FINAL REPORT

THE CRITICALITY OF SIEVE SIZE IN ASPHALTIC CONCRETE MIXES AS MEASURED BY VOLUMETRIC PROPERTIES AND STABILITIES

by
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SUMMARY

The purpose of this study was to investigate the effects of deviations from the specified aggregate gradation on the stability and volumetric properties of the S-5 mix. The project involved two phases of experimental work.

The first phase consisted of designing a control mix to be used as a standard for comparison with the experimental mixes. The median S-5 specifications were used and an optimum asphalt content of 5.6% was determined through the Marshall design procedure.

The second phase involved the molding and testing of specimens using aggregate gradations that varied systematically from the median S-5 gradation but had the same asphalt content as the control mix (5.6%).

The results showed that the six sieve sizes in the S-5 gradation could be classified into three groups according to their effects on the stability and volumetric properties of the mix. The coarse sieves (3/8",#4 and #8) displayed similar curves, the #30 appeared to be a transition size, and the fine sieves (#50 and #200) showed characteristics which were generally opposite those of the coarse sieves. The #30 sieve was the most critical size with regard to stability. Another finding was that although the S-5 specifications do not place direct bounds on the volumetric properties of a mix, the gradation requirements seemed to provide fairly consistent control of them.

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INTRODUCTION

The overall suitability of an asphaltic paving mix is determined by its stability and volumetric characteristics, i.e. voids in total mix (VTM), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA)[(1)]. It has been proven that for a given compactive effort these properties are primarily dependent upon the maximum size and gradation of the aggregate and the asphalt content of the mix[(2)]. Any variation in one of these parameters could result in a change in the stability or volumetric characteristics of a specific mix and, therefore, a change in its performance as a paving material.

The Virginia Department of Highways imposes gradation specifications on the aggregates to be used in an asphaltic concrete mixture that define a distinct band within which the gradation curve for the aggregate must lie. Once the job-mix curve has been established there are specified tolerances for each sieve size in the gradation, which place a limit on the amount that the aggregate may vary on either side of the job-mix curve. It is this area of aggregate gradation and its influence on the performance and properties of an asphaltic concrete mix that have been studied in this investigation.

PURPOSE AND SCOPE

This study was conducted to determine the criticality of each sieve size in the aggregate gradation for the Virginia S-5 mix. This determination was made by measuring the effects of systematic deviations from the specified percent passing for each sieve size on the stability and volumetric properties of uniformly compacted specimens. The results have been used to determine which sizes are most critical and, therefore, must be most rigidly inspected for their conformity to specifications during plant mix operations. Another aim was to check the validity of the specified tolerances now used in the specifications with regard to accepted performance criteria for the S-5 mix by determining their effectiveness in keeping the mix properties (stability, VMA, etc.) within the generally accepted bounds.

PHYSICAL PROPERTIES OF BITUMINOUS PAVING MIXTURES

Bituminous concrete consists of an aggregate framework cemented with asphalt and compacted into a homogenous mass. In order to constitute an acceptable pavement, the mix must satisfy three general properties.

"An asphaltic-concrete pavement should be stable, that is, it should resist deformation from imposed loads. Unstable pavements are marked by rutting, shoving, (wavy condition), and deformation under the tires of a stationary vehicle.

"It should be durable. It should not ravel (abrade away) under the action of traffic and weathering.

"It should be skid resistant. The surface texture should be such that it will grip the tire, even when the pavement is wet[2]."

In this study, only stability and durability were considered as factors influenced by gradation, even though skid resistance could be related if pavement "bleeding" were to occur. These properties are determined by other mix characteristics which will now be outlined along with the requirements to produce the proper stability and durability in a mix.

In an ideally compacted mix, an applied load is carried by the framework of the aggregate, which is held together by the asphaltic binder. The mix is, therefore, made up of three components: the aggregate particles, asphaltic binder, and air. The proper structure can be attained only if the voids properties are held within certain bounds.

Assuming that the aggregate in the mix absorbs no bitumen, as was done in this study, the significant voids properties can readily be defined.

The air voids, or voids in the total mix (VTM), after compaction consist of the total volume of the pockets of air between the coated aggregate particles. The Asphalt Institute specifies a minimum of 3% and a maximum of 5% VTM to provide a suitable mixture for a surface course[4]. These air voids are necessary to prevent bleeding and pushing of the pavement in hot weather or under heavy loading conditions. If the VTM of a mix falls below the 3% limit, the framework of the aggregate will be destroyed and the stability lowered due to a "floating" effect of the aggregates caused by excess asphalt in the mix. If, on the other hand, the VTM lies above the 5% limit, the durability of the pavement may be lowered through weathering and the resulting hardening of the asphalt binder even though the stability may still be sufficiently high. The overall effect of a low asphalt content is to produce a mixture that is brittle and therefore likely to ravel and crack under the action of traffic and weather.

The second important volumetric property is the voids in the mineral aggregate (VMA), which is defined as the total volume of the intergranular void space between the aggregate particles in the compacted mixture. Since it is assumed that the aggregate absorbs no bitumen, this means that the VMA consists of the sum of the volumes of the air voids and of the asphalt in the mix, and the calculation of the VMA is therefore based on the ASTM bulk specific gravity of the aggregate.

Specifications for the minimum allowable VMA for a mix are based on the top size of the aggregate used. For the S-5 mix, which has a top size of 1/2 inch, the generally accepted minimum VMA is 15%. As a general rule, poorly-graded aggregates have VMA's ranging as high as 35% and more, while well-graded aggregates usually have a VMA below 20%. It is desirable to reduce the VMA to the lowest possible value through the proper distribution of sizes without using an excess of minus #200 material[2]. The VMA is clearly heavily dependent upon gradation alone and for this study the acceptable range was taken to be 15% to 18%.

A mixture which exhibits a high VMA is probably deficient in minus #200 material and displays poor stability and density characteristics. If the VMA is extremely low, it is a good indication that there is an excess of minus #200 material and the larger aggregate particles are in a sense "floating" in a matrix of smaller particles, which leads to low stabilities.

The third voids property considered is the voids filled with asphalt (VFA), which is defined as the percentage of the volume of the VMA that is occupied by asphalt. To possess the proper consistency, a mix should have between 75% and 85% of its voids filled with bitumen. These requirements will sometimes overlap those for the VTM of a mix, but the two properties are not completely dependent upon each other in their determination of mix quality.

A high value for the VFA of a mixture (above 85%) indicates an excess of bitumen, which could result in "bleeding" and shoving of the pavement. This condition could also result in a loss of stability caused by a breakdown in the aggregate framework due to "floating" of the aggregate. Conversely, if a mix shows a low VFA, it is probably too "dry", even though the aggregate particles may be coated with enough bitumen to give satisfactory stability. The result is a porous mix that is vulnerable to hardening of the binder through oxidation and susceptible to water penetration. Both of these conditions are likely to cause raveling and cracking of the pavement.

To evaluate the effects of the gradation changes imposed on the S-5 mix in this investigation, the following properties were used:

1. Stability
2. Unit Weight
3. Voids Total Mix
4. Voids in Mineral Aggregate
5. Voids Filled with Asphalt

PROCEDURE

Materials

Since this study was intended to find information about gradation deviations that might occur at an asphalt plant, an effort was made to correlate the experimental work as closely as possible with plant operations so that any conclusions drawn might be of practical value.

The first step involved the choosing of gradation specifications to be used for the job-mix curve. It was decided that the median specifications for the S-5 mix would constitute the job-mix curve since they lie in the middle of the allowable gradation band. Table I gives the gradation and asphalt specifications with tolerances based on the average of four specimens.

TABLE I

S-5 Gradation

Sieve Size	1/2"	3/8"	#4	#8	#30	#50	#200
% Pass	100	83-97	53-67	41-49	19-27	11-19	4-8
Median	100	90	60	45	23	15	6
% Tolerance	—	5.5	4.5	4.5	4.5	3.0	1.5

Asphalt Content: 5.0-8.5%
Tolerance : ±0.5%

All of the aggregates used in the mixes were obtained from the Superior Stone Company of Red Hill, Virginia, and their gradation charts are shown in Figures 1-3 (all figures appended). Initially a rough batching (shown in Table II) identical to the cold feed used at the S. L. Williamson Company, Inc. plant, Red Hill, Virginia, was used to obtain the specified sizes for the mix. However, it was found necessary to obtain and grade a quantity of #68 stone to produce enough +3/8" material to complete the batching.

