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AN EVALUATION OF THE GEORGIA AND MARSHALL METHODS OF BITUMINOUS MIX DESIGNS: SENSITIVITY TO CHANGES IN AGGREGATE GRADING AND ASPHALT CONTENT

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF ILLUSTRATIONS

SUMMARY

The State Highway Department of Georgia employs a method of bituminous mix design which is a modification of a procedure developed by Hubbard and Field at the Asphalt Institute. No organized research has been conducted to evaluate the sensitivity of the Georgia procedure to changes in the characteristics and proportions of the aggregate and bitumen components of bituminous mixtures. The present study was conducted to provide such an evaluation. To obtain a comparison between the Georgia procedure and one which has been adopted by many state and Federal agencies, the Marshall method of bituminous mix design was included in the study.

The study was confined to an evaluation of the effect of changes in aggregate grading and asphalt content upon the density, stability, volume of aggregate voids, and volume of air voids of asphaltic concrete mixtures prepared by both test procedures. The aggregate used in the tests was a granite gniess crushed and graded by a local Georgia quarry. An asphalt cement with a penetration grade of 120 to 150 was used as the bitumen component for the test mixes.

The aggregate was separated into fractional sizes and recombined into four test gradings. The maximum size of aggregate particle for each gradation was 3/8 inches. The amount of material passing the No. 200 sieve was maintained between 5 and 8 per cent of the total weight of aggregate for each gradation. To obtain the four test gradings, the

amount of coarse aggregate retained on a No. 8 screen was varied at 20, 30, 40, and 50 per cent of the total weight of aggregate. Test samples were prepared and tested by both the Georgia and Marshall procedures for each of the four test gradings. Asphalt content was varied from 4.5 to 8.5 per cent of the total weight of mix.

A graphical presentation of results showed the Georgia and Marshall methods to be equally sensitive to the changes in aggregate gradation and asphalt content utilized in the test program. Increases in coarse aggregate from 20 to 40 per cent resulted in considerable increases in the density and stability and decreases in aggregate voids and air voids of test specimens prepared by both procedures. A further increase in coarse aggregate of 40 to 50 per cent produced no appreciable changes in the test quantities by either method. The compactive effort of the Marshall procedure was more effective than the Georgia compactive effort in producing mixtures at high asphalt contents whose aggregate voids were completely filled with asphalt. The Georgia stability value was sensitive to changes in aggregate voids, but minimum aggregate voids did not correspond consistently with maximum stability values for a particular grading. The maximum Marshall stability and minimum volume of aggregate voids occurred at the asphalt content which approached the capacity of the aggregate voids.

CHAPTER I

INTRODUCTION

Definition of the Problem.--To give adequate service, a bituminous roadway must be stable under the imposed loads and durable through extremes in weather. The mixture of bitumen and aggregates comprising the pavement must exhibit sufficient flexibility and workability during construction to allow placing and compaction to the desired density. Some method of design must be utilized to determine the proportions of a bituminous mix which will have all of these properties.

The method of design employed by the State Highway Department of Georgia is based upon a laboratory selection of the proportions of aggregate and bitumen. Before a particular combination of bitumen and aggregate is considered in the design procedure, the materials must conform to physical and chemical requirements established in the Standard Specifications for the State Highway Department of Georgia (1). The minimum and maximum sizes of aggregate particles and the allowable per centages of each intermediate size for varying types of construction are incorporated in the Specifications. The gradation of aggregate required for a particular mix design is determined by whether the mixture is to serve as a riding surface or as an intermediate layer in the completed pavement. Thus, with the physical and chemical requirements of the component materials established, the laboratory design procedure functions as the means for selection of the proportion of bitumen to aggregate for optimum strength, density, and durability. The proportions of aggregate and bitumen determined in the laboratory are blended and compacted during construction within limits allowed by construction specifications.

A successful mix design method procedure must be sensitive to changes in the characteristics of the materials being tested, and capable of evaluating the relative rigidity, durability, and density of test samples prepared with varying proportions of aggregate and bitumen. No formal study has been conducted with the Georgia procedure to determine the method's sensitivity to changes in aggregate gradation and amount of bitumen. It was believed that such a study would be of value to the Department in future design work and provide a means for determining possible improvements in the design procedure.

Another laboratory procedure for the design of bituminous mixtures which is widely used by state and Federal agencies is the Marshall method. Some previous correlation studies have been conducted by the United States Army, Corps of Engineers between the Marshall method and the Hubbard-Field method from which the Georgia method was adapted (2). To expand the basic knowledge in this area, it was decided to submit the Marshall procedure to the same variables of aggregate gradation and amount of bitumen.

The Empirical Approach to Bituminous Mix Design.--Both the Georgia and the Marshall methods utilize an empirical approach to the design of bituminous mixes. In utilizing an empirical approach to the design of bituminous mixes, samples composed of aggregates and bitumen are prepared and tested according to an established procedure. Design criteria obtained from the tests are evaluated against minimum requirements for serviceability which have been established by correlation of laboratory designs with field performance. Such correlation may have been developed by past experience, research, or a combination of both.

Procedures for the preparation and testing of samples vary among the many methods of design. However, the design criteria obtained from the tests are expressed as quantities whose definitions are common to all empirical methods of bituminous mix design. These quantities are stability, density, per cent of bitumen by weight or volume, volume of voids in the mineral aggregate, and total volume of air voids in the compacted mix.

The stability of a bituminous test sample is the maximum strength developed by the sample during a destructive load test. For a given test procedure, the magnitude of the stability value will be determined by the arrangement and physical properties of the aggregate particles and the amount of bitumen contained in the mixture.

The density of a bituminous test sample is expressed as the bulk specific gravity of the compacted mixture of aggregate and bitumen. The density obtained by a particular method of sample preparation is dependent upon the shape, surface texture, and grading of the aggregate particles and the amount of bitumen.

For a given compactive effort, the minimum voids in the aggregate and the maximum density are obtained with no bitumen (3). As bitumen is added to the aggregate, the film coating around each particle resists compaction. Increases in bitumen are accompanied by incremental increases in aggregate voids and decreases in density. The thickness of the bitumen coating varies as the per cent of bitumen in the mix. At some bitumen content, the coating ceases to act as a deterrent to compaction and begins to function as a lubricant for the aggregate particles. In theory, stability and density will reach maximum values and aggregate voids will reach a minimum when the volume of bitumen approaches the capacity of the aggregate voids. Further increases in bitumen result in sharp decreases in density and stability as the capacity of the aggregate voids is exceeded.

The values for stability, density, per cent bitumen, volume of voids in the aggregate, and total volume of air voids in the compacted mix obtained from the testing of samples are presented for analysis graphically to facilitate the selection of the per cent bitumen for optimum performance.

State Highway Department of Georgia Method.--The State Highway Department of Georgia employs a modification of a bituminous mix design procedure evolved by D. Hubbard and F. C. Field at the Asphalt Institute in the middle 1920s (4). As first developed, the method was applied only to the design of fine aggregate-asphalt mixes. The method was later extended to accomodate the design of coarse aggregate-asphalt mixes for sizes of stone up to 3/4 of an inch. With the exception of the compaction of coarse aggregate test samples, the Georgia method is the same as the Hubbard-Field procedure of mix design published by the Asphalt Institute (5). Whereas the Hubbard-Field method combines a manual compaction with a static compaction for coarse aggregate samples, the Georgia modification utilizes only a manual compaction for coarse aggregate samples.

For the design of fine aggregate-asphalt mixes, the stability value is obtained by extruding a cylindrical 2.0 inch diameter by 1.0 inch high sample through a 1.75 inch orifice. Coarse aggregate-asphalt stabilities are obtained by extruding a cylindrical 6.0 inch diameter by 2.0 inch high sample through a 5.75 inch orifice. A constant rate of loading is applied to the opposite face of the sample from the extrusion orifice, and the stability is taken as the maximum strength developed by the sample during extrusion.

A determination of density of the compacted specimen before destruction permits the calculation of volume of voids in the aggregates and total air voids.

The Hubbard-Field or some modification is still utilized by state agencies other than Georgia. In 1957, eleven state agencies reported the use of the Hubbard-Field or a modification for the design of bituminous mixes (6).

Marshall Method.--The Marshall method of bituminous mix design was developed by Bruce G. Marshall while associated with the Mississippi State Highway Department (2). After conducting an extensive evaluation study, the U. S. Army, Corps of Engineers adopted the Marshall method for use in the design of bituminous mixes for airfield pavements. The method has been adopted by a considerable number of state agencies. In 1957, twenty state agencies were reported to use the Marshall stability procedure in the design of bituminous paving mixes (6). The procedure has been standardized by the American Society for Testing Materials (7), and is described in detail in the Asphalt Institute Manual Series No. 2 (5).

The Marshall method employs a cylindrical test sample 4.0 inches in diameter by 2.50 inches high. After a determination of density, the sample is subjected to a destructive compression test. Loading is applied at a uniform rate through curved collars which fit against the circumferential surface of the test sample. The stability is recorded as the maximum strength developed by the sample during the test. During the stability test, the deformation of the sample in the direction of the applied load is measured and recorded as the flow value. Thus, the Marshall stability test provides an index of strength and resistance to deformation which can be correlated with field performance to establish minimum acceptable values for laboratory design.

