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Characterization of NJ HMA – Part I

FINAL REPORT
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16. Abstract

The research project encompassed developing a testing procedure to accompanying the HMA volumetric design. Currently, there does not exist a simple performance test that addresses whether or not a HMA mix will perform adequately once compacted in the field. Recent efforts through the NCHRP program has proposed a method that could be used, however, the method utilizes sample coring and cutting methods that make the test procedure highly labor intensive. Therefore, it was proposed to develop a testing method that could be conducted immediately after the mix design procedure without the need for extensive sample preparation. The test method to be used also had to have an accepted testing procedure and simulate the rutting mechanisms found in the field.

A rutting criteria is proposed to be used with the Asphalt Pavement Analyzer (APA). The APA is a loaded-wheel test that uses a 100 lb. steel wheel load applied to a 100 psi pressurized hose that lays overtop of the asphalt samples. The samples are easily compacted to a required 77mm tall and air void content of 7% using the gyratory compactor, with no need to cutting or coring. The samples are heated to a temperature of 64oC for fours hours prior to testing. After this conditioning stage is complete, the steel wheels then run back and forth over the samples for a total of 8,000 loading cycles. The total rutting that occurs after the 8,000 loading cycles is then used in the proposed pass/fail criteria.

The criteria was developed by testing eleven different mix designs. Six designed for very heavy traffic, four designed for heavy traffic and one designed for medium to low traffic. Both coarse and fine gradations were used, as well a three different PG binder grades; PG64-22, PG70-22, and PG76-22. The results of the testing allowed for the construction of the criteria based on the design gyration number. The rutting criteria was verified in the laboratory by using the NY/NJ Port Authority's Heavy Volume Mixes (HVM), as well as other industry mixes. However, as to this date, field verification has not been conducted.

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TABLE OF CONTENTS

LIST OF FIGURES Page #

LIST OF TABLES

ABSTRACT

The goal of the research project was to develop a test method that could be used after the volumetric mix design to predict the rutting performance. Although a recent NCHRP study is finalizing a proposed method to be used for the 2002 Mechanistic Pavement Design procedure, the sample preparation methods are very labor intensive. What is needed is a test that simulates the traffic loading that causes rutting, as well as the testing procedures and data interpretation being easy to use and understand. Therefore, the Asphalt Pavement Analyzer (APA) was chosen.

The APA is a second-generation loaded wheel tester. It has the capability of testing compacted brick or pill samples under various environmental conditions in both rutting (high temperature permanent deformation) and fatigue (low temperature cracking). This project utilized the rutting feature of the APA. The device can also be linked to a computer and data acquisition system so the user can measure the rutting of the HMA for each load cycle.

Basically, a moving wheel load is applied at a rate of about one cycle per second to a ¾ inch pressurized hose that rests atop the HMA samples. This simulates (on a small scale) the loading of wheel loads on actual road sections. However, as to date, there have been no successful attempts at directly comparing the results of the APA to an actual roadway in the field. Therefore, the major use of the device is as a comparative tool for mixture selection (i.e. one would select the mix that ruts the least from the APA testing).

The APA is typically run at a test temperature of 64^{o}C. The samples are conditioned under this temperature for minimum of 4 hours prior to testing. The loading configurations typically used within the APA are a wheel load of 100 lbs and a hose pressure of 100 psi. Once conditioned, the samples under-go a 25 cycle seating load. Once the 25 cycles have completed, the initial rut depths are measured. Testing then usually continues until a minimum of 8,000 cycles are completed. The difference between the initial and final rut depth measurements is calculated as the APA rut depth.

The rutting criteria was developed using the data from laboratory prepared HMA samples. The HMA samples were designed for three different traffic levels (very heavy, heavy, and medium to low), two different aggregate gradations (fine and coarse), and with different performance-graded asphalt binders (PG64-22, PG70-22, and PG76-22). A literature search conducted to provide background on currently proposed APA rutting criteria indicated that the APA rutting criteria proposed by the Arkansas DOT matched the criteria proposed for the NJDOT. Verification was further conducted by using the NY/NJ Port Authority's Heavy Volume Mixes (HVM). However, field verification has not been conducted. The field verification would provide the final tested needed ensure proper rutting characterization using the APA.

INTRODUCTION

Permanent deformation (rutting) in hot mix asphalt (HMA) is one of the most common pavement distresses. Rutting in HMA is the accumulation of permanent strains from applied wheel loads. The contributions of both shear failure and volume distortion play significant roles in the rutting of HMA, which typically occurs within the top 100 mm of the HMA structure (Brown and Cross, 1992). The combination of increased higher traffic volumes and tires that allow for higher inflation pressures has created a growing concern among pavement engineers of the potential for rutting.

At the moment, an NCHRP study, "NCHRP Report 465 – Simple Performance Test for Superpave Mix Design", is being finalized. The main goal of the research is to develop a simple performance test that could be used after the mix design procedure to verify whether the HMA will be rut susceptible. Under the proposed procedure, a rigorous sample preparation procedure requires cutting and coring to extremely tight tolerances. The test also requires a servo-hydraulic loading device capable of applying loads at frequencies as high as 25 Hz over a variety of temperatures. It is estimated that the test will take approximately three to four days to compact, prepare, and test the HMA samples. Although the equipment and testing procedures may be "simple" for academia and state trained officials, the sophistication and delicate nature of the equipment may not be suitable in the high production environment of the mixing plant.

A common HMA test used today that does not require the rigorous sample preparation nor the complicated testing equipment is the Asphalt Pavement Analyzer (APA). The APA is classified as a simulative test since it tests the HMA under loading schemes that are similar to field loading. The APA is a hybrid form of the older Georgia Loaded Wheel Tester (GLWT). In this test, a wheel load is applied to an air pressurized hose that lays over top of the HMA samples. The wheel load is tracked back and forth causing the pressurized hose to induce rutting on the HMA samples. The test is generally conducted until 8,000 loading cycles (back and forth) have been applied. Therefore, the only data analysis that needs to be conducted is the rutting measurement before and after testing. The approximate time of testing is two days to compact, prepare, and test the HMA samples. Based on the ease of sample preparation and test equipment, the APA has been recognized as the only simple performance test ready for immediate implementation (Brown et al., 2001).

At the moment, the APA has strictly been used as a tool to compare the performance of two or more HMA mixes. The HMA mix that accumulates the lowest amount of APA rutting would be selected for use. However, the goal of this research was to develop a pass/fail criterion to be used with the APA. In essence, the HMA mix would be tested in the APA and based on the amount of rutting, it would either be recommended or declined for use. The research for this project was conducted in the following manner:

1) Literature Search – a literature search was conducted to determine if other state agencies are using a rutting criteria with the APA and what criteria they are using;

2) Laboratory Evaluation – a laboratory evaluation was conducted using mixes of different gradations (fine and coarse), different performance graded binders (PG76-22, PG70-22, and PG64-22), and different design gyration levels for different traffic levels (very heavy (VH), heavy (H), and medium to low (M)). The samples were tested in the APA to provide estimated tolerances of APA rutting.
3) Criteria Verification – a laboratory evaluation was conducted using HMA mixes that have been traditionally used with success. This mainly consisted of the NY/NJ Port Authority's heavy volume mixes (HVM). These mixes have been used for years by the Port Authority on highly traveled infrastructure, such as the George Washington Bridge with great success. Therefore, it was anticipated that if these mixes passed the rutting criteria, then it would provide a strong confirmation of the selected pass/fail criteria.

LITERATURE SEARCH

<u>Background of the Asphalt Pavement Analyzer (APA)</u>

The use of the loaded wheel tester has become a popular test for transportation agencies to use. The test has shown to be both robust and repeatable. It is simple to use, with a minimal amount of data processing.

The first type of loaded wheel test used for the rutting evaluation of HMA was by the Georgia DOT (Collins et al., 1996). This device was developed in the mid 1980's through the cooperative work between the Georgia DOT and the Georgia Institute of Technology. Since this time, a number of other institutions have developed similar versions of loaded-wheel tracking devices (Table 1).

Table 1 – Loaded-Wheel Tracking Devices and the Developer(s)

Loaded-Wheel Device	Developer
Georgia Loaded Wheel Tester (GLWT)	Georgia DOT/Georgia Institute of Tech.
Hamburg Wheel-Tracking Device (HWTD)	Helmut-Wind Incorporated
LCPC (French) Wheel Tracker	Laboratoire Central des Ponts et Chausees
PurWheel	Purdue University
Model Mobile Load Simulator (MMLS3)	South African Government

But perhaps the most popular type of loaded-wheel testing device is the Asphalt Pavement Analyzer (APA) (Figure 1). The APA has been called the second-generation

Figure 1 – Asphalt Pavement Analyzer

loaded-wheel tester, as it has a similar design to the GLWT. It has the capability of testing compacted brick or pill samples under various environmental conditions in both rutting (high temperature permanent deformation) and fatigue (low temperature cracking) (Figure 2). The device can also be linked to a computer and data acquisition system so the user can measure the rutting of the HMA for each load cycle.