TABLE II

Approximate Required Gradation of Mix

#8 Stone :	50%
#10 Screenings:	25%
Sand :	25%

All of the stone was produced from crushed granite having a specific gravity of 2.77. The sand was obtained from the Rivanna River. The asphalt was the standard 85-100 penetration type obtained from the Humble Oil and Refining Company.

Design of Asphalt Content

In order to study the effects of gradation changes on the properties of the S-5 mix it was necessary to adopt a standard or control mix to be used for the purpose of comparison with the deviant mixes. As stated previously, the median specifications for the S-5 band were chosen for the gradation of this control mix. The optimum asphalt content for this gradation was caluclated by use of the Marshall method of mix design with the specimens compacted as follows:

1. The aggregate and asphalt (85/100 penetration) were heated to 300°F and 275°F respectively, and then mixed for 3 minutes in a mechanical mixer.

2. The batch was then placed in a standard Marshall mold and spaded 15 times around the perimeter and 10 times over the interior with a hot spatula.

3. The specimen was then compacted with 50 blows on each side with a standard 10 pound Marshall hammer with an 18-inch height of drop.

4. Next the compacted specimen was cooled for approximately 30 seconds under cool running water and immediately extracted from the mold with a hydraulic jack.

5. The specimen was allowed to cool overnight and then weighed in air and water to obtain density values.

6. The stability testing was performed on a standard Marshall testing machine with a rate of deformation of 2 inches/minute. Prior to testing, the specimens were heated in a water bath (140^{o}F) for 30 to 40 minutes.

7. Stability and flow readings were taken at the point where stability failed to increase with increased deformation.

Four specimens were made for each asphalt content and the optimum was calculated from the design curves shown in the appendix. Asphalt contents were determined for the following:

1.) Maximum stability
2.) Maximum unit weight
3.) Median of limits for VTM (4%)

The optimum was calculated as the numerical average of these three values and then adjusted slightly lower to a value of 5.6% to produce better values for the VFA and VTM.

Throughout the entire design process, a great deal of trouble was encountered in reproducing consistent stability results. For most asphalt contents, at least two sets of Marshall specimens were made and each time the stability values showed large variations between sets. It was decided to average the values of the two sets in order to get a reasonable curve for stability vs. asphalt content. All of the volumetric properties, on the other hand, showed highly consistent results between sets and for this reason the design was based more heavily on the voids properties than on the stability.

Control Mix Properties

In order to obtain good values for the stability and volumetric properties of the control mix, sets of four specimens each were made at various times throughout the study. A total of four sets was made having the median S-5 gradation and an asphalt content of 5.6% and the average of the four values for each property was used for the control mix. Table III shows a summary of the average properties for the control mix. The design charts are shown in Figure 4.

TABLE III

Summary of Control Mix Properties

Asphalt Content:	5.6%
Stability:	1472 lb.
Density:	151.55 pcf
Voids Total Mix:	3.9%
Voids in Mineral Aggregates:	17.3%
Voids Filled with Asphalt:	77.1%
Flow:	11.0/100 inches

Method for Investigation of Sieve Criticality

Since the purpose of this study was to determine the criticality of each size in the S-5 gradation it was necessary to form a method of batching which would cause any change in the properties of a single mix to be due to changes in only one sieve size in the gradation. So by maintaining the specified percent passing for the S-5 gradation for all sieve sizes except one, deviations from the control mix properties could be attributed entirely to the one size that was varied.

The control mix, which was used as a standard, conformed exactly to the S-5 specifications and, therefore, had "zero deviation" from the median curve at all sieve sizes. To investigate the criticality of each sieve size, a mix was batched according to the median S-5 gradation with the exception of that size which was being examined. Four different mixes were made with varying amounts of that size aggregate: two above the median curve and two below it. The amount that each size was varied was based on the tolerance specification for that size. A variation equal to the specified percent tolerance (Table I) was defined as a deviation of 100 percent. For each sieve size the percent passing was varied in deviations equal to 75 to 150 percent of the tolerance both above and below the median curve. There were, therefore, four mixes for each sieve size, two of which were within the S-5 band and two outside of it. An example of the four gradations for the #8 sieve variation is shown in Figure 5.

This mixing process was repeated for each sieve size so that there were twenty-four different mixes. For each mix, four Marshall specimens were made since the tolerances in Table I are based on the average of four samples. A constant asphalt content of 5.6% was used for all the mixes. This was for the purpose of simulating the conditions that would prevail at the asphalt plant since the deviation would be accidental and the asphalt content would not be adjusted to compensate for it.

TABLE IV

Gradations for Experimental Mixes

Mix Identification		Percent Passing						
		1/2"	3/8"	#4	#8	#30	#50	#200
3/8" Sieve	150% High	100	98.25	60	45	23	15	6
	75% High	100	94.12	60	45	23	15	6
	75% Low	100	85.87	60	45	23	15	6
	150% Low	100	81.75	60	45	23	15	6
#4 Sieve	150% High	100	90	66.75	45	23	15	6
	75% High	100	90	63.37	45	23	15	6
	75% Low	100	90	56.62	45	23	15	6
	150% Low	100	90	53.25	45	23	15	6
#8 Sieve	150% High	100	90	60	51.75	23	15	6
	75% High	100	90	60	48.37	23	15	6
	75% Low	100	90	60	41.62	23	15	6
	150% Low	100	90	60	38.25	23	15	6
#30 Sieve	150% High	100	90	60	45	29.75	15	6
	75% High	100	90	60	45	26.37	15	6
	75% Low	100	90	60	45	19.62	15	6
	150% Low	100	90	60	45	16.25	15	6
#50 Sieve	150% High	100	90	60	45	23	19.5	6
	75% High	100	90	60	45	23	17.25	6
	75% Low	100	90	60	45	23	12.25	6
	150% Low	100	90	60	45	23	10.5	6
#200 Sieve	150% High	100	90	60	45	23	15	8.25
	75% High	100	90	60	45	23	15	7.12
	75% Low	100	90	60	45	23	15	4.87
	150% Low	100	90	60	45	23	15	3.75

RESULTS

The results of the sieve deviations on mix properties are shown for each sieve size in Figures 6-11 in appendix. On each chart the two vertical dotted lines represent "100 percent deviation" from the S-5 median curve; that is, a deviation equal to the specified tolerance for that sieve above and below the median. If the specifications are valid, each property curve should lie within its respective bounds between the two vertical lines because a mix is considered acceptable when it is within these limits of percent passing. For example, the curve of VTM for the 3/8" sieve should always be greater than 3% and less than 5% between the gradation tolerance of 84.5 and 95.5 percent passing. The results were analyzed by properties rather than by sieve size to give greater clarity.

Unit Weight

There is no actual limit on the unit weight of a mix but it is desirable to have as large a value as possible for a mix while still maintaining satisfactorily all other properties.

The first three sieves (3/8", #4 and #8) all showed characteristic curves that increased with a decrease in percent passing. The #30 sieve had more of a bell-shaped curve that peaked at the median percent passing. Conversely the sieves smaller than #30 (#50 and #200) showed a decrease in unit weight with a decrease in percent passing. From these results it appears that the #30 sieve was a transition size in determining the behavior of the unit weight of the mix.

These results seem to indicate that for the sieves larger than the #30, it is preferable to allow the percent passing that sieve to fall below the lower tolerance, while for the sieves below the #30 the unit weight is increased when the percent passing goes above the upper limit of percent passing.

Stability

Although specifications for a minimum stability for a suitable mix vary, a standard of 1,300 pounds (corrected Marshall stability) was adopted as the minimum for this study for the purpose of comparison between mixes.