<u>Previous Research with the Marshall and Hubbard-Field</u>.--In 1943, the United States Army, Corps of Engineers began a research program to determine a method of bituminous mix design which could function as a quality control test during construction as well as a procedure for laboratory design (2). The Tulsa District, Corps of Engineers initiated the program with comparative laboratory tests with the design methods then in general use. These tests were the Hubbard-Field, the Texas Punching Shear, Hveem, and Skidmore methods of bituminous mix design. Although the Hubbard-Field apparatus is difficult to transport, the Corps concluded that the Hubbard-Field procedure was the most adaptable

for use as a control during construction and as a procedure for laboratory design.

With the development of the Marshall method, the Waterways Experiment Station of the Corps of Engineers began an evaluation study between the Hubbard-Field and the Marshall procedures to determine which method was more suitable for the design and control of airfield pavements. Test samples were prepared and tested according to both procedures. Five gradations of coarse aggregate were used with the per cent of the total weight of aggregate greater than a U. S. Standard No. 8 screen varying from 30 to 70 per cent. The maximum size of stone was varied up to one inch with the amount of filler material smaller than a U. S. Standard No. 200 sieve varying from 4.0 to 8.0 per cent of the total weight of aggregate. Penetration grade asphalt cements (60-110) were used in the preparation of all test samples, and the tests were repeated with several types of aggregates.

Within the limits of the test variables and for the materials tested, the Corps concluded that both the Marshall and the Hubbard-Field exhibited adequate sensitivity to changes in aggregate gradation, amount of filler material, type of aggregate, and variations in the per cent of asphalt which would permit the selection of an aggregate gradation and mix proportions for optimum performance. The Hubbard-Field densities obtained generally were greater than the Marshall densities and resulted in approximately 2 per cent less asphalt at the optimum. This was attributed to a greater compactive effort for the Hubbard-Field than for the Marshall procedure.

The Marshall procedure has the advantage over the Hubbard-Field of utilizing apparatus which is compact enough to be easily transported and operated in the field. For this reason, the Corps adopted the Marshall for use in the design and construction of bituminous airfield pavements.

Not stressed in the discussion of the test results was the effect of a variation in the volume of voids in the aggregates upon stability values. A change in the aggregate voids of the compacted mix is indicative of a change in the orientation of the aggregate particles. It might be expected that the maximum stability value for a particular grading of aggregate would occur at the asphalt content which produced the minimum aggregate voids under a given compactive effort. It was anticipated that the present study would extend the existing knowledge of the sensitivity of the Georgia and Marshall stability tests to changes in aggregate voids.

CHAPTER II

MATERIALS AND PROCEDURE

Materials

<u>Aggregate and Aggregate Gradings</u>.--The mineral aggregate used was a crushed granite gniess obtained from a local Georgia quarry. Fine and coarse aggregate was obtained as two separate gradings conforming to the grading requirements of the Standard Specifications for the State Highway Department of Georgia. As obtained from the quarry, the grading of the fine aggregate was Georgia Size No. 810, and the grading of the coarse aggregate was Georgia Size No. 89. Both sizes of aggregate were separated into seven size fractions by screening over U. S. Standard screens in a Gilson grading machine. The size fractions into which the aggregates were separated were 3/8 inch to No. 4, No. 4 to No. 8, No. 8 to No. 16, No. 16 to No. 50, No. 50 to No. 100, No. 100 to No. 200, and material less than a No. 200 sieve. The fractions were stored in separate bins for recombination into the test gradings.

The volume of aggregate voids in a compacted mixture of asphalt and aggregate is affected by the grading of the aggregates. Campen and others (8) conducted an investigation to determine the effect of varying the ratio of coarse to fine aggregate upon the aggregate voids in a compacted bituminous mix. It was found that the minimum aggregate voids decreased with an increase in the coarse to fine ratio to a minimum value and that a further increase in the coarse to fine ratio would cause a sharp increase in the minimum aggregate voids. To determine how well the Georgia and Marshall methods would distinguish changes in aggregate voids with changes in the coarse to fine ratio, four gradings of aggregates were used in the tests. The per cent of the total weight of aggregates retained on a No. 8 screen (coarse aggregate) for the four test gradings was varied at 20, 30, 40, and 50 per cent. The four test gradings used are given in Table I on page 31 of the Appendix.

Determination of Aggregate Specific Gravities.--The specific gravities of the aggregates were obtained in accordance with the American Society for Testing Materials Designation C 127-42 for coarse aggregate and Designation C 128-42 for fine aggregate. Determinations of specific gravities were made for the coarse and fine portions of each of the four gradings in Table 1. The results of the specific gravity determinations are given in Table 2 on page 32 of the Appendix.

Asphalt Cement.--The asphalt cement used in the preparation of test samples was obtained at one time from the heated storage tank of a local bituminous hot-mix plant. While still in a liquid state, the asphalt was poured into one quart cans, capped and stored at room temperature until required for testing.

Physical tests were conducted to determine the penetration grade and specific gravity of the asphalt cement. Penetration tests were conducted in accordance with American Society for Testing Materials

Designation D 5, and specific gravity tests were conducted in accordance with Designation D 70. From the results of the tests, the asphalt cement was determined to have a penetration grade of 120 to 150 and a specific gravity of 1.023.

Procedure

Variation of Per Cent Asphalt.--For each of the four test gradings, the per cent of the total weight of the mix as asphalt cement was varied at 0.5 per cent increments. The minimum per cent of asphalt for each grading was taken as the content at which all of the aggregate particles could be coated. The maximum per cent of asphalt for each grading was determined by the capacity of the aggregate voids. Incremental increases in asphalt were continued until the voids of the compacted mix appeared to be overfilled.

Number of Test Samples Prepared.--For both methods, three test samples were prepared for each increment in asphalt content. Samples whose bulk density varied more than 0.02 from the average of the three samples were discarded. Additional samples were prepared at the same asphalt content until a satisfactory average was obtained.

Georgia Procedures.--Investigation of the Georgia method was confined to the preparation and testing of the 6.0 inch diameter specimen for asphaltic concrete mixtures. A detailed description of the Hubbard-Field forming molds, testing molds, and compaction hammers for the 6.0 inch diameter specimen is given in the Asphalt Institute Manual Series No. 2, (5).

The Georgia method requires hand tamping of the samples with Hubbard-Field compaction hammers. The compaction procedure requires only that "reasonably strong blows" be struck with the compaction hammers. Practice samples were prepared until successive samples could be prepared whose bulk densities were within the 0.02 limit of variation established for the tests. Procedure used for compacting the samples is given on page 40 of the Appendix.

A Tinius-Olsen hydraulic testing machine is used for the Georgia stability test. The test samples are placed in the standard Hubbard-Field testing mold and immersed in a 140°F water bath for one hour before testing. The testing mold and sample are transferred from the water bath to the test machine, and a constant rate of loading of 2.4 inches per minute is applied to the sample. The maximum strength in pounds developed by the sample is recorded as the Georgia stability value.

Marshall Procedure.--The compaction and testing of the Marshall samples was done in accordance with the standard procedure described in the Marshall Consulting and Testing Laboratory Manual (3), and is reproduced on page 42 of the Appendix. This manual also describes in detail the Marshall compaction molds, compaction hammer, stability machine, and flow meter used in the tests.

The compactive effort applied to a Marshall sample is independent of the operator. The Marshall hammer consists of a 10 pound weight which has a controlled free fall of 18 inches. The compaction procedure allows either 50 or 75 blows to be applied to each face of a sample.

The 50 blows are applied to mixes expected to withstand tire pressures up to 100 pounds per square inch. Seventy-five blows are utilized for tire pressures up to 200 pounds per square inch. Only the compactive effort of 50 blows per face was used in the preparation of the Marshall samples.

Preparation of Aggregate Gradings and Asphalt for Testing.--Each test sample required approximately 2000 grams for the Georgia method and 1200 grams for the Marshall method. Individual aggregate grading samples were prepared for each test sample by recombining the seven size fractions in mixing pans according to the gradings in Table 1. The pans were placed in a 300°F oven until the aggregate had acquired a temperature of 300°F. When an aggregate sample had reached 300°F, it was taken from the oven and placed in a round bottom mixing bowl. The bowl was placed on a pair of scales which could be read directly to one gram. The desired amount of asphalt at 280°F was weighed into the aggregate to the nearest gram and mixed with a long handled spoon until all of the aggregate was thoroughly coated and the asphalt evenly distributed throughout the mixture. When the mixture had reached the temperature required by the test procedure (230°F for the Georgia method and not less than 250°F for the Marshall), it was placed in the compaction mold and compacted according to the test procedure being followed.