The APA's loading mechanism is as such; a moving wheel load is applied at a rate of about one cycle per second to a ¾ inch pressurized hose that rests atop the HMA samples. This simulates (on a small scale) the loading of the standard 80 kN (18 kip) wheel loads on actual road sections. However, as to date, there have been no successful attempts at directly comparing the results of the APA to an actual roadway in

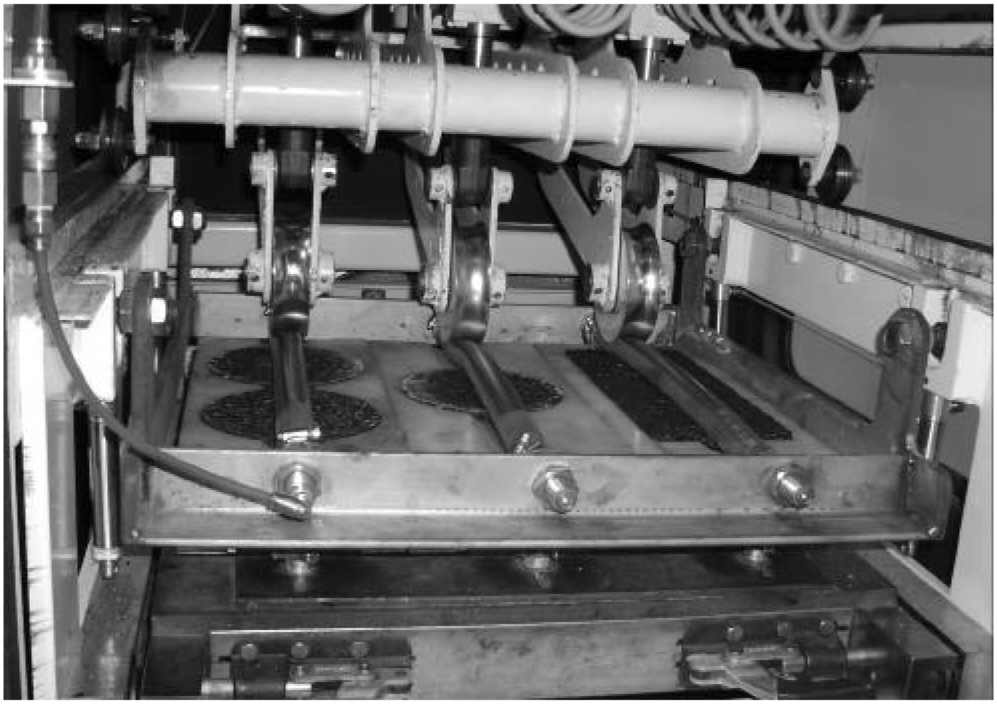

Figure 2 – Inside the Asphalt Pavement Analyzer

the field. Therefore, the major use of the device is as a comparative tool for mixture selection (i.e. one would select the mix that ruts the least from the APA testing).

The APA is typically run at a test temperature of 64^{o}C. The samples are conditioned under this temperature for minimum of 4 hours prior to testing. The loading configurations typically used within the APA are a wheel load of 100 lbs and a hose pressure of 100 psi, although some other researchers have had success with increased loads and pressures (Williams and Prowell, 1999). However, both the APA User's Group (2000) and the National Center for Asphalt Technology (Kandhal and Cooley, 2002) have recommended using 100 psi hose pressure with 100 lbs wheel load. Once conditioned under the test temperature, the samples under-go a 25 cycle seating load. Once the 25 cycles have been completed, the initial rut depths are measured. Testing then usually continues until a minimum of 8,000 cycles are completed. The difference between the initial and final rut depth measurements is calculated as the APA rut depth.

Recently, Brown et al. (2001) evaluated a number of different performance tests as a result for the immediate need of a simple performance test in the asphalt industry. A total of 26 different asphalt tests were evaluated in the study. As a result of the study, only the APA was recommended for immediate use as a means of evaluating permanent deformation in HMA.

Factors Affecting the Results of the APA

The most common use of the APA is to evaluate the rutting potential of different hot mix asphalt mixes. However, depending the organization conducting the testing, different test parameters are used. Table 2 shows the results of the APA User's Group 2000 survey. The survey was developed to exam the different testing parameters that are currently used in APA testing.

Table 2 - APA Testing Specifications Used by Various State Agencies

State	Test Temp. (^oC)	Voids (Target / Range)	Compactor Type(s)	Seating Cycles	Cycles
AL	67	4/1	SGC	25	8000
AR	64	4/1	SGC	25	8000
CN	PG	7/1	SGC/AVC	25	8000
DE	67	7/0.5	AVC	25	8000
FL	64	7/0.5	AVC	25	8000
GA	49	6/1	SGC	50	8000
IL	64	7/1	SGC	25	8000
KS	(<PG)	7/1	SGC	25	8000
KY	64	7/1	SGC	25	8000
LA	64	7/1	AVC	25	8000
MI	PG	4 to 7	SGC/LKC	25	8000
MS	64	7/1	SGC	50	8000
MO	64	7/1	SGC	25	8000
NJ	60	4&7/1	SGC	25	8000
NC	64	7/1	SGC/AVC	25	8000
OK	64	7/1	SGC	25	8000
SC	64	7/1	AVC	25	8000
TN	64	7/1	SGC	----	8000
TX	64	7/1	SGC	50 (25)	8000
UT	64	7/1	LKC	50	8000
WV	60	7/1	SGC	----	8000
WY	52	6/1	AVC	25	8000

SGC = Superpave Gyratory Compactor
AVC = Asphalt Vibratory Compactor
LKN = Linear Kneading Compactor

At the time the study was conducted, the Rutgers University Asphalt/Pavement Laboratory (RAPL) was just starting to use the device. It was recommended by the manufacturer that a test temperature of 60^oC was commonly used. However, the APA Users Group again changed the recommended test temperature soon after the start of this study.

As can be seen from Table 2, most state users are in general agreement with the testing parameters. A test temperature of 64^oC, an air voids (target/range) of 7% (+/-

1%), and 8,000 loading cycles, although there exists some disagreement on the type of compactor to use to fabricate the HMA samples.

A recent research project at RAPL was developed to evaluate the effects of both sample configuration and sample compaction the APA rutting results. Four HMA mixes were compacted using the gyratory compactor (Figure 3) and a vibratory compactor (Figure 4). The vibratory compactor was used to compact both pill and brick samples. The samples were tested in the APA for 8,000 loading cycles to evaluate if the compaction method effects the APA rutting. Figure 5 is a summary from the research.

Figure 3 – Superpave Gyratory Compactor at RAPL

As shown in Figure 5, a slight, visual difference exists between rutting results. A statistical analysis was conducted using a Student's t-test analysis (two sample assuming equal variances). The analysis was utilized to determine if the samples were statistically equal or statistically not equal among the measured APA rutting from the

Figure 4 – Vibratory Compactor at RAPL

different configurations and compaction methods. A 95 percent confidence interval was chosen for the analysis.

The statistical analysis indicated that the rutting results from the coarse graded samples were statistically Equal with respect to sample compaction (vibratory or gyratory) and configuration (pill or brick). However, the statistical analysis conducted on the fine gradation indicated that the APA rutting results were statistically Not Equal when comparing the compaction method (vibratory or gyratory) and sample configuration (pill or brick).

