FINAL REPORT

DEVELOPMENT OF A BASE MIX DESIGN PROCEDURE

by

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SUMMARY

This paper reports an investigation into the development of a compaction procedure for base mixes containing aggregates of 1 1/2" (38 mm) maximum size. The specimens were made in a manner similar to that given in ASTM Designation 1561-71, except that a 6" diameter mold was used instead of a 4" mold.

The compaction procedure was developed using a mix in the middle of the gradation for a B-3 mix. Once an acceptable procedure was found, it was checked by making specimens using four different mixes.

It was found that the procedure which gave generally acceptable results for one mix did not give acceptable results for the other mixes. Therefore, the adoption of a compaction procedure for basic mixes is not recommended at this time.

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INTRODUCTION AND BACKGROUND

Bituminous paving mixtures containing aggregates with maximum sizes of 1 inch (25.4 mm) or less are designed in Virginia through the use of the Marshall method.[1] This method has been proven to be quite useful, being adaptable for both laboratory design and field control testing but since the base mixes used in Virginia contain aggregates with 1 1/2" (38.1 mm) maximum size, the Marshall method cannot be used.[2] Therefore, an acceptable method for designing and testing base mixes is needed.

Methods currently available for designing and testing base mixes are limited. The one developed by McDowell and Smith of the Texas Highway Department utilizes a gyratory testing device.[3] This device compacts 6" (152.4 mm) diameter by 8" (203.2 mm) high specimens to a uniform density and then tests them.

An investigation performed by McGhee of the Virginia Highway & Transportation Research Council involved the testing of cylindrical specimens in unconfined compression.[4] He utilized a vibratory table to compact the specimens.

Since the above methods do not have the simplicity of sample preparation and testing of the Marshall method, an investigation that hopefully would lead to the adoption of a method similar to the Marshall method was proposed. Other factors that were considered in deciding to seek a method utilizing Marshall specimens were: (1) the Marshall method is being used by the Virginia Department of Highways and Transportation for the design of surface mixes, and (2) the equipment needed for preparing and testing such specimens was available at the Research Council.

PURPOSE AND SCOPE

The purpose of this investigation was to develop a compaction procedure for asphaltic mixes containing aggregates of 1 1/2" (38.1 mm) maximum size. The development of the procedure was done by choosing a mix and then attempting various compaction procedures without varying the mix. Once a procedure was found that gave acceptable results, four mixes containing various materials were used to make specimens for checking the procedure. At a later date, a test procedure and criteria will be developed which can be used to design base mixes.

PROCEDURE

General Approach

The compaction procedure was developed using a typical base mix (B-3) that had been laid in the field. The mix chosen was close to the middle of the gradation. Cores were taken to obtain field densities of the mix for comparisons with those obtained on the laboratory specimens.

The procedure was developed by using the procedure designed by L. E. Wood, Jr., materials technician, for use on the California kneading compactor. This procedure is that used for making a standard Marshall specimen. After several unsuccessful adjustments of this method, the method given in ASTM Designation D 1561-71 was attempted and modified until suitable results were obtained.

The laboratory specimens were made according to the job mix formula supplied by the district materials office. By reproducing the field mix in the laboratory, it was hoped that a compaction procedure would be found that was capable of producing a specimen having a density comparable to the density of the field cores. The criteria established for determining if a compaction procedure was acceptable were: (1) the average laboratory densities should vary from average field densities by no more than $\pm$ 1.5 pcf (10.3 Kg/m^3), and (2) the specimen should be uniform throughout its depth. Uniformity was checked by sawing each specimen into three sections and an acceptable uniformity was defined as a range of 1.7 pcf (11.7 Kg/m^3) between the highest and lowest densities. The densities of the sections were determined by soaking them in paraffin wax. Then the densities of all the top sections were averaged to obtain the average density of the top section. This was also done for the middle and bottom sections and the average values were used to determine uniformity.

Once a compaction procedure was found on the initial mix that fulfilled the established criteria, several additional mixes were compacted to check the procedure. The same criteria were used for checking the compaction procedure as were used in developing it.