Calculation of Test Quantities.--The specific gravities of the coarse and fine portions of each grading were combined to obtain an average specific gravity for use in the calculation of the test quantities. The Marshall method employs the apparent specific gravity. The Georgia method employs an effective specific gravity whose value is intermediate between the bulk and apparent specific gravities. Use of the bulk specific gravity assumes that the external voids of the aggregate particles will absorb no asphalt. An effective bulk specific gravity assumes that the voids will be partially filled with asphalt. Since it was desired to compare the results of the two methods in relative rather than absolute terms, the average bulk specific gravity was utilized for both methods. The values of the average bulk specific gravities calculated for the four test gradings are included in Table 1 on page 31 of the Appendix.

After each test sample had been compacted, it was removed from the compaction mold and allowed to cool to room temperature. The bulk density of the sample was obtained as the ratio of the bulk weight in air to the weight of the volume of water displaced by the sample immersed in water.

Subsequent to the determination of bulk density, the per cent of total volume as aggregate voids and the per cent of air voids in the total mix were calculated by use of the formulas given in the Definitions and Formulas section on page 38 of the Appendix.

CHAPTER III

RESULTS

Effect of Changes in Aggregate Grading

Isometric Design Charts.--Figures 1 and 2 illustrate the changes in bulk specific gravity with changes in per cent asphalt and per cent of aggregate retained on a No. 8 screen. Bulk specific gravity of the mix was plotted as isomers for varying asphalt content and per cent coarse aggregate. This type of representation can be used effectively to analyze changes in three variables of mixture composition. Vokac (9) has adapted the isometric chart to the design of bituminous mixes.

Georgia Method.--Figure 1 illustrates the effect of aggregate grading on densities obtained with the Georgia procedure. As the per cent of aggregate retained on a No. 8 screen was increased, the maximum density (as indicated by the bulk specific gravity of the mix) attained for varying asphalt contents increased. At approximately 7.0 per cent asphalt and 40 to 50 per cent coarse aggregate, the density obtained reached a maximum. The density isomers in this vicinity indicate that increases in coarse aggregate beyond 50 per cent would result in a decrease in the maximum density obtainable for varying asphalt contents. Figure 3 shows the density curve for 50 per cent coarse aggregate to coincide closely with the 40 per cent coarse aggregate curve. The

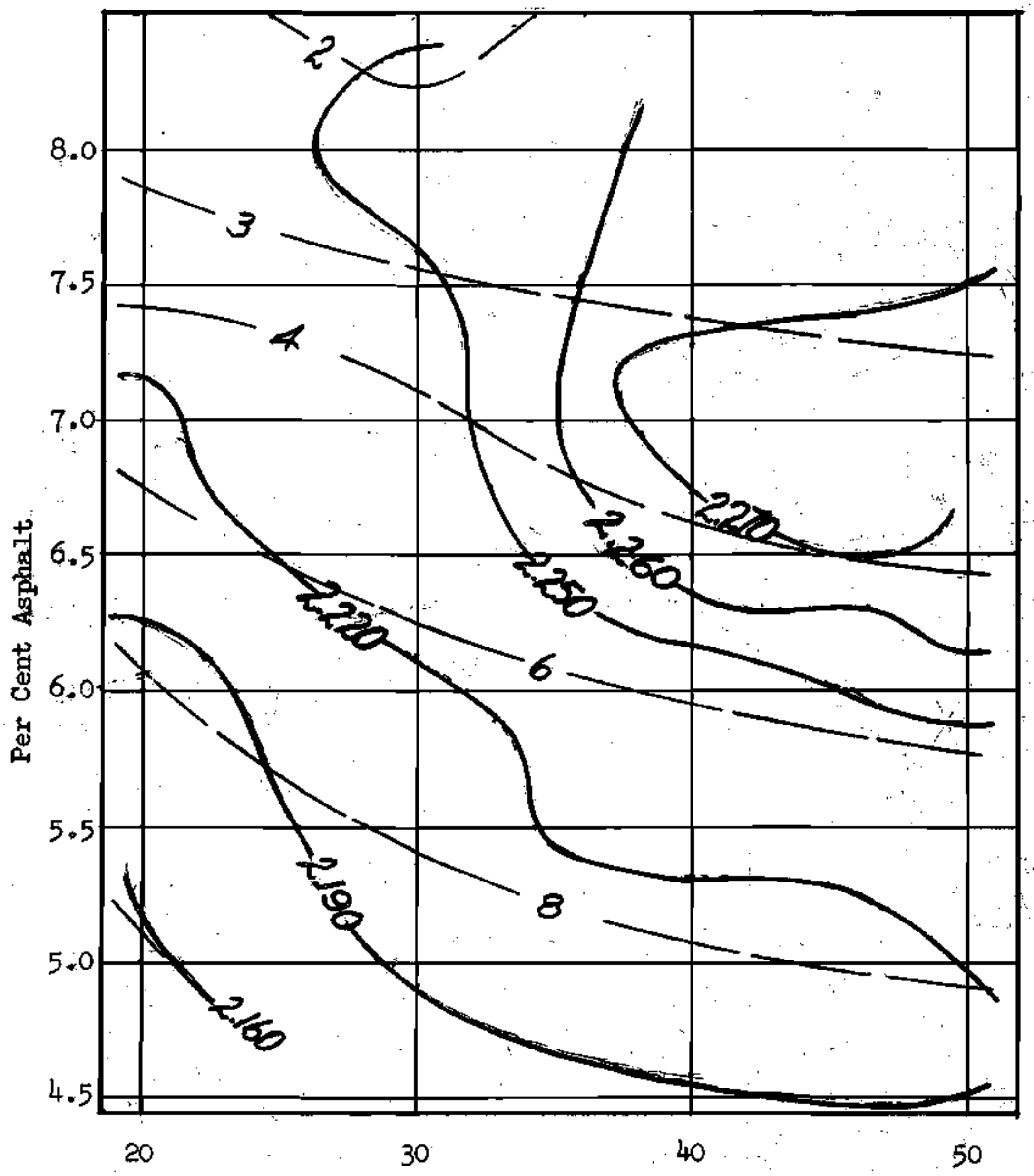

Figure 1. Effect of Aggregate Grading on Air Voids and Bulk Density, Georgia Method

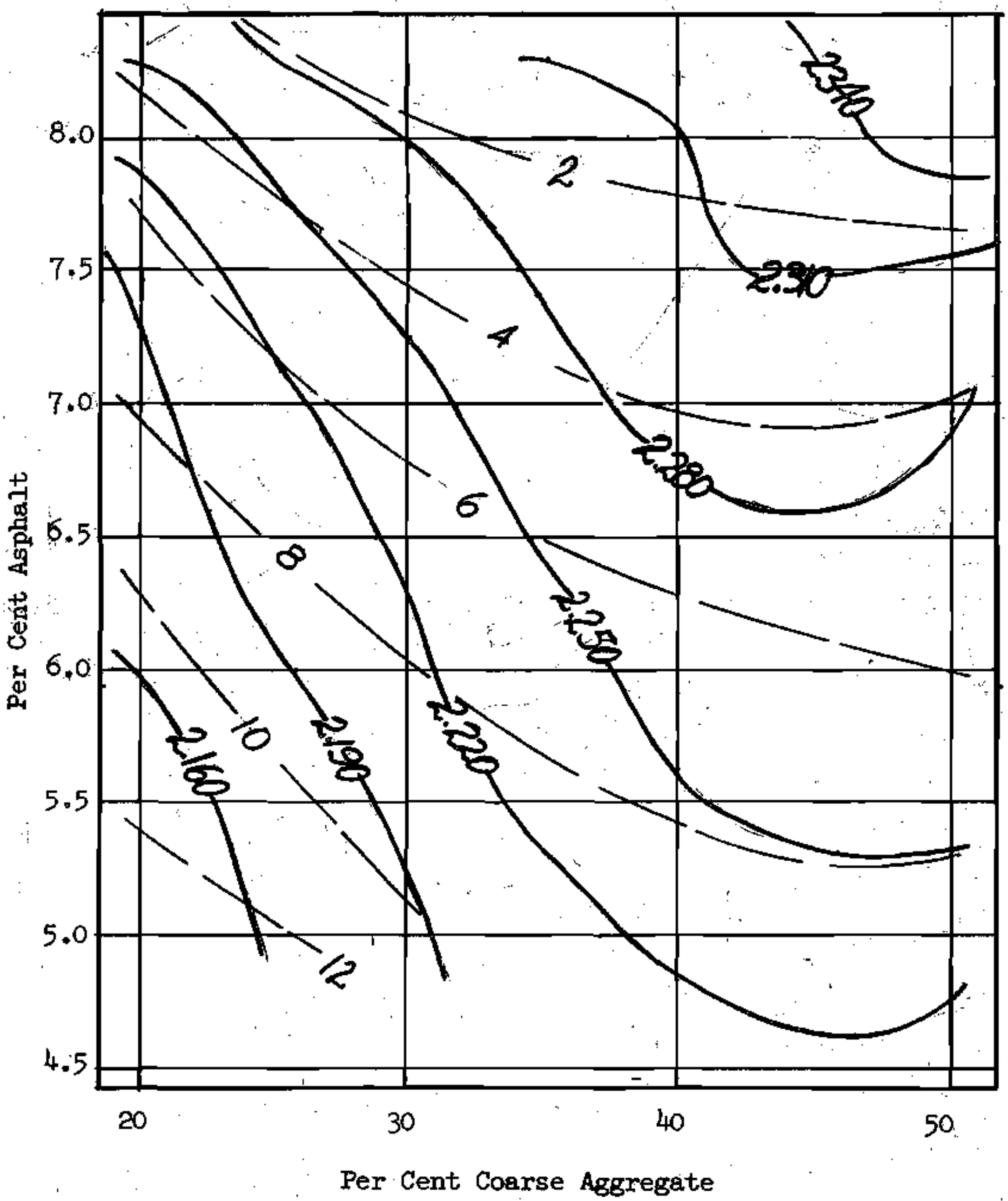

Figure 2. Effect of Aggregate Grading on Air Voids and Bulk Density, Marshall Method

