A Ruggedness Study of the Asphalt Pavement Analyzer Rutting Test

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Executive Summary

This report provides information regarding a screening or ruggedness study to evaluate factors that may contribute to variability in the Asphalt Pavement Analyzer rutting test procedure. This type of study is used in the development of new test methods to refine the written procedure so as to eliminate unnecessary variability. The experimental design used in this research was set up based upon guidelines of ASTM C 1067. Six factors (i.e. variables) were investigated: (1) air void contents of the test specimens, (2) the test temperature, (3) specimen preheating time (4) wheel load, (5) hose pressure, and (6) specimen compaction method.

Analyses of the results show that the allowable range of ± 1.0% air voids for test specimens should be reduced, the test temperature must be accurately calibrated, and the method of compaction should be standardized. The current procedural ranges permitted for wheel load, hose pressure, and preheat time did not significantly effect results.

Additional information gathered from this study provides insight on repeatability and reproduceability of the APA rutting test, and evaluation of possible outlier data.

Recommendations are given on changes to improve the test method and calibration of the equipment. The findings of this study should be very helpful to users of the APA rut test procedure in evaluating hot mix asphalt paving mixtures.

Acknowledgement

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Table of Contents

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I. INTRODUCTION

For years, asphalt paving technologists have sought a simple and reliable method of evaluating the rutting susceptibility of asphalt concrete mixtures. Although researchers have used a wide variety of devices and procedures to rate HMA mixtures in terms of their anticipated field performance, no technique has proven to meet the goal of reliability. A particular shortcoming for many of the methods is the problem of excessive procedural variability.

One category of rut test methods is laboratory wheel tracking tests. The most popular wheel tracking test in the U.S. is the rutting test in the Asphalt Pavement Analyzer. Despite the critical argument that wheel tracking tests are purely empirical and therefore limited to specific conditions, several studies have shown reasonably good correlation between wheel tracking tests and full scale field rutting performance.

Purpose of the Ruggedness Study

The purpose of a ruggedness study is to determine which factors in a test procedure have the greatest influence on the outcome of the test so that those factors can be more closely controlled. A ruggedness experiment is an important step that should be undertaken in the development of any new testing procedure. A round-robin study generally follows a ruggedness study to provide estimations of within laboratory and between laboratory variability statistics that can be used to develop precision statements for the method.

It is important to note that a ruggedness study does not determine the setting of the factors that yields the best relationship to field performance. A separate research project, recently initiated as NCHRP 9-*17 Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer*, should provide information as to how the factors can be set to provide the strongest correlation between the APA rutting test and actual roadway performance.

Background

The rutting test evaluated in this ruggedness study is a procedure which has evolved through more than a decade. Early development of the rut test procedure was initiated in the late 1980's by the Georgia Department of Transportation and the Georgia Institute of Technology. Since then, numerous improvements have been made in the equipment and the procedure. The most significant changes in equipment occurred when Pavement Technologies Inc. began commercial development of the Asphalt Pavement Analyzer (APA). Recently, owners of the APA formed an APA Users Group to share ideas and collectively work toward refining the rut test procedure and other test procedures using the APA. Several changes to the rut test procedure have emerged from discussions and surveys of this group.

Research Plan

The experimental research and analysis plan used in this research study closely followed the guidelines given in ASTM C 1067 *Standard Practice for Conducting A Ruggedness or Screening Program for Test Methods for Construction Materials*. Representatives from several laboratories that had extensive experience with the APA met on March 6, 1998 to discuss the details for conducting the research. One of the important discussions held by the group were what factors or test variables should be evaluated in the study. The factors identified by the group were:

1. Air void content of test specimens
2. Specimen preheating time
3. Test temperature
4. Wheel load
5. Hose Pressure
6. Specimen type: beam or cylinder

The sixth factor, specimen type, actually included two variables, compaction method and specimen geometry, that were confounded or could not be separated. Also, a seventh "dummy" factor was included in the analysis in order to follow the example provided in ASTM C 1067.

Three laboratories volunteered to perform the testing:

1. The Georgia Department of Transportation, Office of Materials & Research, Forest Park, GA
2. Superfos Construction (U.S.) Inc. Research and Development Laboratory, Dothan, AL
3. APAC Inc. Materials Services, Smyrna GA

The National Center for Asphalt Technology at Auburn University prepared all specimens and distributed them to the three laboratories. Preparation of instructions and procedures, and collection of the data were conducted by APAC Materials Services. Analysis of results was done in a cooperative effort among APAC, Superfos, and NCAT.

II. EXECUTION OF THE RESEARCH

Experimental Design

The experimental plan given in C 1076 is a fractional factorial experiment designed to evaluate only the main effects (factors) of the experiment. Interactions among factors, although they probably exist, are not considered in this statistical analysis technique. The statistical model for the experiment can be expressed as:

$$Z = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + e$$

Where:

Z is the response variable, rut depth,
B_0 through B_7 are unknown coefficients,
X_1 through X_7 are the main effects as shown in Table 1, and
e is random experimental error.

Each of the six factors were tested at two levels representing the high and low range for the factors given in the draft procedure. As an example, the draft procedure stated the air void contents of the test specimens must be 7 ±1%. Therefore, in the ruggedness study, specimens were prepared with target air void contents of 6.0% and 8.0%. The levels used for each of the factors in the experiment identified by the group are shown in Table 1.

Table 1. APA Ruggedness Study Experimental Factors

Factors	Range in Standard Procedure	Low Level Target	High Level Target
Specimen Air Void Contents	7 ± 1%	6 ± 0.5%	8 ± 0.5%
Test Temperature	Not specified	55 ± 0.4 C	60 ± 0.4 C
Specimen Preheat Time	5 hrs. min./ 24 hrs. max	6 hrs.	24 hrs.
Wheel Load	100 ± 5 lbs.	95 lbs.	105 lbs.
Hose Pressure	100 ± 5 psi	95 psi	105 psi
Specimen Type	Multiple options	AVC beams	SGC cylinders

The primary method of analysis to determine the significance of each factor was the multiple orthogonal contrast technique. Further information on this method of analysis can be found in Annex 2 of ASTM C 1067 and most general statistical texts. The study data also provided opportunities for additional useful analyses using some simple, straightforward comparisons and more rigorous statistical techniques.

Each lab conducted a total of 32 tests in a predetermined sequence. As with typical APA testing, each test involved testing a set of either three rectangular beams or a set of six cylinders. In each test, selected factor levels were changed. Sixteen tests were performed in the first round, the equipment was then recalibrated, and then the same sixteen tests were repeated for the second round.

Mixtures

The guidelines of ASTM C 1076 recommend that the study include a number of materials that cover the range of properties expected to be encountered with the test method. Since rut depth was the response variable under evaluation, it was desirable to have a mixture with relatively low rutting potential (about 3 mm) and a mixture with relatively high rutting potential (about 8 mm). This was accomplished by using a mixture of known test performance utilized in prior research by NCAT as the low rut potential mix, and by adding an additional 1.5% asphalt to make a mixture with high rutting potential. Mix design information is given in Appendix A.

Preparation of Specimens

NCAT prepared all specimens according to the test plan and randomly distributed them to the three testing laboratories. The experimental factors fabricated into the specimens were the air void contents, the rutting potential (asphalt content), and compaction method/specimen type (SGC cylinders or AVC beams). Air void contents were determined by NCAT in accordance with AASHTO T 269.

