Mississippi Transportation Research Center

U.S. Department of Transportation Federal Highway Administration

Mississippi Department of Transportation

Mississippi State University CMRC Construction Materials Research Center

"An Industry, Agency & University Partnership"

Use of the Asphalt Pavement Analyzer to Study In-Service Asphalt Mixture Performance

REPORT NO.
FHWA/MS-DOT-RD-04-155

Prepared by
Dr. M. Shane Buchanan, Dr. Thomas D. White, and Ben J. Smith
Mississippi State University
Department of Civil Engineering
Construction Materials Research Center

December 30, 2004

James Worth Bagley College of Engineering
Mississippi State University
Civil Engineering

Technical Report Documentation Page

1.Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/MS-DOT-RD-04-155		

4. Title and Subtitle Use of the Asphalt Pavement Analyzer to Study In-Service Asphalt Mixture Performance	5. Report Date December 30, 2004 6. Performing Organization Code
7. Author(s) M. Shane Buchanan, Thomas D. White, and Benjamin J. Smith	8. Performing Organization Report No.
9. Performing Organization Name and Address Mississippi State University Department of Civil Engineering P.O. Box 9546 Mississippi State, MS 39762	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Mississippi Department of Transportation Research Division P.O. Box 1850 Jackson, MS 39215-1850	13. Type Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Permanent deformation or rutting is a major hot mix asphalt (HMA) performance distress. Implementation of the Superior Performing Asphalt Pavement (Superpave) HMA mix design system was due, in part, to limit HMA rutting. Along with the Superpave system, performance testing equipment was developed to evaluate rutting potential; however, this equipment proved largely ineffective. As a result, agencies developed their own performance equipment, with the Asphalt Pavement Analyzer (APA) currently being used by many agencies for HMA rutting evaluation.

The Mississippi Department of Transportation (MDOT) is utilizing the APA to evaluate HMA performance, but does not currently have established pass/fail criteria. Field rutting analysis and coring were conducted for twenty-four pavements throughout Mississippi to determine in-service performance. Asphalt pavement analyzer testing was conducted on field cores and lab prepared specimens to evaluate mix characteristic influence on rutting and to develop APA failure criteria. Based on the analysis, an APA rut depth criteria of 6.0 mm was established for HT mixes and 12.0 for ST and MT mixes.

17. Key Words	18. Distribution Statement Unclassified

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I INTRODUCTION

1.1 INTRODUCTION AND PROBLEM STATEMENT

Hot mix asphalt (HMA) pavement deformation, or rutting, is a distress that affects pavement performance and ride quality. Rutting is influenced by many variables such as aggregate type and gradation, asphalt viscosity, and mixture volumetric properties. Additionally, a number of other variables such as construction procedures, traffic volume, and environmental conditions significantly influence HMA rutting.

The two primary components of HMA are asphalt binder and aggregate. Because asphalt binder is a visco-elastic material, its stiffness is dependent upon temperature and rate of loading. It is very important to select the correct asphalt binder for a given climate and loading situation, especially in a hot climate.

In Mississippi, the most widely available coarse and fine aggregates are gravel and sand, respectively. Gravel aggregate, due primarily to its size prior to crushing, tends to be more rounded than crushed or quarried aggregate. Sand aggregate also tends to be slightly more rounded than manufactured fine aggregate. Generally, mixes with rounded aggregate exhibit more rutting than mixes with crushed aggregate.

One of the Superior Performing Asphalt Pavement (Superpave) mix design system goals was to limit HMA rutting. Original plans for the Superpave system called for advanced levels of performance testing during mix design to predict HMA rutting and cracking performance. While Superpave has proven to be effective in reducing rutting potential, the intended advanced testing was never utilized to any significant degree.

Because of this deficiency in the Superpave system, several devices have been developed to evaluate HMA rutting potential during mix design and quality control processes. One device, the Asphalt Pavement Analyzer (APA), a second-generation version of the Georgia wheel loaded tester (GLWT), is being utilized by many state agencies, including the Mississippi Department of Transportation (MDOT) for HMA mix rutting evaluation.

1.2 OBJECTIVES AND SCOPE

Research study objectives were 1) evaluate in-place rutting performance of a range of Mississippi HMA pavements and 2) develop APA rut depth criteria for Mississippi, based on measured in-service rutting and APA laboratory test results.

Twenty-four pavements were selected for evaluation following a comprehensive review of the MDOT pavement management database. This review was necessary to select projects encompassing a range of aggregate type, nominal maximum aggregate size (NMAS), performance grade (PG) binder, and traffic level. For each pavement, field rutting was measured and cores obtained for in-place volumetric property determination. Aggregates were obtained from original or similar aggregate sources. Asphalt binder, comparable to original binder performance grade, was also obtained.

Asphalt pavement analyzer testing was conducted on the obtained field cores. Mix design verification work was conducted for each mix. After verification, APA testing was conducted on laboratory prepared specimens. Field rutting and laboratory APA results were then evaluated to establish appropriate APA rut depth criteria.

CHAPTER 2 LITERATURE REVIEW

2.1 BACKGROUND

Hot mix asphalt (HMA) rutting is a major distress resulting in decreased pavement service life and increased pavement life cycle cost. Hydroplaning, due to water retention in surface ruts, is a major safety hazard to the traveling public. Because of the rutting problem numerous research studies have been conducted to determine mechanisms and causes or factors affecting HMA rutting potential.

2.2 MECHANISMS OF RUTTING

Mechanisms of HMA rutting can be categorized into two main types:

1) Plastic deformation
2) Densification

Rutting from plastic deformation typically occurs early in a pavement's life. According to White et al. (*1*), "Typically with the application of traffic, a small amount of permanent deformation (3-5 mm) due to densification of both unbound and bound layers within the structure will occur. Christensen and Bonaquist (*2*) state that plastic deformation and densification occur simultaneously when substantial rutting occurs. Specifically, "…both processes are likely to occur when substantial rutting occurs; plastic deformation occurs as aggregate particles move slightly relative to one another, which is accompanied by viscous flow in the asphalt cement binding these particles together."

2.3 RUTTING TYPES AND CAUSES

Hot mix asphalt rutting can be categorized into two main types: surface and subgrade. Surface rutting is pavement deformation occurring within the top few inches of pavement surface. Subgrade rutting occurs due to densification or shear failure in the subgrade material. Researchers have attempted to better understand rutting causes so more rut resistance pavements can be designed. Some major rutting causes are as follows:

1) Increased truck loading
2) Low mix shear strength (resulting from over-asphalted mix and/or use of marginal aggregates)
3) Poor construction techniques (e.g., inadequate compaction)
4) Reduced subgrade support

This study is focused on evaluating the effect of traffic and HMA properties on rutting performance.

2.4 HOT MIX ASPHALT PROPERTIES INFLUENCE ON RUTTING

Hot mix asphalt properties have been extensively evaluated to better understand mix rutting potential. Properties shown to influence rutting include the following.

1) Asphalt binder grade
2) Aggregate type
3) Aggregate gradation
4) Volumetric properties

Asphalt binder and aggregate characteristics influence HMA shear strength. Research (2, 3) has been conducted to quantify asphalt binder and aggregate influence on rutting potential. Figure 2.1 shows a schematic of typical HMA shear stress behaviors using a low viscosity ("weak" binder) and a high viscosity asphalt binder ("strong" binder). The "strong" binder increases HMA mix shear strength from increased cohesion or viscosity.

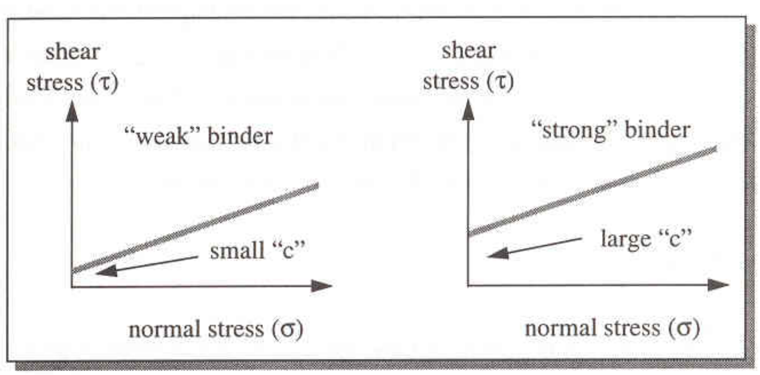


Figure 2.1 Stress Diagram for Asphalt Binders (3)

Aggregate characteristics also influence HMA mix rutting. Numerous aggregate characteristics influence rutting behavior; including aggregate shape. Aggregate shape directly controls HMA mix internal friction. Mixes using crushed aggregates generally have higher internal friction angles than rounded aggregate mixes. Figure 2.2 is a schematic illustration of differing angle of repose for angular and rounded aggregates. Similar effects result when these materials are used in HMA mixes. Figure 2.3 shows stress diagrams for "weak" rounded aggregate and "strong" angular aggregate and illustrates the increased friction provided by the angular aggregate (3).

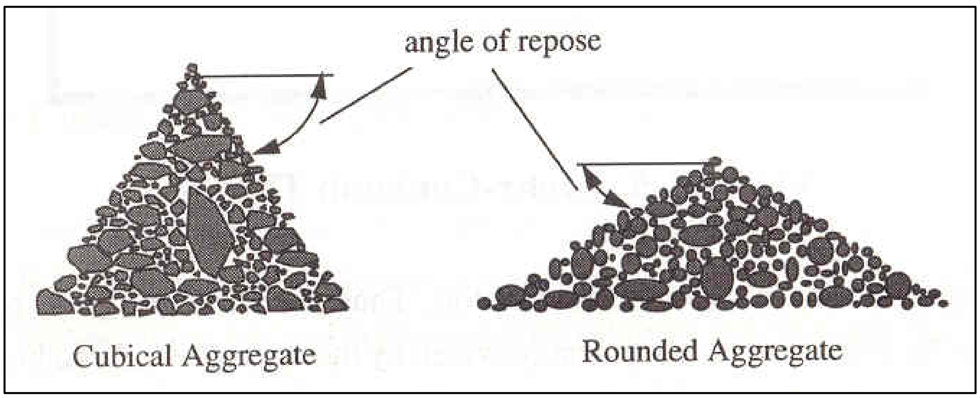


Figure 2.2 Angle of Repose for Cubical and Rounded Aggregate (3)

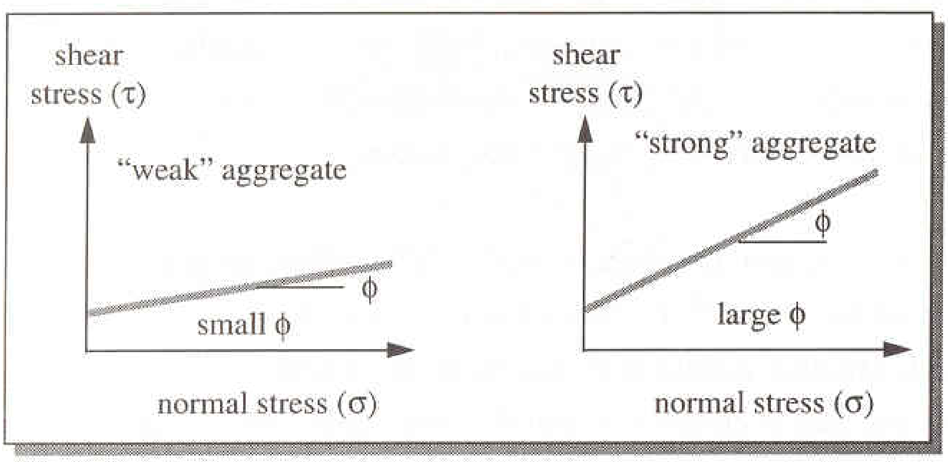


Figure 2.3 Stress Diagrams for Weak and Strong Aggregate (3)

Polymer modified asphalt binder mixes have been shown to be more rut resistant in the APA than unmodified asphalt binder mixes. Moseley et al. (4) used the APA to determine binder influence on HMA rutting resistance in Florida. Testing included four binder types: PG 67-22, PG 76-22; ARB-5 and ARB-12 with 5 and 12 percent ground rubber tire, respectively. Each binder was used in three mix types: fine-graded 9.5 and 12.5 mm mixes, and a coarse-graded 12.5 mm mix. Results showed PG 76-22 binder mixes performed best with an average APA rut depth of 2.2 mm. Average rut depths ARB-5, ARB-12, and PG 67-22 mixes were 3.4 mm, 3.0 mm, and 4.2 mm, respectively.

Williams (5) used the APA to evaluate rutting performance of several Arkansas HMA mixes, including five 12.5 mm surface mixes and two 25.0 mm surface mixes. Binder types included PG 64-22, PG 70-22, and PG 76-22. Results indicated that as binder grade increased, rut depths decreased.

Brown and Cross (6) concluded coarse aggregate angularity and uncompacted void content significantly affected HMA mix rutting performance by evaluating field and APA performance of mixes, indicating more angular aggregate mixes are more rut resistant.

Aggregate gradation also affects HMA mix rutting potential. Kandhal and Cooley (7) used the APA to evaluate coarse and fine-graded HMA mix rutting resistance. Mixes consisting of 9.5 and 19.0 mm nominal maximum aggregate size, two coarse aggregates and four fine aggregates were evaluated with the APA. Results showed the rutting potential of coarse and fine-graded HMA mixes were approximately the same. Specifically, coarse-graded mixes averaged 14.0 mm of rutting while fine-graded mixes averaged 13.0 mm.

Parker and Brown (8) investigated aggregate gradation effects on HMA rutting with the APA, with specific focus on percent passing the 9.5 mm and 0.075 mm sieves. Relationships between percent passing the 9.5 mm and the 0.075 mm sieves yielded correlation coefficients of -0.47 and 0.37 respectively. The low correlation coefficients were contrary to the belief that rutting is significantly influenced by gradation (percent passing 9.5 mm and 0.075 mm in this case).

Hot mix asphalt volumetric properties also influence rutting performance. Voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) are two properties related to rutting. Williams (5) concluded that as VMA increases, rut depth increases. Brown and Cross (6) evaluated Marshall 75-blow mix designs and concluded that as VFA decreases, rutting resistance increases.

2.5 ASPHALT PAVEMENT ANALYZER LOADED WHEEL TESTING

Performance testing with the APA has proven beneficial to HMA mix performance. The following section presents significant APA research.

The Georgia Department of Transportation and the Georgia Institute of Technology jointly developed the Georgia Loaded Wheel Tester (GLWT) in 1985. The GLWT, shown in Figure 2.4 was first developed to test slurry seals and then modified to evaluate HMA rut potential. The Asphalt Pavement Analyzer (APA), shown in Figure 2.5, was developed as a second generation GLWT. The APA has capabilities of testing three specimens simultaneously, while also being able to evaluate HMA moisture susceptibility and fatigue cracking. A data acquisition system is also incorporated on the APA, which eliminates manual rut depth measurements and potential for human recording errors.

Kandhal and Cooley (9) conducted a multiphase project (NCHRP 9-17) aimed at determining the APA's ability to predict HMA rut potential. Numerous HMA mixes were evaluated to determine APA test parameters best simulating mix field performance. Variables included specimen type (gyratory compacted cylinder or vibratory compacted beam), nominal maximum aggregate size, specimen air void content (4 and 7 percent for cylinders and 5 and 7 percent for beams), and asphalt binder type. The HMA mixes evaluated included in-service mixes located throughout the country. The APA was evaluated by performing testing under different test configurations, including varying hose diameter (25 to 38 mm) and chamber temperature.

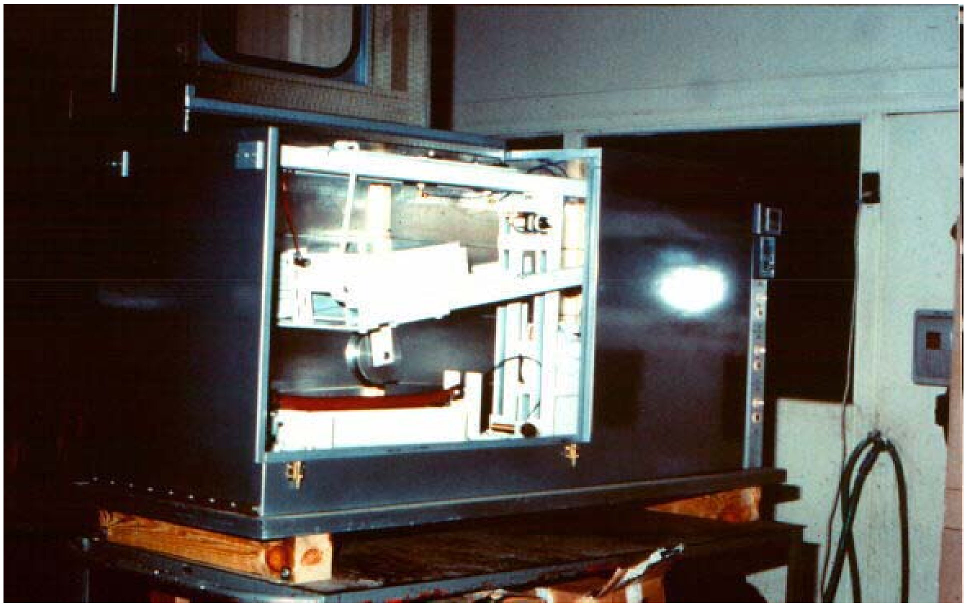


Figure 2.4 Georgia Loaded Wheel Tester

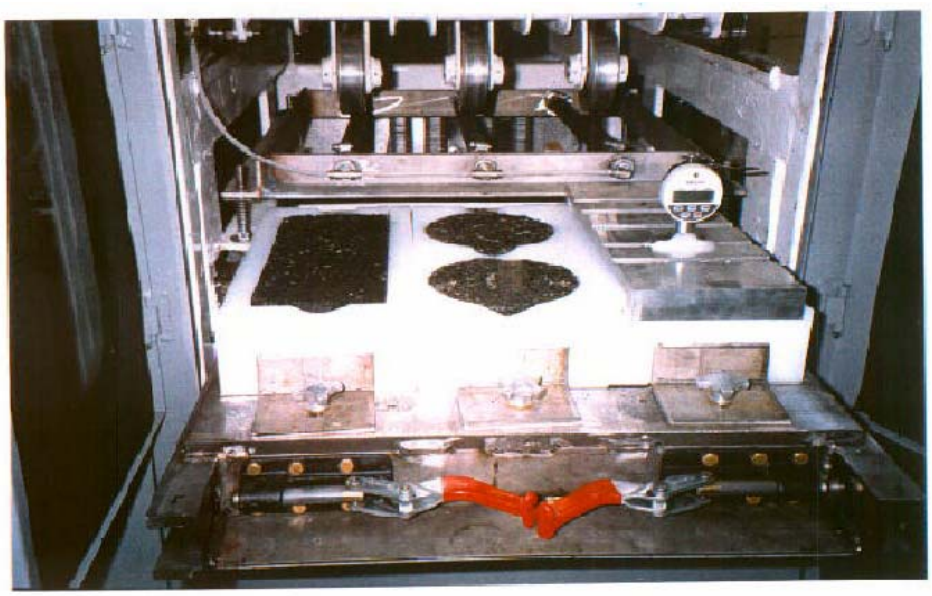


Figure 2.5 Asphalt Pavement Analyzer

Among the study conclusions were that gyratory compacted specimens compacted to 4 percent air voids correlated best with field performance. The test temperature best correlating with field performance was the standard performance grade high temperature for the asphalt binder. There was no significant difference between standard (25 mm) and larger (38 mm) diameter hoses. It was concluded the APA is not capable of predicting HMA field rutting for a specific project, but is capable of differentiating between mixes.

Numerous studies have been conducted to evaluate the APA's ability to predict rutting in HMA pavements. Kandhal and Mallick (10) conducted a study for the Alabama Department of Transportation (ALDOT), focused on determining the APA's ability to evaluate rutting potential of HMA mixes with different asphalt binders, aggregate types and gradations. Fine and coarse-graded mixes with gravel, limestone, and granite aggregates were evaluated, along with PG 64-22 and PG 58-22 asphalt binders. Asphalt Pavement Analyzer testing was conducted on gyratory compacted specimens at 4 percent air voids. Test parameters of 8000 cycles with 445 N (100 lbs) wheel load and 690 kPa (100 psi) hose pressure were used. Dry testing was conducted at 64°C for PG 64-22 mixes and 58°C for PG 58-22 mixes. Aggregate type comparisons showed coarse-graded mixes with both granite and limestone aggregates had higher rut depths compared with the same aggregates in fine-graded mixes. However, coarse-graded gravel mixes exhibited less rutting than fine-graded gravel mixes. Rut depths were significantly lower for PG 64-22 mixes compared to PG 58-22 mixes. Based on the limited study data, a maximum APA rut depth of 4.5 mm was recommended.

Jackson and Baldwin (11) conducted research for the Tennessee Department of Transportation (TDOT) to determine if the APA could predict rutting potential of commonly used HMA mixes. Eight mixes throughout Tennessee with a range of field rutting performance were evaluated. Asphalt binders ranged from PG 64-22 to PG 76-22 with a range of aggregate gradations. Testing was conducted using gyratory compacted specimens at 7 ± 1 percent air voids. Testing parameters were 8000 cycles at 49ºC (120º F), hose pressure of 690 kPa (100 psi) and wheel load of 445 N (100 lbs). Results showed the APA distinguished between good and poor performing mixes based on field rutting performance. Other notable conclusions were that the APA was sensitive to asphalt binder grade, as well as dust-to-effective asphalt ratio. Half of the PG 67-22 mixes exhibited greater than 5 mm rutting while no PG 76-22 mix exceeded 5 mm. All mixes with rut depths greater than 5 mm had gradations passing through the restricted zone, while no mix with a gradation outside the restricted zone exhibited rutting greater than 5 mm.

Choubane et al. (*12*) compared APA test results with field rutting performance. A secondary objective was to compare APA results of beam specimens to gyratory compacted specimens. Asphalt Pavement Analyzer results were also to be compared to previously obtained GLWT results. Three Florida test sections with varying field rutting performances were evaluated. Pavements were cored and their in-place volumetric properties determined. Beam and gyratory compacted specimens at 7±1 percent air voids were prepared and tested for 8000 cycles at 41º C (105º F), hose pressure of 690 kPa (100 psi), and wheel pressure of 540 N (120 lbs). The APA accurately ranked HMA mixes based on field performance. While rut depths between gyratory and beam specimens were statistically different, there was a strong correlation between the two measurements. Due to the small number of test sections, there was insufficient data to develop an APA pass/fail criteria.

Sholar and Page (*13*) performed a follow-up study to the Florida Department of Transportation's original evaluation of the APA (*12*). The study objective was to analyze the APA's testing variability along with comparing manual and automated rut depth measurements. Additional HMA pavements were evaluated with the APA and added to the previously developed database. Coarse and fine-graded 9.5 and 12.5 mm nominal maximum aggregate size mixes were evaluated. The 9.5 mm mixes were comprised of Georgia granite and coarse sand, while 12.5 mm mixes were comprised of South Florida limestone. All mixes used an unmodified AC-20 asphalt binder. Asphalt pavement analyzer testing was conducted with beam specimens at 7 ± 0.5 percent air voids. Specimens were tested at 64º C (147º F), hose pressure of 690 kPa (100 psi), and wheel load of 445 N (100 lbs). Results showed no statistical difference in rut depth for mixes within the allowable tolerance of air voids. Comparison of automated and manual measurements showed no significant difference. Also, coarse-graded mixes performed better than fine-graded mixes, with 12.5 mm mixes performing better than 9.5 mm mixes.

Field mix performance evaluation was planned to evaluate the APA's ability to predict performance.

2.5.1 Asphalt Pavement Analyzer Pass / Fail Criteria

The APA's ability to distinguish between good and poor performing mixes has made it a valuable tool for evaluating HMA mix rut potential. A number of states have developed APA pass/fail rut criteria for HMA mixes. A brief summary of those studies is provided.

Prowell (*14*) conducted a study for the Virginia Department of Transportation to evaluate the APA's ability to predict rutting in Virginia HMA mixes and to develop APA pass/fail rutting criteria. Asphalt Pavement Analyzer testing was conducted using 8000 cycles, hose pressure of 690 kPa (100 psi), and wheel load of 445 N (100 lbs). Hot mix samples were taken from over 180 paving projects in Virginia during construction, gyratory specimens compacted, and APA testing conducted. As a result of the study pass/fail criteria were developed as follows in Table 2.1.

Table 2.1 Virginia DOT APA Rut Depth Criteria

Mix Type	Maximum Rut Depth, mm
SM-1 (Fine-graded 9.5 mm NMAS - Low Traffic)	8.5
SMA (Stone Matrix Asphalt with PG 70-22 or PG 76-22)	4.0
SM-12.5D (Coarse-graded 12.5 mm NMAS with PG 70.22)	4.0

Hawkins (*15*) evaluated high traffic HMA mixes in South Carolina with the APA. The testing approach was to test mixes prepared with aggregates commonly used in HMA mixes throughout South Carolina. Aggregates included marble and two granites. Two asphalt binder grades were used, PG 64-22 and PG 76-22. Three mix types were tested: 19.0 mm, 12.5 mm, and a Marshall Surface T-1C. Each mix type, aggregate and binder type were combined resulting in a total of 18 mixes. Beam specimens were compacted at 7 ± 1 percent air voids and tested in the APA for 8000 cycles at 64º C (147º F), a hose pressure of 690 kPa (100 psi), and 445 N (100 lbs) wheel load. The study concluded that as binder grade increases rut depth decreases. However, there was no significant difference between aggregate type and nominal maximum aggregates size. Developed rut depth criteria of 7.0 mm for intermediate courses with PG 64-22, 5.0 mm for surface courses with PG 64-22, and 3.0 mm for intermediate and surface courses with PG 76-22.

Kandhal and Cooley (9) described a procedure for establishing APA mix acceptance criteria. In their procedure, the relationship was first determined between field rutting rate (rutting / square root of ESALs) and laboratory rut depth for mixes from Westrack and MnRoad. Once the relationship was established, a maximum allowable field rut depth of 12.5 mm was arbitrarily assumed. Using the 12.5 mm rut depth, allowable APA laboratory rut depths were determined using the developed relationship. The developed APA criteria are illustrated in Figure 2.6, which was developed for cylindrical specimens compacted to 4 percent air voids tested at the base PG binder temperature.

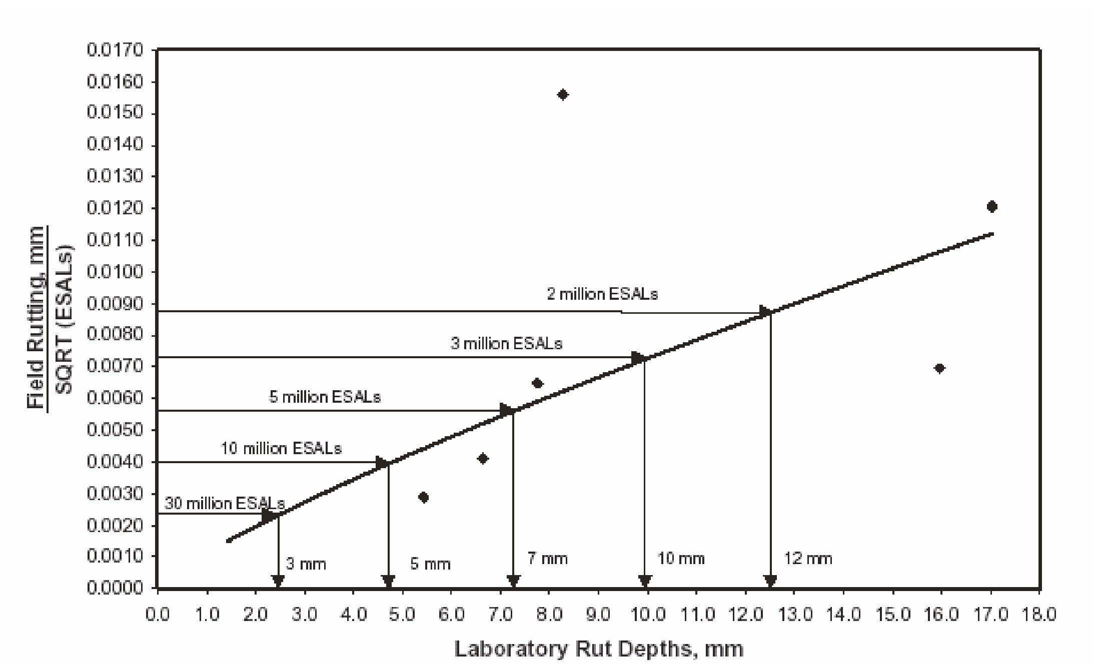


Figure 2.6 APA Mix Acceptance Criteria (9)

Based on the research results from Kandhal and Mallick (*10*), the Alabama Department of Transportation specifies a maximum allowable rut depth of 4.5 mm for ESAL Range "E" mixes (i.e., mixes with greater than 10 million ESALS). Lower volume mixes are not required pass any APA test criteria for mix design approval (*16*).

2.6 HMA MIX PERFORMANCE AT THE NCAT TEST TRACK

The Mississippi Department of Transportation participated in the accelerated testing program at the NCAT test track (*17*). Two commonly used Mississippi HMA mixes were placed during the first testing phase, which included 10 million ESALs applied over two years. Table 2.2 summarizes the mix type and characteristics used at the test track.

