STATE OF FLORIDA

FOLLOW-UP EVALUATION OF THE ASPHALT PAVEMENT ANALYZER

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EXECUTIVE SUMMARY

There has been much interest nationally and in the state of Florida for a simple test for measuring the rutting susceptibility of asphalt paving mixtures. The Asphalt Pavement Analyzer (APA), a loaded wheel-tracking rutting device evolved from the Georgia Loaded Wheel Tester, has received considerable attention in the United States in the past few years. The Florida Department of Transportation (FDOT) had previously purchased and evaluated the APA and found the variability to be high. After several modifications to the APA by the manufacturer and purchase upgrades by FDOT, this study was undertaken to reassess the variability of the APA, compare the new automated data acquisition system to the manual method of measurement and to examine the rutting potential of four laboratory produced and one field produced Superpave mix. This study has shown that the variability has decreased and consistent results can be obtained as long as the average of three beams are used as a test result. However, a problem still exists with the center position consistently rutting more than the left or right positions. The automated data acquisition system is very accurate compared to the manual method of measuring the rut depths. Of the five Superpave mixes tested, the 12.5 mm mixes rutted less than the 9.5 mm mixes and the coarse graded mixes rutted less than the fine graded mixes.

INTRODUCTION

In the Superpave mix design system, as originally developed under the Strategic Highway Research Program, Level I is the volumetric mix design methodology, and Levels II and III were intended to be used for performance prediction of asphalt mixtures with respect to rutting and cracking. However, the performance prediction aspect is still under development and is not anticipated to be completed until after the year 2005. Consequently, there has been much interest nationally and in the state of Florida for a simple test for the prediction of rutting performance of an asphalt mixture.

The Florida Department of Transportation is currently evaluating the Asphalt Pavement Analyzer (APA) for use as a tool that can rank asphalt mixtures with respect to their rutting potential and also use it as a pass/fail criteria with respect to rutting at the mix design stage. For example, a pass/fail criteria might state that any mix that ruts more than 5 mm after 8000 cycles in the APA would not be an acceptable mix.

The APA is a wheel-tracking device that applies a vertical load to a steel wheel. The wheel rolls back and forth over a pressurized rubber hose which is placed on top of the asphalt mixture sample. At various intervals during the test duration, rut depth measurements are obtained. The test is empirical in nature, but has been shown through research conducted by others to correlate with actual pavement rutting *(1)*. FDOT concluded in 1991 that the Georgia Loaded Wheel Tester, the predecessor of the APA, correlated well with actual pavement rutting *(2)*.

Prior to this study, FDOT had performed two studies to evaluate the APA. The first study resulted in data with such high variability that it was decided the experiment was invalid. Some modifications were made to the APA including the installation of new air cylinders for applying the vertical load. The study was redone with slightly better results. The report stated that the APA may be effective in ranking asphalt mixtures with respect to rutting performance, but due to the high variability encountered, it was not yet suitable as a clear pass/fail device *(3)*. Subsequent to that study, Pavement Technology, Inc. (PTI), the manufacturer of the APA, installed new pressure regulators and reconfigured the air supply tubing in an attempt to reduce the variability. FDOT then purchased the automated data acquisition upgrade which included a different type of air cylinder for applying the vertical load. The new air cylinders were necessary to accommodate the LVDTs used for the automated measuring of rut depths. Because of these modifications, it was decided that another variability study would be necessary, which is the subject of this study.

OBJECTIVE OF STUDY

The objectives of this study were threefold: 1) to analyze the variability of the APA, 2) to compare the automated data recording system to the manual method of obtaining measurements, and 3) to look at the rutting potential of four Superpave mixes (two 12.5 mm mixes, one coarse graded and one fine graded, each of the same aggregate type, and two 9.5 mm mixes, one coarse graded and one fine graded, each of the same aggregate type).

TESTING PLAN

Four Superpave mixes would be prepared in the laboratory and used for testing as mentioned previously. The mixes were actual mixes that had been used in the state of Florida. The

Superpave mix design properties had been previously verified at the State Materials Office. Existing mixes were used to eliminate the additional work of designing four Superpave mixtures. The two coarse graded mixes had gradations that passed below the restricted zone and the two fine graded mixes had gradations that passed above the restricted zone. The 12.5 mm mixes were composed of South Florida limestone from White Rock Quarries. The coarse graded mix had been designed at N_{des} = 96 gyrations. The fine graded mix had been designed at N_{des} = 86 gyrations. The 9.5 mm mixes were primarily composed of Georgia granite from Martin Marietta Aggregates and a small percentage of local sand from the Panama City, Fl area. Both 9.5 mm mixes had been designed at N_{des} = 86 gyrations. All four mixtures contained an unmodified AC-30 binder. **Table 1** identifies each mix type, corresponding gradation and design binder content.