Some difficulty was encountered in achieving the air void targets within the ±0.5% tolerance as established by the research plan. Hitting the air void range was essentially a trial-and-error process and a significant percentage of the specimens had to be discarded because they were not within the range. Overall, the success rate for AVC beams was 62%, and for SGC cylinders it was 84%. NCAT reported that the percentages increased as they gained experience with fabricating specimens. The actual air void contents of the specimens used in the study are given in Appendix B.

Calibration of Equipment

Procedures and forms for calibration of the APA and preheating ovens were developed and sent to each of the participating labs. Calibration of the APA included determining the set points for controlling the wheel loads of the three air cylinders, the hose pressure, and the chamber temperature at the high and low level for each factor. Separate ovens were required for preheating the specimens to the high and low test temperatures. Each oven was calibrated to the appropriate temperature with a NIST traceable thermometer. The calibration instructions are given in Appendix C. All calibrations were checked before initiating the first round and rechecked prior to the second round of tests.

It was noted by all three labs that the actual APA temperature was about 5°C higher than the set point temperature on the APA control panel.

Testing

Detailed instructions were provided to each of the testing labs. Of particular importance was the requirement that all testing at each lab had to be performed by the same technician. The test schedule and procedure are given in Appendix D. Measurements of rut depths were made manually and were only taken initially (after seating) and after 8000 cycles. Although, rut depths are typically taken at other intermediate periods, using only the final rut depth was felt to be a significant simplification and avoided the problem with heat loss from the test chamber while taking intermediate measurements.

III. RESULTS AND ANALYSIS

Test Data and Results

Raw data and factor levels for the three laboratories are given in Tables 2, 3, and 4. Very few problems were experienced in testing. The most significant difficulty was that some specimens rutted so much that the ruts exceeded the travel of the digital gauges used to make the measurements. Two labs corrected the problem by adding an extension to the gauge. The other lab reported the ruts as too deep to measure, but later made an attempt to estimate the rut depth on those specimens by taking measurements on the beams and in the ruts. The estimated rut depths from this alternate technique are shown in italics. Other isolated problems, such as loss of pressure control or hose failure, are noted in the tables.

Average rut depths for each test were computed from the set of three beams or three pairs of cylinders in the left, center, and right positions. Measurements on each beam were made only at the three interior template locations. Measurements on cylinder pairs were made on the four outer template locations. Standard deviations of the rut

Table 2. Results from Lab 1

Round 1																
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	25	18 / 21	19 / 41	10	11	15 / 55	3 / 14	17	16	3 / 13	17 / 23	28	25	6 / 13	20 / 25	18
Center	32	28 / 35	46 / 69	48	32	61 / 67	26 / 39	37	18	24 / 44	33 / 43	39	43	54 / 61	65 / 71	45
Right	74	59 / 54	71 / 73	67	53	70 / 82	49 / 72	40	44	71 / 72	61 / 62	4	61	80 / 99	96 / 97	46
Rut Depths																
Left	2.80	3.15	3.24	3.34	2.06	3.97	3.87	5.53	7.43	4.91	6.57	7.47	9.20	6.34	7.82	10.20
Center	2.31	1.96	3.18	3.39	2.42	3.27	4.88	5.30	6.44	5.58	5.28	7.58	10.37	6.42	8.42	12.76
Right	3.91	2.48	3.59	3.08	1.89	3.22	4.46	5.49	7.64	5.47	7.58	11.96	10.70	7.05	7.58	13.26
Average	3.01	2.53	3.34	3.27	2.12	3.49	4.40	5.44	7.17	5.32	6.48	9.00	10.09	6.60	7.94	12.07
Std. Dev.	0.82	0.60	0.22	0.17	0.27	0.42	0.51	0.12	0.64	0.36	1.15	2.56	0.79	0.39	0.43	1.64
Coef. Of Var.	27%	24%	7%	5%	13%	12%	12%	2%	9%	7%	18%	28%	8%	6%	5%	14%
Round 2																
Test No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	18	30 / 32	37 / 42	4	6	11 / 13	12 / 18	7	15	5 / 18	6 / 16	12	24	1 / 10	2 / 28	72
Center	33	47 / 49	43 / 45	34	46	20 / 33	23 / 71	35	25	51 / 53	38 / 54	22	41	44 / 55	33 / 57	44
Right	50	64 / 74	52 / 66	55	49	37 / 77	81 / 85	44	37	64 / 75	66 / 67	31	56	67 / 89	84 / 91	55
Rut Depths																
Left	2.85	3.57	4.36	2.58	1.86	3.36	5.24	4.56	5.35	5.57	6.55	6.19	8.84	6.10	8.29	15.30
Center	2.81	3.02	3.73	5.15	1.65	3.25	3.50	4.77	7.37	5.67	6.89	5.06	9.94	6.59	8.49	13.00
Right	2.46	2.48	3.71	2.13	1.74	3.82	3.53	5.10	6.14	4.97	7.19	6.69	13.37	7.32	8.33	14.38
Average	2.71	3.02	3.93	3.29	1.75	3.48	4.09	4.81	6.29	5.40	6.88	5.98	10.72	6.67	8.37	14.23
Std. Dev.	0.21	0.55	0.37	1.63	0.11	0.30	1.00	0.27	1.02	0.38	0.32	0.84	2.36	0.61	0.11	1.16
Coef. Of Var.	8%	18%	9%	50%	6%	9%	24%	6%	16%	7%	5%	14%	22%	9%	1%	8%

test #16 - wheel load fluctuations, esp. right wheel - before next test, wheel was down, oil was under cylinder

test #17 -order of specinens unknown

test #20 - center specimen was noticably thicker

test #11 - order of specimens unknown

test #22 - hose pressure fluctuation between 102 & 105 psi, compressor adjusted

test #27 - hose pressure fluctuating between 102 & 105 psi, compressor releaf valve popped off during test, problem corrected, but still fluctuating

Table 3. Results from Lab 2.

Round 1																
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	24	27 / 55	40 / 68	52	57	31 / 7	47 / 24	58	38	4 / 74	47 / 69	42	40	27 / 94	32 / 24	21
Center	15	61 / 1	33 / 51	23	48	27 / 86	29 / 78	41	43	32 / 30	25 / 37	36	26	77 / 36	30 / 35	50
Right	69	48 / 58	75 / 24	37	20	74 / 51	73 / 38	19	21	35 / 65	63 / 10	20	59	16 / 49	86 / 88	47
Rut Depths																
Left	1.77	2.88	4.06	3.47	2.51	3.24	3.89	3.54	5.35	5.85	5.86	7.37	9.79	5.40	7.23	10.83
Center	2.80	3.00	3.68	3.91	2.55	3.59	4.13	4.88	5.37	4.85	6.00	8.57	10.26	4.13	7.18	11.53
Right	2.90	3.46	3.32	4.18	3.30	3.43	5.40	4.84	5.44	5.75	7.09	8.46	10.25	5.11	10.97	11.54
Average	2.49	3.11	3.69	3.85	2.79	3.42	4.47	4.42	5.39	5.48	6.32	8.13	10.10	4.88	8.46	11.30
Std. Dev.	0.63	0.31	0.37	0.36	0.45	0.18	0.81	0.76	0.05	0.55	0.67	0.66	0.27	0.67	2.17	0.41
Coef. Of Var.	25%	10%	10%	9%	16%	5%	18%	17%	1%	10%	11%	8%	3%	14%	26%	4%
Round 2																
Test No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	59	29 / 11	62 / 34	62	13	84 / 57	87 / 30	55	41	52 / 21	77 / 1	40	20	64 / 56	18 / 12	27
Center	14	70 / 56	83 / 38	22	39	28 / 64	52 / 2	38	9	15 / 76	41 / 19	32	28	66 / 23	15 / 53	32
Right	39	15 / 36	63 / 81	42	54	48 / 9	62 / 75	9	30	39 / 26	34 / 22	17	53	59 / 47	11 / 4	54
Rut Depths																
Left	1.25	2.48	2.53	1.81	2.72	1.49	3.66	2.76	4.92	5.20	5.47	5.10	7.98	4.20	7.15	
Center	2.22	3.40	2.49	2.26	3.16	3.40	4.70	4.03	4.83	4.82	6.17	7.65	9.10	6.50	7.66	
Right	3.14	4.15	4.05	3.25	2.54	3.80	6.40	3.97	6.58	5.77	7.99	6.18	10.00	6.37	9.38	
Average	2.20	3.34	3.02	2.44	2.81	2.90	4.92	3.59	5.44	5.26	6.54	6.31	9.03	5.69	8.06	*13.52*
Std. Dev.	0.95	0.84	0.89	0.74	0.32	1.23	1.38	0.72	0.99	0.48	1.30	1.28	1.01	1.29	1.17	
Coef. Of Var.	43%	25%	29%	30%	11%	43%	28%	20%	18%	9%	20%	20%	11%	23%	14%	
test #17 - specimen #59 had spalled area near ceter, byt outside of hosepath, beam height 65 to 68 mm																
test # 20 - specimen #42 had chipped area on corner, beam height 65 to 68 mm																
test # 21 - specimen # 54 had chipped area on corner, no effect expected																
test # 24 - beam heights 65 to 68 mm																
test #25 - beam heights 65 to 68 mm																
test #28 - specimen #32 had chipped corner, beam height 65 to 68 mm																
test #29 - beam heights 65 to 68 mm																
test #32 - beams 6 to 10 mm below mold, could not obtain readings with correct technique																