Table 2.2 HMA Mixture Characteristics

Section	S2	S3
Gradation Type	BRZ	BRZ
Aggregate Type	Grv	Grv/Lms
Sieve Size, mm	% Passing	% Passing
25	100	100
19	100	100
12.5	100	100
9.5	96	100
4.75	67	70
2.36	41	43
1.18	29	29
0.6	22	21
0.3	15	15
0.15	10	11
0.075	8.4	8.9
QC Lab Air Voids, %	4.7	3.5
N_{design}	100	100
In-Place Air Voids, %	6.2	7.3
Asphalt Content, %	6.0	5.6
PG Grade	76-22	76-22
Modifier Type	SBS	SBS

Rutting was the major performance distress evaluated. Rutting was measured for all sections during the traffic phase and at completion. Rut depths for both MDOT sections were among the lowest of all the 46 test sections at 0.7 mm each. These test sections can be considered to have performed very well under the accelerated loading conditions. Most high volume highways in Mississippi will not have 10 million ESALs applied until many years after construction (10 million were applied in only 2 years at this track), so these mixes would likely experience even less rutting in actual field service.

Cylindrical specimens from the Mississippi sections were tested at 4 percent air voids in the APA for 8000 cycles at 64°C (147°F) , 534 N (120 lbs) load, and 827 kPa (120 psi) hose pressure. The APA rut depths for Mississippi sections S2 and S3 were 1.43 and 1.32, respectively. Figure 2.7 illustrates the relationship of field rutting and APA laboratory rutting for all 46 mixes at the test track. The trend of increasing APA with increasing field rutting is as expected; however, the relationship is only marginal (R^2 = 0.31).

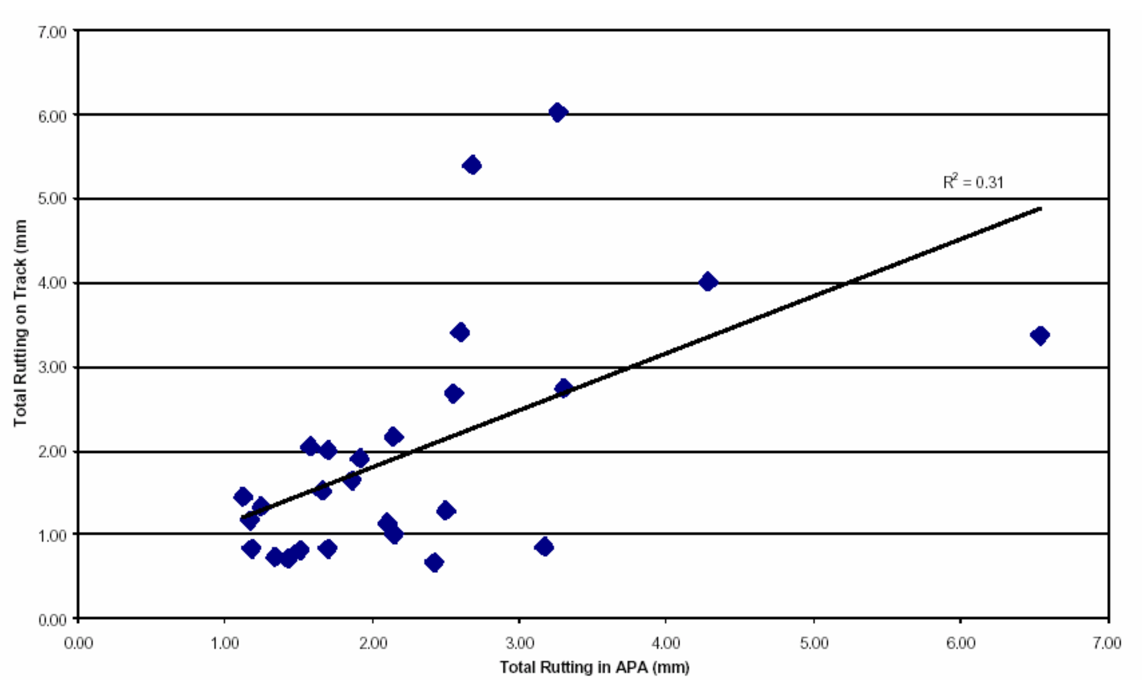


Figure 2.7 Test Track Rutting versus APA Rutting (*17*)

CHAPTER 3 RESEARCH TEST PLAN

This chapter describes the project test plan and procedures jointly developed by the Mississippi Department of Transportation (MDOT) and the Department of Civil Engineering at Mississippi State University (MSU).

3.1 TEST PLAN DEVELOPMENT

The overall study test plan is illustrated in Figure 3.1. In-service pavements selected for study were classified by current MDOT Superpave traffic classifications, ST [< 1million Equivalent Single Axle Loads (ESALs)], MT (1-3 million ESALs), and HT (>3 million ESALs). Other project selection requirements were aggregate type, nominal maximum aggregate size, and asphalt binder performance grade. Also, projects were selected throughout the state to account for variations in climate, traffic, construction and aggregate origin.

Gravel and gravel/limestone aggregate mixes were evaluated due to their extensive statewide use. Since only surface course mixes were examined, nominal maximum aggregate sizes were limited to 9.5 and 12.5 mm. Performance grade 67-22 binder is used in ST and MT mixes, while PG 76-22 is used for many HT mixes. All HT mixes evaluated in the study used PG 76-22.

For each combination of study variables, it was initially decided to evaluate two projects. A list of possible projects was identified by MDOT from a review of their pavement management database and sent to MSU for preliminary review. A more detailed review was then made using MDOT pavement management video analysis system. The video review was conducted to locate possible evaluation sections (i.e., tangent sections with little or no grade change).

In some cases, problems were encountered obtaining replicate projects for a test matrix combination. In these situations, projects were added to closely related cells. For example, difficulty was encountered locating 9.5 mm HT gravel and 9.5 mm HT gravel/limestone mixes, so a 12.5 mm HT gravel mix and a 12.5 mm HT gravel/limestone mix were supplemented. In another case, a 9.5 mm MT gravel/limestone mix was substituted for a 12.5 mm MT gravel/limestone mix.

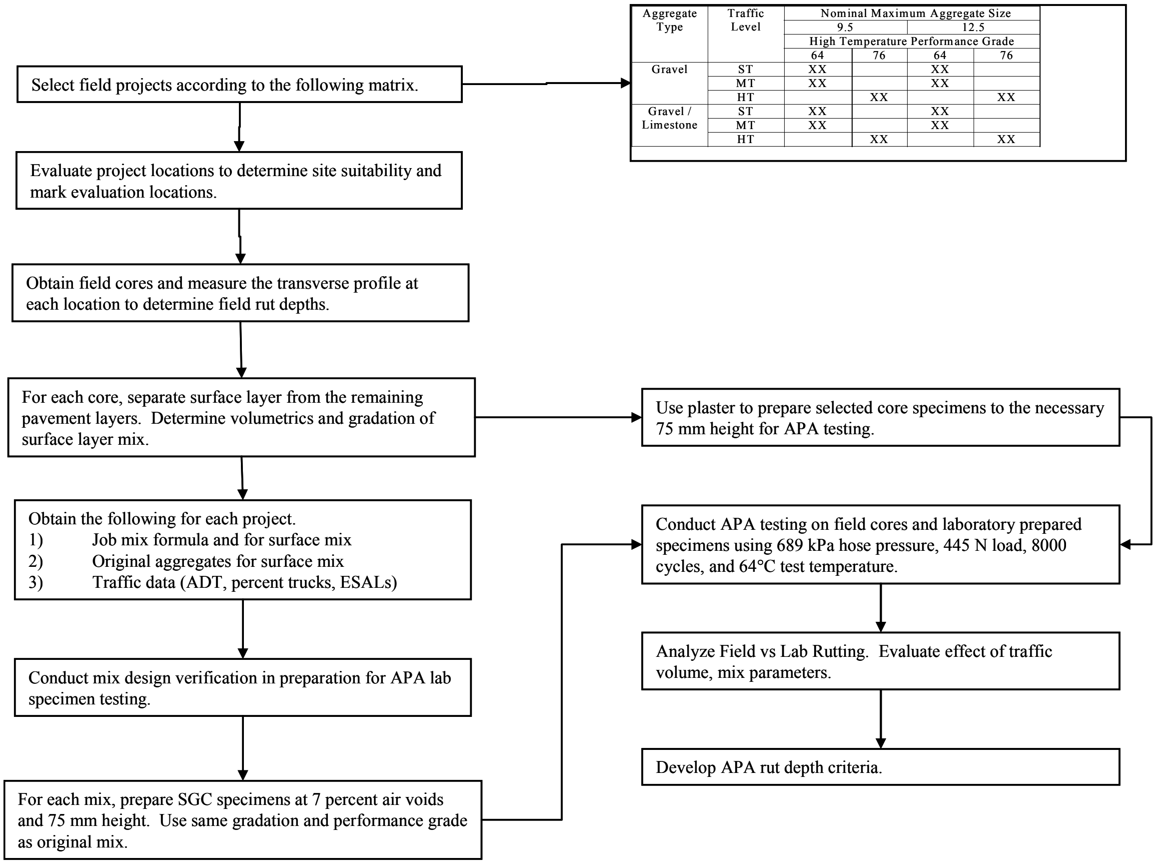


Figure 3.1 Research Test Plan for APA Study

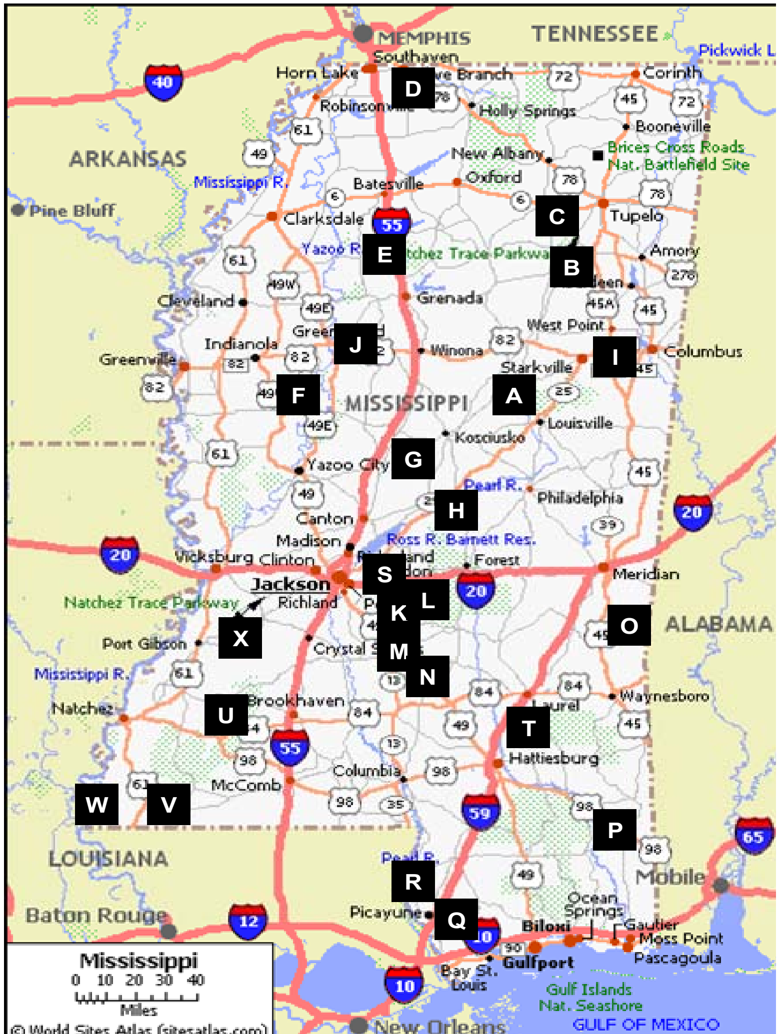
Once projects were selected, traffic data were obtained from MDOT to estimate equivalent single axle loads (ESALs) on each project. Average daily traffic at construction (ADT_o), directional distribution (D), growth factor (G), percent trucks (T), truck factor (T_f), and lane distribution (L) were used in conjunction with the number of years the pavement has been in service (Y) to calculate ESALs as shown below.

$$ESALs = (ADT)_o(T)(T_f)(G)(D)(L)(365)(Y) \qquad \text{Equation 3.1}$$

Table 3.1 shows the completed test matrix with county and route number. Figure 3.2 shows the location of each site in the state.

Table 3.1 APA Test Matrix

<table>
<tr><th rowspan="4">Aggregate Type</th><th rowspan="4">Traffic Level</th><th colspan="4">Nominal Maximum Aggregate Size, mm</th></tr>
<tr><th colspan="2">9.5</th><th colspan="2">12.5</th></tr>
<tr><th colspan="4">High Temperature Performance Grade</th></tr>
<tr><th>67</th><th>76</th><th>67</th><th>76</th></tr>
<tr><td rowspan="6">Gravel</td><td rowspan="2">ST</td><td>1. Claiborne, Hwy 18</td><td rowspan="4">NONE</td><td>1. Lincoln , Hwy 550</td><td rowspan="4">NONE</td></tr>
<tr><td>2. Amite, Hwy 33</td><td>2. Wilkinson, Hwy 24</td></tr>
<tr><td rowspan="2">MT</td><td>1. Copiah, Hwy 28</td><td>1. Leake, Hwy 35</td></tr>
<tr><td>2. Pearl River, Hwy 11</td><td>2. Jones, Hwy 11</td></tr>
<tr><td rowspan="2">HT</td><td rowspan="2">NONE</td><td rowspan="2">1. Rankin, I-20</td><td rowspan="2">NONE</td><td>1. Covington, Hwy 49</td></tr>
<tr><td>2. Simpson, Hwy 49</td></tr>
<tr><td rowspan="9">Gravel / Limestone</td><td rowspan="2">ST</td><td>1. Leflore, Hwy 7</td><td rowspan="5">NONE</td><td>1. Winston, Hwy 15</td><td rowspan="5">NONE</td></tr>
<tr><td>2. Wayne, Hwy 510</td><td>2. Smith, Hwy 13</td></tr>
<tr><td rowspan="3">MT</td><td>1. Chickasaw, Hwy 32</td><td rowspan="3">1. Ponotoc, Hwy 278</td></tr>
<tr><td>2. Attala, Hwy 12</td></tr>
<tr><td>3. Pearl River, Hwy 43</td></tr>
<tr><td rowspan="4">HT</td><td rowspan="4">NONE</td><td rowspan="4">1. Carroll, Hwy 82</td><td rowspan="4">NONE</td><td>1. DeSoto, Hwy 78</td></tr>
<tr><td>2. Panola, I-55</td></tr>
<tr><td>3. Lowndes, Hwy 82</td></tr>
<tr><td>4. George, Hwy 98</td></tr>
</table>



A = Project Location

Figure 3.2 Project Location

APA Project List

	No.	Aggregate	Traffic Level	NMS	PG	County	Highway
A	15	Gravel/Limestone	ST	12.5	67-22	Winston	15
B	17	Gravel/Limestone	MT	9.5	67-22	Chickasaw	32
C	19	Gravel/Limestone	MT	12.5	67-22	Pontotoc	278
D	23	Gravel/Limestone	HT	12.5	76-22	Desoto	78
E	24	Gravel/Limestone	HT	12.5	76-22	Panola	I-55
F	13	Gravel/Limestone	ST	9.5	67-22	Leflore	7
G	18	Gravel/Limestone	MT	9.5	67-22	Attala	12
H	7	Gravel	MT	12.50	67-22	Leake	35
I	9	Gravel/Limestone	HT	12.5	76-22	Lowndes	82
J	22	Gravel/Limestone	HT	9.5	76-22	Carroll	82
K	5	Gravel	MT	9.5	67-22	Simpson	13
L	16	Gravel/Limestone	ST	12.5	67-22	Smith	13
M	12	Gravel	HT	12.5	76-22	Simpson	49
N	11	Gravel	HT	12.5	76-22	Covington	49
O	14	Gravel/Limestone	ST	9.5	67-22	Wayne	510
P	21	Gravel/Limestone	HT	12.5	76-22	George	98
Q	20	Gravel/Limestone	MT	9.5	67-22	Pearl River	43
R	6	Gravel	MT	9.50	67-22	Pearl River	11
S	10	Gravel	HT	9.5	76-22	Rankin	I-20
T	8	Gravel	MT	9.5*	67-22	Jones	11
U	3	Gravel	ST	12.5	67-22	Lincoln [43]	550
V	2	Gravel	ST	9.5	67-22	Amite	33
W	4	Gravel	ST	12.5	67-22	Wilkinson	24
X	1	Gravel	ST	9.5	67-22	Claiborne	18

3.2.1 Field Study

Mississippi DOT personnel first visited each project site to layout three evaluation sections. Field support for pavement evaluations was coordinated by the MDOT research division and involved traffic control, core location marking, and coring. For the evaluation, each site was divided into three lots with coring within each lot being conducted as illustrated in Figure 3.3. Three core locations within each lot were separated by 30 meters (100 feet), with each location being referred to as a sublot. Lots were separated by approximately 300 meters (1000 feet) so a better project representation of the pavement could be obtained. At each sublot, 150 mm (6 inch) cores were obtained in the right wheel path and between the left and right wheel paths, yielding 18 cores for each project. All cores were placed on ice to prevent damage during transport to the laboratory.

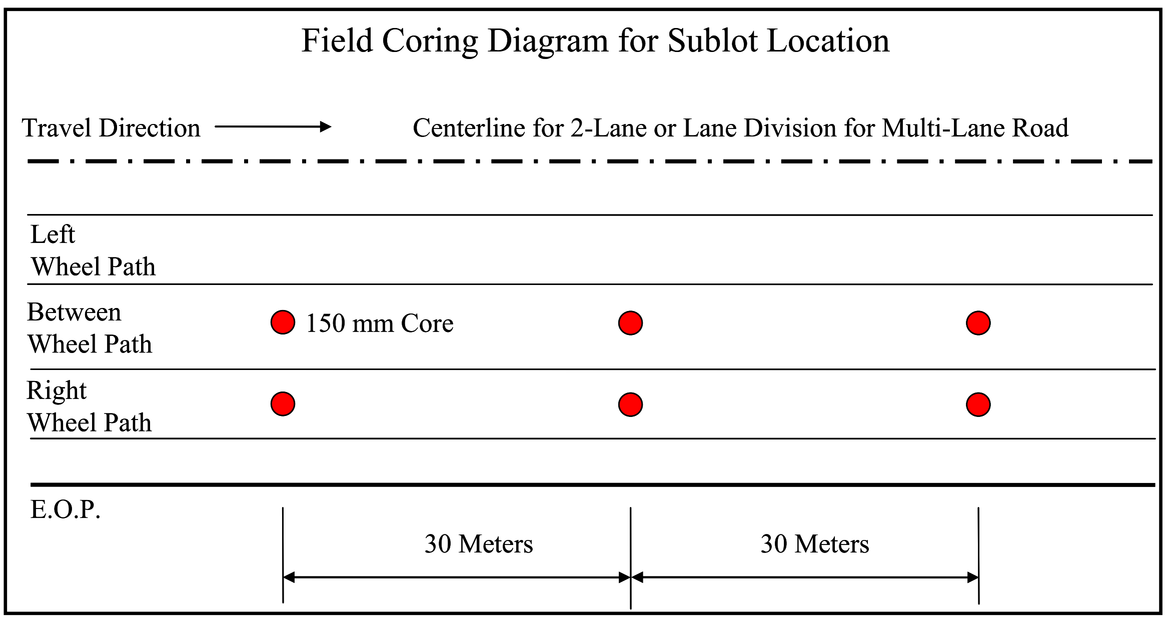


Figure 3.3 Field Coring Diagram

Field rut depth measurements were obtained within each sublot using a horizontal straight edge (referred to as the rut bar), shown in Figure 3.4, which was developed and built by MSU. The rut bar was modeled after other manual rut depth measurement devices. Rut readings are referred to as "profiles" and were taken within 1 m (3 ft) of the core locations. For measurement, the rut bar was placed perpendicular to the traffic direction and leveled using vertical adjustment screws on each end. A level was used at various locations along the top of the rut bar to insure the bar was level. A device similar to a surveying level rod was used to measure the distance from the top of the rut bar to the pavement surface. Measurements, recorded to the nearest 0.1 millimeter, were obtained every 50 mm (2 in.) across the lane. Actual pavement profile was developed by removing pavement cross slope, which was calculated from the 10 measurements nearest the left edge (i.e., edge opposite the shoulder).

Figure 3.4 Field Rut Bar

3.2.2 Core Analysis

Prior to testing, the surface layer of the obtained cores was identified and separated from the underlying layers. Core thicknesses were determined, followed by volumetric property and gradation analysis. Bulk specific gravities were determined in accordance with AASHTO T166 (*18*). Asphalt binder extractions, in accordance with AASHTO T164 (*19*) and ALDOT -371-90 (*20*), were conducted on three cores, one from each lot. Maximum specific gravity was determined in accordance with AASHTO T209 (*21*). Gradation analysis was conducted in accordance with AASHTO T11 (*22*) and T21 (*23*).

3.2.3 Asphalt Pavement Analyzer Core Testing

Asphalt Pavement Analyzer testing was conducted in two stages. In the first stage, cores from between wheel paths were tested. These cores were assumed to have air voids comparable to that at construction. Cores with air voids closest to 7 percent were selected for APA testing. Figure 3.5 shows a typical graph of air voids for a set of cores from one project.

Asphalt Pavement Analyzer test specimens are required to be 75 mm ± 5 mm in height; however, surface layers for the evaluated pavements were all less than 50 mm. Therefore, plaster was used to achieve the 75 mm height. Plastering was accomplished using plaster of Paris and empty APA molds. The bottom plate attached to the APA molds was removed and the molds turned upside down. Cores were placed top down in the molds, plaster mixed and placed, and allowed to cure for approximately 1 hour. Excess plaster was struck off with a straight edge. Figure 3.6 shows a core after plastering.

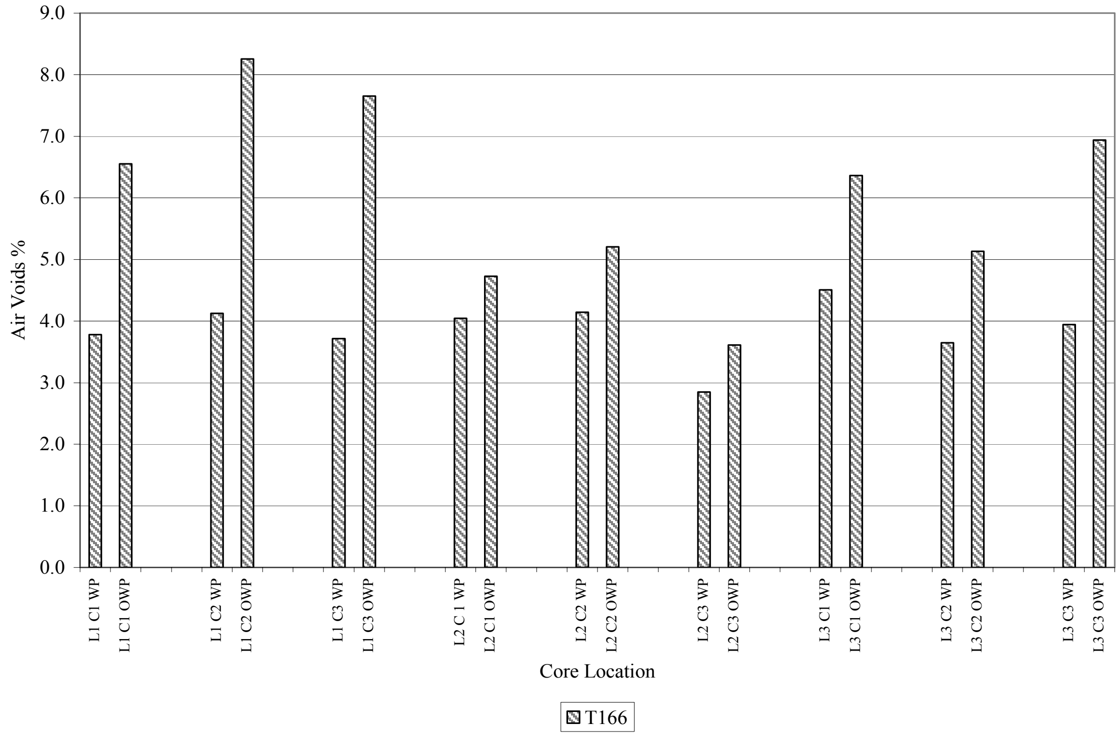


Figure 3.5 Sample Core Air Void Analysis

Figure 3.6 Core After Plastering.

For APA testing, two specimens from the same lot were placed in one APA test mold. This resulted in cores from one project being tested during one complete APA test (i.e., mold 1 had cores from lot 1, mold 2 had cores from lot 2, etc.). All APA testing was done at 64° C (147° F) with a wheel load of 445 N (100 lbs), hose pressure of 690 kPa (100 psi), and test duration of 8000 cycles. Automatic APA data collection was utilized and manually verified upon test completion.

3.2.4 Mix Design Verification

Before APA testing could be conducted on laboratory prepared specimens, each mix design was verified. For each mix, the job mix formula (JMF) was obtained from MDOT to determine material constituents. Asphalt binder and hydrated lime were obtained from Ergon Inc., and Falco Lime Inc., respectively. Aggregates were obtained in sufficient quantities for mix design verification and subsequent APA testing. The respective asphalt pavement contractors were first contacted to determine original material availability. If original aggregates were available, samples were obtained. If original aggregates were not available, the contractor recommended similar available aggregates.

Gradation and specific gravity tests were conducted on all aggregates. Aggregate blends using original JMF aggregate percentages were compared with core gradations. During aggregate blending there was an effort to keep percentages of aggregate types consistent with the original JMF design (i.e., if 60 percent gravel and 40 percent limestone was used originally the same percentages were used for laboratory blends). In some cases, stockpile percentages of crushed gravel and/or limestone were adjusted slightly. Sand content was kept at its JMF percent, so overall mix angularity would be approximately the same. Once a final blend was established, specimens were mixed at the asphalt content determined from extractions and compacted in the gyratory compactor to the required N_{design} level to verify the mix design.

The target mixing and compaction temperatures for the PG 67-22 and PG 76-22 asphalt binders are provided in Table 3.2. All mixing was conducted using a bucket mixing device as shown in Figure 3.7.

Table 3.2 Target Mixing, Curing, and Compaction Temperatures

Asphalt Binder	Temperature, C (F)		
	Mixing	Curing	Compaction
PG 67-22	155 (310)	152 (305)	146 (295)
PG 76-22	163 (325)	160 (320)	155 (310)

Figure 3.7 Project Mixing

A standard procedure was used for preparing the PG 76-22 asphalt binder. Per Ergon's Inc., recommendations, the asphalt binder was heated to 150°C (300°F) and stirred continuously using a low shear mixer for 1-hour prior to incorporation with aggregates.

All aggregates were heated to 175°C (345°F) for four hours prior to mixing. Mixing time varied, but was normally approximately 2 to 3 minutes to insure adequate aggregate coating. After mixing, specimens were short-term aged at 5°C (10°F) above the compaction temperature for 1.5 hours.

After aging, specimens were compacted to the specified number of gyrations (N_{design}) in a Pine Superpave Gyratory Compactor (Model AFGC125X). Duplicate maximum specific gravity specimens were also prepared for each project mixes. Bulk specific gravities were determined for all compacted specimens. An air void tolerance of 4 ± 1 percent was utilized during verification.

3.2.5 APA Laboratory Specimen Testing

After laboratory mix design verification, laboratory prepared specimens were compacted to 7 ± 1 percent air voids for APA testing. To compact 75 mm specimens at 7 percent air voids, a trial and error procedure was utilized to find the mix mass that would produce the specified air voids, at the target height. Three varying mix masses were prepared and compacted to 75 mm. Air voids of each mix was determined and plotted versus mass and the mass yielding 7 percent air voids determined. Once a specimen mass was found, duplicate specimens were compacted and air void content verified to be 7 ± 1 percent. Four additional specimens were then compacted and APA testing completed using the same testing protocols described previously for cores.

CHAPTER 4 DATA AND ANALYSIS

This chapter includes test results and analysis. Data includes site reports, APA core testing results, APA lab specimen testing results, and determination of APA rut depth criteria

4.1 SITE REPORTS

For each project a brief project summary is provided which discusses location, traffic, observed rutting, in-place air voids, and gradation.