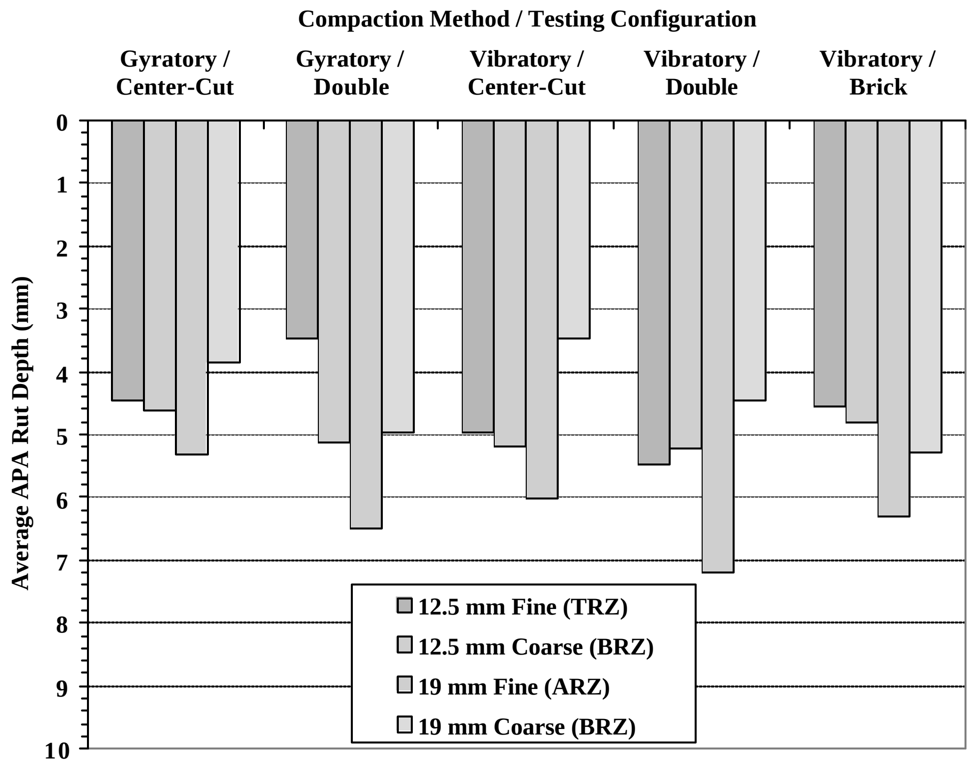

Figure 5 – APA Rutting Results of Different Compaction and Sample Configurations

A similar statistical analysis was conducted with respect to the measurement location of the rutting. Traditionally, a double pill mold is utilized. This allows two pill (round) samples to be tested under one hose and wheel load. However, it was hypothesized that the samples may incur more rutting in this manner due to the slowing of the wheel loads at the end of the molds. If the pill sample was placed in the center of the mold, it would ensure that the HMA sample would be loaded under a constant speed. Figure 6 illustrates the differences between the double and single pill mold measurement locations. To evaluate this, center-cut molds were constructed so only one pill sample would be tested per hose and wheel load.

The statistical analysis indicated that the rutting was dependent on the compaction method. When comparing the vibratory pill samples, it was found that the center-cut and double pill molds had statistically Equal APA rutting depths. Meanwhile, the gyratory compacted samples produced statistically Not Equal APA rutting depths when comparing the center-cut and double pill mold.

The gyratory center-cut and double pill mold samples were thought to be statistically Not Equal for two reasons:

1. The two of the APA rutting measurements in the center-cut mold were relatively close to the end of the mold. This may have an effect on the

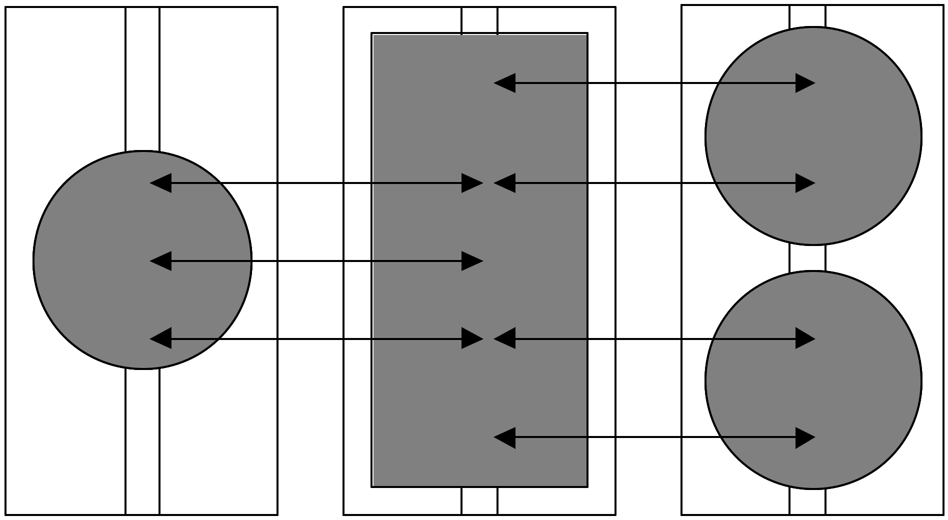

Figure 6 – Schematic of APA Rutting Measurement Locations

rutting.

2. Unequal density gradients within the gyratory sample itself. The inner core of the gyratory sample may have a different density and air void content than the outer area of the gyratory sample.

Since the vibratory compacted samples obtained statistically Equal APA rutting depths when comparing the center-cut and double pill molds, it was concluded that the rutting measurement locations towards the end of the mold had a minimal affect on the rutting. It was therefore concluded that the density gradient of the gyratory sample caused the difference. This was further evaluated by comparing only the center APA rutting measurement to the double mold APA rutting. After this was conducted, it showed that center rutting measurement from the center-cut mold was statistically Equal to APA rutting of the double molds. This concluded two things:

1. The APA rutting measurement, when using gyratory samples, needed to take place within the inner 2/3 of the sample.
2. The APA rutting measurement was similar among the entire length of the sample mold.

Based on these findings, the study concluded that the double mold could be used for APA testing. Also, since the compaction is easier to control using the gyratory compactor, it was recommended that the gyratory compactor be used for sample preparation.

Rutting Criteria for the Asphalt Pavement Analyzer (APA)

A literature search was conducted to determine if other state agencies are using the Asphalt Pavement Analyzer (APA) and if they have developed a rutting criteria based on its use. Tables 3a and 3b show the current state agencies using the APA, along with the test configurations and rutting criteria. The following interesting observations from the tables are as follows:

1) A majority of the state agencies use 5 mm as a rutting criteria. This is most likely due to the early work of the Georgia State DOT with the GLWT rutting criteria (Lai, 1989).
2) HMA samples are compacted to air voids ranging from 4% to 8%, with 7% being the most common.
3) All states run the APA until 8,000 loading cycles.
4) The APA test temperatures range from 49^{o}C to 67^{o}C, with 64^{o}C being the most common.

But perhaps the most interesting aspect of the tables is that most of the rutting criteria for the state agencies is not based on traffic type or mix type. Only Virginia, which bases the criteria on the PG binder grade, and Oklahoma and Arkansas, which is based on traffic, use an hierarchal approach to the rutting criteria. Initial discussions at the Rutgers Asphalt/Pavement Laboratory (RAPL) involving the development of a rutting criteria emphasized the need to have the criteria based on traffic. This is justified since lower volume roads will not need to have the rutting resistance of the higher volume roads. In fact, the true low volume roads (ESAL's < 0.3 million) failure is due more to durability issues than rutting.

Results of the literature search indicated that the rutting criteria of both the Oklahoma and Arkansas DOT meet the traffic methodology requirements proposed for this study, and therefore would provide a valid starting point. Another factor that was weighed is determining a starting point for evaluation was that the criteria had to be based on identical testing conditions used at RAPL. This consisted of:

- 100 psi hose pressure
- 100 lb wheel load
- compacting samples to 7% (+/- 0.5%) air voids
- test temperature of 64^{o}C
- 8,000 loading cycles
- samples compacted using the Superpave Gyratory Compactor

Both the Oklahoma and Arkansas use the identical testing configurations currently used by RAPL. Therefore, the criteria from Oklahoma and Arkansas were used a starting point and comparison for the New Jersey APA Criteria. Figure 7 shows both the Oklahoma and Arkansas APA Rutting Criteria.

Table 3a – State Used/Proposed Rutting Criteria for the Asphalt Pavement Analyzer (APA)

State	Chamber Temp degrees (C/F)	Cycles	Air Voids (%)	Hose Pressure (psi)	Rutting at 100 lbs. Load Failure	No. of Gyra-tions	Remarks
Alabama	67/153	8000	4	100	greater than 4.5 mm		
Arkansas	64/147	8000		100	8.0 mm	115	
					5.0 mm	160	
					3.0 mm	205	
Florida	64/147	8000			Not Available		Device is still in the development stage nationally and is used only for research at FDOT.
Georgia	49/120		6+/-1	100	greater than 5.0 mm		
Kentucky	64/147	8000			5.0 mm		All of the testing is done using Superpave Gyratory Compacted specimens at 75 mm in height.
Missouri	64/147	8000		100	5.0 mm		Using 25 cycles to seat the specimen (6 inch gyratory produced) then 8000 cycles at 100 psi for rut determinations.
North Carolina	67/153	8000		100	Not Available (in process)		The most common used binder in NC is 64-22 which always grades out to be a 67-22.
Ohio	49/120	8000	7		5.0 mm		

The results of the literature search and the discussed methodology concluded that the NJDOT APA Rutting Criteria is to be based the N_{design} value. The N_{design} value is the number of gyrations from the gyratory compactor used for HMA design. The N_{design} value is based the applied traffic level, as shown in Table 4. Therefore, the NJDOT APA Rutting Criteria provides a link between the volumetric design process, and the needed rut resistance for higher traffic level pavements.