Materials

The materials available in Virginia for use in base mixes come from a variety of aggregate sources. Because of this variety, it was felt that the test mixes should contain several types of aggregates.

The mix chosen to develop the compaction procedure was a B-3 mix in the middle of the gradation requirements. This mix was laid on Route 1 in Fairfax County in the fall of 1973. The materials used were:

30%	#68 Traprock	Vulcan Materials, Manassas, Virginia
25%	#5 Traprock	Vulcan Materials, Manassas, Virginia
10%	Concrete Sand	Lone Star Industries, Upper Marlboro, Maryland
35%	#10 Screenings	Vulcan Materials, Manassas, Virginia

This mix will be designated as mix #1 for future reference.

After the compaction procedure was developed a check was performed using various mixes obtained from three districts. These mixes are also numbered for easy reference and the properties are given below:

Mix #2 Culpeper District, Route 17, Fauquier County

Materials

50%	#57 Granite	Vulcan Materials, Occoquan, Virginia
30%	Grade "B" Sand	Massaponax Sand and Gravel, Fredericksburg, Virginia
20%	#68 Gravel	Massaponax Sand and Gravel, Fredericksburg, Virginia

Mix #3 Salem District, Route 419, Roanoke County

Materials

60%	#5 Limestone	Rockydale Quarries, Roanoke, Virginia
30%	Limestone Screenings	Rockydale Quarries, Roanoke, Virginia
10%	Natural Sand	Martin's Property, Roanoke, Virginia

Mix #4 Staunton District, Route 50, Frederick County

Materials

25%	#5 Limestone	Stuart M. Perry, Inc., Winchester, Virginia
50%	3/4" Limestone Crusher Run	Stuart M. Perry Inc., Winchester, Virginia
25%	#10 Limestone	Stuart M. Perry, Inc., Winchester, Virginia

Mix #5 Staunton District, Route 340, Warren County

Materials

25%	#5 Limestone	Riverton Lime & Stone Co., Riverton, Virginia
45%	#26 Limestone Crusher Run	Riverton Lime & Stone Co., Riverton, Virginia
30%	#10 Limestone	Riverton Lime & Stone Co., Riverton, Virginia

All mixes were made using AC-20 asphalt, with mixes #1 and #2 containing 4.4% asphalt and mixes #3, #4, and #5 containing 4.5% asphalt.

Equipment

The compaction procedure was developed using the California kneading compactor and mold, with accessories, shown in Figure 1. The compactor had to be modified because the specimen made was 6" (152 mm) in diameter instead of the 4" (101 mm) diameter standard Marshall. The 6" mold was used to minimize the influence of boundary conditions and other irregularities caused by the 1 1/2" (38 mm) top size aggregates.[5] The modifications required were an increase in the compactor foot size from 3.1 in.^{2} (2000 mm^2) to 7.2 in.^{2} (4600 mm^2) and the construction of a mold holder to fit the 6" mold.