4.1.1 Project A – Highway 15 in Winston County

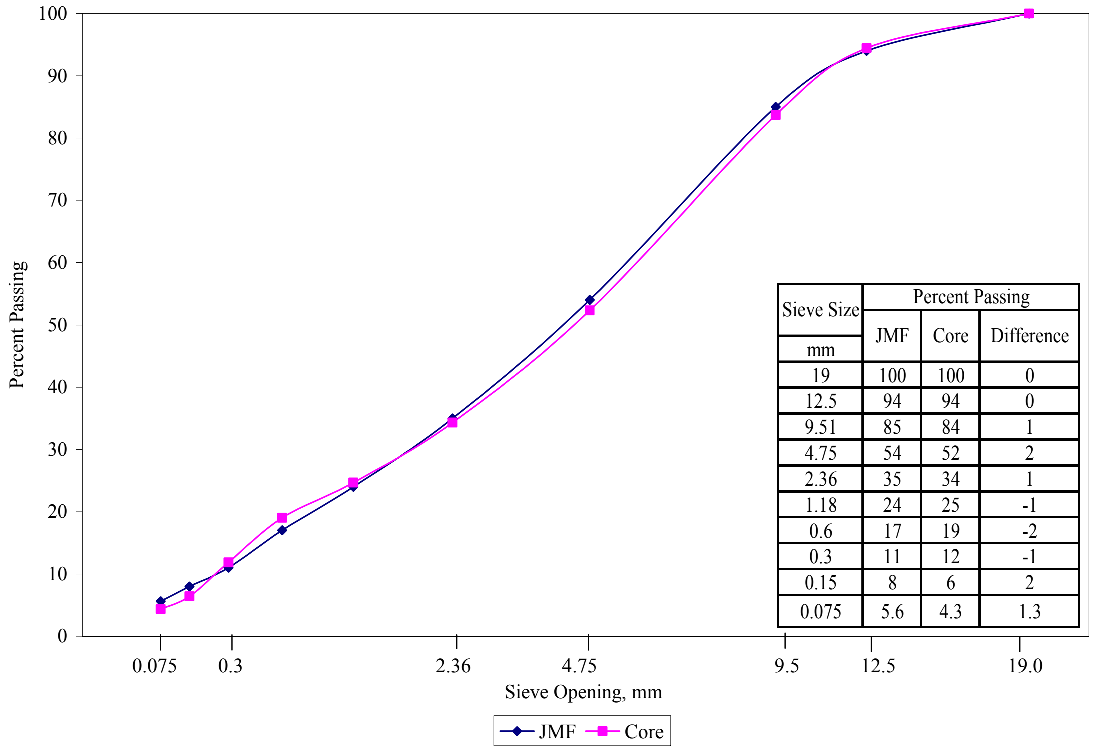
This two-lane roadway north of Louisville was last rehabilitated in July 2000. The surface mix is a 12.5 mm NMS ST with 82 percent gravel, 8 percent limestone, 10 percent recycled asphalt pavement (RAP) and a PG 67-22 asphalt binder. The annual daily traffic (ADT) was 2,200 vehicles per day (vpd) with 33 percent trucks.

The project was evaluated on July 7, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.1. Actual and JMF blend gradations are provided in Figure 4.1. Field rutting was minimal with average and maximum rut depths of 2.20 mm and 5.59 mm, respectively. Average air voids of between wheel path and wheel path cores were 6.1 and 3.8 percent, respectively. Core extractions indicated asphalt content was 0.2 percent higher than the JMF. Aggregate gradation closely matched closely the JMF.

Table 4.1 Project A: Winston County - Highway 15 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids %		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	5.59	2.240	2.175	2.328 (2.358)[1]	3.8	6.6	42.8	6.0 (5.8[1])
Lot 1 Profile 2	3.70	2.232	2.136		4.1	8.3	42.4	
Lot 1 Profile 3	1.02	2.242	2.150		3.7	7.7	44.0	
Lot 2 Profile 1	2.03	2.234	2.218		4.0	4.7	49.3	
Lot 2 Profile 2	1.96	2.232	2.207		4.1	5.2	44.8	
Lot 2 Profile 3	2.36	2.262	2.244		2.8	3.6	45.5	
Lot 3 Profile 1	1.40	2.223	2.180		4.5	6.4	39.5	
Lot 3 Profile 2	0.54	2.243	2.209		3.6	5.1	43.5	
Lot 3 Profile 3	1.19	2.236	2.166		3.9	6.9	42.4	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Percent Passing Core	Percent Passing Difference
19	100	100	0
12.5	94	94	0
9.51	85	84	1
4.75	54	52	2
2.36	35	34	1
1.18	24	25	-1
0.6	17	19	-2
0.3	11	12	-1
0.15	8	6	2
0.075	5.6	4.3	1.3

Figure 4.1 Project A: Winston County - Highway 15 Core Gradation Analysis

4.1.2 Project B – Highway 32 in Chickasaw County

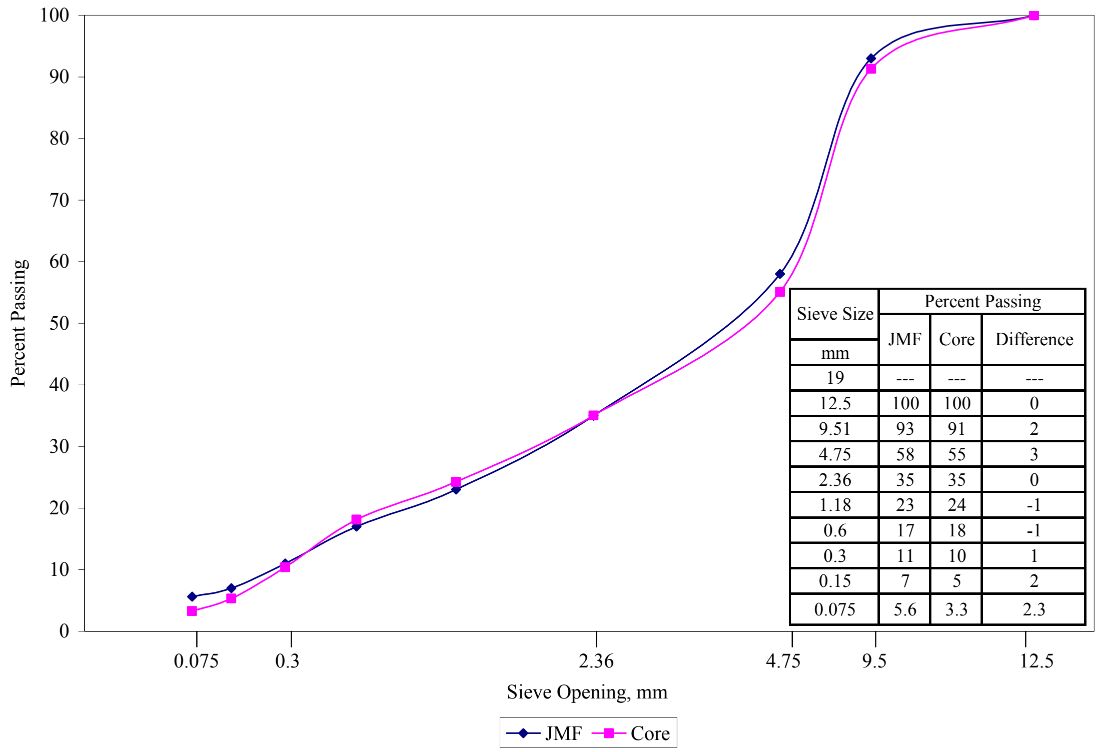
This project, a two-lane facility located west of Okolona, was last rehabilitated in November 1999. The mix evaluated is a 9.5 mm NMS MT with PG 67-22, 92 percent gravel and 8 percent limestone aggregate. Based on MDOT information, ADT is 3,200 vpd with 23 percent trucks.

The site was evaluated on July 8, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.2. Actual and JMF blend gradations are provided in Figure 4.2. Field rutting measured an average rut depth of 3.93 mm and a maximum of 6.42 mm. Average air voids of between wheel path cores and in-wheel path cores were 7.4 percent and 7.2 percent, respectively, indicating the pavement has not densified substantially under traffic. Core extractions indicated asphalt content was 0.2 percent higher than the JMF. Core aggregate gradation matched closely with JMF values, with the exception of the minus 0.075mm, which was over 2 percent lower than the JMF value.

Table 4.2 Project B: Chickasaw County – Highway 32 Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids %		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	2.95	2.175	2.163		7.1	7.5	39.1	
Lot 1 Profile 2	3.00	2.191	2.179		6.4	6.9	36.5	
Lot 1 Profile 3	2.82	2.184	2.190		6.6	6.4	45.0	
Lot 2 Profile 1	4.35	2.169	2.128		7.3	9.1	37.9	
Lot 2 Profile 2	4.97	2.128	2.154	2.340 (2.313[1])	9.0	8.0	33.8	6.7% (6.5%[1])
Lot 2 Profile 3	3.82	2.211	2.211		5.5	5.5	41.5	
Lot 3 Profile 1	4.78	2.185	2.169		6.6	7.3	40.2	
Lot 3 Profile 2	6.42	2.131	2.143		8.9	8.4	39.6	
Lot 3 Profile 3	2.26	2.173	2.170		7.1	7.2	36.5	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	93	91	2
4.75	58	55	3
2.36	35	35	0
1.18	23	24	-1
0.6	17	18	-1
0.3	11	10	1
0.15	7	5	2
0.075	5.6	3.3	2.3

Figure 4.2 Project B: Chickasaw County – Highway 32 Core Gradation Analysis

4.1.3 Project C – Highway 278 in Pontotoc County

The project is a two-lane roadway located west of Pontotoc, which was last rehabilitated in the summer of 2000. The mix is a 12.5 mm NMS MT with PG 67-22, 45 percent gravel and 55 percent limestone aggregate. Traffic data indicated an ADT of 2,400 vpd with 13 percent trucks.

The site was visited on July 9, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.3. Actual and JMF blend gradations are provided in Figure 4.3. Field rutting for this project was very minimal. Average and maximum rut depth were 0.52 mm and 0.69 mm, respectively. Based on between wheel path core densities the average air voids were 7.3 percent, with air voids inside the wheel path being 6.3 percent. Core extractions conducted showed the asphalt content to be within 0.2 percent of the JMF value. Aggregate gradation analysis indicated cores was coarser (approximately 3 percent) than the JMF from the 4.75 mm through the 0.075 mm sieves.

Table 4.3 Project C: Pontotoc County – Highway 278 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids, %		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	0.53	2.200	2.182	2.335 (2.303[1])	5.8	6.6	57.5	6.3% (6.1%[1])
Lot 1 Profile 2	0.28	2.166	2.160		7.3	7.5	47.9	
Lot 1 Profile 3	0.69	2.181	2.112		6.6	9.5	51.3	
Lot 2 Profile 1	0.53	2.184	2.184		6.5	6.5	48.8	
Lot 2 Profile 2	0.55	2.193	2.158		6.1	7.6	46.2	
Lot 2 Profile 3	0.55	2.187	2.149		6.3	8.0	43.3	
Lot 3 Profile 1	0.41	2.199	2.169		5.8	7.1	55.5	
Lot 3 Profile 2	0.60	2.177	2.168		6.8	7.2	47.9	
Lot 3 Profile 3	0.54	2.201	2.192		5.7	6.1	53.5	

[1] Values from Job Mix Formula

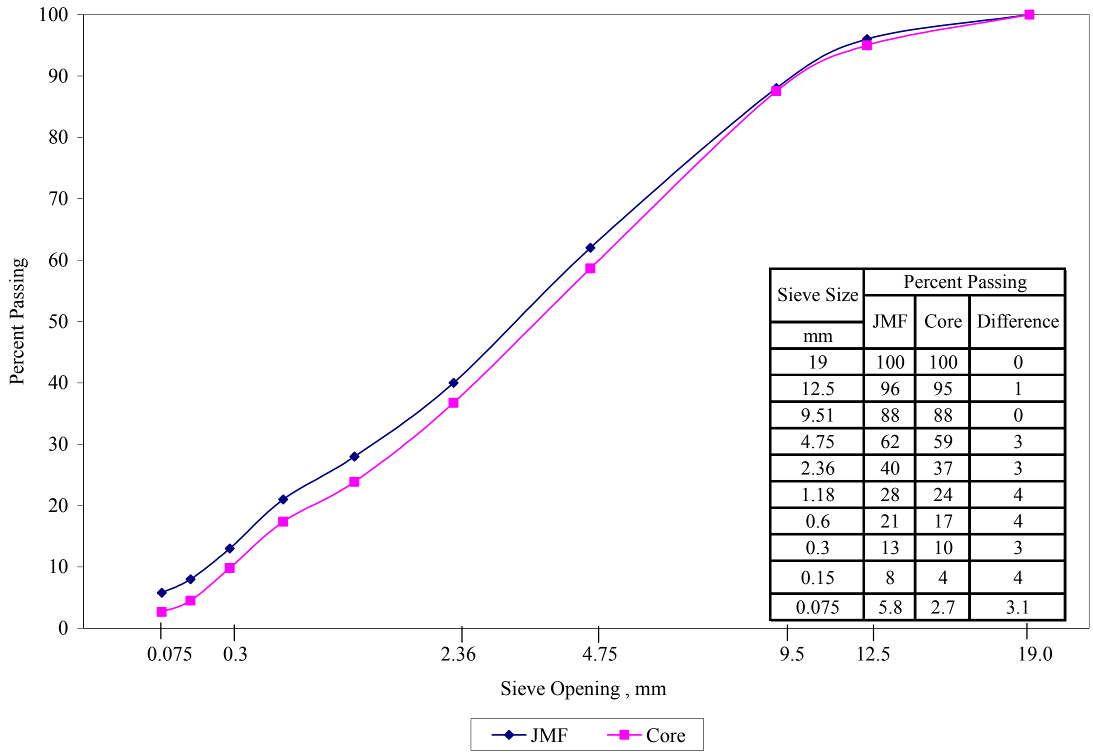


Figure 4.3 Project C: Pontotoc County – Highway 278 Core Gradation Analysis

4.1.4 Project D – Highway 78 in DeSoto County

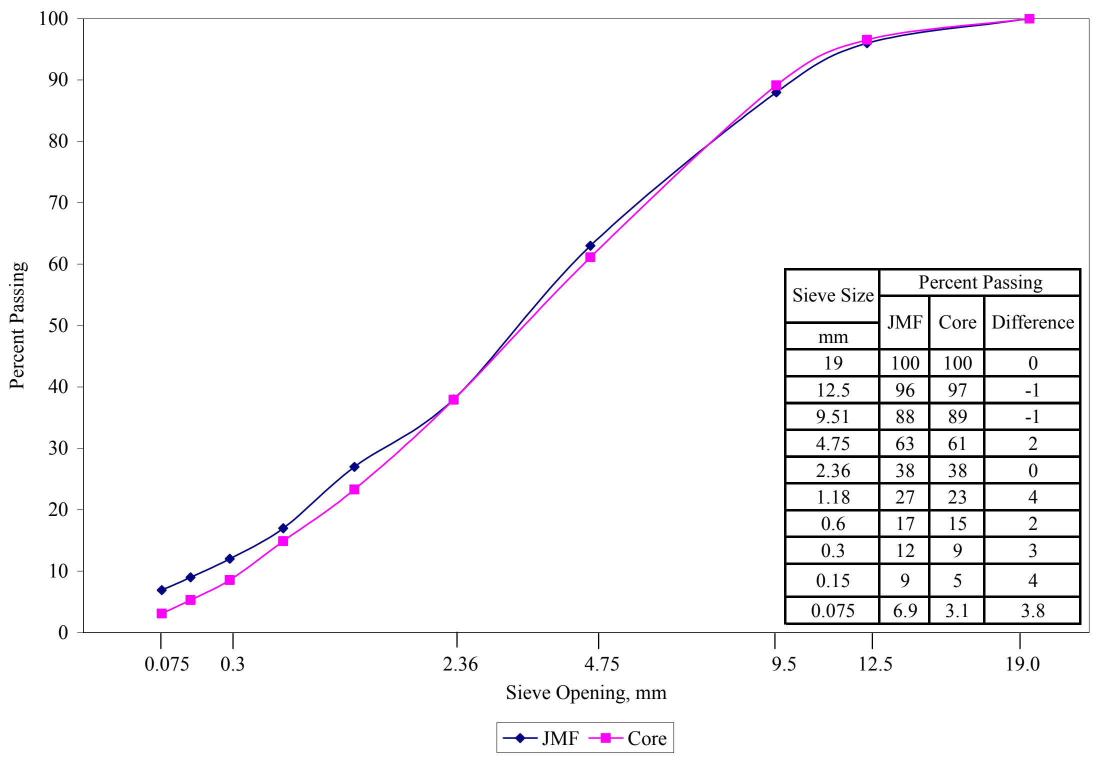
Project D is located on Highway 78, a four-lane divided highway, near the Coldwater River in Desoto County. Highway 78 was last rehabilitated in August 2000. The surface mix is a 12.5 mm NMS HT with PG 76-22, 72 percent gravel, 13 percent limestone aggregates, and 15 percent RAP. Traffic data showed an ADT of 26,000 vpd with 17 percent trucks.

The site was visited on July 10, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.4. Actual and JMF blend gradations are provided in Figure 4.4. Rutting averaged 3.09 mm with a maximum rut depth of 5.59 mm. Average air voids between the wheel path cores were 4.7 percent, with average air voids inside the wheel path being 4.5 percent. Core extractions conducted showed no deviation of asphalt content from the JMF, while aggregate gradation tests indicated cores were generally coarser from the 1.18 mm through the 0.075 mm sieves.

Table 4.4 Project D: Desoto County – Highway 78 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids, %		Thickness, mm	Asphalt Content
		In	Out		In	Out		
Lot 1 Profile 1	2.41	2.252	2.236	2.371 (2.371[1])	5.0	5.7	55.1	5.8% (5.8%[1])
Lot 1 Profile 2	5.59	2.252	2.250		5.0	5.1	61.6	
Lot 1 Profile 3	5.33	2.260	2.246		4.7	5.3	64.0	
Lot 2 Profile 1	2.79	2.268	2.277		4.3	4.0	50.8	
Lot 2 Profile 2	1.57	2.275	2.278		4.0	3.9	53.2	
Lot 2 Profile 3	4.32	2.262	2.252		4.6	5.0	48.6	
Lot 3 Profile 1	0.89	2.268	2.269		4.4	4.3	48.5	
Lot 3 Profile 2	2.79	2.279	2.282		3.9	3.7	49.4	
Lot 3 Profile 3	2.08	2.257	2.244		4.8	5.3	47.3	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	96	97	-1
9.51	88	89	-1
4.75	63	61	2
2.36	38	38	0
1.18	27	23	4
0.6	17	15	2
0.3	12	9	3
0.15	9	5	4
0.075	6.9	3.1	3.8

Figure 4.4 Project D: Desoto County – Highway 78 Core Gradation Analysis

4.1.5 Project E – Interstate 55 in Panola County

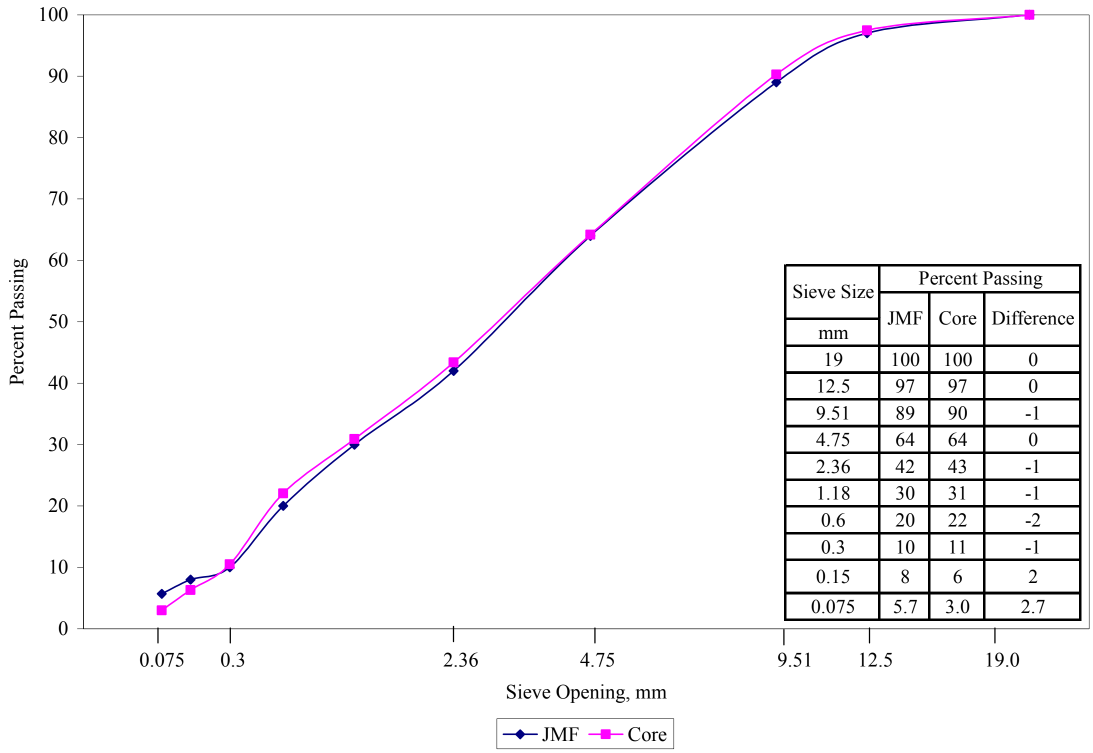
Interstate 55 in Panola County is divided four-lane facility last rehabilitated in May 2000. The surface mix is a 12.5 mm NMS HT with PG 76-22, 75 percent gravel, 10 percent limestone aggregates, and 15 percent RAP. Traffic data showed an ADT of 20,000 vpd and 25 percent trucks.

The site was visited on July 14, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.5. Actual and JMF blend gradations are provided in Figure 4.5. Measured rutting for this site was minimal, with an average and maximum rut depth of 1.81 mm and 3.28 mm, respectively. Average air voids between the wheel path cores were 4.9 percent, while air voids inside the wheel path were 4.1 percent. Core extractions indicated that asphalt content was 0.2 percent higher than the JMF value, while the aggregate gradation was with 2 percent of the JMF for all sieves.

Table 4.5 Project E: Panola County – Interstate 55 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids, %		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.81	2.298	2.278	2.374 (2.391[1])	3.2	4.1	57.4	5.6% (5.4%[1])
Lot 1 Profile 2	3.28	2.258	2.240		4.9	5.6	55.4	
Lot 1 Profile 3	2.96	2.265	2.243		4.6	5.5	63.2	
Lot 2 Profile 1	1.69	2.269	2.265		4.4	4.6	62.6	
Lot 2 Profile 2	2.60	2.283	2.253		3.8	5.1	58.2	
Lot 2 Profile 3	0.89	2.279	2.268		4.0	4.4	52.9	
Lot 3 Profile 1	0.89	2.263	2.245		4.7	5.4	52.4	
Lot 3 Profile 2	1.08	2.269	2.245		4.4	5.4	56.8	
Lot 3 Profile 3	1.11	2.302	2.275		3.0	4.2	50.3	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	97	97	0
9.51	89	90	-1
4.75	64	64	0
2.36	42	43	-1
1.18	30	31	-1
0.6	20	22	-2
0.3	10	11	-1
0.15	8	6	2
0.075	5.7	3.0	2.7

Figure 4.5 Project E: Panola County – Interstate 55 Core Gradation Analysis

4.1.6 Project F - Highway 7 in Leflore County

This project, located on Highway 7 approximately 20 miles south of Itta Bena in Leflore County, is a two-lane highway most recently rehabilitated in May 2000. The surface mix is a 9.5 mm ST with PG 67-22, 80 percent gravel and 20 percent limestone aggregate. Average ADT is 1,600 vpd with 10 percent trucks.

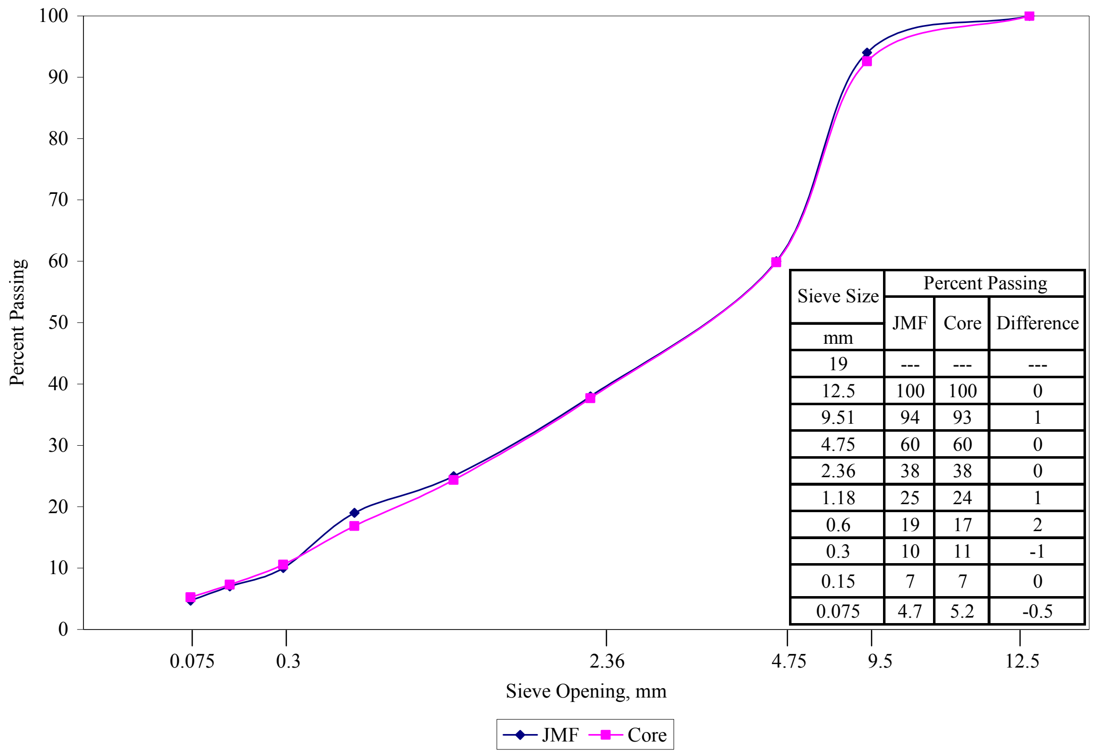
The site was visited on July 15, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.6. Actual and JMF blend gradations are provided in Figure 4.6. Field rutting measured for this site had an average and maximum rut depth of 2.76 mm and 4.67 mm, respectively. Based on the between wheel path core densities average air voids were 7.2 percent, with air voids inside the wheel path being 5.6 percent.

Analysis of the cores indicated the asphalt content to be within 0.2 percent of the JMF. Core aggregate gradation was within 2 percent of the JMF all sieves.

Table 4.6 Project F: Leflore County – Highway 7 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	4.51	2.306	2.287	2.400 (2.390[1])	3.9	4.7	38.1	6.6% (5.9%[1])
Lot 1 Profile 2	1.48	2.322	2.241		3.3	6.6	34.4	
Lot 1 Profile 3	2.24	2.316	2.257		3.5	5.9	35.3	
Lot 2 Profile 1	1.72	2.275	2.246		5.2	6.4	39.5	
Lot 2 Profile 2	2.42	2.270	2.247		5.4	6.4	42.0	
Lot 2 Profile 3	2.11	2.275	2.227		5.2	7.2	41.3	
Lot 3 Profile 1	3.85	2.227	2.203		7.2	8.2	23.2	
Lot 3 Profile 2	4.67	2.185	2.149		8.9	10.4	20.6	
Lot 3 Profile 3	1.82	2.201	2.180		8.3	9.2	27.4	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	94	93	1
4.75	60	60	0
2.36	38	38	0
1.18	25	24	1
0.6	19	17	2
0.3	10	11	-1
0.15	7	7	0
0.075	4.7	5.2	-0.5

Figure 4.6 Project F: Leflore County – Highway 7 Core Gradation Analysis

4.1.7 Project G – Highway 12 in Attala County

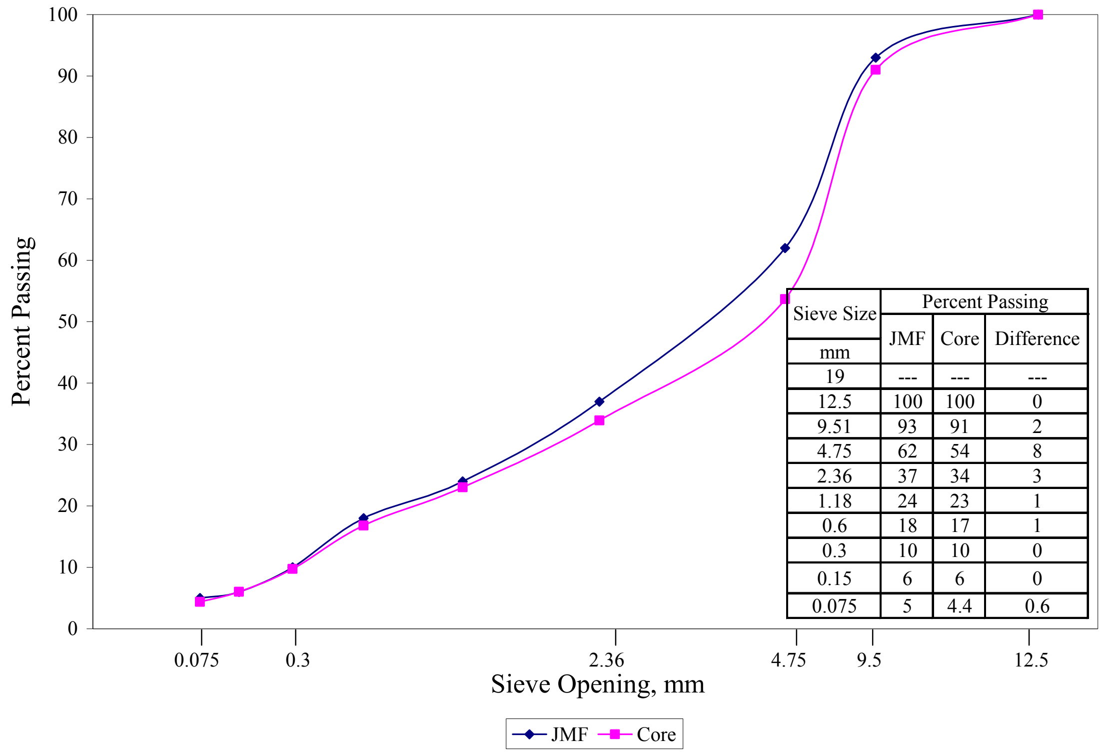
Project G, located on Highway 12, is a two-lane facility rehabilitated in the fall of 1999. The surface mix is a 9.5 mm NMS MT with PG 67-22, 84 percent gravel and 16 percent limestone aggregate. The ADT is approximately 3,700 vpd with 13 percent trucks.

