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US Army Corps
of Engineers

TECHNICAL REPORT GL-87-8

MAXIMUM THEORETICAL SPECIFIC GRAVITY OF BITUMINOUS PAVING MIXTURES

DTIC FILE COPY

by

Robert R. Johnson, Karen L. Kelley

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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To calculate the percentage of voids in a bituminous pavement mixture, it is necessary to determine the maximum theoretical specific gravity of the mixture. Test procedures being used to determine the maximum theoretical specific gravity of bituminous mixtures made with absorptive aggregates have proved to be troublesome. The specified procedure has also been found to be questionable when used for recycled asphalt pavement testing. This report discusses and compares test results and void calculations when different test procedures are used to determine the maximum theoretical specific gravity of absorptive aggregates in bituminous mixtures. (key words:

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PREFACE

This study was conducted by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the Office, Chief of Engineers (OCE), US Army, under the Facilities Investigation and Studies Program. Mr. A. F. Muller, OCE, was the Technical Monitor. This report describes the results obtained from the project entitled "Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures."

The study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL; Mr. H. H. Ulery, Jr., Chief, Pavements System Division (PSD), GL; Mr. J. W. Hall, Jr., Chief, Engineering Investigation, Testing, and Validation Group (EIT&V), PSD, GL; and Dr. E. R. Brown, Chief, Material Research Center, EIT&V, PSD, GL. Personnel of PSD actively engaged in the planning, testing, analyzing, and reporting phases of this study were Mr. R. R. Johnson, Ms. K. L. Kelley, Mr. L. N. Lynch, Mr. R. T. Graham, and Mr. J. K. Simmons. This report was written by Mr. Johnson and Ms. Kelley, PSD.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
inches	2.54	centimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms

MAXIMUM THEORETICAL SPECIFIC GRAVITY OF BITUMINOUS PAVING MIXTURES

PART I: INTRODUCTION

Background

1. The maximum theoretical specific gravity of bituminous paving mixtures is the specific gravity at which zero air voids are present in the mix. There are currently three methods commonly being used by asphalt technologists to determine the maximum theoretical specific gravity: (a) a computation using the apparent specific gravity of the aggregate and asphalt cement; (b) a computation based on the bulk-impregnated specific gravity; and (c) a measurement in accordance with American Society for Testing and Materials' (ASTM) D 2041. Presently, the Corps of Engineers allows only methods (a) and (b) to be used (Headquarters, Department of the Army 1971).

2. Corps of Engineers specifications for asphalt concrete require that Test Method 105 (Military Standard 620A) entitled "Determination of Bulk-Impregnated Specific Gravity of Aggregate Proposed for Use in Bituminous Paving Mixes," be used for determining the specific gravity of aggregate blends having a water absorption in excess of 2.5 percent (Department of Defense 1966). Problems have been experienced with this test procedure primarily because of the unfamiliarity of laboratory technicians with the test.

3. Test Method 105 specifies that 85 to 100 penetration grade asphalt be used in the test. If another grade of asphalt cement is used in the field, this makes the tests with 85 to 100 penetration grade asphalt cement somewhat erroneous. Requiring the job asphalt cement to be used in determining the bulk-impregnated specific gravity would be more realistic and should be specified if use of this procedure is continued.

4. Past experience has also indicated that the bulk-impregnated specific gravity test procedure has produced wide variations in results on identical samples when the tests are conducted by different operators. Most laboratories have not had experience with this test method because the Corps of Engineers is the only agency using it. There is an obvious advantage in

selecting a method in common use for determining maximum theoretical specific gravity.

5. Additional problems have been encountered when determining specific gravities for the materials used in recycled asphalt pavements. The technique using apparent specific gravity requires the specific gravities of virgin materials and the reclaimed asphalt pavement materials to be combined to calculate the properties of the recycled mixture. To obtain the specific gravities of the reclaimed asphalt, extractions of large samples of the material are necessary. Following extraction, the aggregates are separated into fine and coarse aggregates, and the specific gravity is determined for each size range. Also, after the extraction test, the asphalt is separated from the solvent and the asphalt specific gravity is determined. Some recycled materials require the addition of a recycling agent (RA), and the specific gravity of this material is also required. Percentages of the separate components are used in calculating the maximum theoretical specific gravity of the mixture. With this large number of materials, these procedures are cumbersome and require that tests be conducted by an experienced technician to minimize the margin of error.

Objective

6. The objective of this study was to determine, through a literature review and a testing program, the feasibility of replacing the bulk-impregnated specific gravity procedure with the test method described in ASTM D 2041 for determining maximum theoretical specific gravity of mixes containing absorptive aggregates. A comparison was also made between the maximum theoretical specific gravity, measured in accordance with ASTM D 2041, and the maximum theoretical specific gravity computed from the apparent specific gravity.

Scope

7. The objectives of this study were accomplished by a review of (a) the ASTM procedures, (b) American Association of State Highways and Transportation Officials (AASHTO) testing procedures, and (c) the US Army Engineer Waterways Experiment Station reports written during the development of the

bulk-impregnated specific gravity test procedure (US Army Engineer Waterways Experiment Station 1953; Buck 1954; Department of Defense 1966; McRae 1955, 1956a, 1956b). In addition to the literature review, a testing program was conducted using two absorptive aggregates and two nonabsorptive aggregates. The maximum theoretical specific gravity was calculated from the measured bulk-impregnated specific gravity for asphalt mixture prepared with the two absorptive aggregates and compared with the maximum theoretical specific gravity determined from ASTM D 2041. This information was used to calculate the voids of the two mixtures at various asphalt contents to evaluate differences in the two test methods. The maximum theoretical specific gravity was computed from the apparent specific gravity for asphalt mixture prepared with the two nonabsorptive aggregates and compared with the maximum theoretical specific gravity determined from ASTM D 2041. This information was used to calculate and compare the voids of the two mixtures at various asphalt contents.

PART II: TESTING PROGRAM

8. Four aggregates were selected for the study: (a) blast furnace slag; (b) Florida limerock from Maule Industries, Miami, Florida; (c) Alabama limestone from Vulcan Materials Company, Birmingham, Alabama; and (d) crushed gravel from Runyon and Sons, Vicksburg, Mississippi. Both the blended gradation of the slag and the blended gradation of the Florida limerock had a water absorption in excess of 2.5 percent. The blended gradation of the Alabama limestone and the blended gradation of the crushed gravel had a water absorption less than 2.5 percent. The apparent specific gravity and absorption for each of these aggregates are provided in Table 1.

Table 1

Aggregate Test Results

Aggregate	Apparent Specific Gravity	Percent Absorption of Blend
Slag	2.694	3.90
Florida limerock	2.638	3.89
Alabama limestone	2.735	0.49
Crushed gravel	2.641	1.15

Blast Furnace Slag

9. A mix design was prepared for the slag aggregate and AC 20 asphalt cement. Samples at a number of asphalt contents were mixed and the samples were split, with one-half of each sample used to prepare Marshall specimens and the other half used to determine the maximum theoretical specific gravity in accordance with ASTM D 2041. The gyratory compactor, set at 100 psi,* 1-deg angle, and 30 revolutions (similar to 50-blow compaction with Marshall hammer), was used to compact the specimens in accordance with Military Standard 620A (Method 102).