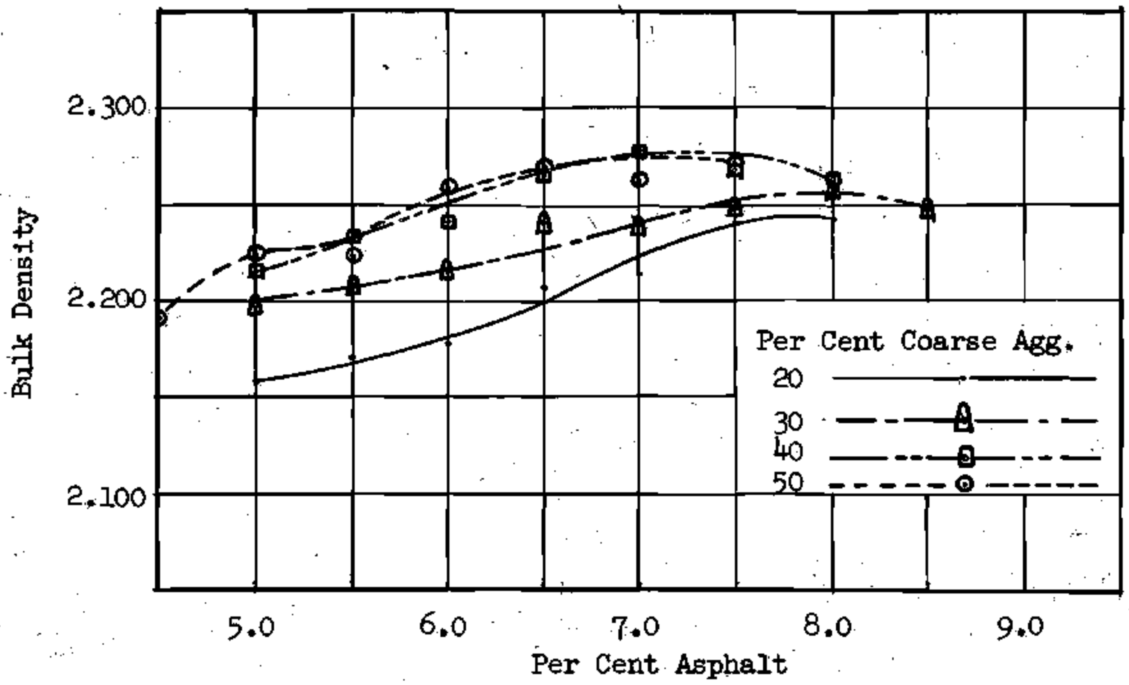

Figure 3. Bulk Densities, Georgia Method

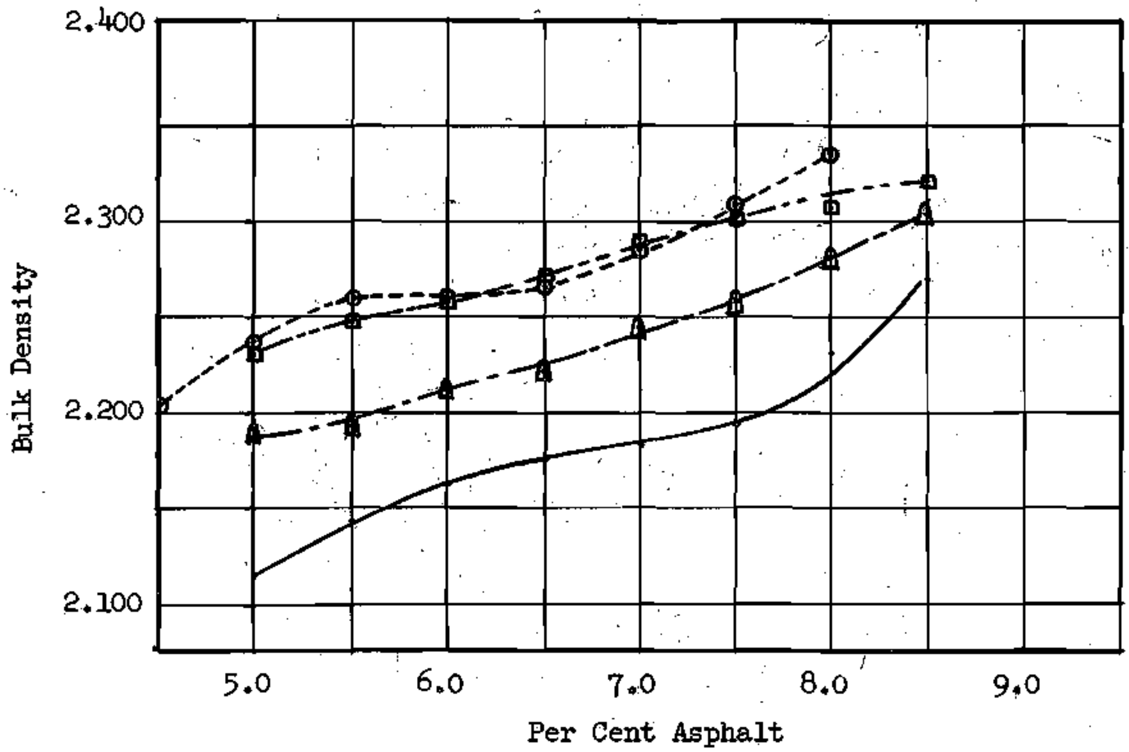

Figure 4. Bulk Densities, Marshall Method

amount of asphalt required for a given density decreased with increases in the per cent of coarse aggregate. Between 40 and 50 per cent coarse aggregate, the amount of asphalt for a given density approached a minimum.

Figures 1 and 3 illustrate also the effect of aggregate grading upon per cent of asphalt required for maximum density. As the per cent of coarse aggregate was increased, the per cent of asphalt required for maximum density decreased. Within the range of 20 to 50 per cent coarse aggregate, the asphalt content required for maximum density was reduced to approximately 1.0 per cent.

The density isomers of Figure 1 also reflect the ability of a constant compactive effort to be maintained with the Georgia procedure. Some variation in compactive effort is indicated by the slightly irregular shape of the isomer for a bulk density of 2.220.

Marshall Method.--Figure 2 is the isometric plot of Marshall densities for varying aggregate gradings and asphalt contents. As in the Georgia method, an increase in the per cent of coarse aggregate produced an increase in the maximum density obtained. No distinct area of maximum density was indicated within the 20 to 50 per cent coarse aggregate variation. However, the upward trend of the isomers in the area between 40 and 50 per cent coarse aggregate suggest that further increases in the per cent coarse aggregate would produce an area of maximum density at approximately 50 per cent coarse aggregate and 8.0 per cent asphalt. Figure 4 indicates that no appreciable increase in density was obtained by increasing coarse aggregates from 40 to 50 per cent.

No distinct values of maximum density for each grading were obtained with the Marshall procedure. As in Figure 1, the isomers of Figure 2 indicate that less asphalt was required to maintain a given density as the per cent of coarse aggregate increased. Between 40 and 50 per cent coarse aggregate the amount of asphalt for a given density reached a minimum.

Variation of Aggregate Voids

Georgia Method.--Figure 5 shows the variation of aggregate voids obtained with the Georgia procedure. For each test grading, the variation of per cent asphalt produced a point of minimum voids. As the per cent of coarse aggregate was increased, the minimum volume of voids decreased.

Marshall Method.--Figure 6 shows the variation of aggregate voids obtained with the Marshall method. The 30 per cent coarse aggregate curve indicated a minimum volume of aggregate voids at about 7.0 per cent asphalt. The 20, 40, and 50 per cent coarse aggregate gradings produced no distinct minimum values of aggregate voids for the range of asphalt contents. As the per cent of coarse aggregate was increased, the aggregate voids were reduced.