The site was visited on July 16, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.7. Actual and JMF blend gradations are provided in Figure 4.7. Field rutting was minimal, with an average and maximum rut depth of 1.59 mm and 2.60 mm, respectively. Average between wheel path and in wheel path core air voids were 6.4 percent and 4.7 percent, respectively. Core extractions showed that the asphalt content was 0.1 percent lower than the JMF, while core aggregate gradation was close from the 1.18 mm through the 0.075 mm sieves, but considerable coarser than JMF values for the 4.75 mm and 2.36 mm sieves.

Table 4.7 Project G: Attala County – Highway 12 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.58	2.284	2.207	2.372 (2.371[1])	3.7	7.0	42.4	6.2% (6.3%[1])
Lot 1 Profile 2	1.85	2.276	2.205		4.1	7.0	42.3	
Lot 1 Profile 3	2.60	2.283	2.247		3.8	5.3	44.9	
Lot 2 Profile 1	0.82	2.253	2.225		5.0	6.2	42.0	
Lot 2 Profile 2	1.49	2.282	2.241		3.8	5.5	42.7	
Lot 2 Profile 3	1.68	2.204	2.195		7.1	7.5	41.0	
Lot 3 Profile 1	0.74	2.265	2.242		4.5	5.5	42.3	
Lot 3 Profile 2	2.44	2.241	2.203		5.5	7.1	36.8	
Lot 3 Profile 3	1.12	2.249	2.211		5.2	6.8	38.3	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Percent Passing Core	Percent Passing Difference
19	---	---	---
12.5	100	100	0
9.51	93	91	2
4.75	62	54	8
2.36	37	34	3
1.18	24	23	1
0.6	18	17	1
0.3	10	10	0
0.15	6	6	0
0.075	5	4.4	0.6

Figure 4.7 Project G: Attala County – Highway 12 Core Gradation Analysis

4.1.8 Project H – Highway 35 in Leake County

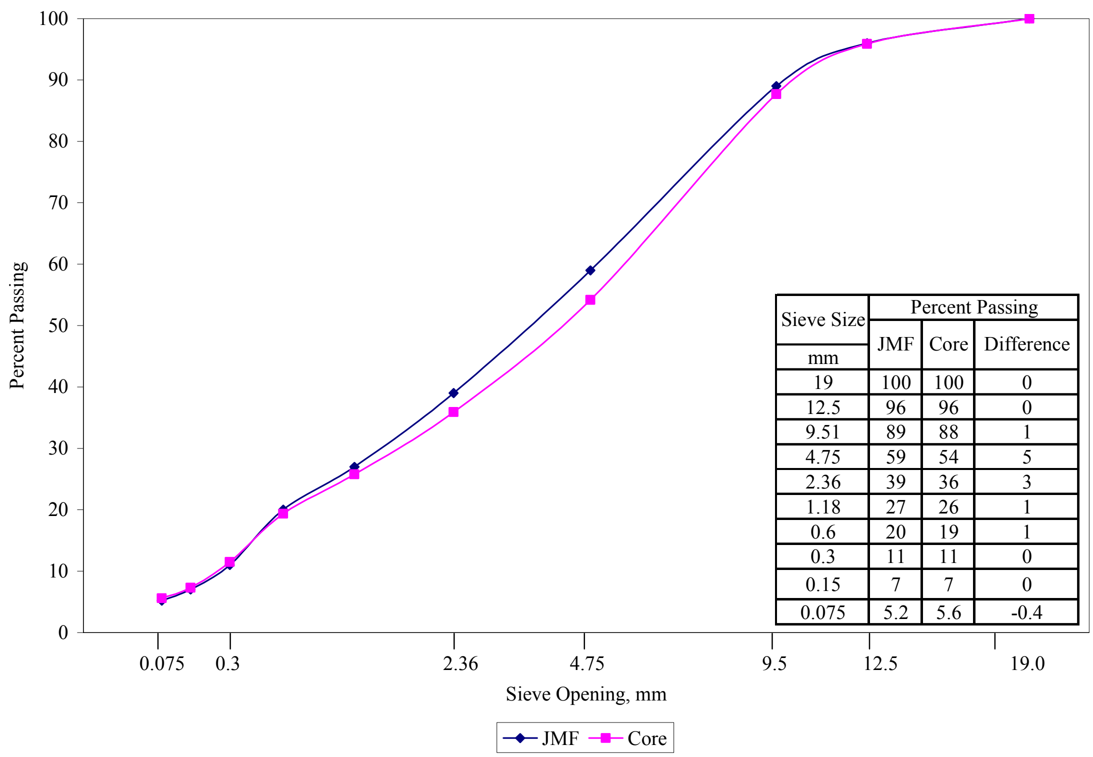
Highway 35 is a two-lane facility last rehabilitated in May 2000. The surface mix is a 12.5 mm MT using all gravel aggregate and a PG 67-22 asphalt binder. Traffic data indicated an ADT of 3,600 vpd with 8 percent trucks.

The site was visited on July 17, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.8. Actual and JMF blend gradations are provided in Figure 4.8. Field rutting was minimal, averaging a rut depth of 1.02 mm with a maximum of 2.50 mm. Average core air voids between and in the wheel path were 4.5 and 4.2 percent, respectively. With the exception of the 4.75 mm and 2.36 mm sieves being coarser than the JMF, core aggregate gradation was very close to the JMF. Asphalt binder content was the same as the JMF value.

Table 4.8 Project H: Leake County – Highway 35 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	0.22	2.271	2.269	2.379 (2.377[1]	4.6	4.6	42.8	5.4% (5.4%[1])
Lot 1 Profile 2	0.50	2.250	2.243		5.4	5.7	42.0	
Lot 1 Profile 3	0.67	2.267	2.249		4.7	5.5	39.6	
Lot 2 Profile 1	1.22	2.309	2.276		2.9	4.3	34.5	
Lot 2 Profile 2	1.12	2.294	2.277		3.6	4.3	32.9	
Lot 2 Profile 3	0.74	2.317	2.319		2.6	2.5	41.6	
Lot 3 Profile 1	1.22	2.275	2.276		4.4	4.3	44.8	
Lot 3 Profile 2	0.95	2.285	2.283		4.0	4.1	42.1	
Lot 3 Profile 3	2.50	2.248	2.245		5.5	5.6	43.5	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	96	96	0
9.51	89	88	1
4.75	59	54	5
2.36	39	36	3
1.18	27	26	1
0.6	20	19	1
0.3	11	11	0
0.15	7	7	0
0.075	5.2	5.6	-0.4

Figure 4.8 Project H: Leake County – Highway 35 Core Gradation Analysis

4.1.9 Project I – Highway 82 in Lowndes County

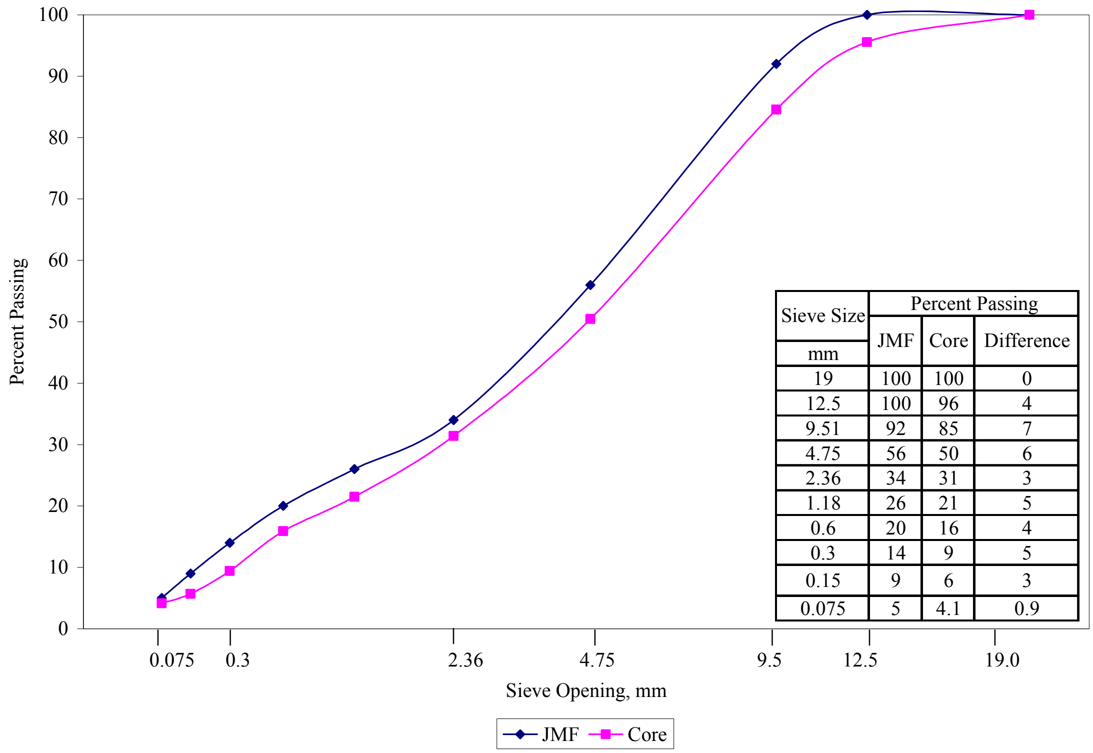
Project I is located on Highway 82 between Starkville and Columbus. Highway 82 is a divided four-lane facility last rehabilitated in September 1998. The surface mix is a 12.5 mm NMS HT using a PG 76-22 asphalt binder with 70 percent gravel and 30 percent limestone aggregate. The ADT was 16,000 vpd with 15 percent trucks.

The site was visited on July 21, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.9. Actual and JMF blend gradations are provided in Figure 4.9. Field rutting was slight, with an average and maximum rut depth of 2.76 mm and 3.21 mm, respectively. Based on between wheel path core densities, average air voids were 8.2 percent. Air voids of inside the wheel path cores were 6.7 percent. Core extractions conducted showed asphalt content was much lower and aggregate gradation was much coarser when compared to JMF values.

Table 4.9 Project I: Lowndes County – Highway 82 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	2.84	2.252	2.272	2.411 (2.375[1])	6.6	5.7	31.0	5.5% (6.1%[1])
Lot 1 Profile 2	2.41	2.176	2.208		9.7	8.4	35.4	
Lot 1 Profile 3	2.73	2.216	2.248		8.1	6.8	32.1	
Lot 2 Profile 1	3.21	2.172	2.240		9.9	7.1	33.1	
Lot 2 Profile 2	2.79	2.206	2.250		8.5	6.7	32.0	
Lot 2 Profile 3	2.65	2.238	2.246		7.2	6.8	31.5	
Lot 3 Profile 1	3.10	2.239	2.261		7.2	6.2	27.5	
Lot 3 Profile 2	2.68	2.235	2.258		7.3	6.3	30.9	
Lot 3 Profile 3	2.40	2.178	2.230		9.7	7.5	29.5	

[1] Values from Job Mix Formula



Sieve Size	Percent Passing		
mm	JMF	Core	Difference
19	100	100	0
12.5	100	96	4
9.51	92	85	7
4.75	56	50	6
2.36	34	31	3
1.18	26	21	5
0.6	20	16	4
0.3	14	9	5
0.15	9	6	3
0.075	5	4.1	0.9

Figure 4.9 Project I: Lowndes County – Highway 82 Core Gradation Analysis

4.1.10 Project J – Highway 82 in Carroll County

Project J is located on Highway 82 about 20 miles east of Greenwood in Carroll County. This project, a divided four-lane facility, was rehabilitated in May 1999. The mix is a 9.5 mm NMS HT using PG 76-22 asphalt binder with 80 percent gravel and 20 percent limestone aggregate. The ADT was 7900 vpd with 17 percent trucks.

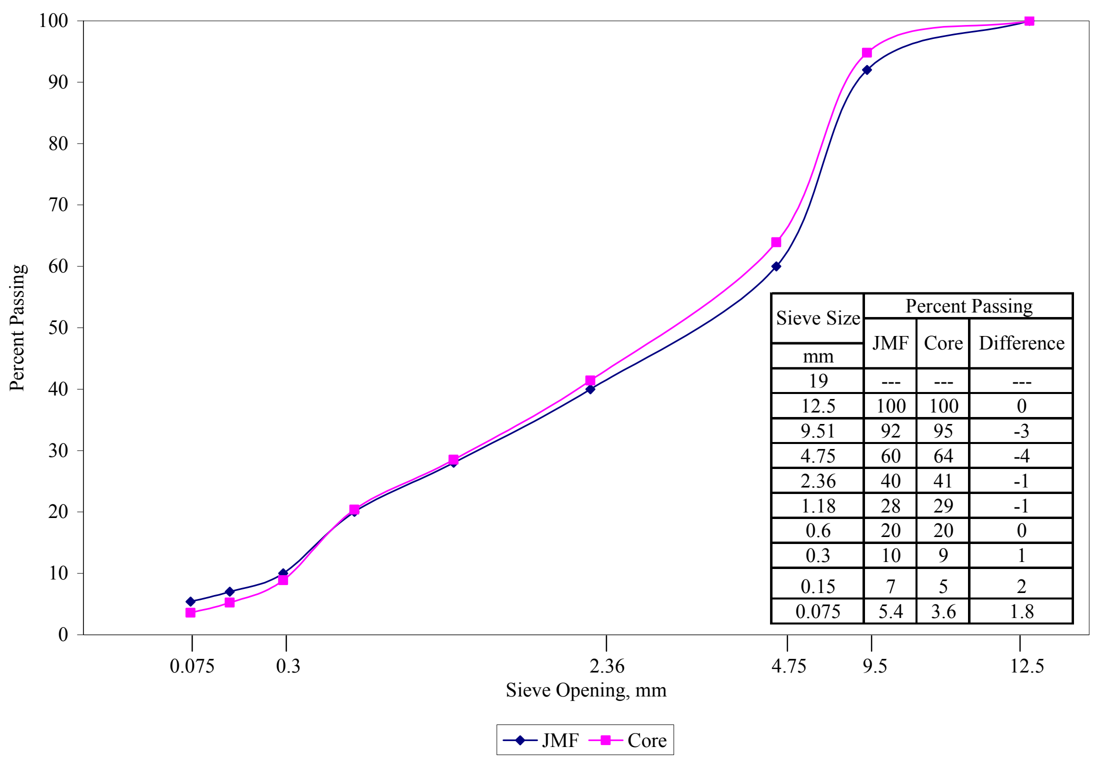
The site was visited on July 22, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.10. Actual and JMF blend gradations are provided in Figure 4.10. Field rutting was minimal with average and maximum rut depths of 1.68 mm and 2.87 mm, respectively. Average between wheel path and in wheel path core densities were 6.9 percent and 8.2 percent, respectively. The fact that densities of cores inside the wheel path are have lower densities found between wheel paths could be attributed to observed asphalt stripping and cracking along with sampling and testing variability. Core analysis showed the asphalt content 0.2 percent lower than the JMF.

Aggregate gradations were finer for larger sieves (9.5 mm and 4.75 mm) and coarser for finer sieves (0.30 mm, 0.15 mm and 0.075 mm).

Table 4.10 Project J: Carroll County – Highway 82 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.10	2.209	2.224	2.430 (2.401[1])	9.1	8.5	32.3	5.3% (5.5%[1])
Lot 1 Profile 2	0.89	2.236	2.219		8.0	8.7	31.9	
Lot 1 Profile 3	2.87	2.201	2.207		9.4	9.2	35.4	
Lot 2 Profile 1	2.13	2.246	2.197		7.6	9.6	40.4	
Lot 2 Profile 2	1.33	2.244	2.229		7.7	8.3	39.9	
Lot 2 Profile 3	1.56	2.241	2.208		7.8	9.1	35.3	
Lot 3 Profile 1	2.25	2.259	2.210		7.0	9.1	31.0	
Lot 3 Profile 2	1.96	2.248	2.224		7.5	8.5	30.9	
Lot 3 Profile 3	1.01	2.172	2.224		10.6	8.5	27.5	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	92	95	-3
4.75	60	64	-4
2.36	40	41	-1
1.18	28	29	-1
0.6	20	20	0
0.3	10	9	1
0.15	7	5	2
0.075	5.4	3.6	1.8

Figure 4.10 Project J: Carroll County – Highway 82 Core Gradation Analysis

4.1.11 Project K – Highway 13 in Simpson County

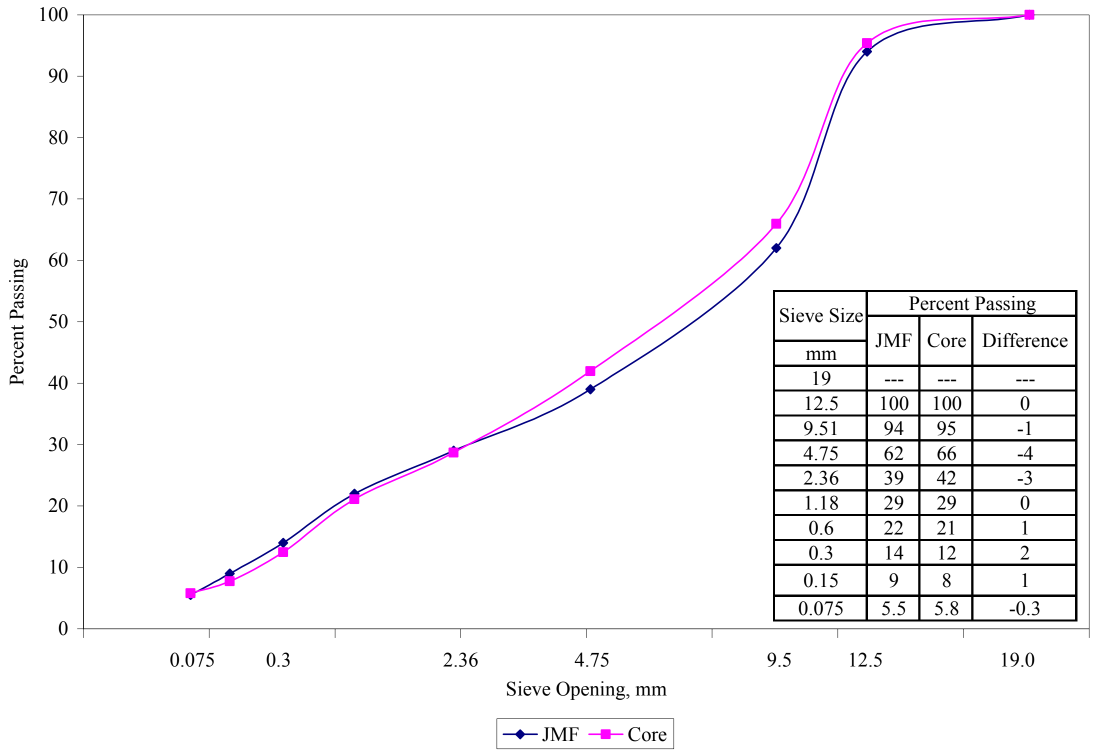
Highway 13 is a two lane highway last rehabilitated in the fall of 1999. The surface mix is a 9.5 mm MT using PG 67-22 with 85 percent gravel and 15 percent RAP. The ADT was 2,100 vpd with 15 percent trucks.

The site was visited on July 28, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.11. Actual and JMF blend gradations are provided in Figure 4.11. Field rutting was low, averaging a rut depth of 0.82 mm with a maximum of 1.55 mm. Average air voids of between wheel path cores were 6.9 percent, while air voids inside the wheel path were 5.8 percent. Core extractions conducted showed the asphalt content to be 0.5 percent lower than the JMF value while the core gradation was finer in the top sieves (4.75 mm and 2.36 mm) and slightly coarser in the finer sieves (0.3 mm and 0.15 mm).

Table 4.11 Project K: Simpson County – Highway 13 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.55	2.243	2.237	2.350 (2.332[1])	4.5	4.8	42.4	5.9% (6.4%[1])
Lot 1 Profile 2	1.05	2.200	2.168		6.4	7.7	40.4	
Lot 1 Profile 3	0.70	2.217	2.174		5.6	7.5	32.3	
Lot 2 Profile 1	0.63	2.207	2.171		6.1	7.6	40.5	
Lot 2 Profile 2	0.65	2.227	2.198		5.2	6.5	47.8	
Lot 2 Profile 3	0.73	2.201	2.158		6.3	8.2	41.2	
Lot 3 Profile 1	0.80	2.198	2.181		6.5	7.2	45.9	
Lot 3 Profile 2	0.73	2.217	2.192		5.7	6.7	38.3	
Lot 3 Profile 3	0.51	2.214	2.214		5.8	5.8	41.7	

[1] Values from Job Mix Formula



Sieve Size	Percent Passing		
mm	JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	94	95	-1
4.75	62	66	-4
2.36	39	42	-3
1.18	29	29	0
0.6	22	21	1
0.3	14	12	2
0.15	9	8	1
0.075	5.5	5.8	-0.3

Figure 4.11 Project K: Simpson County – Highway 13 Core Gradation Analysis

4.1.12 Project L – Highway 13 in Smith County

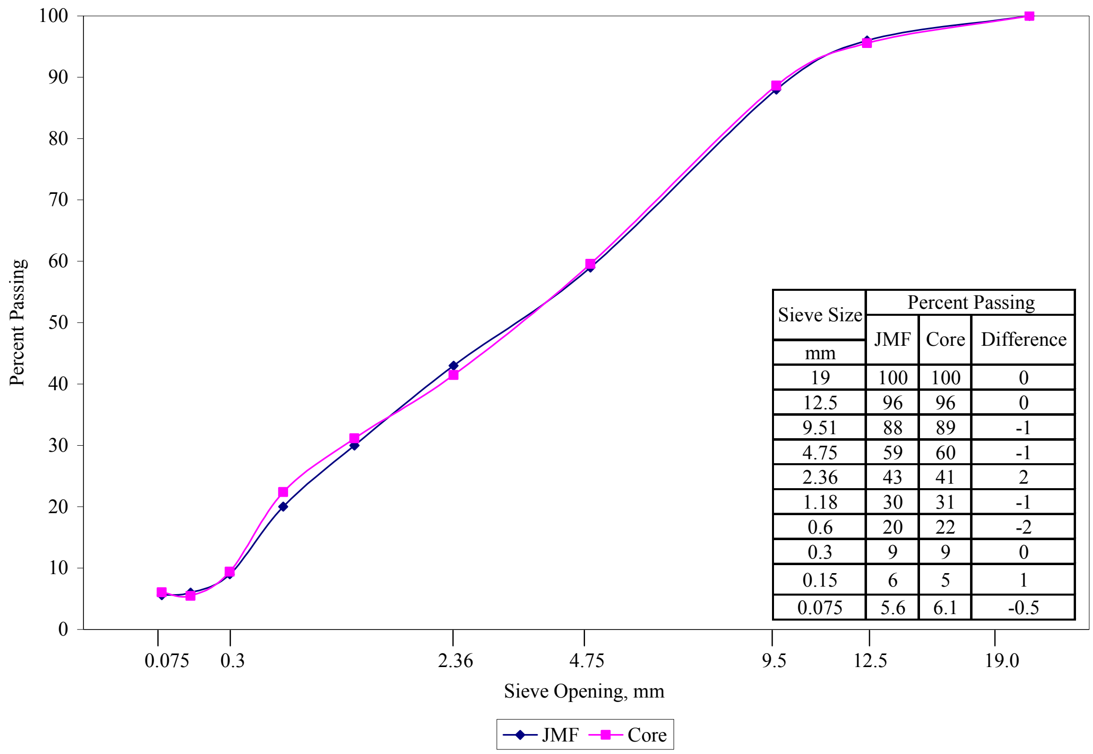
Highway 13 is a two-lane facility last was rehabilitated in April 1999. The surface mix is a 12.5 mm ST with PG 67-22 asphalt binder with 80 percent gravel and 10 percent limestone, and 10 percent RAP. The ADT was 1,100 vpd with 22 percent trucks.

The site was visited July 28, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.12. Actual and JMF blend gradations are provided in Figure 4.12. Field rutting was minimal, with an average and maximum rut depth of 2.20 mm and 3.26 mm, respectively. Average between wheel path and in wheel path core air voids were 7.2 percent and 7.3 percent, respectively. As with a previous project, wheel path core densities are lower than between wheel path core densities. Core analysis showed the asphalt content 0.2 percent higher than the JMF. Core gradation was within 2 percent of the JMF for all sieves.

Table 4.12 Project L: Smith County – Highway 13 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	2.65	2.155	2.142	2.400 (2.390[1])	10.2	10.7	44.6	5.8% (5.6%[1])
Lot 1 Profile 2	1.21	2.179	2.183		9.2	9.0	43.8	
Lot 1 Profile 3	1.47	2.164	2.200		9.8	8.3	50.1	
Lot 2 Profile 1	2.82	2.241	2.226		6.6	7.3	44.1	
Lot 2 Profile 2	3.23	2.205	2.237		8.1	6.8	46.1	
Lot 2 Profile 3	3.26	2.218	2.232		7.6	7.0	50.0	
Lot 3 Profile 1	1.84	2.301	2.282		4.1	4.9	59.2	
Lot 3 Profile 2	1.38	2.287	2.243		4.7	6.6	68.3	
Lot 3 Profile 3	1.91	2.266	2.298		5.6	4.2	54.6	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	96	96	0
9.51	88	89	-1
4.75	59	60	-1
2.36	43	41	2
1.18	30	31	-1
0.6	20	22	-2
0.3	9	9	0
0.15	6	5	1
0.075	5.6	6.1	-0.5

Figure 4.12 Project L: Smith County – Highway 13 Core Gradation Analysis

4.1.13 Project M – Highway 49 in Simpson County

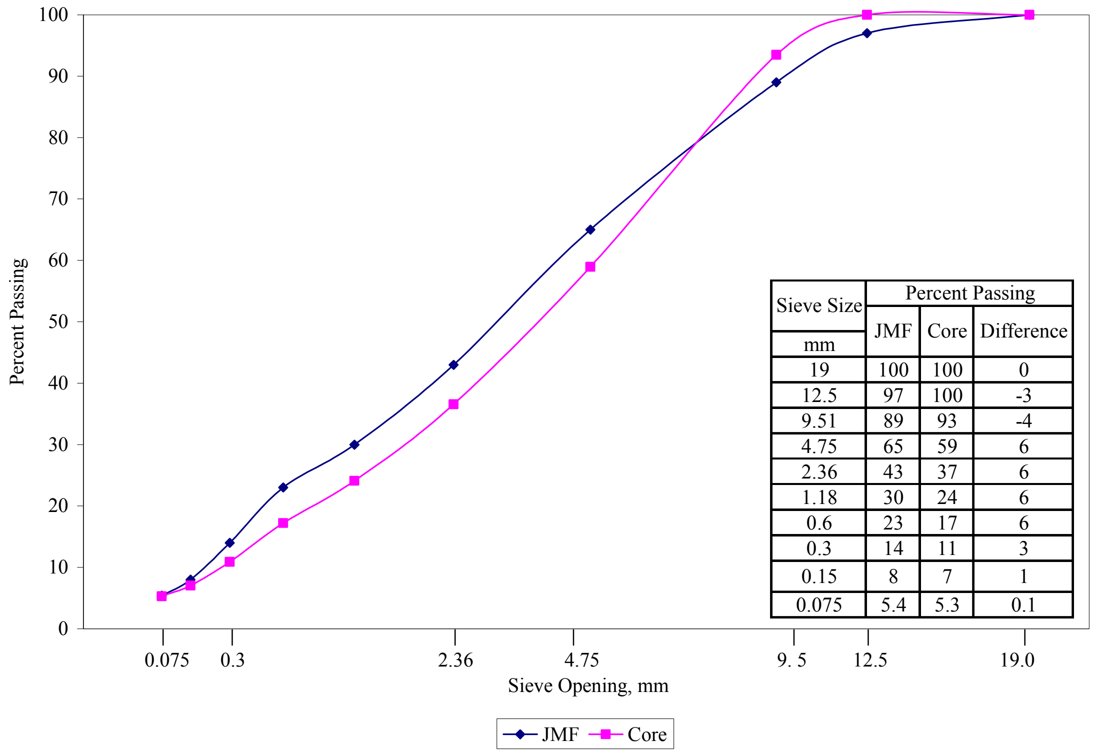
Project M, Highway 49 in Simpson County, is a divided four-lane facility rehabilitated in May 1998. The mix is a 12.5 mm HT using PG 76-22 with 89 percent gravel and 11 percent RAP. Traffic data indicated an ADT of 21,000 vpd and 19 percent trucks.

