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DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
OFFICE OF MATERIALS ENGINEERING AND TESTING SERVICES

A FIELD PROCEDURE FOR DETERMINING THE TEST MAXIMUM DENSITY OF ASPHALT CONCRETE

REPORT NUMBER FHWA/CA/TL-95/12
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A procedure for determining the test maximum density of asphalt concrete in a field laboratory was developed and then tried on several paving projects. This test maximum density is required to determine the in-situ relative compaction of asphalt concrete per California Test 375. The procedure involves the use of a hydraulic jack to apply a 133 500 N static load for compaction in lieu of using a kneading compactor. Although the test maximum densities achieved by this static loading are normally lower than the values determined using a kneading compactor, a correlation factor can be determined and applied. In most cases, the test results can be available within two hours of obtaining a sample of the material.

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ACKNOWLEDGMENTS

This report contains the findings of the research project titled, "Develop a Field Method to Determine the Test Maximum Density of Asphalt Concrete" which was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

The laboratory testing phase of this study was done by the Flexible Pavement Branch of the Office of Pavement. Duane Anderson conducted most of the compaction and specific gravity tests with assistance from other members of that group.

Materials and construction personnel in several Caltrans districts participated in the field testing phase. The number of people who contributed to this phase of the study is too large to list without the risk of overlooking some. However, special acknowledgment is extended to Jose Arguello (District 06) and John LaBar and Chuck Oaks (District 11). Their efforts accounted for more than half of the total number of individual field tests included in this study.

Appreciation is also extended to Linda Petavine for her efforts in typing and editing this report as well as the accompanying California Test 375.

INTRODUCTION

The objective of this study was to develop a quick, reliable procedure for determining the test maximum density of asphalt concrete in a field laboratory. This test maximum density is required to determine the in-situ relative compaction of asphalt concrete pavement in accordance with California Test 375. A procedure was developed that involves using a portable hydraulic jack and loading frame which can be transported in a pick-up truck or van. When necessary and/or desirable, the compaction phase of the procedure can be done in the transport vehicle at the job site.

Under most conditions, the test results can be available within two hours of obtaining a sample of the material for testing. Some materials, such as rubberized asphalt mixes, may require more time to allow the test samples to cool sufficiently to prevent deformation when they are removed from the compaction mold.

The test maximum densities determined by the proposed field procedure are not the same as the test maximum densities determined by the current laboratory procedure, but the correlation between the two values is consistent enough that a correlation factor can be applied.

FINDINGS AND CONCLUSIONS

The proposed static loading method of compacting asphalt concrete test specimens to determine test maximum density is a practical procedure that can be used in a field laboratory or in the back of a pick-up truck at the paving site.

The proposed compaction procedure is as repeatable as the current laboratory test procedure which requires the use of a kneading compactor that must be maintained and operated in a permanent laboratory.

The test maximum density values determined by the proposed field procedure are almost always lower than the values determined by the current laboratory procedure. However, these differences are generally predictable and can be compensated for by applying a correlation factor to the test maximum density determined by the field procedure or by revising the relative compaction requirements based on the lower test maximum density value. In most cases, the test maximum density values determined by the field procedure are approximately 97% to 98% of the test maximum density values determined by the laboratory procedure.

The use of asphalt rubber binder has a significant effect on the correlation between the test maximum density values determined by the two methods. On each of the two field projects where asphalt rubber binder was used, the test maximum density determined by the field procedure was only 92% of the test maximum density determined by the laboratory procedure.

RECOMMENDATIONS

It is recommended that the proposed field procedure be adopted as an alternative to the current laboratory procedure for determining the test maximum density of asphalt concrete.

At the beginning of a paving project where relative compaction is specified, a correlation factor should be determined. This correlation factor would then be used to adjust the field test maximum density values to coincide with laboratory test maximum values for all subsequent testing on the project.

All relative compaction testing using the field test maximum density procedure over the first year of use should be monitored to determine if the relative compaction requirements can be revised to allow the use of the field test maximum density without adjustment.

Additional testing should be done to identify and correct the causes of the large difference between the field and laboratory test maximum densities when asphalt rubber is used.

IMPLEMENTATION

California Test 375 has been revised to allow the use of the field procedure for determining test maximum density. Even though final approval of this change has not been received at the time of this writing, many of the Caltrans Districts are anxious to adopt it. Several Caltrans Districts have purchased the equipment necessary to perform the test in anticipation of putting it into use as soon as authorization to do so is received.

BACKGROUND

In 1985, Caltrans completed a research project[1] to develop a test procedure for determining the in-place density and relative compaction of asphalt concrete (AC) pavements and an end-result specification for evaluation and acceptance. These procedures and specifications were then applied to selected projects on a trial basis and the results were reported in a follow-up study completed in 1988[2]. The outcome of these studies has been a greater acceptance and an increasing use of end-result compaction specifications for AC pavements in California.

As use of the relative compaction test[3] and application of end-result specifications[4] increased, there has also been an increasing need for a field procedure which can be used to provide a test maximum density (TMD) in a short period of time. The current TMD procedure requires that the test specimens be compacted using a kneading compactor which is available only in a district central laboratory or at the Caltrans headquarters laboratory. Because of time lost in transporting and reheating the material and work loads in these central laboratories, completion of the TMD tests are frequently delayed for several days. This inability to provide timely TMD values makes it difficult to effectively administer the end-result compaction specifications.

Data presented in a minor research project[5] indicated that compacting test specimens by static load, in lieu of with a kneading compactor, could make it possible to determine the TMD in a field laboratory. Tests on materials from five paving projects showed compaction by static load resulted in densities that were consistent, but slightly lower than, the densities of samples compacted using a kneading compactor. The correlation between the results by the two procedures was close enough to prompt further evaluation of this alternative procedure.

TESTING PROCEDURES

The objective of this study was to develop a quick, reliable field procedure for establishing the TMD of asphalt concrete paving materials. It was not believed to be necessary to duplicate the TMD currently being determined in the central laboratories using kneading compactors as long as there was a reasonably consistent relationship between the densities achieved by the two procedures.

A static loading method of compaction was selected for trial because of the simplicity of both equipment and procedure. In the central laboratory, the static load could be applied by a broad variety of testing machines. A hydraulic jack with appropriate load frame could provide an inexpensive, portable compression apparatus for the field laboratory or job site.

The test procedures and equipment used in this study to compact asphalt concrete to test maximum density were adaptations from California's procedure for testing cement treated bases (CTB)[6]. Some modifications to the CTB testing procedures were made prior to beginning this study while other changes and refinements were made as the need became apparent during the course of the work.

The procedure for preparing CTB test specimens requires placing the loose material in the compaction mold and then working it with a 9.5 mm diameter rod to eliminate rock pockets. Preliminary testing revealed that this was not always possible with AC materials. Frequently, asphalt sticking to the rod actually pulled the sample apart, thereby creating voids and making it difficult to keep the material in the mold. This step was eliminated from the procedure prior to beginning the field testing. Compaction of CTB specimens is accomplished by first tamping the material with a 2.7 kg, 25.0 mm diameter bar followed by application of a 66 750 N static load. To simplify the test and reduce the time required, it was decided to eliminate the tamping procedure and increase the static load to 133 500 N.

Three methods were used to determine the specific gravity of the compacted test specimens. One method used height and diameter measurements to calculate the volume of the compacted specimen. The other two methods followed the procedures in California Test 308[7] Method A (waxed specimen) and Method C (unwaxed specimen) to determine the volume by water displacement. All three methods were used in this study to determine which is best suited for determining specific gravity under field conditions.

The findings of this study, as well as additional modifications and refinements, are discussed below.

LABORATORY TESTING

The objective of the laboratory testing phase of this study was to determine if the correlation between densities achieved by the current laboratory compaction procedure and the densities achieved by the proposed field compaction procedure is affected by variations in the AC mix. Variables of concern were the grading, angularity and porosity of the aggregate, the source of the asphalt cement, and the temperature of the mix at the time of compaction.

Two sources of aggregate were selected for this determination. One was a non-absorptive material which required from 4.5% to 6.0% asphalt (by dry weight of the aggregate) depending on the grading of the aggregate. The other was more absorptive and required from 5.5% to 7.8% asphalt for the same variation in grading. Both sources consisted of naturally rounded aggregate with sufficient quantities of large rock for crushing to allow preparation of either Type A (90% crushed particles) or Type B (25% crushed particles) mixes.

Three aggregate gradings were selected for use with both aggregates. These gradings covered the widest range possible under the California Standard Specifications. At the one extreme, the coarsest allowable grading for 31.5 mm maximum AC base was used and at the other extreme the finest allowable grading for 9.5 mm maximum AC was used. The third grading was the mid-point between these two extremes.

The coarse graded mixes were prepared as Type A mixes and the fine graded mixes were prepared as Type B mixes. Both Type A and Type B mixes were prepared using the mid-range grading. The gradings used in the different mixes are tabulated in Table 1. The following discussion will refer to these various mixes as "Ac" (Type A coarse), "Am" (Type A medium), "Bm" (Type B medium), and "Bf" (Type B fine).

Asphalt cements were obtained from Conoco and Golden Bear. AR-4000 asphalt from each source was used with each of the aggregate gradings. A limited number of tests were also performed using AR-2000 and AR-8000 asphalts.

The testing of the Type A mid-range aggregate also included some variation in the temperature at the time of compaction.

Table 1
GRADINGS OF AGGREGATES
USED IN LABORATORY TESTING
(Percent Passing)

Sieve Size (mm)	Non-Absorptive Aggregate				Absorptive Aggregate			
	Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
31.5								
25.0	100	100			100			
19.0	83	99	100		83	100	100	
12.5	64	84	85		66	85	85	
9.5	52	76	76	100	52	76	75	100
4.75	36	56	54	79	38	61	55	84
2.36	28	43	46	67	25	43	39	65
1.18	18	30	33	53	17	32	32	52
0.60	14	24	25	40	12	24	24	42
0.30	9	14	12	21	9	15	19	26
0.15	7	9	8	12	6	10	12	15
0.075	5	6	5	10	4	6	7	9

The work plan called for laboratory testing to be completed prior to conducting the field testing. Heavy work loads and higher priority testing in the laboratory made it impossible to complete the laboratory testing in a timely manner. As a result, most of the field testing was completed before the laboratory testing. Because of this change in the order of the work and because of the success of the field testing, it was possible to reduce the amount of laboratory testing indicated in the work plan.

For the laboratory testing phase of the study, the "field" compaction procedure was performed using a universal testing machine in lieu of the portable hydraulic jack. The loading rate of the testing machine was controlled manually to gradually increase the load over a one-half-minute time period to the specified 133 500 N total load.

Presentation and Analysis of Test Data

The results of all of the laboratory testing are included in Tables A-1 through A-8 in the Appendix of this report. These tables include the specific gravity of each individual test specimen and their averaged value which is used to establish the TMD values. Summaries of the TMD data are presented in Tables 2 and 3. The specific gravity and TMD values were determined on both wax-coated and non-waxed test specimens in accordance with California Test 308, Methods A and C, respectively. Values determined by the two methods are tabulated in separate tables. Unless otherwise noted, all of the following discussion is based on specific gravity and TMD values determined by California Test 308, Method A.

In addition to the specific gravity of each of the three test specimens used to establish the test maximum densities, Tables A-1 through A-8 also include the standard deviations for each set of three test specimens. These standard deviations, when grouped by compaction procedure and mathematically averaged, show that compaction by static loading is at least as repeatable as compaction by the kneading compactor. The average standard deviation of the 32 sets of three test specimens compacted by the laboratory procedure was 0.016, while the average standard deviation of the duplicate series of test specimens compacted by the field procedure was 0.014.

