	333.8	398.8
40	10	358.9	288.2	249.6	305.9
40	5	292.2	230.4	200.1	246.0
40	1	162.7	127.2	110.1	134.7
40	0.5	129.9	100.8	88.4	109.1
40	0.1	72.8	56.0	49.6	65.1
40	0.01	34.2	27	24.5	37.6

Table 3-8. Rutting Properties of Loop 820 Test Sections.

Rutting Properties	Section 0 PG 64-22, control mix	Section 1 PG 6422, Advera blended with RAP/RAS	Section 2 PG 64-28	Section 3 PG 64-22 with 0.4% more binder
α	0.6921	0.7311	0.6674	0.7102
μ	0.312	0.671	0.4915	0.548

Table 3-9. Cracking Properties of Loop 820 Test Sections.

Cracking Properties	Section 0 PG 64-22, control mix	Section 1 PG 6422, Advera blended with RAP/RAS	Section 2 PG 64-28	Section 3 PG 64-22 with 0.4% more binder
OT cycles	8	12	22	24
A	8.2469E-5	3.8011E-5	1.1941E-5	1.0112E-5
n	3.1366	3.3491	3.6667	3.7123

Loop 820 Test Section Prediction Results

The research team used TxACOL to predict the performance of the Loop 820 test sections. The traffic volume was assumed to be 5 million ESALs during 20 years. The climatic data from the Fort Worth weather station were selected to determine the pavement temperature. The prediction results in terms of monthly reflective cracking and rut development are shown in Figures 3-16 and 3-17, respectively.

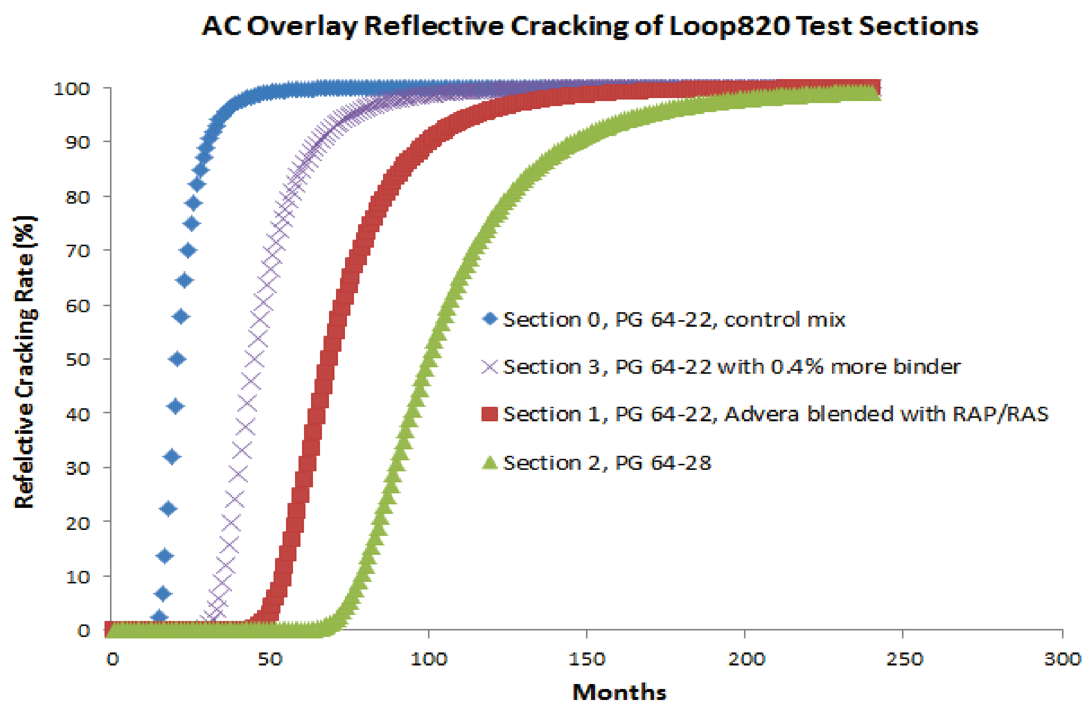


Figure 3-16. Cracking Performance of Loop 820 Test Sections.

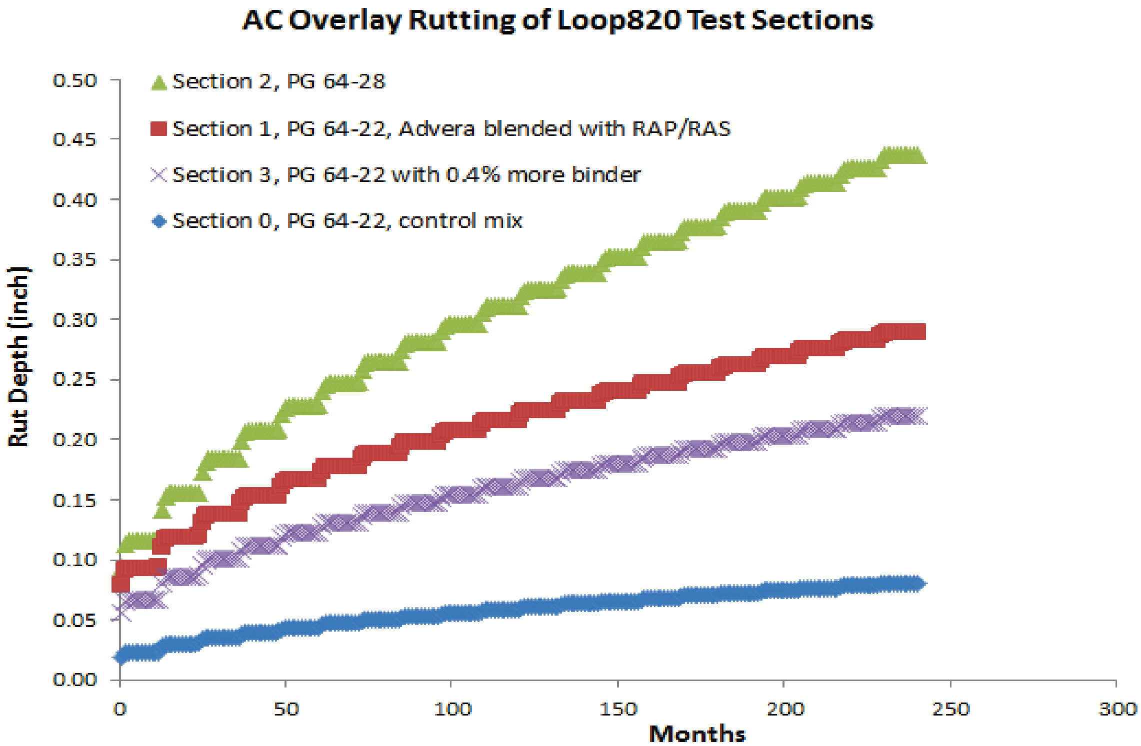


Figure 3-17. Rutting Performance of Loop 820 Test Sections.

According to Figures 3-16 and 3-17, the reflective cracking resistance and AC rutting resistance of the Loop 820 test sections can be ranked:

- AC reflective cracking resistance ranking: Section 2 > Section 1 > Section 3 > Section 0.
- AC rutting resistance ranking: Section 0 > Section 3 > Section 1 > Section 2.

In this case, the rut resistance ranking is exactly the opposite of the cracking resistance ranking. Further observation shows that the dynamic modulus ranking and the OT cycles/fracture properties ranking (Tables 3-7 and 3-9) are:

- Dynamic modulus ranking: Section 0 > Section 3 > Section 1 > Section 2.
- OT cycles ranking: Section 3 > Section 2 > Section 1 > Section 0.

Both the AC cracking and rutting resistance rankings are consistent with the dynamic modulus ranking. There is a little difference between the cracking resistance ranking and the OT cycles ranking because the OT cycles of the sections are basically pretty close to each other (e.g., 12, 22, and 24), and the difference in the dynamic modulus plays a dominant role.

FIELD TEST SECTION SURVEY

The field survey results for all the test sections are presented below. So far, the surveyed performance of these test sections has been consistent with the prediction results. Undoubtedly, these test sections need to be monitored for a longer time, and more comparisons need to be made between the prediction and survey results.

SH 15 Test Section Field Survey Results

The field survey for the SH 15 test sections was conducted on June 7, 2014, 8 months after construction, including a winter. Researchers observed no rutting or cracking on these sections (see Figure 3-18). A segregation area was found on Section 4.

Figure 3-18. Field Survey of SH 15 Test Sections.

US 62 Test Section Field Survey Results

The field survey for the US 62 test sections was conducted on June 6, 2014, also 8 months after construction. Researchers observed no rutting or cracking on these sections (see Figure 3-19).

Figure 3-19. Field Survey of US 62 Test Sections.

Loop 820 Test Section Field Survey Results

The field survey for the Loop 820 test sections was conducted on February 10, 2013, and June 12, 2014, 7 and 23 months after construction, respectively. No cracking was observed on these sections (see Figure 3-20). No obvious rutting was observed either; however, the 3 m ruler was not put on the lanes to confirm since no traffic control was taken.

Figure 3-20. Field Survey of US 62 Test Sections.

SUMMARY

The research team sampled and tested the plant mixes of 11 test sections (four on SH 15, three on US 62, and four on Loop 820). These test results were input into TxACOL or TxME to predict performance in terms of cracking and rutting. All the crack predictions during the first 2 years were close to zero or very small, which was consistent with the field observations. The predicted rutting depths on the SH 15 and US 62 test sections were small (less than 0.1 inch), which the field survey also confirmed. According to the prediction results, the asphalt mixes with PG 64-34, the softer but highly modified binders, showed both good rutting and cracking resistance. The predicted performance ranking and the differences among test sections were reasonable and helpful for validating the embedded models (cracking model and rutting model). Researchers will continue to monitor these test sections and will make more comparisons between the prediction and survey results for further model refining/calibration.

CHAPTER 4
CRACKING PERFORMANCE SIMULATIONS AND STATEWIDE BINDER RECOMMENDATIONS

INTRODUCTION

As stated in Chapter 1, one objective of this research project was to identify optimal asphalt binder/aggregate combinations for different environmental zones in Texas. To achieve this, the researchers developed a partial factorial design to consider all critical influential factors including environmental zones, traffic levels, binder types, aggregate types, mix types, and overlay thicknesses. The implemented TxACOL was used to simulate these factorial designs and to predict overlay performance, mainly cracking performance since it is currently the main issue in Texas overlays.

In total, 2700 cracking performance simulations were conducted during this research. Researchers then developed a statewide catalogue of binder recommendations based on the simulation results. The partial factorial design, simulation methods and results, and statewide binder type recommendation catalogue are presented below.

PARTIAL FACTORIAL DESIGN

To conduct the cracking performance simulations, researchers needed the factorial design to identify the typical value or range of critical factors such as environmental zone, traffic level, overlay thickness, overlay mixture type, and existing pavement structure type. The following sections present the proposed value and range for each factor.

Environmental Zone

For this research, Texas was divided into five environmental zones: dry-cold, wet-cold, moderate, dry-warm, and wet-warm. Figure 4-1 shows the environmental zones and the corresponding districts in different colors. For each environmental zone, a representative district was identified, and its weather station data were used in the simulation. The five representative districts were:

- Amarillo, for the dry-cold zone.
- Paris, for the wet-cold zone.
- Odessa, for the dry-warm zone.
- Beaumont, for the wet-warm zone.
- Austin, for the moderate zone.