Table 4. Results from Lab 3

Round 1																
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	7	10 / 13	12 / 20	5	42	8 / 45	19 / 68	50	2	14 / 29	7 / 20	14	36	9 / 21	3 / 26	35
Center	21	23 / 67	25 / 50	20	14	34 / 56	36 / 79	2	35	36 / 46	31 / 48	45	51	31 / 41	39 / 58	52
Right	65	82 / 44	60 / 85	57	33	25 / 80	53 / 63	34	26	57 / /68	55 / 70	34	4	62 / 90	87 / 95	5
Rut Depths																
Left	4.69	4.81	5.74	6.66	3.95	4.32	7.45	5.67	7.45	5.88	*10.16*	*16.00*	8.69	7.85	11.65	*17.80*
Center	2.30	4.10	5.30	1.79	2.98	4.77	6.62	6.04	6.16	6.39	*11.75*	*17.50*	8.66	7.34	10.83	*19.70*
Right	2.50	2.60	4.28	3.73	2.78	4.02	7.04	5.15	7.50	6.12	*10.70*	*16.90*	7.81	7.65	12.42	*19.60*
Average	3.16	3.84	5.11	4.06	3.24	4.37	7.04	5.62	7.04	6.13	*10.87*	*16.80*	8.39	7.61	11.63	*19.03*
Std. Dev.	1.33	1.13	0.75	2.45	0.63	0.38	0.42	0.45	0.76	0.26	*0.81*	*0.75*	0.50	0.26	0.80	*1.07*
Coef. Of Var.	42%	29%	15%	60%	19%	9%	6%	8%	11%	4%	7%	4%	6%	3%	7%	6%
Round 2																
Test No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Rut Potential	low	low	low	low	low	low	low	low	high	high	high	high	high	high	high	high
Air Voids, %	6	6	6	6	8	8	8	8	6	6	6	6	8	8	8	8
Test Temp., C	55	55	60	60	55	55	60	60	55	55	60	60	55	55	60	60
Preheat Time, hrs.	24	6	24	6	24	6	24	6	24	6	24	6	24	6	24	6
Wheel Load, lbs.	105	105	95	95	95	95	105	105	105	105	95	95	95	95	105	105
Hose Press., psi	105	95	105	95	95	105	95	105	105	95	105	95	95	105	95	105
Compactor Type	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC	AVC	SGC	SGC	AVC
Specimen No.s																
Left	11	14 / 76	57 / 77	17	36	21 / 46	22 / 58	24	19	9 / 40	2 / 11	23	23	5 / 8	7 / 19	31
Center	29	39 / 72	22 / 31	43	22	32 / 54	60 / 65	46	29	56 / 59	28 / 50	33	58	17 / 81	29 / 42	60
Right	73	26 / 17	16 / 65	46	30	59 / 66	76 / 83	15	27	73 / 45	60 / 49	24	2	75 / 98	76 / 93	19
Rut Depths																
Left	2.52	3.36	5.68	1.84	3.05	6.37	6.19	4.99	6.03	6.38	9.88	12.15	12.61	7.50	11.23	15.58
Center	3.19	3.84	5.79	4.12	3.76	5.66	6.72	5.08	9.28	5.65	7.40	12.54	11.61	7.51	9.17	15.21
Right	2.58	3.33	4.11	3.77	3.30	4.65	6.45	3.38	9.05	6.71	7.46	12.75	9.09	6.60	9.26	13.60
Average	2.76	3.51	5.19	3.24	3.37	5.56	6.45	4.48	8.12	6.25	8.25	12.48	11.10	7.20	9.89	14.80
Std. Dev.	0.37	0.29	0.94	1.23	0.36	0.86	0.27	0.96	1.81	0.54	1.41	0.30	1.81	0.52	1.16	1.05
Coef. Of Var.	13%	8%	18%	38%	11%	16%	4%	21%	22%	9%	17%	2%	16%	7%	12%	7%

depths and coefficients of variation were also calculated for each test using the results of the three positions (left, right, and center). Any test with a standard deviation greater than 2.00 mm was reviewed in greater detail to identify possible extraneous sources of error. Only four tests out of the 96 tests had standard deviations greater than 2.00 mm. Two tests from Lab 1 had standard deviations greater than 2.00 mm, and one test each from Labs 2 and 3. In each case, one of the three measurement positions (left, center, right) was obviously different than the other two positions. Although a variety of possible causes for the apparent outlier measurements were evaluated, no definitive cause could be attributed to any of the four cases. All of the analyses in the following sections were conducted with these outlier measurements included in the data and also without the outlier measurements. The conclusions were not changed by the inclusion or exclusion of the apparent outlier results.

One possible source of variation that was investigated was differences between the left, center, and right rut depth measurements. Although each wheel load was individually calibrated, it has been observed that the wheel loads are not necessarily independent. During calibration, the load applied by any wheel is affected by whether or not the other wheels are up or down. Table 5 shows the number of tests each lab reported with the left, center, or right position having the highest rut depth measurement. For Lab 1, the highest rut depths were relatively evenly distributed among the three positions. For Lab 2, the right wheel load position was often the highest rut depth and the left position was rarely the highest rut depth. For Lab 3, the highest rut depth was evenly distributed among the left and center position, but the right position had a disproportionately low number of high rut occurrences. This may indicate that the wheel positions were not applying uniform loads to the specimens. Further work should be considered to improve the uniformity of the loads among the three positions.