Table 2
SUMMARY OF LABORATORY TESTING
(Specific Gravity Determined by California Test 308A)

			Test Maximum Density								Percent			
			Lab Procedure				Field Procedure				Field TMD/Lab TMD			
			Mix				Mix				Mix			
Agg-regate*	Asphalt*	Temp °C	Ac	Am	Bm	Bf	Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
NA	C/4000	110	2.43	2.35	2.40	2.37	2.38	2.31	2.34	2.27	97.9	98.3	97.5	95.8
"	"	93		2.37				2.34				98.7		
"	"	149		2.36				2.31				97.9		
"	C/2000	110			2.44				2.35				96.3	
"	C/8000	110	2.45				2.38				97.1			
"	GB/4000	110	2.46	2.42	2.40	2.40	2.38	2.34	2.30	2.31	96.7	96.7	95.8	96.3
"	"	93		2.41				2.37				98.3		
"	"	149		2.43				2.35				96.7		
"	GB/2000	110			2.40				2.31				96.3	
"	GB/8000	110	2.44				2.39				98.0			
Abs	C/4000	110	2.26	2.30	2.31	2.24	2.24	2.24	2.28	2.19	99.1	97.4	98.7	97.8
"	"	93		2.27				2.20				96.9		
"	"	149		2.27				2.23				98.2		
"	C/2000	110			2.31				2.27				98.3	
"	C/8000	110	2.24				2.27				101.3			
"	GB/4000	110	2.22	2.30	2.31	2.25	2.23	2.26	2.26	2.19	100.5	98.3	97.8	97.3
"	"	93		2.30				2.27				98.7		
"	"	149		2.31				2.24				97.0		
"	GB/2000	110			2.32				2.26				97.4	
"	GB/8000	110	2.23				2.27				101.8			
Average Percent											99.0	97.8	97.3	96.8
Standard Deviation											1.9	0.8	1.0	0.9
Combined Average Percent													97.9	
Standard Deviation													1.4	

* NA = Non-absorptive; C = Conoco; GB = Golden Bear

Table 3

SUMMARY OF LABORATORY TESTING
(Specific Gravities Determined by California Test 308C)

Agg-regate*	Asphalt	Temp °C	Test Maximum Density: Lab Procedure Mix Ac	Am	Bm	Bf	Field Procedure Mix Ac	Am	Bm	Bf	Percent Field TMD/Lab TMD Mix Ac	Am	Bm	Bf
NA	C/4000	110	2.47	2.36	2.41	2.37	2.41	2.32	2.35	2.28	97.6	98.3	97.5	96.2
"	"	93		2.36				2.34				99.2		
"	"	149		2.38				2.32				97.5		
"	C/2000	110			2.43				2.34				96.3	
"	C/8000	110	2.48				2.42				97.6			
"	GB/4000	110	2.49	2.42	2.40	2.40	2.42	2.36	2.31	2.31	97.2	97.5	96.3	96.3
"	"	93		2.40				2.36				98.3		
"	"	149		2.43				2.36				97.1		
"	GB/2000	110			2.41				2.31				95.9	
"	GB/8000	110	2.45				2.40				98.0			
Abs	C/4000	110	2.32	2.29	2.33	2.25	2.29	2.23	2.29	2.20	98.7	97.4	98.3	97.8
"	"	93		2.26				2.22				98.2		
"	"	149		2.29				2.25				98.3		
"	C/2000	110			2.32				2.28				98.3	
"	C/8000	110	2.32				2.29				98.7			
"	GB/4000	110	2.32	2.29	2.33	2.25	2.29	2.26	2.28	2.19	98.7	98.7	97.9	97.3
"	"	93		2.30				2.27				98.7		
"	"	149		2.31				2.25				97.4		
"	GB/2000	110			2.33				2.28				97.9	
"	GB/8000	110	2.31				2.32				100.4			
Average Percent											98.4	98.1	97.3	96.9
Standard Deviation											1.0	0.7	1.0	0.8
Combined Average Percent													97.8	
Standard Deviation													1.0	

* NA = Non-absorptive; C = Conoco; GB = Golden Bear

The data show that the TMD of an aggregate source is affected by changes in the grading and/or angularity of the aggregate being used in the mix. With the four gradings used in this study, the TMD values differed by as much as 0.09 g/cc when compacted by the laboratory procedure and 0.11 g/cc when compacted by the field procedure. The highest TMD values for the non-absorptive aggregate were established with the "Ac" grading. There was no clear pattern between grading and TMD of the other three gradings. The highest TMD values for the absorptive aggregate were established with the "Bm" grading and the order of the other three varied. It should be noted that the asphalt content, as well as the asphalt source, varied with the different combinations of aggregate sources and gradings. The asphalt content to be used with each combination of aggregate and asphalt was determined by the procedures in California Test 367[8]. Thus, the asphalt content for specific aggregate gradings differed because of changes in the asphalt source. However, the higher asphalt content was not always associated with the same asphalt source.

Some of the differences between the TMD values of different mixes may have been due to these differences in asphalt content. Because of time and monetary constraints, no effort was made to verify the established optimum bitumen contents or to determine the effect of allowable deviations from the selected asphalt content. Although this information could be of value, it was not necessary for evaluating the correlation between Laboratory TMD values and Field TMD values.

Temperature at the time of compaction had very little, if any, effect on the TMD. Only the "Am" grading of each of the two aggregates was used in this evaluation. Differences of up to 0.03 g/cc and 0.04 g/cc are seen, respectively, in the Lab TMD and Field TMD values with compaction temperatures of 93°C, 110°C, and 149°C. These differences in TMD are probably not temperature related since they do not correspond with the changes in temperature. The highest TMD was achieved at 149°C on two of the four laboratory series and none of the field series. In contrast, the highest TMD was achieved at 93°C on one of the laboratory series and three of the four field series. On the other two series of tests the highest TMD value was achieved at 110°C.

None of the variation in TMD could be correlated with changes in the AR grade of the asphalt. The greatest difference in the TMD of samples prepared with AR-4000 and AR-2000 asphalt, or between samples prepared with AR-4000 and AR-8000 asphalt, was 0.04 g/cc. In most cases, the difference was 0.02 g/cc or less and the higher value was not consistent with the AR grade.

The asphalt source was also eliminated as a predictable factor in the variability of TMD values. Most of the differences in TMD were 0.02 g/cc or less and the greatest difference was 0.04 g/cc. The highest values were not consistent with either source of asphalt.

Based on the observations made in the preceding discussion, it is concluded that neither the source of the asphalt, the AR grade of the asphalt, nor the temperature of the mix during compaction had a definable effect on the TMD of the asphalt concrete mix. The variations observed during the evaluation of these factors are random and, therefore, unpredictable.

Correlation Between Results of Laboratory and Field Procedures

The final step in the laboratory testing phase was to determine if there is a correlation between TMD values determined by the laboratory procedure and TMD values determined by the proposed field procedure. Because of the broad range in TMD values for the different combinations of aggregate and asphalt, the TMD values determined by the field procedure were converted to a percentage of the corresponding TMD values determined by the laboratory procedure. These percentages are listed in the right hand columns of Tables 2 and 3.

With the exception of the absorptive "Ac" mix, the relationship between the Field TMD values and Laboratory TMD values is consistent. The percentages determined by dividing the Field TMD by the Laboratory TMD of the same mix varies from 95.8 to 101.8 when all of the test results are included. The average value is 97.9 with a standard deviation of 1.4. When the values determined for the absorptive "Ac" mix are deleted from this analysis, the highest value becomes 98.7, the average is reduced to 97.4, and the standard deviation is reduced to 0.9.

The reason for the different percentage for the absorptive "Ac" aggregate appears to be the relatively low Laboratory TMD value for this mixture. The TMD values for the non-absorptive "Ac" mix were consistently higher than the TMD values of other mixes from the same aggregate source. However, the Laboratory TMD of the absorptive "Ac" mix is consistently lower than the Laboratory TMD values from other mixes from the same source. A review of the mix design data reveals that the asphalt content of this mixture was significantly less than the asphalt content of the other mixes. Although not verified, it is speculated that the low asphalt content made compaction of the mix more difficult. Both the Laboratory TMD and Field TMD were affected, but the effect was greater when the kneading compactor was used to compact the test specimens.

FIELD TESTING

The work plan called for field trails to be made on ten active construction projects throughout the State. A minimum of five samples were to be tested from each project. To reduce the effect of random variations in materials and procedures, each TMD value is the average of five test specimens from a single sample of paving material delivered from the street.

It was anticipated that District personnel would be available to assist in the actual field testing. In many cases this was true, and their observations and input were largely responsible for the success of the study. District personnel were not available on some projects, thus making it necessary for laboratory personnel to gather as much information as possible in the short period of time they could spend on the project. As a result, there were large differences in the amount of data gathered from individual projects. Fewer than five tests were performed on some projects, but in some other instances, the number of tests performed was much greater. Totals of 17 and 67 TMD tests were completed, respectively, on Projects 1 and 3. These additional tests provided a great deal of information over the duration of these extended projects.

Several of the projects incorporated more than one AC mix. As a result, the 14 projects referenced in this study provided data for 19 different mixtures including two with asphalt rubber, one with 30% recycled AC, and nominal maximum aggregate sizes ranging from 12.5 mm to 37.5 mm.

<u>Presentation of Test Data</u>

All of the test data obtained from the various projects are tabulated in Tables A-9 through A-27 of the Appendix. These tabulations include the specific gravity of each individual test specimen as well as the average and standard deviation for each set of five test specimens prepared from the same sample of material. The results from each of the three alternative methods of determining specific gravity are included. Because of the large number of tests performed on Project 3, it was not possible to show all of the data on a single page. However, Table A-11 does include the average and standard deviation values for all of the 67 tests in addition to the results of the eleven tests that are tabulated.

Sample Preparation

The trial procedure specified the use of a riffle splitter to obtain representative 1200 gram portions of the material. It also required maintaining the temperature of these split portions at 110 ± 3°C until they were compacted. This procedure was followed on Project 1, but it quickly became obvious that these requirements would be extremely difficult to meet. Because asphalt concrete mixtures do not always flow freely through the splitter, it was very difficult to obtain test portions of the required size. Also, the excessive handling and exposure to air caused a rapid loss of heat, thus making it necessary to place the material in an oven to regain the specified temperature. In an effort to prevent a rapid loss of heat during the compaction process, the technician on Project 1 also preheated the compaction molds and accessories to 110°C prior to their use.

The data obtained from Project 1 indicated that the proposed test method had potential as a field procedure; however, the use of a riffle splitter and the need to reheat the "split" material were considered to be major draw-backs. Splitting the material to the required portion was labor intensive and reheating the test portions sometimes delayed compaction until the following day. Preheating the compaction molds and accessories also greatly increased the risk of the technician being burned.

Use of the riffle splitter to obtain representative portions was discontinued after the first project. On subsequent projects, the temperature of the bulk sample was monitored but not controlled. In lieu of splitting, the bulk sample was retained in the 18.9 L sample bucket and a small scoop was used to dip out proper sized portions as they were tested. It was found that the bulk sample was not subject to rapid heat loss and, if the technician worked quickly, the loss of heat during weighing and transferring the sample was not sufficient to affect the compaction.

A review of the test data from subsequent projects indicates that the repeatability of the test results was not reduced by allowing the test portions to be dipped rather than split.

No effort was made to determine if the dipped portions were any less representative of the bulk sample than split portions. Although this method of preparation subjected the material to a greater opportunity for segregation and variations in aggregate size distribution, the differences in specific gravities among test specimens in a set of five was usually small. In most cases, the maximum difference between any two test specimens in a set was less than 0.03 g/cc. In some instances, the difference was larger when the mix included 37.5 mm aggregate or asphalt rubber. Overall, the variations were no greater than those for routine laboratory prepared samples.

Effect of Temperature Variations

In some instances, the initial temperature of the mix was well above 110°C when compaction was begun. Also, on several occasions, the temperature was purposely allowed to drop well below 93°C for individual test portions. As a result, there were times when the temperature of individual test portions varied by as much as 38°C with no noticeable effect on the specific gravity of the compacted material. Examples of these temperature variations and corresponding densities are recorded in Table 4. It is assumed that the 133 500 N loading was effective in limiting the effects of variations in temperature.