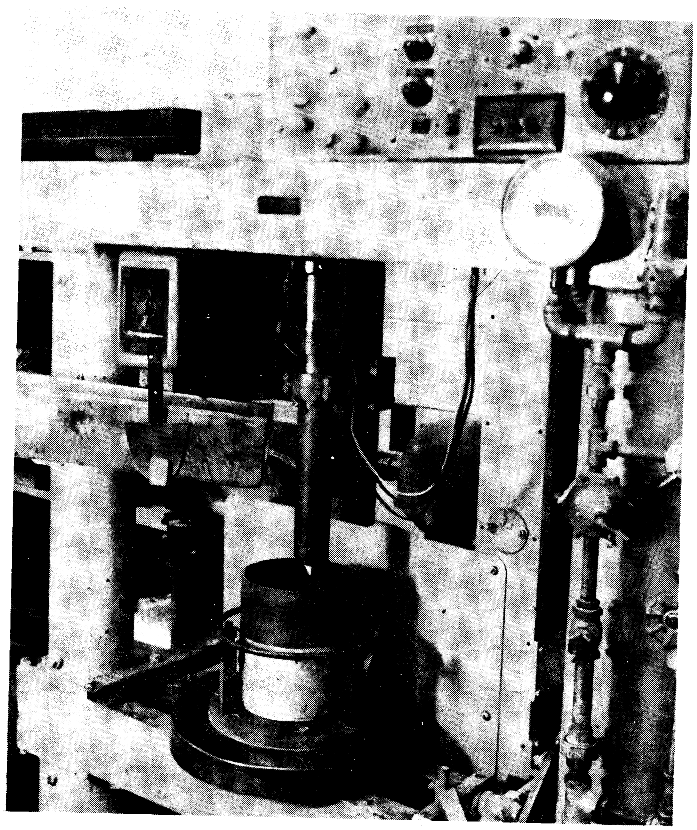

Figure 1. California kneading compactor, 6" mold, and accessories used to make specimens.

Compaction Procedure

The objective of this study was to develop a compaction procedure to produce a specimen 6" (152.4 mm) in diameter and approximately 3 3/4" (95.2 mm) high that would fulfill the criteria described earlier.

Various compaction procedures were attempted, with the first six basically following the procedure developed by L. E. Wood, Jr. for making the standard 4" Marshall specimens. Results obtained from those procedures were not satisfactory, so, a modified method of ASTM Designation D 1561-71 was attempted. The compaction procedures that were attempted are listed in the Appendix.

The first four procedures were tried on the fabrication of five specimens. The primary reason for making this number of specimens was to check the reproducibility of densities. It was found that reproducibility offered no apparent problems so the number of specimens made was reduced to two for each of the remaining compaction procedures attempted.

Once an acceptable compaction procedure was developed, eight specimens were made using that procedure. To perform a check on the compaction procedure, five specimens for each of the four additional mixes were made.

EVALUATION AND RESULTS

For each compaction procedure attempted, two specimens were sawed into three sections as shown in Figure 2. The sections were then coated with paraffin and densities were obtained. The results from each attempted compaction procedure are shown in Table 1.