The first three sieves (3/8", #4 and #8) all satisfy the 1,300 lb. requirement within the tolerances and show the same general shape, reaching a peak at the median and another sharp rise outside the lower band on percent passing. However, the #30 sieve shows a very sharp peak at the median and then drops below 1,300 lb. at the lower limit before again increasing at lower values of percent passing. The #50 sieve shows this same general shape, but it peaks above the median before dropping below 1,300 lb. at the lower limit. The #200 sieve, unlike all the others, has a stability curve which steadily decreases with decreasing percent passing, although it levels off slightly at the median.

The results indicate that in order to maintain the proper stability in a mix, the percent passing must be kept very close to the median, especially for the #30 and smaller sieves.

Voids Total Mix

For a surface mix such as the S-5, the VTM should be somewhere between 3 and 5 percent.

All of the sieves had VTM values within these bounds when the percent passing was within the tolerance band. Again the first three sieves had similar curves in that the VTM decreased toward 3% as the percent passing decreased. The #30 curve was practically horizontal, which seems to indicate that the VTM of the S-5 mix is hardly affected by changes in the amount of #30 material in the mix. The two lower sieves showed an increase in VTM with a decrease in percent passing, with their curves again being very similar.

All of the curves, except that for the #30 sieve, show that the tolerances place appropriate bounds on the percent passing, for they indicate that once the mix gradation moves outside these bounds the VTM becomes unsatisfactory.

Voids in Mineral Aggregate

The minimum VMA for the S-5 mix is specified as 15% and a generally accepted upper bound is 18% although this is not as critical as the minimum, which is to prevent "bleeding" of the asphalt.

Again the first three sieves (3/8", #4 and #8) show almost identical curves that decrease with decreasing percent passing. All three reach 18% VMA at their upper tolerance but show that the lower bound could be extended considerably before 15% would be reached. The #30 and #50 curves are almost horizontal but show some sign of an increasing VMA as both bounds are exceeded. The #200 curve indicates an increase in the VMA as the percent passing is decreased, which is consistent with theory since it is expected that an increase in the amount of fines in the mix reduces the VMA by replacing the void space.

The results show that for the first three sieves, the gradation should be most closely watched for conformity to the upper bound while the #30 and #50 sieves show good VMA properties well outside of the tolerances. The #200 curve indicates that the lower bound is critical while the 150% high deviation is still well above the 15% VMA.

Voids Filled with Asphalt

To prevent a mix from being too "dry" and subject to weathering, specifications require that between 75 and 85 percent of the VMA be filled with asphalt. For all of the sieves, the VFA curves were rather low, which is probably the result of a low asphalt content from the design.

The VFA increased with decreasing percent passing on the 3/8", #4 and #8 sieves, while the #30 and #50 sieves had practically no change in the VFA over the range tested. The #200 curve, however, showed a marked decrease in the VFA as the percent passing was decreased.

From these results, it is evident that a "dry" mix can be counteracted in two ways:

1. by decreasing the percent passing one of the coarse sieves (#8 or larger), or

2. by adding more fines (minus #200).

CONCLUSIONS

On the basis of the results of this investigation, it is concluded that:

1. Although the scope of this study was too limited to provide sufficient evidence for deleting sieve sizes from the S-5 gradation, the results indicate that there is a definite similarity between some of the sieves with respect to their influence on mix properties.

2. The coarse sieves in the S-5 gradation (3/8", #4 and #8) all display similar effects where deviations occur. The #30 sieve appears to be a transitional size in the gradation and is most critical to stability. The fine sieves (#50 and #200) show similar trends that are completely opposite to those of the coarse sieves.

3. The volumetric properties of an asphaltic concrete mix should be considered to be at least as important as the stability of the mix.

4. Deviations in asphalt content are far more critical than deviations in gradation.

5. The specifications for the S-5 mix should include requirements for the volumetric properties as well as for gradation.

6. The specifications for the S-5 gradation constitute a reasonable indirect control of the volumetric requirements necessary to provide a durable mix.

REFERENCES

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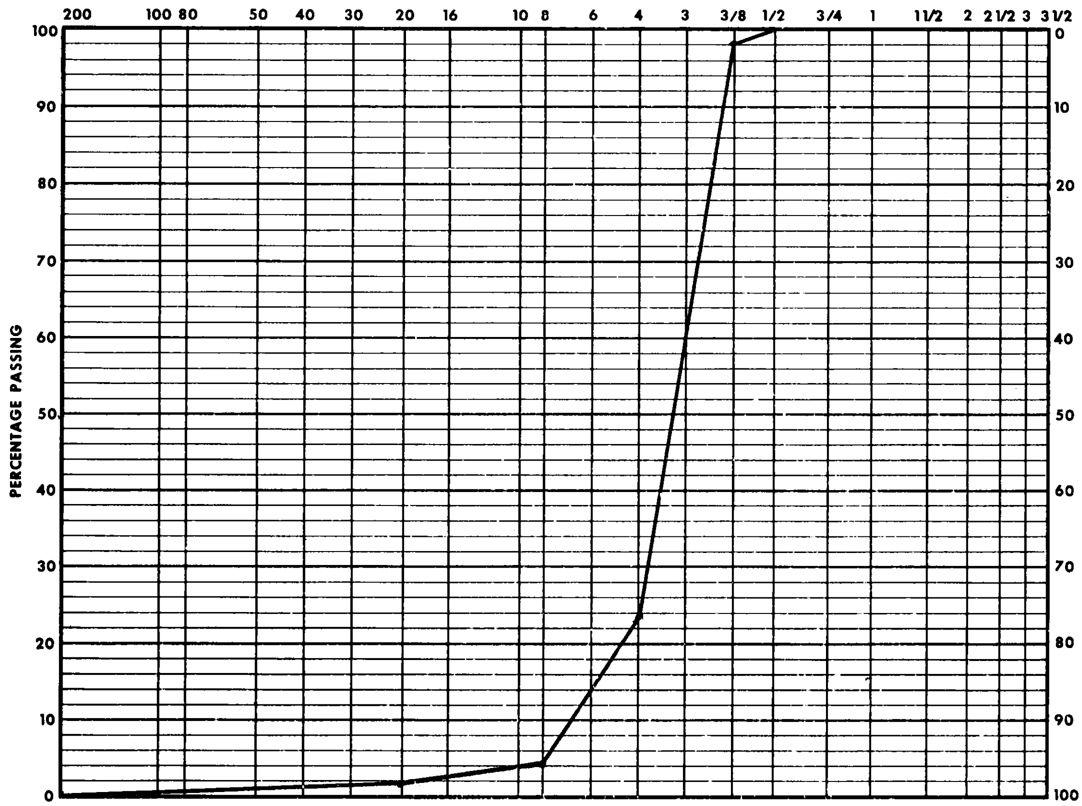
3. Campen, W. H., Smith, J. R., Erickson, L. G., and Martz, L. R., "The Control of Voids in Aggregates for Bituminous Paving Mixtures", Proceedings of the Association of Asphalt Paving Technologists, Vol. 26, 1957.

4. The Asphalt Institute, Mix Design Methods for Asphalt Concrete and other hot-mix types, Manual Series No. 2 (MS-2), Third Edition, October, 1969.

Form No. R-188

GRADATION CHART

Date: June 1970 File:



SAMPLE OF #8 stone FROM Red Hill, Va. PRODUCER Superior Stone Co.

TESTED BY J.W. Aderhold FOR FIN. MOD.