Table 4
EFFECT OF TEMPERATURE ON COMPACTED DENSITY

Project	Sample Number	Density of Compacted Specimen					Temperature (°F) of Specimen at Compaction				
		1	2	3	4	5	1	2	3	4	5
3	3	2.29	2.28	2.30	2.28		127	118	118	99	
	6	2.25	2.25	2.26	2.25	2.25	124	121	113	99	93
	7	2.26	2.25	2.26	2.27	2.26	146	141	135	110	88
	8	2.27	2.27	2.27	2.26	2.26	146	141	121	116	113
	17	2.26	2.24	2.25	2.26	2.25	143	132	118	116	99
	20	2.25	2.26	2.26	2.27	2.26	132	116	110	104	99
	21	2.28	2.27	2.27	2.26	2.26	102	93	88	82	77
	35	2.26	2.26	2.25	2.26	2.27	121	110	104	99	96
	59	2.27	2.27	2.28	2.28	2.27	160	157	149	143	138
	60	2.27	2.26	2.26	2.26	2.26	113	107	104	102	82
5a	1	2.24	2.24	2.23	2.24	2.26	171	143	118	104	79
6	3	2.21	2.21	2.21	2.21	2.21	143	*	*	*	107
	4	2.21	2.22	2.21	2.22	2.23	135	*	*	*	99
7	1	2.10	2.11	2.12	2.11	2.10	127	124	118	*	99
	2	2.12	2.10	2.11	2.10	2.12	121	*	*	*	88
8a	5	2.19	2.19	2.18	2.17	2.18	138	*	*	121	82
8b	1	2.24	2.25	2.21	2.24	2.20	102	*	*	*	88
	3	2.19	2.20	2.22	2.20	2.21	127	124	118	104	88
	4	2.18	2.18	2.18	2.20	2.17	110	*	102	*	91
8c	5	2.19	2.18	2.19	2.19	2.19	129	*	121	093	82
8d	1	2.08	2.06	2.08	2.08	2.02	141	*	*	121	93
	2	2.06	2.07	2.06	2.06	2.05	127	*	*	*	107
10	1	2.23	2.21	2.20	2.21	2.20	110	*	*	*	71
	2	2.26	2.27	2.25	2.26	2.24	110	*	*	79	66
	3	2.24	2.22	2.18	2.21	2.20	99	*	*	*	82
	4	2.24	2.26	2.24	2.30	2.25	110	*	*	77	54

* The temperature of this intermediate specimen was not determined.

Change in Compaction Mold

The compaction mold used to prepare CTB specimens is designed to hold a 101.6 mm diameter by 101.6 mm high tin liner. Following compaction, the tin liner provides continuing containment of the test specimen after it is removed from the mold. Since the CTB testing equipment was being used in this study, it was necessary to compact the AC in these liners. Two unnecessary safety hazards became apparent. The first was the weight of the mold, which is approximately 178 N excluding the sample and the upper and lower plungers. The second was the sharp, jagged edges created by tearing away the tin liners.

Both of these hazardous conditions were eliminated by replacing the heavy CTB mold with molds routinely used in the stabilometer test (see AASHTO T246). These molds weigh less than 22.3 N each. Because the compacted AC specimens can be removed from the mold as soon as they have cooled sufficiently to avoid distortion, the liners were not necessary for long term confinement. It is necessary, however, to provide individual compaction molds for each test specimen in the series of five. This change in equipment provided a significant reduction in operating expense, since the tin liners are not reusable and cost approximately $7.00 each. The time required to perform the test was also reduced by eliminating the repeated assembly and disassembly of the compaction mold and the need to strip off the tin liners.

Because the early testing was done using the CTB mold and tin liners, the effect of the change to the stabilometer molds was evaluated on Projects 4, 6, and 7. The data in Tables A-12, A-15, and A-16 reveal no detectable difference in density because of this change.

Data Analysis

The TMD values from each of the projects are summarized in Tables 5 and 6. These tables are similar except that the TMD data in Table 6 are the average values of the first three test specimens in each set of five. The purpose and results of this second tabulation are discussed under the heading "Reduction in Number of Test Specimens." Both tables also include the average Laboratory TMD value for the project and the relative value determined by dividing the Field TMD by the respective Laboratory TMD.

These summaries provide the basis for most of the conclusions and recommendations of this study.

The first observation that must be made to establish the credibility of the proposed Field TMD procedure is its repeatability. The standard deviation values listed in Table 5 are averages of the standard deviations from each set of five test specimens making up the Field TMD values on a project. The standard deviations for all of the projects also have been mathematically combined and the average standard deviation calculated.

Table 5
SUMMARY OF FIELD TMD DATA
(5 Specimens Per Test)

PROJECT	MIX (mm)*	NO. OF TESTS	AVERAGE FIELD TMD			AVERAGE STANDARD DEVIATION			LAB TMD	% OF LAB TMD		
			Dim.	Waxed	w/o Wax	Dim.	Waxed	w/o Wax		Dim.	Waxed	w/o Wax
1	12.5	17	2.18	2.20	2.21	.012	.007	.010	2.27	96.0	96.9	97.4
2	19.0	4	2.22	2.25	2.27	.010	.004	.007	2.32	95.7	97.0	97.8
3	19.0	67	2.19	2.27	2.27	.007	.006	.007	2.34	93.6	97.0	97.0
4	19.0	13	2.19	2.27	2.28	.007	.005	.007	2.34	93.6	97.0	97.4
5a	19.0	3	2.15	2.25	2.29	.009	.010	.015	2.35	91.5	95.7	97.4
5b	19.0 Rub	5	2.08	2.17	-	.010	.017	-	2.34	88.9	92.3	-
6	19.0	8	2.18	2.22	-	.009	.005	-	2.31	94.4	96.1	-
7	19.0 PBA3	5	2.06	2.11	-	.010	.007	-	2.16	95.4	97.3	-
8a	19.0	6	2.15	2.19	2.24	.017	.011	**	2.27	94.7	96.5	98.7
8b	37.5	8	2.14	2.20	2.22	.017	.014	.014	2.28	93.9	96.5	97.4
8c	19.0 Rec	5	2.16	2.20	2.25	.009	.006	**	2.27	95.2	96.9	99.1
8d	19.0 Rub	5	2.01	2.06	-	.021	.016	-	2.25	89.3	91.6	-
9	19.0	5	2.35	2.40	2.42	.014	.008	.007	2.48	94.8	96.8	97.6
10	37.5	5	2.22	2.24	2.31	.016	.016	.021	2.38	93.3	94.9	97.1
11a	37.5	4	2.32	2.39	2.40	.021	.015	.024	2.43	95.5	98.4	98.8
11b	19.0	2	2.34	2.40	2.39	.010	.007	.019	2.43	96.3	98.8	98.4
12	19.0	5	2.32	-	2.35	.011	-	.014	2.39	97.1	-	98.3
13	19.0	5	2.31	-	2.43	.013	-	.011	2.47	93.5	-	98.4
14	19.0	4	2.33	-	2.41	.014	-	.013	2.47	94.3	-	97.6
Avg. (all projects N=19, 16, 15)						.013	.009	.013		94.05	96.23	97.89
SD										2.16	1.91	.66
Avg. (excl. rubber N=17, 14, 15)						.013	.009	.013		94.64	96.84	97.89
SD										1.35	.98	.66
Avg. (rubber only, N=2)						.016	.017	-		89.10	91.95	-
SD										.28	.49	-
Avg. (37.5 mm only, N=3)						.018	.015	.020		94.23	96.60	97.77
SD										1.14	1.75	.91

* Dim = per dimensions; Rec = Recycled
** Not applicable--tested only one specimen per set.

It can be seen that the average standard deviation for the wax coated water displacement procedure is less than for either of the other methods, thus indicating better repeatability. The average standard deviation of 0.01 for the wax coated test specimens indicates that each test specimen in a set of five will be within ± 0.02 of their average 95% of the time. The data also shows that mixes which include rubberized asphalt or 37.5 mm maximum sized aggregate can be expected to have somewhat higher variability between test specimens and the more conventional 19.0 mm and smaller mixes will have less variability.

The actual values are slightly different when the specific gravities were determined from the dimensions of the specimen or when the water displacement samples were not wax coated. However, the relationship between types of material is similar.

In every instance, the specific gravities which were calculated using the measured dimensions of the compacted test specimens were less than the specific gravities determined by either of the water displacement methods. When compared with the specific gravities of wax coated test specimens, this difference ranged from 0.02 on Projects 1 and 10 to 0.10 on Project 5a. This difference is not unexpected since the volume determined from the dimensions of the compacted specimen includes all of the surface voids whereas both water displacement methods exclude the surface voids from the calculated volume. Which method is most appropriate for establishing the TMD is debatable and depends to some extent on whether or not the surface voids are representative of the internal void structure of the compacted material. However, water displacement is the most widely accepted procedure for determining specific gravity.

The differences in specific gravity between non-waxed and wax coated test specimens ranged from 0 on Project 3 to 0.07 on Project 10. The average difference was less than 0.03. In only one instance did the specific gravity of the waxed specimen exceed that of the non-waxed specimen. The data from Project 11b indicates that the waxed test specimens had a specific gravity 0.01 higher than the non-waxed test specimens.

When the Field TMD values are compared with the Lab TMD values from the same project, the Field TMD values are always less. To normalize the data, and to aid in the analysis, the Field TMD values are shown as a percentage of their respective Lab TMD values in the last three columns of Tables 5 and 6.

Table 6
SUMMARY OF FIELD TMD DATA
(3 Specimens Per Test)

PROJECT	MIX (mm)*	NO. OF TESTS	AVERAGE FIELD TMD			AVERAGE STANDARD DEVIATION			LAB TMD	% OF LAB TMD		
			Dim.*	Waxed	w/o Wax	Dim.	Waxed	w/o Wax		Dim.	Waxed	w/o Wax
1	12.5	17	2.18	2.20	2.21	.010	.008	.011	2.27	96.0	96.9	97.4
2	19.0	4	2.21	2.25	2.27	.013	.005	.005	2.32	95.3	97.0	97.8
3	19.0	67	2.19	2.26	2.27	.007	.006	.007	2.34	93.6	96.6	97.0
4	19.0	13	2.19	2.27	2.28	.006	.005	.007	2.34	93.6	97.0	97.4
5a	19.0	3	2.15	2.25	2.29	.011	.006	.016	2.35	91.5	95.7	97.4
5b	19.0 Rub	5	2.08	2.17	-	.008	.014	-	2.34	88.9	92.7	-
6	19.0	8	2.17	2.22	-	.007	.006	-	2.31	93.9	96.1	-
7	19.0 PBA3	5	2.07	2.11	-	.011	.008	-	2.16	95.8	97.3	-
8a	19.0	6	2.15	2.20	2.24	.016	.010	*	2.27	94.7	96.9	98.7
8b	37.5	8	2.14	2.20	2.22	.015	.013	.012	2.28	93.9	96.5	97.5
8c	19.0 Rec	5	2.17	2.20	2.25	.009	.007	*	2.27	95.6	96.9	99.1
8d	19.0 Rub	5	2.01	2.06	-	.011	.017	-	2.25	89.3	91.6	-
9	19.0	5	2.35	2.40	2.42	.013	.009	.006	2.48	94.8	96.8	97.6
10	37.5	5	2.22	2.23	2.31	.018	.017	.019	2.38	93.3	93.7	97.1
11a	37.5	4	2.32	2.39	2.40	.013	.016	.023	2.43	95.5	98.4	98.8
11b	19.0	2	2.34	2.40	2.39	.010	.006	.008	2.43	96.3	98.8	98.4
12	19.0	5	2.32	-	2.35	.013	-	.014	2.39	97.1	-	98.3
13	19.0	5	2.31	-	2.43	.013	-	.011	2.47	93.5	-	98.4
14	19.0	4	2.32	-	2.42	.015	-	.011	2.47	93.9	-	98.0
Avg. (all projects)						.012	.010	.012		94.03	96.18	97.93
SD										2.18	1.93	.66
Avg. (excl. rubber)						.012	.010	.012		94.61	96.76	97.93
SD										1.39	1.19	.66
Avg. (rubber only, N=2)						.012	.016	-		89.10	92.15	-
SD										.28	.78	-
Avg. (37.5 mm only, N=3)						.015	.015	.018		94.23	96.20	97.80
SD										1.14	2.36	.88

* Dim = per dimensions; Rec = Recycled

** Not applicable --Only one specimen per set tested.

The average percentages of the Lab TMD are approximately 94, 96 and 98, respectively, for the three methods of calculating the Field TMD values. It can be readily seen that the Field TMD values for asphalt rubber are several percentage points below the values determined for conventional asphalt concrete mixtures. It should be noted that during the testing of the asphalt rubber mixes, it was observed that these materials remained pliable for a much longer period of time than conventional mixes. When left unsupported in the compaction mold during the cooling period, the compacted material would sag and pull apart, thus deforming the test specimen and actually increasing its volume. It is also possible that compacted asphalt rubber mixtures may rebound to some degree if they are too hot at the end of the compaction procedure. During the routine laboratory compaction of asphalt rubber mixes, the material was heated to 149°C prior to compaction with the kneading compactor but a static load was also applied after the temperature stabilized at 60°C.