The site was visited on July 29, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.13. Actual and JMF blend gradations are provided in Figure 4.13. Field rutting was low, with an average and maximum rut depth of 0.95 mm and 1.85 mm, respectively. Based on between wheel path cores had an average air void of 5.6 percent. Average air voids inside the wheel path were 5.3 percent. Core extractions conducted showed that while asphalt content matched the JMF value, aggregate gradation was finer (3 to 4 percent) for top sieves (12.5 mm and 9.5 mm) and extremely coarser (6 percent) for the intermediate and fine sieves (4.75 mm through 0.15 mm).

Table 4.13 Project M: Simpson County – Highway 49 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.02	2.233	2.209	2.350 (2.369[1])	5.0	6.0	35.2	5.7% (5.7%[1])
Lot 1 Profile 2	0.51	2.216	2.226		5.7	5.3	38.7	
Lot 1 Profile 3	0.76	2.242	2.198		4.6	6.5	41.3	
Lot 2 Profile 1	1.22	2.210	2.203		6.0	6.3	38.8	
Lot 2 Profile 2	0.84	2.263	2.250		3.7	4.2	42.1	
Lot 2 Profile 3	1.85	2.217	2.208		5.7	6.0	40.5	
Lot 3 Profile 1	0.66	2.215	2.223		5.8	5.4	39.7	
Lot 3 Profile 2	0.94	2.227	2.216		5.2	5.7	42.6	
Lot 3 Profile 3	0.79	2.213	2.227		5.8	5.2	40.5	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing		
	JMF	Core	Difference
19	100	100	0
12.5	97	100	-3
9.51	89	93	-4
4.75	65	59	6
2.36	43	37	6
1.18	30	24	6
0.6	23	17	6
0.3	14	11	3
0.15	8	7	1
0.075	5.4	5.3	0.1

Figure 4.13 Project M: Simpson County – Highway 49 Core Gradation Analysis

4.1.14 Project N – Highway 49 in Covington County

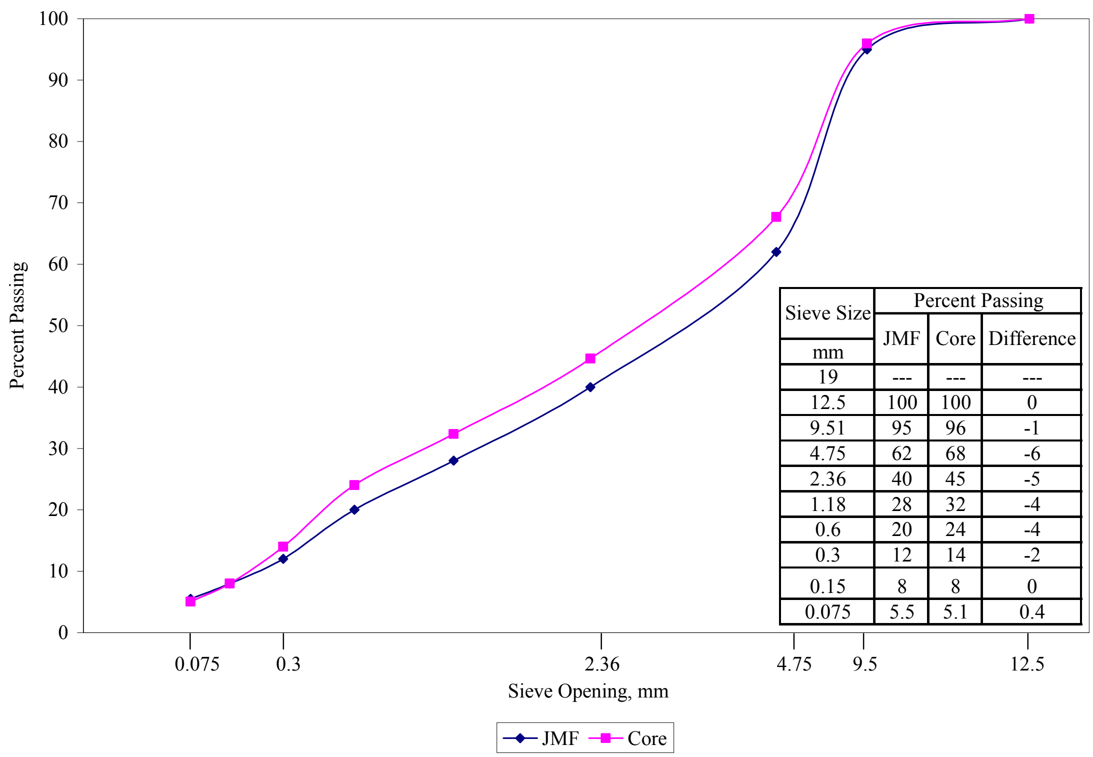
Project N is located on Highway 49 about 75 miles south of Jackson in Covington County. This project, a divided four-lane facility, was last rehabilitated in May 1998. The mix is a 12.5 mm HT with PG 76-22 asphalt binder with 85 percent gravel and 15 percent RAP. The ADT was 21,000 vpd with 23 percent trucks.

The site was visited on July 30, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.14. Actual and JMF blend gradations are provided in Figure 4.14. Field rutting was minimal, averaging a rut depth of 1.24 mm with a maximum of 2.62 mm. Average between wheel path and in wheel path core air voids were 9.7 percent and 9.0 percent, respectively. Analysis of the cores resulted in values for asphalt content to be slightly lower (0.4 percent) than JMF values, while the core aggregate gradation was considerably finer than the JMF from the 4.75 through the 0.3 mm sieves.

Table 4.14 Project N: Covington County – Highway 49 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.63	2.164	2.143	2.370 (2.354[1])	8.7	9.6	36.4	5.8% (6.2%[1])
Lot 1 Profile 2	0.36	2.126	2.145		10.3	9.5	39.2	
Lot 1 Profile 3	0.46	2.176	2.099		8.2	11.4	45.2	
Lot 2 Profile 1	1.02	2.151	2.198		9.2	7.2	43.6	
Lot 2 Profile 2	1.17	2.139	2.129		9.8	10.2	35.8	
Lot 2 Profile 3	1.55	2.136	2.144		9.9	9.6	38.8	
Lot 3 Profile 1	2.62	2.256	2.119		4.8	10.6	48.0	
Lot 3 Profile 2	0.71	2.086	2.162		12.0	8.8	35.1	
Lot 3 Profile 3	1.63	2.149	2.121		9.3	10.5	39.9	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	95	96	-1
4.75	62	68	-6
2.36	40	45	-5
1.18	28	32	-4
0.6	20	24	-4
0.3	12	14	-2
0.15	8	8	0
0.075	5.5	5.1	0.4

Figure 4.14 Project N: Covington County – Highway 49 Core Gradation Analysis

4.1.15 Project O – Highway 510 in Wayne County

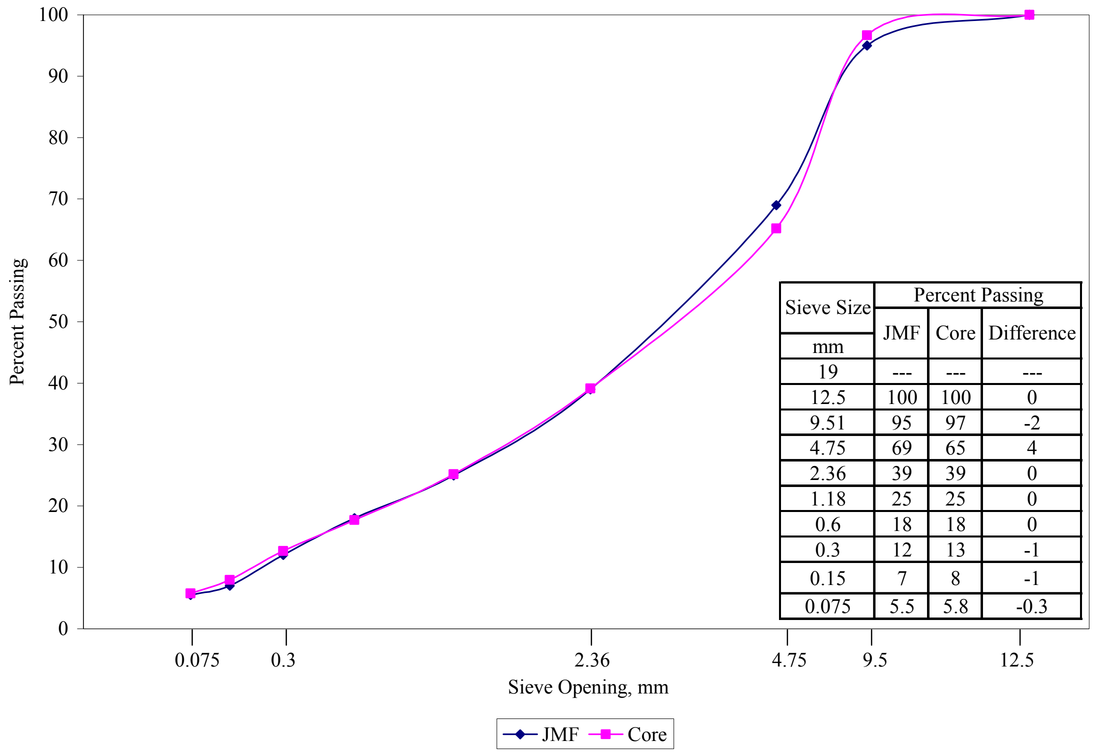
Project O, Highway 510, is a two-lane road rehabilitated in July 1999. The surface mix is a 9.5 mm ST PG with 67-22 asphalt binder using 60 percent gravel, 30 percent limestone aggregates along with 10 percent RAP. Traffic data indicated a very low ADT of 90 vpd with 10 percent trucks.

The site was visited on August 4, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.15. Actual and JMF blend gradations are provided in Figure 4.15. Field rutting was slight to moderate, with an average and maximum rut depth of 3.02 mm and 7.11 mm, respectively. Average between wheel path and in wheel path core air voids were 7.0 percent and 7.6 percent, respectively. Analysis of the cores resulted in values for asphalt content to be slightly higher (0.3 percent) than JMF values, while aggregate gradations matched closely with the JMF, with the exception of the 4.75 mm sieve where the core gradation was 4 percent coarser.

Table 4.15 Project O: Wayne County – Highway 510 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	6.10	2.209	2.223	2.370 (2.372[1])	6.8	6.2	35.4	6.9% (6.6%[1])
Lot 1 Profile 2	3.30	2.188	2.171		7.7	8.4	40.4	
Lot 1 Profile 3	7.11	2.202	2.272		7.1	4.1	36.7	
Lot 2 Profile 1	1.78	2.188	2.167		7.7	8.6	34.6	
Lot 2 Profile 2	2.54	2.199	2.263		7.2	4.5	32.3	
Lot 2 Profile 3	3.30	2.213	2.232		6.6	5.8	30.9	
Lot 3 Profile 1	1.02	2.189	2.211		7.6	6.7	38.5	
Lot 3 Profile 2	1.02	2.147	2.164		9.4	8.7	38.9	
Lot 3 Profile 3	1.02	2.183	2.149		7.9	9.3	39.9	

[1] Values from Job Mix Formula



Sieve Size	Percent Passing		
mm	JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	95	97	-2
4.75	69	65	4
2.36	39	39	0
1.18	25	25	0
0.6	18	18	0
0.3	12	13	-1
0.15	7	8	-1
0.075	5.5	5.8	-0.3

Figure 4.15 Project O: Wayne County – Highway 510 Core Gradation Analysis

4.1.16 Project P – Highway 98 in George County

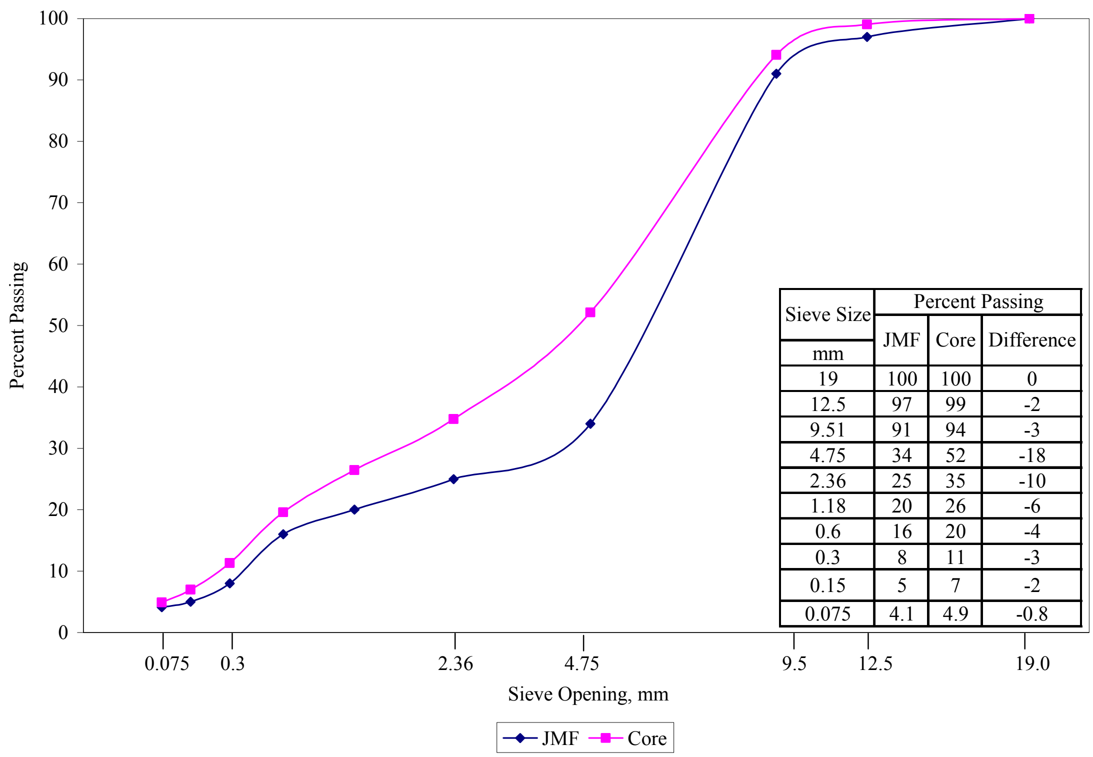
Project P is located on Highway 98 about 20 miles West of Mobile, Alabama, in George County. Highway 98 is a divided four-lane facility, was rehabilitated in November 2000. The mix is a 12.5 mm HT with PG 76-22 asphalt binder, 10 percent gravel, 50 percent limestone, 20 percent granite, and 20 percent RAP. The ADT was 7,200 vehicles with 17 percent trucks.

The site was visited on August 5, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.16. Actual and JMF blend gradations are provided in Figure 4.16. Field rutting was low, averaging 0.93 mm with a maximum of 2.79 mm. Between wheel path core air voids had an average of 6.2 percent, with average air voids inside the wheel path being 6.3 percent. Core analysis showed the asphalt content 0.2 percent higher than the JMF, and core gradation much finer when compared to JMF values.

Table 4.16 Project P: George County – Highway 98 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.02	2.295	2.287		6.6	6.9	37.4	
Lot 1 Profile 2	0.25	2.309	2.295		6.0	6.6	37.2	
Lot 1 Profile 3	0.25	2.338	2.346		4.8	4.5	31.5	
Lot 2 Profile 1	0.00	2.320	2.326		5.6	5.3	34.6	5.1% (4.9%[1])
Lot 2 Profile 2	0.25	2.276	2.241	2.456 (2.479[1])	7.3	8.8	27.7	
Lot 2 Profile 3	1.27	2.289	2.281		6.8	7.1	33.4	
Lot 3 Profile 1	0.25	2.349	2.347		4.4	4.4	34.1	
Lot 3 Profile 2	2.79	2.257	2.315		8.1	5.7	30.5	
Lot 3 Profile 3	2.29	2.271	2.292		7.6	6.7	26.6	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	97	99	-2
9.51	91	94	-3
4.75	34	52	-18
2.36	25	35	-10
1.18	20	26	-6
0.6	16	20	-4
0.3	8	11	-3
0.15	5	7	-2
0.075	4.1	4.9	-0.8

Figure 4.16 Project P: George County – Highway 98 Core Gradation Analysis

4.1.17 Project Q – Highway 43 in Pearl River County

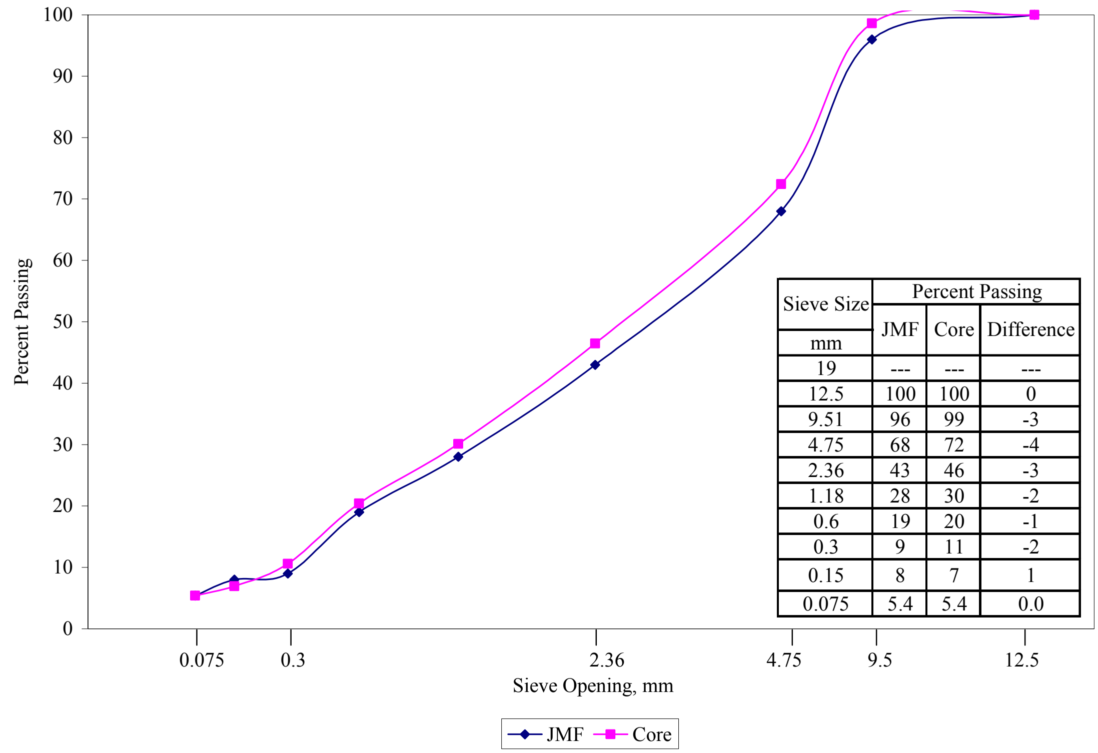
This roadway is a two-lane facility rehabilitated in April 1999. The mix is a 9.5 mm MT PG 67-22 asphalt binder with 85 percent gravel and 15 percent limestone aggregate. The ADT was 510 vpd with 10 percent trucks.

The site was visited on August 6, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.17. Actual and JMF blend gradations are provided in Figure 4.17. Field rutting was minimal, averaging a rut depth of 0.93 mm with a maximum of 2.54 mm. Average between wheel path and in wheel path core air voids were 3.9 percent and 3.2 percent, respectively. Core analysis conducted showed the asphalt content 0.15 percent lower than the JMF, while aggregate gradation was generally finer than JMF values.

Table 4.17 Project Q: Pearl River County – Highway 43 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.02	2.251	2.253	2.328 (2.337[1])	3.3	3.2	35.8	7.0% (7.15%[1])
Lot 1 Profile 2	1.02	2.257	2.271		3.1	2.4	47.7	
Lot 1 Profile 3	0.51	2.262	2.261		2.8	2.9	50.7	
Lot 2 Profile 1	2.54	2.249	2.235		3.4	4.0	38.8	
Lot 2 Profile 2	0.51	2.257	2.236		3.0	3.9	49.3	
Lot 2 Profile 3	0.76	2.244	2.209		3.6	5.1	41.9	
Lot 3 Profile 1	1.52	2.259	2.235		3.0	4.0	46.2	
Lot 3 Profile 2	0.25	2.267	2.231		2.6	4.2	52.0	
Lot 3 Profile 3	0.25	2.245	2.204		3.6	5.3	48.0	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Percent Passing Core	Percent Passing Difference
19	---	---	---
12.5	100	100	0
9.51	96	99	-3
4.75	68	72	-4
2.36	43	46	-3
1.18	28	30	-2
0.6	19	20	-1
0.3	9	11	-2
0.15	8	7	1
0.075	5.4	5.4	0.0

Figure 4.17 Project Q: Pearl River County – Highway 43 Core Gradation Analysis

4.1.18 Project R – Highway 11 in Pearl River County

Project R is located on Highway 11 in Pearl River County. This facility is a two-lane road rehabilitated in April 1999. The mix is a 9.5 mm MT PG 67-22 asphalt binder with 100 percent gravel aggregate. The ADT was 4,000 vpd with 10 percent trucks.

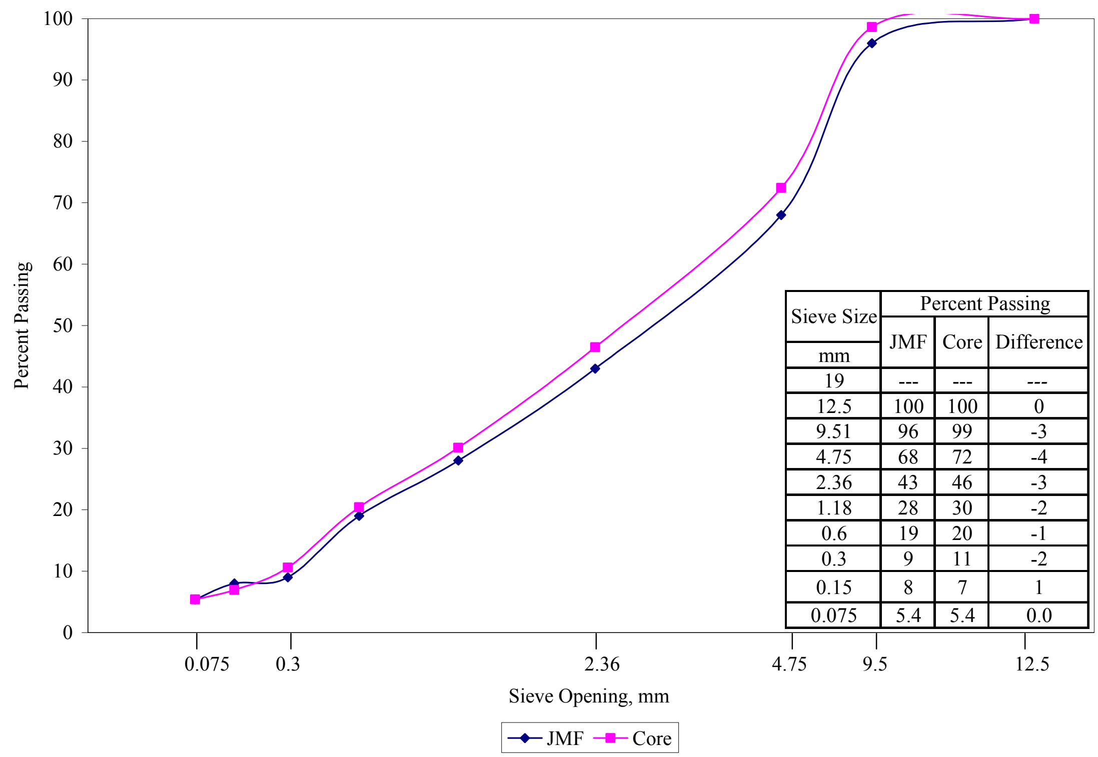
The site was visited on August 6, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.18. Actual and JMF blend gradations are provided in Figure 4.18. Field rutting was low, with average and maximum rut depth of 0.93 mm and 1.78 mm, respectively. Analysis of core densities showed average air voids for between wheel path cores were 4.2 percent, with air voids inside the wheel path being 3.7 percent. Core analysis showed that the asphalt content 0.2 percent less than the JMF, with aggregate gradations generally finer than the JMF.

Table 4.18 Project R: Pearl River County – Highway 11 Field Rut Depths and Core

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.02	2.204	2.184	2.290 (2.306[1])	3.8	4.6	66.2	4.9% (5.1%[1])
Lot 1 Profile 2	0.00	2.205	2.169		3.7	5.3	62.7	
Lot 1 Profile 3	0.51	2.233	2.208		2.5	3.6	66.4	
Lot 2 Profile 1	1.78	2.206	2.186		3.7	4.5	58.4	
Lot 2 Profile 2	1.52	2.210	2.221		3.5	3.0	48.1	
Lot 2 Profile 3	1.27	2.188	2.202		4.5	3.8	62.9	
Lot 3 Profile 1	0.76	2.194	2.171		4.2	5.2	42.2	
Lot 3 Profile 2	0.25	2.182	2.195		4.7	4.1	58.9	
Lot 3 Profile 3	1.27	2.227	2.201		2.7	3.9	50.3	

[1] Values from Job Mix Formula

Data



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	96	99	-3
4.75	68	72	-4
2.36	43	46	-3
1.18	28	30	-2
0.6	19	20	-1
0.3	9	11	-2
0.15	8	7	1
0.075	5.4	5.4	0.0

Figure 4.18 Project R: Pearl River County – Highway 11 Core Gradation Analysis

4.1.19 Project S – Interstate 20 in Rankin County

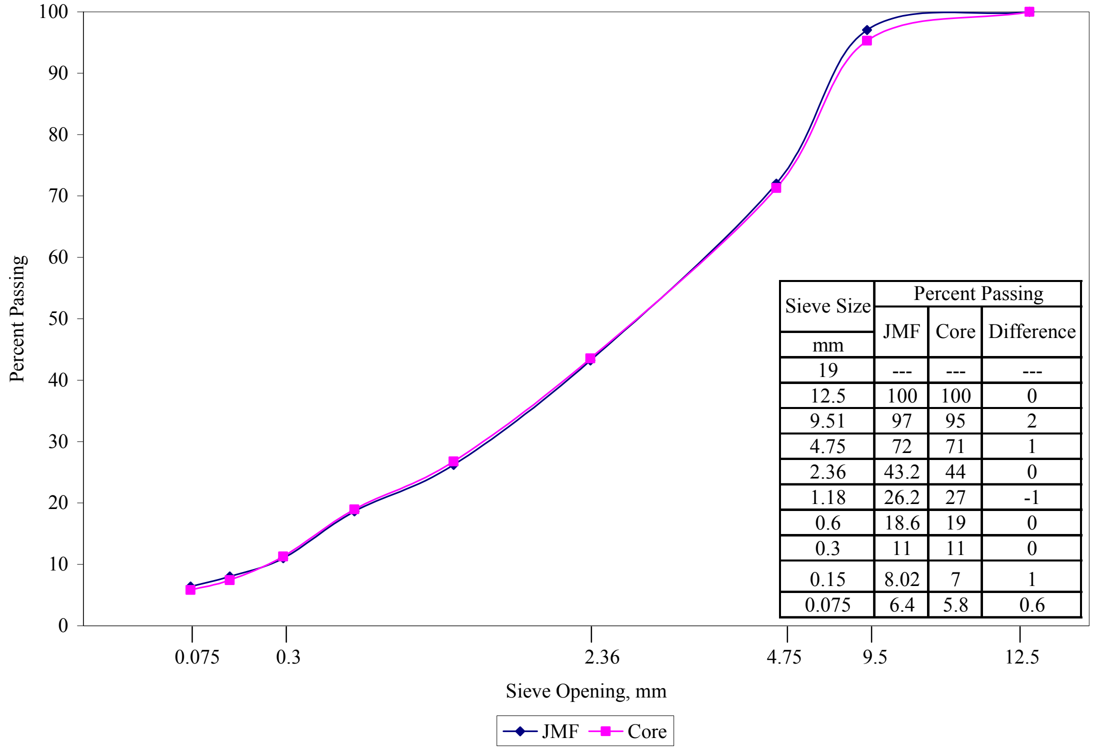
Project S is located on Interstate 20 about 15 miles east of Jackson in Rankin County. This highway, a divided four-lane facility, was last rehabilitated in May 2000. The mix is a 9.5 mm NMS HT with PG 76-22 asphalt binder using 75 percent gravel and 25 percent limestone aggregate. The ADT was 23,000 vpd with 36 percent trucks.

The site was visited on August 7, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.19. Actual and JMF blend gradations are provided in Figure 4.19. Field rutting for this project was minimal, with average and maximum rut depths of 1.19 mm and 2.03 mm, respectively. Average between path and in wheel path core air voids were 5.7 percent and 5.3 percent, respectively. Core analysis indicated the asphalt content 0.1 percent higher than the JMF, with the gradation being with 2 percent of the JMF.