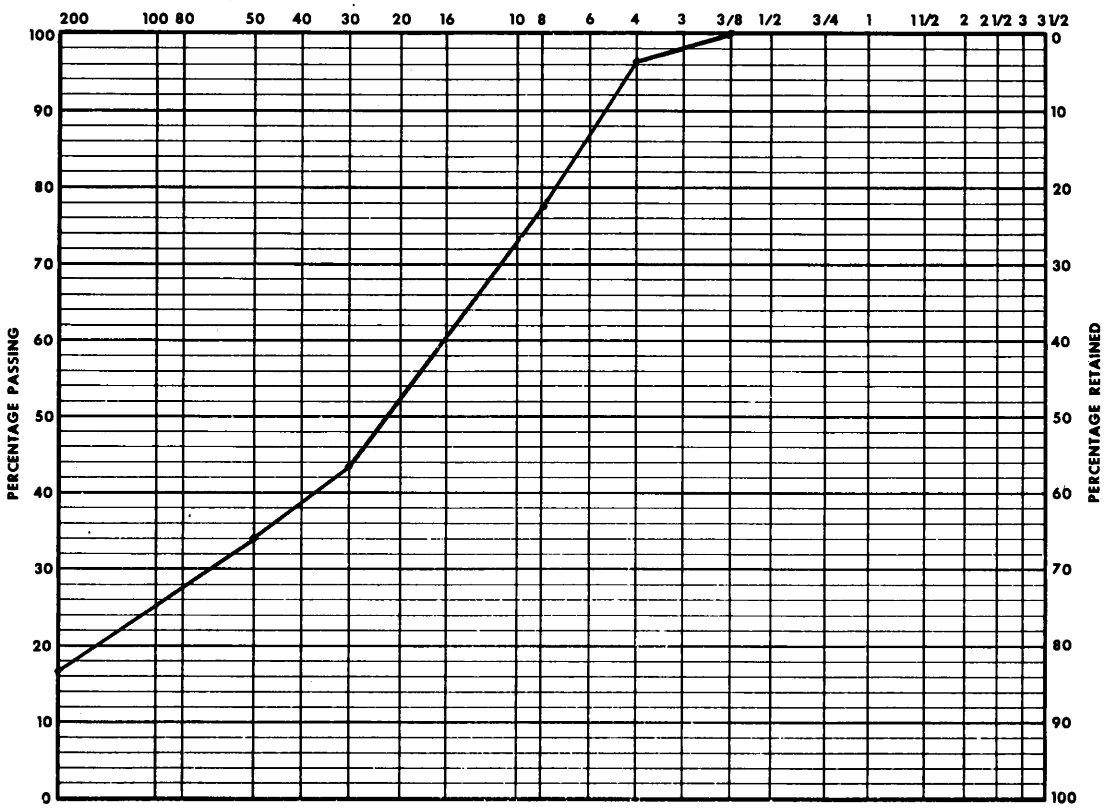
MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.	MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.
	3 1/2					6	.132				
	3					8	.0937	702.0	4.1	95.9	
	2 1/2					10	.0787				
	2					16	.0469				
	1 1/2					20	.0331	722.4	1.4	98.6	
	1					30	.0232				
	3/4					40	.0165				
	1/2					50	.0117				
	3/8	13.2	98.2	1.8		80	.0070				
3	.265					100	.0059				
4	.187	560.3	23.5	76.5		200	.0029				
TOTAL						TOTAL		732.2	0	100	

Figure 1

Form No. R-188

GRADATION CHART

Date: June 1970 File:



SAMPLE OF #10 stone FROM Red Hill, Va. PRODUCER Superior Stone Co.

TESTED BY J. W. Aderhold FOR FIN. MOD.

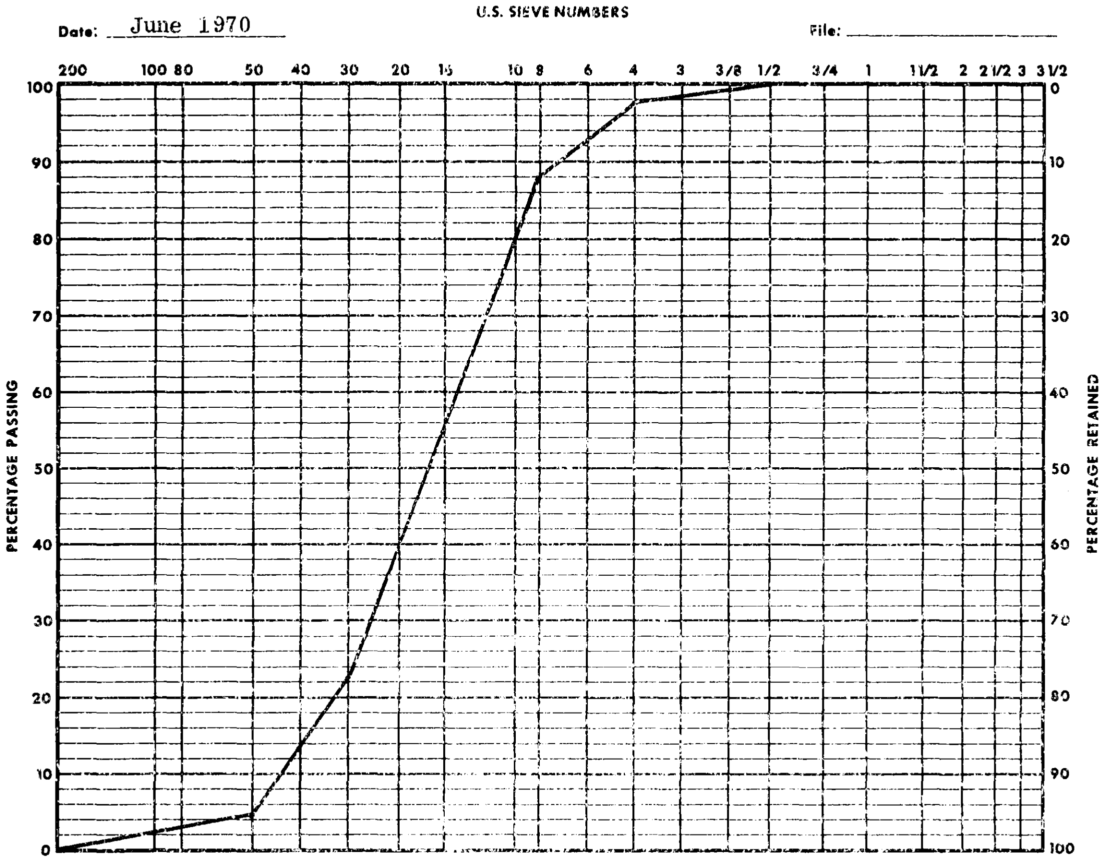
MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.	MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.
	3 1/2					6	.132				
	3					8	.0937	91.8	77.4	22.6	
	2 1/2					10	.0787				
	2					16	.0469				
	1 1/2					20	.0331				
	1					30	.0232	230.0	43.4	56.6	
	3/4					40	.0165				
	1/2					50	.0117	267.8	34.1	65.9	
	3/8	0	100	0		80	.0070				
3	.265					100	.0059				
4	.187	14.3	96.5	3.5		200	.0029	338.5	16.7	83.3	
TOTAL						TOTAL		406.4	0	100	

Figure 2

Form No. R-188

GRADATION CHART

Date: June 1970 File:



SAMPLE OF Sand FROM Red Hill, Va. PRODUCER S. L. Williamson

TESTED BY J. W. Aderhold FOR FIN. MOD.

MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.	MESH	OPEN INCHES	WEIGHT	PERCENT PASS	PERCENT RETAIN	PERCENT CUMUL.
	3 1/2					6	.132				
	3					8	.0937	94.7	88.1	11.9	
	2 1/2					10	.0787				
	2					16	.0469				
	1 1/2					20	.0331				
	1					30	.0232	614.0	22.5	77.5	
	3/4					40	.0165				
	1/2					50	.0117	758.0	4.4	95.6	
	3/8					80	.0070				
3	.265					100	.0059				
4	.187	18.9	97.6	2.4		200	.0029	789.9	0.3	99.7	
TOTAL						TOTAL		792.4	0	100	