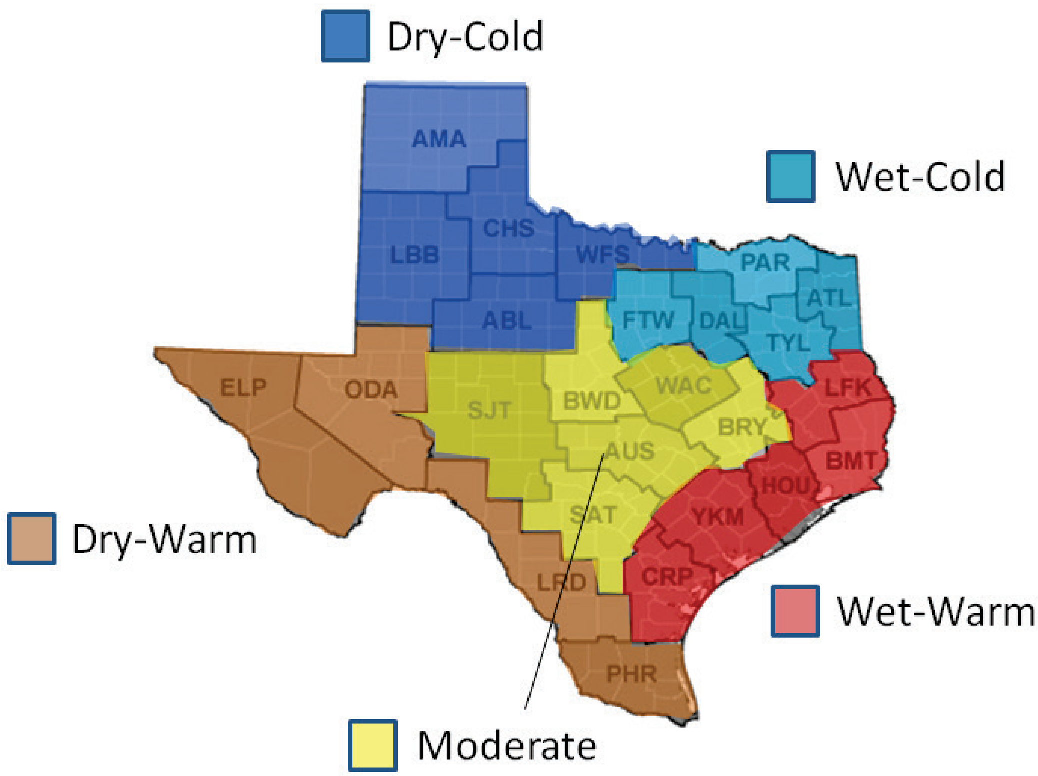


Figure 4-1. Texas Environmental Zones.

Traffic Level

The research team considered four levels of traffic in the simulation: light, medium, heavy, and super heavy. TxACOL accepts the traffic input as accumulated ESALs in 20 years (Figure 4-2), which is similar to the current TxDOT flexible pavement design system FPS 21. The corresponding ESALs numbers for the simulations were 3 million, 5 million, 10 million, and 30 million, respectively. In this research, the traffic speed was assumed to be the same (60 mph) for all simulations.

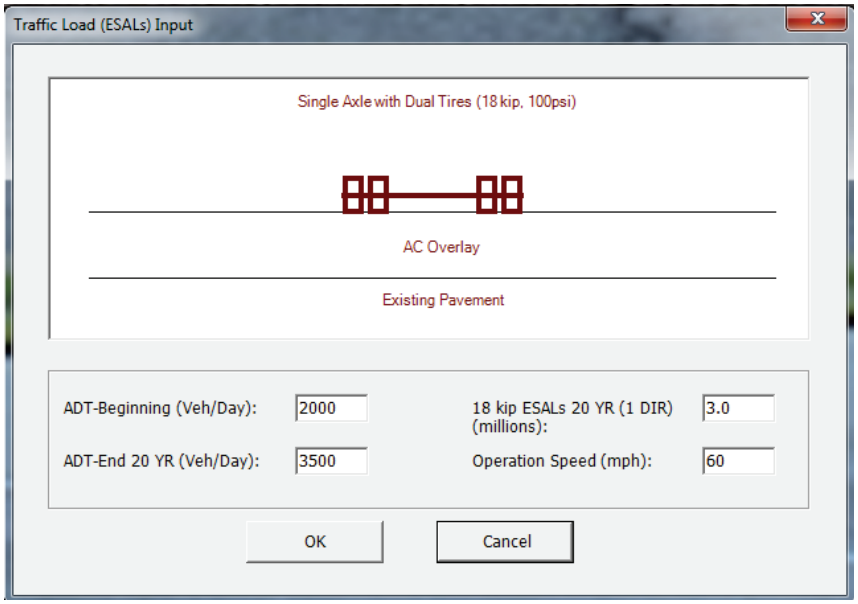


Figure 4-2. TxACOL Traffic Input Screen.

Overlay Thickness

The most common overlay thickness in Texas is between 2 to 4 inches. The research team assumed three thicknesses for the simulations: 2 inches, 3 inches, and 4 inches.

Overlay Mixture Type

Three types of aggregates (limestone, crushed gravel, and granite) and five binders (PG 64-22, PG 64-28, PG 64-34, PG 70-22, and PG 76-22) were mixed together, and a total of 15 mixes were used for this study. For each aggregate type, the same asphalt binder content and gradation were used for all the mixes, and the only variable was asphalt binder type.

Researchers used the OT to evaluate the cracking resistance of the asphalt mixes. The OT was performed following Tex-248-F: *Test Procedure for Overlay Test* (TxDOT 2009). Five trimmed specimens from each mixture targeting an air void of 7 percent ± 1 percent were prepared. Before testing, individual OT specimens were conditioned in an environmental chamber with a target temperature of 77°F (25°C). The sliding block applied tension in a cyclic triangular waveform to a constant maximum displacement of 0.025 inch. The sliding block reached the maximum displacement and then returned to its initial position in 10 sec. The time, displacement, and load corresponding to a certain number of loading cycles were recorded during the tests. The number of cycles to failure was determined for each specimen when the maximum load reached 7 percent of the initial maximum load recorded in the first cycle. The average of the OT cycles of five specimens was reported. The larger the OT cycles, the better cracking resistance was.

Figure 4-3 shows the OT results of the 15 mixes. As the figure illustrates, the PG 64-34 binder had the best cracking resistance, followed by PG 64-28. It seems that the PG 64-22 and PG 70-22 binders performed similarly. The PG 76-22 binder had the smallest OT cycles and was ranked last.

Figure 4-3. OT Test Results of 15 Asphalt Mixes.

Existing Pavement Structure Type

After careful discussion, the research team selected three typical scenarios of existing pavement structures that often have reflective cracking concerns, as follows:

- Conventional existing AC (5 inches) over granular base (GB); the GB was assumed to be 12 inches with 50 ksi resilient modulus.
- Thinner existing AC (3 inches) over cement treated base (CTB); the CTB was assumed to be 10 inches with 200 ksi resilient modulus.
- Existing Jointed Plain Concrete Pavement (JPCP; 10 inches) over GB; the GB was assumed to be 6 inches with 50 ksi resilient modulus.

For all these scenarios, the load transfer efficiency value of the existing layer was assumed to be 70 percent.

Total Simulations

Table 4-1 sums up the factors of the factorial design. The total simulation number for the factorial design was the following: 5 Climatic Zones × 4 Traffic Levels × 3 Overlay Thicknesses × 15 Mixes × 3 Existing Pavement Structures = 2700.

Table 4-1. Summary of Factorial Design.

Factor Name	Numbers
Environmental Zones	5 Zones: Zone 1: Dry-Cold Zone 2: Wet-Cold Zone 3: Dry-Warm Zone 4: Wet-Warm Zone 5: Moderate
Existing Pavement Structure	3 Structures: Structure 1: Thinner Existing AC over CTB Structure 2: Conventional AC over GB Structure 3: Existing JPCP over GB
Traffic Level	4 Levels: 3 million, 5 million, 10 million, and 30 million
Overlay Thickness	3 Thicknesses: 2 inches, 3 inches, and 4 inches
Overlay Mixture	15 Mixes: Limestone + PG 64-22, 190 OT cycles Limestone + PG 64-28, 832 OT cycles Limestone + PG 64-34, 1600 OT cycles Limestone + PG 70-22, 91 OT cycles Limestone + PG 76-22, 89 OT cycles Gravel + PG 64-22, 106 OT cycles Gravel + PG 64-28, 673 OT cycles Gravel + PG 64-34, 1400 OT cycles Gravel + PG 70-22, 111 OT cycles Gravel + PG 76-22, 55 OT cycles Granite + PG 64-22, 259 OT cycles Granite + PG 64-28, 1800 OT cycles Granite + PG 64-34, 5000 OT cycles Granite + PG 70-22, 224 OT cycles Granite + PG 76-22, 120 OT cycles

SIMULATION METHOD AND RESULTS

Researchers used the implemented TxACOL program to perform the simulations. It was envisioned that TxACOL would act as a virtual experiment that would give the pavement engineers the ability to easily evaluate how pavement would respond under each scenario. To perform the simulation work, researchers numbered each simulation, and corresponding information, such as the climate, traffic, pavement structure, and material property (dynamic modulus and cracking property), was processed and organized into TxACOL input format. Generally, one simulation analysis took about 2 minutes to compute. The outputs of each simulation were the monthly reflective cracking rates and monthly rutting depths. More details about the input and output screens can be found in Chapter 3. In this research, the month number needed for the reflective cracking rate to reach 50 percent was picked as the cracking life.

Determination of Cracking Life

The results were tabulated in an Excel file format. Figure 4-4 shows part of the simulation results and the organization. In this figure, the last column in the Excel spreadsheet lists the cracking life in terms of months, corresponding to each simulated scenario.

The spreadsheet divided the 2700 simulation results into 180 groups; each group included 15 simulation results. Based on the results, only the mix OT cycles varied, while the other factors were unchanged. Figure 4-4a shows the cracking life results corresponding to different mixture types for the group of mixtures made up of a thinner existing AC over CTB with 2-inch overlay under 3 million ESALs of traffic in the dry-cold zone, while Figure 4-4b shows the cracking life results corresponding to different mixture types for the group of mixtures with a thinner existing AC over CTB with 2-inch overlay under 5 million ESALs of traffic in the dry-warm zone.

	Environmental Zones	Existing Pavement Structures	Traffic Levels	Overlay Thicknesses	Aggregate Types	Binder Types	Mix OT Cycles	Cracking Life (Months)
1	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-22	190	7
2	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-28	832	53
3	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-34	1600	77
4	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG70-22	91	7
5	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG76-22	89	7
6	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-22	106	7
7	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-28	673	43
8	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-34	1400	68
9	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG70-22	111	7
10	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG76-22	55	7
11	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-22	259	7
12	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-28	1800	79
13	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-34	5000	139
14	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG70-22	224	8
15	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG76-22	120	7

a. Thinner existing AC over CTB with 2-inch overlay under 3 million ESALs of traffic in the dry-cold zone.

226	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	LimeStone	PG64-22	190	32
227	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	LimeStone	PG64-28	832	79
228	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	LimeStone	PG64-34	1600	114
229	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	LimeStone	PG70-22	91	20
230	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	LimeStone	PG76-22	89	20
231	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Gravel	PG64-22	106	24
232	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Gravel	PG64-28	673	69
233	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Gravel	PG64-34	1400	104
234	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Gravel	PG70-22	111	23
235	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Gravel	PG76-22	55	16
236	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Granite	PG64-22	259	41
237	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Granite	PG64-28	1800	117
238	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Granite	PG64-34	5000	196
239	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Granite	PG70-22	224	33
240	Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	5	2	Granite	PG76-22	120	23

b. Thinner existing AC over CTB with 2-inch overlay under 5 million ESALs of traffic in the dry-warm zone.

Figure 4-4. An Example of Simulation Results.

Determination of Required OT Cycles

By sorting the Excel table shown in Figure 4-4a according to mix OT cycles, researchers were able to reorganize the data as shown in Figure 4-5. Assuming the target of expected cracking life is 5 years (60 months), the required mix OT cycle number can easily be determined as 1097 through simple interpolation.

	Environmental Zones	Existing Pavement Structures	Traffic Levels	Overlay Thicknesses	Aggregate Types	Binder Types	Mix OT Cycles	Cracking Life
10	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG76-22	55	7
5	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG76-22	89	7
4	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG70-22	91	7
6	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-22	106	7
9	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG70-22	111	7
15	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG76-22	120	7
1	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-22	190	7
11	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-22	259	7
14	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG70-22	224	8
7	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-28	673	43
2	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-28	832	53
8	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Gravel	PG64-34	1400	68
3	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	LimeStone	PG64-34	1600	77
12	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-28	1800	79
13	Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	3	2	Granite	PG64-34	5000	139

Figure 4-5. Sorted Simulation Results According to OT Cycles.