Variation of Air Voids in the Total Mix

Georgia Method.--Figure 7 shows the variation of air voids in the total mix with aggregate grading and per cent asphalt. The air voids for each grading decreased as the per cent of asphalt was increased. The

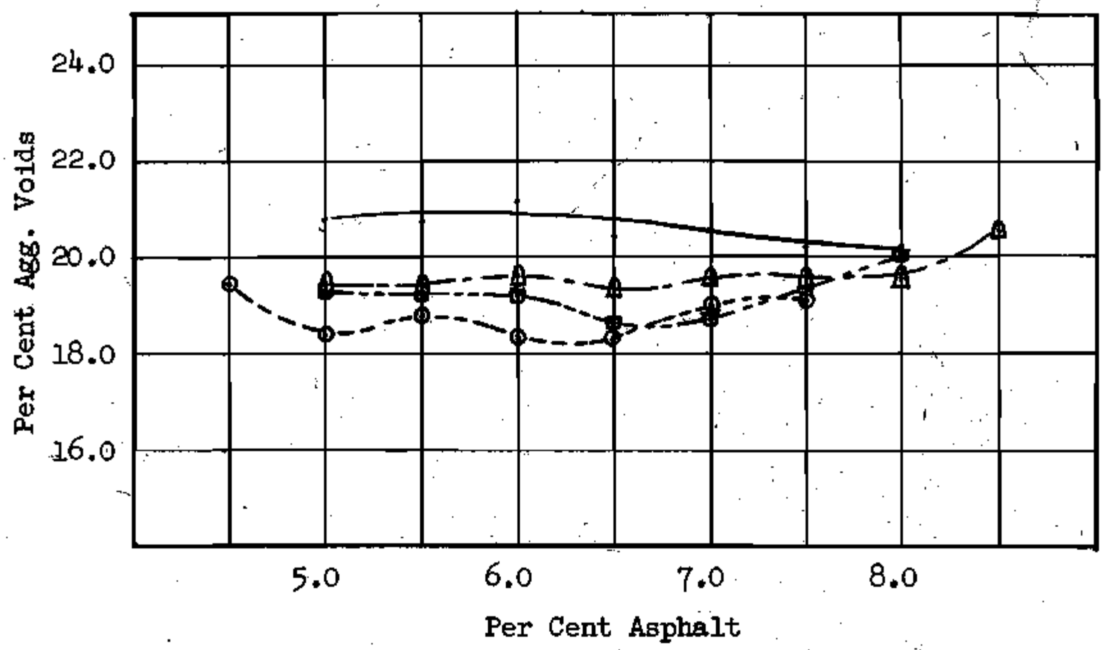

Figure 5. Per Cent Aggregate Voids, Georgia Method

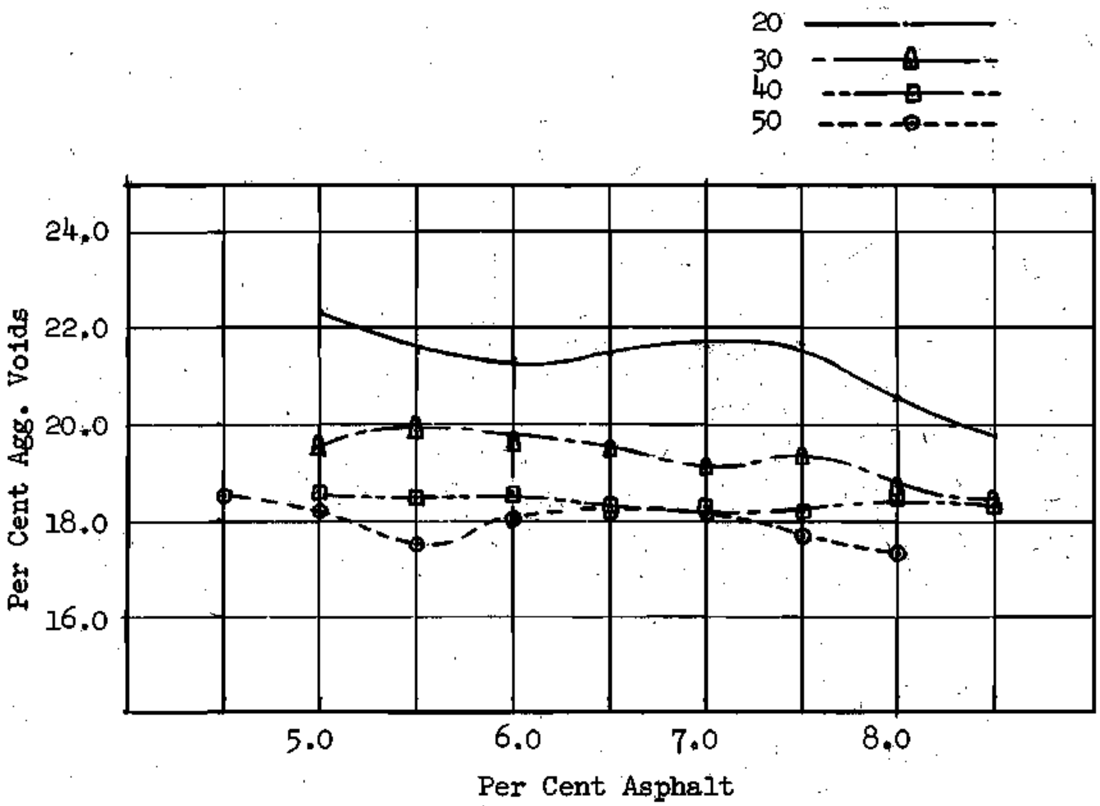

Figure 6. Per Cent Aggregate Voids, Marshall Method

reduction in aggregate voids with increases of per cent of coarse aggregate noted in Figure 5 are reflected in Figure 7 as reductions in the per cent of air voids. The air voids in the total mix curves tend to remain parallel until the asphalt content approaches the capacity of the aggregate voids. Below an air voids content of 4.0 per cent, the curves begin to converge and approach a minimum value of 2.0 per cent.

Marshall Method.--Except for convergence, the Marshall air voids curves in Figure 8 are similar to the Georgia curves. As the amount of asphalt approached the capacity of the aggregate voids, the Marshall curves tended to remain parallel and approach a vlue of zero air voids.

Variation in Stability Value

Georgia Method.--Figure 9 shows the stability values obtained with the Georgia procedure. The maximum stability obtained for the range of asphalt contents increased with each increase in the per cent of coarse aggregate. The 50 per cent coarse aggregate grading produced a well defined maximum stability value at 5.5 per cent asphalt. The 20, 30, and 40 per cent coarse aggregate curves produced well defined peaks of stability which did not coincide with the maximum stability value for each grading.

Marshall Method.--The results of the Marshall stability tests are presented in Figure 10. An increase in coarse aggregate from 20 to 40 per cent produced considerable increases in stability at all asphalt contents up to 8.0 per cent. An increase of coarse aggregate from 40 to 50 per