Nine beams were made for each mixture type for a total of 36 beams. Since the APA tests three beams at a time, this would allow for three complete tests for each mixture. The beams were compacted using the vibratory compactor manufactured by PTI to a targeted air void content of 7 ± 0.5%. Twenty three of the thirty six beams had air voids within this range. The remaining thirteen beams were just outside of this range. The beam with the highest deviation from the range had an air void content of 7.88%. **Table 2** lists the air void contents for all the beams and the average air void content for each group of three beams that was tested.

It should be noted that cylindrical specimens were not tested in this study. The previous FDOT study determined that the variability encountered with cylindrical specimens was significantly higher than with beam samples. Therefore, it was decided that for this study, that only beam samples would be studied to determine if the variability had decreased due to the equipment modifications. The cylindrical specimens would then be tested at a subsequent date if the variability of the beam specimens improved.

The specimens were tested at 64 °C (147.2 °F). This temperature was determined from LTPPBIND version 2 software from the Federal Highway Administration. This represents the high temperature used in the grading of Superpave PG binders for the state of Florida's weather climate. This method for selecting the testing temperature is recommended in the draft ASTM test method developed by the APA User's Group *(4)*. The hose pressure was set for 100 psi and the vertical load was set for 100 lbs. Specimens were allowed approximately 14 hours to reach test temperature prior to testing. The time frame recommended by the APA User Group is 5 to 24 hours.

A 25 cycle seating load was applied and initial rut depths were manually recorded. The APA User Group recommends a 10 cycle seating load, however, when using the automated data acquisition system, PTI recommends a 25 cycle seating load to allow the data acquisition measuring system to zero itself. Manual measurements were also recorded at 500, 2000, 4000, and 8000 cycles. It should be noted that the automated data acquisition system was not functioning properly during testing of the 9.5 mm mixes (which were the first two mixtures tested) due to malfunctioning LVDT's. The LVDT's were replaced by PTI and the automated data acquisition system was functional for testing of both 12.5 mm mixtures.

TEST RESULTS - AIR VOIDS VS. RUT DEPTH

The draft ASTM test procedure requires that the specimens be compacted to 7 ± 1 % air voids, and that in this range the rut depth is supposedly independent of the air void content. As mentioned previously, for this study, the air voids were targeted at 7 ± 0.5 %, though some specimens had air voids slightly out of this range. The reason for compacting specimens to a smaller air void range is based on results of ruggedness testing performed by West *(5)* suggesting that the air void range should be reduced to 7 ± 0.5% in order to eliminate it as a factor in the rut depth. To investigate the relationship between air voids and rut depth in this study, graphs were prepared plotting air voids vs. rut depth for the nine specimens of each mixture type. A best fit line was plotted for each data set (**Figure 1**). Examination of the graphs reveals very small R^2 coefficients (the highest being 0.29 for the 12.5 mm fine mix). This indicates that there was little if no relationship between the air void content and the rut depth within the range of air voids tested, which agrees with the premise of the test procedure.

TEST RESULTS - VARIABILITY

Table 3 shows the manually measured rut depths in millimeters at the different cycle intervals for all of the specimens tested. The middle three of the five positions on the aluminum beam template were used for recording the manual measurements. Values shown in **Table 3** are the average of these three positions. Included in **Table 3** is the average rut depth for the three beams used in each test. Also shown is the average, standard deviation, and coefficient of variation of the three tests performed on each mix type. It might be expected that as the rut depths increase, the variability would also increase. However, the coefficients of variation range from 8 to 15 % for the 8000 cycle measurements, with the 9.5mm fine mix having the lowest coefficient of variation (8%) but the highest average rut depth (13.7 mm). This indicates that the variability of the test apparatus, in terms of coefficient of variation, is independent of the rut depth for the mixes tested in this study.

Table 4 shows the range of differences in rut measurements. Three ranges are examined: 1) the range between locations within the same test, i.e. between beam position (left, middle, right), 2) the range between tests at the same location, i.e. between test 1, 2, and 3 at the left position, and 3) the range between tests <u>and</u> locations. Examination of the range of differences between tests and locations as a percentage of the average rut depth for 8000 cycles shows that the difference was as large as 60 % for the 12.5 fine graded mix. In other words, for the 12.5 mm fine mixture, given three tests of three beams per test for a total of nine beams, the difference between the maximum rut depth and the minimum rut depth divided by the average rut depth of the nine beams equaled 60%. The percentages were slightly lower for the 9.5 coarse and 12.5 coarse mixtures (52 and 51 % respectively) and much lower for the 9.5 mm fine mix (34 %).

Comparison of the averages of the three tests showed a maximum difference of 2.4 mm for the 9.5 coarse mix. This difference was 28 % of the average rut depth for the nine beams, which appears rather high. The % of average rut depth for the other three mixes are: 9.5 fine (16%), 12.5 fine (18%), and 12.5 coarse (21%).