Table 4.19 Project S: Rankin County – Interstate 20 Field Rut Depths and Core Data

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Field Rut Depth (mm)</th><th colspan="2">Gmb</th><th rowspan="2">Gmm</th><th colspan="2">Air Voids</th><th rowspan="2">Thickness, mm</th><th rowspan="2">Asphalt Content, %</th></tr>
<tr><th>In</th><th>Out</th><th>In</th><th>Out</th></tr>
<tr><td>Lot 1 Profile 1</td><td>1.27</td><td>2.237</td><td>2.225</td><td rowspan="9">2.375
(2.354[1])</td><td>5.8</td><td>6.3</td><td>35.9</td><td rowspan="9">6.6%
(6.5%[1])</td></tr>
<tr><td>Lot 1 Profile 2</td><td>0.76</td><td>2.237</td><td>2.233</td><td>5.8</td><td>6.0</td><td>36.6</td></tr>
<tr><td>Lot 1 Profile 3</td><td>0.51</td><td>2.256</td><td>2.260</td><td>5.0</td><td>4.8</td><td>40.1</td></tr>
<tr><td>Lot 2 Profile 1</td><td>1.27</td><td>2.235</td><td>2.225</td><td>5.9</td><td>6.3</td><td>51.1</td></tr>
<tr><td>Lot 2 Profile 2</td><td>1.27</td><td>2.251</td><td>2.238</td><td>5.2</td><td>5.8</td><td>45.6</td></tr>
<tr><td>Lot 2 Profile 3</td><td>1.27</td><td>2.273</td><td>2.224</td><td>4.3</td><td>6.4</td><td>40.8</td></tr>
<tr><td>Lot 3 Profile 1</td><td>2.03</td><td>2.241</td><td>2.259</td><td>5.6</td><td>4.9</td><td>36.6</td></tr>
<tr><td>Lot 3 Profile 2</td><td>1.52</td><td>2.241</td><td>2.249</td><td>5.6</td><td>5.3</td><td>36.1</td></tr>
<tr><td>Lot 3 Profile 3</td><td>0.76</td><td>2.272</td><td>2.250</td><td>4.3</td><td>5.3</td><td>38.9</td></tr>
</table>

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	97	95	2
4.75	72	71	1
2.36	43.2	44	0
1.18	26.2	27	-1
0.6	18.6	19	0
0.3	11	11	0
0.15	8.02	7	1
0.075	6.4	5.8	0.6

Figure 4.19 Project S: Rankin County – Interstate 20 Core Gradation Analysis

4.1.20 Project T – Highway 11 in Jones County

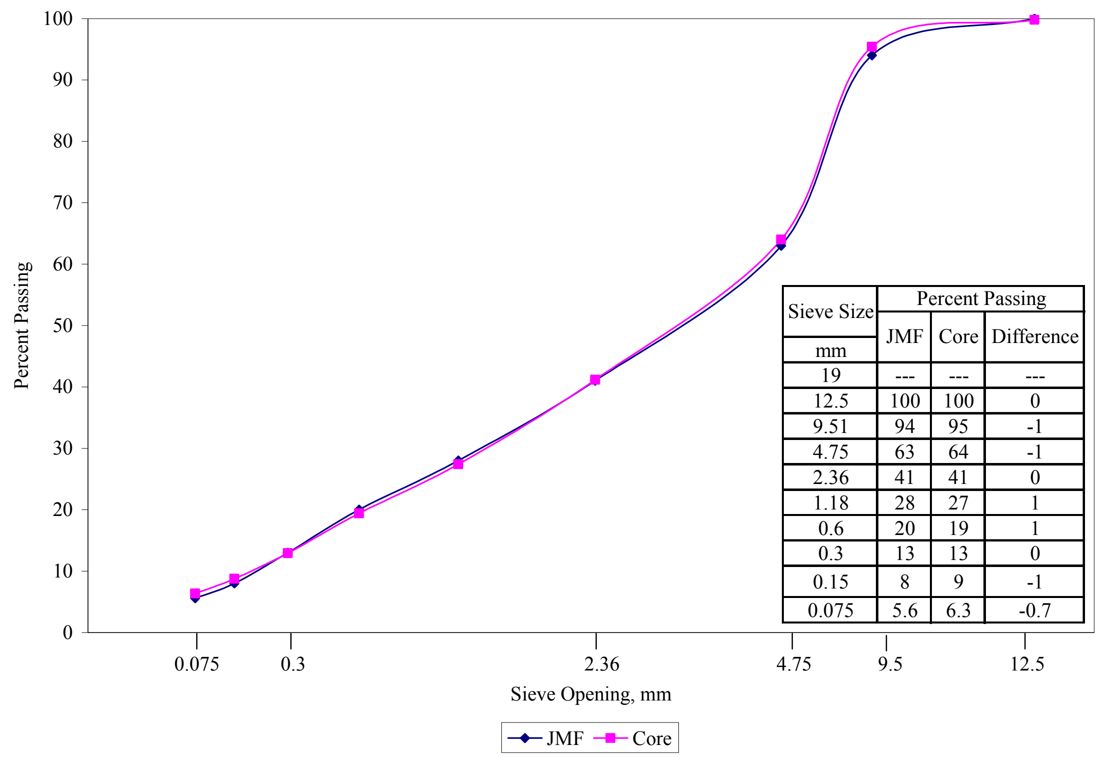
Project T is located on Highway 11 near Moselle in Jones County. The highway is a two-lane facility last rehabilitated in March 1999. The mix is a 9.5 mm MT PG 67-22 asphalt binder using 85 percent gravel and 15 percent RAP. The AADT was of 4,300 vpd with 7 percent trucks.

The site was visited on August 11, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.20. Actual and JMF blend gradations are provided in Figure 4.20. Field rutting was minimal, the average and maximum rut depth was 1.48 mm and 4.57 mm, respectively. Average between wheel path and in wheel path core air voids were 5.3 percent and 5.1 percent, respectively. Core analysis showed the asphalt content 0.1 percent lower than the JMF with the gradation matching within 1 percent of the JMF.

Table 4.20 Project T: Jones County – Highway 11 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.27	2.213	2.186	2.343 (2.346[1])	5.6	6.7	37.3	6.2% (6.3%[1])
Lot 1 Profile 2	1.27	2.264	2.257		3.4	3.7	46.1	
Lot 1 Profile 3	1.02	2.259	2.266		3.6	3.3	42.5	
Lot 2 Profile 1	1.83	2.236	2.197		4.6	6.2	41.3	
Lot 2 Profile 2	1.32	2.233	2.223		4.7	5.1	36.8	
Lot 2 Profile 3	0.25	2.220	2.198		5.3	6.2	31.9	
Lot 3 Profile 1	1.02	2.207	2.196		5.8	6.3	41.6	
Lot 3 Profile 2	4.57	2.163	2.190		7.7	6.5	41.2	
Lot 3 Profile 3	0.76	2.218	2.249		5.3	4.0	37.9	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Percent Passing Core	Percent Passing Difference
19	---	---	---
12.5	100	100	0
9.51	94	95	-1
4.75	63	64	-1
2.36	41	41	0
1.18	28	27	1
0.6	20	19	1
0.3	13	13	0
0.15	8	9	-1
0.075	5.6	6.3	-0.7

Figure 4.20 Project T: Jones County – Highway 11 Core Gradation Analysis

4.1.21 Project U – Highway 550 in Lincoln County

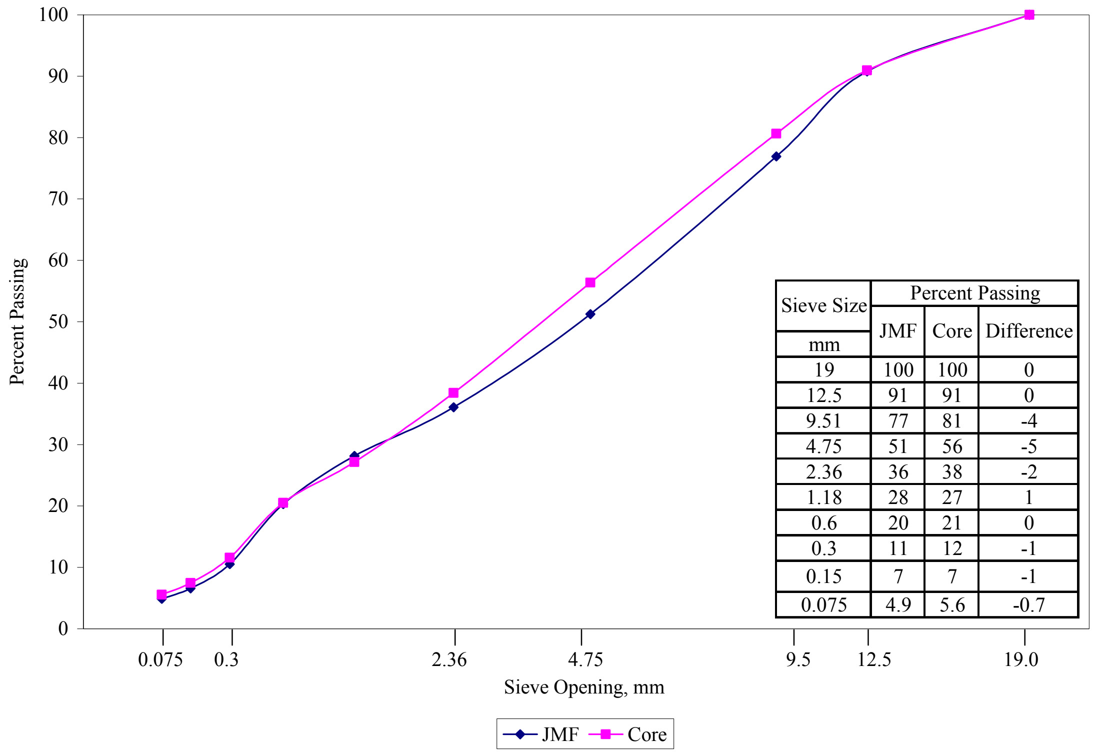
This facility is a two-lane road rehabilitated in December 1998. The surface mix is a 12.5 mm ST PG 67-22 asphalt binder with 100 percent gravel aggregate. The ADT was 1,300 vpd with 10 percent trucks.

The site was visited on August 12, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.21. Actual and JMF blend gradations are provided in Figure 4.21. Field rutting was minimal, with average and maximum rut depths of 0.85 mm and 2.03 mm, respectively. Analysis of core densities showed average air voids for between wheel path cores were 5.7 percent, with air voids inside the wheel path being 5.4 percent. Core analysis conducted showed the asphalt content to be 0.2 percent lower than the JMF with the gradation being was finer for larger sieves (9.5 mm through 2.36 mm sieves).

Table 4.21 Project U: Lincoln County – Highway 550 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	0.51	2.293	2.266	2.399 (2.393[1])	4.4	5.5	61.1	5.2% (5.4%[1])
Lot 1 Profile 2	0.51	2.262	2.294		5.7	4.4	53.0	
Lot 1 Profile 3	0.25	2.268	2.234		5.5	6.9	53.7	
Lot 2 Profile 1	0.51	2.263	2.255		5.7	6.0	32.6	
Lot 2 Profile 2	0.25	2.251	2.262		6.2	5.7	34.7	
Lot 2 Profile 3	0.51	2.248	2.263		6.3	5.6	32.2	
Lot 3 Profile 1	1.78	2.288	2.271		4.6	5.3	59.0	
Lot 3 Profile 2	1.27	2.291	2.284		4.5	4.8	47.7	
Lot 3 Profile 3	2.03	2.254	2.228		6.0	7.1	53.8	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	100	100	0
12.5	91	91	0
9.51	77	81	-4
4.75	51	56	-5
2.36	36	38	-2
1.18	28	27	1
0.6	20	21	0
0.3	11	12	-1
0.15	7	7	-1
0.075	4.9	5.6	-0.7

Figure 4.21 Project U: Lincoln County – Highway 550 Core Gradation Analysis

4.1.22 Project V – Highway 33 in Amite County

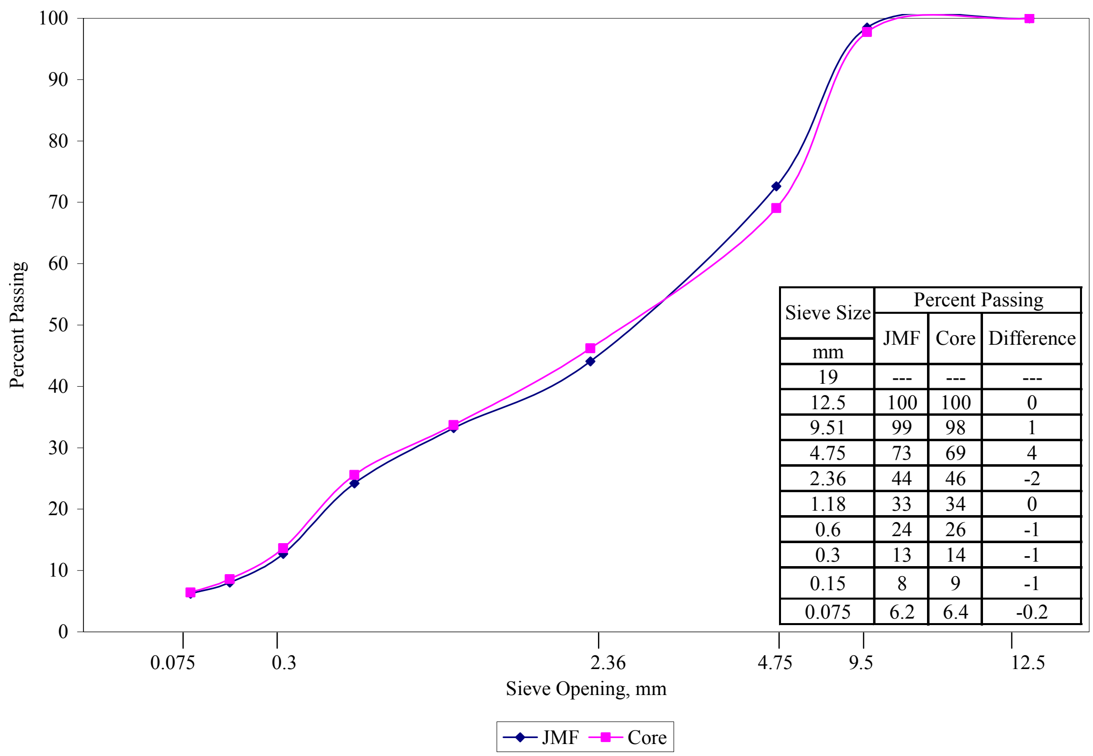
Project V is located on Highway 33 about 38 miles west of McComb in Amite County. This highway, a two lane facility, was rehabilitated in July 2000. The mix is a 9.5 mm NMS ST PG 67-22 asphalt binder with 85 percent gravel and 15 percent RAP. The ADT was 2,000 vpd with 20 percent trucks.

The site was visited on August 13, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.22. Actual and JMF blend gradations are provided in Figure 4.22. Field rutting was minimal, with an average and maximum rut depth of 1.44 mm and 3.81 mm, respectively. Average between wheel path and in wheel path core air voids were 7.5 percent and 6.3 percent, respectively. Core analysis showed asphalt content to be the same as the JMF with gradation matching the JMF, with the exception of the 4.75 mm sieve, which was 4 percent coarser.

Table 4.22 Project V: Amite County – Highway 33 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	0.76	2.279	2.239	2.392 (2.391[1])	4.7	6.4	41.0	5.4% (5.4%[1])
Lot 1 Profile 2	1.02	2.279	2.255		4.7	5.7	37.5	
Lot 1 Profile 3	0.76	2.266	2.236		5.3	6.5	34.7	
Lot 2 Profile 1	1.02	2.239	2.181		6.4	8.8	47.6	
Lot 2 Profile 2	3.81	2.194	2.126		8.3	11.1	33.9	
Lot 2 Profile 3	1.27	2.234	2.254		6.6	5.8	34.6	
Lot 3 Profile 1	1.27	2.220	2.186		7.2	8.6	41.6	
Lot 3 Profile 2	1.27	2.241	2.242		6.3	6.3	30.5	
Lot 3 Profile 3	1.78	2.228	2.204		6.9	7.8	41.9	

[1] Values from Job Mix Formula



Sieve Size mm	Percent Passing JMF	Core	Difference
19	---	---	---
12.5	100	100	0
9.51	99	98	1
4.75	73	69	4
2.36	44	46	-2
1.18	33	34	0
0.6	24	26	-1
0.3	13	14	-1
0.15	8	9	-1
0.075	6.2	6.4	-0.2

Figure 4.22 Project V: Amite County – Highway 33 Core Gradation Analysis

4.1.23 Project W – Highway 33 in Wilkinson County

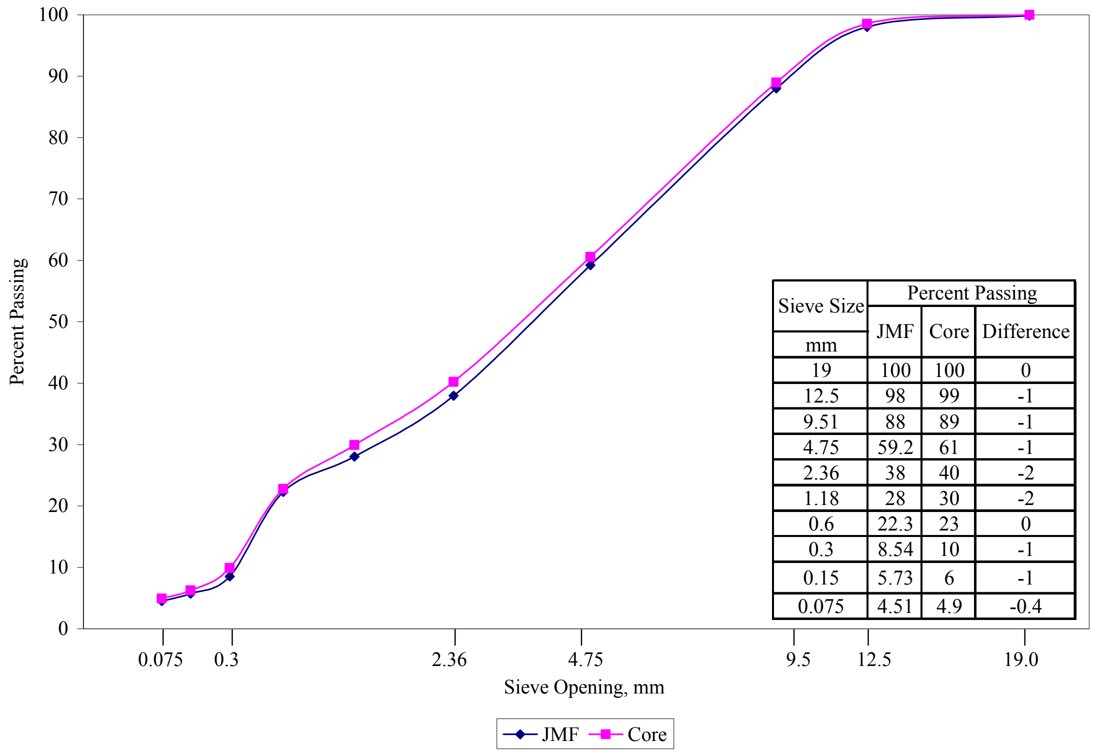
This roadway is a two-lane facility rehabilitated in March 1999. The mix is a 9.5 mm MT PG 67-22 asphalt binder using 85 percent gravel and 15 percent RAP. The ADT was 4,300 vpd with 7 percent trucks.

The site was visited on August 11, 2003. Field and laboratory test results summary is provided in Figure 4.23. Field rutting was minimal, with average and maximum rut depths of 1.10 mm and 2.54 mm, respectively. Average between wheel path and in wheel path core air voids were both 4.3 percent. Core analysis indicated the asphalt content to be the same as the JMF, with the gradation being with 2 percent for all sieves.

Table 4.23 Project W: Wilkinson County – Highway 24 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	0.76	2.280	2.253	2.383 (2.392[1])	4.3	5.4	42.8	5.3% (5.3%[1])
Lot 1 Profile 2	0.25	2.309	2.289		3.1	4.0	43.6	
Lot 1 Profile 3	0.76	2.274	2.278		4.6	4.4	47.0	
Lot 2 Profile 1	2.03	2.288	2.267		4.0	4.9	56.2	
Lot 2 Profile 2	0.51	2.313	2.279		2.9	4.4	45.3	
Lot 2 Profile 3	0.25	2.311	2.257		3.0	5.3	46.3	
Lot 3 Profile 1	2.29	2.183	2.289		8.4	3.9	51.4	
Lot 3 Profile 2	2.54	2.270	2.289		4.7	3.9	46.8	
Lot 3 Profile 3	0.51	2.303	2.325		3.4	2.4	47.8	

[1] Values from Job Mix Formula



Sieve Size	Percent Passing		
mm	JMF	Core	Difference
19	100	100	0
12.5	98	99	-1
9.51	88	89	-1
4.75	59.2	61	-1
2.36	38	40	-2
1.18	28	30	-2
0.6	22.3	23	0
0.3	8.54	10	-1
0.15	5.73	6	-1
0.075	4.51	4.9	-0.4

Figure 4.23 Project W: Wilkinson County – Highway 24 Core Gradation Analysis

4.1.24 Project X – Highway 18 in Claiborne County

This roadway is a two-lane facility rehabilitated in October 1998. The surface mix is a 9.5 mm NMS ST using PG 67-22 asphalt binder with 100 percent gravel aggregate. Traffic data showed an ADT of 2,500 vpd with 10 percent trucks.

The site was visited on August 14, 2003. Field rut depths, core volumetric properties and thickness are provided in Table 4.24. Actual and JMF blend gradations are provided in Figure 4.24. Field rutting was minimal, with average and maximum rut depths of 1.67 mm and 3.81 mm, respectively. Average between wheel path and in wheel path core air voids were 3.8 percent and 3.2 percent, respectively. Core extractions conducted showed asphalt content to be 0.1 percent greater than the JMF with the gradation being with 3 percent for all sieves.

Table 4.24 Project X: Claiborne County – Highway 18 Field Rut Depths and Core Data

Location	Field Rut Depth (mm)	Gmb		Gmm	Air Voids		Thickness, mm	Asphalt Content, %
		In	Out		In	Out		
Lot 1 Profile 1	1.02	2.246	2.278		4.4	3.1	43.4	
Lot 1 Profile 2	1.27	2.284	2.272		2.8	3.3	48.2	
Lot 1 Profile 3	2.79	2.270	2.236		3.4	4.8	45.6	
Lot 2 Profile 1	0.51	2.273	2.262		3.3	3.7	39.4	
Lot 2 Profile 2	3.81	2.252	2.238	2.350 (2.358[1])	4.2	4.8	36.7	*6.6% (6.5%[1])*
Lot 2 Profile 3	2.54	2.288	2.253		2.6	4.1	36.3	
Lot 3 Profile 1	0.76	2.255	2.248		4.0	4.3	43.1	
Lot 3 Profile 2	1.52	2.311	2.296		1.7	2.3	41.2	
Lot 3 Profile 3	0.76	2.293	2.271		2.4	3.3	47.8	

[1] Values from Job Mix Formula

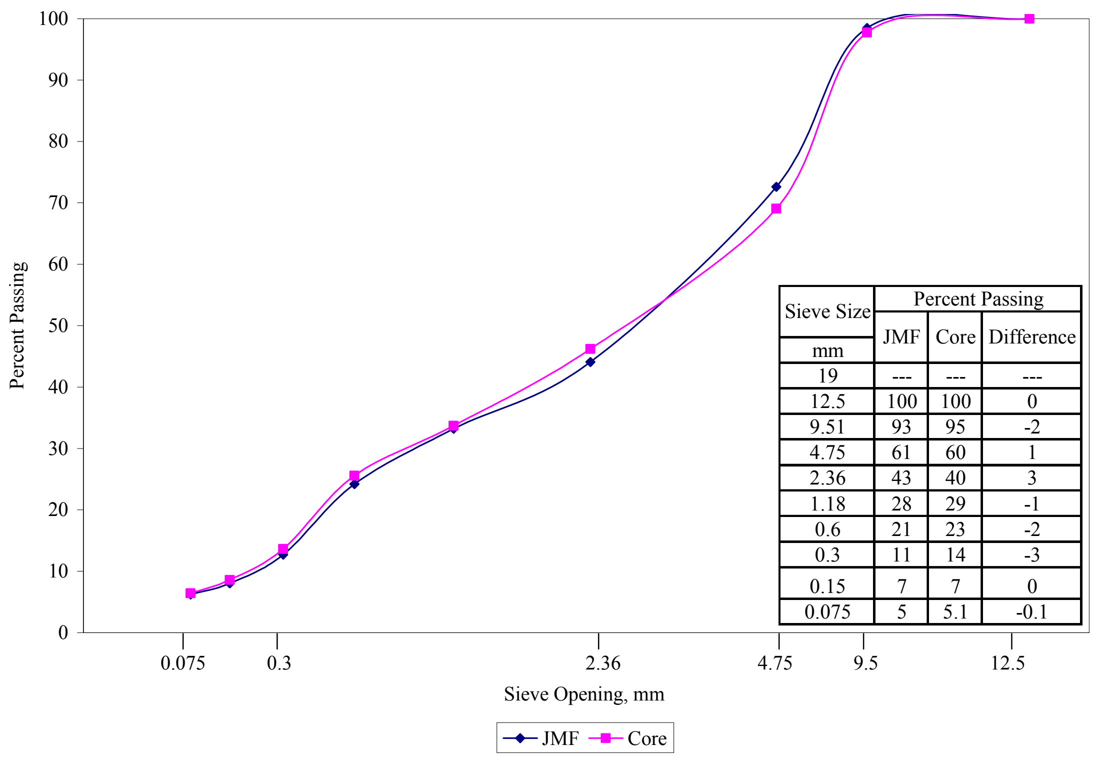


Figure 4.24 Project X: Claiborne County – Highway 18 Core Gradation Analysis

4.1.25 Field Study Summary

A summary of rut depths, wheel path and between wheel path air voids, and accumulated ESALs is provided in Table 4.25. In general, average field rutting was minimal at 1.88 mm, with the maximum average rut depth observed being 5.47 mm (Project C – Pontotoc County Highway 278).

The relatively low observed rut depths were anticipated. Mississippi DOT has seen success with the Superpave mix design system, which has resulted in more rut resistant HMA pavements being constructed. For these reasons, it was difficult to locate pavements, built under Superpave specifications, with excessive rutting. Furthermore, most pavements that exhibit excessive rutting are generally rehabilitated very soon after the distress is noted.

Core analysis indicated the asphalt binder content generally matched well to the JMF. Generally, aggregate gradations were slightly finer than original JMF values. Analysis of core densities showed substantial variability within each project.

It is interesting to observe air voids of cores in and between the wheel path. The overall average air voids in the wheel path and between the wheel paths was 5.7 and 6.1 percent, respectively. Four projects had higher air voids in the wheel path than between. This could be a result of many factors, but is likely due to a large extent to testing variability. In terms of mix type, ST, MT, and HT mixes had average air void differences of 0.39, 0.71, and 0.19 percent, respectively. This is logical since HT mixes use polymer modified binders which increase mix stiffness, and likely reduce densification and rutting. The ST mixes having the least change can be explained by the low traffic volume observed on these roads. MT mixes, which had the greatest average densification, have substantially more traffic volume than ST mixes, while still using a PG 67-22 asphalt binder.

The evaluated pavements were constructed between May 1998 and October 2000 and were evaluated in during the summer of 2003. Therefore, the pavement ages ranged from approximately 2 to 5 years. Because of the relatively low in-service time, the applied ESAL were low for some projects, especially ST and MT mixes.

Table 4.25 Summary of Field Study

Project	Traffic Level	Rut Depth[1], mm	Air Voids[1], %		Change %	ESALs at Coring	Construction Date	Coring Date
			In	Out				
A - Hwy 15	ST	2.20	6.2	6.3	0.1	370,528	Jul-00	Jul-03
B - Hwy 32	MT	3.93	7.2	7.4	0.2	468,410	Oct-99	Jul-03
C - Hwy 278	MT	5.47	6.3	7.3	1.0	161,595	Jul-00	Jul-03
D - Hwy 78	HT	3.09	4.5	4.7	0.2	2,691,826	Aug-00	Jul-03
E - I55	HT	1.81	4.1	4.9	0.8	2,902,735	May-00	Jul-03
F - Hwy 7	ST	2.76	5.6	7.2	1.6	71,147	May-00	Jul-03
G - Hwy 12	MT	1.59	4.7	6.4	1.7	310,771	Sep-99	Jul-03
H - Hwy 35	MT	1.02	4.2	4.5	0.3	190,398	May-00	Jul-03
I - Hwy 82	HT	2.76	8.2	6.9	-1.3	2,127,923	Sep-98	Jul-03
J - Hwy 82	HT	1.68	8.2	8.8	0.6	997,024	May-99	Jul-03
K - Hwy 13	MT	0.82	5.8	6.9	1.1	204,635	Sep-99	Jul-03
L - Hwy 13	ST	2.20	7.3	7.2	-0.1	134,530	Apr-99	Jul-03
M - Hwy 49	HT	0.95	5.3	5.6	0.3	3,693,604	May-98	Jul-03
N - Hwy 49	HT	1.24	9.1	9.7	0.6	4,658,211	May-98	Jul-03
O - Hwy 510	ST	3.02	7.6	6.9	-0.6	6,039	Jul-99	Jul-03
P - Hwy 98	HT	0.93	6.3	6.2	-0.1	709,673	Oct-00	Aug-03
Q - Hwy 43	MT	0.93	3.2	3.9	0.7	33,999	Apr-99	Aug-03
R - Hwy 11	MT	0.93	3.7	4.2	0.5	218,590	Apr-99	Aug-03
S - I20	HT	1.19	5.3	5.7	0.4	6,523,800	May-00	Aug-03
T - Hwy 15	MT	1.48	5.1	5.3	0.2	195,892	Mar-99	Aug-03
U - Hwy 550	ST	0.85	5.4	5.7	0.3	107,435	Dec-98	Aug-03
V - Hwy 33	ST	1.44	6.3	7.5	1.2	197,859	Jul-00	Aug-03
W - Hwy 24	ST	1.10	4.3	4.3	0.0	18,000	Mar-99	Aug-03
X - Hwy 18	ST	1.67	3.2	3.8	0.6	224,665	Oct-98	Aug-03
Avg.	---	1.88	5.7	6.1	0.4	-----------	-----	-----

[1]Values for Rut Depth and Air Voids Represent Average Values.