Similarly, the required OT cycles to reach 5 years of life for the other 179 groups were determined. Table 4-2 shows part of the results.

Table 4-2. Required OT Cycles for Different Environmental Zones, Existing Pavement Structures, Overlay Thicknesses, and Traffic Levels.

Environmental Zones	Existing Pavement Structures	Required OT Cycles to reach 5 years life			
		2", 3 million	4", 30 million	3", 5 million	3", 10 million
Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Conventional Existing AC over GB	397	213	80	209
Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Conventional Existing AC over GB	164	90	31	98
Environmental Zone 3 (Wet-Cold, e.g., Dallas)	Conventional Existing AC over GB	167	93	33	99
Environmental Zone 4 (Wet-Warm, e.g., Beaumont)	Conventional Existing AC over GB	155	77	31	91
Environmental Zone 5 (Moderate, e.g., Austin)	Conventional Existing AC over GB	167	89	33	96
Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Existing JPCP over GB	16,927	511	864	1473
Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Existing JPCP over GB	509	217	147	287
Environmental Zone 3 (Wet-Cold, e.g., Dallas)	Existing JPCP over GB	369	201	106	242
Environmental Zone 4 (Wet-Warm, e.g., Beaumont)	Existing JPCP over GB	240	196	80	216
Environmental Zone 5 (Moderate, e.g., Austin)	Existing JPCP over GB	287	204	90	237
Environmental Zone 1 (Dry-Cold, e.g., Amarillo)	Thinner Existing AC over CTB	1097	1743	394	737
Environmental Zone 2 (Dry-Warm, e.g., Odessa)	Thinner Existing AC over CTB	291	371	102	235
Environmental Zone 3 (Wet-Cold, e.g., Dallas)	Thinner Existing AC over CTB	242	377	102	235
Environmental Zone 4 (Wet-Warm, e.g., Beaumont)	Thinner Existing AC over CTB	232	263	83	167
Environmental Zone 5 (Moderate, e.g., Austin)	Thinner Existing AC over CTB	238	331	95	210

DEVELOPMENT OF STATEWIDE BINDER TYPE RECOMMENDATION CATALOGUE

Since the required OT cycles of overlay mixture were determined for different environmental zones, existing pavement structures, overlay thicknesses, and traffic levels, it was possible for researchers to identify which binder types could meet the requirements for the different scenarios. The following sections discuss the statewide binder type catalogue development method and final recommendations.

Development Method

To develop the statewide binder type recommendation catalogue, the research team followed the methods and steps below.

- Identified the environmental zone for each district, which could be done according to Figure 4-1.
- Chose one typical aggregate type (gravel, limestone, or granite) used in each district.
- Determined the required OT cycles according to the existing pavement structure.
- Decided which binder type (PG 64-22, PG 64-34, PG 64-28, PG 70-22, or PG 76-22) mixed with the typical aggregate could meet the OT cycle requirement.

According to Texas overlay design practices, the overlay thickness is often tied to the traffic level. For example, if the traffic level is super heavy, e.g., 30 million ESALs, the overlay thickness most likely will be 4 inches rather than 2 inches. By comparing the required OT cycles shown in Table 4-2, researchers chose the numbers corresponding to 2 inches of overlay and 3 million ESALs since those numbers were representative and conservative.

Recommended Catalogue

Table 4-3 presents the final recommendations for the statewide binder type. Researchers followed the below steps to develop the final recommendations. The Amarillo District is used as an example here to describe the procedure:

- As Figure 4-1 illustrates, the Amarillo District belongs to the dry-cold environmental zone.
- Gravel was chosen as the typical aggregate type used in the Amarillo District.
- As shown in Table 4-2, the required OT cycles needed to reach 5 years of cracking life were 397, 16,927, and 1097 for the existing pavement structures of conventional AC over GB, existing JPCP over GB, and thinner existing AC over CTB, respectively.
- Since the OT cycles were 106, 643, and 1400 for the mixes of gravel with PG 64-22, PG 64-28, and PG 64-34, respectively, the final binder recommendations for the Amarillo District were the following: PG 64-28, PG 64-34 with higher asphalt content (%AC), and PG 64-34 for the existing pavement structures of conventional AC over GB, existing JPCP over GB, and thinner existing AC over CTB, respectively. In fact, if the existing pavement layer were JPCP in Amarillo, 2 inches of overlay was not recommended since it requires unreasonably high OT cycles of the overlay mixture.

The information shown in Table 4-3 is based on virgin mixes; no RAP/RAS is involved. Also, engineers in hot areas like the Pharr District should exercise caution when using information presented in Table 4-3 because the rutting issue might also be a concern.

Table 4-3. Statewide Binder Type Recommendation Catalogue.

District	Aggregate	Recommended Binder Type		
		Conventional Existing AC over GB	Existing JPCP over GB	Thinner Existing AC over CTB
01 Paris	Gravel	PG64-28	PG64-34	PG64-28
02 Fort Worth	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-34	PG64-28
03 Wichita Falls	Gravel	PG64-28	PG64-34	PG64-28
04 Amarillo	Gravel	PG64-28	PG64-34 (Higher %AC)	PG64-34
05 Lubbock	Gravel	PG64-28	PG64-34 (Higher %AC)	PG64-28 (Higher %AC) or PG64-34
06 Odessa	Gravel	PG64-28	PG64-28	PG64-28
07 San Angelo	Gravel	PG64-28	PG64-28	PG64-28
08 Abilene	Gravel	PG64-28	PG64-34 (Higher %AC)	PG64-28 (Higher %AC) or PG64-34
09 Waco	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28

10 Tyler	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-34	PG64-28
11 Lufkin	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
12 Houston	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
13 Yoakum	Gravel	PG64-28	PG64-28	PG64-28
14 Austin	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
15 San Antonio	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
16 Corpus Christi	Gravel	PG64-22	PG64-22	PG64-22 (Higher %AC) or PG64-28
17 Bryan	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
18 Dallas	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
19 Atlanta	Granite	PG70-22	PG64-28	PG64-28
20 Beaumont	Granite	PG70-22	PG64-28	PG64-22 (Higher %AC) or PG64-28
21 Pharr	Gravel	PG64-22	PG64-22	PG64-22 (Higher %AC) or PG64-28
22 Laredo	Gravel	PG64-22	PG64-22	PG64-22 (Higher %AC) or PG64-28
23 Brownwood	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
24 El Paso	Limestone	PG64-22 (Higher %AC) or PG64-28	PG64-28	PG64-28
25 Childress	Gravel	PG64-28	PG64-34 (Higher %AC)	PG64-28 (Higher %AC) or PG64-34

SUMMARY

The research team developed a partial factorial design to consider all critical influential factors including environmental zones, traffic levels, binder types, aggregate types, mix types, and overlay thicknesses. The implemented TxACOL was used to predict the overlay performance of each scenario of the factorial design, mainly cracking performance since it is currently the main issue in Texas overlays. TxACOL acted as a virtual experiment that gave the pavement engineers the ability to easily evaluate how pavements would respond under each scenario.

To perform the simulation work, researchers numbered each simulation, and corresponding information, such as the climate, traffic, pavement structure, and material property (dynamic modulus and cracking property), was processed and organized into TxACOL input format. In total, 2700 cracking performance simulations were conducted during this research.

Based on the simulation results, researchers determined the required OT cycles of overlay mixture for different environmental zones, existing pavement structures, overlay thicknesses, and traffic levels. Based on those findings, the research team then developed a statewide catalogue of binder recommendations. The recommendations are based on virgin mixes; no RAP/RAS is involved. Engineers in hot areas like the Pharr District should exercise caution when using catalogue recommendations because the rutting issue might also be a concern.

CHAPTER 5
LIFE CYCLING COST ANALYSIS

INTRODUCTION

Based on the performance simulation results and the district binder type recommendations, the research team conducted a pavement life cycling cost analysis (LCCA) to evaluate the financial benefits of the recommendations. The researchers chose the Amarillo, Austin, and Pharr Districts, which represent cold, moderate, and hot areas, respectively, to demonstrate the analysis processes.

Running an LCCA can be done in several ways, but the most widely accepted method is using software. The Federal Highway Administration's (FHWA's) RealCost software is the most versatile package, compared to other existing LCCA packages (Lamptey et al. 2005). RealCost was developed based on a Microsoft Excel macro and has both spreadsheet and screen input interfaces. In this project, researchers used RealCost as a tool to compare the total user and agency costs of project implementation alternatives (mixes using different binders, such as PG 64-22, PG 64-28, and PG 64-34). RealCost is appropriate to be applied in comparing project implementation alternatives that will yield the same level of service and benefits to the project user at any specific volume of traffic.

This chapter first provides an overview of FHWA RealCost and then describes the input information of the alternatives for each district: Amarillo, Austin, and Pharr. Finally, the chapter presents the analysis results and summaries.

OVERVIEW OF FHWA REALCOST

An FHWA interim technical bulletin (Walls and Smith 1998) provides technical guidance and recommendations on good practices in conducting an LCCA in pavement design. It also incorporates risk analysis, a probabilistic approach to describe and account for the uncertainties inherent in the decision process. It deals specifically with the technical aspects of long-term economic efficiency implications of alternative pavement designs. The bulletin is intended for state highway agency personnel responsible for conducting and/or reviewing pavement design LCCAs. The LCCA process steps are:

- Establish design alternatives.
- Determine activity timing.
- Estimate costs (agency and user).
- Compute life-cycle costs.
- Analyze the results.

As the FHWA LCCA software product, the RealCost software incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures.

The RealCost interface requires the user to enter inputs in various screens (see Figure 5-1), and it then applies a series of algorithms to determine which of the given alternatives is the superior choice based on the inputs. To be most accurate, an LCCA requires precise information pertaining to the specific job being assessed. However, for the purposes of this research, some scenarios had to be hypothesized.

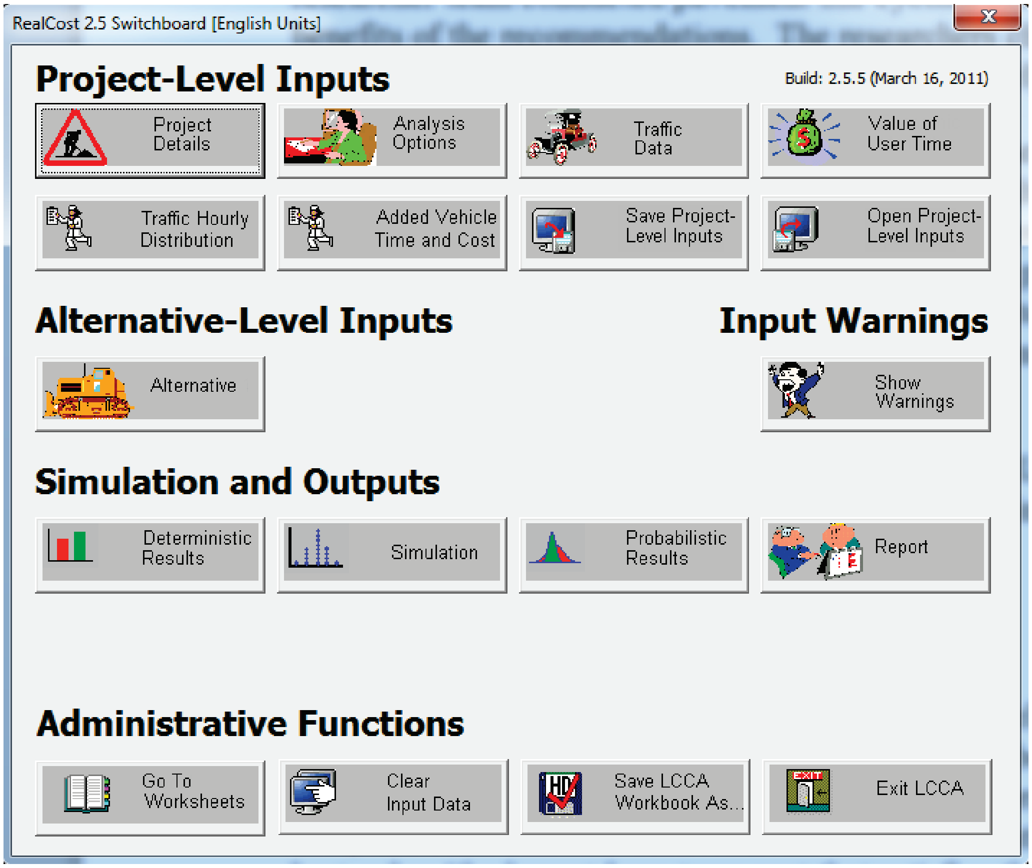


Figure 5-1. Interface of FHWA RealCost Software.