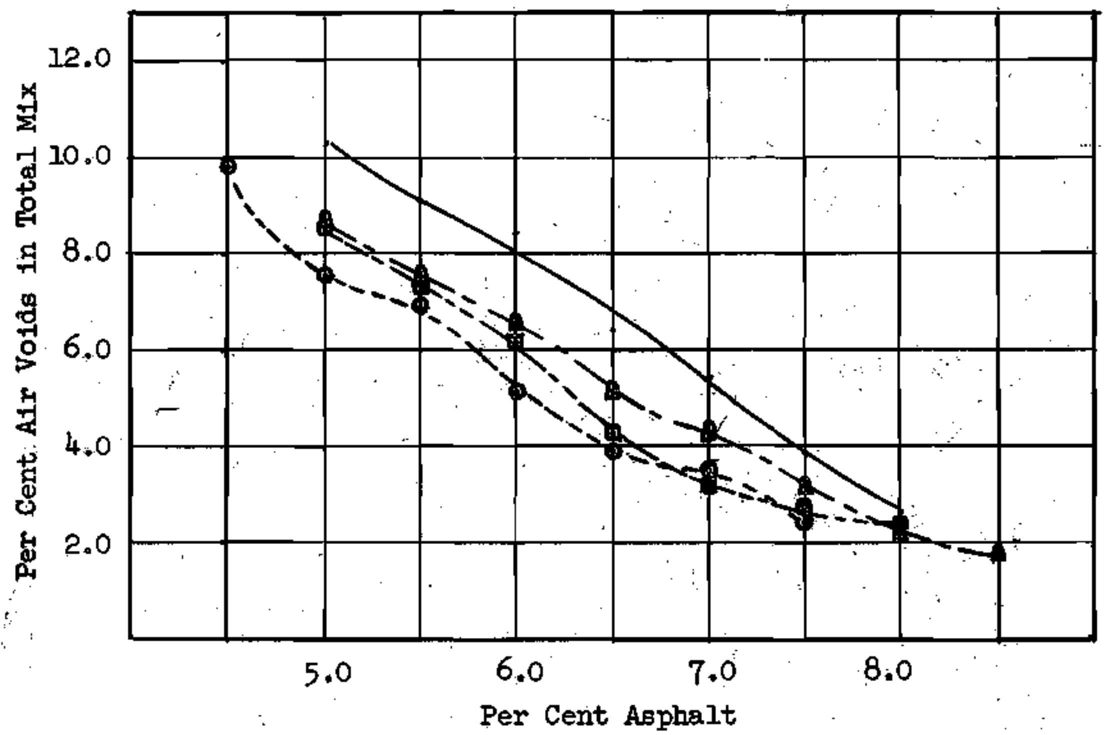

Figure 7. Per Cent Air Voids, Georgia Method

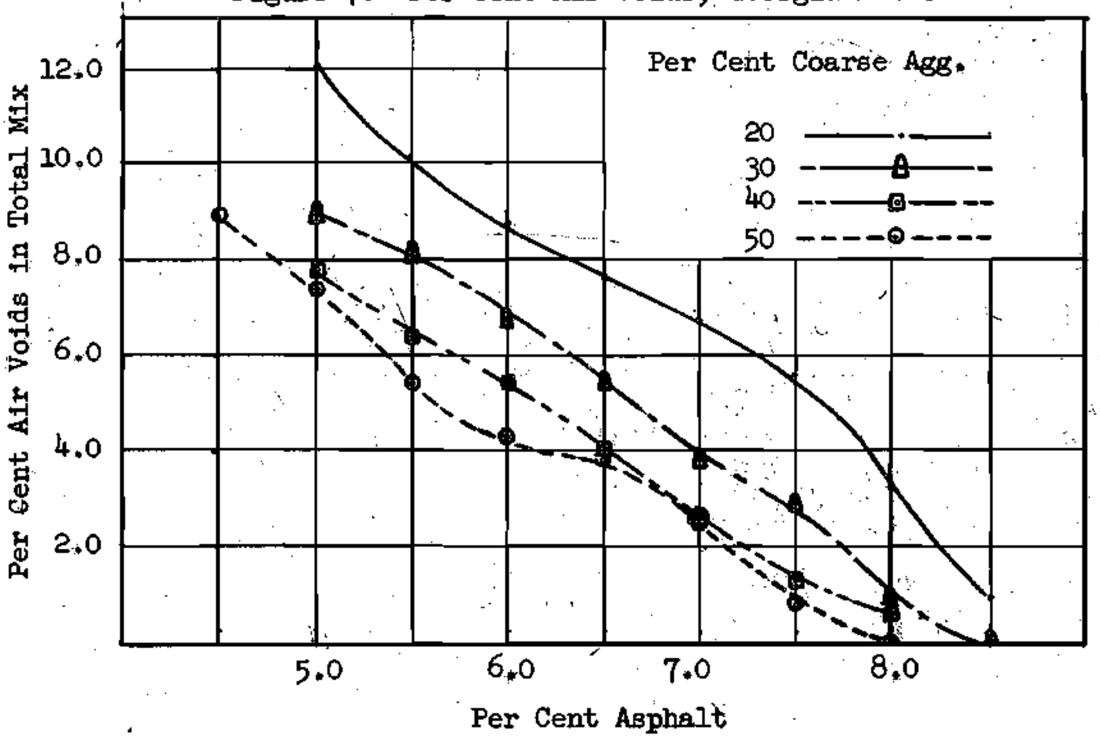

Figure 8. Per Cent Air Voids, Marshall Method

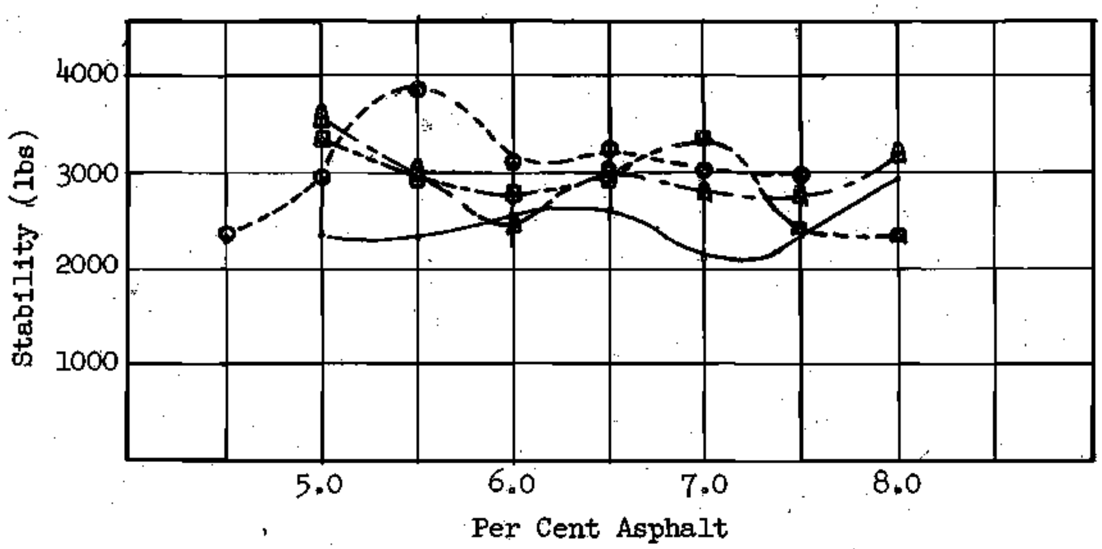

Figure 9. Stability, Georgia Method

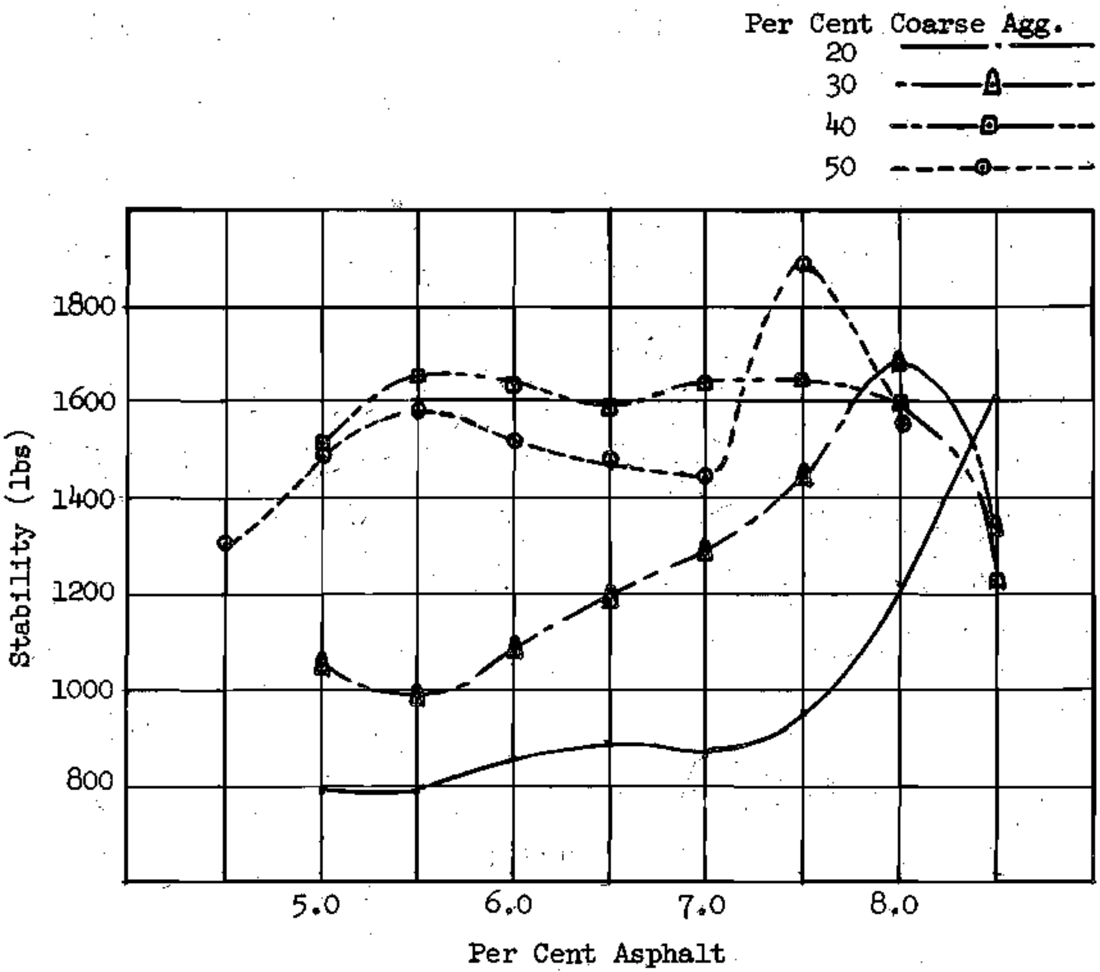

Figure 10. Stability, Marshall Method

cent produced a reduction in stability except for a high peak of stability at 7.5 per cent asphalt. For the 20 and 30 per cent coarse aggregate curves, increases in the asphalt content produced increases in stability up to a maximum. The variation of asphalt content for the 40 and 50 per cent coarse aggregate gradings produced peaks in stability at 5.0 and 7.5 per cent asphalt for both gradings. As the asphalt content approached the capacity of the aggregate voids in the 30, 40, and 50 per cent curves, sharp decreases in stability were produced. An examination of Figure 8 shows the decrease in stability to occur at the per cent of asphalt for which the air voids are approximately 1.0 per cent.