Table 3b – State Used/Proposed Rutting Criteria for the Asphalt Pavement Analyzer (APA)

State	Chamber Temp degrees (C/F)	Cycles	Air Voids (%)	Hose Pressure (psi)	Rutting at 100 lbs. Load Failure	No. of Gyra-tions	Remarks
Oklahoma	64/147	8000	7+/-1	100	3 mm/30M+ ESALs 4 mm/10M+ ESALs 5 mm/ 3M+ ESALs 6 mm/0.3M+ ESALs 7 mm/0.3M- ESALs		Using 50 cycles for seating 150 mm SGC molded specimens. Still investigating mixtures with this device and expecting to set maximum rut depths according to traffic.
South Carolina	64/147	8000			5 mm		
Tenessee	60/140	4000 8000	7+/-1	100	Not Available		
Utah	64/147	8000			5 mm		
Virginia	49/120	8000	8+/-0.5	120	7 mm for PG-64 5.5 mm for PG-70 3.5 mm for PG-76		
West Virginia	60/140	8000	7+/-1		6 mm		

Table 4 – Gyratory Gyration Numbers for the Superpave Design Method

Design ESAL's (Million)	N_{ini}	N_{des}	N_{max}
< 0.3 (Low - L)	6	50	75
0.3 to 3.0 (Medium - M)	7	75	115
3.0 to 30 (Heavy - H)	8	100	160
> 30 (Very Heavy - V)	9	125	205

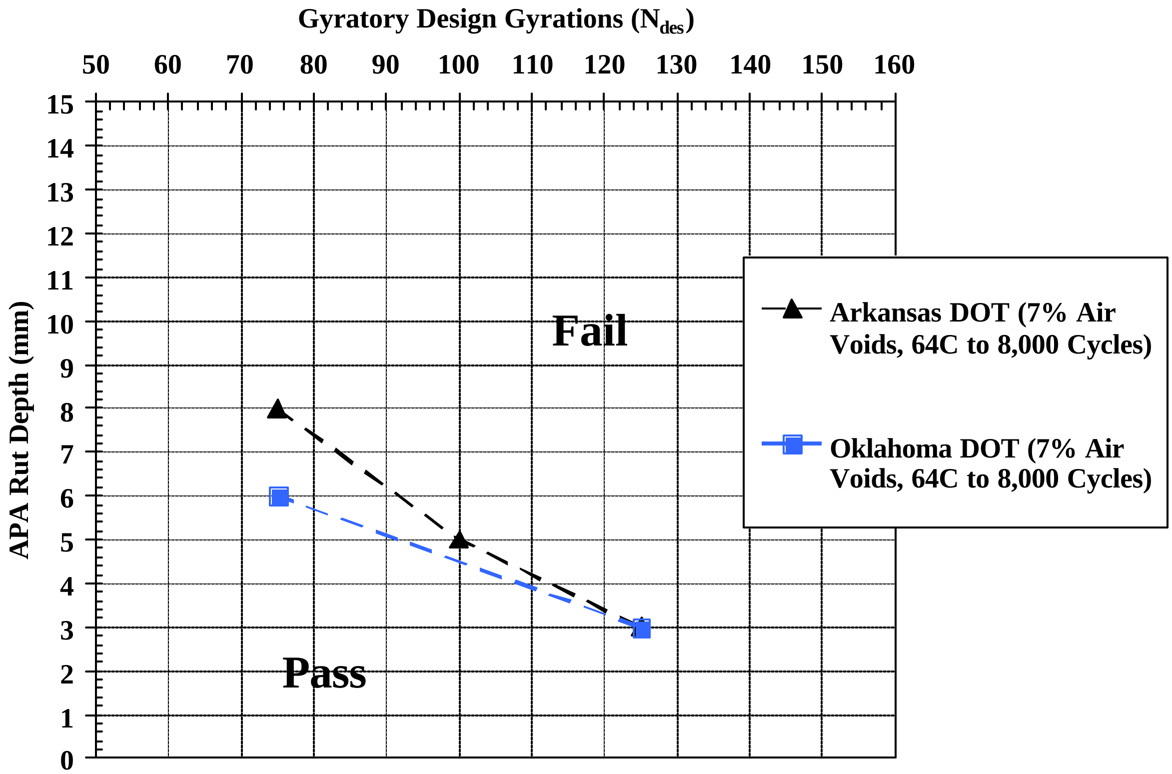

Figure 7 – APA Rutting Criteria for the Oklahoma and Arkansas DOT

EXPERIMENTAL PROGRAM

The experimental program consisted on three sub-programs. The first sub-section involves designing HMA mixes to be used in the evaluation. The mixes to be designed must consider both a coarse and fine gradation, different traffic levels, and different binder performance grades. The second sub-section involves the actual APA testing and the statistical analysis of those results to develop the APA Rutting Criteria. The third sub-section involves verifying the criteria with HMA mixes that have a historical performance record, either rut resistant or rut susceptible.

HMA Mix Design

The HMA mixes that were needed to develop a rutting criteria must encompass a number of factors. First, the gradation needs to be evaluated. The development of Superpave caused a push for coarse graded HMA mixes, with a "restricted zone" in the designated gradations. Aggregate gradations were not supposed to pass through this zone since early Superpave research indicated that these types of mixes were more rut susceptible than mixes that passed above or below the "restricted zone". Recent research (Watson et al., 1997; Hand and Epps, 2001; Kandhal and Mallick, 2001) has indicated that mixes passing through the restricted zone are no more rut susceptible than coarse graded mixes. In fact, many of the studies showed that both the gradations above the restricted zone (fine graded) and gradations going through the restricted zone were less rut susceptible than when the gradations passed below the restricted zone (coarse gradation). Therefore, the gradations used in the analysis consisted of both a fine and coarse gradation. For the very heavy traffic (ESAL's > 30 million), only a 12.5 mm Superpave gradation was used since this is the most common surface mix for this type of application. However, the heavy traffic (ESAL's 3 to 30 million) evaluated both a 12.5 and a 19 mm Superpave gradation. The medium to low traffic (ESAL's 0.3 to 3 million) again only used a 12.5 mm Superpave gradation. Figures 8 and 9 show the gradations used for the 12.5 mm and 19 mm Superpave mixes, respectively. The 12.5 mm fine gradation actually passes through the restricted zone.

The binder type was also varied for the very heavy traffic level design. A PG64-22, PG70-22, and a PG76-22 were used. The modified asphalts were only used on the very heavy traffic levels under the recommendations of the current NJDOT recommendations. A HMA design for low volume (ESAL's < 0.3 million) since the main pavement distress at this level is fatigue cracking, not rutting.

All of the HMA mixes met the Superpave Volumetric design requirements shown in Table 5. Appendix A provides the Superpave mix design information for each of the mixes used.