Table 5. Number of Tests per Position with Highest Rut Depth

	Left	Center	Right
Lab 1	10	8	14
Lab 2	3	8	20
Lab 3	14	14	4

Repeatability

The bar graphs shown in Figures 1, 2, and 3 provide simple comparisons of results from rounds one and two for each of the three labs. Replication of the experiment in the two rounds was necessary to obtain an estimate of the component of variance due to error. It can be seen that most of the results from each of the laboratories were reasonably consistent from round one to round two. The term repeatability is often used to describe how well a laboratory can replicate its own results for a given test and a given set of materials. An arbitrary indication of repeatability of the APA test for each laboratory was made by determining the percentage of the sixteen tests that had less than 1.00 mm difference between round one and round two. Lab 1 had 88% of the replicate tests within 1.00 mm, Lab 2 had 75%, and Lab 3 had 50%. Lab 3 had greater differences between rounds for several tests on the mixture with high rutting potential. More specifically, results of tests 11, 12, 15, and 16 were noticeably greater for round one compared to round two. These tests coincide with the test temperature at the high level (60° C). This may indicate that a problem occurred in calibration of the APA temperature prior to round one. In general for all labs, it is evident that more variability is associated with greater rut depths.

Reproduceability

The results of the three labs were compared to gain insight on between-laboratory test reproduceablity. A visual comparison of the bar graphs of results from the three labs appears to indicate very good agreement. To quantify the comparisons, one-factor ANOVA's were computed to determine if the results from the three labs were significantly different for each of the 16 tests. The outcome of these comparisons, summarized in Table 6, indicate that more than two thirds of the test results from all the three labs were not significantly (NS) different ($\alpha = 0.05$). Two observations were made of the six cases where significant differences did exist. First, five of the six cases with significant differences occurred with tests on gyratory compacted specimens. Second, five of the six cases with significant differences occurred with high results from Lab 3.

Table 6. ANOVA Comparisons of Results from the Three Labs

Test Nos.	Lab 1	Lab 2	Lab 3	MSTrmt.	MSError	F	Significance
1 & 17	3.01, 2.71	2.49, 2.20	3.16, 2.76	0.278	0.056	3.91	NS
2 & 18	2.53, 3.02	3.11, 3.34	3.84, 3.51	0.405	0.067	6.05	NS
3 & 19	3.34, 3.93	3.69, 3.02	5.11, 5.19	1.865	0.134	13.93	
4 & 20	3.27, 3.29	3.85, 2.44	4.06, 3.24	0.137	0.443	0.31	NS
5 & 21	2.12, 1.75	2.79, 2.81	3.24, 3.37	0.953	0.027	35.35	
6 & 22	3.49, 3.48	3.42, 2.90	4.37, 5.56	1.870	0.287	6.52	NS
7 & 23	4.40, 4.09	4.47, 4.92	7.04, 6.45	3.521	0.104	33.89	
8 & 24	5.44, 4.81	4.42, 3.59	5.62, 4.48	0.784	0.398	1.97	NS
9 & 25	7.17, 6.29	5.39, 5.44	7.04, 8.12	2.380	0.324	7.34	NS
10 & 26	5.32, 5.40	5.48, 5.26	6.13, 6.25	0.448	0.012	37.52	
11 & 27	6.48, 6.88	6.32, 6.54	*10.87*, 8.25	6.063	1.180	5.14	NS
12 & 28	9.00, 5.98	8.13, 6.31	*16.80*, 12.48	38.590	4.223	9.14	NS
13 & 29	10.09, 10.72	10.10, 9.03	8.39, 11.10	0.021	1.497	0.01	NS
14 & 30	6.60, 6.67	4.88, 5.69	7.61, 7.20	2.303	0.138	16.67	
15 & 31	7.94, 8.37	8.46, 8.06	11.63, 9.89	4.349	0.562	7.74	NS
16 & 32	12.07, 14.23	11.30, *13.52*	*19.03*, 14.80	13.298	5.439	2.45	NS

$F_{critical} = F_{0.05, 2,3} = 9.55$

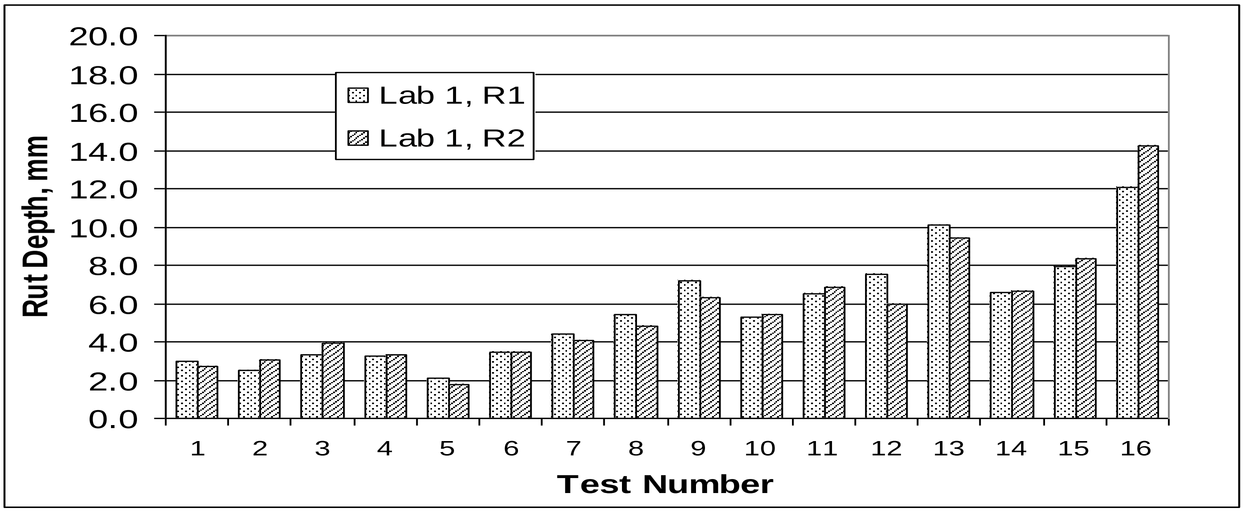

Figure 1. Comparison of Results from Round 1 and 2, Lab 1.

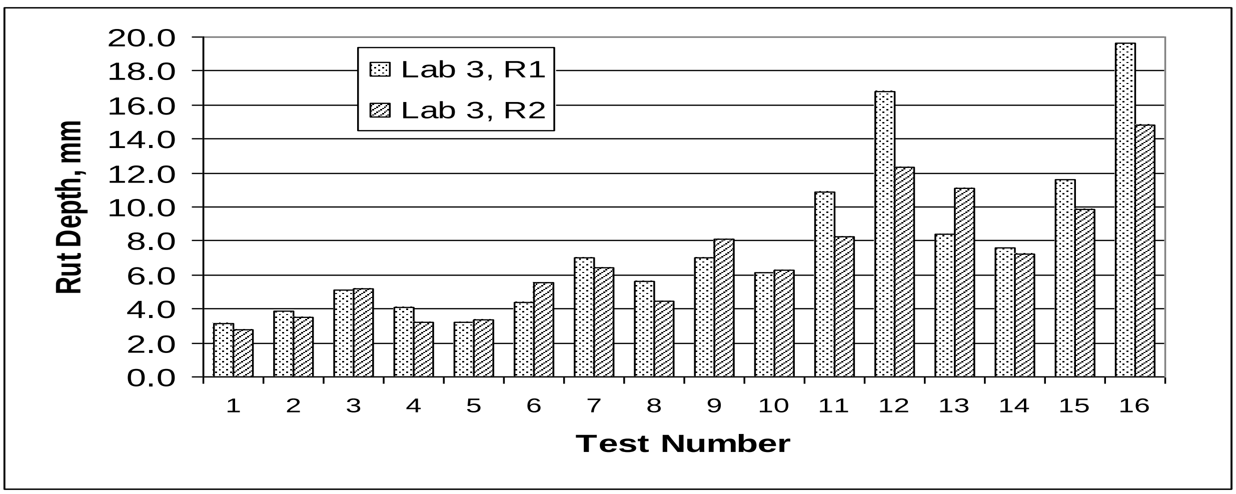

Figure 2. Comparison of Results from Round 1 and 2, Lab 2.