4.2 ASPHALT PAVEMENT ANALYZER RESULTS

4.2.1 APA Core Rutting

Field cores were tested in the APA as described in Chapter 3. Table 4.26 and Figure 4.25 illustrate average APA core rut depths. Table 4.26 illustrates average APA rut depths for each project mix in ascending order. From Table 4.26, rut depths ranged from a low of 0.86 mm for Project P – Highway 98 in George County to 4.39 mm for Project H – Highway 35 in Leake County. From Figure 4.25, it is evident that HT mixes perform better than ST and MT mixes. This is to be expected due to the increased N_{design} level and use of the PG 76-22 asphalt binder. There does not appear to be an obvious difference between aggregate type or nominal maximum aggregate size.

Table 4.26 Asphalt Pavement Analyzer Core Rut Depths

Project	Traffic Level	APA Core Rut Depth, mm
P - Hwy 98	HT	0.86
I - Hwy 82	HT	0.99
B - Hwy 32	MT	1.35
N - Hwy 49	HT	1.44
S - I-20	HT	1.50
T - Hwy 11	MT	1.60
J - Hwy 82	HT	1.61
O - Hwy 510	ST	1.61
Q - Hwy 43	MT	1.84
M - Hwy 49	HT	2.08
F - Hwy 7	ST	2.10
G - Hwy 12	MT	2.39
D - Hwy 78	HT	2.49
U - Hwy 550	ST	2.51
E - I-55	HT	2.60
X - Hwy 18	ST	2.61
R - Hwy 11	MT	2.65
C - Hwy 278	MT	3.07
A - Hwy 15	ST	3.09
V - Hwy 33	ST	3.34
W - Hwy 24	ST	3.71
L - Hwy 13	ST	3.93
K - Hwy 13	MT	4.10
H - Hwy 35	MT	4.39

Binder Grade	Aggregate Type	Nominal Maximum Size, mm	Traffic Level	Projects				Average
67-22	Gravel	9.5	ST	3.34	2.61			2.97
			MT	4.10	2.65	1.60		2.78
		12.5	ST	3.71	4.39			4.05
			MT	4.39				4.39
	Gravel / Limestone	9.5	ST	2.10	1.61			1.85
			MT	1.35	1.84	2.39		1.86
		12.5	ST	3.09	3.93			3.51
			MT	3.07				3.07
76-22	Gravel	9.5	HT	1.50				1.50
		12.5	HT	2.08	1.44			1.76
	Gravel / Limestone	9.5	HT	1.61				1.61
		12.5	HT	2.49	2.60	0.99	0.86	1.74

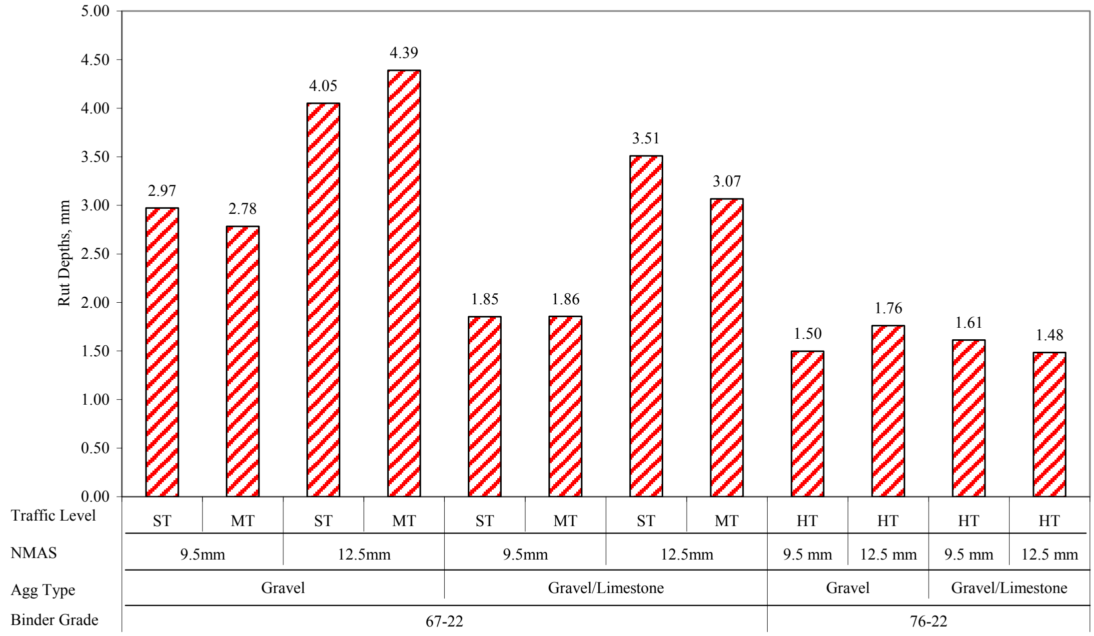


Figure 4.25 Asphalt Pavement Analyzer Core Rut Depth Summary

4.2.1.1 Field Rutting Versus APA Core Rutting

Once core testing was complete, APA (core) rut depths were compared to field rutting. The relationship between field and APA core rutting is provided in Figure 4.26. The data is grouped by traffic level (ST, MT, and HT), because of the obvious traffic level influence, in terms of loading, design compactive effort, and asphalt binder type. Field rutting is represented by a normalized value or rate of rutting, which was obtained by dividing the measured field rut depth by the square root of million ESALs. This approach has been used in previous research with success (*6*). According to Parker and Brown (*8*), dividing the field rut depths by the square root of ESALs in millions has shown some positive relationships.

From Figure 4.26, the relationship between field rutting rate and APA core rut depths is not strong for any of the mix types. As the rate of field rutting increases, APA core rutting should also increase. However, this does not appear to be the case with ST and MT mixes. The APA core rut depth of these mixes increases as the rutting rate decreases. For HT mixes, the trend is correct, but the relationship very poor ($R^2 = 0.151$).

One reason for the poor correlation could be asphalt oxidation. As mentioned previously, all pavements had been in service for at least 2 years during which time some long term aging of the asphalt binder is likely to have occurred, resulting in increased viscosity and a mix less prone to densification. This increased stiffness would potentially lower the rutting observed in the APA. Theoretically, if cores were obtained from the pavement immediately after construction, prior to any in-service aging, APA testing should more closely agree with field rutting.

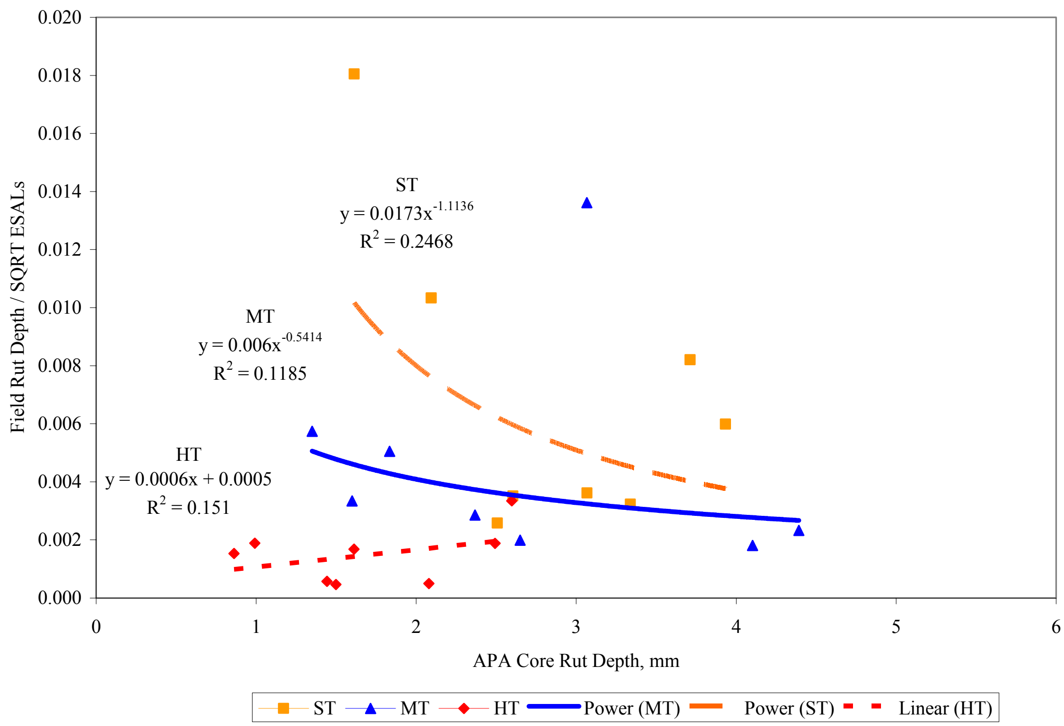


Figure 4.26 Field Rut Depth / SQRT ESALs versus APA Core Rut Depth

4.2.2 Laboratory Specimens Preparation

Prior to preparing APA laboratory specimens, each mix was verified at its respective N_{design} level (ST N_{design} = 68, MT N_{design} = 86, and HT N_{design} = 96). Bulk and maximum specific gravities were determined by AASHTO T166 (*18*) and AASHTO T209 (*21*), and air voids determined. With the lab prepared gradation and JMF asphalt content, air voids for all mixes, except Project P: Highway 98 - George County, was verified to be 4 ± 1 percent. For Project P, the air void content was 2.5 percent, so the mix asphalt binder content was decreased by 0.2 percent to produce an air void content in tolerance. Table 4.27 provides air voids for verification specimens from each project while Table 4.28 illustrates comparisons between core gradations (core) and laboratory prepared specimen gradations (lab), which were tested in the APA. Following the successful mix design verification, six specimens were prepared for each project for subsequent APA testing. The air voids for theses specimens are provided in Table 4.29

Table 4.27 Mix Design Verification Air Voids

Project	Air Voids		
	Replicate 1	Replicate 2	Average
A - Hwy 15	4.3	4.5	4.4
B - Hwy 32	4.7	4.6	4.6
C - Hwy 278	3.4	3.3	3.3
D - Hwy 78	4.6	4.5	4.6
E - I-55	3.5	3.6	3.6
F - Hwy 7	4.4	4.2	4.3
G - Hwy 12	4.6	4.6	4.6
H - Hwy 35	4.1	4.2	4.2
I - Hwy 82	3.2	3.3	3.2
J - Hwy 82	3.6	3.5	3.5
K - Hwy 13	4.0	4.1	4.1
L - Hwy 13	5.0	4.9	4.9
M - Hwy 49	4.6	4.4	4.5
N - Hwy 49	4.7	4.6	4.7
O - Hwy 510	3.4	3.6	3.5
P - Hwy 98	3.7	3.6	3.7
Q - Hwy 43	4.5	4.7	4.6
R - Hwy 11	3.8	3.2	3.5
S - I-20	4.7	4.8	4.8
T - Hwy 11	4.2	4.1	4.2
U - Hwy 550	5.0	5.0	5.0
V - Hwy 33	4.3	4.3	4.3
W - Hwy 24	4.5	4.4	4.4
X - Hwy 18	4.7	4.6	4.6

Table 4.28 Gradation Comparison for Project Mixes

Sieve Size	**A - Hwy 15**		**B - Hwy 32**		**C - Hwy 278**		**D - Hwy 78**		**E - I-55**		**F - Hwy 7**		**G - Hwy 12**		**H - Hwy 35**	
(mm)	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab
19	100	100	---	---	100	100	100	100	100	100	---	---	---	---	100	100
12.5	94	97	100	100	96	92	97	97	97	98	100	100	100	100	96	96
9.51	84	85	92	93	90	88	89	89	90	90	93	91	91	91	88	88
4.75	52	49	58	55	61	61	61	61	63	61	60	62	55	55	54	56
2.36	34	32	36	34	38	36	38	39	42	42	38	44	34	34	36	37
1.18	25	23	24	23	26	25	23	26	29	30	24	32	23	23	26	27
0.6	19	18	18	17	19	19	15	18	20	22	17	22	17	17	19	21
0.3	12	11	10	10	11	12	9	12	9	12	11	11	10	10	11	13
0.15	6	7	5	7	5	8	7	8	6	7	7	8	6	6	7	9
0.075	4.3	5.5	3.1	5.6	3.3	4.2	3.1	4.2	4.6	5.2	5.2	5.8	4.5	5.0	5.6	6.3

Sieve Size	**I - Hwy 82**		**J - Hwy 82**		**K - Hwy 13**		**L - Hwy 13**		**M - Hwy 49**		**N - Hwy 49**		**O - Hwy 510**		**P - Hwy 98**	
(mm)	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab
19	---	---	---	---	---	---	100	100	---	---	---	---	---	---	100	100
12.5	100	100	100	100	100	100	96	99	100	100	100	100	100	100	99	97
9.51	90	94	95	88	95	98	89	89	93	90	96	96	97	95	94	81
4.75	53	60	64	62	66	71	60	63	59	56	68	59	65	59	52	35
2.36	31	35	41	44	42	44	41	44	37	32	45	35	39	36	35	26
1.18	21	23	29	32	29	29	31	33	24	22	32	25	25	24	26	22
0.6	16	15	20	22	21	20	22	24	17	16	24	19	18	18	20	17
0.3	9	9	9	11	12	12	9	11	11	7	14	9	13	11	11	10
0.15	6	5	5	8	8	8	5	7	7	3	8	4	8	8	7	6
0.075	4.1	3.2	3.6	4.8	5.8	6.1	6.1	5.0	5.3	2.1	5.1	2.7	5.8	5.9	4.9	4.7

Sieve Size	**Q - Hwy 43**		**R - Hwy 11**		**S - I-20**		**T - Hwy 11**		**U - Hwy 550**		**V - Hwy 33**		**W - Hwy 24**		**X - Hwy 18**	
(mm)	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab	Core	Lab
19	---	---	---	---	---	---	---	---	100	100	---	---	100	100	---	---
12.5	100	100	100	100	100	100	100	100	91	93	100	100	99	99	100	100
9.51	99	96	99	98	95	96	95	95	81	78	98	99	89	90	95	93
4.75	72	69	72	62	71	71	64	63	56	49	69	71	61	60	60	61
2.36	46	45	46	43	44	44	41	40	38	32	46	46	40	39	40	41
1.18	30	30	30	28	27	27	27	27	27	21	34	33	30	29	29	29
0.6	20	21	20	20	19	18	19	19	21	17	26	25	23	23	23	21
0.3	11	12	11	10	11	10	13	12	12	10	14	15	10	10	14	11
0.15	7	8	7	7	7	6	9	8	7	9	9	11	6	6	7	8
0.075	5.4	6.7	5.4	5.5	5.8	4.7	6.3	6.3	5.6	7.4	6.4	7.5	4.9	4.5	5.1	6.2

Table 4.29 Laboratory Prepared Specimen Air Voids for APA Testing

Project	Specimen Air Voids						
	1	2	3	4	5	6	Average
A - Hwy 15	6.9	6.5	6.9	6.5	6.9	6.9	6.8
B - Hwy 32	7.4	6.4	7.4	7.3	7.3	7.4	7.2
C - Hwy 278	7.6	6.3	7.2	7.2	7.1	7.1	7.1
D - Hwy 78	6.7	6.8	7.0	6.7	6.8	7.0	6.9
E - I-55	7.4	7.3	7.5	7.5	7.4	7.4	7.4
F - Hwy 7	6.8	6.9	6.9	6.9	6.9	6.8	6.9
G - Hwy 12	7.2	6.5	6.9	6.5	7.7	6.6	6.9
H - Hwy 35	7.8	7.6	7.6	7.7	7.7	7.7	7.7
I - Hwy 82	6.3	7.0	7.4	7.1	7.2	7.1	7.0
J - Hwy 82	7.4	7.3	7.7	7.2	7.2	7.2	7.3
K - Hwy 13	7.0	6.8	6.5	6.8	6.8	7.0	6.8
L - Hwy 13	7.1	7.2	7.2	7.2	7.0	7.2	7.1
M - Hwy 49	7.4	7.3	7.3	7.3	7.3	7.2	7.3
N - Hwy 49	7.3	8.0	6.9	7.6	7.3	7.0	7.4
O - Hwy 510	6.6	6.2	6.2	6.6	6.7	6.7	6.5
P - Hwy 98	6.3	6.5	6.7	6.6	6.6	6.7	6.6
Q - Hwy 43	7.5	7.3	7.1	7.4	7.0	7.3	7.3
R - Hwy 11	8.0	7.1	7.6	7.3	7.1	7.3	7.4
S - I-20	7.2	7.2	7.2	7.2	7.2	7.2	7.2
T - Hwy 11	6.9	7.2	7.0	7.0	7.2	7.1	7.1
U - Hwy 550	7.0	7.1	7.1	7.1	7.1	7.0	7.1
V - Hwy 33	7.5	7.4	7.6	7.6	7.5	7.5	7.5
W - Hwy 24	7.5	7.4	7.6	7.3	7.2	7.2	7.4
X - Hwy 18	7.9	7.6	7.5	7.5	7.5	7.4	7.6

4.2.3 APA Laboratory Prepared Specimen Rutting

Results of APA laboratory specimen testing are provided in Table 4.30 and Figure 4.27. Table 4.30 illustrates average APA rut depths for each project mix in ascending order. Rut depths ranged from a low of 2.64 mm for Project I – Highway 82 in Lowndes County to 15.13 mm for Project R – Highway 11 in Pearl River County. From Figure 4.27 there does not appear to be a major difference in performance between ST and MT mixes. However, Figure 4.27 does clearly illustrate the better performance of the HT mixes compared to ST and MT mixes. Also, similar to the core results, from Figure 4.27, there does not appear to be an obvious difference between aggregate type or nominal maximum aggregate size.

Table 4.30 Summary APA Laboratory Specimen Rut Depths

Project	Traffic Level	APA Rut Depth, mm
I - Hwy 82	HT	2.64
M - Hwy 49	HT	2.68
P - Hwy 98	HT	3.07
D - Hwy 78	HT	4.13
U - Hwy 550	ST	5.01
N - Hwy 49	HT	5.30
J - Hwy 82	HT	6.75
T - Hwy 11	MT	6.77
B - Hwy 32	MT	6.86
E - I-55	HT	7.08
S - I-20	HT	7.59
A - Hwy 15	ST	8.19
L - Hwy 13	ST	8.34
K - Hwy 13	MT	8.85
V - Hwy 33	ST	9.71
C - Hwy 278	MT	10.57
O - Hwy 510	ST	10.79
H - Hwy 35	MT	11.26
W - Hwy 24	ST	12.15
G - Hwy 12	MT	12.62
X - Hwy 18	ST	13.33
Q - Hwy 43	MT	14.33
F - Hwy 7	ST	14.34
R - Hwy 11	MT	15.13

Binder Grade	Aggregate Type	Nominal Maximum Size, mm	Traffic Level	Projects				Average
67-22	Gravel	9.5	ST	9.71	13.33			11.52
			MT	8.85	15.13	6.77	6.77	9.38
		12.5	ST	5.01	12.15			8.58
			MT	11.26				11.26
	Gravel / Limestone	9.5	ST	14.34	10.79			12.56
			MT	6.86	14.33	12.62	12.62	11.61
		12.5	ST	8.19	8.34			8.26
			MT	10.57				10.57
76-22	Gravel	9.5	HT	7.59				7.59
		12.5	HT	2.68	5.30			3.99
	Gravel / Limestone	9.5	HT	6.76				6.76
		12.5	HT	4.13	6.75	2.64	3.07	4.15

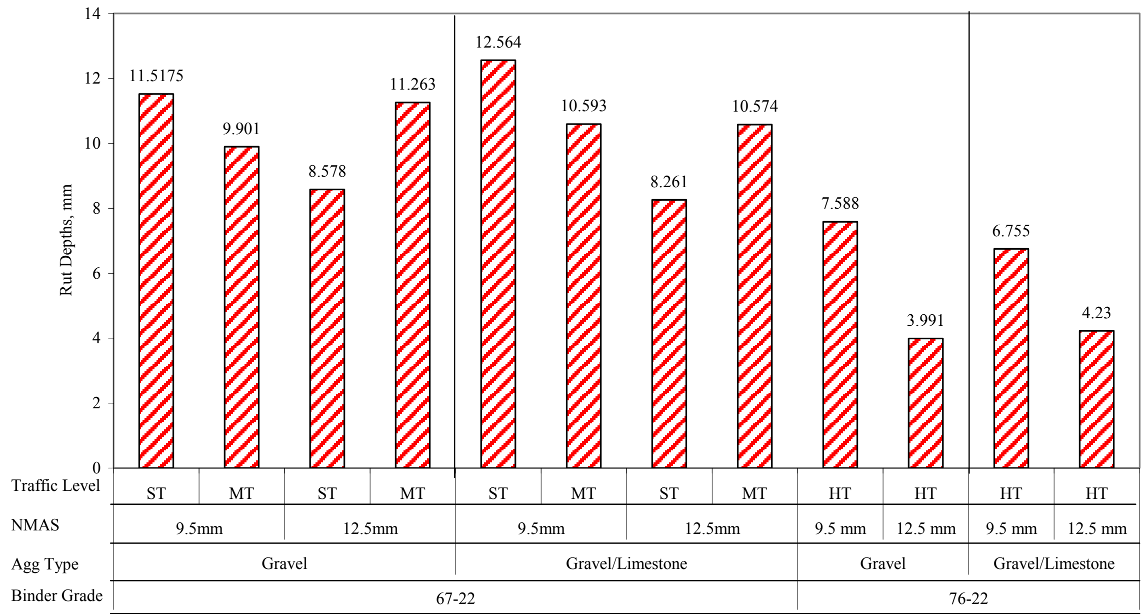


Figure 4.27 Asphalt Pavement Analyzer Laboratory Specimen Rut Depth

Once APA testing was complete, field rut depths were compared to APA rut depths of laboratory prepared specimens. The relationship between field and APA lab rutting is provided in Figure 4.28. Again, the data is grouped by traffic level (ST, MT, and HT), because of the previously mentioned factors. Very poor relationships between field rutting rate and APA lab rut depth exist for the HT and MT mixes while a fair relationship exists for ST mixes. While the relationships are poor, the expected trend of increased APA rut depth with increasing field rutting rate is observed for ST and HT mixes. The trend for the MT mixes was slightly opposite from the expected.

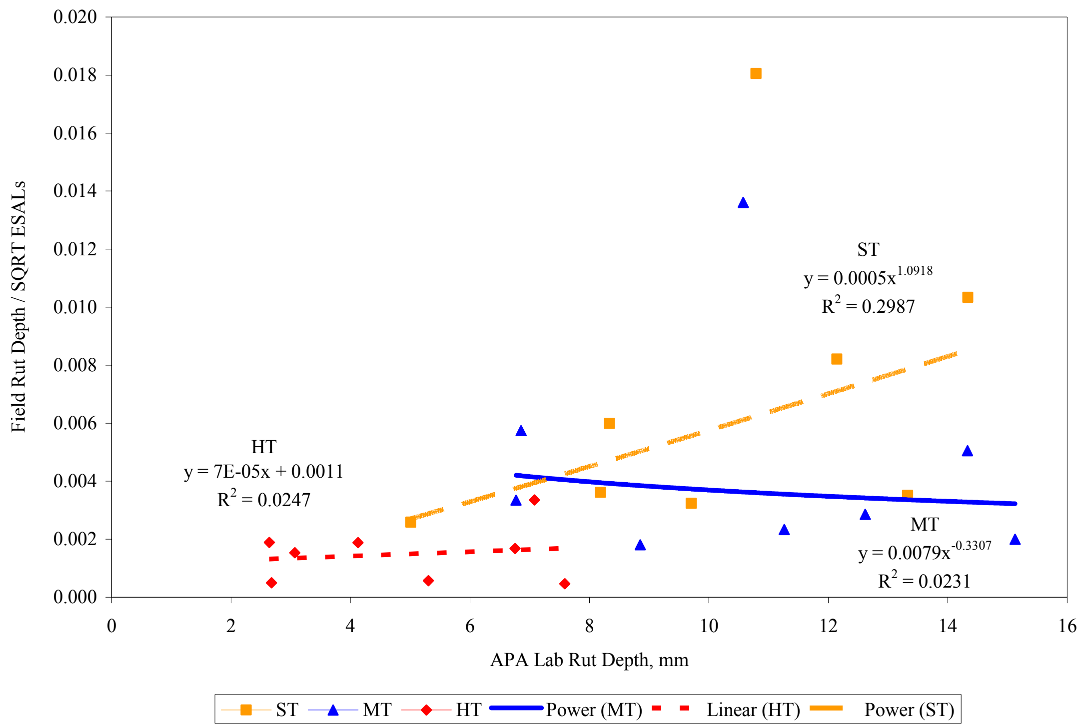


Figure 4.28 Field Rutting versus APA Lab Rut Depth

4.2.4 APA Core Rutting versus APA Laboratory Specimen Rutting

Figure 4.29 shows the relationships for APA (lab mix) rut depths versus APA (core) rut depths. The data clearly show a large bias, in which the rut depth of lab prepared specimens are much greater than those for cores. In addition to the bias, very poor relationships exist for all the mix types. For MT and HT mixes, the trend of increasing lab specimen rut depth with increase core rut depth is correct, but with ST mixes the trend is opposite. Possible explanations for these relationships may lie in excessive asphalt binder oxidation of cores, differences in specimen heights, and difference in aggregate orientation due to methods of compaction.

Laboratory prepared specimens were only “short-term” aged. Short-term aging represents that occurring during HMA construction and production. Cores, on the other hand, were at least 2 years old and had undergone some “long-term” aging, as previously discussed. No field core rutted over 5.0 mm, while 20 of 24 (83 percent) of the projects had APA rut depths of 5.0 mm or greater.

As previously mentioned, core heights were around 40 mm and therefore had to be plastered to meet the required APA test height of 75 mm. It is possible that while the air void contents between the core and lab specimens were similar, the smaller core thickness reduced the amount of aggregate particle reorientation, resulting in less rutting. Additionally, aggregate arrangement or orientation from field compaction may be different from that obtained with gyratory compaction, which could affect specimen loading response. Field compaction is typically achieved using rollers which apply constant load or stress to the pavement. Additionally, the pavement is not as confined, as it is during lab compaction. During laboratory compacting with the gyratory compactor, specimens are compacted using a constant angle of gyration, which can be thought of as constant strain. Constant stress and strain compaction may result in differences in aggregate orientation and density profile which could ultimately influence mix rutting potential.

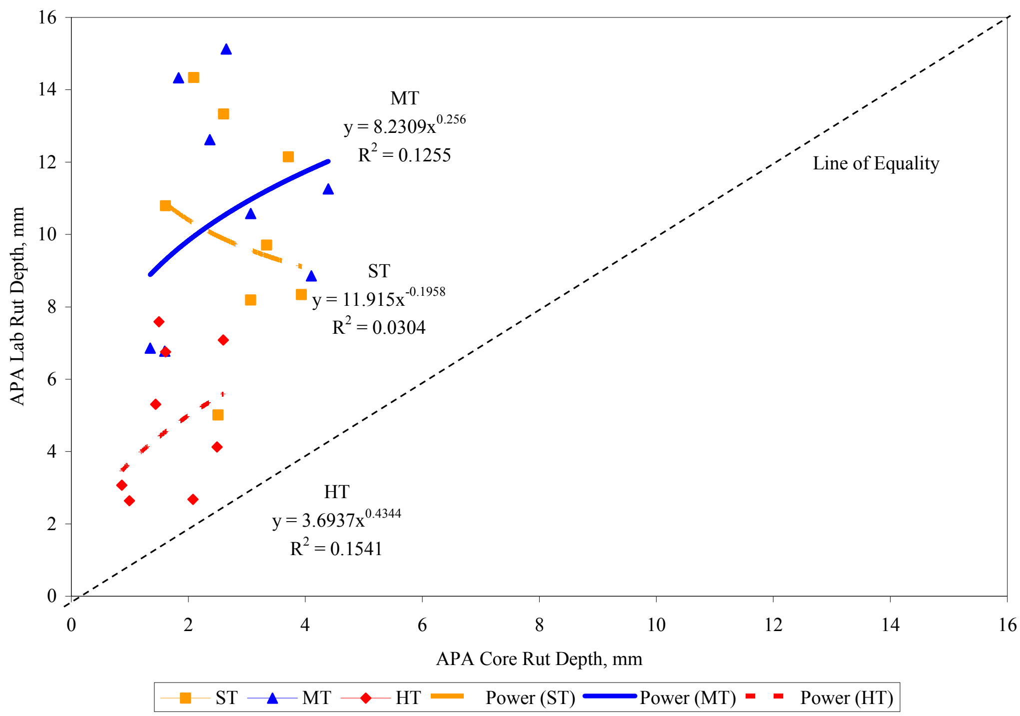


Figure 4.29 APA Lab and Core Rutting

4.2.5 Statistical Analysis of Laboratory APA Testing

To better understand the study factor effects on laboratory prepared APA rut depth, an analysis of variance (ANOVA), was performed. Factors evaluated were aggregate type (gravel mixes and gravel/limestone), nominal maximum aggregate size (9.5 and 12.5 mm), and traffic level (ST, MT, and HT). Asphalt binder grade was not included in the analysis because traffic level indirectly accounts for binder grade. For example, traffic level ST and MT mixes use only PG 67-22, while the HT mixes in this study used PG 76-22, exclusively.