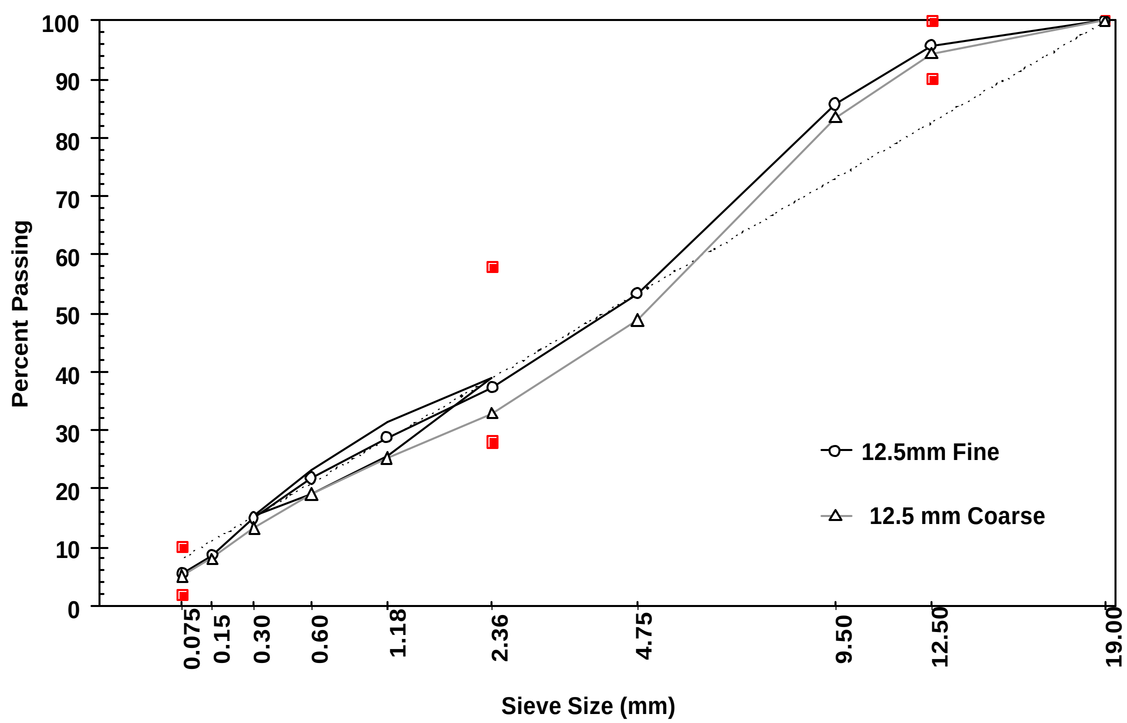

Figure 8 – 12.5 mm Superpave Gradations Used for APA Rutting Study

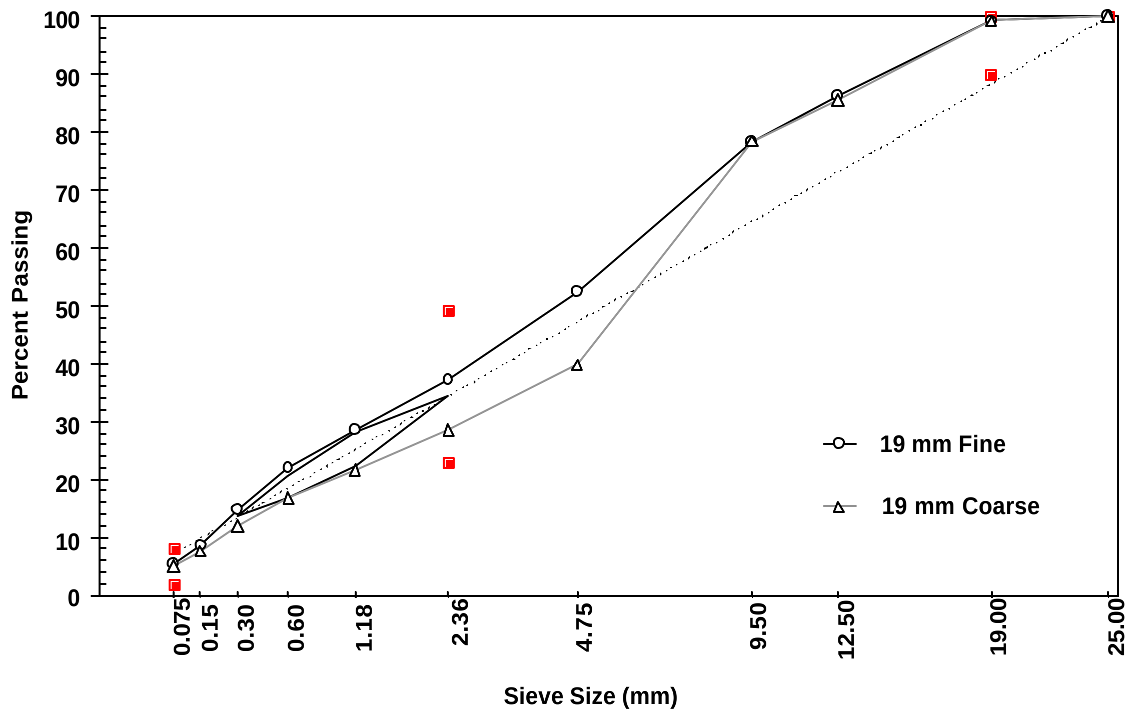

Figure 9 – 19 mm Superpave Gradation Used for APA Rutting Study

Table 5 – Superpave Hot Mix Asphalt Design Requirements

Design ESAL's (millions)	Required Density (% of Theoretical Max. Specific Gravity)			VMA % (minimum) Nom. Max. Agg. Size (mm)					Voids Filled with Asphalt	Dust-to-Binder Ratio#
	N_{ini}	N_{des}	N_{max}	37.5	25.0	19.0	12.5	9.5	(VFA) %	
< 3 (L,M)	90.5	96.0	98.0	11.0	12.0	13.0	14.0	15.0	65 – 78	0.6 – 1.2
> 3 (H,V)	89.0	96.0	98.0	11.0	12.0	13.0	14.0	15.0	65 – 75*	0.6 – 1.2

* For 9.5mm nominal maximum size mixtures the specified VFA range shall be 73% to 76% of design traffic levels of 30 million ESAL's

* For 37.5mm nominal maximum size mixtures the specified lower limit of the VFA shall be 64% for all design traffic levels

For production, the upper limit is 1.3

HMA Sample Preparation

All asphalt mixes tested were prepared at the Rutgers University Asphalt/Pavement Laboratory (RAPL). Samples were produced in lots of 6 to 12. The aggregates were blended based on percentages to replicate the gradations shown earlier. The aggregates were heated to 148 ^{o}C, and once the aggregates were to temperature, the appropriate amount of asphalt binder (either the neat or modified) at 148 ^{o}C was added. The batch was then mixed using a rotating 5-gallon stainless steel mixing bucket for a minimum of 5 minutes (Figure 10). Immediately after mixing, the batch was transferred to a pan and cured for 2 hours at the compaction temperature of 144 ^{o}C. This is said to model the aging of the mix that occurs at the mixing plant and in the truck in route from the asphalt plant to the construction site. After the samples had been 'short termed aged', the mix was transferred to the gyratory compaction mold and compacted.

All samples were compacted to a height of 77mm and a target air void content of 7% (+/- 0.5%). A total of 6 gyratory samples for each mix design were used for the APA testing.

Figure 10 - Rotating 5-gallon Stainless Steel Mixing Bucket

<u>APA Rutting Results</u>

The APA rutting results for the samples tested are shown in figure 11. As can be seen from the figure, the mixes designed for the very heavy traffic sustained the lowest amount of rutting, with the modified asphalts having the least. As the design traffic levels went down, the APA rutting increased.

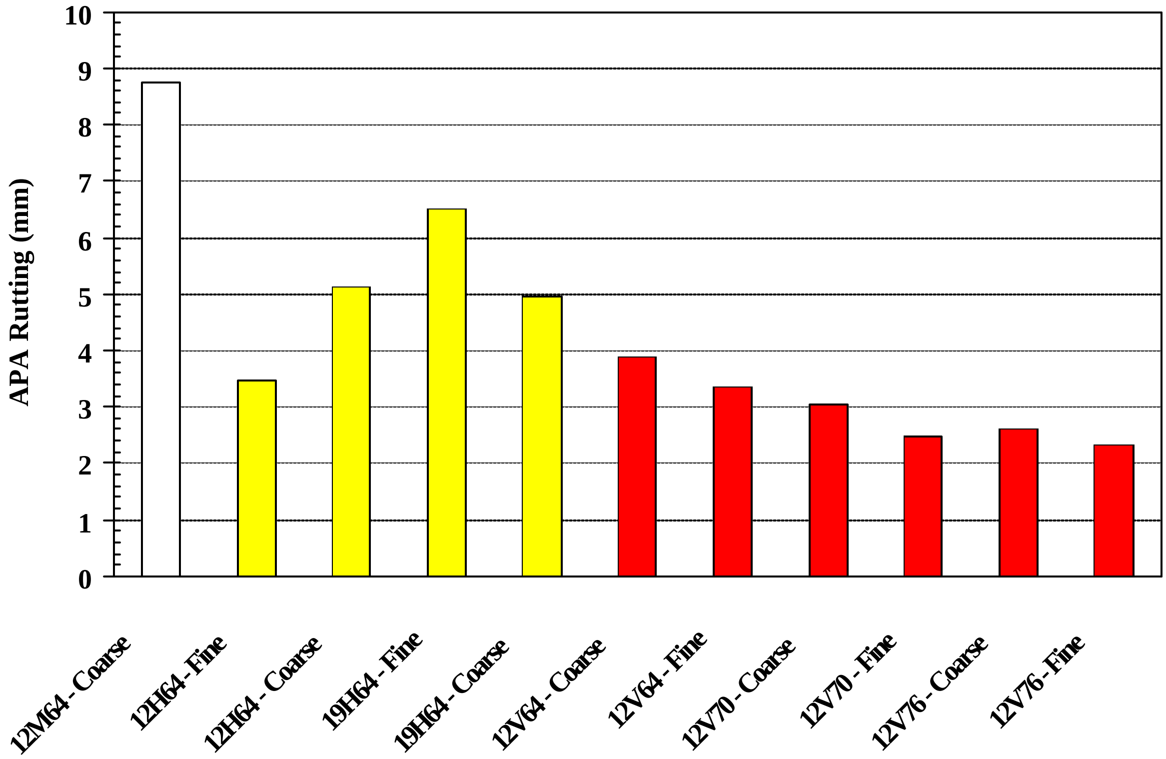

Figure 11 – APA Rutting Results for the Various Mixes Tested

The APA rutting results were reviewed using descriptive statistics. This was conducted to determine the appropriate value for rutting criteria selection. The assumption was that there was a 50% probability that the mixes designed RAPL may be rut susceptible.