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

10. Results of mix design tests conducted on the compacted samples are shown in Figures 1 and 2. A comparison of the voids filled and voids total mix computed from the bulk-impregnated specific gravity and the ASTM D 2041 maximum theoretical specific gravity is shown in Figure 3. The values for the two methods are approximately equal. The maximum theoretical specific gravities used for the void calculations at the various asphalt contents are listed in Table 2. The results are similar for the two methods. The test results

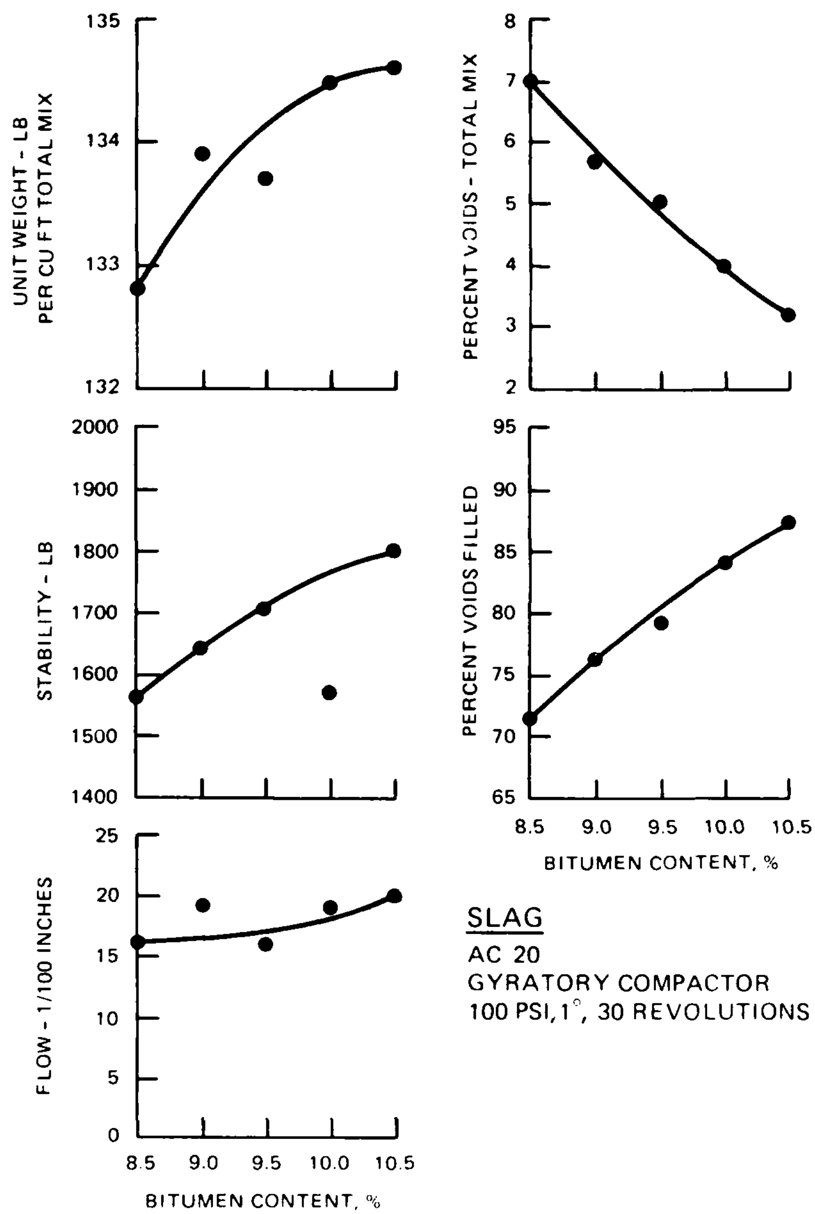

Figure 1. Slag aggregate mix design. Voids calculated using bulk-impregnated specific gravity

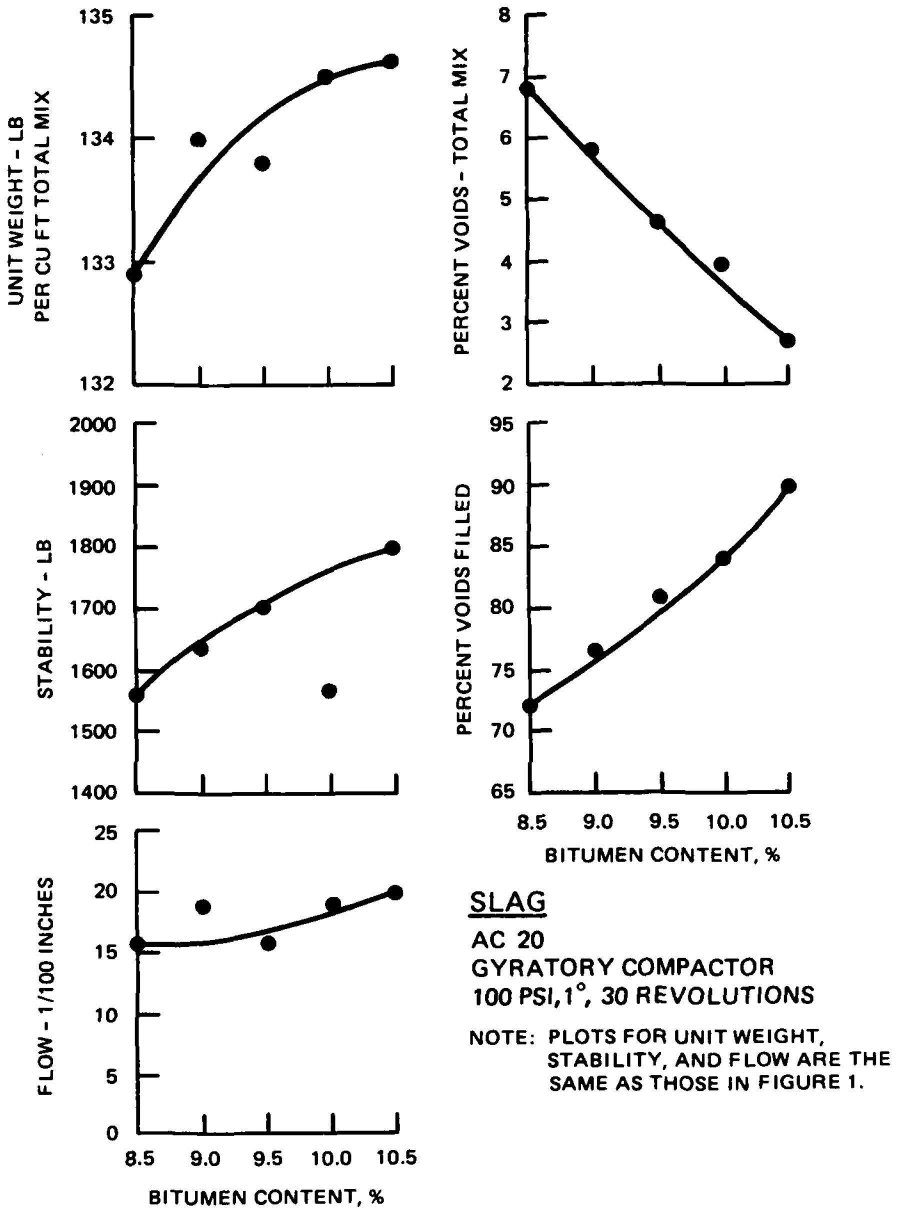

Figure 2. Slag aggregate mix design. Voids calculated using theoretical maximum specific gravity--ASTM D 2041