INPUTS OF FHWA REALCOST

Due to the complex nature of the inputs required, and in order to obtain the best representative numbers, researchers gathered inputs from several sources to perform the LCCAs for the case studies contained below. The inputs are discussed in the order in which they appear in the RealCost program. After the general discussion of inputs that apply to all cases, the specific inputs are discussed for different districts.

For this project, researchers hypothesized a 2-inch overlay 2 mi long for all analyses; the traffic was assumed to be 3 million ESALs. Two of the existing pavement structures described in Chapter 4—the conventional existing AC over GB and the thinner existing AC over CTB—were assumed.

Project Detail Inputs

The project details consist of the general information of a project being analyzed. Figure 5-2 shows an example of the project details screen.

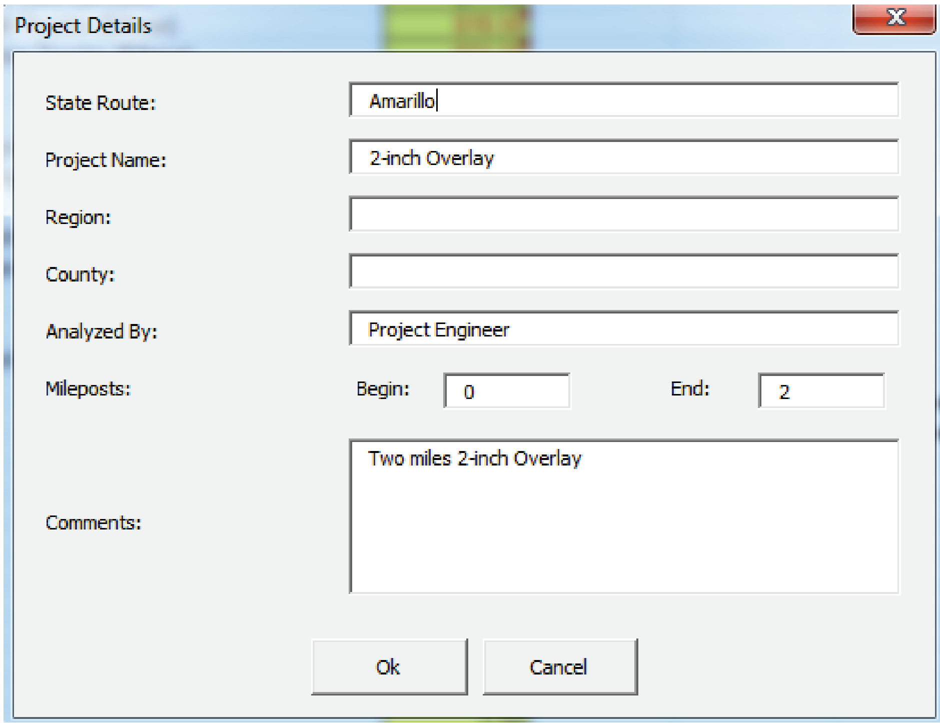


Figure 5-2. Example of Project Details Screen.

Analysis Option Inputs

The analysis option inputs include:

- Analysis Units—English or metric. All LCCAs in this project used English.
- Analysis period (years)—The number of years for which the program would run the analysis.
- Discount Rate (percent)—The discount rate the program would apply to the costs for the analysis period. This number is generally between 2–4 percent nationally. A discount rate of 4 percent was used on all LCCAs in this project.
- Beginning of Analysis Period—The year the user wants the analysis to begin. All LCCAs in this project were run beginning in 2014.
- Include Agency Cost Remaining Service Life Value (check box)—This box was left checked in all LCCAs run.
- Include User Costs in Analysis (check box)—This box was left checked in all LCCAs run.
- User Cost Computation Method—Users choose "calculated" or "specified." "Calculated" was selected for all LCCAs run.
- Traffic Direction—Users select "one-way" or "both." "Both" was specified for all LCCAs in this project.

- Include User Cost Remaining Value (check box)—This box was left checked for all LCCAs run in this project.
- Number of Alternatives—Researchers selected 3 since the alternatives in this project included mixes using binders PG 64-22, PG 64-28, or PG 64-34.

Figure 5-3 shows an example of the analysis options screen.

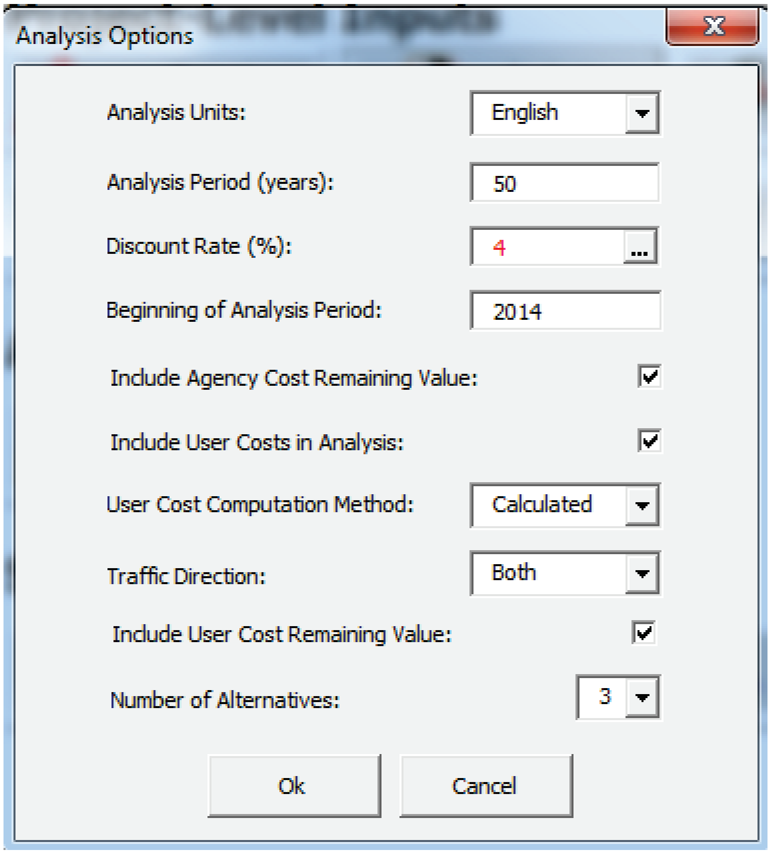


Figure 5-3. Example of Analysis Options Screen.

Traffic Data Inputs

To calculate user costs, the program uses work zone traffic data. The inputs include:

- AADT at Beginning of Analysis Period (total both directions)—the annual average daily traffic (AADT) level for the year in which the analysis period is set to begin. An AADT of 20,000 was used for this study since this traffic level is similar to 3 million ESALs (20 years) based on past research experiences (Hu et al. 2014).
- Single Unit Trucks as Percentage of AADT—Based on both national and local information (Ryu et al. 2013), the single unit truck percentage was set at 7 percent.
- Combination Trucks as Percentage of AADT—Based on both national and local information, the combination unit truck percentage was set at 8 percent.
- Annual Growth Rate of Traffic—An average annual growth rate of 2.5 percent was assumed for this analysis.

- Speed Limit under Normal Operating Conditions—This input was defined as 70, as that is a common speed limit in Texas on two-lane state highways.
- Lanes Open in Each Direction under Normal Conditions—As the example was set as a two-lane condition, the input here was defined as 1.
- Free Flow Capacity (vphpl)—RealCost has a built-in free flow capacity calculator, which was used to calculate the free flow capacity.
- Queue Dissipation Capacity (QC)—An 1800 passenger cars per hour per lane (pcphpl) value was used, which represented a good physical feature of the road.
- Maximum AADT (both directions)—The default value 100,000 was used for this project.
- Maximum Queue Length—Research suggests that 7 mi is the maximum acceptable queue length (Ryu et al. 2013); thus, that number was used in this project.
- Rural or Urban Hourly Traffic Distribution—"Urban" was assumed for this project.

Figure 5-4 shows an example of the traffic data screen. Note that traffic data have no impact on the agency cost; thus, this input was not considered a key focus.

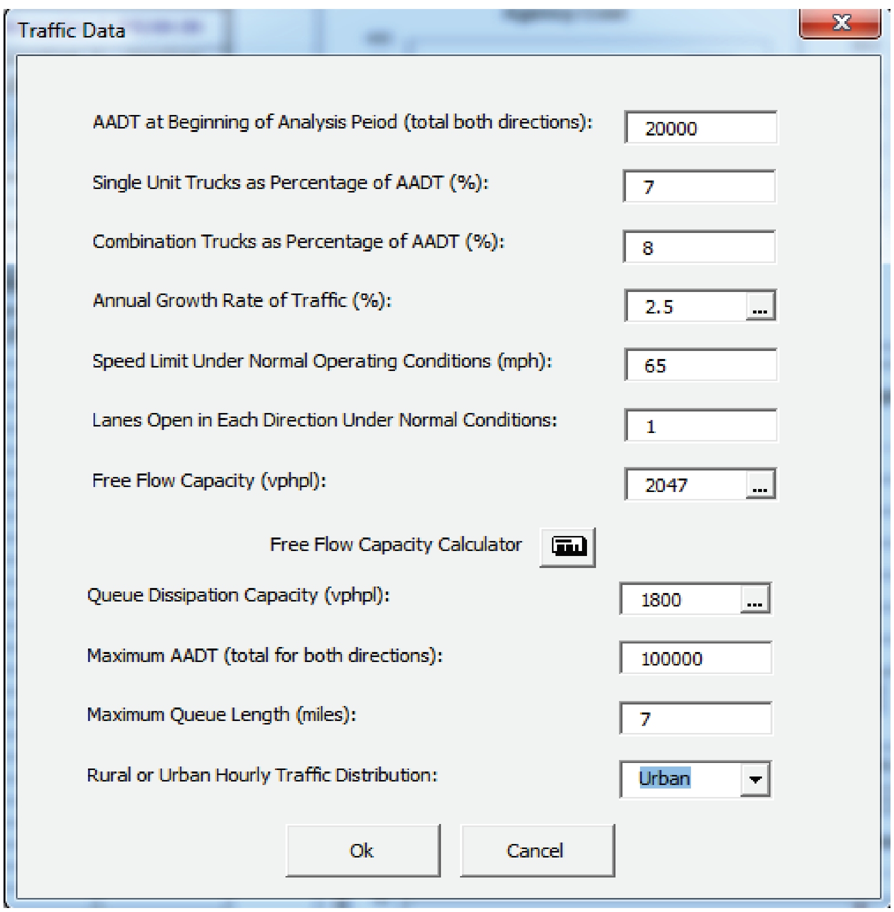


Figure 5-4. Example of Traffic Data Screen.

Value of User Time Inputs

The value of user time is used to calculate user costs. There are many factors to consider when calculating user cost, and the process can be very complicated. For this project, researchers based calculations on predetermined average highway user cost, and the default values in the software were accepted:

- Value of Time for Passenger Cars ($/hour)—$11.50.
- Value of Time for Single Unit Trucks ($/hour)—$18.50.
- Value of Time for Combination Trucks ($/hour)—$21.50.

Figure 5-5 shows an example of the value of user time screen.