The ANOVA results are provided in Table 4.31. Results indicate nominal maximum aggregate and traffic level are significant, but no significance between aggregate types. No interactions were significant, although the two way interaction of nominal maximum aggregate size and traffic level was very close with a P-value of 0.053.

Table 4.31 ANOVA Results for Lab Prepared APA Rut Depths

Source	Degrees of Freedom	Mean Squares	F-Stat	Prob > F-Stat	Statistically Significant (Yes/No)[1]
Agg	1	0.058	0.01	0.9255	NO
NMS	1	69.709	10.62	0.0018	YES
Traffic	2	148.176	22.58	<.0001	YES
Agg*NMS	1	1.748	0.27	0.6077	NO
Agg*Traffic	2	0.640	0.1	0.9073	NO
NMS*Traffic	2	20.258	3.09	0.053	NO
Agg*NMS*Traffic	2	2.443	0.37	0.6908	NO
Model	11	58.748	8.95	<.0001	YES
Error	60	6.563			

[1] Conducted at a level of significance of 5 percent

4.2.5.1 Aggregate Type

Two levels of aggregate type were evaluated, gravel and a gravel/limestone blends. Mixes with gravel aggregate had an average rut depth of 8.88 mm and gravel/limestone aggregate blends had an average of 8.41 mm. Analysis of variance of results, in Table 4.31, indicated no significant effect between the two aggregate types.

4.2.5.2 Nominal Maximum Aggregate Size

Two levels of aggregate nominal maximum aggregate size (NMS) were analyzed: 9.5 and 12.5 mm. Analysis of variance results, Table 4.31, and Tukey comparisons, Table 4.32, both show a significant difference in rutting between 9.5 and 12.5 mm NMS mixes. Average rut depths of 9.5 and 12.5 mm NMS mixes were 10.59 mm and 6.67 mm, respectively. This indicates mixes with larger NMS are likely to rut less than mixes with smaller NMS. This could be attributed to more inter-granular contact. While both NMS levels may have the same amount of stone on stone contact it can be reasoned that larger aggregate would have more surface area in contact. This larger surface area provides more shear strength.

Table 4.32 Tukey's Multiple Comparison Test Results

Study Variable and Level		APA Rut Depth, mm	Tukey's Grouping[1]
Agg	Gravel	8.888	A
	Gravel/Limestone	8.413	A
NMS	9.5 mm	10.588	A
	12.5 mm	6.674	B
Traffic	ST	10.799	A
	MT	10.230	A
	HT	4.864	B

[1]Level of significance = 5 percent. Levels with the same letter are not statistically different.

4.2.5.3 Traffic Level

Binder grade is selected based on traffic level, and traffic level was shown to be significant according to ANOVA results, as shown in Table 4.31. Tukey comparisons, in Table 4.32, showed no significant difference between ST mixes and MT mixes, but a difference between ST and MT mixes and HT mixes. This is explained largely by HT mixes using PG 76-22 (polymer modified) binders exclusively and ST and MT mixes using PG 67-22 (neat asphalt). There is also a difference in compaction requirements for those traffic levels. The number of gyrations (N_{design},) for HT, MT, and ST mixes are 96, 86, and 68, respectively.

4.2.5.4 Performance Grade Binder

As discussed previously, performance grade binder was not included in the ANOVA because of its relationship to traffic level. By comparing average rut depths of mixes with PG 67-22 and PG 76-22 asphalt binders, it is clearly seen that binder grade has a substantial influence on mix rutting. As shown in Figure 4.30, PG 76-22 mixes rutted an average of 54 percent less than PG 67-22 mixes (4.86 mm for PG 76-22 mixes compared to 10.51 mm for PG 67-22 mixes).

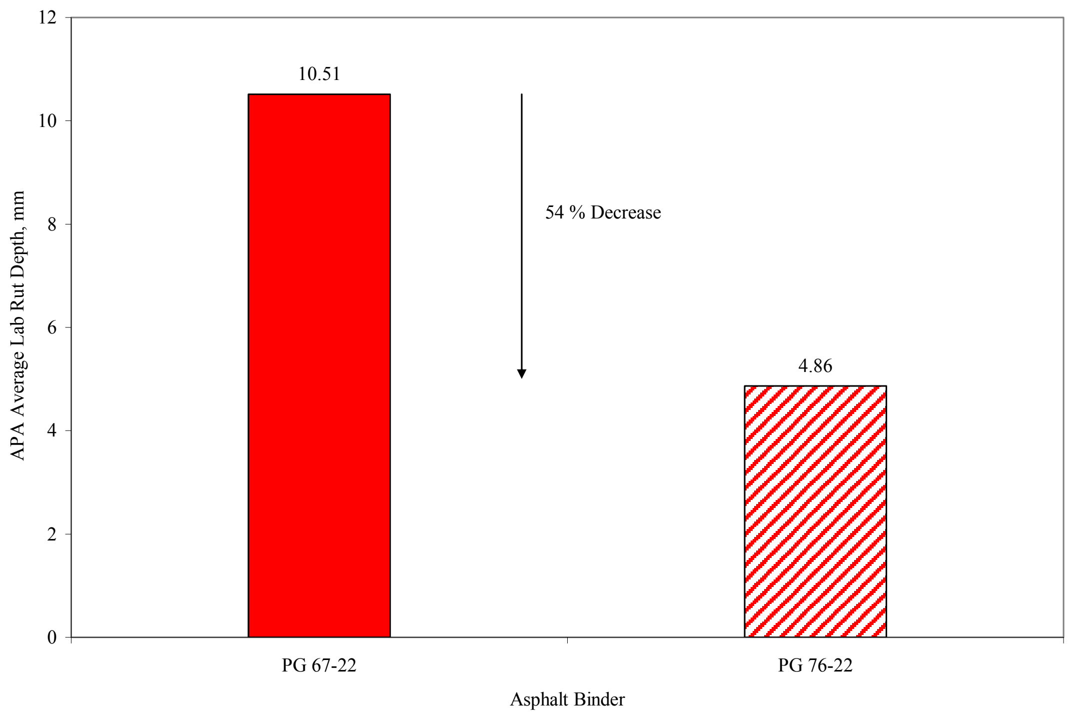


Figure 4.30 Comparison of Binder Grades on APA Rut Depths.

While the above results indicate PG 76-22 mixes rut substantially less than PG 67-22 mixes, the analysis did not consider the possible effects of the slightly reduced asphalt binder content of the HT mixes relative to the ST and MT mixes.

Therefore, to specifically evaluate rutting resistance of PG 67-22 asphalt binder relative to PG 76-22, two HT gravel/limestone mixes (Projects D and E) were prepared with PG 67-22 in lieu of PG 76-22. Six specimens for each project were tested in the APA with the results shown in Figure 4.31. The results indicate that the use of PG 76-22 results in 60 and 43 percent less rutting for projects D and E mixes, respectively. This agrees closely with the 50 percent less rutting observed with HT mixes relative to ST and MT mixes.

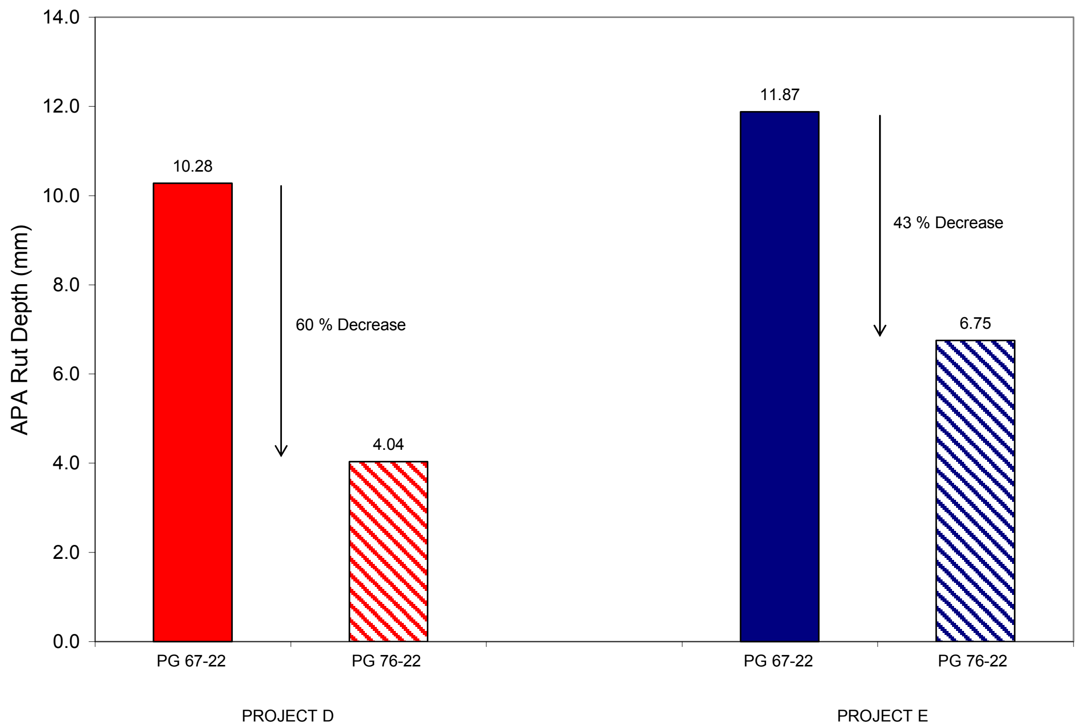


Figure 4.31 PG 67-22 and PG 76-22 APA Rutting Comparison for HT Mixes

4.3 Determination of APA Rut Depth Criteria

One of the primary study objectives was to recommend laboratory APA rut depth criteria to MDOT. These criteria could then be used during for mix design acceptance.

Any proposed criteria should be based on traffic level (i.e., ST, MT, and HT mixes) due to the differences in compactive effort and expected performance. The simplest and most logical approach to establishing an APA rut criteria would be to determine a limiting field rutting amount and separate mixes as either acceptable or not acceptable based on field rutting. Laboratory rut criteria could then be established based on the known field performance. However, this approach is not possible since all the evaluated mixes are performing well with minimal rutting. Therefore, establishing rut criteria becomes a more difficult task.

A number of agencies have developed APA rut depth criteria. Prowell (14), used a 95 percent confidence limit based on a normal distribution to develop the Virginia DOT's APA rut depth criteria. Using such an approach will theoretically result in only a 5 percent chance or risk of a mix failing the criteria when it should pass.

Using a similar approach, the APA criteria were determined using a Student's t-distribution as follows:

$$RutDepth = Mean + t_{\alpha/2}\left(\frac{S}{\sqrt{n}}\right) \qquad \text{Equation 4.1}$$

where

Rut Depth = maximum allowable rut depth,

Mean = average rut depth,

S = sample standard deviation,

$t_{\alpha/2}$ = *t value for Student's t distribution with n-1 degrees of freedom,*

n = number of samples.

Applying this approach to the study results in the criteria shown in Table 4.33.

Table 4.33 APA Rut Depth Criteria Using the VDOT Approach

Parameter	Traffic Level		
	ST	MT	HT
Mean Rut Depth, mm	10.23	10.80	4.91
Standard Deviation, mm	0.82	0.69	0.50
Maximum Allowable Rut Depth, mm	12.0	12.0	6.0

Results from using this approach appear reasonable for the HT mixes. A maximum allowable APA rut depth of 6.0 mm is near that used by other states. For example VDOT, South Carolina, and Alabama have maximum APA rut depth criteria of 4.0, 4.5, and 3.0 mm for high volume highways (*14*, *15*, *16*).

For ST and MT mixes, the determined maximum allowable rut depth of 12.0 mm appears high. It should be noted that none of the ST and MT mixes exhibited excessive rutting in the field. Therefore, it appears that the severity of APA testing is much worse that the field loading conditions experienced by these mixes.

A few other states have rut depth criteria developed for low to medium volume mixes. Virginia DOT (*14*) set a limit of 8.5 mm for their SM-1 mixes (low volume). South Carolina (*15*) has a maximum rut depth of 7.0 for their intermediate course mixes with PG 64-22 asphalt binder. Alabama does not require APA testing for their low to medium volume mixes (*16*).

Kandhal and Cooley (*9*) developed rut criteria of 12, 10, 7, 5, and 3 mm for traffic levels of 2, 3, 5, 10, and 30 million ESALs, respectively. Considering this, the developed rut criteria of 12.0 mm for ST and MT mixes is reasonable. As mentioned earlier, ST mixes have less than 1 million ESALs while MT mixes have between 1 and 3 million ESALs.

The approach, as discussed in Chapter 2, used by Kandhal and Cooley (*9*) will be replicated using the study data to determine another possible set of APA rut criteria for comparison with the criteria in Table 4.33. The one exception will be to use a limiting field rut depth of 6.35 mm (0.25 in.), instead of 12.5 mm (0.5 in). It is

MDOT standard practice on state maintained roads to use a rut depth of 6.35 mm (0.25 in.) as a "trigger" value for maintenance operations (*24*).

Figure 4.32 shows the relationship between field rutting rate (i.e., rutting / square root of ESALs) and laboratory APA rut depth for the 24 study mixes. Using the developed relationship and a limiting field rut depth of 6.35 mm (0.25 in.), maximum allowable APA lab rut depths were determined and are shown in Table 4.34.

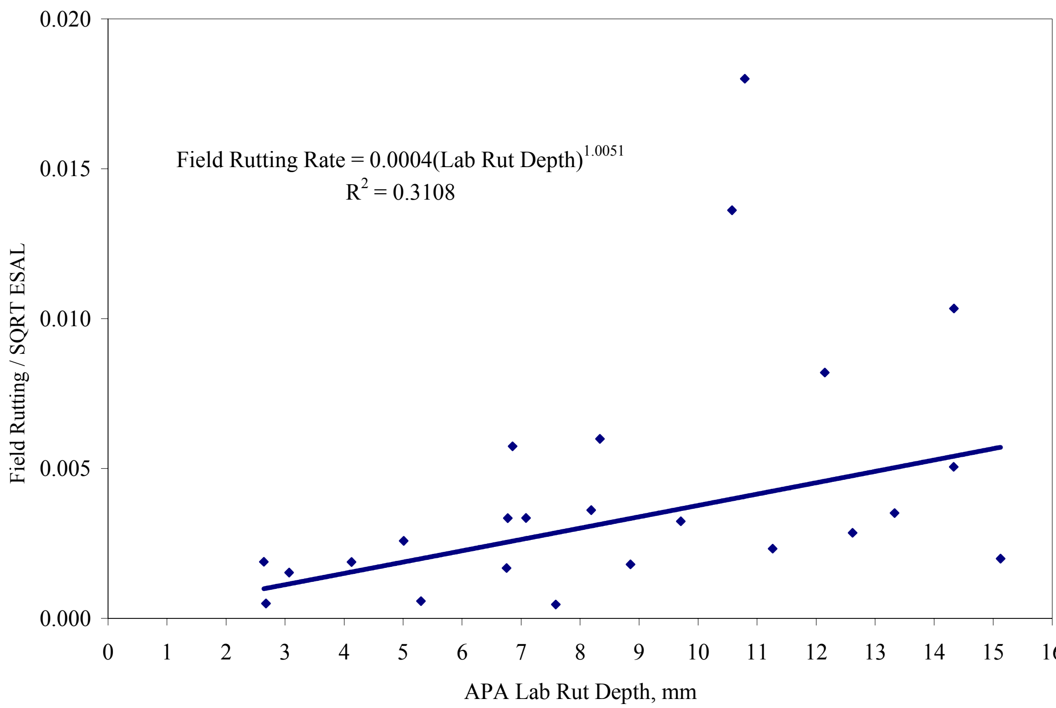


Figure 4.32 Field Rutting versus Laboratory Rutting Rate Summary

Table 4.34 APA Lab Rut Criteria Based on Limiting Field Rutting

ESALs (Million)	Field Rutting / SQRT ESALS	Maximum Allowable APA Lab Rutting, mm
1	0.0064	15.7
2	0.0045	11.1
3	0.0037	9.1
5	0.0028	7.0
7	0.0024	5.9
10	0.0020	5.0
15	0.0016	4.1
20	0.0014	3.5
30	0.0012	2.9

The APA rut criteria developed for this approach range from over 15 mm for 1 million ESALs down 2.9 mm for 30 million ESALs. In Mississippi, there are very few pavements that will see 30 million ESALs over their design life. For the 8 HT mixes in the study, an average of 820,000 ESALs per year was calculated. These sites represent a wide spectrum of HT mixes throughout the state. Assuming a 10 year design pavement design life, 8,200,000 ESALs would be applied to an average HT mix. The rut criteria for 8,200,000 million ESALs, based on the above analysis, are 5.5 mm, which is just slightly less than the 6.0 mm rut depth determined from the previous approach.

Rut criteria development for ST and MT mixes can be viewed in much the same manner. For ST mixes, used for less than 1 million ESALs, the rut criteria of 15.7 mm is too great and is not appropriate. Rut depths in the APA of this magnitude can cause damage to APA loading mechanisms and should be avoided. For MT mixes, the design ESALs range is from 1 to 3 million. For an average of 2 million ESALs, the maximum allowable rut depth is 11.1 mm. Again, this value is just slightly less than the 12 mm rut depth determined previously through the VDOT procedure.

Two options appear to exist for ST mix rut depth criteria. Either have no criteria or use the same criteria established for MT mixes. Asphalt pavement analyzer testing should be conducted on the ST mixes during design to insure some minimal level of mix performance. Field and lab rutting for ST and MT mixes were very similar. Therefore, it appears logical to use the same rut criteria for ST and MT mixes.

One item to remember in the development of APA rut criteria is that MDOT recently lowered its N_{design} levels for ST, MT, and HT mixes to 50, 65, and 85 gyrations, respectively. Recall, the previous N_{design} levels were 68, 86, and 96 gyrations, respectively. This change was made due to durability concerns (i.e., premature fatigue and top-down cracking) of in-service pavements. Lower compactive efforts will result in slightly higher design asphalt binder contents. As a result, field and laboratory rutting potential will likely increase. If the developed criteria are applied to mixes designed with the new compactive efforts, it is possible that slightly more mixes will exceed the APA failure criteria during design. This should be monitored over time to determine the significance of the change in N_{design} levels.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions and observations are made regarding the field investigation.

- Field rutting was minimal, ranging from 0.9 to 5.5 mm (0.04 to 0.22 in.), with an average rut depth of 1.88 mm (0.07 in).
- In general, gradation and asphalt binder content of obtained cores agreed closely with the job mix formula values.
- Density differentials between locations in the wheel path and between wheel paths for ST, MT, and HT mixes were 0.39, 0.71, and 0.19 percent, respectively. This is logical since HT mixes use polymer modified binders (PG 76-22), which increase mix stiffness and likely reduce densification. The lack of substantial densification coincides with the minimal field rut depths observed.

Based on APA testing the following conclusions and observations are made.

- Performance asphalt binder grade appears to substantially influence APA rutting. Mixes with PG 76-22 (i.e., HT mixes) rutted an average of 54 percent less than mixes with PG 67-22 (i.e., ST and MT mixes).
- For two HT mixes prepared with PG 67-22 and PG 76-22, the PG 76-22 mixes rutted an average of 52 percent less than the PG 67-22 mixes. This indicates that the primary cause of HT mixes rutting less than the ST or MT mixes is the use of PG 76-22 asphalt binder, not the slightly reduced design asphalt binder content as a result of the higher N_{design} level for HT mixes.
- Aggregate type (gravel or gravel / limestone blend) did not significantly influence rutting.
- Nominal maximum aggregate size was significant on rutting, with 12.5 mm NMS mixes rutting 35 percent less than 9.5 mm mixes.

- Inverse relationships were found for field rutting rate versus APA rutting of cores. Field rutting rate was found to decrease with increasing APA rutting, which is contrary to the expected.
- Better relationships were determined for field rutting rate and APA lab prepared specimen rut depth with the best relationship found for ST mixes.
- A bias existed between APA rut depths of lab prepared specimens and cores. This is likely an influence of core aging and decreased thickness, relative to lab specimens.

5.2 Recommendations

This study showed the APA to be sensitive to changes in mix design parameters. The APA can be used to determine relative mix performance, but should not be used to predict mix field rutting. While results indicated no significant difference in APA rutting between ST and MT mixes, more research needs to be done to determine if this is actually the case or a product of small sample size variability.

Based upon the field analysis and laboratory APA testing using the parameters found in Table 5.1, recommended APA rut depth criteria are provided in Table 5.2.

Table 5.1 APA Test Parameters

Test Temperature	64°C (147°F)
Test Condition	Dry
Specimen Type	Cylinder
Air Voids	7 ± 0.5 %
Load	0.445 kN (100 lbs)
Hose Pressure	690 kPa (100 psi)
Test Duration	8,000 cycles
Rut Depth Measurement	Automatic

Table 5.2 APA Rut Depth Criteria

Mix Type	ESALs	Maximum Allowable APA Lab Rutting, mm
ST	< 1 million	12.0
MT	1 to 3 million	
HT	> 3 million	6.0

A maximum APA rut depth of 6.0 mm should be used for HT mixes and a maximum of 12.0 mm utilized for ST and MT mixes. It is important to note that these criteria were based on only 24 projects throughout the state. While this may initially sound like a substantial evaluation, it is a relatively small number of projects. Therefore, mix performance should be monitored in the future to determine what changes in performance result from specification changes to the mix N_{design} levels. It is recommended that MDOT continue to maintain a complete database of mix design APA testing and field performance so APA rut depth criteria can be modified, if necessary, in the future.

CHAPTER 6 REFERENCES

1. White, Thomas D., John E. Haddock, Adam J.T. Hand, Hongbing Fang, “Contributions of Pavement Structural Layers to Rutting of Hot Mix Asphalt Pavements.” NCHRP Report 468, National Academy Press, Washington D.C., 2002

2. Christensen, D. W. and Ramon Bonaquist, "Use of Strength Tests for Evaluating the Rut Resistance of Asphalt Concretes," *Journal of the Association of Asphalt Pavement Technologist*, vol. 71, Association of Asphalt Pavement Technologists, St. Paul, Minnesota, 1998

3. McGennis, Robert B., R. Michael Anderson, Thomas W. Kennedy, Mansour Solaimanian, “Background of Superpave Asphalt Mixture Design and Analysis.” Federal Highway Administration, Office of Technology Applications, FHWA-SA-95-003, 1994.

4. Moseley, Howard L., G.C. Page, J.A. Musselman, G.A. Sholar, Patrick B. Upshaw, "Laboratory Mixture and Binder Rutting Study," Research Report FL/DOT/SMO/03-465, August 2003.

5. Williams, Stacey G., "The Effects of HMA Mixture Characteristics on Rutting Susceptibility" TRB Report, Transportation Research Board, Washington D.C., 2003

6. Brown, E. R. and Cross, "A National Study of Rutting In Hot Mix Asphalt (HMA) Pavements." NCAT Report No. 92-5, National Center for Asphalt Technology, 1991.

7. Kandhal, Prithvi S., Allen L. Cooley Jr., "Coarse Versus Fine-Graded Superpave Mixtures: Comparative Evaluation of Resistance To Rutting" NCAT Report No. 2002-02, National Center for Asphalt Technology, 2002.

8. Parker, F. and E. R. Brown, "Effects of Aggregate Properties on Flexible Pavement Rutting in Alabama," Effects of Aggregates and Mineral Fillers on Asphalt Mixture Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Materials, Philadelphia, 1992

9. Kandhal, Prithvi S., Cooley Allen L. Jr., "Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer." NCHRP Report 508, National Academy Press, Washington D.C., 2001

10. Kandhal, Prithvi S. and Mallick, Rajib B., "Evaluation of Asphalt Pavement Analyzer for HMA Mix Design," NCAT Report No. 99-4, National Center for Asphalt Technology, June 1999.

11. Jackson, N. Mike and Baldwin, Christopher D., "Evaluation of the Asphalt Pavement Analyzer to Predict the Relative Rutting Susceptibility of HMA in Tennessee." Paper Submitted to International Conference on Accelerated Pavement Testing, Paper No. CS6-3, 1999.

12. Choubane, B., G.C. Page, and J.A. Musselman, "Investigation of the Asphalt Pavement Analyzer for Predicting Pavement Rutting." Research Report FL/DOT/SMO/98-427, 1998.

13. Sholar, Gregory A., G.C. Page, "Follow-up Evaluation of the Asphalt Pavement Analyzer." Research Report FL/DOT/SMO/99-436, 1999.

14. Prowell, B.D., "Development of Rutting Criteria for the Asphalt Pavement Analyzer." Paper submitted for consideration for presentation and publication at the 1999 International Conference on Accelerated Pavement Testing, Paper No. CS6-4, 1999.

15. Hawkins, Chad W., "Investigation of SCDOT Asphalt Mixtures Using the Pavement Analyzer – Phase 1." South Carolina Department of Transportation, FHWA-SC-01-11, 2001.

16. Alabama Department of Transportation Standard Specifications for Highway Constructions, Section 424 Superpave Bituminous Concrete Base, Binder, and Wearing Surface Layers, 2004Edition.

17. Brown, E.R., L. Allen Cooley, Jr., Doug Hanson, Cynthia Lynn, Buzz Powell, Brian Prowell, Don Watson, "NCAT Test Track Design, Construction, and Performance." NCAT Report No. 2002-12, National Center for Asphalt Technology, November 2002.

18. AASHTO. (2001). "Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens.", T166, Washington D.C.

19. AASHTO (2001). "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures.", T164, Washington D.C.

20. "Rapid Method to Determine the Asphalt Content and Gradation of Asphalt Paving Mixtures using Biodegradable Extractant.", ALDOT-371-90, Alabama Department of Transportation, Bureau of Materials and Tests, 1994.

21. AASHTO (2001). "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures.", T209, Washington D.C.

22. AASHTO (2001). "Materials Finer Than 75µm (No. 200) Sieve in Mineral Aggregates by Washing.", T11, Washington D.C.

23. AASHTO (2000). “Sieve Analysis of Coarse and Fine Aggregates.”, T27, Washington D.C.

24. E-mail Correspondence with James Watkins, Mississippi Department of Transportation, August 5, 2004.

APPENDIX A
PROJECT INFORMATION SUMMARY WITH MDOT PROJECT NUMBERS

No.	Aggregate	Traffic Level	NMS	PG	County	Highway	Section ID	Project ID
1	Gravel	ST	9.5	67-22	Claiborne	18	786	91-3018-11-005-10
2	Gravel	ST	9.5	67-22	Amite	33	1371	91-7033-03-002-10
3	Gravel	ST	12.5	67-22	Lincoln	550	4290	91-7550-43-008-10
4	Gravel	ST	12.5	67-22	Wilkinson	24	1090	91-7024-79-007-10
5	Gravel	MT	9.5	67-22	Simpson	13	522	91-7013-64-003-10
6	Gravel	MT	9.5	67-22	Pearl River	11	410	91-6011-55-017-10
7	Gravel	MT	12.5	67-22	Leake	35	1409	91-5035-40-016-10
8	Gravel	MT	9.5	67-22	Jones	11	382	91-6011-34-009-10
9	Gravel/Limestone	HT	12.5	76-22	Lowndes	82	3043	46-0011-03-064-10
10	Gravel	HT	9.5	76-22	Rankin	I-20	962	59-0020-01-135-10
11	Gravel	HT	12.5	76-22	Covington	49	1864	11-0008-02-081-10
12	Gravel	HT	12.5	76-22	Simpson	49	1962	11-0008-02-082-10
13	Gravel/Limestone	ST	9.5	67-22	Leflore	7	241	91-2007-42-005-10
14	Gravel/Limestone	ST	9.5	67-22	Wayne	510	4230	91-6510-77-001-10
15	Gravel/Limestone	ST	12.5	67-22	Winston	15	690	91-1015-80-008-10
16	Gravel/Limestone	ST	12.5	67-22	Smith	13	526	91-7013-65-003-10
17	Gravel/Limestone	MT	9.5	67-22	Chickasaw	32	1351	91-1032-09-007-10
18	Gravel/Limestone	MT	9.5	67-22	Attala	12	421	91-2012-04-007-10
19	Gravel/Limestone	MT	12.5	67-22	Pontotoc	278	207	91-1006-58-007-10
20	Gravel/Limestone	MT	9.5	67-22	Pearl River	43	1590	91-6043-55-024-10
21	Gravel/Limestone	HT	12.5	76-22	George	98	3298	46-0014-03-052-10
22	Gravel/Limestone	HT	9.5	76-22	Carroll	82	3013	91-2082-00-007-10
23	Gravel/Limestone	HT	12.5	76-22	Desoto	78	2827	11-0006-01-060-10
24	Gravel/Limestone	HT	12.5	76-22	Panola	I-55	2377	59-0055-04-062-10