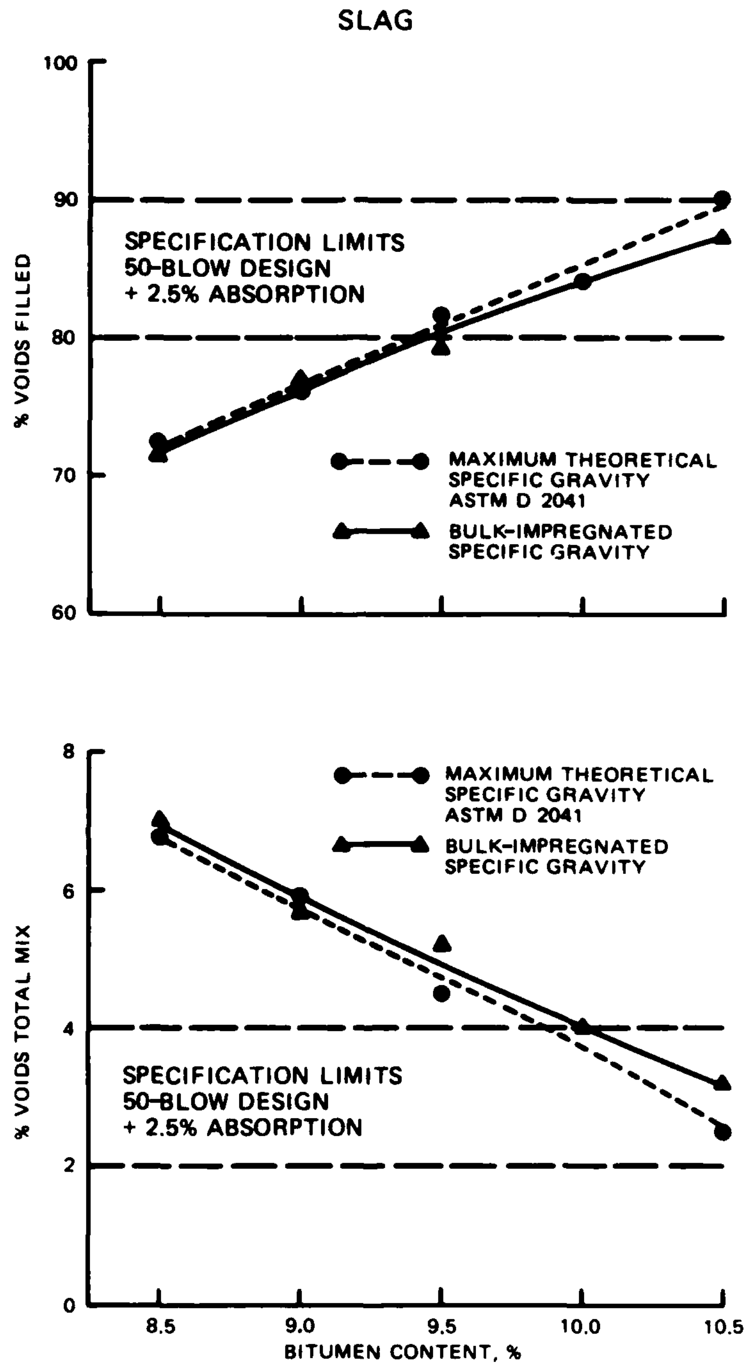

Figure 3. Slag aggregate mix design. Comparison of voids filled and voids total mix

Table 2

Comparison of Maximum Theoretical Specific Gravities

	Slag Aggregate	
Percent Asphalt	ASTM D 2041 Method	Bulk-Impregnated Method
8.5	2.284	2.289
9.0	2.280	2.274
9.5	2.242	2.259
10.0	2.245	2.244
10.5	2.212	2.229

determined by ASTM D 2041 were an average of two tests conducted on the material taken from the split sample, whereas the bulk-impregnated specific gravities were calculated from an average of four tests.

11. The two test procedures were also investigated to compare the variability of the test methods. Six individual tests were conducted on identical materials using the two test methods so that the standard deviation could be calculated (Table 3). The results indicate that there is very little difference in variability between the two methods; however, personnel familiar with both test methods conducted these laboratory tests.

Table 3

Comparison of Reproducibility Slag Aggregate

	Slag Aggregate	
Test Number	ASTM D 2041 Method	Bulk-Impregnated Method
1	2.258	2.281
2	2.259	2.304
3	2.252	2.304
4	2.286	2.302
5	2.261	2.318
6	2.241	2.309
Average	2.260	2.303
Standard Deviation	0.015	0.012

Florida Limerock

12. The same tests conducted on the slag aggregates were also conducted on the Florida limerock aggregate. During mixing, it was noticed that the mixture contained porous uncoated aggregate; therefore, the supplemental procedure in ASTM D 2041 was used to determine the maximum theoretical specific gravity. The supplemental procedure involves using the saturated surface dry weight of the sample to calculate the specific gravity. This procedure is noted and specified in ASTM D 2041 as well as AASHTO T 209 as a "Supplemental Procedure for Mixtures Containing Porous Aggregate Not Completely Coated."

13. Results of mix design tests conducted on the compacted samples are shown in Figures 4 and 5. A comparison of the voids filled and the voids

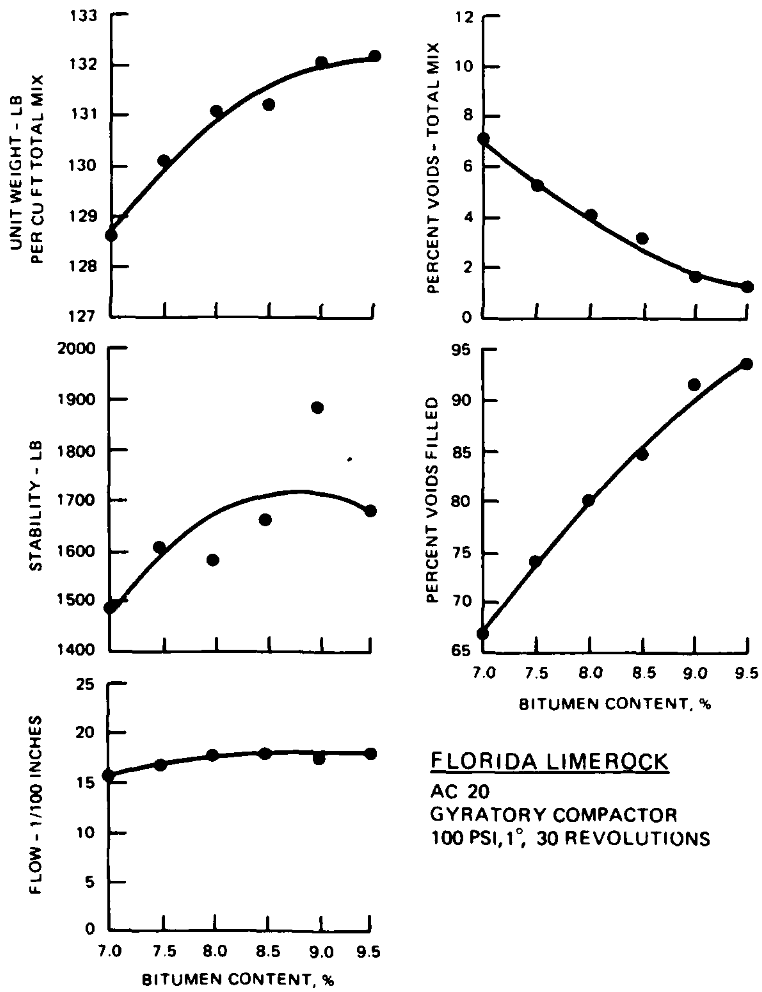

Figure 4. Florida limerock mix design. Voids calculated using bulk-impregnated specific gravity