A paired difference analysis of the data at 8000 cycles was performed to further examine the differences among: 1) the averages for the three groupings of tests and 2) the three testing locations (left, center, right), (**Table 5**). A significance level of $\alpha = 0.05$ was used. For the analysis of the averages for the three tests, the degrees of freedom (df) = 4 mix types - 1 = 3. The critical value of t based on $\alpha = 0.05$ and df = 3 is 3.182. As **Table 5** shows, comparisons of Test

1 vs. Test 2, Test 1 vs. Test3, and Test 2 vs. Test 3 all have calculated t values less than the critical value 3.182. Therefore, the null hypothesis of no difference between the respective tests can not be rejected at the chosen significance level of 0.05. For the analysis of the three testing locations (left, center, right), the degrees of freedom (df) = 12 tests - 1 = 11. The critical value of t based on α = 0.05 and df = 11 is 2.201. As **Table 6** shows, comparisons of the left and center testing positions and the center and right testing positions have calculated t values exceeding 2.201, while the comparison of the left and right positions have a calculated t value less than 2.201. This would indicate that the center position is reading on a different mean level than the right and left positions whereas the right and left positions are reading on the same mean level. Further investigation of the rut depth data for 8000 cycles revealed that of the 12 tests performed, the center position had the highest rut depth nine out of twelve times and tied for the highest rut depth two additional times. The right position had the highest rut depth only once and the left position tied for the highest rut depth twice. This data clearly supports the results of the paired difference analysis. West *(5)* had found a similar result in the ruggedness study with one particular laboratory, except in that case it was with the right position and was not quite as extreme as the situation encountered during this study.

To investigate the higher rutting occurring in the center position, a flat “pancake” type load cell was installed between the wheel and the pressurized air cylinder (**Figure 2**). The load cell provided the ability to measure the vertical load in real time as the machine was operating. This was first done for the center position, and then the right and left positions. Two fittings were machined in order mount the load cell in this position. The load output was displayed on an oscilloscope (**Figure 3**). Three new beams were prepared so that the rut depth of an existing beam would not influence the results. Surprisingly, the loads displayed on the oscilloscope did not show any difference between the three testing positions. As a secondary method of checking the applied load, a pressure transducer was installed at the top of the center and left air cylinders. This would also provide the ability to measure the air pressure in the cylinder in real time as the machine was operating. The measured pressure varied less than 0.5 psi in either the center or left air cylinder during operation. This is equivalent to approximately 1.5 lbs. of vertical load. In the ruggedness study, West *(5)* found that a load variation of 100 ± 5 lbs. was insignificant in terms of rut depth. Therefore, it can be concluded that the reason for the center position rutting more is not due to higher dynamic loads being applied by the middle air cylinder as compared to the left and right cylinders during operation. At this point, the reason for the higher rut depths in the center position is uncertain.

TEST RESULTS - AUTOMATED MEASURING SYSTEM

As mentioned previously, the automated data acquisition system was not operating properly during the testing of the first two mixes (9.5 mm fine and coarse). However, after replacing two LVDT's, the system was functional for the testing of the 12.5 mm fine and coarse laboratory prepared mixes and a third 12.5 mm coarse field produced mix. **Table 7** shows the rut depth and air void data for the field produced mix. **Tables 8, 9 and 10** show the comparison between the manual and automated measurements for these three mixes respectively. The manual method and automated system compared very well. The maximum average difference for all of the three mixes was -0.17 mm for the field produced mix. The 12.5 mm fine mix had an average difference of 0.03 mm and the 12.5 mm coarse mix had an average difference of -0.16 mm. The standard deviations were also very low; 0.24 mm, 0.17 mm, and 0.33 mm for the 12.5 mm fine, 12.5 mm coarse, and field produced mix respectively. The maximum deviations were 0.57 mm, 0.44 mm, and 0.72 mm for the 12.5 mm fine, 12.5 mm coarse, and field produced mix respectively. Although the manual method of measurement is typically considered the reference, it can occasionally give inaccurate measurements because the small diameter measuring wheel is very sensitive to the rough surface texture of the mixture. Despite this, the two measurement systems compared extremely well.

TEST RESULTS - RUTTING POTENTIAL OF SUPERPAVE MIXES

No conclusive evidence with respect to rutting for coarse and fine gradations and nominal maximum aggregate size can be derived from the data analysis of only four laboratory and one field produced Superpave mix. However, since the APA is an empirical test, it is important to start building a database of rutting performance for Florida Superpave mixes. These five mixes are the first Superpave mixes tested with the APA in Florida. Therefore, the data presented in this section is primarily intended for information only and to start building a database.

A summary of the four laboratory prepared Superpave mixes as well as the field produced Superpave mix is presented in **Table 11**. Examination of the test results for the five mixtures clearly shows that the 12.5 mm mixes rutted much less than the 9.5 mm mixes. The two 12.5 mm coarse mixes rutted the least (2.5 and 2.1 mm) and the 9.5 mm fine mix rutted the most (13.7 mm). Furthermore, the 9.5 mm fine mix rutted more than the 9.5 mm coarse mix (13.7 mm vs. 8.5 mm) and the 12.5 mm fine mix rutted more than the 12.5 mm coarse mix (5.2 mm vs. 2.5 mm). However, this is limited laboratory test data and should not be considered typical unless further testing substantiates it.