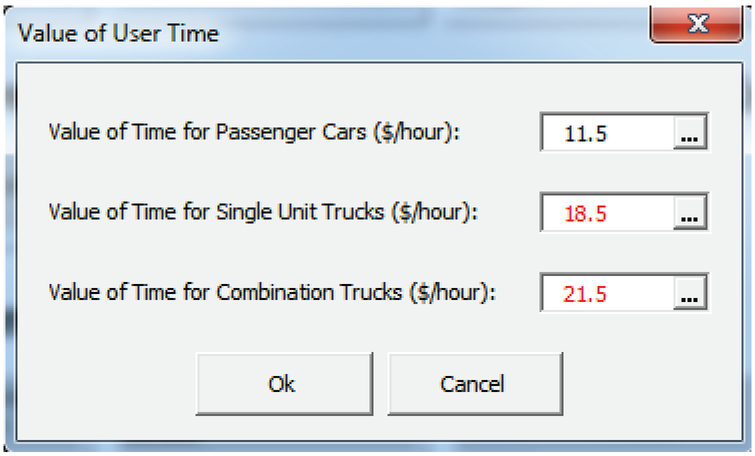


Figure 5-5. Example of Value of User Time Screen.

Alternative-Level Inputs

As mentioned above, during this research, the alternatives included mixes using binders PG 64-22, PG 64-28, or PG 64-34. For each alternative, the initial agency construction cost is calculated below.

According to Copeland (2011), there are four cost categories for asphalt production: material, plant production, trucking, and lay down. Among them, the most expensive production cost category is materials, comprising 70 percent of the cost to produce hot-mix asphalt (HMA). Table 5-1 shows the construction cost for each alternative. The asphalt prices were selected and averaged from *Argus Asphalt Reports* (Argus 2014), January to July 2014. The calculation was performed based on the following assumptions:

- AC overlay thickness: 2 inches.
- Asphalt content: 5 percent.
- Asphalt mixture density after compaction: 145 lb per cubic ft (SF).
- Aggregate price: $30/ton.

Table 5-1. Initial Construction Agency Cost Calculation.

Binder Type	Asphalt Binder Price ($/ton)	Asphalt Mixture Price ($/ton)	Material and Construction Cost ($/ton)	Material and Construction Cost ($/CF)	Agency Construction Cost ($)
Formula	**A**	**B=(A*0.05+25*0.95)**	**C=B/0.7**	**D=C*145/2000**	**E=D*2*5280*24*2/12**
PG 64-22	565	56.75	81.1	5.88	248,273
PG 64-28	640	60.5	86.4	6.27	264,679
PG 64-34	780	67.5	96.4	6.99	295,303

The price given in the TxDOT statewide average bid prices for construction of dense-graded HMA, Item 341, Series 2106, is $83.8356/ton (Ryu et al. 2013), which is in line with the calculation results shown in Table 5-1.

For each alternative input, rehabilitation activity data need to be provided. To determine the activity timing, the asphalt overlay cracking life should be predicted. Table 5-2 lists the performance predictions presented in Chapter 4, which were then used to determine the activity timing in RealCost. In these cases, the overlay thickness was 2 inches and the traffic level was 3 million ESALs. The existing pavement structures were conventional existing AC over GB and thinner existing AC over CTB. As Chapter 4 indicated, the typical aggregate types were gravel for Amarillo, limestone for Austin, and gravel for Pharr.

Table 5-2. Predicted Cracking Life for Different Alternatives.

District	Binder Type	Aggregate Type	Cracking Life (Months)	
			Conventional Existing AC over GB	Thinner Existing AC over CTB
Amarillo	PG 64-22	Gravel	49	7
	PG 64-28	Gravel	134	43
	PG 64-34	Gravel	189	68
Austin	PG 64-22	Limestone	66	55
	PG 64-28	Limestone	148	126
	PG 64-34	Limestone	200	174
Pharr	PG 64-22	Gravel	149	123
	PG 64-28	Gravel	193	162
	PG 64-34	Gravel	272	233

Since the cracking life is defined as the month number needed for the reflective cracking rate to reach 50 percent, the rehabilitation activity hypothesized that at the end of the cracking life, half of the cracked area (25 percent of the whole pavement area) needed to be replaced. Thus, both the activity timing and cost could be estimated.

Researchers determined the other activity inputs based on various factors, as discussed below.

- User Work Zone Costs—This was left as "Calculated" on the analysis options screen, so the user was not able to enter any input in this box.
- Work Zone Duration—This was the number of days lanes would be closed; it was assigned a value of "0" for initial construction and then 5 days for the other maintenance activities.
- Number of Lanes Open in Each Direction During Work Zone—As this was a two-lane highway, traffic had to be able to move even when there was work going on, so one lane was assumed to be open in each direction, whether by diversion to a frontage road or other means.
- Activity Service Life—This was the amount of time the activity was intended to survive with minimal maintenance until another activity was needed. The predicted cracking life for each alternative was provided here. For example, 4 was the input for the case of alternative PG 64-22 in the Amarillo District.
- Activity Structural Life—The activity service life of the first activity was the anticipated service life of the pavement. For concrete roads, this was assumed to be 50 years.
- Maintenance Frequency—The number of years maintenance was to be performed. It was assumed the cracks needed to be sealed every 5 years. The crack number was assumed to be 704 cracks for 2 mi (15 ft long between two cracks), which is 16,896 ft (24 ft long for each crack); at $2/ft crack sealing cost, that is $33,792 every 5 years. Spread out annually, that cost is 6758.4 per year.
- Work Zone Length (mi)—The work zone length is the length of the lane closure. This was assumed as 1 mile.
- Work Zone Speed Limit (mph)—Typically 5–10 mi less than the posted speed limit. Researchers used "65" as the input here, 5 mph less than the normal posted speed of 70 on most state highways.
- Work Zone Capacity (WC)—20 percent of maximum pcphpl, which is 360, was assumed.
- Traffic Hourly Distribution—"Weekday 1" was chosen for all LCCAs run for this project.

Figure 5-6 shows an example of activity input under Alternative 1 (PG 64-22) in the Amarillo District case. In this case, 13 activities were assigned to cover the analysis period of 50 years. In this input screen, the agency cost of Activity 1 was the initial construction cost, $248,273. The agency cost of other activities was the rehabilitation cost, assumed to be 25 percent of the initial construction cost. The milling cost was assumed to be included in this rehabilitation cost. Thus, the agency cost of each activity (starting from Activity 2) for the alternatives PG 64-22, PG 64-28, and PG 64-34 were $62,000, $66,000, and $74,000, respectively.

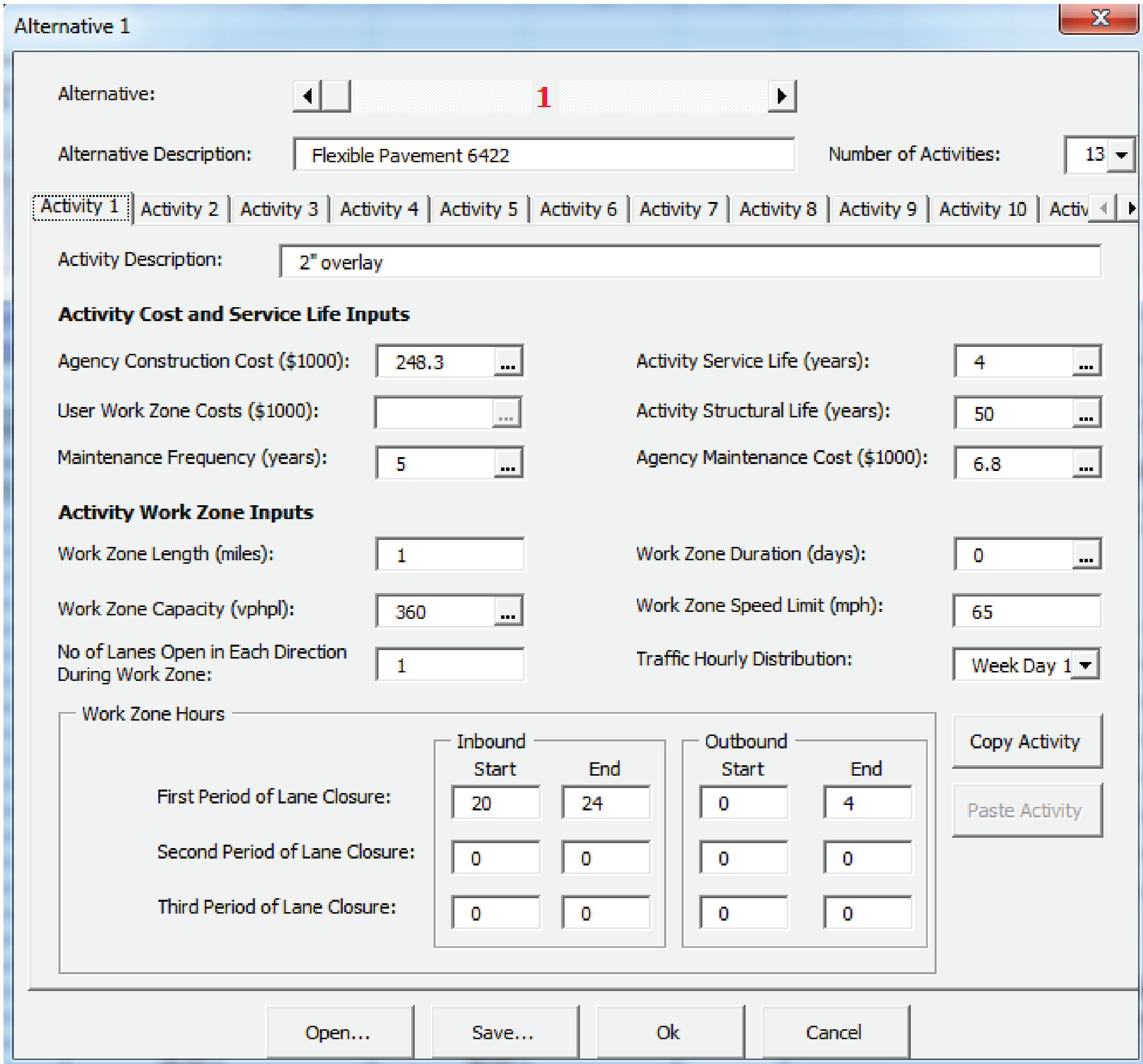


Figure 5-6. Example of Alternative and Activity Input Screen.

Specific Inputs for Each District and Each Alternative

As discussed above, the researchers chose the Amarillo, Austin, and Pharr Districts, representing cold, moderate, and hot areas, respectively, to evaluate the life cycling cost of using alternative binders such as PG 64-22, PG 64-28, and PG 64-34. Since the overlay mix with different binders has different cracking life in different districts, the corresponding activity numbers and activity service life are different. Table 5-3 lists the activity number and activity service life for each district and each alternative. The activity service life is determined based on the predicted cracking life shown in Table 5-2, and the activity number is the total number of activities that can cover the analysis period of 50 years.

Table 5-3. Activity Numbers and Activity Service Life.

District	Alternative	Conventional Existing AC over GB		Thinner Existing AC over CTB	
		Activity Service Life (years)	Activity Number	Activity Service Life (years)	Activity Number
Amarillo	PG 64-22	4	13	0.6	84
	PG 64-28	11	5	3.6	14
	PG 64-34	15.7	4	5.7	9
Austin	PG 64-22	5.5	10	4.6	11
	PG 64-28	12.3	5	10.5	5
	PG 64-34	16.7	3	14.5	4
Pharr	PG 64-22	12.5	4	10.3	5
	PG 64-28	16	4	13.6	4
	PG 64-34	22.6	3	19.4	3

After researchers input the necessary information for each district and each alternative, the FHWA RealCost software was ready to perform the calculation. The next section presents the life cycling cost analysis results.

LIFE CYCLING COST ANALYSIS RESULTS

Below are the alternative comparison results for each district. It is important to understand that LCCA is a concept of the time value of money. A given amount of money received one day has a higher value than the same amount received at a later date. One way to understand this concept is to think about how funds received today may be invested and immediately begin to earn interest. A number of techniques based on the concept of discounting are available (FHWA 2002). In FHWA RealCost, costs occasioned at different times are converted to the present value approach (also known as present worth), but the equivalent uniform annual cost (EUAC) is also provided.