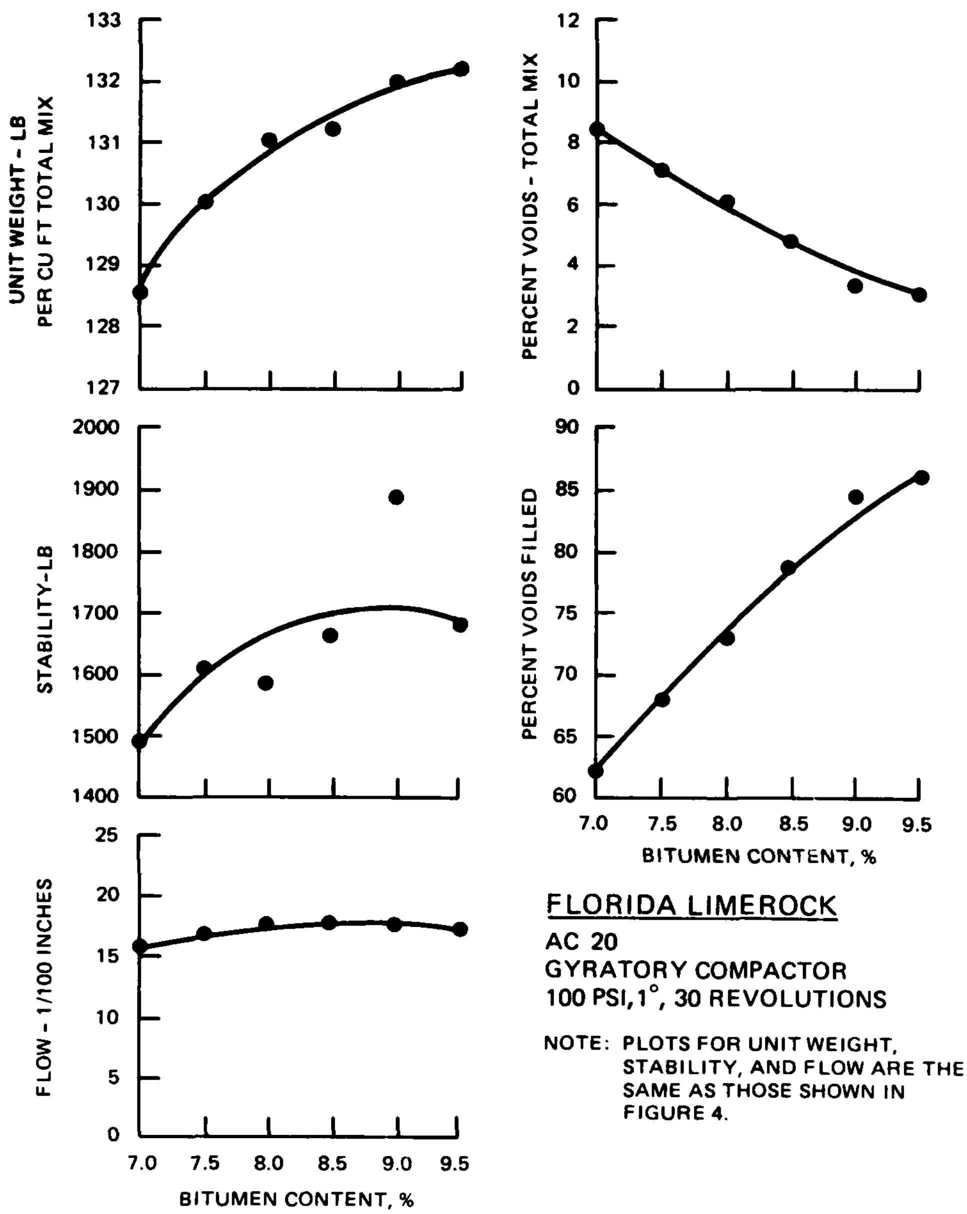

Figure 5. Florida limerock mix design. Voids calculated using theoretical maximum specific gravity--ASTM D 2041

total mix computed from the bulk-impregnated specific gravity and the ASTM D 2041 specific gravity methods are shown in Figure 6. The specific gravities used for the void calculations of the various asphalt contents are listed in Table 4. The test results from ASTM D 2041 were an average of two tests conducted on the material taken from the split sample, whereas the bulk-impregnated specific gravities were calculated from an average of four tests.