The average values were recalculated after separating the asphalt rubber and conventional asphalt mixtures. This caused a slight increase in the average relative specific gravity of the Field TMD values. It also accentuates the extent of the difference in relative specific gravity of the asphalt rubber mixtures. More important, however, is the improvement in the correlation between Field and Laboratory TMD values as indicated by the smaller standard deviation.

Each of the three methods of determining the specific gravity of the field compacted test specimens has advantages as well as disadvantages. Using the dimensions of the test specimen to determine its volume has the advantage of not requiring a water tank and adaptations to the scale for weighing the specimen both in air and in water. However, the results by this method do not correlate as well with the Lab TMD as the water displacement methods. In addition to the better correlation with Lab TMD values, the water displacement methods are more readily accepted by materials testing personnel even though they require some additional equipment and effort.

The data indicates that either of the water displacement methods could be adopted as the standard for determining the relative compaction of asphalt concrete if the specification limits were revised accordingly. For example, the Field TMD procedure using wax coated test specimens could be adopted as the standard for determining relative compaction. However, since the Field TMD is only 97% of the Laboratory TMD, the required relative compaction would need to be set at 98% in lieu of 95% to retain the same target density for the finished pavement. In addition, with the exception of the asphalt rubber mixes, the target compaction density of only one material would have changed by more than 0.02 g/cc if 97% of the non-waxed Field

TMD value had been used as the target. For the one material that did exceed 0.02 g/cc, the non-waxed specific gravity was not actually measured but was estimated from the specific gravity of the waxed test specimens.

Although it appears that the change in specifications discussed above would not appreciably affect the required density of the finished pavement nor the contractors ability to achieve that density, contractors might perceive the higher relative compaction requirement as an increase in the compaction requirements. For this reason, the direct application of the Field TMD is not being recommended at this time.

Reduction in Number of Test Specimens

In all except a few cases, the reported Field TMD was the average specific gravity of five individual test specimens prepared from the same sample of mix. It was decided to determine if the number of test specimens from a sample could be reduced to three without adversely affecting the average TMD value. To make this evaluation, the Field TMDs were recalculated using only the specific gravities determined for the first three specimens from each set of five. These values are shown on the data sheets for the individual projects and are also summarized in Table 6.

Tables A-9 through A-27 include the results of Field TMD tests on 100 samples on which the dimensional measurement method was used to determine the specific gravity. Reducing the number of test specimens from five to three resulted in a minor change in TMD for 35% of these samples. On only one sample did this change exceed ± 0.01 g/cc. Of the 92 samples tested by water displacement after being wax coated, the TMD values of 26% changed when only the first three values were averaged. Again, the change exceeded ± 0.01 g/cc for only one sample. The TMD values of 30% of the 66 samples tested without being waxed coated changed when the number of test specimens was reduced from five to three. None, however, exceeded ± 0.01 g/cc.

In each case, the number of samples that had an increase in density because of the change in the number of test specimens was equal or nearly equal to the number that had a decrease in density. Rounding to the nearest 0.01 was responsible for most of these changes in TMD value. In most cases, the actual difference between densities of three and five specimen sets was much less than 0.01 g/cc.

Testing Time

After the use of the splitter was discontinued, it was found that the five test portions could be prepared and compacted in less than one-half hour. Removing the compacted specimens from the compaction molds, weighing them in air and in water, and calculating their densities could also be completed in less than one-half hour. Reducing the number of test portions per sample from five to three should further reduce the total testing by 15 or 20 minutes.

Most dense graded AC materials can be removed from the mold soon after compaction is completed. However, some mixtures may require a cooling period to allow the mix to set before removal. For example, mixes containing asphalt rubber have a tendency to slump and fall apart if they are removed without adequate cooling. The cooling process can be expedited by placing the specimens in a cool environment with circulating air.

Field sampling and transportation to the testing area are the most variable time periods since they are dependent upon availability of material to the paving site and the distance between the paving site and the testing area.

Even with some delay due to transportation and cooling periods, it was usually possible to complete the TMD determination within two hours of obtaining the sample. On Project 3, a single technician was responsible for all of the sampling and testing for TMD as well as determining in-place density and relative compaction of the pavement. Over the ten week period, this technician completed the testing on 80 material lots on two projects representing a 60-mile stretch of 4-lane freeway. To accomplish this amount of testing, the technician obtained his first sample soon after paving began in the morning. He then transported the sample to the field laboratory where he determined the TMD and then returned to the street to determine the in-place density of the pavement. Upon completing the in-place density tests, he then obtained a second sample and repeated the process. On some days, it was necessary for the technician to drive more than 200 miles in the process of completing this testing.

Reliability of Laboratory TMD

Since the inception of California Test 375, concerns have been raised regarding the precision and bias of the procdrures used to determine both in-situ density and TMD.

Data collected during this study revealed major differences between duplicate tests performed by the headquarters laboratory and the district laboratories.

In some cases, the results represent split portions of the sample. In other cases, the results represent separate samples taken at different times from the same project. It should be pointed out that the value attributed to one laboratory may be the average of many tests, while the value attributed to the other laboratory may represent only one or two tests.

The differences between the results of the two laboratories ranged from 0 to 0.09 g/cc with the district laboratories always having the higher value when there was a difference. The average difference was 0.04 g/cc. In an effort to determine if these differences in Laboratory TMD values are an ongoing problem, the results of recent Caltrans Correlation Testing Programs were reviewed. This review revealed large variations in densities when different laboratories tested representative portions of the same materials. For example, in August 1992, a bulk sample of AC mix was obtained from a commercial hot plant. This sample was split into representative portions and distributed to the district laboratories for testing. In this series of tests, the maximum difference in specific gravity of laboratory compacted test specimens was 0.07 g/cc. It has not been determined whether these differences in specific gravity were the result of actual differences in the compacted densities or apparent differences due to deviations in determining the specific gravity. This does, however, suggest that there may be a need for a concerted effort to improve the reproducibility of the TMD procedure using the kneading compactor.

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6. California Test 312, "Designing and Testing of Classes A and B Cement Treated Bases," State of California, Department of Transportation, Transportation Laboratory Manual of Tests, 1978.

7. California Test 308, "Methods of Test for Bulk Specific Gravity and Weight per Cubic Foot of Bituminous Mixtures," State of California, Department of Transportation, Transportation Laboratory Manual of Tests, 1978.

8. California Test 367, "Method for Recommending Optimum Bitumen Content (OBC)," Transportation Laboratory Manual of Tests, November 1984.

APPENDIX

The following tables contain all of the test data gathered during the laboratory and field studies on this project. Appropriate summaries of these data are included in the text of the report.

TABLE A-1
TEST MAXIMUM DENSITY
(Non-Coated Test Specimens)
Non-Absorptive Aggregate/Golden Bear Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.48	2.44	2.40	2.38	2.41	2.35	2.28	2.30
		2	2.46	2.40	2.41	2.43	2.37	2.34	2.31	2.29
		3	2.45	2.43	2.39	2.38	2.37	2.33	2.30	2.34
		Avg.	2.463	2.423	2.400	2.397	2.383	2.340	2.297	2.310
		SD	.015	.021	.010	.029	.023	.010	.015	.026
AR-4000	93°C	1		2.40				2.36		
		2		2.44				2.34		
		3		2.41				2.40		
		Avg.		2.417				2.367		
		SD		.021				.031		
AR-4000	149°C	1		2.45				2.37		
		2		2.42				2.34		
		3		2.41				2.34		
		Avg.		2.427				2.350		
		SD		.021				.017		
AR-2000	110°C	1			2.41				2.32	
		2			2.40				2.32	
		3			2.40				2.28	
		Avg.			2.403				2.307	
		SD			.006				.023	
AR-8000	110°C	1	2.44				2.41			
		2	2.44				2.39			
		3	2.43				2.38			
		Avg.	2.437				2.393			
		SD	.006				.015			

TABLE A-2
TEST MAXIMUM DENSITY
(Non-Coated Test Specimens)
Non-Absorptive Aggregate/Golden Bear Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.50	2.42	2.40	2.39	2.43	2.37	2.32	2.31
		2	2.49	2.41	2.41	2.43	2.42	2.36	2.30	2.29
		3	2.49	2.44	2.40	2.39	2.41	2.35	2.30	2.34
		Avg.	2.493	2.423	2.403	2.403	2.420	2.360	2.307	2.313
		SD	.006	.015	.006	.023	.010	.010	.012	.025
AR-4000	93°C	1		2.39				2.35		
		2		2.43				2.35		
		3		2.39				2.39		
		Avg.		2.403				2.363		
		SD		.023				.023		
AR-4000	149°C	1		2.45				2.38		
		2		2.43				2.36		
		3		2.41				2.35		
		Avg.		2.430				2.363		
		SD		.020				.015		
AR-2000	110°C	1			2.41				2.32	
		2			2.40				2.32	
		3			2.41				2.29	
		Avg.			2.407				2.310	
		SD			.006				.017	
AR-8000	110°C	1	2.46				2.42			
		2	2.45				2.39			
		3	2.44				2.39			
		Avg.	2.450				2.400			
		SD	.010				.017			

TABLE A-3
TEST MAXIMUM DENSITY
(Wax Coated Test Specimens)
Absorptive Aggregate/Golden Bear Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.21	2.31	2.30	2.27	2.26	2.27	2.26	2.20
		2	2.25	2.30	2.33	2.29	2.21	2.25	2.26	2.22
		3	2.21	2.30	2.30	2.23	2.22	2.25	2.26	2.15
		Avg.	2.223	2.303	2.310	2.247	2.230	2.257	2.260	2.190
		SD	.023	.006	.017	.038	.026	.012	.000	.036
AR-4000	93°C	1		2.28				2.33		
		2		2.31				2.34		
		3		2.32				2.34		
		Avg.		2.303				2.337		
		SD		.021				.006		
AR-4000	149°C	1		2.31				2.32		
		2		2.29				2.32		
		3		2.33				2.30		
		Avg.		2.310				2.313		
		SD		.020				.012		
AR-2000	110°C	1			2.33				2.26	
		2			2.32				2.26	
		3			2.30				2.27	
		Avg.			2.317				2.263	
		SD			.015				.006	
AR-8000	110°C	1	2.22				2.25			
		2	2.26				2.30			
		3	2.20				2.26			
		Avg.	2.227				2.270			
		SD	.031				.026			

TABLE A-4

TEST MAXIMUM DENSITY

(Non-Coated Test Specimens)

Absorptive Aggregate/Golden Bear Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.33	2.30	2.33	2.22	2.30	2.27	2.29	2.21
		2	2.30	2.29	2.34	2.29	2.29	2.25	2.28	2.21
		3	2.32	2.29	2.32	2.23	2.28	2.25	2.28	2.16
		Avg.	2.317	2.293	2.330	2.247	2.290	2.257	2.283	2.193
		SD	.015	.006	.010	.038	.010	.012	.006	.029
AR-4000	93°C	1		2.28				2.29		
		2		2.30				2.26		
		3		2.31				2.27		
		Avg.		2.297				2.273		
		SD		.015				.015		
AR-4000	149°C	1		2.31				2.26		
		2		2.30				2.23		
		3		2.33				2.25		
		Avg.		2.313				2.247		
		SD		.015				.015		
AR-2000	110°C	1			2.36				2.28	
		2			2.33				2.27	
		3			2.31				2.28	
		Avg.			2.333				2.277	
		SD			.025				.006	
AR-8000	110°C	1	2.30				2.32			
		2	2.31				2.33			
		3	2.31				2.30			
		Avg.	2.307				2.317			
		SD	.006				.015			