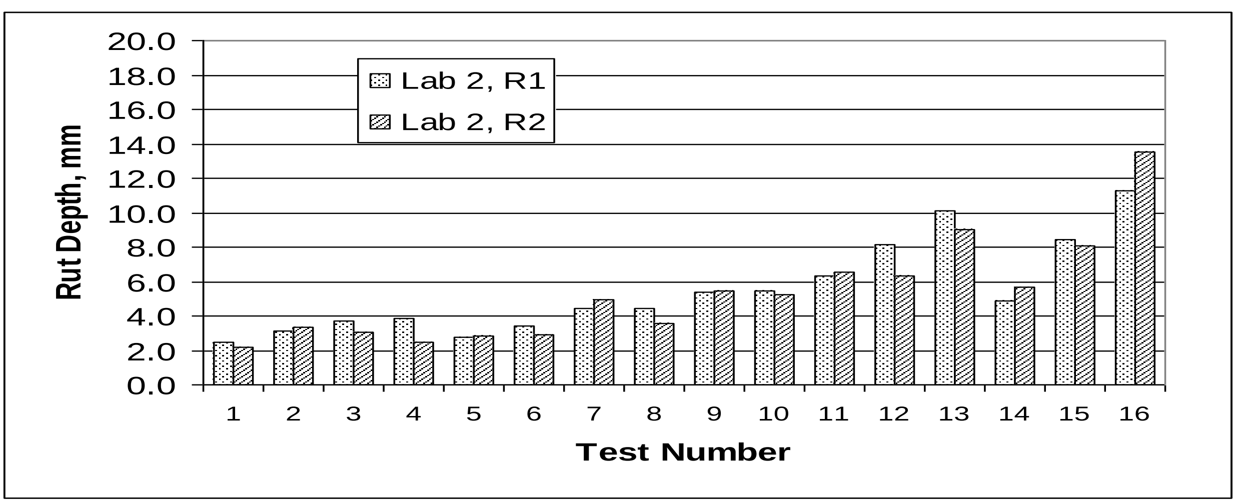

Figure 3. Comparison of Results from Round 1 and 2, Lab 3.

Ruggedness Analysis

The ruggedness data analyzed in accordance with ASTM C 1067 are summarized in Table 7. This table shows F values, which are statistical parameters used to identify the significance of each factor. In simplified terms, the F value is the ratio of the variation associated with the factor (e.g. air voids) to the variation attributed to experimental error. A higher F value indicates that the factor has a greater effect on the test results. For this experiment, F values greater than 5.59 are considered to be statistically significant. These results are shown as shaded cells in the table. Analysis of the experiment is conducted on the results from the three labs independently. This independence prevents the possibility of variations associated with one lab from affecting the results from other labs.

It can be seen that test temperature was significant for both mixtures in all labs. Also, air void contents and compactor type were significant in five of the six cases. The other factors do not appear to have a consistent effect on results.

Results from Lab 1, Material 1 were unusual in that this was the only experiment that showed preheat time, wheel load, and hose pressure as significant factors. A more thorough review of these results indicated that the relatively high F values were largely due to a very small experimental error (the denominator in the F ratio). The small experimental error can be attributed to the very good repeatability from round one to round two for the low rut mixture in Lab 1.

Table 7. Ruggedness Study Analysis, F values

Lab	Material	Air Voids	Test Temp	Preheat Time	Wheel Load	Hose Press.	Comp. Type	Dummy Factor
1	1	13.28	73.79	10.89	18.76	21.56	2.20	0.48
	2	33.37	9.21	0.10	1.09	0.72	27.33	9.92
2	1	9.00	18.19	0.15	4.44	1.36	6.14	0.00
	2	41.72	25.45	0.13	2.95	0.26	29.03	19.46
3	1	20.79	31.30	0.63	1.76	0.57	30.10	1.25
	2	3.74	32.37	4.31	0.01	0.02	16.66	0.40

Note: shaded cells indicate results that were statistically significant.

Analysis from a Simple Approach

The study data were also evaluated in an alternate manner that may be less statistically valid but was felt to provide a more common sense perspective on the magnitude of the variations caused by the study factors. Following is a description of this method of analysis.

1. An average rut depth for each of the 32 tests was calculated from the results of the three labs. No data were excluded.
2. The test results were grouped according to the mix type (high or low rutting potential). Tests on the low rut potential mixture were tests 1 through 8 and 17 through 24; tests on the high rut potential were tests 9 through 16 and 25 through 32.
3. For each of the seven study factors, test results corresponding to the high factor level were averaged and compared to the average of results from low factor level. For example, on the low rut potential mix, the tests conducted with 6% air void contents were test numbers 1, 2, 3, 4, 17, 18, 19 and 20; tests conducted with 8% air void contents were test numbers 5, 6, 7, 8, 21, 22, 23, and 24.

4. Table 8 was constructed to summarize the comparison of average results for each of the study factors.

Table 8. Average Results (mm) at Each Factor Level

Factor	Factor Level	Mix 1	Mix 2
Air Voids	6%	3.34	7.38
	8%	4.13	9.92
	Difference	0.79	2.53
Test Temperature	55 C	3.13	7.14
	60 C	4.34	10.16
	Difference	1.22	3.02
Preheat Time	6 hrs.	3.80	9.07
	24 hrs.	3.67	8.77
	Difference	0.13	0.80
Wheel Load	105 lbs.	3.98	8.92
	95 lbs.	3.49	8.42
	Difference	0.48	0.51
Hose Pressure	105 psi	3.84	8.75
	95 psi	3.63	8.59
	Difference	0.22	0.16
Compactor / Specimen Type	AVC	3.40	10.17
	SGC	4.09	7.19
	Difference	-0.69	2.99
Dummy factor		3.80	7.96
		3.67	9.38
	Difference	0.13	-1.42

Based on the experience of the analysis team, it was felt that differences observed for wheel load and hose pressure were relatively minor for both mixtures. The largest differences for both mixtures were observed with test temperature, air voids, and compactor/specimen type. The outcome of these comparisons provides confirmation of the findings of the formal analysis.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The greatest variations from the low factor level to the high factor level are test temperature, specimen air void contents, and compactor type/specimen type. These factors must be controlled more closely than the ranges used in the ruggedness study.

The analysis clearly showed that the test temperature has a major effect on the test results. The temperature range evaluated in this study was from 55° to 60°C. Calibration measurements in one laboratory indicate that the temperature of the APA testing chamber is uniform to within 0.4°C in a static condition. However, results of the calibration also demonstrated that the set point temperature on the APA and the actual chamber temperature were about 5°C different. Proper calibration of the APA chamber temperature and ovens for preheating specimens is critical in obtaining meaningful test results.

For specimen air void contents, the current procedure allows a range of 6.0 to 8.0 percent. Tightening of this range will reduce the variability in the rut test results. However, reducing the air void range will also affect the productivity of labs because of having to discard samples out of the tighter range. In this study, approximately one third of the beams compacted in the AVC were discarded, and one sixth of the cylinders compacted in the SGC were discarded, due to the ±0.5% tolerance on air void contents.

The third factor that had a significant effect on test results was method of compaction/specimen type. Analysis of the data indicated that for the low rut mixture, the cylinders compacted in the SGC tended to yield higher rut depths than beams compacted with the AVC. However, the trend was reversed for the high rut mix; the results of the SGC cylinders were lower on average than the AVC beams. A plausible explanation for the latter effect is that the center part of the cylinder mold between the two specimens supports the load when the rut depth advances to the depth of the contour at the center of the mold.