CONCLUSIONS

Following are the conclusions based on the data determined from this study:

1. Within the range of air voids tested (7 ± 0.5 %), there is no relationship between air voids and rut depth. This is a desirable characteristic of the test.
2. The variability between tests and locations is still high, however, by using the average rut depth for three beams it is possible to get fairly consistent results from test to test.
3. The center position on this particular APA consistently resulted in higher rut depths than the left or right positions. Statistical analysis indicates that the center position is not reading on the same mean level as the left or right positions. Therefore, as mentioned previously, an average of three beams is necessary to get fairly consistent results. Comparisons of only right or left specimens vs. center specimens should not be made at this time.
4. The automated data acquisition system is very accurate when compared to the manual method of measuring rut depth and is much less time consuming.
5. A database of four laboratory and one field Superpave mix has been established. Results of these five mixes indicate that the 12.5 mm mixes rutted less than the 9.5 mm mixes and that the coarse graded mixes rutted less than the fine graded mixes for a given nominal maximum aggregate size. However, these results have not been correlated to actual field performance.

RECOMMENDATIONS

1. The cause of the higher rut depths in the center position needs to be investigated further. This data will be presented to the manufacturer and a cooperative effort will be used to

resolve the problem.

2. More Superpave mixes need to be tested to increase the size of the database for this empirical test.
3. An effort needs to be made to monitor the field performance of these mixes to verify if the APA has the ability to predict field performance.
4. The automated data acquisition system will be used on all mixes in the future with occasional manual measurements taken to verify the accuracy of the automated system.

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Table 1 - Gradations and Binder Contents of Asphalt Mixtures

	Mixture Type / Percent Passing Sieve Size							
	9.5 mm Fine		9.5 mm Coarse		12.5 mm Fine		12.5 mm Coarse	
Sieve Size	Design	Reproduced	Design	Reproduced	Design	Reproduced	Design	Reproduced
3/4" 19.0 mm	100	100	100	100	100	100	100	100
1/2" 12.5 mm	100	100	100	100	97	97	98	98
3/8" 9.5 mm	100	100	99	100	88	89	91	92
No. 4 4.75 mm	81	82	63	65	73	76	54	56
No. 8 2.36 mm	56	56	36	36	46	48	28	29
No. 16 1.18 mm	42	42	25	25	34	35	19	21
No. 30 600μm	30	30	18	18	26	27	15	15
No. 50 300μm	19	19	13	13	19	19	8	10
No. 100 150μm	11	11	8	8	7	6	5	5
No. 200 75μm	5.6	5.9	6.0	6.1	4.6	4.6	4.0	4.0
% Binder Content (by wt. of total mix)	5.9	5.9	6.1	6.1	6.3	6.3	6.6	6.6

Table 2 - Air Void Contents for Beam Specimens

9.5 mm Fine Mixture			9.5 mm Coarse Mixture		
Beam #	% Air Voids	Average	Beam #	% Air Voids	Average
1	6.99		1	7.43	
2	7.35		2	7.03	
3	7.75	7.36	3	7.31	7.26
5	7.29		4	6.71	
6	7.62		6	7.45	
10	7.29	7.40	8	7.61	7.26
7	7.34		5	7.66	
8	7.68		7	7.07	
9	7.01	7.34	10	6.75	7.16
12.5 mm Fine Mixture			12.5 mm Coarse Mixture		
Beam #	% Air Voids	Average	Beam #	% Air Voids	Average
7	7.16		2	7.51	
8	6.44		3	6.62	
9	6.51	6.70	11	7.03	7.05
3	7.24		1	6.76	
4	6.54		10	6.43	
10	6.45	6.74	17	7.88	7.02
1	6.77		7	7.33	
2	6.38		8	7.67	
6	6.80	6.65	12	6.49	7.16