TABLE A-5
TEST MAXIMUM DENSITY
(Wax Coated Test Specimens)
Non-Absoprtive Aggregate/Conco Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.42	2.34	2.39	2.38	2.37	2.32	2.35	2.26
		2	2.43	2.34	2.41	2.35	2.39	2.30	2.34	2.28
		3	2.45	2.37	2.39	2.37	2.38	2.30	2.34	2.26
		Avg.	2.433	2.350	2.397	2.367	2.380	2.307	2.343	2.267
		SD	.015	.017	.012	.015	.010	.012	.006	.012
AR-4000	93°C	1		2.37				2.33		
		2		2.37				2.34		
		3		2.36				2.34		
		Avg.		2.367				2.337		
		SD		.006				.006		
AR-4000	149°C	1		2.35				2.32		
		2		2.37				2.32		
		3		2.37				2.30		
		Avg.		2.363				2.313		
		SD		.012				.012		
…2000	110°C	1			2.43				2.35	
		2			2.44				2.35	
		3			2.43				2.34	
		Avg.			2.433				2.347	
		SD			.006				.006	
…000	110°C	1	2.42			2.40				
		2	2.47			2.38				
		3	2.47			2.35				
		Avg.	2.453			2.377				
		SD	.029			.025				

TABLE A-6
TEST MAXIMUM DENSITY
(Non-Coated Test Specimens)
Non-Absorptive Aggregate Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.46	2.36	2.40	2.38	2.41	2.33	2.36	[illegible]
		2	2.45	2.35	2.42	2.36	2.42	2.31	2.35	[illegible]
		3	2.50	2.38	2.40	2.37	2.41	2.32	2.35	[illegible]
		Avg.	2.470	2.363	2.407	2.370	2.413	2.320	2.353	[illegible]
		SD	.026	.015	.012	.010	.006	.010	.006	[illegible]
AR-4000	93°C	1		2.36				2.33		
		2		2.37				2.34		
		3		2.36				2.34		
		Avg.		2.363				2.337		
		SD		.006				.006		
AR-4000	149°C	1		2.36				2.33		
		2		2.38				2.32		
		3		2.39				2.31		
		Avg.		2.376				2.320		
		SD		.015				.010		
AR-2000	110°C	1				2.42				[illegible]
		2				2.43				[illegible]
		3				2.43				[illegible]
		Avg.				2.426				[illegible]
		SD				.006				[illegible]
AR-8000	110°C	1	2.47				2.45			
		2	2.49				2.41			
		3	2.49				2.41			
		Avg.	2.483				2.423			
		SD	.012				.023			

TABLE A-7
TEST MAXIMUM DENSITY
(Wax Coated Test Specimens)
Absorptive Aggregate Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.28	2.31	2.32	2.27	2.26	2.26	2.28	2.19
		2	2.26	2.29	2.33	2.21	2.23	2.24	2.28	2.21
		3	2.24	2.29	2.29	2.25	2.22	2.22	2.29	2.18
		Avg.	2.260	2.297	2.313	2.243	2.237	2.240	2.283	2.193
		SD	.020	.012	.021	.031	.021	.020	.006	.015
AR-4000	93°C	1		2.24				2.18		
		2		2.20				2.20		
		3		2.24				2.21		
		Avg.		2.270				2.197		
		SD		.023				.015		
AR-4000	149°C	1		2.30				2.25		
		2		2.28				2.23		
		3		2.22				2.22		
		Avg.		2.267				2.233		
		SD		.042				.015		
AR-2000	110°C	1			2.30				2.28	
		2			2.23				2.27	
		3			2.31				2.27	
		Avg.			2.310				2.273	
		SD			.010				.006	
AR-8000	110°C	1	2.25				2.28			
		2	2.24				2.27			
		3	2.23				2.27			
		Avg.	2.240				2.273			
		SD	.010				.006			

TABLE A-8
TEST MAXIMUM DENSITY
(Non-coated Aggregate/Conoco Asphalt)
Absorptive Aggregate Asphalt

Asphalt Grade	Temperature at Compaction	Test Specimen	Laboratory Procedure Aggregate Grading				Field Procedure Aggregate Grading			
			Ac	Am	Bm	Bf	Ac	Am	Bm	Bf
AR-4000	110°C	1	2.33	2.30	2.34	2.27	2.30	2.25	2.29	2.20
		2	2.30	2.29	2.35	2.22	2.29	2.23	2.29	2.22
		3	2.33	2.28	2.31	2.26	2.28	2.21	2.30	2.18
		Avg.	2.320	2.290	2.333	2.250	2.290	2.230	2.293	2.200
		SD	.017	.010	.021	.026	.010	.020	.006	.020
AR-4000	93°C	1		2.25				2.22		
		2		2.25				2.22		
		3		2.27				2.23		
		Avg.		2.257				2.223		
		SD		.012				.006		
AR-4000	149°C	1		2.31				2.26		
		2		2.29				2.24		
		3		2.27				2.24		
		Avg.		2.290				2.247		
		SD		.020				.012		
AR-2000	110°C	1			2.31				2.29	
		2			2.32				2.28	
		3			2.32				2.28	
		Avg.			2.317				2.283	
		SD			.006				.006	
AR-8000	110°C	1	2.32				2.30			
		2	2.33				2.30			
		3	2.32				2.28			
		Avg.	2.323				2.930			
		SD	.006				.012			

TABLE A-9

FIELD TMD DATA FOR PROJECT 1

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	AVG.	SD	% LAB TMD
Dimensions	1	2.21	2.19	2.18	2.17	2.21	2.13	2.18	2.17	2.17		2.19	2.19	2.18	2.17	2.17	2.18	2.17			
	2	2.20	2.19	2.18	2.19	2.21	2.20	2.17	2.16	2.16		2.19	2.20	2.18	2.18	2.18	2.16	2.19			
	3	2.21	2.19	2.18	2.18	2.19	2.20	2.18	2.15	2.19		2.19	2.20	2.16	2.18	2.17	2.13	2.17			
	4	2.20	2.19	2.18	2.19	2.18	2.13	2.16	2.15			2.19	2.18	2.15	2.19	2.18	2.16	2.19			
	5	2.21	2.19	2.19	2.19	2.16	2.20	2.17	2.20			2.18	2.18	2.16	2.19	2.18	2.15	2.18			
	Avg. (5)	2.21	2.19	2.18	2.18	2.19	2.17	2.17	2.17			2.19	2.19	2.17	2.18	2.18	2.16	2.18	2.18	.012	96.0
	SD	.005	.000	.004	.009	.021	.038	.008	.021			.004	.010	.013	.008	.005	.018	.010	.012		
	Avg. (3)	2.21	2.19	2.18	2.18	2.20	2.18	2.18	2.16	2.17		2.19	2.20	2.17	2.18	2.17	2.16	2.18	2.18	.014	96.0
	SD	.005	.000	0.00	.001	.012	.040	.006	.010	.015		.000	.006	.012	.006	.006	.025	.012	.010		
Water Displacement (Waxed)	1											2.20	2.18	2.20	2.19	2.19	2.18	2.20			
	2											2.21	2.20	2.20	2.18	2.20	2.19	2.20			
	3											2.22	2.21	2.19	2.19	2.21	2.19	2.19			
	4											2.20	2.18	2.19	2.19	2.20	2.19	2.21			
	5											2.21	2.18	2.20	2.19	2.20	2.19	2.21			
	Avg. (5)	2.21	2.20	2.19	2.19	2.21	2.20	2.20	2.17	2.18		2.21	2.19	2.20	2.19	2.20	2.19	2.20	2.20	.011	96.9
	SD											.008	.014	.005	.004	.007	.004	.008	.007		
	Avg. (3)											2.21	2.20	2.20	2.19	2.20	2.19	2.20	2.20	.007	96.9
	SD											.010	.015	.006	.006	.010	.006	.006	.008		
Water Displacement (Without Wax)	1	2.22	2.24	2.21	2.21	2.25	2.23	2.18	2.15		2.19	2.21	2.21	2.23	2.21	2.22	2.21	2.22			
	2	2.20	2.22	2.21	2.20	2.22	2.23	2.19	2.15		2.19	2.23	2.23	2.23	2.22	2.23	2.22	2.22			
	3	2.24	2.22	2.22	2.23	2.22	2.22	2.18	2.13	2.17	2.20	2.24	2.23	2.23	2.23	2.23	2.21	2.21			
	4	2.22	2.22	2.22	2.20	2.22	2.23	2.18	2.15	2.19	2.19	2.22	2.21	2.22	2.23	2.23	2.20	2.25			
	5	2.23	2.22	2.22	2.21	2.22	2.23	2.19	2.15	2.22	2.17	2.24	2.21	2.23	2.22	2.22	2.21	2.24			
	Avg. (5)	2.22	2.22	2.22	2.21	2.23	2.23	2.18	2.15		2.19	2.23	2.22	2.23	2.22	2.23	2.21	2.23	2.21	.023	97.4
	SD	.015	.009	.005	.012	.013	.004	.005	.009		.011	.013	.011	.004	.011	.005	.007	.016	.010		
	Avg. (3)	2.22	2.23	2.21	2.21	2.23	2.23	2.18	2.14	2.19	2.19	2.23	2.22	2.23	2.22	2.23	2.21	2.22	2.21	.024	97.4
	SD	.020	.012	.006	.015	.017	.006	.006	.012	.025	.006	.015	.012	.000	.010	.006	.006	.006	.011		
TMD TM375		2.29	2.28	2.29	2.27	2.27	2.28	2.26	2.26	2.26	2.26	2.28	2.27	2.26	2.26	2.27	2.27	2.28	2.27	.011	

TABLE A-10
FIELD DATA FOR PROJECT 2

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	AVG.	SD	% LAB TMD
Dimensions	1	2.20	2.21	2.23	2.21			
	2	2.24	2.22	2.22	2.21			
	3	2.20	2.21	2.20	2.22			
	4	2.21	2.21	2.22	2.23			
	5	2.21	2.21	2.21	2.22			
	Avg. (5)	2.21	2.21	2.22	2.22	2.22	.006	95.7
	SD	.016	.004	.011	.008	.010		
	Avg. (3)	2.21	2.21	2.22	2.21	2.21	.005	95.3
	SD	.023	.006	.015	.006	.013		
Water Displacement (Waxed)	1	2.22	2.24	2.25	2.26			
	2	2.24	2.24	2.25	2.25			
	3	2.22	2.24	2.25	2.26			
	4	2.23	2.24	2.24	2.26			
	5	2.23	2.24	2.24	2.26			
	Avg. (5)	2.23	2.24	2.25	2.26	2.25	.012	97.0
	SD	.008	.000	.005	.004	.004		
	Avg. (3)	2.23	2.24	2.25	2.26	2.25	.013	97.0
	SD	.012	.000	.000	.006	.005		
Water Displacement (Without Wax)	1	2.25	2.28	2.29	2.28			
	2	2.25	2.28	2.27	2.28			
	3	2.25	2.28	2.26	2.29			
	4	2.24	2.28	2.27	2.28			
	5	2.26	2.27	2.28	2.28			
	Avg. (5)	2.25	2.28	2.27	2.28	2.27	.014	97.8
	SD	.007	.004	.011	.004	.007		
	Avg. (3)	2.25	2.28	2.27	2.28	2.27	.014	97.8
	SD	.000	.000	.015	.006	.005		
TMD TM375		2.30	2.31	2.32	2.34	2.32	.006	