Very Heavy Traffic Level

The descriptive statistics for the very heavy traffic level were as follows:

Mean	2.948
Standard Error	0.244
Median	2.825
Standard Deviation	0.5989
Sample Variance	0.3587

Assuming a normal distribution, a cumulative probability of the APA rutting data was constructed The cumulative probability is used to determine the probability of obtaining a Z value that is less than or greater than specified value. In this case, 0.5 or 50%, was used to indicate the APA Rutting Value. The analysis is assuming that there could be a 50% chance of RAPL possibly producing a rut susceptible mix. The selected value based on the normal distribution was 3.0 mm.

Heavy Traffic Level

The descriptive statistics for the heavy traffic level were as follows:

Mean	5.015
Standard Error	0.621
Median	5.04
Standard Deviation	1.243
Sample Variance	1.545

The same analysis that was conducted for the very heavy traffic was conducted for the heavy traffic. The data was super-imposed with the very heavy traffic level to produce the rutting criteria selection for both the very heavy and heavy traffic levels (Figure 13).

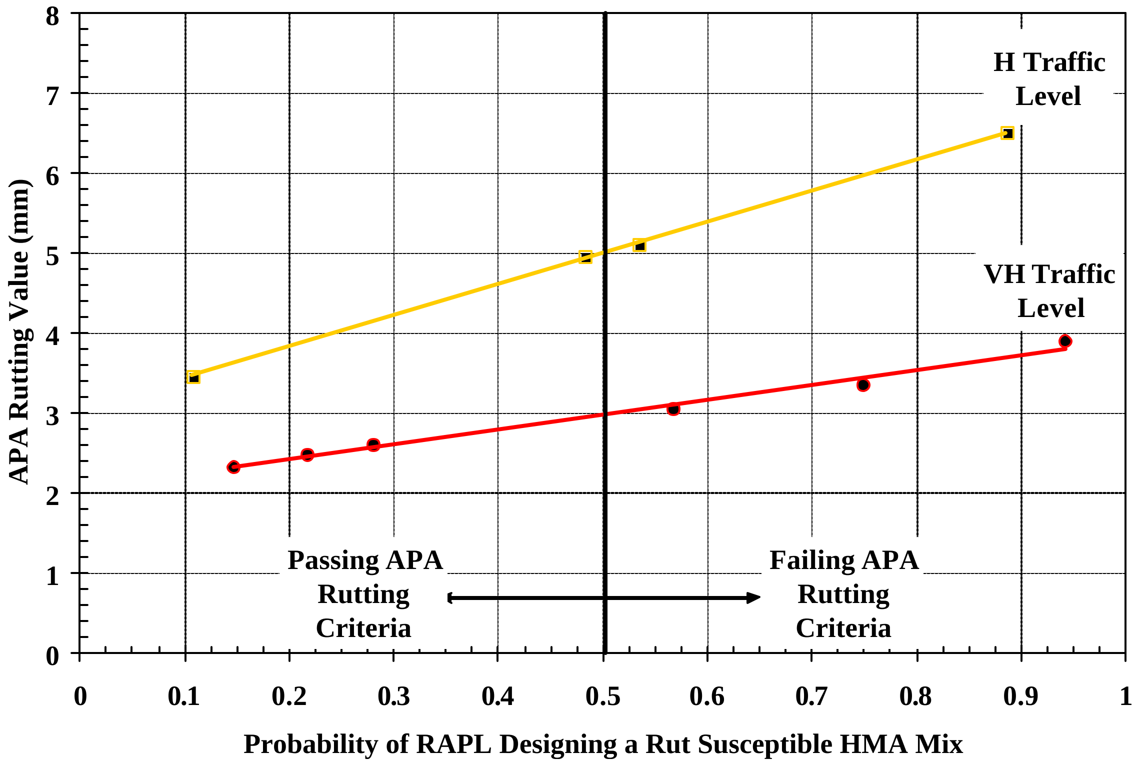

Figure 12 – 50% Probability Determination for the APA Rutting Criteria

Medium Traffic Level

Only one mix design was conducted for the medium traffic. Again, the rutting problem is not as severe for the lower volume trafficked roads. The APA rut depth was measured as 8.75. The APA Rutting Criteria was rounded down to a rut depth of 8 mm for medium traffic level. Therefore, the final APA Rutting Criteria, based on the design gyration number (i.e. traffic level) is shown as Table 6.

Table 6 – Proposed NJDOT APA Rutting Criteria

Superpave N_{design}	APA Rutting Criteria
75 (Medium)	< 8.0 mm
100 (Heavy)	< 5.0 mm
125 (Very Heavy)	< 3.0 mm

The proposed criteria was compared to the Oklahoma and Arkansas DOT criteria and is shown as Figure 13. From the figure, it is obvious that the NJDOT criteria falls exactly on the Arkansas DOT criteria.

