Influence of Fine Aggregates on Asphaltic Concrete Paving Mixtures

JOHN M. GRIFFITH AND B. F. KALLAS,
*Respectively, Engineer of Research and Assistant Engineer of Research,
The Asphalt Institute, College Park, Md.*

Asphalt paving engineers have long been aware of the importance of the physical properties of fine aggregates used for sand or sheet asphalt type paving mixes. Recent investigations by The Asphalt Institute have indicated that type of fine aggregate has very pronounced effects on the properties of dense graded asphaltic concrete paving mixtures as measured by the Marshall and Hveem test methods.

Two types of fine aggregate, material passing the No. 8 sieve and retained on the No. 200 sieve, with different angularity and surface texture were used for the study in combination with several crushed rocks and uncrushed gravels. The coarse aggregates were sized from the ¾-in. sieve to the No. 8 sieve. Mineral dust was also used. Material passing the No. 200 sieve was obtained by processing a commercial limestone dust.

Seven basic gradations of mineral aggregate were used ranging from mixes in which all aggregate was finer than the No. 8 sieve size to those containing up to 75 percent of the aggregate from the ¾ in. size to the No. 8 size. An 85-100 penetration grade asphalt cement binder was used for all mixes.

Families of curves showing stability values at optimum asphalt content plotted against the relative proportions of coarse and fine aggregates used in the mixes showed that the type of fine aggregate greatly influenced stability values as measured by the Marshall and Hveem test methods. For mixes containing up to 50 percent fine aggregate the effect of the type of fine aggregate was pronounced and had a greater effect on stability than changes in the relative proportions of coarse and fine aggregate or type of coarse aggregate used. For mixes containing less than 50 percent fine aggregate the effect of the type of fine aggregate decreased, but still remained significant with as little as 25 percent fine aggregate.

In addition to the effect of fine aggregate type on Marshall and Hveem stability values, families of minimum aggregate voids curves indicated that fine aggregate type also had considerable effect on the aggregate voids characteristics of mixes.

While the stability test methods used for evaluation of the effect of fine aggregate type on the asphaltic concrete paving mixes are empirical, these stability methods are being widely used and have been extensively correlated with asphalt pavement performance. It is felt that these investigations will provide the designer of asphalt paving mixes with basic information helpful in proportioning and selection of fine aggregate for mixes.

• ASPHALT PAVING TECHNOLOGISTS have long been aware of the importance of the physical properties of fine aggregates used for sand or sheet asphalt type paving mixes. As early as 1905, when sand was the predominant mineral aggregate used for asphalt paving mixes, Richardson (*1*) stated: "Altogether there seems to be nothing more important for construction of a satisfactory asphalt surface mixture than a thorough understanding of the peculiarities of the various sands and their adaptability to the purposes for which they are used."

In recent studies Goetz and Lottman (*2*) stated: "The addition of crushed gravel fine aggregate to round natural sand materially increased the strength of bituminous concrete mixtures and sand asphalt mixtures prepared with all round natural sand in the fine aggregate."

Part of The Asphalt Institute's research activities are devoted to a comprehensive investigation of the characteristics of asphalt paving mixes. These investigations include a study of the relative effects of the variable components of the mix on the properties and characteristics of the compacted asphalt pavement. A wide variety of aggregate types, gradations, and combinations has been subjected to extensive tests by the Marshall, Hveem, Hubbard-Field, and triaxial test methods.

The data obtained from these tests indicate that both type and quantity of fine aggregate have pronounced effects on the properties of asphaltic concrete paving mixes as measured by the Marshall and Hveem test methods, the two asphalt-mix test methods most widely used at present.

ASPHALT

Asphalt cement used in the study was from a single and uniform source. It was an 85-100 penetration grade meeting all specification requirements of The Asphalt Institute.

AGGREGATES

The study was based on the use of two coarse aggregate types and two fine aggregate types. The coarse aggregates were:

1. California granite, crushed.
2. Washington gravel, uncrushed.

Fine aggregates were:

1. New York trap rock, crushed.
2. Maryland sand, uncrushed.

The California granite coarse aggregate and the New York trap rock fine aggregate were highly angular and rough textured, composed entirely of crushed particles. The Washington gravel coarse aggregate and the Maryland sand fine aggregate were aggregates of medium angularity and relatively smooth surface texture, both composed entirely of uncrushed particles.

The coarse aggregate fraction of a given mix was composed entirely of material passing the ¾-in. sieve and retained on the No. 8 sieve from one of these sources. The fine aggregate fraction contained material passing the No. 8 sieve and retained on the No. 200 sieve.