TABLE A-11
FIELD DATA FOR PROJECT 3

METHOD	SPECIMEN	SAMPLE NUMBER 6	12	18	24	30	36	42	48	54	60	66	AVG.(1)	SD(1)	% LAB TMD	AVG.(2)	SD(2)	% LAB TMD(2)
Dimensions	1	2.20	2.19	2.20	2.20	2.20	2.18	2.17	2.18	2.18	2.17	2.18						
	2	2.20	2.21	2.20	2.20	2.20	2.18	2.16	2.20	2.18	2.18	2.18						
	3	2.18	2.22	2.21	2.20	2.20	2.18	2.19	2.18	2.19	2.17	2.19						
	4	2.18	2.21	2.20	2.19	2.19	2.18	2.18	2.19	2.18	2.18	2.19						
	5	2.20	2.20	2.18	2.20	2.20	2.18	2.17	2.19	2.18	2.19	2.19						
	Avg. (5)	2.19	2.21	2.20	2.20	2.20	2.18	2.17	2.19	2.18	2.18	2.19	2.19	.012	93.6	2.19	.010	93.6
	SD	.011	0.11	.011	.004	.004	.000	.011	.008	.004	0.01	.005	.007			.007		
	Avg. (3)	2.19	2.21	2.18	2.20	2.20	2.18	2.17	2.19	2.17	2.18	2.19	2.19	.013	93.6			
	SD	.012	.015	.006	.000	.000	.000	.015	.012	.006	0.01	.000	.007					
Water Displacement (Waxed)	1	2.25	2.27	2.26	2.26	2.25	2.28	2.26	2.29	2.27	2.27	2.26						
	2	2.25	2.28	2.25	2.26	2.26	2.27	2.27	2.26	2.28	2.26	2.26						
	3	2.26	2.27	2.25	2.25	2.26	2.27	2.26	2.28	2.28	2.26	2.26						
	4	2.25	2.29	2.24	2.25	2.26	2.28	2.27	2.28	2.26	2.26	2.26						
	5	2.25	2.27	2.24	2.26	2.26	2.27	2.27	2.27	2.27	2.26	2.27						
	Avg. (5)	2.25	2.28	2.25	2.26	2.26	2.27	2.27	2.28	2.27	2.26	2.26	2.26	.010	96.9	2.27	.013	97.0
	SD	.004	.009	.008	.005	.004	.005	.005	.011	.008	0.04	.004	.006			.006		
	Avg. (3)	2.25	2.27	2.25	2.26	2.26	2.27	2.26	2.28	2.28	2.26	2.26	2.26	0.01	96.6			
	SD	0.01	.006	.006	.006	.006	.006	.006	.015	.006	0.01	.000	.006					
Water Displacement (Without Wax)	1	2.26	2.27	2.27	2.27	2.27	2.26	2.28	2.29	2.29	2.28	2.27						
	2	2.25	2.27	2.27	2.28	2.28	2.25	2.27	2.27	2.29	2.27	2.27						
	3	2.26	2.26	2.26	2.25	2.27	2.26	2.27	2.27	2.29	2.27	2.25						
	4	2.26	2.28	2.25	2.27	2.27	2.27	2.27	2.27	2.28	2.27	2.26						
	5	2.25	2.25	2.26	2.27	2.28	2.25	2.28	2.27	2.29	2.27	2.27						
	Avg. (5)	2.26	2.27	2.26	2.27	2.27	2.26	2.27	2.27	2.29	2.27	2.26	2.27	.009	97.0	2.27	.010	97.0
	SD	.005	.011	.008	.011	.005	.008	.005	.009	.004	0.00	.009	.007			.007		
	Avg. (3)	2.26	2.27	2.27	2.27	2.27	2.26	2.27	2.28	2.29	2.27	2.26	2.27	.009	97.0			
	SD	.006	.006	.006	.015	.006	.006	.006	.012	.000	0.01	.012	.007					
TMD TM375		2.33	2.35	2.33	2.33	2.35	2.34	2.35	2.33	2.34	2.34	2.35	2.34	.009		2.34	.011	

(1) Based on one test of every six.
(2) Based on a total of 67 tests.

TABLE A-12
FIELD DATA FOR PROJECT 4

METHOD	SPECIMEN	SAMPLE NUMBER											AVG.	SD	AVG.	SD	AVG.	SD	%
		1(1)	2(2)	3(1)	4(2)	5(1)	6(2)	7(1)	8(2)	9(1)	10(2)	11(1)	(N=6) tin liners		(N=5) w/o liners		N=11 all sample		LTMD
Dimensions	1	2.19	2.17	2.19	2.20	2.17	2.19	2.19	2.18	2.20	2.19	2.19							
	2	2.19	2.18	2.19	2.20	2.19	2.19	2.20	2.19	2.19	2.18	2.20							
	3	2.20	2.18	2.20	2.19	2.19	2.19	2.20	2.18	2.20	2.18	2.20							
	4	2.20	2.19	2.20	2.20	2.19	2.18	2.20	2.18	2.19	2.18	2.21							
	5	2.17	2.18	2.18	2.19	2.19	2.18	2.19	2.18	2.19	2.19	2.20							
	Avg. (5)	2.19	2.18	2.19	2.20	2.19	2.19	2.20	2.18	2.19	2.18	2.20	2.19	.005	2.19	.010	2.19	.008	93.6
	SD	.012	.007	.008	.005	.009	.005	.005	.004	.005	.005	.007	.008		.005		.007		
	Avg. (3)	2.19	2.18	2.19	2.20	2.18	2.19	2.20	2.18	2.20	2.18	2.20	2.19	.008	2.19	.009	2.19	.009	93.6
	SD	.006	.006	.006	.006	.012	.000	.006	.006	.006	.006	.006	.007		.005		.006		
Water Displacement (Waxed)	1	2.26	2.27	2.28	2.27	2.26	2.26	2.28	2.27	2.26	2.26	2.29							
	2	2.27	2.26	2.29	2.27	2.25	2.26	2.27	2.27	2.27	2.27	2.28							
	3	2.28	2.26	2.28	2.28	2.26	2.26	2.27	2.27	2.26	2.26	2.29							
	4	2.27	2.26	2.28	2.27	2.26	2.27	2.27	2.27	2.26	2.28	2.29							
	5	2.28	2.27	2.27	2.27	2.26	2.28	2.27	2.27	2.27	2.26	2.29							
	Avg. (5)	2.27	2.26	2.28	2.27	2.26	2.27	2.27	2.27	2.26	2.27	2.29	2.27	.012	2.27	.004	2.27	.009	97.0
	SD	.004	.009	.008	.005	.004	.005	.005	.011	.008	.004	.004	.006		.007		.005		
	Avg. (3)	2.27	2.26	2.28	2.27	2.26	2.26	2.27	2.27	2.26	2.26	2.29	2.27	.012	2.26	.005	2.27	.010	97.0
	SD	.010	.006	.006	.006	.006	.000	.006	.000	.006	.006	.006	.007		.004		.005		
Water Displacement (Without Wax)	1	2.27	2.29	2.29	2.28	2.27	2.27	2.28	2.27	2.27	2.28	2.29							
	2	2.28	2.27	2.29	2.27	2.26	2.26	2.28	2.28	2.28	2.29	2.28							
	3	2.28	2.28	2.28	2.27	2.28	2.26	2.27	2.27	2.28	2.28	2.29							
	4	2.28	2.28	2.28	2.27	2.28	2.26	2.28	2.28	2.27	2.30	2.30							
	5	2.28	2.29	2.28	2.28	2.28	2.28	2.28	2.27	2.27	2.28	2.29							
	Avg. (5)	2.28	2.28	2.28	2.27	2.27	2.27	2.28	2.27	2.27	2.29	2.29	2.28	.008	2.28	.009	2.28	.008	97.4
	SD	.005	.011	.008	.011	.005	.008	.005	.009	.004	.004	.009	.006		.009		.007		
	Avg. (3)	2.28	2.28	2.29	2.27	2.27	2.26	2.28	2.27	2.28	2.28	2.29	2.28	.008	2.27	.008	2.28	.009	97.4
	SD	.006	.010	.006	.006	.010	.006	.006	.006	.006	.006	.006	.007		.007		.007		
TMD TM375		2.33	2.32	2.33	2.34	2.33	2.32	2.36	2.35	2.35	2.32	2.34					2.34	.013	

TABLE A-13
PROJECT 5A
Conventional AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	AVG.	SD	% OF LAB TMD DIST	M&R
Dimensions	1	2.15	2.16	2.16				
	2	2.14	2.16	2.13				
	3	2.15	2.15	2.17				
	4	2.16	2.15	2.15				
	5	2.15	2.15	2.14				
	Avg. (5)	2.15	2.15	2.15	2.15	.000	91.5	94.7
	SD	.007	.005	.016	.009			
	Avg. (3)	2.15	2.16	2.15	2.15	.006	91.5	94.7
	SD	.006	.006	.021	.011			
Water Displacement (Waxed)	1	2.24	2.26	2.24				
	2	2.24	2.27	2.23				
	3	2.23	2.27	2.24				
	4	2.24	2.29	2.23				
	5	2.26	2.27	2.22				
	Avg. (5)	2.24	2.27	2.23	2.25	.021	95.7	99.1
	SD	.011	.011	.008	.010			
	Avg. (3)	2.24	2.27	2.24	2.25	.017	95.7	99.1
	SD	.006	.006	.006	.006			
Water Displacement (Without Wax	1	2.28	2.26					
	2	2.30	2.30					
	3	2.29	2.29					
	4	2.29	2.31					
	5	2.31	2.29					
	Avg. (5)	2.29	2.29		2.29	.000	97.4	100.9
	SD	.011	.019		.015			
	Avg. (3)	2.29	2.28		2.29	.007	97.4	100.9
	SD	.010	.021		.016			
	DIST	2.34	2.34	2.38	2.35	.023		
TMD TM375	M&R	2.27			2.27			

TABLE A-14
PROJECT 5B
Rubberized AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	AVG.	SD	% OF LAB TMD DIST	M&R
Dimensions	1	2.10	2.05	2.08	2.09	2.09				
	2	2.09	2.05	2.06	2.09	2.09				
	3	2.12	2.05	2.06	2.10	2.08				
	4	2.13	2.05	2.06	2.10	2.10				
	5	2.10	2.03	2.05	2.10	2.09				
	Avg. (5)	2.11	2.05	2.06	2.10	2.09	2.08	.026		88.9
	SD	.016	.009	.011	.005	.007	.010			
	Avg. (3)	2.10	2.05	2.07	2.09	2.09	2.08	.020		88.9
	SD	.015	.000	.012	.006	.006	.008			
Water Displacement (Waxed)	1	2.26	2.16	2.15	2.19	2.13				
	2	2.24	2.17	2.13	2.17	2.15				
	3	2.21	2.15	-	2.18	2.15				
	4	2.23	2.14	2.04	2.18	2.16				
	5	2.19	2.13	-	2.16	2.17				
	Avg. (5)	2.23	2.15	2.11	2.18	2.15	2.17	.036		92.3
	SD	.027	.016	.059	.011	.015	.017			
	Avg. (3)	2.24	2.16	2.11	2.18	2.14	2.17	.041		92.3
	SD	.025	.010	.059	.010	.012	.014			
Water Displacement (Without Wax)	1									
	2									
	3									
	4									
	5									
	Avg. (5)									
	SD									
	Avg. (3)									
	SD									
TMD TM375	DIST									
	M&R						2.34			