Amarillo District

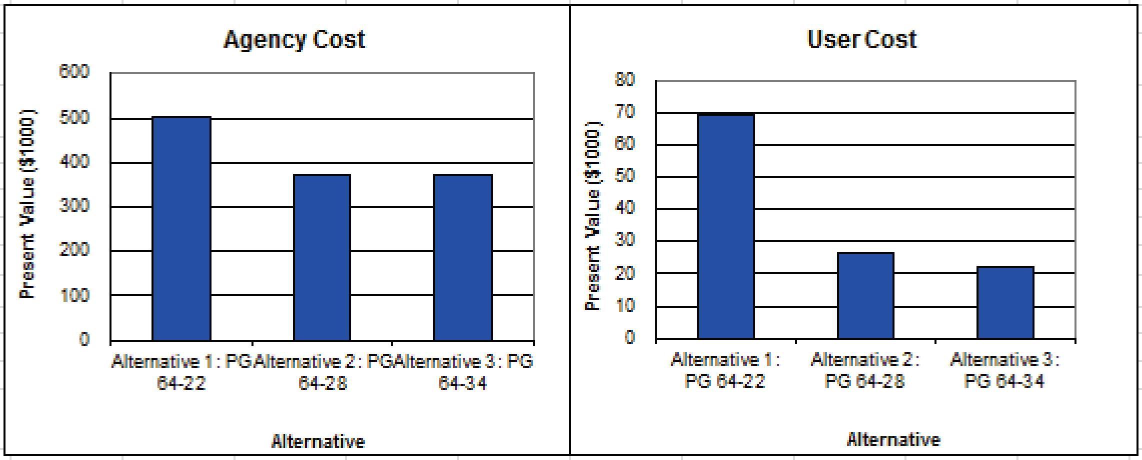
Table 5-4, Table 5-5, and Figure 5-7 show the LCCA results for the Amarillo District. According to the results and based on the lowest agency cost, the best option is PG 64-28 for the Amarillo District when the existing pavement structure is conventional AC over GB and PG 64-34 when the pavement structure is thinner AC over CTB. When the alternative is PG 64-22 for the thinner existing AC over CTB, the activity service life is 0.6 years and the corresponding activity number is 84, which is beyond the maximum activities (24 activities) that RealCost can support. Thus, only two alternatives, PG 64-28 and PG 64-34, are compared in this scenario.

Table 5-4. LCCA Results of Amarillo for Conventional Existing AC over GB.

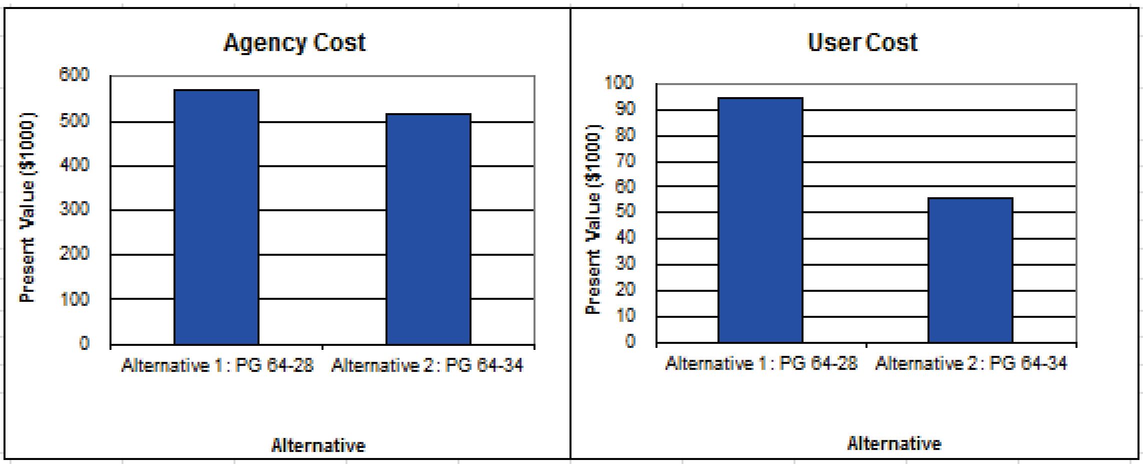
Total Cost						
	Alternative 1: PG 64-22		Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$605.42*	*$114.48*	*$445.06*	*$44.24*	*$432.06*	*$35.80*
Present Value	**$503.32**	**$69.66**	**$369.95**	**$26.65**	**$372.23**	**$22.17**
EUAC	$23.43	$3.24	$17.22	$1.24	$17.33	$1.03
Lowest Present Value Agency Cost		Alternative 2: PG 64-28				
Lowest Present Value User Cost		Alternative 3: PG 64-34				

Table 5-5. LCCA Results of Amarillo for Thinner Existing AC over CTB.

Total Cost				
	Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$691.56*	*$155.05*	*$623.62*	*$91.45*
Present Value	**$569.99**	**$94.81**	**$515.35**	**$55.80**
EUAC	$26.53	$4.41	$23.99	$2.60
Lowest Present Value Agency Cost		Alternative 2: PG 64-34		
Lowest Present Value User Cost		Alternative 3: PG 64-34		



a. Conventional Existing AC over GB.



b. Thinner Existing AC over CTB.

Figure 5-7. LCCA Results of Amarillo: Present Value of Agency and User Cost.

Austin District

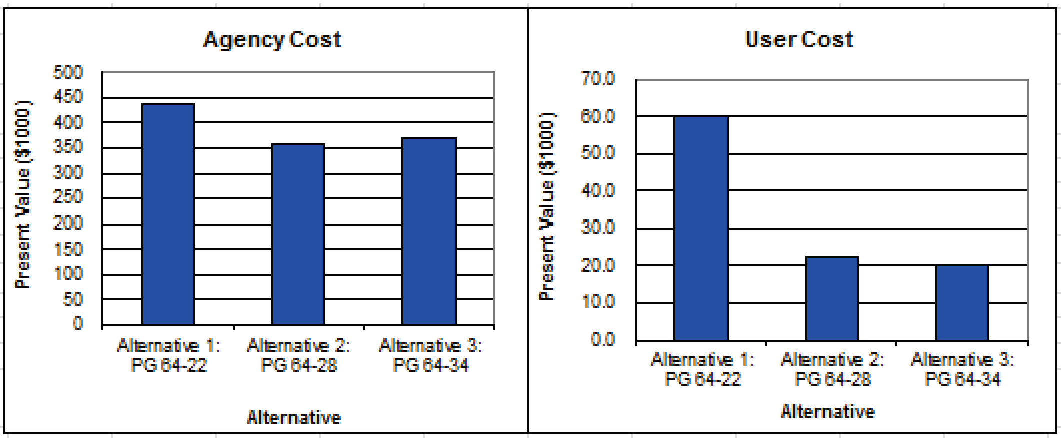
Table 5-6, Table 5-7, and Figure 5-8 show the LCCA results for the Austin District. According to the results and based on the lowest agency cost, the best option is PG 64-28 for both pavement structures in Austin: conventional AC over GB and thinner AC over CTB.

Table 5-6. LCCA Results of Austin for Conventional Existing AC over GB.

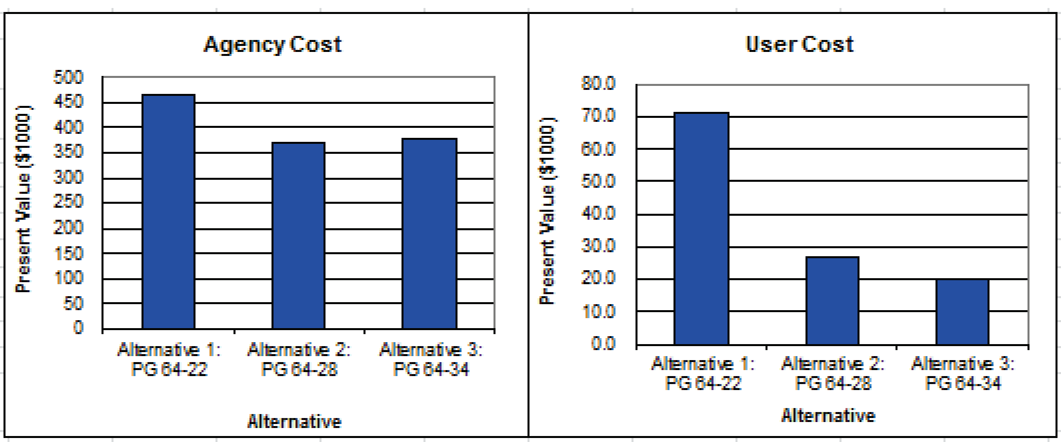
Total Cost						
	Alternative 1: PG 64-22		Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$526.60*	*$98.22*	*$421.05*	*$37.63*	*$430.15*	*$32.37*
Present Value	**$436.75**	**$59.98**	**$355.91**	**$22.63**	**$367.96**	**$20.51**
EUAC	$20.33	$2.79	$16.57	$1.05	$17.13	$0.95
Lowest Present Value Agency Cost	Alternative 2: PG 64-28					
Lowest Present Value User Cost	Alternative 3: PG 64-34					

Table 5-7. LCCA Results of Austin for Thinner Existing AC over CTB.

Total Cost						
	Alternative 1: PG 64-22		Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$554.58*	*$116.72*	*$438.08*	*$44.87*	*$435.89*	*$32.68*
Present Value	**$465.74**	**$71.52**	**$370.89**	**$26.86**	**$376.79**	**$19.99**
EUAC	$21.68	$3.33	$17.27	$1.25	$17.54	$0.93
Lowest Present Value Agency Cost	Alternative 2: PG 64-28					
Lowest Present Value User Cost	Alternative 3: PG 64-34					



a. Conventional Existing AC over GB.



b. Thinner Existing AC over CTB.

Figure 5-8. LCCA Results of Austin: Present Value of Agency and User Cost.

Pharr District

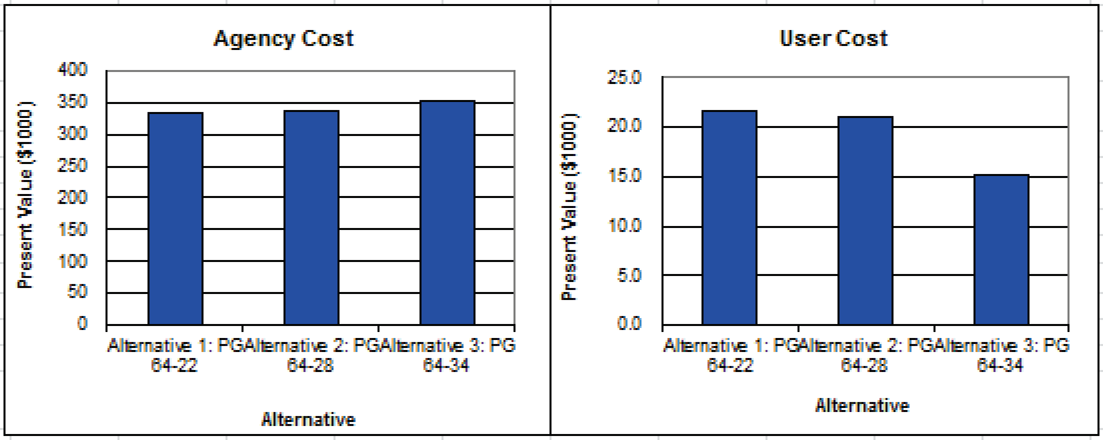
Table 5-8, Table 5-9, and Figure 5-9 show the LCCA results for the Pharr District. In this case, according to the results and based on the lowest agency cost, the best option is PG 64-22 for the Pharr District when the existing pavement structure is conventional AC over GB and PG 64-28 when the pavement structure is thinner AC over CTB.

Table 5-8. LCCA Results of Pharr for Conventional Existing AC over GB.