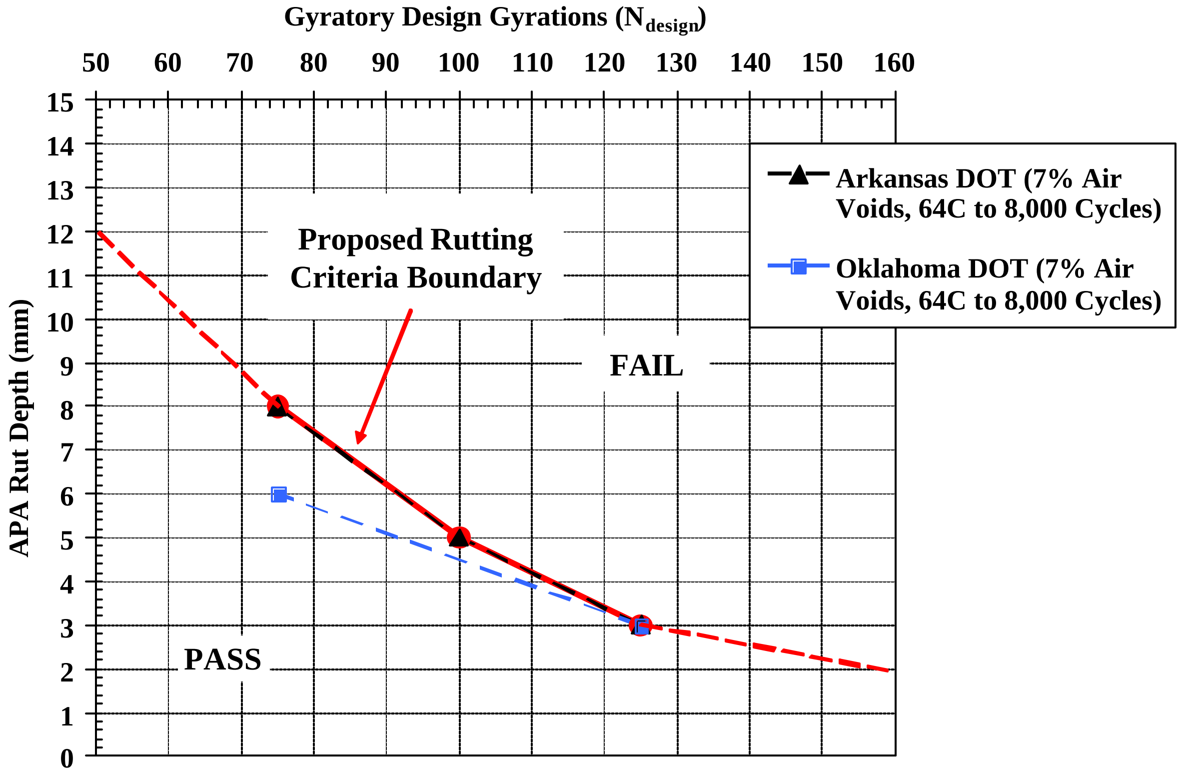

Figure 13 – NJDOT APA Rutting Criteria Compared with Current DOT Criteria

APA RUTTING CRITERIA VERIFICATION

The APA Rutting Criteria that was developed from the HMA designs of the RAPL needed to be verified with HMA mixes with historical performance. Prior to this research project, the RAPL conducted an APA laboratory study for the Port Authority of NY/NJ. The main goal of the study was to evaluate the Port Authority's heavy volume mixes (HVM). The HVM mixes of the Port Authority are HMA mixes that are used under some of the heaviest traffic volume in the Northeast corridor. These mixes have a historical background of being well performing HMA mixes. The HVM mixes consisted of a number of different gradations, different asphalt binder, and even additives (fibers). It was concluded that if the HVM mixes met the very heavy traffic volume APA Rutting Criteria of 3.0 mm, then this would be sufficient for this traffic level verification. However, also included in the very heavy evaluation were 2 mixes from Trap Rock Industries (TRI). Both mixes were compacted in the gyratory the night of field placement for Rt. 78 and Rt. 195. The Rt. 195 mix actually had some problems this particular night, so it was anticipated that the TRI Rt. 78 mix would pass the criteria and the Rt. 195 mix would fail the criteria. Figure 14 shows the results. As anticipated, the TRI Rt. 195 mix failed the criteria, while the TRI Rt. 78 mix passed. Meanwhile, all of the Port Authority's HVM mixes passed, except for the 2 PG64-22 mixes. During the construction of the rutting criteria, both of the RAPL PG64-22 very heavy volume mixes failed the eventual 3.0 mm criteria, emphasizing the need for polymer-modified binders at this traffic volume.

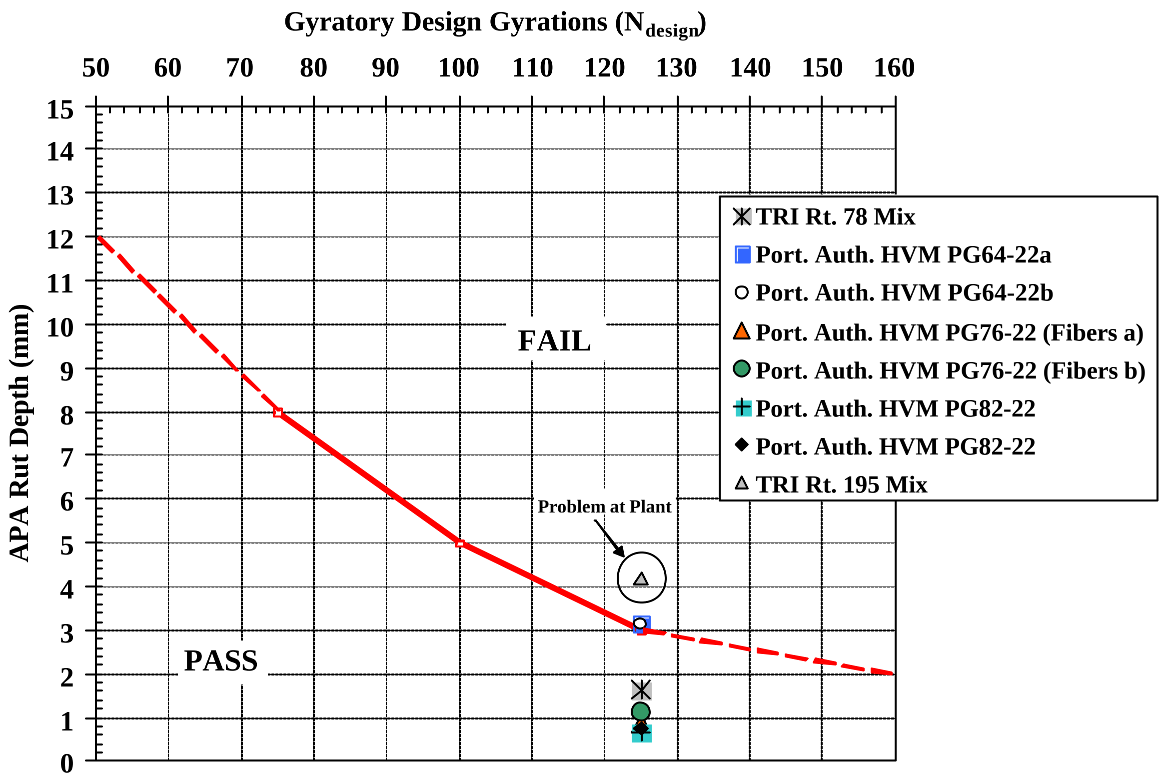

Figure 14 – Verification of the Very Heavy Traffic Mix

Only one mix could be found to compare to the heavy (N_{design} = 100) traffic level. This was a project conducted for Citgo Refineries for a 9.5 mm PG76-22 surface mix to be placed in New York City. The gyratory samples were made at the mix plant facility. Unfortunately, the air voids did not meet the 7% (+/- 0.5%), as there were determined to be approximately 6%. The heavy traffic volume mix is shown on the APA Rutting Criteria in Figure 15. As can be seen, the mix passes the criteria set for the heavy volume traffic (N_{design} = 100). The addition of the polymer-modified asphalt binder is most likely the reason a 9.5 mm gradation was able to pass this criteria.

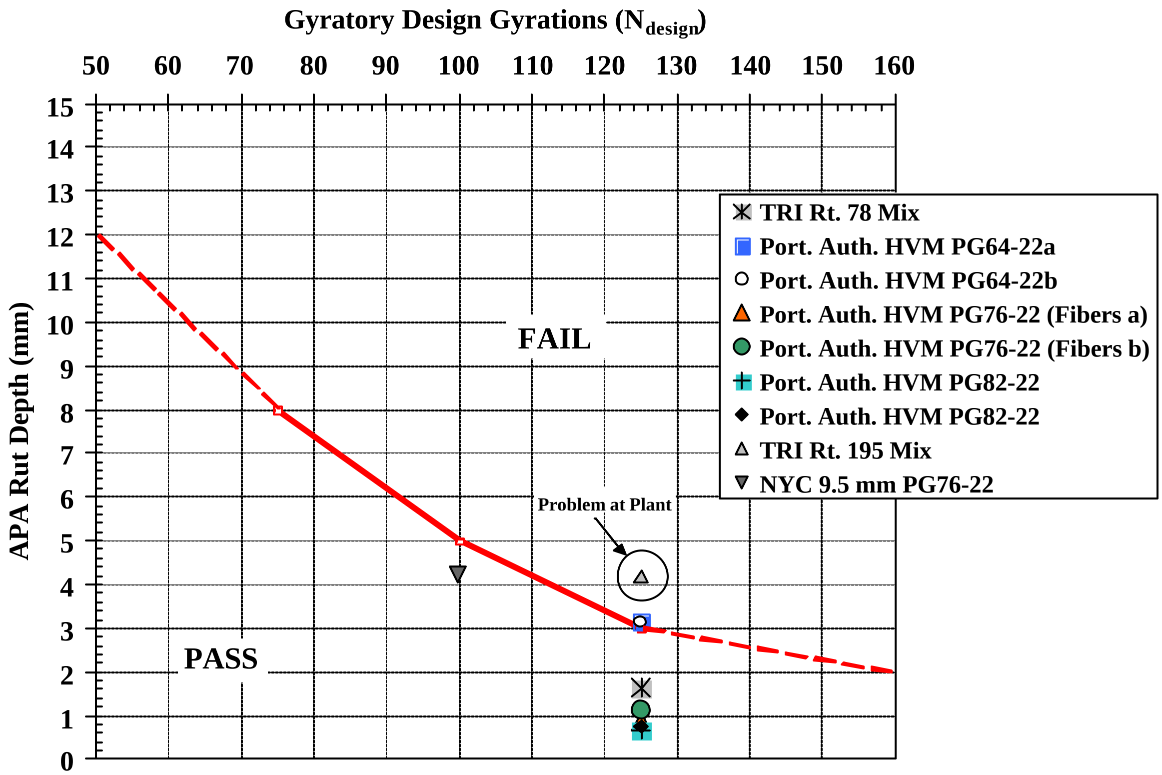

Figure 15 – Verification of the Heavy Traffic Volume Mix

With respect to the medium traffic designation, samples were not able to be found that conformed to APA testing criteria of 7% (+/- 0.5%) air voids. Mix plants had been asked if they could volunteer mixes that were compacted in the gyratory compactor from jobs that they were currently working on, however, most of the time the mixes had air voids ranging from 4 to 6 % air voids. One mix was used despite the fact the air voids were only 5.5%. The mix was an I-5 PG58-22 that contained 30% RAP. The results are again super-imposed on the APA Rutting Criteria chart, shown as Figure 16. The results show that the mixes just pass the criteria set for medium traffic (N_{design} = 75).