TABLE A-15
PROJECT 6

METHOD	SPECIMEN	SAMPLE NUMBER 1(1)	1a(2)	2(1)	2a(2)	3(1)	3a(2)	4(1)	4a(2)	AVG. (N=4) tin liners	SD	AVG. (N=4)w/o liners	SD	AVG. N=8 all sample	SD	% LAB TMD DIST	M&R
Dimensions	1	2.19	2.18	2.17	2.15	2.15	2.15	2.20	2.19								
	2	2.19	2.18	2.17	2.16	2.16	2.16	2.19	2.17								
	3	2.18	2.18	2.17	2.17	2.17	2.15	2.18	2.18								
	4	2.20	-	2.18	2.19	2.15	2.16	2.17	2.18								
	5	2.17	-	2.19	2.17	2.16	2.14	2.19	2.19								
	Avg. (5)	2.19	2.18	2.18	2.17	2.16	2.15	2.19	2.18	2.18	.014	2.17	.008	2.18	.014	94.4	95.6
	SD	.011	0.00	.009	.015	.008	.008	.011	.008	.010		.008		.009			
	Avg. (3)	2.19	2.18	2.17	2.16	2.16	2.15	2.19	2.18	2.18	.015	2.17	.015	2.17	.015	93.9	95.2
	SD	.006	.000	.000	.010	.010	.006	..010	.010	.007		.007		.007			
Water Displacement (Waxed)	1	2.23	2.22	2.21	2.21	2.21	2.21	2.21	2.22								
	2	2.23	2.23	2.23	2.21	2.21	2.21	2.22	2.21								
	3	2.23	2.23	2.22	2.22	2.21	2.20	2.21	2.23								
	4	2.23	-	2.22	2.22	2.21	2.20	2.22	2.23								
	5	2.23	-	2.22	2.21	2.21	2.19	2.23	2.23								
	Avg. (5)	2.23	2.23	2.22	2.21	2.21	2.20	2.22	2.22	2.22	.008	2.22	.013	2.22	.010	96.1	97.4
	SD	.000	.006	.007	.005	.000	.008	.008	.009	.004		.007		.005			
	Avg. (3)	2.23	2.23	2.22	2.21	2.21	2.21	2.21	2.22	2.22	.010	2.22	.010	2.22	.009	96.1	97.4
	SD	.000	.006	.010	.006	.000	.006	.006	.010	.004		.007		.006			
Water Displacement (Without Wax)	1																
	2																
	3																
	4																
	5																
	Avg. (5)																
	SD																
	Avg. (3)																
	SD																
	DIST			2.31				2.31						2.31			
LAB TMD	M&R	2.30		2.29		2.26		2.27						2.28			

(1) Compacted in tin liners
(2) Tin liners not used
(3) District TMD test on other samples

TABLE A-16
PROJECT 7

METHOD	SPECIMEN	SAMPLE NUMBER 1(1)	2(2)	3(1)	4(2)	5(1)	AVG.	SD	% LAB TMD DIST	M&R
Dimensions	1	2.04	2.07	2.05	2.06	2.07				
	2	2.04	2.05	2.09	2.08	2.08				
	3	2.04	2.06	2.09	2.07	2.08				
	4	2.03	2.05	2.06	2.05	2.08				
	5	2.03	2.06	2.09	2.07	2.06				
	Avg. (5)	2.04	2.06	2.08	2.07	2.07	2.06	.015	95.4	97.6
	SD	.005	.008	.019	.011	.009	.010			
	Avg. (3)	2.04	2.06	2.08	2.07	2.08	2.07	.017	95.8	98.1
	SD	.000	.010	.023	.010	.006	.011			
Water Displacement (Waxed)	1	2.10	2.12	2.11	2.11	2.11				
	2	2.11	2.10	2.12	2.11	2.12				
	3	2.12	2.11	2.12	2.10	2.11				
	4	2.11	2.10	2.12	2.12	2.12				
	5	2.10	2.12	2.13	2.11	2.11				
	Avg. (5)	2.11	2.11	2.12	2.11	2.11	2.11	.004	97.3	100.0
	SD	.008	.010	.007	.007	.005	.007			
	Avg. (3)	2.11	2.11	2.12	2.11	2.11	2.11	.004	97.3	100.0
	SD	.010	.010	.006	.006	.006	.008			
Water Displacement (Without Wax)	1									
	2									
	3									
	4									
	5									
	Avg. (5)									
	SD									
	Avg. (3)									
	SD									
LAB TMD	DIST						2.16(3)	.016		
	M&R	2.11	2.11	2.13	2.10	2.11	2.11	.011		

(1) Compacted in tin liners.
(2) Tin liners not used.
(3) District TMD test on different samples.

TABLE A-17
PROJECT 8a
Conventional 19.0 mm AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	6	AVG.	SD	% LAB TMD DIST	M&R
Dimensions	1	2.15	2.14	2.13	2.19	2.17	2.16				
	2	2.14	2.15	2.15	2.14	2.15	2.14				
	3	2.17	2.15	2.15	2.13	2.16	2.12				
	4	2.17	2.14	2.17	2.15	2.13	2.04(1)				
	5	2.14	2.15	2.16	2.16	2.14	2.10				
	Avg. (5)	2.15	2.15	2.15	2.15	2.15	2.13(2)	2.15	.008	94.7	96.4
	SD	.015	.005	.015	.023	.016	.026(2)	.017			
	Avg. (3)	2.15	2.15	2.14	2.15	2.16	2.14	2.15	.008	94.7	96.4
	SD	.015	.006	.012	.032	.010	.020	.016			
Water Displacement (Waxed)	1	2.19	2.20	2.17	2.21	2.19	2.20				
	2	2.21	2.19	2.20	2.19	2.19	2.19				
	3	2.22	2.20	2.20	2.20	2.18	2.20				
	4	2.21	2.18	2.21	2.21	2.17	2.20				
	5	2.19	2.19	2.20	2.20	2.18	2.17				
	Avg. (5)	2.20	2.19	2.20	2.20	2.18	2.19	2.19	.008	96.5	98.2
	SD	.013	.008	.015	.008	.008	.013	.011			
	Avg. (3)	2.21	2.20	2.19	2.20	2.19	2.20	2.20	.008	96.9	98.7
	SD	.015	.006	.017	.010	.006	.006	.010			
Water Displacement (Without Wax) (3)	1	2.23	2.25	2.23	2.23	-	-	2.24	.010	98.7	100.4
	2										
	3										
	4										
	5										
	Avg. (5)										
	SD										
	Avg. (3)										
	SD										
LAB TMD	DIST							2.27			
	M&R	2.23	2.23	2.24	2.24	2.20	2.24	2.23	.015		

(1) Probable error in measuring specimen height.
(2) Specimen 4 deleted.
(3) One specimen from each set of 5 was tested without wax.

TABLE A-18
PROJECT 8b
37.5 mm AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	6	7	8	AVG.	SD	% LAB TMD DIST	% LAB TMD M&R
Dimensions	1	2.15	2.17	2.15	2.14	2.15	2.15	2.13	2.10				
	2	2.18	2.17	2.15	2.16	2.15	2.17	2.10	2.10				
	3	2.15	2.19	2.17	2.15	2.12	2.13	2.15	2.09				
	4	2.16	2.16	2.16	2.17	2.13	2.15	2.16	2.07				
	5	2.14	2.15	2.18	2.13	2.12	2.12	2.14	2.12				
	Avg. (5)	2.16	2.17	2.16	2.15	2.13	2.14	2.14	2.10	2.14	.022	93.9	96.0
	SD	.015	.015	.013	.016	.015	.019	.023	.018	.017			
	Avg. (3)	2.16	2.18	2.16	2.15	2.14	2.15	2.10	2.10	2.14	.029	93.9	96.0
	SD	.017	.012	.012	.010	.017	.020	.029	.006	.015			
Water Displacement (Waxed)	1	2.24	2.22	2.19	2.18	2.19	2.19	2.18	2.18				
	2	2.25	2.22	2.20	2.18	2.20	2.20	2.19	2.21				
	3	2.21	2.24	2.22	2.18	2.20	2.16	2.20	2.21				
	4	2.24	2.19	2.20	2.20	2.19	2.19	2.19	2.17				
	5	2.20	2.21	2.21	2.17	2.21	2.19	2.21	2.20				
	Avg. (5)	2.23	2.22	2.20	2.18	2.20	2.19	2.19	2.19	2.20	.017	96.5	98.7
	SD	.022	.018	.011	.011	.008	.015	.011	.018	.014			
	Avg. (3)	2.23	2.23	2.20	2.18	2.20	2.18	2.19	2.20	2.20	.020	96.5	98.7
	SD	.021	.012	.015	.000	.006	.021	.010	.017	.013			
Water Displacement (Without Wax)	1	2.25	2.23	2.20	2.20	2.22	2.21	2.21	2.23				
	2	2.25	2.23	2.22	2.20	2.22	2.22	2.24	-				
	3	2.23	2.26	2.25	2.20	2.22	2.19	2.22	-				
	4	2.27	2.20	2.21	2.21	2.22	2.21	2.23	-				
	5	2.22	2.23	2.23	2.19	2.23	2.21	2.25	-				
	Avg. (5)	2.24	2.23	2.22	2.20	2.22	2.21	2.23	-	2.22	.013	97.4	99.6
	SD	.019	.021	.019	.007	.004	.011	.016	-	.014			
	Avg. (3)	2.24	2.24	2.22	2.20	2.22	2.21	2.22	-	2.22	.015	97.4	99.6
	SD	.012	.017	.025	.000	.000	.015	.015	-	.012			
LAB TMD	DIST	2.26	2.29							2.28			
	M&R		2.23	2.23	2.21	2.23			2.23	2.23	.009		

TABLE A-19

PROJECT 8c

19.0 mm Recycled AC (70/30)

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	AVG.(1)	SD	% LAB TMD DIST	M&R
Dimensions	1	2.16	2.17	2.18	2.18	2.16				
	2	2.16	2.16	2.16	2.19	2.15				
	3	2.17	2.14	2.17	2.18	2.16				
	4	2.16	2.15	2.17	2.18	2.16				
	5	2.15	2.13	2.15	2.17	2.16				
	Avg. (5)	2.16	2.15	2.17	2.18	2.16	2.16	.011	95.2	96.0
	SD	.007	.016	.011	.007	.004	.009			
	Avg. (3)	2.16	2.16	2.17	2.18	2.16	2.17	.009	95.6	96.4
	SD	.006	.015	.010	.006	.006	.009			
Water Displacement (Waxed)	1	2.19	2.21	2.20	2.20	2.19				
	2	2.20	2.20	2.20	2.22	2.18				
	3	2.20	2.20	2.21	2.21	2.19				
	4	2.19	2.20	2.21	2.21	2.19				
	5	2.20	2.19	2.21	2.21	2.19				
	Avg. (5)	2.20	2.20	2.21	2.21	2.19	2.20	.008	96.9	97.8
	SD	.005	.007	.005	.007	.004	.006			
	Avg. (3)	2.20	2.20	2.20	2.21	2.19	2.20	.007	96.9	97.8
	SD	.006	.006	.006	.010	.006	.007			
Water Displacement (Without Wax)	1	2.24	2.26	2.25	-	-				
	2									
	3									
	4									
	5									
	Avg. (5)	2.24	2.26	2.25	-	-	2.25	.010	99.1	100.0
	SD									
	Avg. (3)	2.24	2.26	2.25	-	-	2.25	.010	99.1	100.0
	SD									
LAB TMD	DIST						2.27			
	M&R	2.24	-	2.25	2.26	2.25	2.25	.008		

(1) One specimen from each set of five was tested without wax.

TABLE A-20

PROJECT 8d

19.0 mm Rubberized AC

METHOD	SPECIMEN	SAMPLE NUMBER					AVG.	SD	% LAB TMD	
		1 (1)	2	3	4	5			DIST	M&R
Dimensions	1	1.95	2.04	2.04	2.01	2.00				
	2	1.94	2.04	2.05	2.03	1.98				
	3	1.94	2.01	2.05	2.04	1.98				
	4	1.89	2.01	2.07	2.03	1.99				
	5	1.98	2.04	2.06	2.08	2.03				
	Avg. (5)	1.94	2.03	2.05	2.04	2.00	2.01	.044	89.3	91.4
	SD	.032	.016	.011	.025	.021	.021			
	Avg. (3)	1.94	2.03	2.05	2.03	1.99	2.01	.044	89.3	91.4
	SD	.006	.017	.006	.015	.012	.011			
Water Displacement (Waxed)	1	2.08	2.06	2.10	2.03	2.07				
	2	2.01	2.07	2.09	2.05	2.04				
	3	2.06	2.06	2.10	2.03	2.02				
	4	2.08	2.06	2.11	2.04	2.08				
	5	2.08	2.05	2.10	2.05	2.08				
	Avg. (5)	2.06	2.06	2.10	2.04	2.06	2.06	.022	91.6	92.8
	SD	.030	.007	.007	.010	.027	.016			
	Avg. (3)	2.05	2.06	2.10	2.04	2.04	2.06	.025	91.6	92.8
	SD	.036	.006	.006	.012	.025	.017			
Water Displacement (Without Wax)	1									
	2									
	3									
	4									
	5									
	Avg. (5)									
	SD									
	Avg. (3)									
	SD									
LAB TMD	DIST						2.25			
	M&R	2.23	2.21	2.20	2.23	2.21	2.22	.013		

(1) One specimen from each set of five was tested without wax.