Table 3 - Summary of Rut Depths in Millimeters

	Test 1				Test 2				Test 3						
	Sample Location Within APA Testing Set-Up				Sample Location Within APA Testing Set-Up				Sample Location Within APA Testing Set-Up				Avg. of Averages	Std. Dev. of Avgs.	Coef. of Variation (%)
Mix Type	Left	Center	Right	Avg.	Left	Center	Right	Avg.	Left	Center	Right	Avg.			
	500 Cycles														
9.5 Fine	3.9	5.0	4.0	4.3	3.8	4.2	3.8	3.9	5.3	6.3	4.8	5.5	4.6	0.8	18
9.5 Coarse	1.6	1.3	2.0	1.6	2.1	3.2	1.6	2.3	2.0	3.0	1.5	2.1	2.0	0.4	18
12.5 Fine	1.0	2.6	2.1	1.9	0.7	1.3	1.0	1.0	1.3	1.3	0.6	1.1	1.3	0.5	36
12.5 Coarse	0.7	0.7	0.8	0.7	0.5	0.4	0.7	0.5	0.6	0.9	0.6	0.7	0.6	0.1	15
	2000 Cycles														
9.5 Fine	7.4	8.7	7.4	7.8	7.6	7.5	6.8	7.3	9.1	10.3	8.2	9.2	8.1	1.0	12
9.5 Coarse	3.6	3.1	3.7	3.5	4.1	5.7	3.8	4.5	3.7	5.1	3.4	4.1	4.0	0.5	13
12.5 Fine	2.5	4.9	3.6	3.7	2.1	3.7	2.4	2.7	3.2	3.0	2.2	2.8	3.1	0.5	18
12.5 Coarse	1.5	1.2	1.4	1.4	1.6	1.1	1.5	1.4	1.2	2.2	1.2	1.5	1.4	0.1	5
	4000 Cycles														
9.5 Fine	9.7	11.1	10.0	10.3	10.0	9.5	8.9	9.5	11.4	12.9	10.4	11.6	10.4	1.1	10
9.5 Coarse	4.9	4.1	5.2	4.7	5.7	7.5	5.8	6.3	5.7	6.8	5.2	5.9	5.7	0.8	14
12.5 Fine	3.3	5.9	4.5	4.6	3.2	4.8	3.1	3.7	4.4	4.4	3.2	4.0	4.1	0.5	11
12.5 Coarse	1.9	1.7	1.8	1.8	2.0	1.8	2.1	2.0	1.6	2.7	1.6	2.0	1.9	0.1	6
	8000 Cycles														
9.5 Fine	12.9	14.9	13.5	13.8	13.0	13.0	11.9	12.6	14.6	16.6	13.2	14.8	13.7	1.1	8
9.5 Coarse	7.0	6.2	8.1	7.1	8.6	10.7	9.2	9.5	8.5	9.9	8.7	9.0	8.5	1.3	15
12.5 Fine	4.5	7.0	5.5	5.7	4.2	6.1	3.9	4.8	5.6	5.8	4.4	5.3	5.2	0.5	9
12.5 Coarse	2.2	2.2	2.1	2.2	2.5	3.1	2.5	2.7	2.5	3.3	2.0	2.6	2.5	0.3	11

Table 4 - Range of Differences in Rut Measurements

Mix Type	Between Locations (same test)			Between Tests (same location)			Tests & Locations	% of Avg. Rut Depth	Between Averages	% of Avg. Rut Depth
	Test 1	Test 2	Test 3	Left	Center	Right				
	500 Cycles									
9.5 Fine	1.1	0.5	1.5	1.5	2.1	1.1	2.6	56	1.6	34
9.5 Coarse	0.7	1.5	1.4	0.6	1.9	0.5	1.9	94	0.7	34
12.5 Fine	1.7	0.6	0.7	0.6	1.3	1.4	2.0	149	0.9	66
12.5 Coarse	0.1	0.3	0.4	0.2	0.5	0.2	0.5	82	0.2	29
	2000 Cycles									
9.5 Fine	1.3	0.8	2.1	1.7	2.7	1.4	3.5	43	1.9	23
9.5 Coarse	0.6	1.9	1.7	0.5	2.6	0.4	2.6	65	1.1	26
12.5 Fine	2.4	1.5	1.0	1.1	1.9	1.5	2.8	91	1.0	32
12.5 Coarse	0.3	0.4	1.0	0.4	1.0	0.2	1.0	70	0.1	9
	4000 Cycles									
9.5 Fine	1.4	1.2	2.4	1.6	3.4	1.6	4.0	39	2.1	20
9.5 Coarse	1.1	1.8	1.6	0.8	3.4	0.6	3.4	60	1.6	28
12.5 Fine	2.6	1.7	1.2	1.3	1.5	1.4	2.8	68	0.9	22
12.5 Coarse	0.2	0.3	1.1	0.4	1.0	0.6	1.1	59	0.2	11
	8000 Cycles									
9.5 Fine	2.0	1.1	3.4	1.7	3.6	1.6	4.7	34	2.2	16
9.5 Coarse	1.9	2.0	1.4	1.6	4.4	1.1	4.4	52	2.4	28
12.5 Fine	2.5	2.2	1.3	1.4	1.3	1.6	3.1	60	0.9	18
12.5 Coarse	0.1	0.6	1.3	0.3	1.1	0.5	1.3	51	0.5	21

Table 5 - Paired Difference Analysis of Three Test Groups

Mix Type	Average Rut Depths (mm)			Difference	Difference	Difference
	Test 1	Test 2	Test 3	Test 1 - Test 2	Test 1 - Test 3	Test 2 - Test 3
9.5 Fine	13.8	12.6	14.8	1.2	-1.0	-2.2
9.5 Coarse	7.1	9.5	9.0	-2.4	-1.9	0.5
12.5 Fine	5.7	4.8	5.3	0.9	0.4	-0.5
12.5 Coarse	2.2	2.7	2.6	-0.5	-0.4	0.1
			Average Difference	-0.2	-0.7	-0.5
			Standard Deviation	1.648	0.997	1.171
			Calculated t-value	-0.247	-1.464	-0.898
			t-value (0.05) 2 sided (3 df)	3.182	3.182	3.182