The ranges evaluated in this study for preheat time, wheel load, and hose pressure did not have a significant effect on the rut test results. Therefore, the current procedure gives adequate guidance on the control of each of these test parameters. However, calibration of the wheel loads and the hose pressure are necessary to assure that the loads and pressures are as accurate and uniform as possible.

Comparisons of the results from replicate tests within each lab indicate that the procedure can give very good repeatability. A greater attention to calibration and the use of single operators in the labs probably contributed to the consistent results.

Recommendations

Each of the following changes or additions to the procedure should result in improved precision of the APA rutting test.

1. The air void content range of specimens given in the procedure should be changed from 7 ±1.0% to 7 ±0.5 %.
2. Calibration of the APA test chamber temperature, preheating ovens, wheel loads, and hose pressure should be required at a minimum frequency of once per year.
3. The method of compaction and specimen geometry should be standardized by individual agencies based upon their particular preferences. Since neither compaction method has been demonstrated superior, it is not appropriate to define one method as the standard on a national basis. However, since significantly different results may be obtained depending on the method of compaction and/or specimen geometry, it is important for an agency to establish which method will be used to make judgements on mixture quality.
4. The preheated APA chamber should not be opened more than 6 minutes when securing the test specimens into the machine.
5. For manual measurements of rut depths, as used in this study, the time that the chamber doors are opened to make the measurements should be 6 minutes or less. After the measurements are taken and the doors are closed, a 10 minute temperature restabilization period should be observed prior to resuming the test.
6. For evaluating potential outlier data from within a test set, it is recommended that the standard deviation of the average rut depths from the three test positions be

determined for all tests. A standard deviation ∃ 2.0 mm is suggested as a preliminary criterion to identify test results with potential outlier data. For test results exceeding this limit, the position with the rut depth farthest from the average can be discarded. The testing procedure and calibration should be investigated to determine possible causes for the excessive variation.

Additional studies should be made in regard to the following issues.

1. The confounding of specimen type and compactor type should be studied in further experiments to determine if the observed differences are due to mold effects, specimen geometries, aggregate particle orientations, or density gradients.
2. The potential of density gradients (air void gradients) within specimens should be studied. Such a study should evaluate density variations with specimens compacted in the gyratory compactor, the vibratory compactor, and field compacted specimens. This study should help determine if differences may occur if the top or bottom of the specimen is tested in the APA.
3. More information needs to be provided to users on how often the hoses should be replaced. The guidance from PTI on how to replace the hoses should be referenced in the test method.

APPENDIX A
Mix Design Information

Mix Design Information

Materials Description	Source
#67 granite	Vulcan Materials, Columbus, GA
M10's granite	Vulcan Materials, Columbus, GA
PG 64-22	Ergon, Inc., Jackson, MS

Combined Aggregate Gradation:

Sieve	Percent Passing
19.0 mm (3/4")	100
12.5 mm (1/2")	95
9.5 mm (3/8")	86
4.75 mm (No.4)	61
2.36 mm (No.8)	33
1.18 mm (No.16)	23
0.60 mm (No.30)	16
0.30 mm (No.50)	13
0.15 mm (No.100)	9
0.075 mm (No.200)	4.0

The mixture was designed in accordance with Superpave to the following compaction level:

$N_{initial} = 7$
$N_{design} = 76$
$N_{maximum} = 117$

The design asphalt content was determined by stopping compaction at N_{design}.

Design asphalt content was 5.1% by weight of total mix. This was the asphalt content used for Mix 1. For Mix 2, the asphalt content was increased by 1.5% to 6.6% to make a high rutting mixture.

APPENDIX B
Air Void Contents of Test Specimens

Tests on Beam Specimens							
Lab	Test	Sample Numbers			Air Void Contents		
		L	C	R	L	C	R
1	1	74	32	25	5.5	5.5	5.9
1	4	67	48	10	5.7	6.3	6.4
1	5	32	53	11	8.1	8.4	8.1
1	8	17	40	37	8.0	7.8	7.8
1	9	44	16	18	6.0	6.2	5.8
1	12	39	4	28	6.2	6.0	6.4
1	13	43	61	25	7.6	8.1	8.1
1	16	18	45	46	8.0	7.9	8.2
1	17	18	33	50	6.5	6.2	6.0
1	20	55	4	34	6.5	6.5	5.9
1	21	49	6	45	8.2	7.9	8.2
1	24	35	44	7	7.8	8.1	7.8
1	25	25	37	15	5.9	5.9	6.0
1	28	31	12	22	5.8	5.5	5.6
1	29	24	41	56	7.9	8.4	8.5
1	32	44	55	22	8.0	7.7	7.8
2	1	24	15	69	5.7	5.7	6.3
2	4	52	23	37	6.3	6.0	6.3
2	5	57	48	20	8.4	8.3	8.5
2	8	58	41	19	8.3	7.8	7.5
2	9	38	43	21	5.8	5.8	5.5
2	12	42	36	20	5.8	5.6	5.9
2	13	40	26	59	8.3	8.4	7.8
2	16	21	50	47	7.5	7.8	8.0
2	17	59	14	39	6.1	6.2	6.5
2	20	62	22	42	5.5	5.5	6.1
2	21	13	39	54	7.9	7.7	8.0
2	24	55	38	9	8.1	7.5	7.5
2	25	41	9	30	6.4	5.7	6.2
2	28	40	32	17	5.8	6.1	6.1
2	29	20	28	53	8.1	8.5	7.6
2	32	27	32	54	8.0	8.1	7.9
3	1	7	21	65	5.7	5.9	5.6
3	4	5	20	57	6.3	6.1	6.3
3	5	42	14	33	8.1	7.7	7.9
3	8	50	2	34	7.7	7.5	7.9
3	9	2	35	26	5.7	6.0	5.5
3	12	14	45	34	6.1	5.9	6.2
3	13	36	51	4	8.1	8.4	7.5
3	16	35	52	5	7.7	8.5	8.2
3	17	11	29	73	5.9	5.7	5.9
3	20	17	43	46	6.5	6.1	5.6
3	21	36	22	30	7.6	7.5	8.1
3	24	46	15	28	8.5	7.5	8.2
3	25	19	29	27	6.5	6.0	5.6
3	28	23	33	24	5.8	5.9	5.9
3	29	23	58	2	7.8	8.5	7.6
3	32	31	60	19	8.0	7.5	7.9