The Marshall flow values are presented in Figure 11. The values were obtained during the stability tests with a Marshall flow meter which measures the deformation of the sample in the direction of applied load. The flow value was recorded as the total deformation up to the point of maximum stability developed by the sample. One unit of flow is equal to 0.01 inches of deformation. The 20 per cent coarse aggregate grading produced a constant deformation up to an asphalt content of 7.0 per cent. Beyond 7.0 per cent asphalt, the rate of deformation increased sharply for increases in asphalt content. The 30, 40, and 50 per cent aggregate gradings showed similar increases in the rate of deformation beyond asphalt contents of 6.0 per cent.

Effect of Aggregate Voids Upon Stability

Georgia Method.--A comparison of the aggregate void curves of Figure 5 with the stability curves of Figure 9 indicated that the Georgia

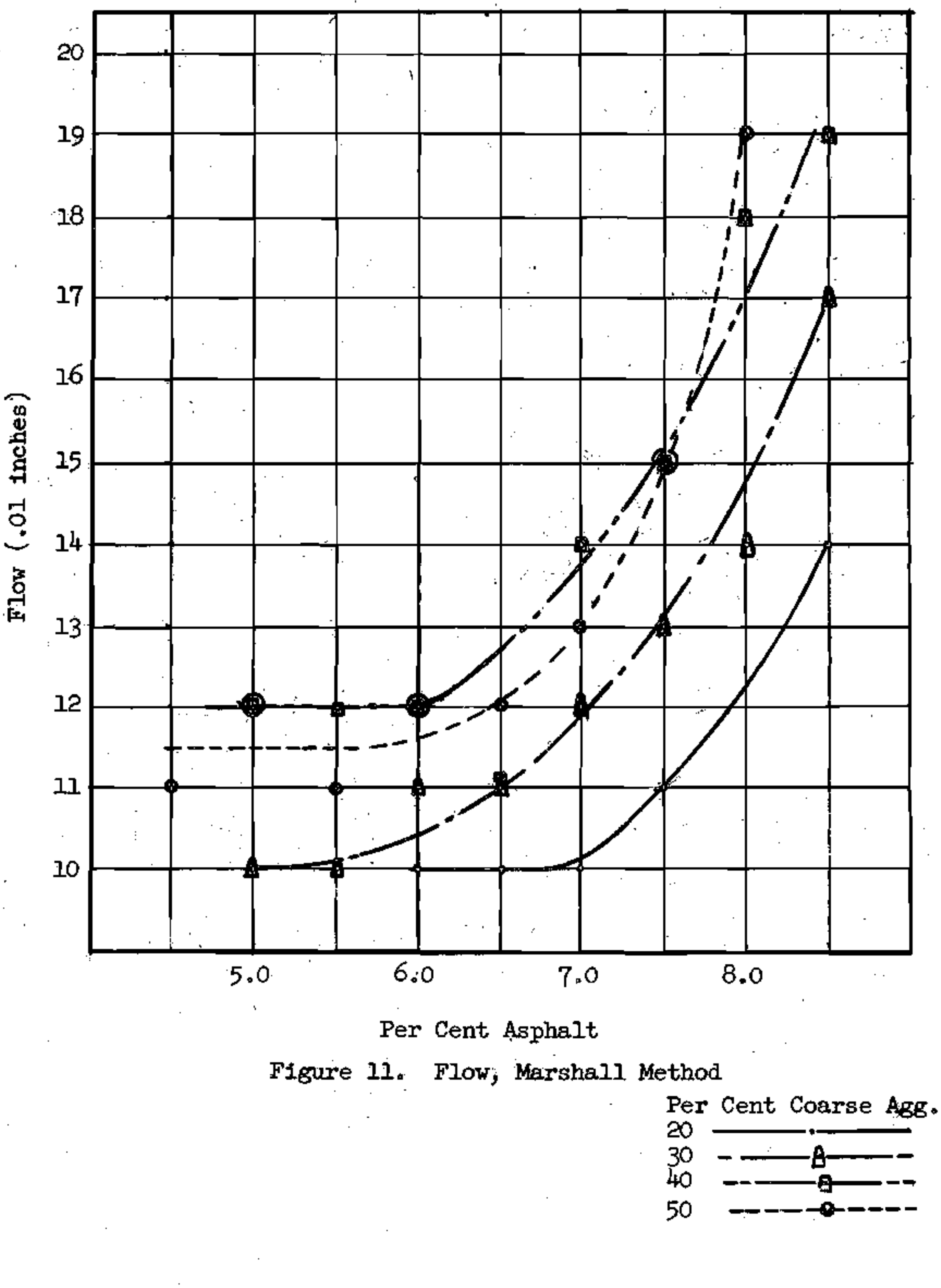

Figure 11. Flow, Marshall Method

stability value was sensitive to some degree to changes in aggregate voids. Values of minimum aggregate voids coincided with peaks of stability for each of the gradings. However, the point of maximum stability and minimum voids coincided only for the 20 per cent coarse aggregate grading.

Marshall Method.--The Marshall stability reflected considerable sensitivity to changes in aggregate voids. Peaks in the stability curves were reflected as minimum values for the aggregate void curves. The maximum stability value for the 20, 30, and 40 per cent coarse aggregate curves coincided closely with the minimum value of aggregate voids. For each of the grading curves, the point of maximum stability and minimum voids occurred at the asphalt content which approached the capacity of the aggregate voids.

CHAPTER IV

SUMMARY OF RESULTS AND CONCLUSIONS

Summary of Results.--As the per cent of coarse aggregate was increased, higher maximum densities were obtained by both methods. An increase in coarse aggregate from 20 to 30 and from 30 to 40 per cent produced considerable increases in density. An increase in coarse aggregate from 40 to 50 per cent produced no appreciable gains in density by either method.

Reductions in per cent of aggregate voids in the total mix resulted from the variation of coarse aggregate from 20 to 50 per cent. An increase of 20 to 30 per cent coarse aggregate caused the greatest reduction in aggregate voids for both methods. Minimum values for aggregate voids were obtained at the highest asphalt contents for the Marshall method, and at some intermediate asphalt content for the Georgia method.

The per cent of air voids in the total mix obtained by the Georgia and the Marshall methods was reduced as the per cent of coarse aggregate was increased. The greatest reduction in air voids occurred for a change in coarse aggregate from 20 to 30 per cent. For the Georgia method, the air voids in the total mix for all gradings approached a minimum of 2.0 per cent.

For the Georgia method, a variation of coarse aggregate from 20 to 50 per cent was reflected as a general increase in stability at most asphalt contents. For each test grading, the variation of asphalt content produced an irregular plot of stability.

An increase in coarse aggregate from 20 to 40 per cent caused increases in Marshall stability up to an asphalt content of 8.0 per cent. A further increase in coarse aggregate from 40 to 50 per cent caused decreases in Marshall stability except at an asphalt content of 7.5 per cent. For each test grading, the variation of asphalt content produced plots of Marshall stability with well defined maximum values.

Conclusions.--The Georgia and Marshall methods exhibited equal sensitivity to changes in aggregate grading and asphalt content.

The uncontrolled compactive effort of the Georgia method was reflected as irregularities in bulk density over the range of aggregate gradings and asphalt contents.

The Marshall compactive effort was more effective than the Georgia compactive effort in reducing the mixtures to voidless masses at high asphalt contents.

The Georgia stability value was sensitive to changes in aggregate voids, but minimum aggregate voids did not correspond consistently with maximum stability for a particular grading.

The maximum Marshall stability and minimum volume of aggregate voids occurred at the asphalt content which approached the capacity of the aggregate voids.