Figure 3

Marshall Design Charts

Median S-5 Gradation
Red Hill Crushed Granite

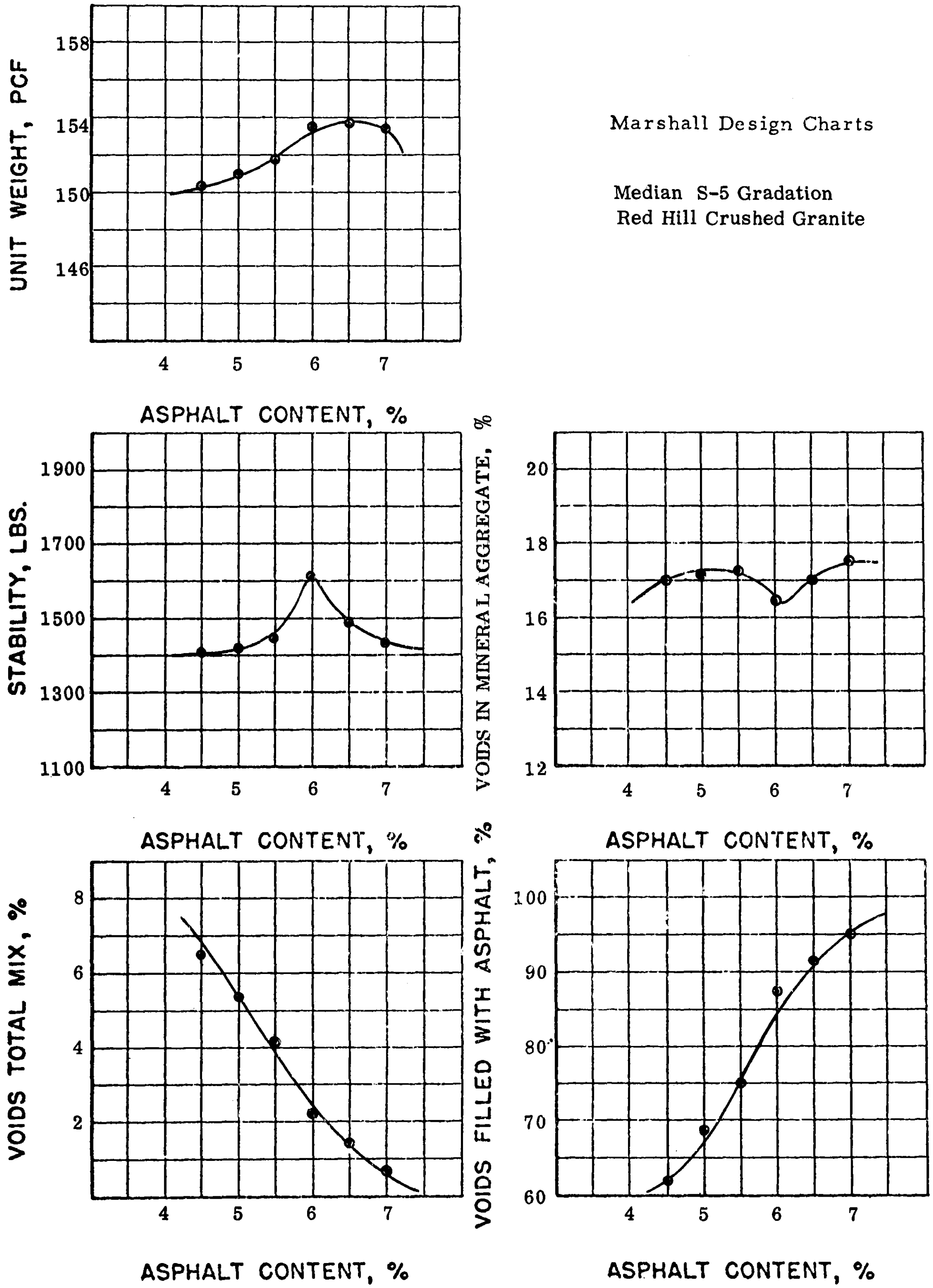


Figure 4

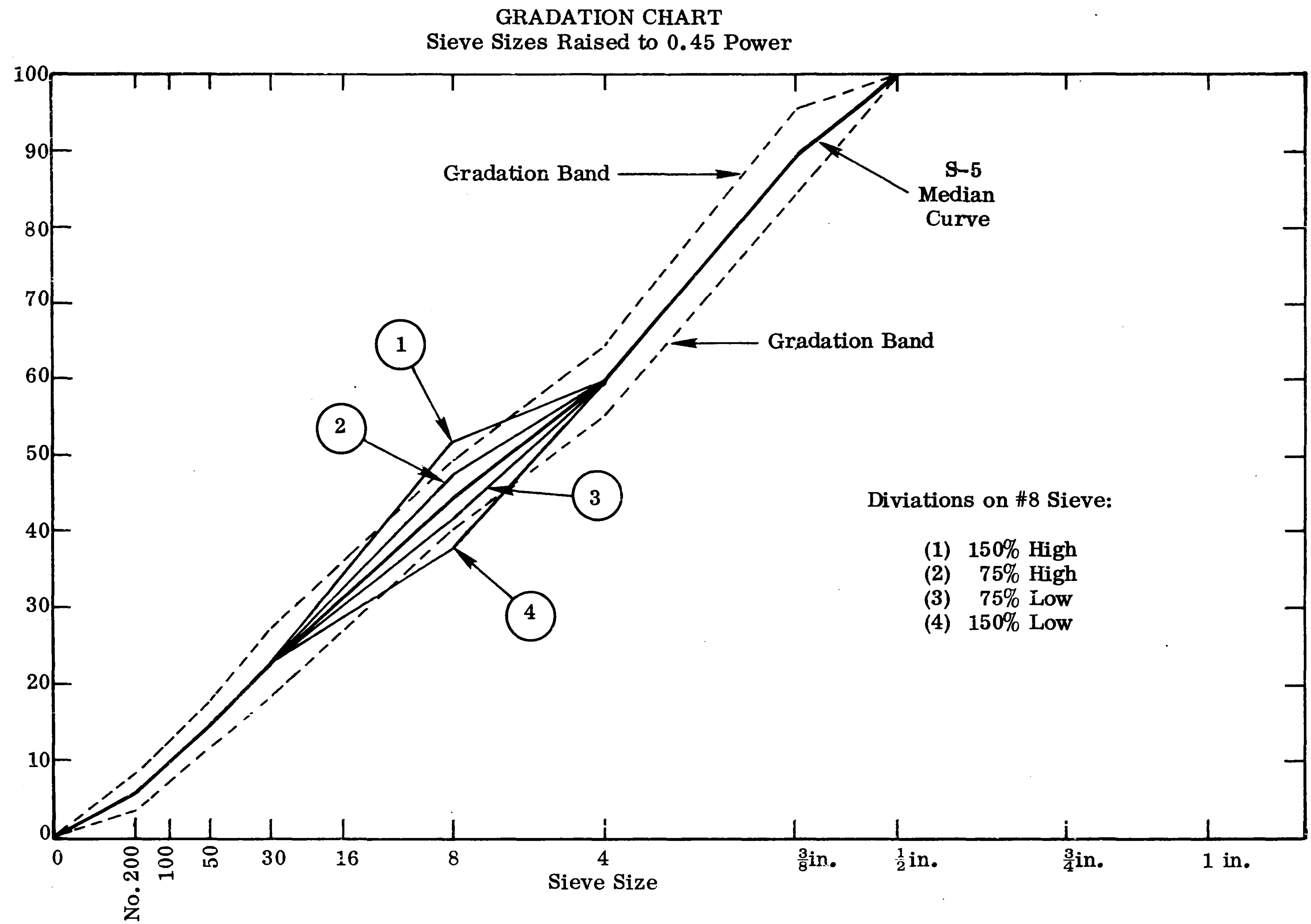