Tests on Cylindrical Specimens													
Lab	Test	Sample Numbers						Air Void Contents					
		L1	L2	C1	C2	R1	R2	L1	L2	C1	C2	R1	R2
1	2	54	59	28	21	35	18	5.8	6.0	5.9	5.9	5.8	6.2
1	3	41	69	19	73	46	71	5.8	5.8	6.1	5.8	5.8	5.9
1	6	67	61	82	55	70	15	7.9	8.1	7.9	7.8	7.8	7.7
1	7	3	72	14	49	26	39	8.1	7.9	8.5	7.6	7.8	7.5
1	10	3	71	13	72	44	24	5.7	5.8	5.9	6.0	6.2	6.4
1	11	61	33	17	23	62	43	5.9	6.3	5.7	6.2	6.0	6.2
1	14	13	99	6	80	61	54	8.1	7.5	7.8	8.1	7.9	8.5
1	15	65	20	97	71	96	25	8.4	8.0	7.6	8.4	8.5	7.9
1	18	32	49	64	47	30	74	6.1	6.1	5.8	5.9	6.1	5.9
1	19	52	45	42	66	37	43	6.1	5.9	5.9	5.9	6.0	5.6
1	22	37	13	77	20	11	33	8.2	8.1	8.0	7.8	8.4	7.8
1	23	23	85	18	71	12	81	8.1	7.7	7.7	7.6	8.5	7.7
1	26	75	64	51	5	18	53	5.7	6.3	6.0	6.0	5.9	5.9
1	27	66	16	54	6	67	38	6.4	5.9	5.8	5.8	6.2	6.0
1	30	1	44	55	89	10	67	7.7	8.2	8.1	7.7	8.0	8.4
1	31	2	91	84	28	33	57	7.8	7.9	7.6	7.8	7.7	8.0
2	2	27	55	61	1	48	58	5.9	5.8	6.0	6.3	5.9	6.3
2	3	40	68	33	51	75	24	6.0	5.7	5.8	6.0	5.9	5.9
2	6	31	7	27	86	74	51	7.6	8.5	8.2	8.3	7.7	7.7
2	7	47	24	29	78	73	38	7.7	8.1	7.9	8.0	7.7	7.6
2	10	4	74	32	30	35	65	6.0	6.5	5.7	6.0	6.0	6.0
2	11	47	69	25	37	63	10	5.7	6.0	5.7	5.5	6.2	5.7
2	14	27	94	77	36	16	49	8.2	8.2	7.7	8.2	8.1	8.1
2	15	32	24	30	35	86	88	8.4	8.1	8.2	8.5	8.3	8.1
2	18	29	11	70	56	15	36	6.0	5.7	5.7	5.5	6.4	5.7
2	19	62	34	83	38	63	81	6.0	6.0	6.2	6.2	5.7	5.8
2	22	84	57	28	64	48	9	7.5	7.9	7.5	8.1	7.6	7.9
2	23	87	30	52	2	62	75	8.1	7.7	8.0	8.0	7.7	7.8
2	26	52	21	15	76	39	26	5.6	6.0	6.2	6.0	6.3	5.8
2	27	77	1	41	19	34	22	5.6	6.4	6.2	5.8	5.9	5.7
2	30	64	56	66	23	59	47	8.4	7.7	8.4	8.0	8.0	8.5
2	31	18	12	15	53	11	4	8.5	7.6	7.7	7.5	7.8	7.8
3	2	10	13	23	67	82	44	5.9	6.3	5.9	5.8	6.2	5.9
3	3	12	20	25	50	60	85	5.5	5.5	5.8	5.7	5.9	
3	6	8	45	34	56	25	80	8.3	7.7	7.8	7.7	7.8	7.9
3	7	19	68	36	79	53	63	8.0	7.7	7.8	8.3	7.9	8.2
3	10	14	29	36	46	57	68	5.9	5.9	6.0	6.0	6.2	6.3
3	11	7	20	31	48	55	70	5.8	5.7	6.1	6.2	6.1	6.2
3	14	9	21	31	41	62	90	8.0	7.5	7.6	8.3	8.1	7.9
3	15	3	26	39	58	87	95	7.5	8.3	8.1	8.5	7.6	8.2
3	18	14	76	39	72	26	17	5.9	5.8	5.8	5.9	5.9	6.1
3	19	57	77	22	31	16	65	5.7	5.8	5.9	5.8	6.3	5.8
3	22	21	46	32	54	59	66	8.0	7.9	8.4	7.7	8.2	7.9
3	23	22	58	60	65	76	83	8.1	8.0	7.9	7.9	8.1	7.5
3	26	9	40	56	59	73	45	6.2	6.3	5.8	6.0	6.0	6.0
3	27	2	11	28	50	60	49	6.2	6.2	5.6	5.8	5.7	6.2
3	30	5	8	17	51	75	98	7.8	8.2	7.8	8.3	7.9	8.4
3	31	7	19	29	42	76	93	8.2	8.0	7.8	8.5	8.2	8.0

APPENDIX C
Calibration Instructions

Calibration

Each of the three participating labs should calibrate the following items: (1) preheating ovens, (2) APA temperature, (3) APA wheel load, and (4) APA hose pressure. Instructions for each of these calibration checks is included in this section. Calibrations should be performed before beginning test #1 and test #17.

<u>Preheating Ovens Calibration</u>

1. The ruggedness testing schedule requires that you have two ovens for preheating samples. One oven will be set at a temperature of 55 C and the other will be set at 60 C.
2. The ovens must be calibrated with a NIST traceable thermometer (an ASTM 65 C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.

<u>Temperature Stability</u>

3. Set the oven to the chosen temperature (55 or 60 C). Place the thermometer in the well and place them on the center of the shelf where the samples and molds will be preheated.
4. It usually takes an hour or so for the oven chamber, well and thermometer to stabilize. After one hour, open the oven door and read the thermometer without removing it from the well. Record this temperature. Close the oven door.
5. Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature.
6. If the readings from step 4 and 5 are within 0.4 C, then average the readings. If the readings differ by more than 0.4 C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4 C on two consecutive readings.

<u>Temperature Uniformity</u>

7. To check the uniformity of the temperature in the oven chamber, move the thermometer and well to another location in the oven so that they are on a shelf where samples and molds will be preheated, but as far as possible from the first location.
8. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4 C.
9. Compare the average of the two readings at the first location with the average of the stabilized temperature at the second location. If the average temperatures from the two locations are within 0.4 C, then the oven temperature is relatively uniform and it is suitable for use in the ruggedness study. If the average of the readings at the two locations differ by more than 0.4 C then you must find another oven that will hold this level of uniformity and meets calibration.

<u>Temperature Accuracy</u>

10. Average the temperatures from the two locations. If that average temperature is within 0.4 C of the set point temperature on the oven, then the oven is reasonably accurate and calibration is complete.
11. If the set point differs from the average temperature by more than 0.4 C, then adjust the oven set point appropriately to raise or lower the temperature inside the chamber so that the thermometer and well will be at the desired temperature (55 or 60 C).
12. Place the thermometer and well in the center of the shelf. At thirty minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4 C, and the average of the two consecutive readings are within 0.4C of the desired test temperature (either 55 C or 60 C), then the oven has been properly adjusted and calibration is complete. If these two conditions are not met, then repeat steps 11 and 12.

APA Temperature Calibration

1. The APA will be calibrated for testing at two temperatures: 55 C and 60 C.
2. The APA must be calibrated with a NIST traceable thermometer (an ASTM 65 C calibrated thermometer is recommended) and a metal thermometer well to avoid rapid heat loss when checking the temperature.

Temperature Stability

3. Turn on the APA main power and set the chamber temperature controller so that the temperature inside the testing chamber is about 55 C. Also, set the water temperature controller to achieve approximately 55 C water temperature. (Note-experience with the APAC APA has shown that it is necessary to set the controller to about 119 F to achieve a chamber temperature of 55 C.)
4. Place the thermometer in the well and place them on the left side of the shelf where the samples and molds will be tested. (Note-it may be helpful to remove the hose rack from the APA during temperature calibration to avoid breaking the thermometer.)
5. It usually takes about five hours for the APA to stabilize. After the temperature display on the controller has stabilized, open the chamber doors and read the thermometer without removing it from the well. Record this temperature. Close the chamber doors.
6. Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature.
7. If the readings from step 4 and 5 are within 0.4 C, then average the readings. If the readings differ by more than 0.4 C then continue to take readings every thirty minutes until the temperature stabilizes within 0.4 C on two consecutive readings.