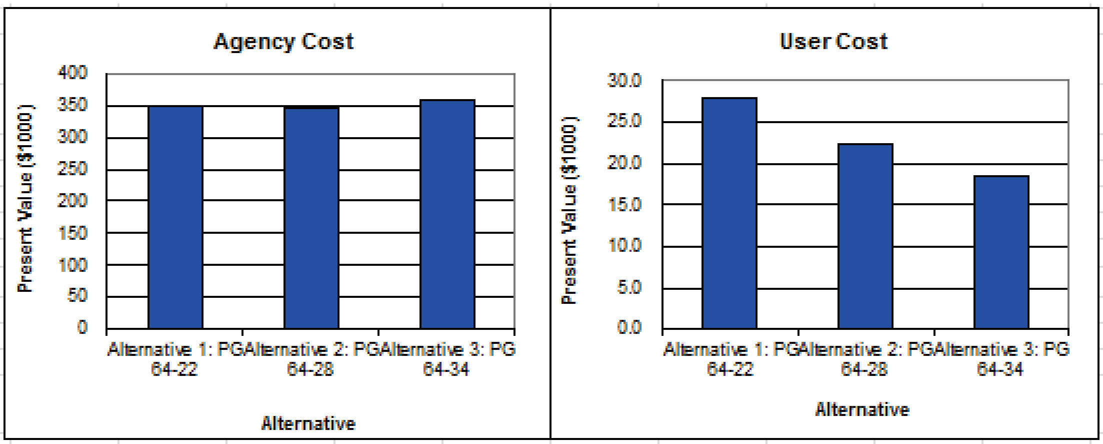
Total Cost						
	Alternative 1: PG 64-22		Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$395.70*	*$35.72*	*$397.40*	*$33.95*	*$406.68*	*$25.24*
Present Value	**$333.67**	**$21.60**	**$336.50**	**$21.03**	**$351.13**	**$15.20**
EUAC	$15.53	$1.01	$15.66	$0.98	$16.35	$0.71
Lowest Present Value Agency Cost	**Alternative 2: PG 64-22**					
Lowest Present Value User Cost	**Alternative 3: PG 64-34**					

Table 5-9. LCCA Results of Pharr for Thinner Existing AC over CTB.

Total Cost						
	Alternative 1: PG 64-22		Alternative 2: PG 64-28		Alternative 3: PG 64-34	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$409.38*	*$46.32*	*$402.86*	*$36.45*	*$411.40*	*$29.93*
Present Value	**$347.92**	**$27.84**	**$344.66**	**$22.40**	**$357.02**	**$18.57**
EUAC	$16.20	$1.30	$16.04	$1.04	$16.62	$0.86
Lowest Present Value Agency Cost	**Alternative 2: PG 64-28**					
Lowest Present Value User Cost	**Alternative 3: PG 64-34**					



a. Conventional Existing AC over GB.



b. Thinner Existing AC over CTB.

Figure 5-9. LCCA Results of Pharr: Present Value of Agency and User Cost.

SUMMARY

Table 5-10 summarizes the best options for each scenario according to the LCCA results.

Table 5-10. Best Options for Each District per LCCA Results.

District	Aggregate Type	Best Option Based on Lowest Agency Cost	
		Conventional Existing AC over GB	Thinner Existing AC over CTB
Amarillo	Gravel	PG 64-28	PG 64-34
Austin	Limestone	PG 64-28	PG 64-28
Pharr	Gravel	PG 64-22	PG 64-28

Comparing Table 5-9 with Table 4-3 shows that the best options (based on lowest agency costs) are consistent with the binder recommendations (based on cracking life and mixture OT cycles) for each scenario. These results further justify the statewide binder type recommendation catalogue from a financial point of view. In addition, the potential use of softer but highly modified binders, like PG 64-34, in Texas, especially in cold areas like Amarillo, shows financial benefits as well.

A user cost comparison was not the focus of this research since the inputs of traffic were assumed to be identical for each scenario. Traffic inputs are typically difficult to quantify, and the values associated with user costs are often disputed. A rough finding from this research is that PG 64-34 has the lowest cost for all cases since it has the longest service life and hence the lowest rehabilitation requirements, which lead to the smallest impact on traffic capacity.

CHAPTER 6
SUMMARY AND CONCLUSIONS

This report documents the research work on field test section surveys, field performance predictions and simulations, and life cycling cost analysis. The research work and findings are summarized below.

- Researchers oversaw the construction of and then monitored and analyzed 11 test sections: four on SH 15 in north Amarillo, three on US 62 in Childress, and four on Loop 820 in Fort Worth. The softer but highly modified binders, PG 64-34, were built in some sections for comparison. The relevant information of constructed field test sections was documented and includes (a) the locations, such as GPS coordinates, of each test section; (b) the existing pavement structures and pavement conditions; (c) the asphalt mix type of each test section; and (d) the construction information, such as laying temperature and compaction pattern. This information combined with binder/mix properties provided a preliminary catalogue to track the field performance of test sections.
- For each test section, seven buckets of mixes were sampled and taken back to TTI to conduct dynamic modulus, repeated load, Hamburg, and OT tests. Field cores were also taken from each test section and were used for parallel lab tests. Researchers input these test results into TxACOL or TxME to predict the performance in terms of cracking and rutting. All the crack predictions during the first 2 years were close to zero or very small, which was consistent with the field observation. The predicted rutting depths in SH 15 and US 62 test sections were small (less than 0.1 inch), which was also confirmed by the field survey. According to the prediction results, the asphalt mixes with PG 64-34, the softer but highly modified binders, did show both good rutting and cracking resistance. The predicted performance ranking and the difference among test sections were reasonable and helpful for validating the embedded models (cracking model and rutting model).
- A partial factorial design was developed to consider all critical influential factors including environmental zones, traffic levels, binder types, aggregate types, mix types, and overlay thicknesses. The implemented TxACOL was used to predict the overlay performance of each scenario of the factorial design, mainly cracking performance since it is currently the main issue in Texas overlays. TxACOL acted as a virtual experiment that gave the pavement engineers the ability to easily evaluate how pavement would respond under each scenario.
- In total, 2700 cracking performance simulations were conducted during this research to cover different asphalt mixtures, climatic zones, overlay thicknesses, traffic levels, and existing pavement structures. Each simulation was numbered, and corresponding information, such as the climate, traffic, pavement structure, and material property (dynamic modulus and cracking property), was processed and organized into TxACOL input format.
- According to the simulation results, researchers determined the required OT cycles of overlay mixture for different environmental zones, existing pavement structures, overlay thicknesses, and traffic levels. Based on those results, the research team developed the statewide catalogue of binder recommendations.

- Based on the performance simulation results and the district binder type recommendations, the research team conducted the pavement life cycling cost analysis to evaluate the financial benefits of the recommendations. The researchers chose the Amarillo, Austin, and Pharr Districts—representing cold, moderate, and hot areas, respectively—to demonstrate the analysis processes. The FHWA RealCost analysis results showed that the best options (based on lowest agency costs) are consistent with the binder recommendations (based on cracking life and mixture OT cycles) for each scenario. These results further justify the statewide binder type recommendation catalogue from a financial point of view. In addition, the potential use of softer but highly modified binders, like PG 64-34, in Texas, especially in cold areas like Amarillo, shows financial benefits as well.

Based on the results presented in this report (0-6674-2) and Report 0-6674-1, the project objectives were achieved. The covered areas/topics are summarized in the following sections.

LABORATORY MEASURED ENGINEERING PROPERTIES FOR A RANGE OF DIFFERENT BINDERS AND MIXES

The measured engineering properties for binders and mixes using different test methods are tabulated and plotted in the Appendix.

IDENTIFICATION OF THE STRENGTHS AND WEAKNESSES OF THE NEW AASHTO/ASTM BINDER GRADING SYSTEM

In Report 0-6674-1, the researcher reported that the MSCR test and associated specification works better than the current G*/sin δ based PG specification, especially for highly modified asphalt binders (such as PG 64-34). This finding is further validated in this report, 0-6674-2, through field test section performance results. MSCR round robin results among five laboratories clearly indicated that both $J_{nr0.1}$ and $J_{nr3.2}$ results are very repeatable and reproducible. The $R_{3.2}$ results are acceptable in terms of repeatability and reproducibility, but both J_{nrdiff} and $R_{0.1}$ have high variability. Since J_{nrdiff} is one of the parameters for grading asphalt binder, TxDOT should exercise caution when grading the slightly modified asphalt binders (such as PG 64-28) using the MSCR specification.

CANDIDATE TEST METHODS FOR BINDER AND ADHESION PROPERTIES

Report 0-6674-1 confirms the poor relationship between the parameter G*sinδ and the binder fatigue resistance. Neither the MSCR nor the elastic recovery test shows good correlation with the asphalt mix OT cracking test. Both the Linear Amplitude Sweep (LAS) and the Double Edged Notched Tension (DENT) tests provide similar rankings as the asphalt mix OT cracking test. Considering the test equipment requirements of both the LAS and DENT tests, the Dynamic Shear Rheometer (DSR) based LAS test is recommended for asphalt binder fracture tests since the DSR has been widely used in the last 20 years and laboratory technicians and researchers are very familiar with it.

PREDICTED PERFORMANCE OF DIFFERENT AGGREGATE/BINDER COMBINATIONS

The 2700 cracking performance simulations conducted during this research included 15 typical aggregate/binder combinations and provided a solid base for binder catalogue recommendations and LCCA.

OVERLAY DESIGN RECOMMENDATIONS FOR THE DIFFERENT PARTS OF TEXAS

Based on the simulation results, researchers determined the required OT cycles of overlay mixture for different environmental zones of Texas, existing pavement structures, overlay thicknesses, and traffic levels. Based on those findings, the research team developed the statewide catalogue of binder recommendations and confirmed the recommendations via cost-benefit analysis.

RECOMMENDED BINDER SPECIFICATION CHANGES

Based on both the lab and field research findings, the changes suggested herein include the recommendations of statewide binder type selection and the test methods aforementioned. However, these recommendations are based on limited lab testing, field test sections, and short performance histories. The researchers recommend that the test sections continue to be monitored and that more comparisons be made between predictions and survey results for further model refining/calibration. The specification change recommended for binder test and statewide binder type selection should be exercised with caution. Additionally, it is important to remember that the binder alone does not determine rutting, fatigue cracking, and moisture damage of asphalt pavements. Mix characteristics as well as the pavement structure itself, traffic, and the environment within which the pavement is located have a significant role in determining pavement performance.

COST-BENEFIT ANALYSIS OF USING SOFTER BUT RUT RESISTANT BINDERS IN TEXAS

The field test section performance and LCCA indicated that softer but highly modified binders, like PG 64-34, in Texas, especially in cold areas like Amarillo, have comparably good performance and financial benefits as well.

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APPENDIX
LABORATORY MEASURED ENGINEERING PROPERTIES FOR DIFFERENT BINDERS AND MIXES

Table A-1. Test Results of the Five Asphalt Binders.

Asphalt Binder		PG 64-22	PG 64-28	PG 64-34	PG 70-22	PG 76-22
Binder PG Grading	Continuous Grade	69.85-24.96	68.06-29.27	68.14-34.39	74.60-24.83	84.46-22
	True Grade at Intermediate Temperature (°C)	20.32	16.815	11.14	23.045	9.7
	Overall Ranking	**D**	**C**	**B**	**E**	**A**
TxDOT Elastic Recovery	Method A(0s Holding)	28.71%	74.19%	89.50%	56.78%	69.41%
	Overall Ranking	**E**	**B**	**A**	**D**	**C**
Multiple Stress Creep Recovery RTFO	Percent Recovery-100Pa	2.0%	41.6%	75.3%	37.8%	83.8%
	Percent Recovery-3,200 Pa	0.6%	24.0%	65.8%	25.5%	78.6%
	Percent Difference between Average Recovery Values	70.0%	42.3%	12.6%	32.5%	6.2%
	Overall Ranking	**E**	**D**	**B**	**C**	**A**
LAS	Parameter a	2.18E+07	2.43E+07	1.24E+07	5.94E+07	9.61E+07
	Parameter b	-5.31	-4.94	-4.99	-5.88	-6.54
	Fatigue life at γ_{max}=2.5%	168,810	262,320	1,276,157	270,786	240,382
	Fatigue life at γ_{max}=5%	4,268	8,530	40,155	4,587	2,586
	Overall Ranking	**D**	**B**	**A**	**C**	**E**
DENT	CTOD(mm)	12	27	69	16	14
	Overall Ranking	**E**	**B**	**A**	**C**	**D**