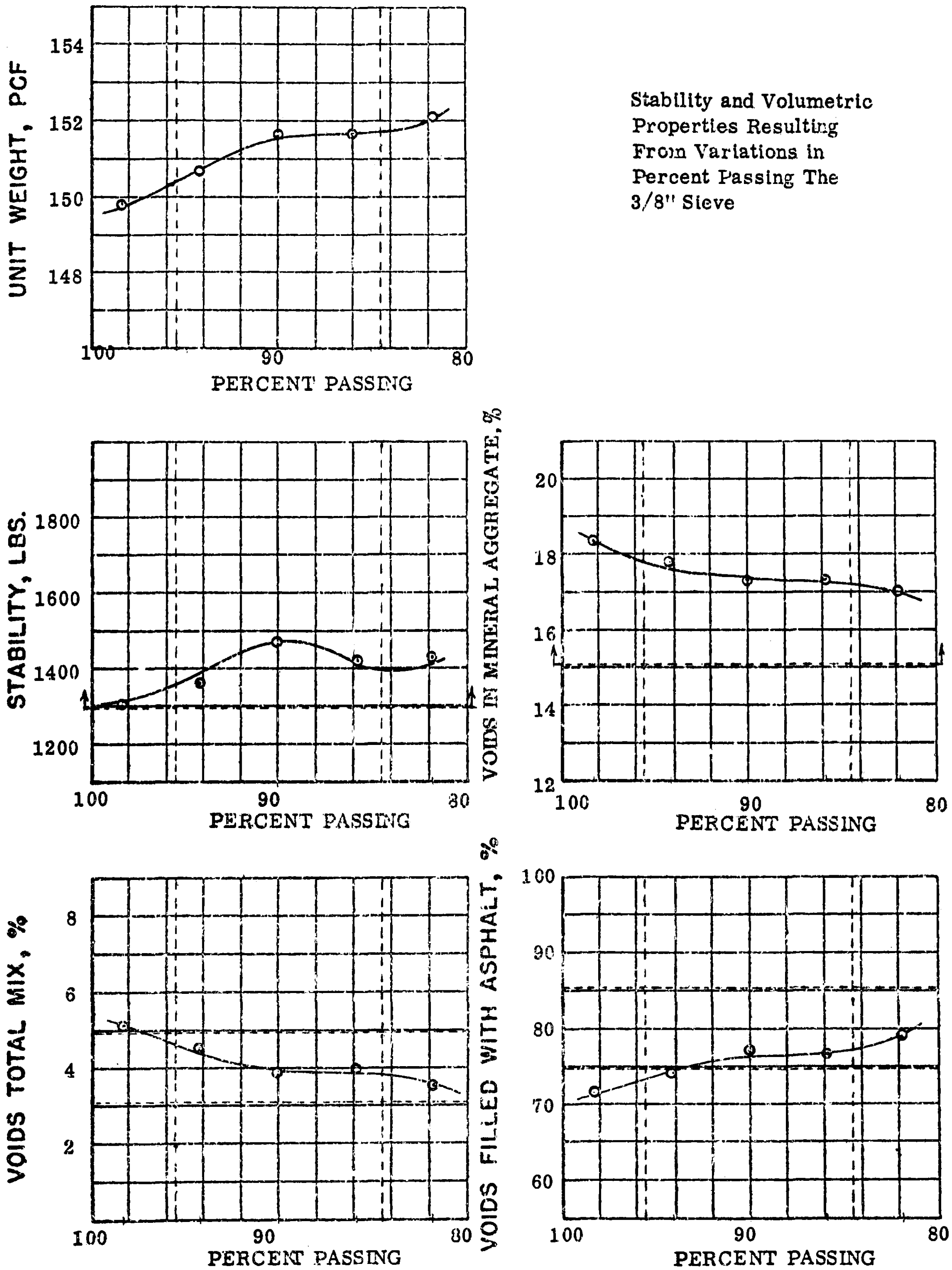
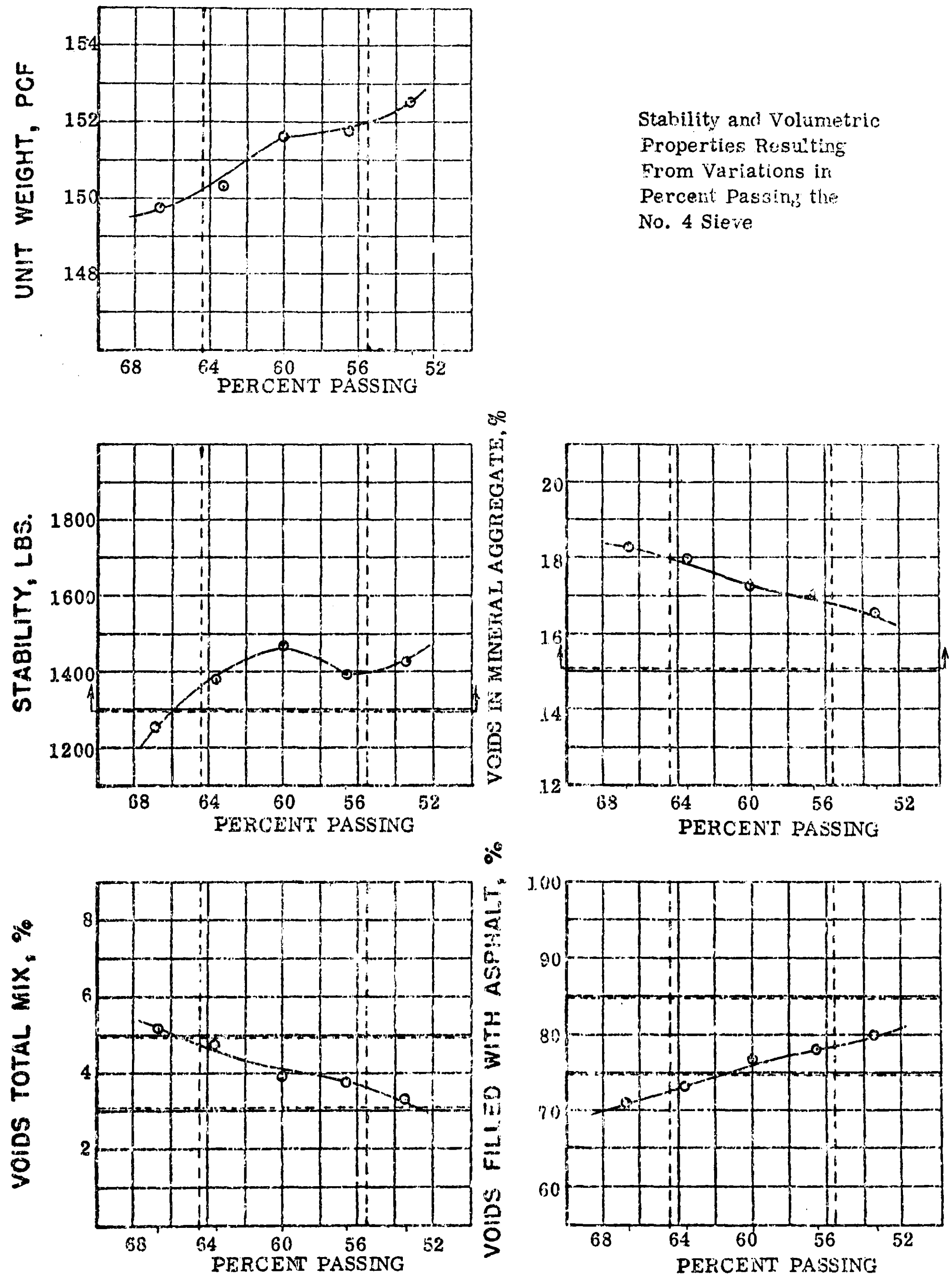


Figure 5. Virginia S-5 Gradation showing the four test mixes for the #8 sieve study.