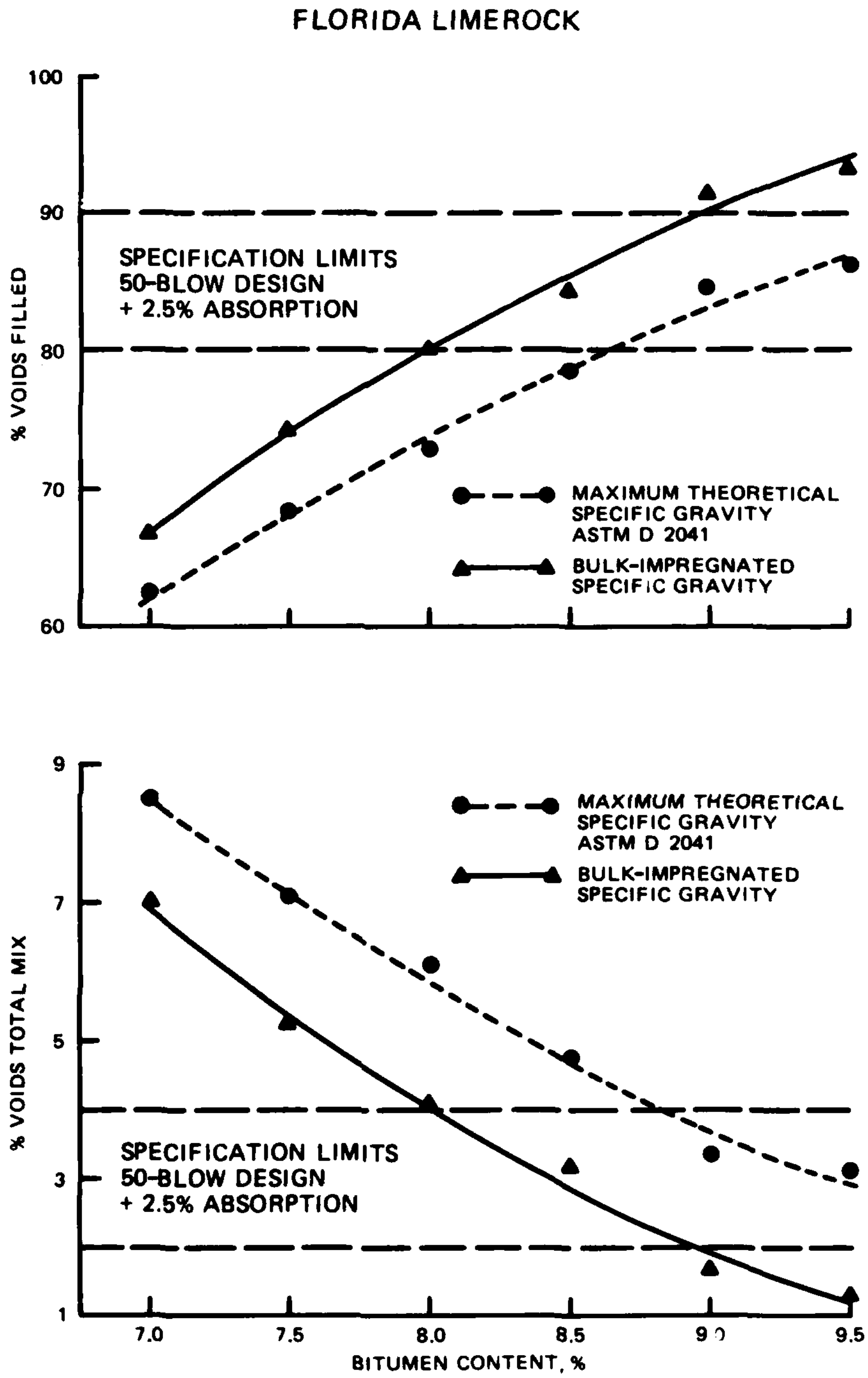

Figure 6. Florida limerock mix design. Comparison of voids filled and voids total mix

Table 4

Comparison of Maximum Theoretical Specific Gravity

Florida Limerock		
Percent Asphalt	ASTM D 2041 Method (Supplemental Procedure)	Bulk-Impregnated Method
7.0	2.253	2.216
7.5	2.244	2.202
8.0	2.236	2.189
8.5	2.209	2.172
9.0	2.191	2.153
9.5	2.188	2.149

Alabama Limestone

14. A mix design was prepared for the Alabama limestone aggregate and AC 20 asphalt cement. The same tests conducted on the slag aggregate and the Florida limerock were also conducted on the Alabama limestone aggregate.

15. Results of mix design tests conducted on the compacted samples are shown in Figures 7 and 8. A comparison of the voids filled and the voids total mix computed from the apparent specific gravity and the ASTM D 2041 maximum theoretical specific gravity is shown in Figure 9. The ASTM D 2041 test method resulted in slightly higher voids total mix than did that calculated from the apparent specific gravity. However, this difference is attributed to testing variability and is within the acceptable range of single-operator testing precision. The maximum theoretical specific gravities used for the void calculations at the various asphalt contents are listed in Table 5. The test results determined by the ASTM D 2041 method and the apparent specific gravity method were an average of two tests conducted on the material taken from the split sample.

Crushed Gravel

16. A mix design was prepared for the crushed gravel aggregate and AC 20 asphalt cement. The same tests conducted on the slag aggregate, the

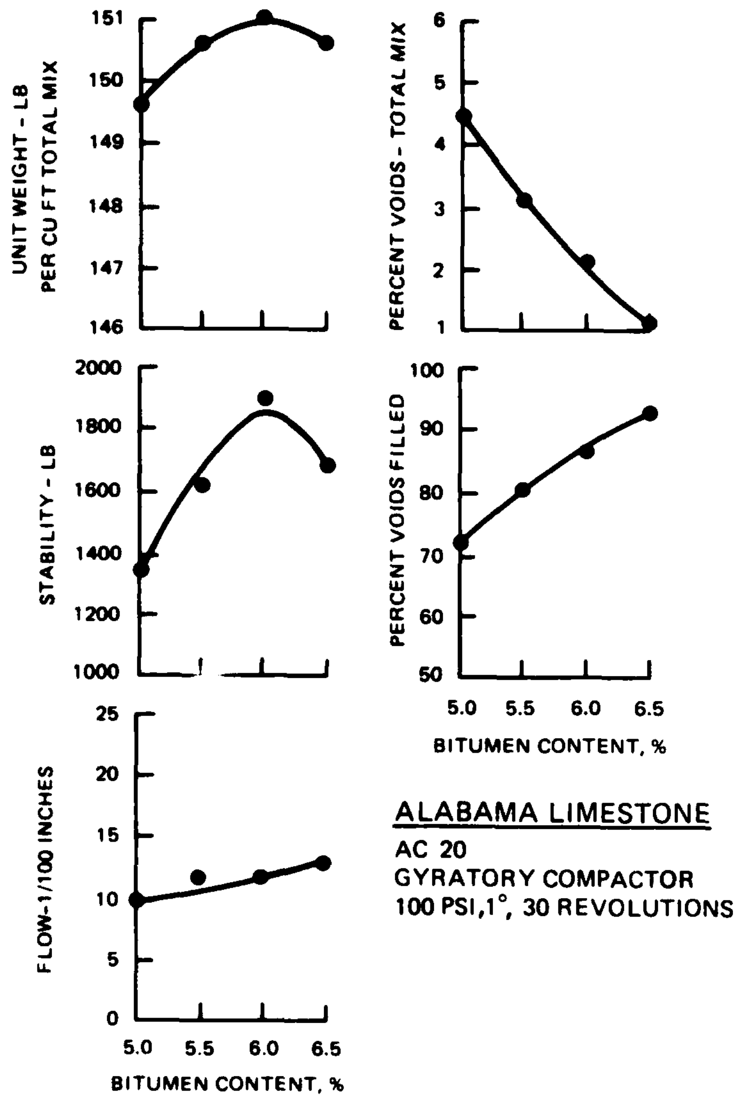

Figure 7. Alabama limestone mix design. Voids calculated using apparent specific gravity