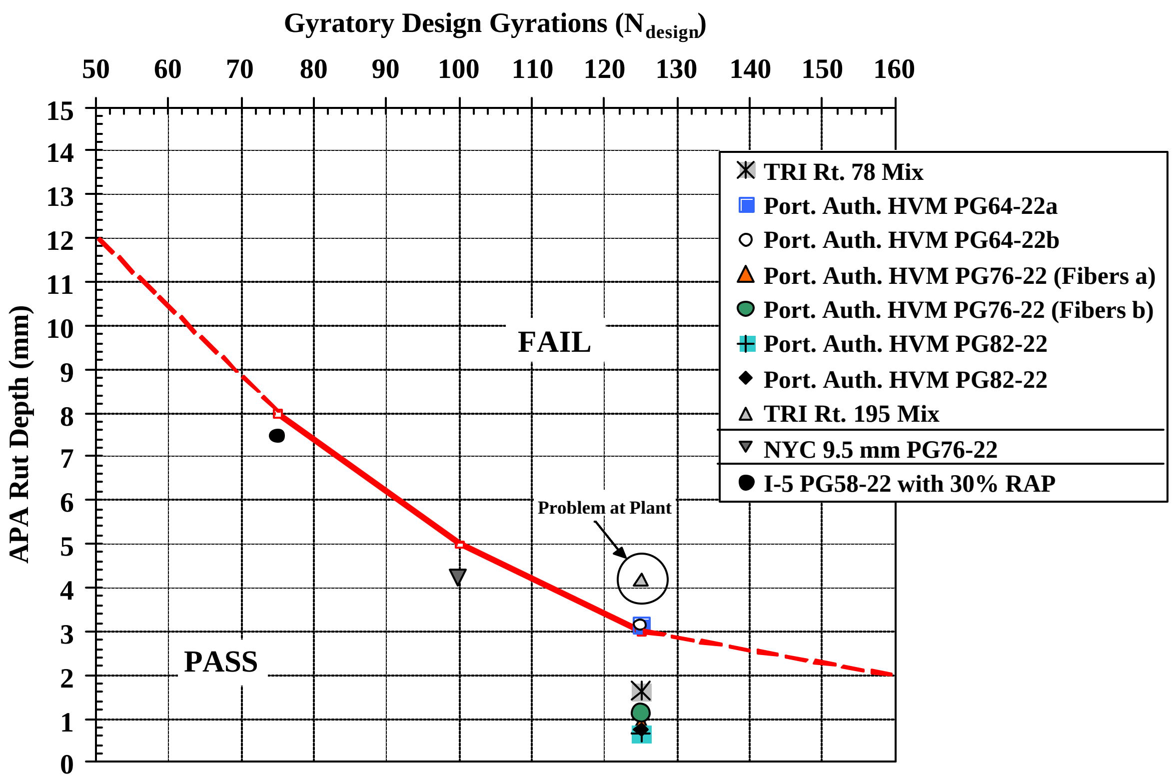

Figure 16 – Verification of Medium Traffic APA Rutting Criteria

CONCLUSIONS

A rutting criteria was developed for the Asphalt Pavement Analyzer (APA) to be used after the volumetric mixture design. The rutting criteria is somewhat of a pseudo-simple performance test to check if a HMA mix is rut susceptible. The laboratory mixes developed at the Rutgers Asphalt/Pavement Laboratory (RAPL) consisted of different gradations (coarse and fine) and 12.5 and 19mm, different binders (PG64-22, PG70-22, and PG76-22), and designed for different traffic levels (very heavy, heavy, and medium). The following are the conclusions from the study.

1. A total of 6 laboratory mixes were developed at RAPL to evaluate the very heavy traffic criteria. The mixes consisted of 12.5mm (both coarse and fine graded) and used all three binders (PG64-22, PG70-22, and PG76-22). The APA rutting was determined for each mix and a criteria was set based on a 50% probability using the mean value. This essentially means that it was probable that RAPL had a 50% success rate at constructing an asphalt mix that was rut resistant. This was done so the initial chart would start on the conservative side (causing a better design), and with experience, could change in the future when more data is available. The final APA Rutting Criteria for the very heavy traffic was

determined to be 3.0 mm. This value was verified using the heavy volume mixes (HVM) of the Port Authority.
2. A total of 4 laboratory mixes were developed at RAPL to evaluate the heavy traffic criteria. The mixes consisted of both a 12.5mm and a 19mm (both coarse and fine) with a PG64-22 asphalt binder. The same conservative approach was followed as discussed earlier for the very heavy traffic. This led to a final APA Rutting Criteria of 5.0 mm for heavy traffic. This criteria was verified using a gyratory sample designed by Citgo Refineries.
3. Only one sample was evaluated to determine the rutting criteria for medium traffic level. The APA rutting measurement on the 12.5 mm PG64-22 sample was 8.75 mm. This was simply rounded down to 8.0 mm for the APA Rutting Criteria, again to be on the conservative side. This value was verified using a low volume mix that had an air void content that did not meet APA testing specifications.
4. The final NJDOT Rutting Criteria turned out to be exactly the same as the one developed for the Arkansas DOT and slightly more forgiving than the one developed for the Oklahoma DOT (Figure 13).
5. The NJDOT Rutting Criteria was developed and verified using only laboratory prepared samples. Field cores were not used during the development since the main goal was to have a method that could be used after mix design to determine if the mix was rut susceptible. The future use of the Rutting Criteria should solely be used for laboratory prepared samples.

RECOMMENDATIONS

The following recommendations based on the work conducted in this research project are as follows:

1. The verifications that were used during this project were mainly based on HMA that has a history of good performance. It is recommended that future evaluation of the rutting criteria be done on HMA mixes that were recorded to perform poorly (rut early). Past discussions with NJDOT representatives concluded that data like this is not typically recorded. Perhaps future emphasis could be placed on recording such instances.
2. The APA Rutting Criteria should not be used with field cores since it was solely developed with laboratory prepared samples. However, if interest in warranted in using the APA as quality control check for NJDOT cores, further evaluation would need to be conducted on such samples. Possibility of different aging affects and compaction densities that occur during field compaction would warrant the development of a different criteria.

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APPENDIX A – HMA Mix Design Parameters

APPENDIX A.1 – Medium Traffic Level Design

Asphalt Grade:	**64-22**
Compaction Temp. (°F)	142
Mixing Temp. (°F)	148
Traffic	**Medium**
Design ESAL's (millions)	**< 3**
Gyrations: Nini	7
N_{des}	75
N_{max}	115
Mix Type:	**12.5 mm Coarse**
% Air Voids (Va)	4.0
% Voids in the Mineral Aggregate (VMA)	16.2
% Voids Filled with Asphalt (VFA)	75.4
Dust / Asphalt Ratio	1.0
Max. Specific Gravity (Gmm)	2.690
Bulk Specific Gravity (Gmb)	2.620
% Gmm @ Nini	86.6
% Gmm @ Ndes	96.0
% Gmm @ Nmax	97.4
Specific Gravity of the Binder (Gb)	1.030
Effective Specific Gravity of the Blend (Gse)	2.957
Specific Gravity of the Aggregate Blend (Gsb)	2.919
Optimum Asphalt Content (%AC)	5.3

APPENDIX A.2 – Heavy Traffic Level Design

Asphalt Grade:	**PG 64-22**	**Design ESAL's (millions)**	**3-30**	
Compaction Temp. (^oF)	**142**	**Gyrations: N_{ini}**	**8**	
Mixing Temp. (^oF)	**148**	**N_{des}**	**100**	
		N_{max}	**160**	
	12.5 mm Fine	**12.5 mm Coarse**	**19 mm Fine**	**19 mm Coarse**
% Air Voids (V_a)	4.0	4.0	4.0	4.0
% Voids in the Mineral Aggregate (VMA)	15.2	14.9	14.6	14.9
% Voids Filled with Asphalt (VFA)	72.7	73.1	72.5	73.1
Dust / Asphalt Ratio	1.2	1.1	1.2	1.1
Max. Specific Gravity (G_{mm})	2.693	2.731	2.731	2.741
Bulk Specific Gravity (G_{mb})	2.615	2.653	2.654	2.663
% G_{mm} @ N_{ini}	87.3	87.3	87.2	87.3
% G_{mm} @ N_{des}	96.0	96.0	96.0	96.0
% G_{mm} @ N_{max}	97.3	97.1	97.2	97.1
Specific Gravity of the Binder (G_b)	1.03	1.03	1.03	1.03
Effective Specific Gravity of the Blend (G_{se})	2.951	2.974	2.973	2.985
Specific Gravity of the Aggregate Blend (G_{sb})	2.925	2.936	2.926	2.940
Optimum Asphalt Content (%AC)	4.7	4.9	4.7	4.7

APPENDIX A.3 – Very Heavy Traffic Level Design

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