TABLE A-21
PROJECT 9

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	AVG.	SD	% LAB TMD DIST	M&R
Dimensions	1	2.36	2.33	2.35	2.38	2.37				
	2	2.35	2.32	2.34	2.36	2.32				
	3	2.36	2.33	2.33	2.35	2.32				
	4	2.36	2.32	2.38	2.36	2.34				
	5	2.35	2.31	2.36	2.34	2.33				
	Avg. (5)	2.36	2.32	2.35	2.36	2.34	2.35	.014	94.8	96.3
	SD	.005	.008	.019	.015	.021	.017			
	Avg. (3)	2.36	2.33	2.34	2.36	2.34	2.35	.013	94.8	96.3
	SD	.006	.006	.010	.015	.029	.013			
Water Displacement (Waxed)	1	2.42	2.39	2.41	2.43	2.40				
	2	2.41	2.39	2.41	2.41	2.40				
	3	2.40	2.37	2.40	2.40	2.40				
	4	2.42	2.38	2.41	2.40	2.39				
	5	2.40	2.38	2.41	2.39	2.39				
	Avg. (5)	2.41	2.38	2.41	2.41	2.40	2.40	.013	96.8	98.4
	SD	.010	.008	.004	.002	.005	.008			
	Avg. (3)	2.41	2.38	2.41	2.41	2.40	2.40	.013	96.8	98.4
	SD	.010	.012	.006	.015	.000	.009			
Water Displacement (Without Wax)	1	2.43	2.39	2.42	2.43	2.42				
	2	2.42	2.39	2.42	2.42	2.42				
	3	2.42	2.38	2.42	2.42	2.44				
	4	2.43	2.39	2.43	2.41	2.42				
	5	2.43	2.40	2.42	2.41	2.42				
	Avg. (5)	2.43	2.39	2.42	2.42	2.42	2.42	.015	97.6	99.2
	SD	.005	.007	.004	.008	.009	.007			
	Avg. (3)	2.42	2.39	2.42	2.42	2.43	2.42	.015	97.6	99.2
	SD	.006	.006	.000	.006	.012	.006			
LAB TMD	DIST						2.48(1)			
	M&R	2.46	2.40		2.46	2.44	2.44	.028		

(1) Average TMD of six samples taken prior to the other tests shown.

TABLE A-22
PROJECT 10
37.5 mm AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	AVG.	SD	% LAB TMD
Dimensions	1	2.16	2.20	2.21	2.22	2.22			
	2	2.22	2.22	2.22	2.23	2.23			
	3	2.21	2.19	2.27	2.22	2.23			
	4	2.23	2.21	2.24	2.22	2.23			
	5	2.23	2.22	2.21	2.24	2.23			
	Avg. (5)	2.21	2.21	2.23	2.23	2.23	2.22	.011	93.3
	SD	.029	.013	.025	.009	.004	.016		
	Avg. (3)	2.20	2.20	2.23	2.22	2.23	2.22	.015	93.3
	SD	.032	.015	.032	.006	.006	.018		
Water Displacement (Waxed)	1	2.23	2.26	2.24	2.24	2.22			
	2	2.21	2.26	2.22	2.26	2.26			
	3	2.20	2.17	2.18	2.24	2.23			
	4	2.21	2.25	2.21	2.24	2.25			
	5	2.20	2.26	2.20	2.30	2.23			
	Avg. (5)	2.21	2.26	2.21	2.26	2.24	2.24	.025	94.1
	SD	.012	.007	.022	.026	.015	.016		
	Avg. (3)	2.21	2.26	2.21	2.25	2.24	2.23	.023	93.7
	SD	.015	.006	.031	.012	.021	.017		
Water Displacement (Without Wax)	1	2.28	2.32	2.32	2.32	2.31			
	2	2.27	2.28	2.29	2.34	2.37			
	3	2.28	2.31	2.27	2.32	2.32			
	4	2.28	2.31	2.32	2.34	2.37			
	5	2.26	2.28	2.28	2.38	2.31			
	Avg. (5)	2.27	2.30	2.30	2.34	2.34	2.31	.030	97.1
	SD	.009	.019	.023	.024	.031	.021		
	Avg. (3)	2.28	2.30	2.29	2.33	2.33	2.31	.023	97.1
	SD	.006	.021	.025	.012	.032	.019		
LAB TMD		—	2.37	2.38	—	—	2.38	—	

(1) Average TMD of six samples taken prior to the other tests shown.

TABLE A-23
PROJECT 11A
37.5 mm AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	AVG.	SD	% LAB TMD
Dimensions	1	2.30	2.33	2.30	-			
	2	2.30	2.32	-	-			
	3	2.32	2.32	2.34	-			
	4	2.35	2.30	2.31	-			
	5	-	-	2.28	-			
	AVG (5)	2.32	2.32	2.31	-	2.32	.006	95.5
	SD	.024	.013	.025	-	.021		
	AVG (3)	2.31	2.32	2.32	-	2.32	.006	95.5
	SD	.012	.006	.021	-	.013		
Water Displacement (Waxed)	1	2.36	2.36	2.42	2.43			
	2	2.34	2.36	-	2.44			
	3	2.37	2.34	2.39	2.45			
	4	2.37	2.34	2.37	2.45			
	5	-	-	2.38	2.42			
	AVG. (5)	2.36	2.35	2.39	2.44	2.39	.040	98.4
	SD	.014	.012	.022	.013	.015		
	AVG. (3)	2.36	2.35	2.39	2.44	2.39	.040	98.4
	SD	.015	.012	.025	.010	.016		
Water Displacement (Without Wax)	1	2.38	2.40	2.40	2.43			
	2	2.40	2.44	-	2.44			
	3	2.39	2.41	2.34	2.40			
	4	2.43	2.43	2.33	2.38			
	5	-	-	2.35	2.42			
	AVG. (5)	2.40	2.42	2.36	2.41	2.40	.026	98.8
	SD	.022	.018	.031	.024	.024		
	AVG. (3)	2.39	2.42	2.36	2.42	2.40	.029	98.8
	SD	.010	.021	.038	.021	.023		
LAB TMD		2.47	2.40	2.44	2.41	2.43	.032	

TABLE A-24
PROJECT 11B
19.0 mm Rubberized AC

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	AVG.	SD	% LAB TMD
Dimensions	1	2.33	—			
	2	2.34	—			
	3	2.35	—			
	4	2.33	—			
	5	—	—			
	Avg. (5)	2.34	—	2.34	—	96.3
	SD	.010	—	.010		
	Avg. (3)	2.34	—	2.34	—	96.3
	SD	.010	—	.010		
Water Displacement (Waxed)	1	2.40	2.41			
	2	2.40	2.40			
	3	2.41	2.40			
	4	2.40	2.39			
	5	—	—			
	Avg. (5)	2.40	2.40	2.40	—	98.8
	SD	.005	.008	.007		
	Avg. (3)	2.40	2.40	2.40	—	98.8
	SD	.006	.006	.006		
Water Displacement (Without Wax)	1	2.40	2.38			
	2	2.41	2.38			
	3	2.39	2.39			
	4	2.36	2.35			
	5		2.38			
	Avg. (5)	2.39	2.38	2.39	—	98.4
	SD	.022	.015	.019		
	Avg. (3)	2.40	2.38	2.40	—	98.8
	SD	.010	.016	.008		
LAB TMD		2.43	2.43	2.43		

TABLE A-25
PROJECT 12

METHOD	SPECIMEN	SAMPLE NUMBER 1	2	3	4	5	AVG.	SD	% LAB TMD
Dimensions	1	2.33	2.32	2.31	2.30	2.32			
	2	2.33	2.33	2.31	2.34	2.33			
	3	2.33	2.35	2.29	2.35	2.32			
	4	2.33	2.32	2.31	2.32	2.32			
	5	2.31	2.34	2.31	2.34	2.32			
	Avg. (5)	2.33	2.33	2.31	2.33	2.32	2.32	.009	97.1
	SD	.009	.013	.009	.020	.004	.011		
	Avg. (3)	2.33	2.33	2.30	2.33	2.32	2.32	.013	97.1
	SD	.000	.015	.012	.026	.006	.012		
Water Displacement (Waxed)	1								
	2								
	3								
	4								
	5								
	Avg. (5)								
	SD								
	Avg. (3)								
	SD								
Water Displacement (Without Wax)	1	2.35	2.34	2.35	2.38	2.33			
	2	2.35	2.33	2.40	2.35	2.34			
	3	2.34	2.34	2.42	2.36	2.33			
	4	2.35	2.36	2.35	2.36	2.35			
	5	2.36	2.35	2.37	2.37	2.33			
	Avg. (5)	2.35	2.34	2.38	2.36	2.34	2.35	.017	98.3
	SD	.007	.011	.031	.011	.009	.014		
	Avg. (3)	2.35	2.34	2.39	2.36	2.33	2.35	.023	98.3
	SD	.006	.006	.036	.015	.006	.014		
Lab TMD		2.38	2.37	2.40	2.41	2.40	2.39		

TABLE A-26
PROJECT 13

METHOD	SPECIMEN	SAMPLE METHOD 1	2	3	4	5	AVG.	SD	% LAB TMD
Dimensions	1	2.26	2.28	2.30	2.35	2.33			
	2	2.28	2.27	2.34	2.34	2.35			
	3	2.26	2.27	2.34	2.32	2.34			
	4	2.26	2.26	2.34	2.35	2.34			
	5	2.27	2.29	2.36	2.32	2.35			
	Avg. (5)	2.27	2.27	2.34	2.34	2.34	2.31	.038	93.5
	SD	.009	.011	0.02	.015	.008	.013		
	Avg. (3)	2.27	2.27	2.33	2.34	2.34	2.31	.037	93.5
	SD	.012	.006	0.02	.015	.010	.013		
Water Displacement (Waxed)	1								
	2								
	3								
	4								
	5								
	Avg. (5)								
	SD								
	Avg. (3)								
	SD								
Water Displacement (Without Wax)	1	2.42	2.44	2.47	2.41	2.39			
	2	2.42	2.45	2.44	2.42	2.42			
	3	2.41	2.44	2.43	2.42	2.42			
	4	2.41	2.44	2.42	2.42	2.42			
	5	2.42	2.44	2.42	2.41	2.43			
	Avg. (5)	2.42	2.44	2.44	2.42	2.42	2.43	.011	98.4
	SD	.005	.004	0.02	.005	.015	.010		
	Avg. (3)	2.42	2.44	2.45	2.42	2.41	2.43	.016	98.4
	SD	.006	.006	0.02	.006	.017	.011		
Lab TMD		—	—	2.47	2.47	2.46	2.47		

TABLE A-27
PROJECT 14

METHOD	SAMPLE	SAMPLE NUMBER 1	2	3	4	AVG.	SD	% LAB TMD
Dimensions	1	2.30	2.34	2.32	2.31			
	2	2.31	2.33	2.31	2.33			
	3	2.33	2.32	2.33	2.36			
	4	2.34	2.33	2.32	2.33			
	5	2.33	2.32	2.34	2.32			
	Avg. (5)	2.32	2.33	2.32	2.33	2.33	.006	94.3
	SD	.016	.008	.011	.019	.014		
	Avg. (3)	2.31	2.33	2.32	2.33	2.32	.010	93.9
	SD	.015	.010	.010	.025	.015		
Water Displacement (Waxed)								
	1							
	2							
	3							
	4							
	5							
	Avg. (5)							
	SD							
	Avg. (3)							
	SD							
Water Displacement (Without Wax)								
	1	2.43	2.36	2.43	2.43			
	2	2.42	2.40	2.42	2.43			
	3	2.44	2.39	2.42	2.42			
	4	2.42	2.39	2.44	2.42			
	5	2.39	2.40	2.43	2.44			
	Avg. (5)	2.42	2.39	2.43	2.43	2.41	.021	97.6
	SD	.019	.016	.008	.008	.013		
	Avg. (3)	2.43	2.38	2.42	2.43	2.42	.024	98.0
	SD	.010	.021	.006	.006	.011		
Lab TMD		——	2.46	2.47	2.47	2.47		