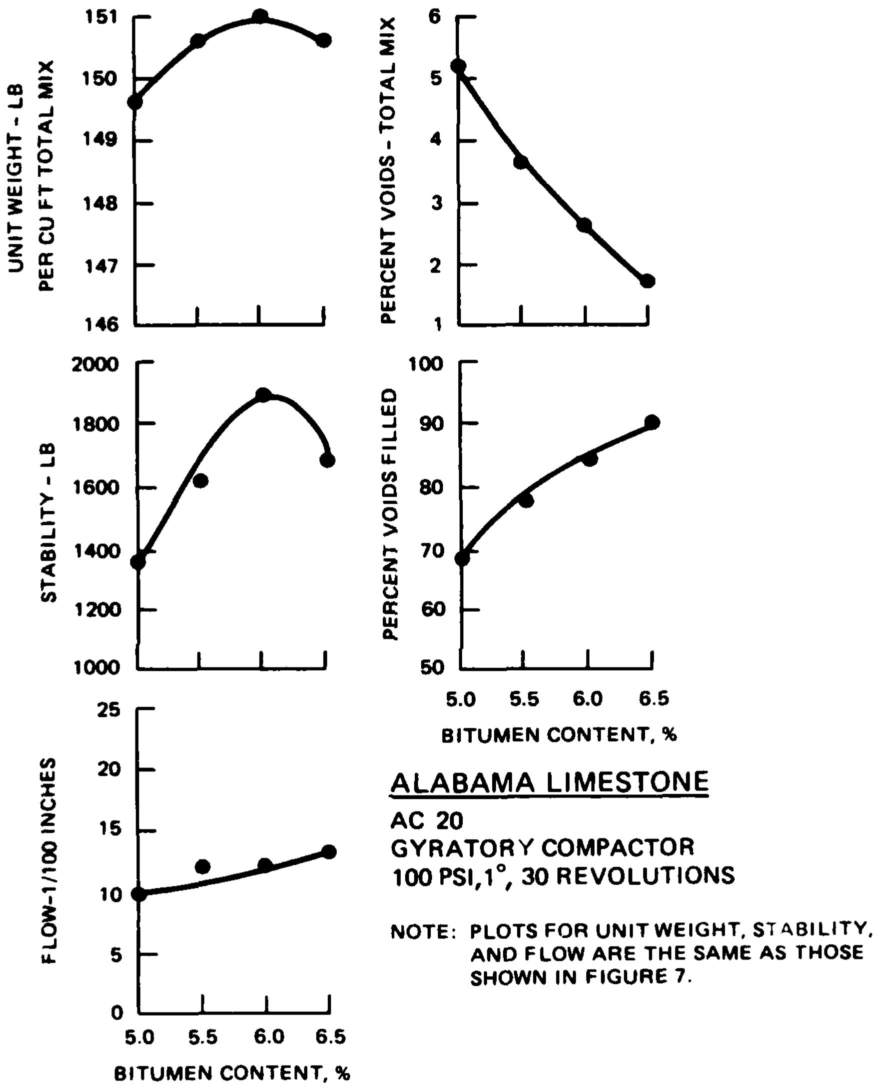

Figure 8. Alabama limestone mix design. Voids calculated using theoretical maximum specific gravity--ASTM D 2041

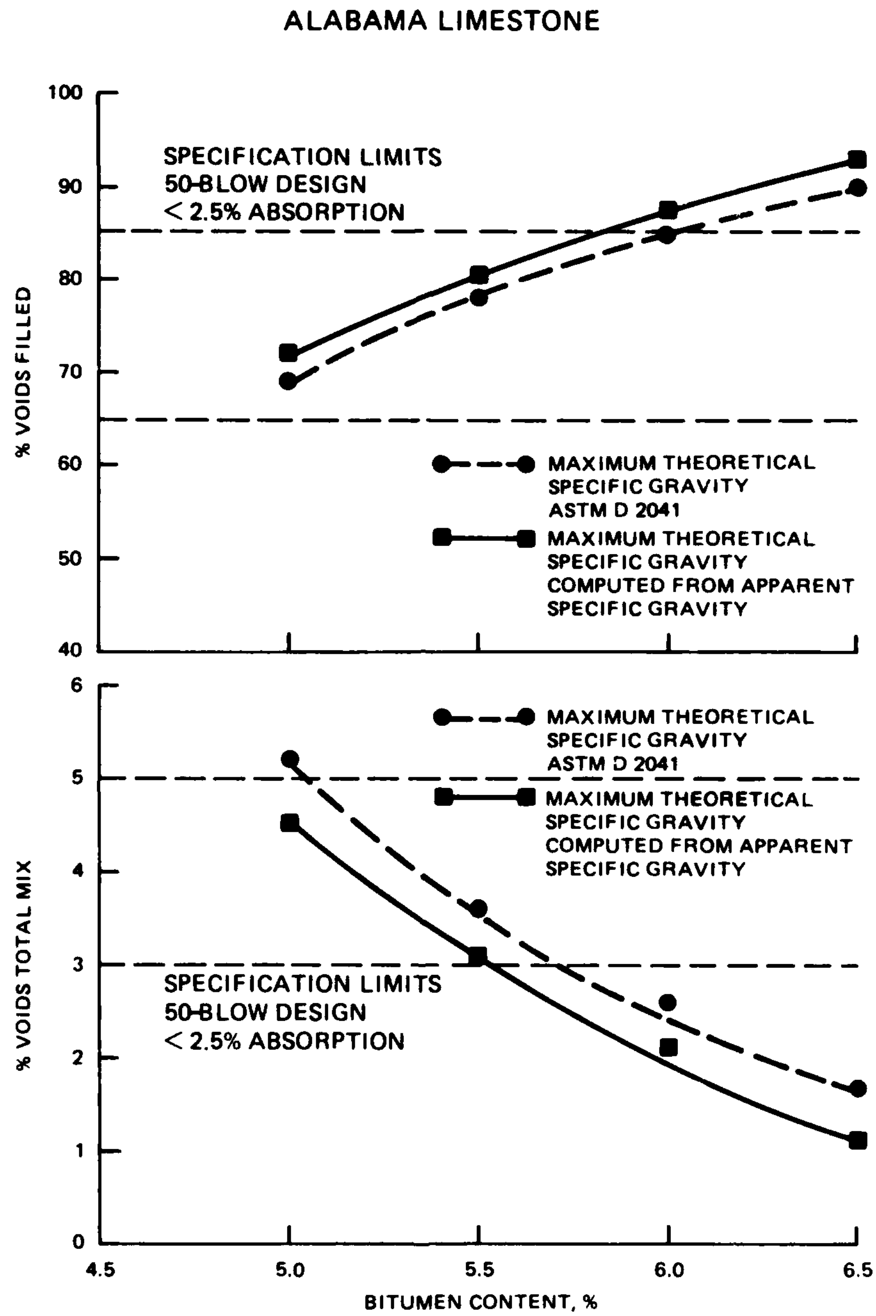

Figure 9. Alabama limestone mix design. Comparison of voids filled and voids total mix

Table 5

Comparison of Maximum Theoretical Specific Gravity

Alabama Limestone		
Percent Asphalt	ASTM D 2041 Method	Apparent Specific Gravity Method
5.0	2.529	2.510
5.5	2.505	2.491
6.0	2.484	2.473
6.5	2.469	2.455

Florida limerock, and the Alabama limestone were also conducted on the crushed gravel.

17. Results of mix design tests conducted on the compacted samples are shown in Figures 10 and 11. A comparison of the voids filled and the voids total mix computed from the apparent specific gravity and the ASTM D 2041 maximum theoretical specific gravity is shown in Figure 12. The maximum theoretical specific gravity calculated from the apparent specific gravity resulted in percent voids total mix higher than did the ASTM D 2041 test method. The maximum theoretical specific gravities used for the void calculations at the various asphalt contents are listed in Table 6. The test results determined by the ASTM D 2041 method and the apparent specific gravity method were an average of two tests conducted on the material taken from the split sample.