APPENDIX

Table 1. Test Gradations

Size of Screen or Sieve	Per Cent of Total Weight Passing 20% Coarse Agg.	30% Coarse Agg.	40% Coarse Agg.	50% Coarse Agg.
3/8"	100	100	100	100
No. 4	90	85	80	75
No. 8	80	70	60	50
No. 16	68	56	46	35
No. 50	34	28	21	15
No. 100	15	14	13	10
No. 200	8	7	7	5

Table 2. Specific Gravity of Aggregates

	Per Cent of Coarse Aggregate			
	20	30	40	50
Bulk Sp. Gr., Coarse	2.570	2.570	2.570	2.570
Bulk Sp. Gr., Fine	2.594	2.594	2.625	2.625
Apparent Sp. Gr., Coarse	2.650	2.650	2.650	2.650
Apparent Sp. Gr., Fine	2.631	2.631	2.645	2.645
Average Bulk Sp. Gr.	2.589	2.587	2.603	2.597

Table 3. Bulk Density

Per Cent Asphalt	Per Cent of Coarse Aggregate 20 Mar.	20 Ga.	30 Mar.	30 Ga.	40 Mar.	40 Ga.	50 Mar.	50 Ga.
4.5	---	---	---	---	---	---	2.204	2.190
5.0	2.114	2.156	2.187	2.198	2.231	2.216	2.236	2.224
5.5	2.143	2.169	2.193	2.206	2.248	2.226	2.260	2.222
6.0	2.162	2.175	2.212	2.215	2.257	2.240	2.260	2.258
6.5	2.175	2.205	2.221	2.239	2.272	2.265	2.266	2.269
7.0	2.182	2.212	2.244	2.239	2.292	2.277	2.281	2.260
7.5	2.193	2.238	2.258	2.247	2.302	2.267	2.307	2.270
8.0	2.231	2.243	2.282	2.256	2.308	2.262	2.336	---
8.5	2.269	---	2.304	2.248	2.322	---	---	---

Table 4. Aggregate Voids, Per Cent Total Volume

Per Cent Asphalt	Per Cent of Coarse Aggregate 20 Mar.	20 Ga.	30 Mar.	30 Ga.	40 Mar.	40 Ga.	50 Mar.	50 Ga.
4.5	---	---	---	---	---	---	18.6	19.4
5.0	22.4	20.8	19.6	19.4	18.7	19.3	18.3	18.4
5.5	21.5	20.8	20.0	19.4	18.5	19.3	17.6	18.8
6.0	21.4	21.1	19.7	19.6	18.7	19.2	18.1	18.3
6.5	21.5	20.4	19.6	19.3	18.4	18.7	18.3	18.3
7.0	21.6	20.6	19.2	19.6	18.3	18.7	18.2	19.0
7.5	21.7	20.2	19.4	19.6	18.2	19.4	17.7	19.1
8.0	20.6	20.2	18.8	19.8	18.5	20.0	17.4	---
8.5	19.8	---	18.5	20.5	18.4	---	---	---

Table 5. Air Voids, Per Cent of Total Volume

Per Cent Asphalt	Per Cent of Coarse Aggregate 20 Mar.	20 Ga.	30 Mar.	30 Ga.	40 Mar.	40 Ga.	50 Mar.	50 Ga.
4.5	---	---	---	---	---	---	8.9	9.8
5.0	12.1	10.3	8.9	8.7	7.8	8.5	7.4	7.5
5.5	10.1	9.1	8.2	7.5	6.4	7.3	5.4	6.9
6.0	8.7	8.4	6.7	6.6	5.5	6.1	4.3	5.1
6.5	7.7	6.4	5.5	5.1	4.0	4.3	3.9	3.9
7.0	6.7	5.5	3.8	4.3	2.6	3.2	2.6	3.5
7.5	5.6	3.8	2.9	3.1	1.3	2.8	0.8	2.5
8.0	3.2	2.6	0.9	2.2	0.5	2.3	0.0	---
8.5	1.0	---	0.0	1.8	0.1	---	---	---

Table 6. Georgia Stability

Per Cent Asphalt	Per Cent Coarse Aggregate 20	30	40	50
	Stability (lbs)			
4.5	----	----	----	2340
5.0	2320	3350	3550	2930
5.5	2320	2900	3000	3890
6.0	2530	2470	2800	3020
6.5	2630	3110	3000	3190
7.0	2030	2760	3370	3000
7.5	2300	2740	2390	2920
8.0	2960	3200	2330	----
8.5	----	----	----	----

Table 7. Marshall Stability and Flow

Per Cent Asphalt	Per Cent of Coarse Aggregate 20 Stab. (lbs)	20 Flow (.01 in.)	30 Stab.	30 Flow	40 Stab.	40 Flow	50 Stab.	50 Flow
4.5	---	--	----	--	----	--	1310	11
5.0	780	11	1050	10	1520	12	1490	12
5.5	780	10	990	10	1660	12	1580	11
6.0	860	10	1090	11	1640	12	1520	12
6.5	880	10	1190	11	1590	11	1480	12
7.0	850	10	1280	12	1650	14	1450	13
7.5	950	11	1450	13	1650	15	1890	15
8.0	1220	14	1690	14	1600	18	1560	19
8.5	1410	14	1330	17	1230	19	----	--

DEFINITIONS AND FORMULAS

The following definitions and formulas for test quantities utilized in this paper are quoted from the Asphalt Institute Manual Series No. 2, (5).

Average specific gravity of aggregate:

$$G_{ag} = \frac{100}{\frac{P_f}{G_f} + \frac{P_c}{G_c}}$$

where: G_{ag} = Average specific gravity of aggregate

G_f, G_c = Specific gravity of fine, coarse aggregate

P_f, P_c = Per cent total aggregate by weight, fine, and coarse respectively.

Bulk Density:

$$D_b = \frac{W_a}{W_a - W_w}$$

where: D_b = Bulk density (expressed as bulk specific gravity)

W_a = Weight of specimen in air

W_w = Weight of specimen in water

Per Cent of Aggregate Voids: The aggregate voids as a per cent of the total volume of the mix.

$$\% \text{ Agg. Voids} = 100 - \frac{P_{ag} \times W_a}{G_{ag}}$$

Per Cent of Air Voids in the Total Mix: Volume of air voids as a per cent of the total volume of the mix.

$$\% V_v = 100 - \frac{P_{ac} \times W_a}{G_{ac}} - \frac{P_{ag} \times W_a}{G_{ag}}$$

P_{ac} = Per cent by weight of total mix, asphalt

P_{ag} = Per cent by weight of total mix, aggregate

G_{ac} = Specific gravity, asphalt

GEORGIA PROCEDURE FOR THE COMPACTION OF TEST SAMPLES

Equipment.--The following equipment required for the compaction of Georgia test samples is described in detail in the Hubbard-Field Method of Bituminous Mix Design found in the Asphalt Institute Manual Series No. 2, (5).

One - 6" diameter Hubbard-Field compaction mold
One - 12" x 12" x 1" Hubbard-Field compaction base plate
One - No. 2 Hubbard-Field compaction hammer (1.875" dia.)
One - No. 3 Hubbard-Field compaction hammer (5.75" dia.)
One - Dial type or armoured thermometer reading to at least 350°F
One - Flat bladed spatula
One - Long handled mixing spoon

Procedure.--The Georgia sample preparation procedure has been standardized as G.H.D. 34, and is found in the State Highway Department of Georgia Field Sampling, Testing, and Inspection Manual, May 1, 1958, page 264 (10). However, the procedure has been altered by the Department to allow compaction of the test sample in one lift instead of the former method of compaction in two lifts. The following procedure is the altered G.H.D. 34 procedure presently in use by the State Highway Department of Georgia.

1. Take a representative sample of the hot mixture (approximately 275-300°F).
2. Weight of sample of mixture should equal 2000 grams plus the weight of asphalt.

Example: $\frac{2000}{100\% - \%\text{ Asphalt}} = \frac{2000}{100\% - 7\%} = 2151$ grams

3. Place the mixture of asphalt and aggregate in the compaction mold which has been previously heated with the base plate to a temperature of 100 to 125°F.
4. Carefully blade around the side of the mold with the spatula to prevent the formation of air pockets.
5. With the No. 2 hanner, tamp the mixture 60 blows using reasonably strong blows as as to secure a dense mixture. Begin the first compaction when the mixture has reached a temperature of approximately 230°F.
6. Tamp the mixture 25 reasonably strong blows with the No. 3 hammer.
7. Reverse the mold, force the specimen to the bottom of the mold, and repeat the compaction of 6 and 7.
8. Force the thermometer into the center of the specimen and allow the mixture to cool to a temperature of 180°F.
9. After the specimen has cooled to 180°F, apply the final compaction with 25 blows to each face of the specimen with the No. 3 hammer.
10. Allow the specimen to cool to air temperature and carefully remove from the mold. This is usually done by laying the compaction mold on its side and gently tamping the top of the specimen with the No. 3 hammer.

MARSHALL PROCEDURE FOR THE COMPACTION OF TEST SAMPLES

Equipment and compaction procedures used for the preparation of Marshall test specimens are described in detail in the Marshall Consulting and Testing Laboratory Manual (3). Only the procedure utilized for compaction of test samples is summarized below.

1. Preheat the compaction mold assembly and compaction hammer face in a bath of boiling water.
2. Assemble the base plate and compaction mold. Place a piece of 4 inch diameter filter paper in the bottom of the compaction mold to prevent the mix from adhering to the base plate.
3. Place 1000 to 1250 grams of the mixture of aggregate and bitumin in the compaction mold. Rod the mixture with 25 blows of a mixing trowel. After rodding, strike off the surface of the mixture approximately 1/2 inch above the top of the forming mold. Place the compaction mold in the compaction mold holder and proceed with the compaction.
4. The temperature of the mixture at the beginning of compaction must not be less than 250°F.
5. Apply 50 blows to the mixture with the Marshall hammer. The top of the specimen should be approximately 3/8 inches below the top of the forming mold after the first 50 blows.
6. Invert the forming mold and apply 50 blows to the opposite face of the specimen.

7. After compaction, allow the specimen to cool under water for approximately 2 minutes.
8. Extrude the cooled sample from the compaction mold.

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