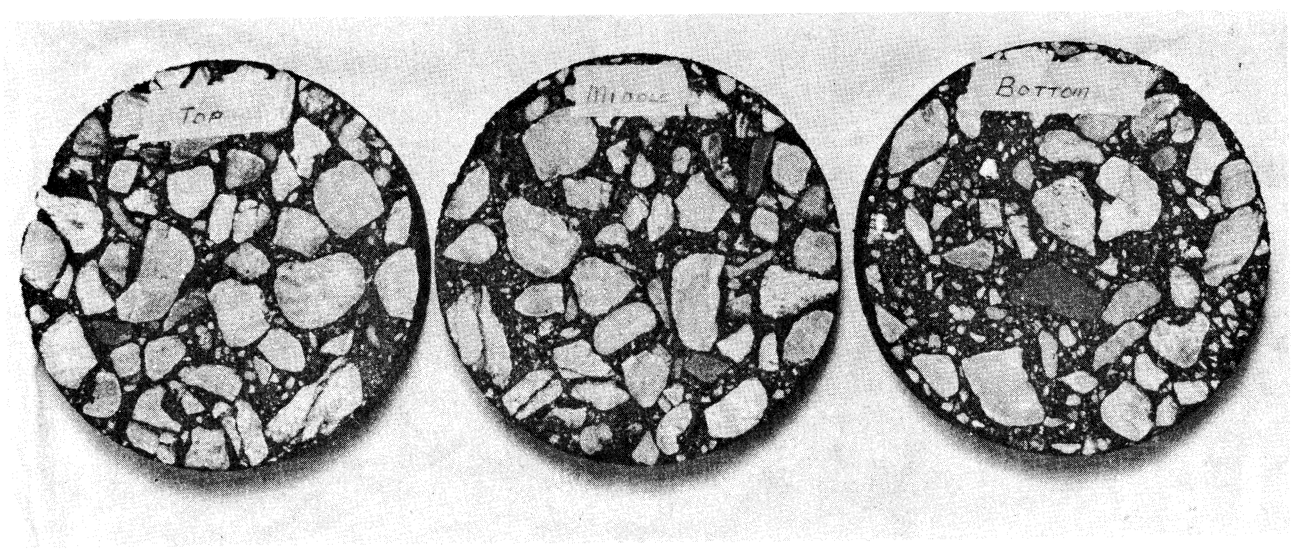

Figure 2. A lab specimen sawed into three sections for obtaining densities.

Table 1

RESULTS FROM ATTEMPTED COMPACTION PROCEDURES USING MIX #1
Basic Conversion Unit: 1 pcf = 16.02 Kg/m^3

Procedure	Portion of Specimen	Density (pcf)	Density of Laboratory Specimen, (pcf)	Avg. Range of Lab Specimens, (pcf)	Range Acceptable?	Difference Between Lab and Avg. Field Density, (pcf)	Difference Acceptable?
1st	Top	151.5	154.9	5.2	No	- 1.8	No
	Middle	156.6					
	Bottom	156.7					
2nd	Top	154.5	156.2	3.7	No	- 0.5	Yes
	Middle	158.2					
	Bottom	156.0					
3rd	Top	154.1	156.4	4.3	No	- 0.3	Yes
	Middle	158.4					
	Bottom	156.6					
4th	Top	154.9	157.2	4.7	No	+ 0.5	Yes
	Middle	159.3					
	Bottom	157.2					
5th	Top	154.1	157.1	5.2	No	+ 0.4	Yes
	Middle	159.3					
	Bottom	157.9					
6th	Top	156.7	156.0	5.5	No	- 0.7	Yes
	Middle	158.3					
	Bottom	157.8					
7th	No tests performed - specimen unsatisfactory due to excessive segregation						
8th	Top	159.6	158.2	4.0	No	+ 1.5	Yes
	Middle	159.5					
	Bottom	155.6					
9th	Top	158.1	156.4	4.7	No	- 0.3	Yes
	Middle	157.6					
	Bottom	153.4					
10th	Top	157.9	157.8	1.5	Yes	+ 1.1	Yes
	Middle	158.5					
	Bottom	157.0					

The average field density was 156.7 pcf.

In looking at the results shown in Table 1 and referring to the attempted compaction procedures given in the Appendix, the adjustments of the procedures to obtain satisfactory results can be seen.

The adjustments to the compaction procedure included increasing or decreasing the number of blows applied, changing the foot pressure, and either using or removing the shims. After a compaction procedure had been attempted and the specimen tested, the procedure was adjusted based on previous results. Taking the fourth compaction procedure as an example, it can be seen that the third procedure had a specimen density lower than the field density and the top section had a very low density. To adjust for this error, the foot pressure was increased from 475 psi (3.32 MPa) to 638 psi (4.41 MPa). This adjustment increased the specimen density, however, it had only a minor effect on the density of the top section. The higher foot pressure tended to push the asphalt more and possibly affected the density. It was later found to be best to keep the foot pressure constant at 475 psi (3.32 MPa). This was because the lower foot pressure did not crush the large aggregate as much as did the high pressure. It was also found that removal of the shims did increase the density of the bottom section to a small degree.

Adjustment of the number of blows placed on the specimen at certain levels had the most effect on the density of the laboratory specimens. This is obvious in the ninth and tenth compaction procedures. The ninth procedure produced a specimen with good density in comparison to field density but the bottom section had a very low density. Therefore, to correct this difference, after the first half of the mix had been placed into the mold and rodded, ten blows were placed on it before the remainder of the mix was added. This procedure caused a significant increase in the density of the bottom section without affecting the top and middle sections. This procedure fulfilled the requirements given in the criteria and four additional mixes were made to check it.