Table 6

Comparison of Maximum Theoretical Specific Gravity

Crushed Gravel		
Percent Asphalt	ASTM D 2041 Method	Apparent Specific Gravity Method
7.0	2.358	2.381
7.5	2.340	2.365
8.0	2.323	2.348
8.5	2.303	2.332

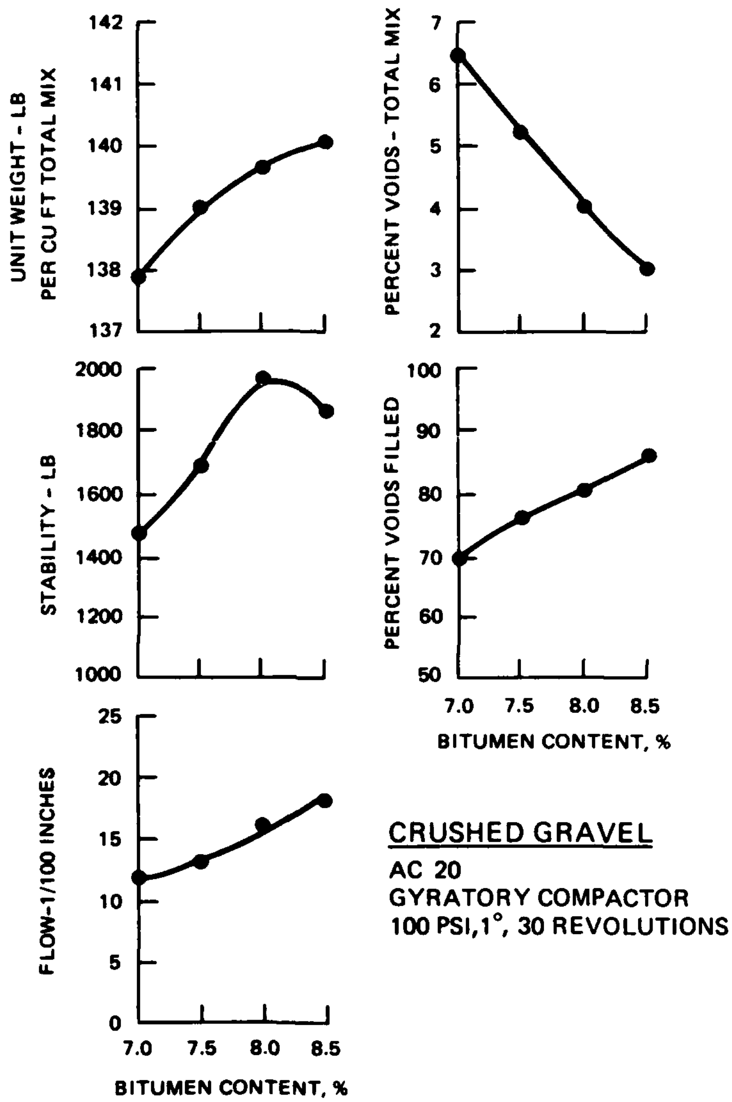

Figure 10. Crushed gravel mix design. Voids calculated using apparent specific gravity

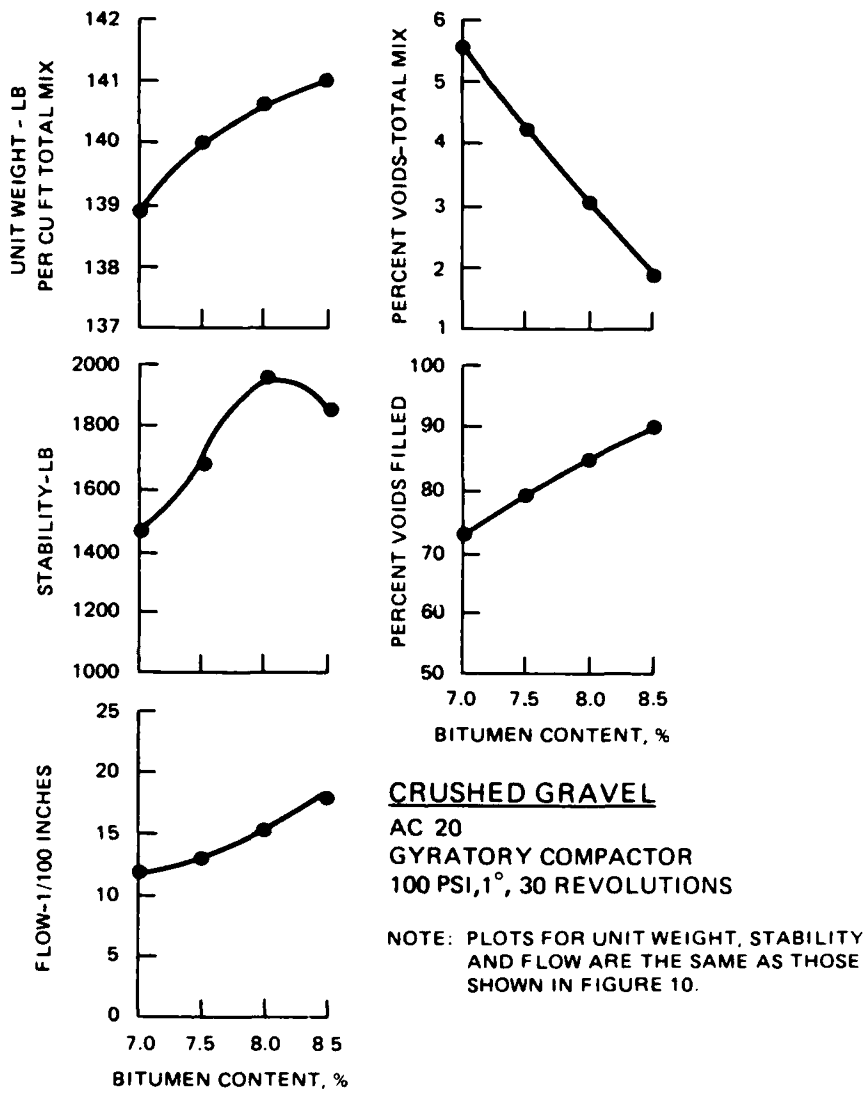

Figure 11. Crushed gravel mix design. Voids calculated using theoretical maximum specific gravity--ASTM D 2041