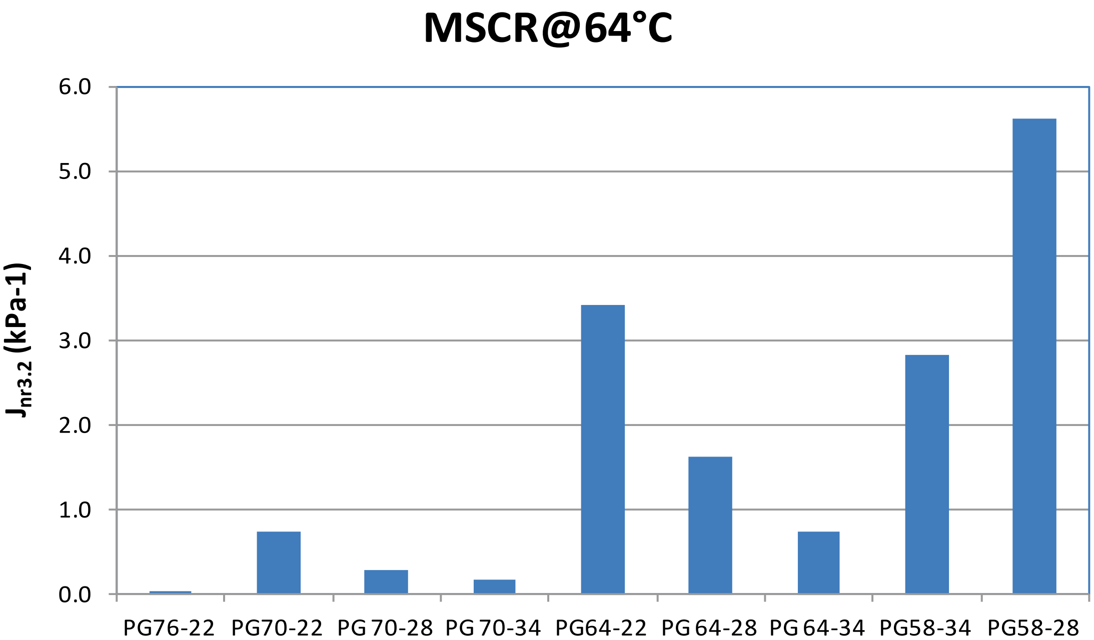

Figure A-1. MSCR Test Results of Nine Asphalt Binders.

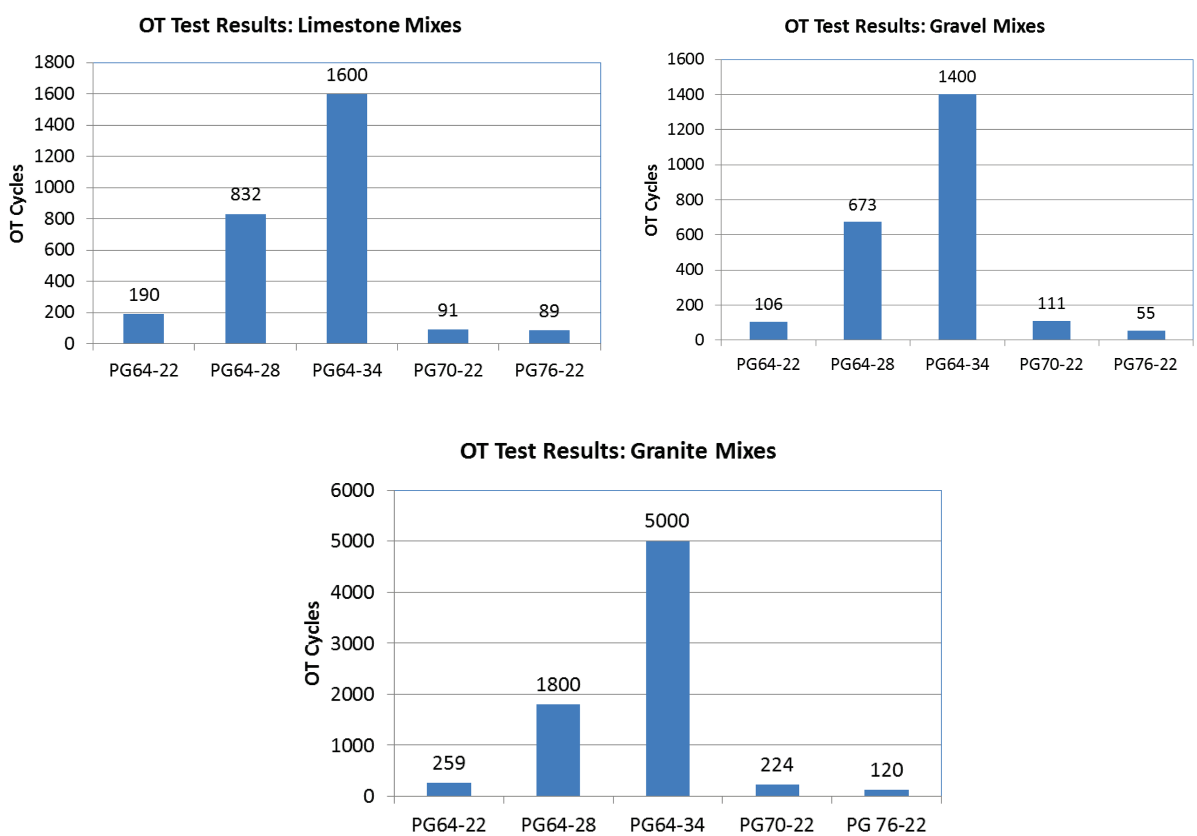

Figure A-2. OT Test Results of 15 Asphalt Mixes.

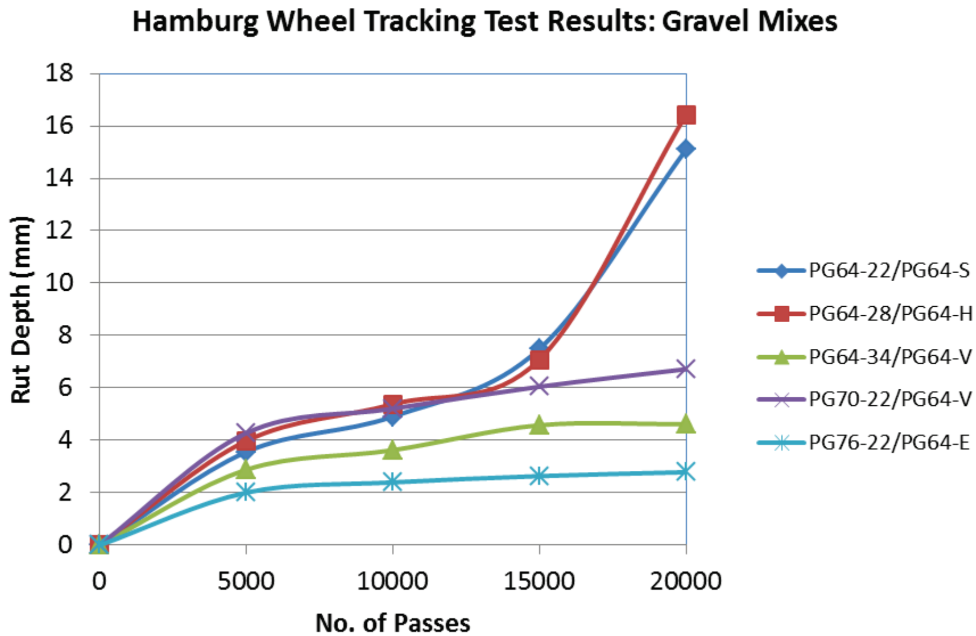

Figure A-3. Hamburg Wheel Tracking Test (HWTT) Results of Gravel Mixes with Five Binders.

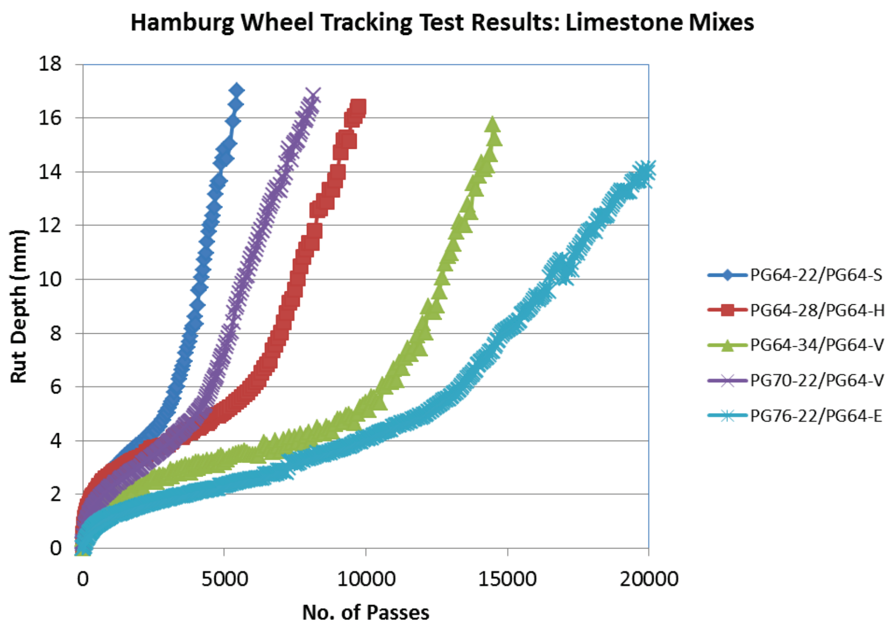

Figure A-4. HWTT Results of Limestone Mixes with Five Binders.

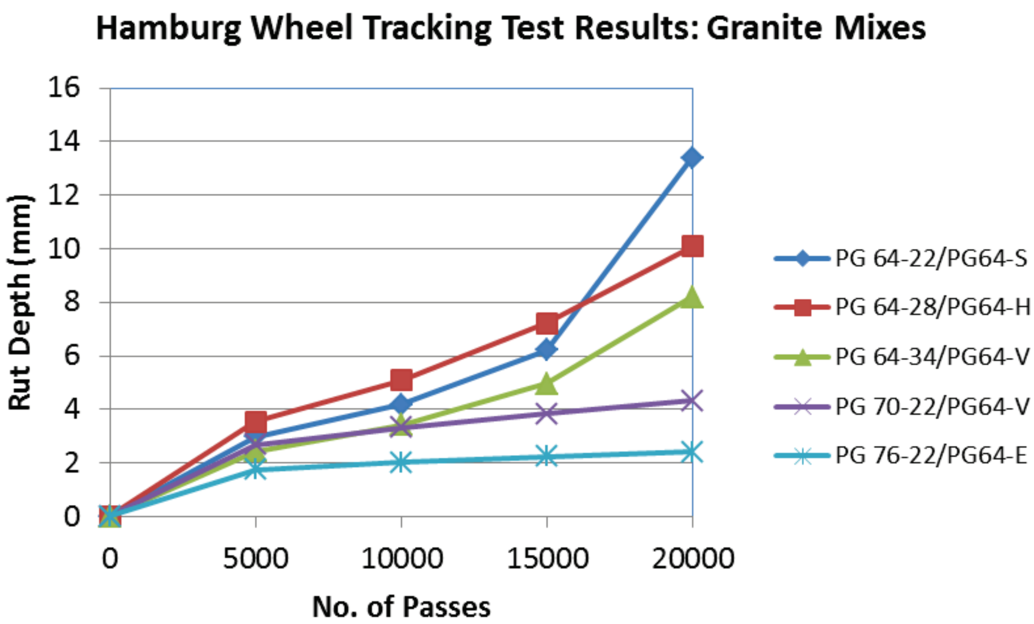

Figure A-5. HWTT Results of Granite Mixes with Five Binders.

Table A-2. DMA Test Results at a Temperature of 86°F and a Strain of 0.25.

Aggregates	Binder	Test Conditions	Fatigue Life (cycles)	Average Fatigue Life (cycles)
Limestone	PG 64-22	Dry	248,855	273,991
			291,524	
			281,596	
		Wet	179,570	271,894
			437,151	
			198,960	
Granite	PG 64-22	Dry	121,909	178,326
			234,508	
			178,561	
		Wet	62,344	68,827
			62,617	
			81,522	
	PG 70-22	Dry	444,237	353,546
			345,187	
			271,214	
		Wet	463,738	556,718
			580,779	
			625,637	