For each mix five specimens were made, sawed, and tested. The results from these mixes are shown in Tables 2 and 3. Table 2 gives a comparison of the average laboratory and average field densities. It is seen that mixes No. 1, No. 3, and No. 4 gave quite good comparisons, being under the ± 1.5 pcf criterion; mix No. 5 gave questionable results; and mix No. 2 gave results that were not acceptable.

Table 3 shows the results obtained by sawing the specimens into sections and checking densities of the sections. The densities of the sections were compared to find the degree of uniformity. Mix No. 1 gave a value that was acceptable and fit the criterion of ± 1.7 pcf difference. Mixes No. 2 and No. 3 had values that were questionable, and mixes No. 4 and No. 5 were not acceptable.

Table 2

COMPARISON OF FIELD AND LABORATORY SPECIMENS
Basic Conversion Unit: 1 pcf = 16.02 Kg/m^3

Mix No.	Avg. Density of Lab Specimens, pcf	Avg. Density of Field Specimens, pcf	Diff. in Lab & Field Densities	*% Compaction of Lab Specimen
No. 1	157.6	156.7	+ 0.9	94.5
No. 2	146.1	142.4	+ 3.7	93.8
No. 3	153.1	152.5	+ 0.6	94.1
No. 4	147.4	147.5	- 0.1	91.5
No. 5	148.6	150.2	- 1.6	93.5

*Percent compaction determined using theoretical density of field cores.

Table 3

UNIFORMITY OF SPECIMENS
Basic Conversion Unit: 1 pcf = 16.02 Kg/m^3

Mix No.	Location of Section	Avg. Density of Section, pcf	Difference of Densities Within Mix, pcf
No. 1	Top	157.7	
	Middle	158.1	1.3
	Bottom	156.8	
No. 2	Top	146.4	
	Middle	147.0	2.0
	Bottom	145.0	
No. 3	Top	154.6	
	Middle	152.6	2.5
	Bottom	152.1	
No. 4	Top	149.5	
	Middle	146.5	3.3
	Bottom	146.2	
No. 5	Top	150.5	
	Middle	147.4	3.1
	Bottom	147.9	

CONCLUSIONS AND RECOMMENDATIONS

The acceptance of this compaction procedure is not recommended without further research. It is felt that the procedure can be further refined to give better results. However it should be noted that no compaction procedure can be developed which will give satisfactory results for every mix tested. Therfore, a wide variety of mixes should be checked when this procedure is further refined.

Observations made during this investigation that might aid future study are:

1. Increased foot pressure does increase specimen density; however, it also causes pushing of the asphalt in the mold, which affects the density of the top portion of the specimen. It is recommended that all compaction be done at 475 psi (3.32 MPa) foot pressure.

2. The mix should be evenly spread in the mold prior to compacting to help reduce problems of segregation.

3. The presence of large aggregates caused a high degree of "crushing" under the foot pressure. This was particularly true of mixes containing limestone. The crushing of the aggregates also increased with increased foot pressure.

When further study is undertaken to refine the compaction procedure, it is recommended that the investigator attempt the following adjustments to the procedure:

1. Increase the number of blows on the first half of the mix from 10 to 15 or 20.

2. Decrease the number of blows after the shims are removed from 80 to 50 or 60.

3. Use a mix containing predominately limestone materials because limestone caused the greatest difficulty in producing a uniform specimen.

The primary concern during the refinement of the compaction procedure should be to produce a specimen that is uniform. The mixes containing limestone had the highest variation of densities between the sawed sections. Therefore, it is felt that by using a limestone mix to refine the compaction procedure, mixes containing other materials will also give acceptable uniformity.

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APPENDIX

COMPACTION PROCEDURES USED

1st Procedure

One-half of the mix was placed into the mold and 20 blows were applied; the remaining mix was added in while 25 blows were applied. The entire mix then received 20 blows, was covered with a steel plate, and given an additional 20 blows. The specimen received 85 total blows, all at 475 psi (3.32 MPa) foot pressure.