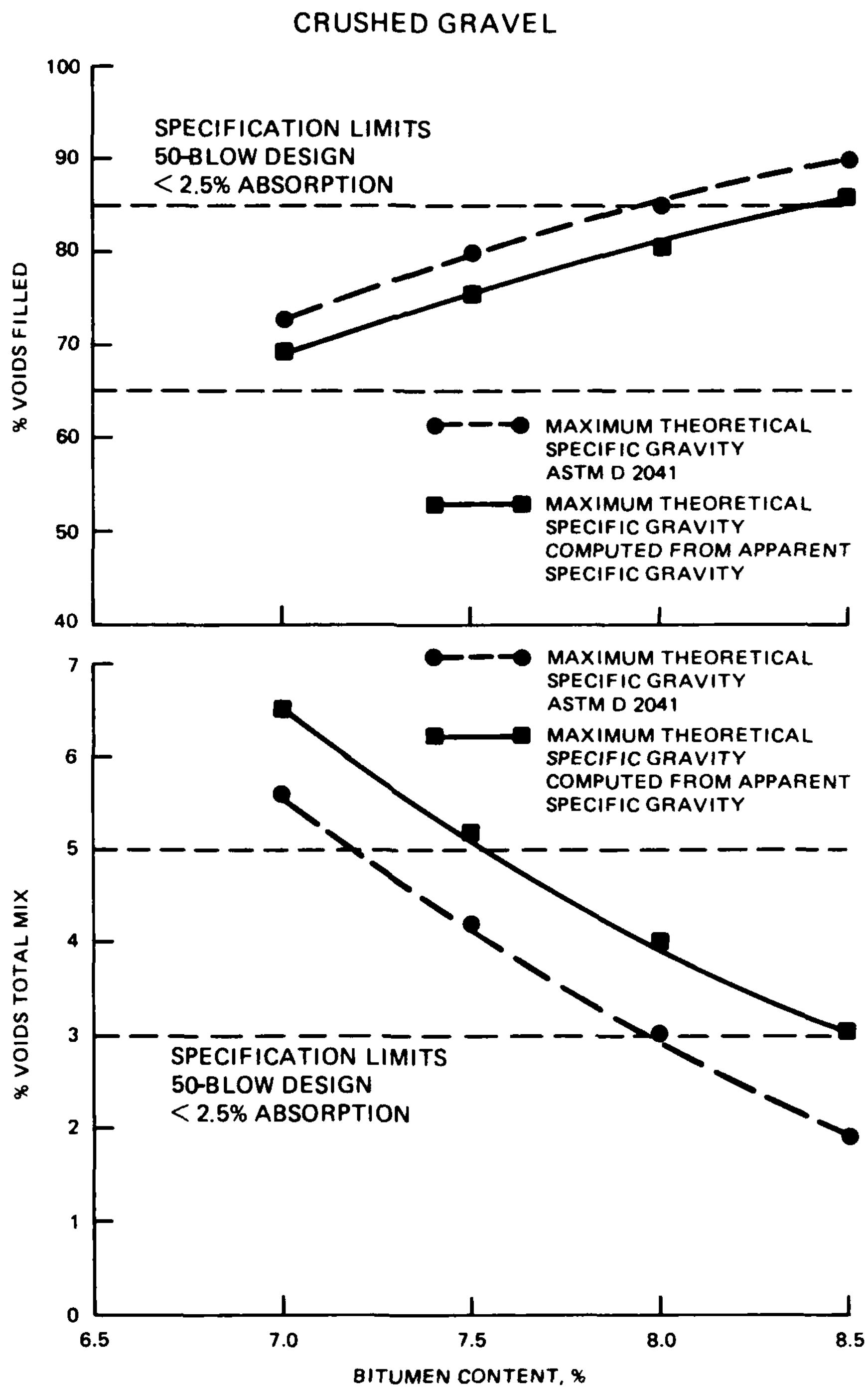

Figure 12. Crushed gravel mix design. Comparison of voids filled and voids total mix

PART III: DISCUSSION

18. Figure 3 indicates that comparable void results can be obtained when either the ASTM D 2041 or bulk-impregnated specific gravity test method is performed on the slag aggregate to determine the maximum theoretical specific gravity. Figure 6, however, demonstrates a larger spread in the void calculations when the two test methods were performed on the Florida limerock aggregate. Figures 9 (Alabama limestone) and 12 (crushed gravel) compare the voids determined from using the maximum theoretical specific gravity (ASTM D 2041 method) with those determined using maximum theoretical specific gravity computed from the apparent specific gravity. Comparable void results are obtained when either test method is performed on the two nonabsorptive aggregates (Alabama limestone and crushed gravel).

19. A possible explanation for the spread in the void results of the Florida limerock aggregate is attributed to the physical makeup of the aggregate. The slag aggregate has larger pores or voids than the limerock aggregate. These voids tend to be filled with asphalt when slag is immersed and stirred, as prescribed by the bulk-impregnated specific gravity test method. When the ASTM D 2041 test procedure is used, these voids are filled with water when the sample is subjected to a vacuum. The ability to fill these larger openings when testing in accordance with the ASTM D 2041 method eliminates most of the entrapment of air, which produces higher specific gravity results than that computed for the bulk-impregnated specific gravity method. The Florida limerock pores are much smaller than those in the slag aggregate and are difficult to fill uniformly. In addition to the small pores, the limerock is not uniform in structure; hence, varying degrees of porosity may be found in the individual aggregate particles. These characteristics contribute to the entrapment of air in the sample, resulting in lower bulk-impregnated specific gravity test results.

20. Table 7 presents a comparison of the percent voids in the total mix using the ASTM D 2041 method with the voids calculated using the method specified in "Bituminous Pavements Standard Practice Manual" (TM 5-822-8) (absorptive aggregate - bulk-impregnated specific gravity; nonabsorptive aggregate - apparent specific gravity). The percent voids in the total mix was determined at optimum asphalt content for each aggregate in the testing

program. The table indicates that the average value of percent voids in the total mix of the absorptive aggregates is 3.6 percent using the bulk-impregnated specific gravity test method, whereas the average value of percent voids total mix is 4.4 percent using the ASTM D 2041 test method for determining maximum theoretical specific gravity. This indicates that the calculated percent voids in the total mix for absorptive aggregate is increased by approximately 1 percent when using the ASTM D 2041 test method. The void criteria for absorptive aggregate should therefore be changed from 2- to 4-percent voids total mix to 3- to 5-percent voids total mix, and from 75- to 85-percent voids filled to 70- to 80-percent voids filled when using ASTM D 2041 to obtain maximum theoretical specific gravity.

21. Table 7 also indicates that the average value of percent voids total mix of the nonabsorptive aggregate is 3.3 percent using the ASTM D 2041 test method, whereas the average of percent voids total mix is 3.5 percent using the apparent method for determining maximum theoretical specific gravity. This indicated that comparable void results are obtained between the ASTM D 2041 test method and the apparent method to obtain maximum theoretical specific gravity for nonabsorptive aggregate.

Table 7

Comparison of Percent Voids Total Mix at Optimum Asphalt Content

Aggregate	ASTM D 2041 Method	TM 5-822-8 Bulk-Impregnated Method	Apparent Method
Absorptive			
Slag	3.9	4.0	-
Florida limerock	4.8	3.2	-
Average	4.4	3.6	-
Nonabsorptive			
Crushed gravel	3.0	-	4.0
Alabama limestone	3.6	-	3.0
Average	3.3	-	3.5

22. The ASTM D 2041 test method for determining maximum theoretical specific gravity has been investigated on a number of recycled asphalt concrete paving jobs and found to produce satisfactory test results. This

simplified testing procedure accelerates testing and reduces the margin of error for recycled mixtures.

PART IV: CONCLUSIONS

23. The following conclusions are based on observations and results of tests conducted during the program:

a. The ASTM D 2041 test procedure is an acceptable replacement for the bulk-impregnated test to determine the maximum theoretical specific gravity of asphalt mixtures containing absorptive aggregates. Void criteria in the "Bituminous Pavements Standard Practice Manual" (TM 5-822-8) should be changed from 2- to 4-percent voids total mix to 3- to 5-percent voids total mix, and from 75- to 85-percent voids filled to 70- to 80-percent voids filled when using ASTM D 2041 to determine the maximum theoretical specific gravity of absorptive aggregate.

b. The ASTM D 2041 test procedure can be used as an alternate to computing the maximum theoretical specific gravity from the apparent specific gravities for nonabsorptive materials. The void criteria should remain 3- to 5-percent voids total mix and 70- to 80-percent voids filled when using ASTM D 2041 for nonabsorptive aggregate.

c. The ASTM D 2041 test procedure should be used on recycled asphalt material containing both absorptive and nonabsorptive aggregates.

d. The ASTM D 2041 test procedure is a more realistic test than the bulk-impregnated specific gravity method to control asphalt mixes during field production in that it is performed on the actual material being manufactured and placed, whereas the bulk-impregnated specific gravity method is calculated during mix design preparations and makes no allowances for variations in materials during production.

e. Use of ASTM D 2041 for high absorption aggregates ensures that more testing laboratories are familiar with the test procedures, which should result in better control of the quality of asphalt mixtures.

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