Table 6 - Paired Difference Analysis of Three Testing Positions

Test #	Mix Type	Rut Depths (mm) Position			Difference	Difference	Difference
		Left	Center	Right	Left - Center	Left - Right	Center - Right
Test 1	9.5 Fine	12.9	14.9	13.5	-2.0	-0.6	1.4
	9.5 Coarse	7.0	6.2	8.1	0.7	-1.1	-1.9
	12.5 Fine	4.5	7.0	5.5	-2.5	-1.0	1.5
	12.5 Coarse	2.2	2.2	2.1	0.1	0.1	0.1
Test 2	9.5 Fine	13.0	13.0	11.9	0.0	1.1	1.1
	9.5 Coarse	8.6	10.7	9.2	-2.0	-0.6	1.4
	12.5 Fine	4.2	6.1	3.9	-1.9	0.3	2.2
	12.5 Coarse	2.5	3.1	2.5	-0.6	0.0	0.5
Test 3	9.5 Fine	14.6	16.6	13.2	-2.0	1.4	3.4
	9.5 Coarse	8.5	9.9	8.7	-1.4	-0.3	1.1
	12.5 Fine	5.6	5.8	4.4	-0.2	1.2	1.3
	12.5 Coarse	2.5	3.3	2.0	-0.8	0.4	1.3
				Average Difference	-1.0	0.1	1.1
				Standard Deviation	1.062	0.843	1.245
				Calculated t-value	-3.409	0.312	3.120
				t-value (0.05) 2 sided (11 df)	2.201	2.201	2.201

Table 7 - Rut Depth and Air Void Data for 12.5 mm Coarse Graded Field Produced Mix

Cycle count	Rut Depth (mm) Beam Id. and Position		
	A (left)	1 (center)	3 (right)
0	0.00	0.00	0.00
500	0.40	0.70	0.55
2000	0.94	1.71	0.99
4000	1.65	2.24	1.22
8000	2.01	2.96	1.40
Air Voids	7.30	7.35	7.15

Table 8 - Comparison of Manual and Automated Readings for 12.5 mm Fine Mix

Beam #	Cycle count	Manual Reading	Automated Reading	Difference Man-Auto
7	500	0.98	0.92	0.07
	2000	2.54	2.37	0.17
	4000	3.33	3.13	0.21
	8000	4.53	3.96	0.57
8	500	2.64	2.39	0.25
	2000	4.89	4.82	0.07
	4000	5.92	5.78	0.14
	8000	7.04	7.02	0.02
9	500	2.05	2.25	-0.20
	2000	3.64	4.01	-0.37
	4000	4.54	4.88	-0.34
	8000	5.54	5.92	-0.38
3	500	0.74	0.75	0.00
	2000	2.11	2.10	0.02
	4000	3.17	3.02	0.15
	8000	4.25	4.04	0.20
4	500	1.33	1.19	0.15
	2000	3.66	3.27	0.39
	4000	4.80	4.48	0.32
	8000	6.13	5.81	0.32
10	500	0.97	0.90	0.07
	2000	2.36	2.16	0.20
	4000	3.13	2.91	0.22
	8000	3.90	3.65	0.26
1	500	1.33	1.40	-0.06
	2000	3.22	3.26	-0.05
	4000	4.43	4.50	-0.07
	8000	5.60	5.53	0.07
2	500	1.32	1.43	-0.11
	2000	2.97	3.35	-0.38
	4000	4.42	4.36	0.06
	8000	5.76	5.84	-0.08
6	500	0.64	1.00	-0.36
	2000	2.18	2.51	-0.33
	4000	3.23	3.39	-0.17
	8000	4.43	4.49	-0.06
			Average	0.03
			Std. Dev.	0.24
			Max Dev.	0.57
			Min Dev.	0.00

Table 9 - Comparison of Manual and Automated Readings for 12.5 mm Coarse Mix

Beam #	Cycle count	Manual Reading	Automated Reading	Difference Man-Auto
2	500	0.69	0.83	-0.14
	2000	1.52	1.58	-0.06
	4000	1.88	1.97	-0.09
	8000	2.24	2.36	-0.12
3	500	0.70	0.83	-0.13
	2000	1.20	1.43	-0.23
	4000	1.67	2.00	-0.32
	8000	2.18	2.52	-0.35
11	500	0.77	0.80	-0.04
	2000	1.43	1.57	-0.14
	4000	1.78	2.06	-0.28
	8000	2.10	2.44	-0.34
1	500	0.49	0.76	-0.26
	2000	1.56	1.56	0.00
	4000	2.01	2.14	-0.12
	8000	2.51	2.75	-0.24
10	500	0.39	0.51	-0.11
	2000	1.14	1.48	-0.33
	4000	1.84	2.09	-0.25
	8000	3.07	2.68	0.38
17	500	0.72	0.87	-0.15
	2000	1.47	1.63	-0.16
	4000	2.12	2.14	-0.02
	8000	2.53	2.62	-0.09
7	500	0.58	0.75	-0.17
	2000	1.18	1.44	-0.26
	4000	1.63	1.94	-0.31
	8000	2.47	2.48	-0.01
8	500	0.92	0.80	0.12
	2000	2.15	2.09	0.06
	4000	2.70	2.67	0.03
	8000	3.30	3.35	-0.05
12	500	0.56	0.90	-0.34
	2000	1.22	1.60	-0.38
	4000	1.57	2.01	-0.44
	8000	2.03	2.33	-0.30
			Average	-0.16
			Std. Dev.	0.17
			Max Dev.	0.44
			Min Dev.	0.00