Stability and Volumetric Properties Resulting From Variations in Percent Passing The 3/8" Sieve

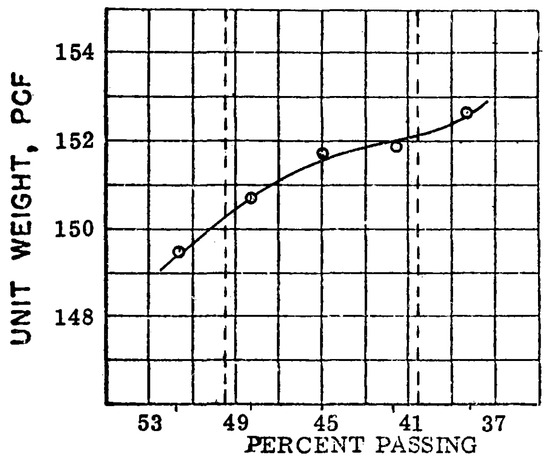
Figure 6

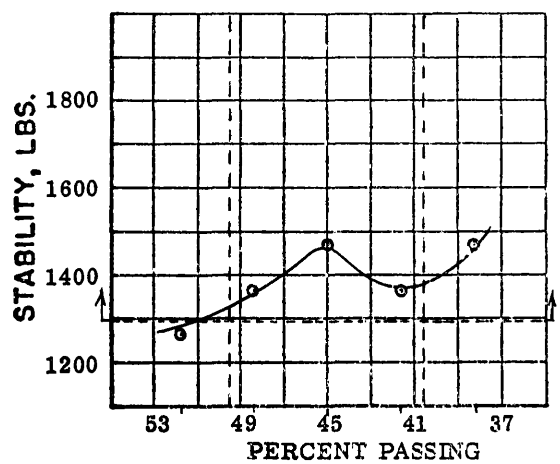


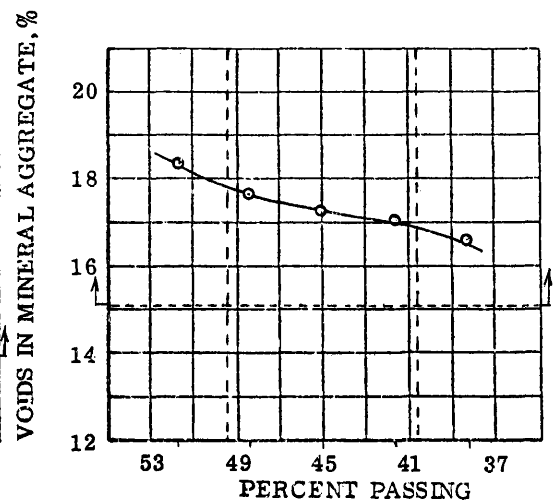
Stability and Volumetric Properties Resulting From Variations in Percent Passing the No. 4 Sieve

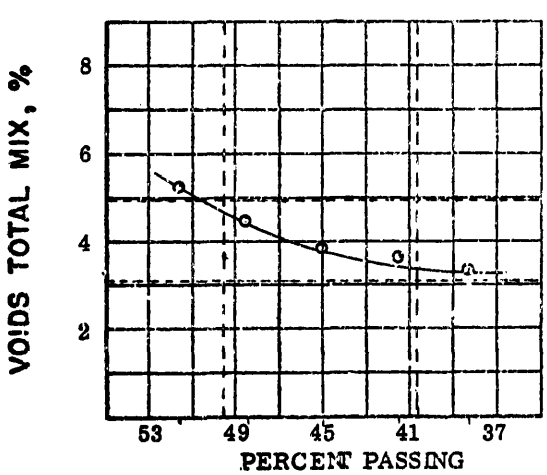
Figure 7

Stability and Volumetric Properties Resulting From Variations in Percent Passing the No. 8 Sieve









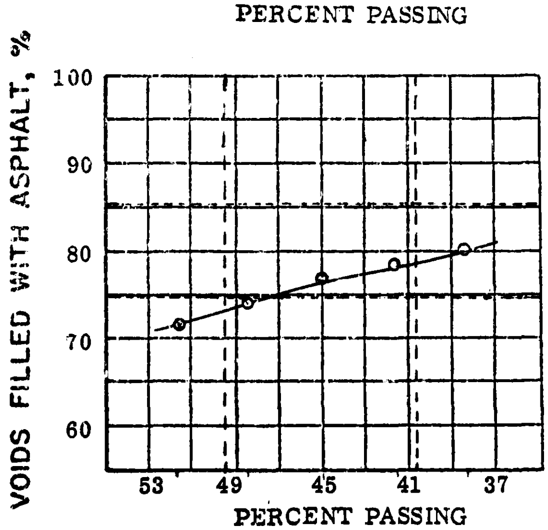
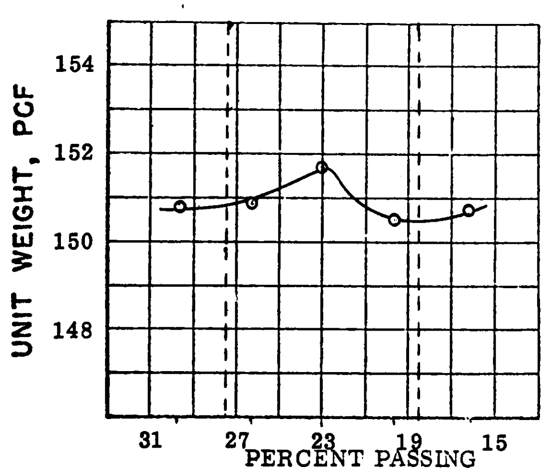


Figure 8



Stability-and Volumetric
Properties Resulting
From Variations in
Percent Passing the
No. 30 Sieve