Temperature Uniformity

8. To check the uniformity of the temperature in the APA chamber, move the thermometer and well to the right side of the shelf where the samples are tested.
9. Take and record readings of the thermometer at the second location every thirty minutes until two consecutive readings at the second location are within 0.4 C.
10. Compare the average of the two readings at the left side with the average of the stabilized temperature at the right side. If the average temperatures from the two locations are within 0.4 C, then the APA temperature is relatively uniform and it is suitable for use in the ruggedness study. If the average of the readings at the two locations differ by more than 0.4 C then consult with PTI on improving temperature uniformity.

Temperature Accuracy

11. Average the temperatures from the two locations. If that average temperature is within 0.4 C of the desired temperature of 55 C, then the APA temperature is reasonably accurate and calibration is complete.
12. If the average temperature differs from the desired temperature of 55 C by more than 0.4 C, then adjust the APA temperature controller so that the thermometer and well will be at the desired temperature of 55 C.
13. Place the thermometer and well in the center of the shelf. At thirty minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4 C, and the average of the two consecutive readings are within 0.4C of the desired test temperature of 55 C, then the oven has been properly adjusted and calibration at that temperature is complete. Record the current set points on the temperature controllers for later reference. If these two conditions are not met, then repeat steps 12 and 13.
14. Adjust the chamber and water temperature controllers to bring the temperature up to 60 C. At thirty minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4 C, and the average of the two consecutive readings are within 0.4C of the desired test temperature of 60 C, then the APA temperature has been properly adjusted and calibration at that temperature is complete. Record the current set points on the temperature controllers for later reference. If these two conditions are not met, then repeat this step.

APA Wheel Load Calibration

1. The APA wheel loads will be checked with the calibrated load cell provided with the APA. The loads will be checked and adjusted one at a time while the other wheels are in the down position and bearing on a dummy sample or wooden block of approximately the same height as a test sample. Calibration of the wheel loads should be accomplished with the APA at room temperature. A sheet is provided to record the calibration loads.
2. Remove the hose rack from the APA.
3. Jog the wheel carriage until the wheels are over the center of the sample tray when the wheels are in the down position.
4. Raise and lower the wheels 20 times to heat up the cylinders.
5. Adjust the bar on top of the load cell by screwing it in or out until the total height of the load cell-load bar assembly is 105 mm.
6. Position the load cell under one of the wheels. Place wooden blocks or dummy samples under the other two wheels.
7. Zero the load cell.
8. Lower all wheels by turning the cylinder switch to CAL.
9. If the load cell is not centered left to right beneath the wheel, then raise the wheel and adjust the position of the load cell.
10. To determine if the load cell is centered front to back beneath the wheel, unlock the sample tray and move it SLOWLY until the wheel rests in the indention on the load cell bar (where the screw is located).
11. After the load cell has been properly centered, adjust the pressure in the cylinder to obtain 95 ∀ 1 lbs. Allow three minutes for the load cell reading to stabilize between adjustments. Record the pressure and the load.
12. With the wheel on the load cell remaining in the down position, raise and lower the other wheels one time. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.
13. With the other wheels remaining in the down position, raise and lower the wheel over the load cell. Allow three minutes for the load cell reading to stabilize. Record the pressure and the load.
14. Repeat steps 6 through 12 for each wheel/cylinder.
15. Return the load cell to the first wheel and repeat steps 6 through 12.
16. Place the load cell under the second wheel and repeat steps 6 through 12.
17. Place the load cell under the third wheel and repeat steps 6 through 12.
18. The current cylinder pressures will be used to set wheel loads to 95 lbs.
19. Repeat steps 6 through 16 except that the target load in step 10 shall be 105 ∀ 1 lbs. The cylinder pressures at the end of these iterations will be the pressures used to set the wheel load to 105 lbs.

APA Hose Replacement and Pressure Check

1. New hoses shall be placed in service prior to test # 1 and test # 17. Only hoses provided by PTI shall be used.
2. Remove the hose rack from the APA.
3. Remove the used hoses from the hose rack. Place the new hoses on the barbed nipples and secure with the hose clamps.
4. Position the hoses in the rack such that the hose curvature is vertical. Tighten the nuts at the ends of the hoses only until the hoses are secure. Over-tightening will effect the contact pressure and hose life.
5. Place the hose rack back into the APA and make sure that the hoses are aligned beneath the wheels.
6. Prior to testing the ruggedness samples, break in the new hoses by conducting one 8000 cycle test at 49 C (120 F) or higher.

APPENDIX D
Ruggedness Test Procedure and Schedule

TEST METHOD FOR RUGGEDNESS STUDY
ON THE ASPHALT PAVEMENT ANALYZER RUTTING TEST PROCEDURE

1. SCOPE

1.1 This procedure is to be used only for the ruggedness study on the APA rutting test procedure. The purpose of the ruggedness study is to identify the test variables, referred to as experimental factors, which cause the greatest amount of variability in test results. The six experimental factors evaluated in the study are: air void content, test temperature, preheating time, wheel load, hose pressure, and compactor type. This is a highly controlled experiment which requires the use of dependable laboratories, equipment, and technicians. All samples have been prepared by one laboratory under controlled batching, mixing, and compaction procedures.

2. GENERAL INSTRUCTIONS

2.1 Store the test specimens at approximately 77° F until preheating is ready to begin. Take care to avoid damaging the specimens during handling.

2.2 Calibration of the preheating ovens and APA settings is very important. Each lab should follow the instructions on calibration prior to test # 1 and test # 17.

2.3 Each laboratory shall carefully follow this procedure and the accompanying schedule. The schedule should be used as a check list to make sure that all test conditions have been properly adjusted. Results shall be recorded on the worksheets provided. Results should be faxed to APAC Materials Services each day where they will be reviewed.

3. PROCEDURE

3.1 Place the preconditioned specimens and molds in the preheated APA and secure. This step shall be timed so that the APA chamber doors are open for exactly 6 minutes. After the doors are closed, wait exactly 10 minutes for the temperature to stabilize back at the designated test temperature before proceeding to the next step.

3.2 Start the APA to apply 10 seating cycles.

3.3 After the 10 seating cycles, stop the APA, open the chamber doors, unlock the sliding tray and pull the tray out.

3.4 Place the rut depth measurement template over the specimen. Make sure that the rut depth measurement template is properly seated and firmly rests on top of the testing mold.

3.5 Zero the digital measuring gauge so that the display shows 0.00 mm with the gauge completely extended. The display should also have a bar below the "inc." position. Take initial readings at each of the center three positions for beams or outer four positions for cylinders. Measurements shall be determined by placing the digital measuring gauge in the template slots and sliding the gauge slowly across the each slot. Record the smallest measurement for each location to the nearest 0.01 mm.

3.6 Repeat steps 3.4 and 3.5 for each beam or cylinder pairs.

3.7 The time for the APA chamber doors to be open during the initial measurements described in 3.3 to 3.6 shall be exactly 6 minutes.

3.8 Push sample holding tray in and secure. Close the chamber doors. Wait exactly 10 minutes to allow the temperature to stabilize back at the designated test temperature before starting the test.

3.9 Set PRESET COUNTER to 8000 cycles.

3.10 Start the test. At 8000 cycles, the APA will stop.

3.11 Open the chamber doors, unlock and pull out the sliding tray. Take rut-depth measurements as stated in steps 3.4 through 3.6.

3.12 Remove the specimens and molds from the APA. If another test is to be completed in the same day, take the final measurements and remove the samples as quickly as possible to minimize heat loss from the APA.

4. CALCULATIONS

4.1 The rut depth at each location is determined by subtracting the measurements at 8000 cycles from the initial measurement.

4.2 Determine the average rut depth for each specimen at 8000 cycles.

4.3 The APA rut depth result for the test is the average of the three beams or three pairs of cylinders.