Table 10 - Comparison of Manual and Automated Readings for 12.5 mm Coarse Graded Field Produced Mix

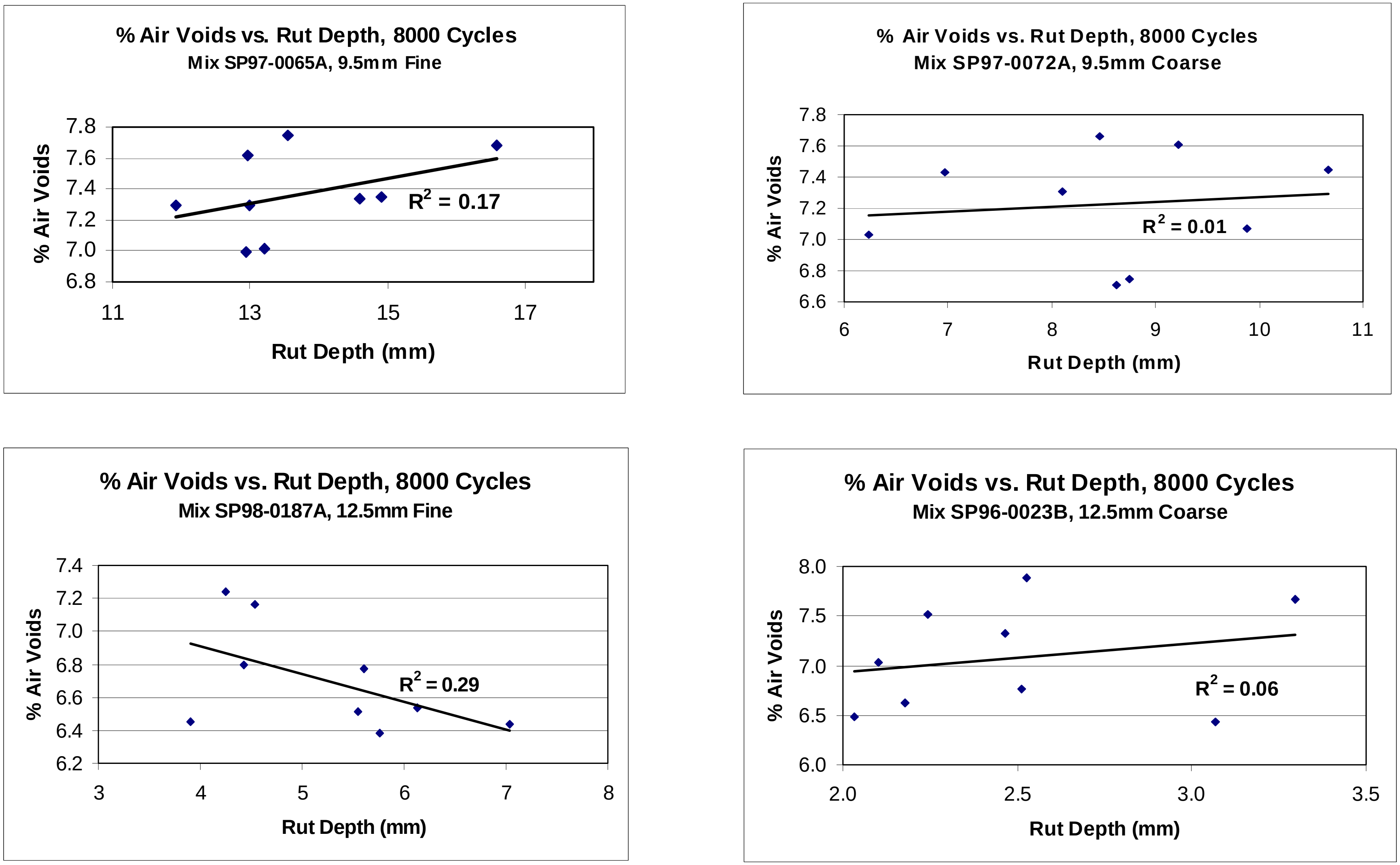
Beam #	Cycle count	Manual Reading	Automated Reading	Difference Man-Auto
A	500	0.40	0.74	-0.34
	2000	0.94	1.27	-0.32
	4000	1.65	1.84	-0.18
	8000	2.01	2.33	-0.31
1	500	0.70	0.70	0.00
	2000	1.71	1.32	0.39
	4000	2.24	2.04	0.20
	8000	2.96	2.68	0.28
3	500	0.55	0.82	-0.27
	2000	0.99	1.30	-0.31
	4000	1.22	1.68	-0.46
	8000	1.40	2.11	-0.72
			Average	-0.17
			Std. Dev.	0.33
			Max Dev.	0.72
			Min Dev.	0.00