2nd Procedure

One-half of the mix was placed into the mold and 10 blows were applied; the remaining mix was added while 25 blows were applied. The entire mix then received 30 blows, was covered with a steel plate, and given additional 20 blows. The specimen received 85 total blows, all at 475 psi (3.32 MPa) foot pressure.

3rd Procedure

One-half of the mix was placed into the mold and 10 blows applied; the remaining mix was added while 25 blows were applied. After the initial 35 blows, the mold was loosened and the shims were removed. Then 30 blows were placed on the entire mix, the mix was covered, and 20 blows were applied to the steel plate used to cover the mix. The specimen received a total of 85 blows, all at 475 psi (3.32 MPa) foot pressure.

4th Procedure

One-half of the mix was placed into the mold and 10 blows applied; the remaining mix was added while 25 blows were applied. After the initial 35 blows, the mold was loosened and the shims were removed. Then 30 blows were placed on the entire mix, the mix was covered, and 20 blows were applied to the steel plate used to cover the mix. The specimen received a total of 85 blows, all at 638 psi (4.46 MPa) foot pressure.

5th Procedure

One-half of the mix was placed into the mold and 10 blows applied; the remaining mix was added while 25 blows were applied. After the initial 35 blows, the mold was loosened and the shims were removed. Then 30 blows were placed on the entire mix, the mix was covered, and 20 blows were applied to the steel plate used to cover the mix. The specimens received a total of 85 blows; a foot pressure of 638 psi (4.46 MPa) was used for the first 45 blows, and then reduced to 509 psi (3.56 MPa) for the remaining blows.

6th Procedure

One-half of the mix was placed into the mold and 20 blows applied; the remaining mix was added while 25 blows were applied. Then 30 blows were placed on the entire mix, the mix was covered, and 20 blows were applied to the steel plate used to cover the mix. The specimen received a total of 95 blows, all at 475 psi (3.32 MPa) foot pressure.

7th Procedure

This procedure was of the same format as ASTM Designation 1561-71, modified as follows. One-half of the mix was placed into the mold and rodded 20 times in the center and 20 times around the circumference. The remaining mix was placed into the mold and the rodding was repeated. The mix was then placed on the kneading compactor and had 20 blows at 475 psi (3.32 MPa) applied to it. The mold was loosened and the shims were removed. After the initial 20 blows, an additional 130 blows were applied at an increased foot pressure of 638 psi (4.46 MPa). After the 130 blows, the mix was covered with a steel plate and 20 blows at 638 psi (4.46 MPa) foot pressure added. The specimen received a total of 170 blows.

8th Procedure

One-half of the mix was placed into the mold and rodded 20 times in the center and 20 times around the edges. The remainder of the mix was placed into the mold and 20 blows were applied at a pressure of 475 psi (3.32 MPa). The mold was loosened and the shims were removed. The mix then had an additional 130 blows placed at a foot pressure of 638 psi (4.46 MPa). A steel plate was used to cover the mix, and 20 blows were applied to the plate with the foot pressure remaining at 638 psi (4.46 MPa). The specimen received a total of 170 blows.

9th Procedure

One-half of the mix was placed into the mold and rodded 20 times in the center and 20 times around the edges. The remainder of the mix was placed into the mold and 20 blows were applied at a pressure of 475 psi (3.32 MPa). The mold was loosened and the shims were removed. The mix then had an additional 80 blows placed at a foot pressure of 638 psi (4.46 MPa). A steel plate was used to cover the mix, and 20 blows were applied to the plate with the foot pressure remaining at 638 psi (4.46 MPa). The specimen received a total of 120 blows.

10th Procedure

One-half of the mix was placed into the mold and rodded 20 times in the center and 20 times around the edges. The mold was then placed on the kneading compactor and given 10 blows. The remainder of the mix was added and 20 blows were applied. The mold was loosened and the shims were removed. The mix then was given an additional 80 blows. A steel plate was used to cover the mix and 20 blows were applied to the plate. The specimen received a total of 130 blows, all at 475 psi (3.32 MPa) foot pressure.

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