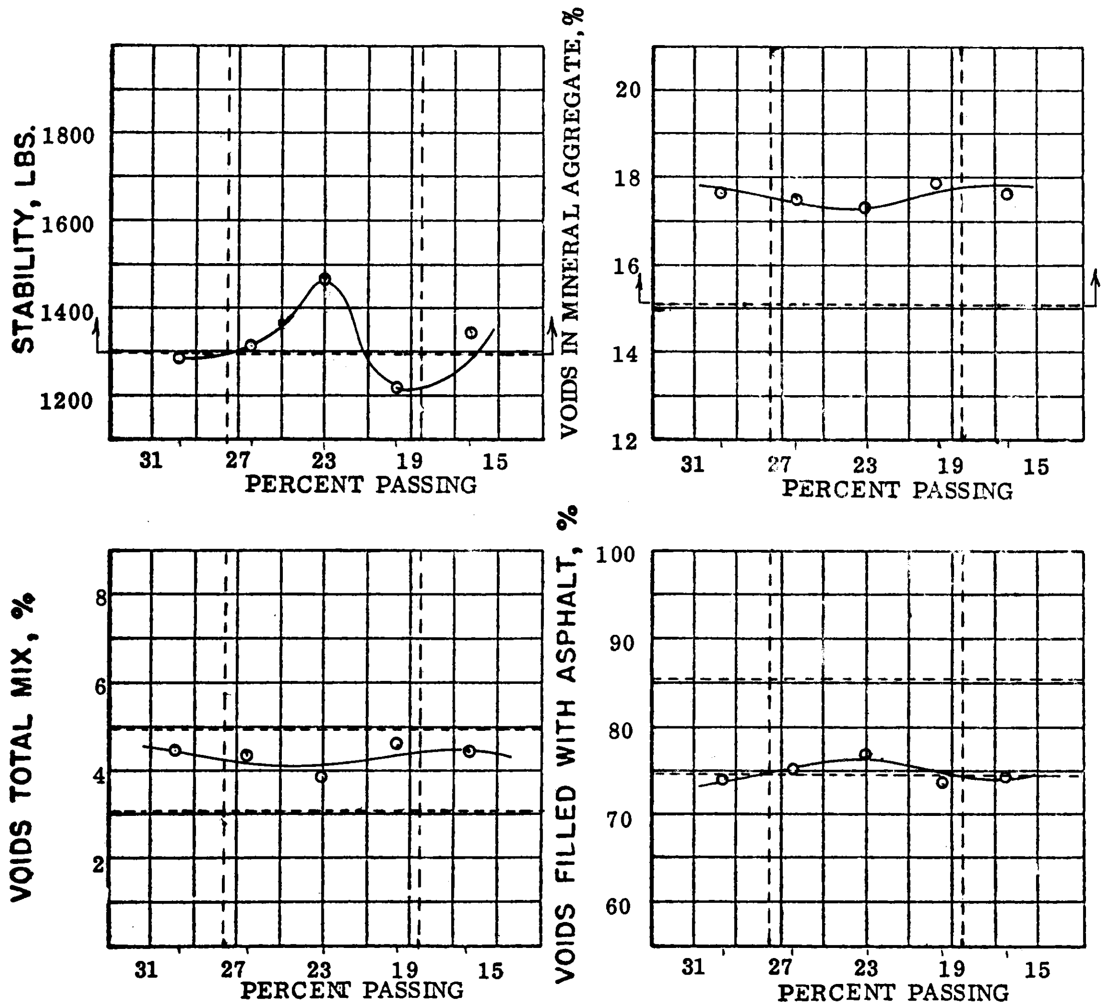
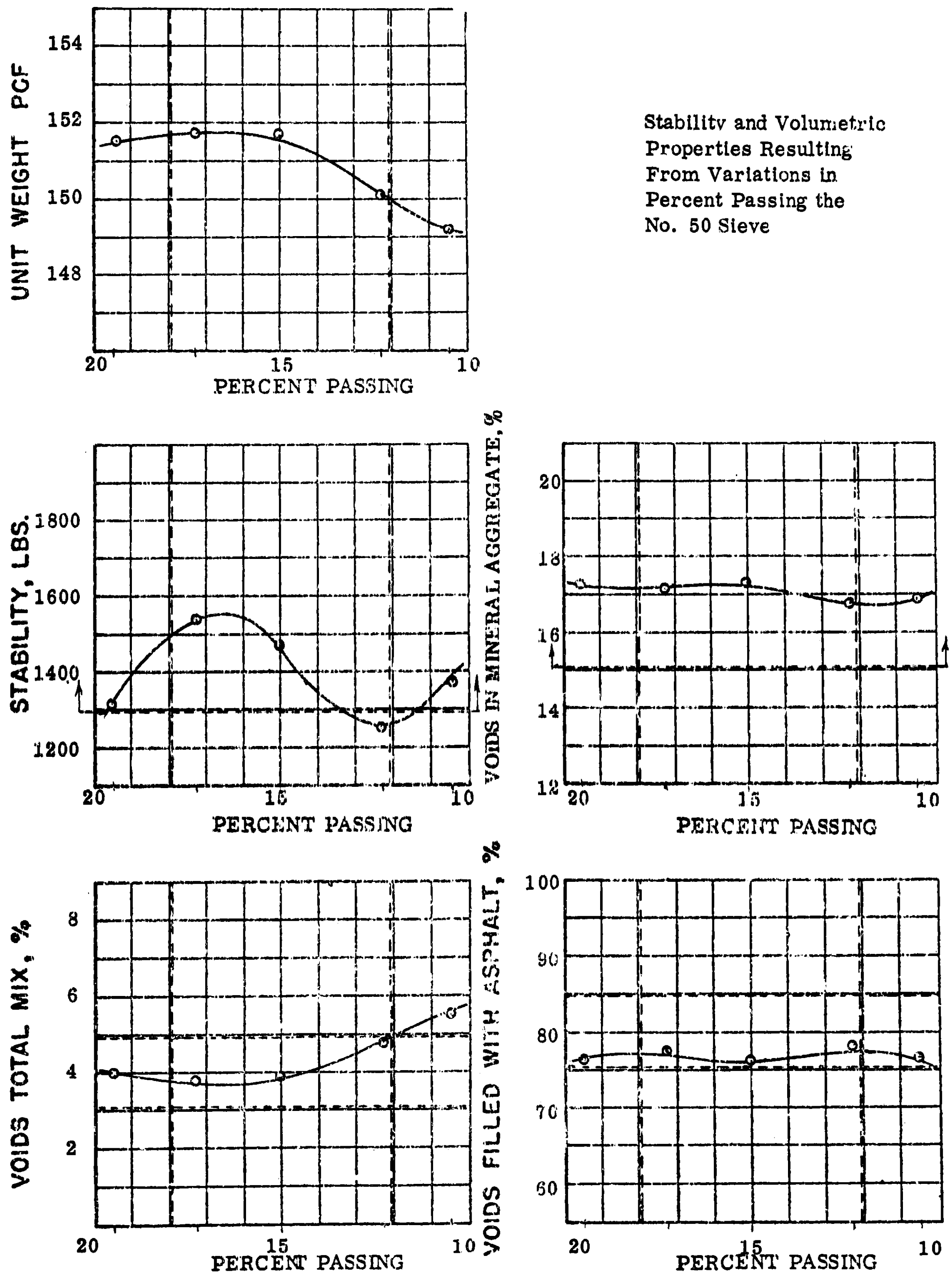
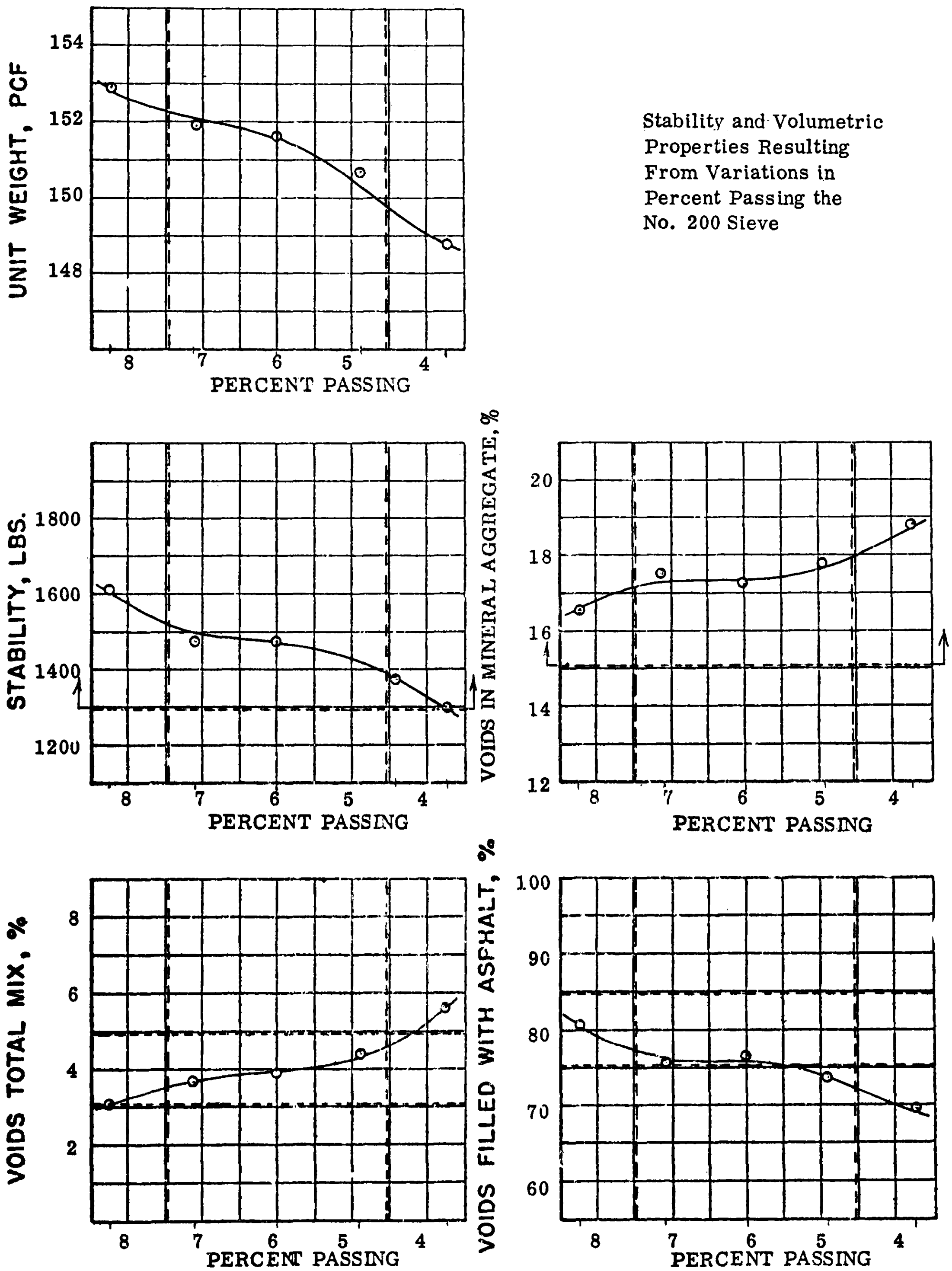


Figure 9



Stability and Volumetric Properties Resulting From Variations in Percent Passing the No. 50 Sieve

Figure 10



Stability and Volumetric Properties Resulting From Variations in Percent Passing the No. 200 Sieve

Figure 11