Table 11 - Summary of Rut Depths for Superpave Mixes

Mix Type (Lab or Field)	Nominal Maximum Aggregate Size	Rut Depth at 8000 Cycles (manual readings; avg. of 9 beams)
Lab	9.5 Fine	13.7
Lab	9.5 Coarse	8.5
Lab	12.5 Fine	5.2
Lab	12.5 Coarse	2.5
Field	12.5 Coarse	2.1*

* Field mix rut depth was average of three beams.

Figure 1 - Air Voids vs. Rut Depth for Superpave Mixes



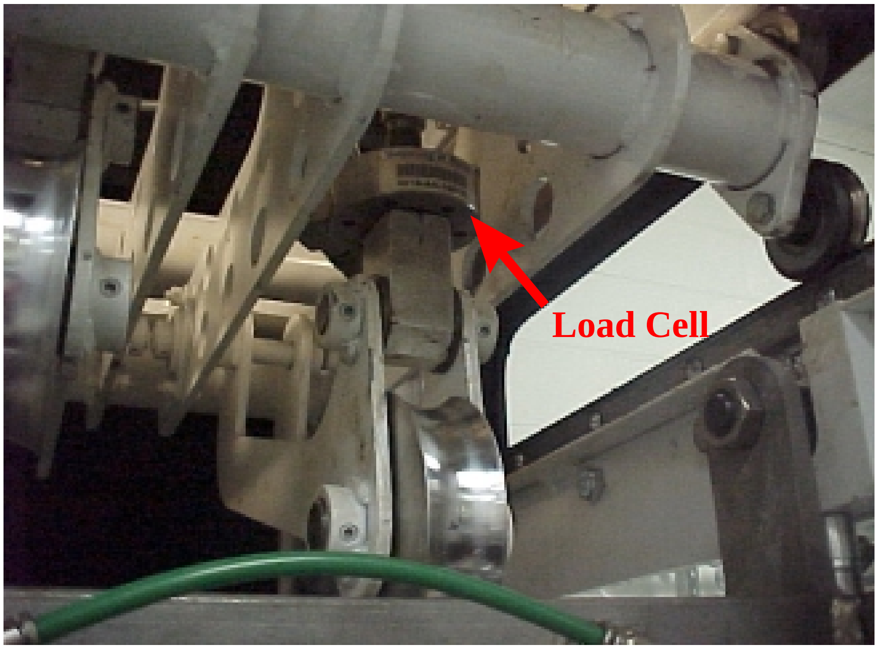


Figure 2 - Load Cell Installed Between Wheel and Air Cylinder

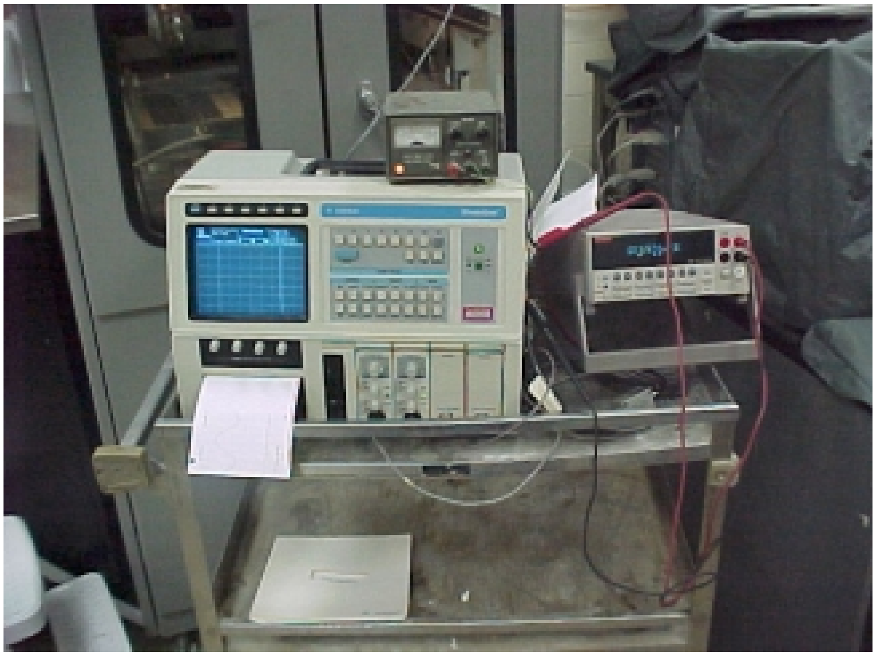


Figure 3 - Power Supply and Oscilloscope for Load Cell