Mineral dust (material passing the No. 200 sieve) was obtained by processing a limestone dust from a single and uniform source. Specific gravities of all the mineral aggregates and mineral dust are given in Table 1.

Seven basic gradations were used, ranging from mixes in which all aggregate was finer than the No. 8 size to those containing up to 75 percent of coarse aggregate, from the ¾-in. to the No. 8 size. The range of gradations used in these studies is shown in Figure 1.

Changes in gradation were accomplished by varying the percentages of the coarse aggregate fraction and the fine aggregate and mineral dust fraction. The coarse aggregate grading remained constant, as did the fine aggregate and filler grading. The ratio of mineral dust to fine aggregate was constant throughout the study. Coarse aggregate, fine aggregate, and mineral dust were separated into sizes corresponding to all of the sieve sizes marked heavily in Figure 1 and

TABLE 1

SPECIFIC GRAVITY OF MINERAL AGGREGATES AND FILLER

Aggregate	Specific Gravity	
	Apparent	Bulk
Washington gravel	2.722	2.697
California granite	2.953	2.875
New York trap rock, fine	2.923	2.754
Maryland sand, fine	2.655	2.632
Limestone mineral dust	2.703 *	—

* ASTM Designation C 188.

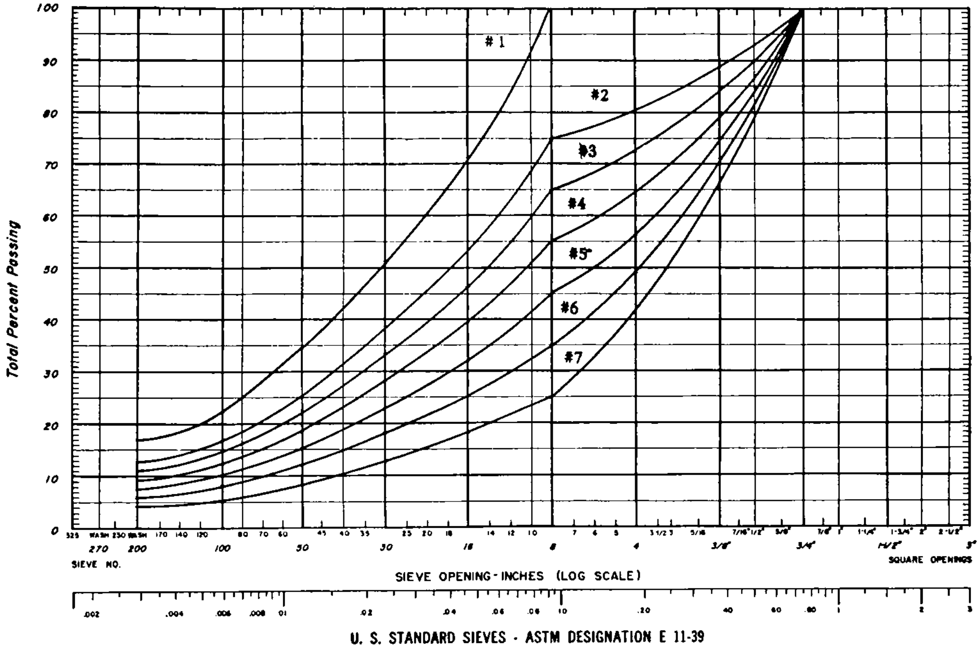


Figure 1. Aggregate gradations.

recombined for individual test specimens to obtain the highest possible degree of gradation control. Gradations were also adjusted to equivalent percentages by volume in order to compensate for variations in the specific gravity of the fine and coarse aggregates used.

TEST METHODS

The Marshall and Hveem test methods were used to measure certain effects of type and quantity of fine aggregate on asphalt paving mixtures. Although these testing methods are empirical in nature, they are widely used throughout the United States and have been extensively correlated with asphalt pavement performance. Data trends derived from these studies have provided a wide variety of information of value to the asphalt paving technologist, as will be shown.

The Marshall and Hveem test procedures as used in these studies are fully described elsewhere (*3*).

BASIC LABORATORY DATA

The basic laboratory data derived from tests on the various aggregate combinations are shown graphically in the Appendix. (Fig. 6 shows Marshall test data for Gradation 1, composed entirely of New York trap rock fine aggregate and limestone dust. Figs. 7 through 12 are Marshall data for various combinations of Washington gravel coarse aggregate, New York trap rock fine aggregate, and limestone dust. Figs. 13 through 18 are Marshall data for various combinations of California granite coarse aggregate, New York traprock fine aggregate, and limestone dust. Fig. 19 shows Marshall data for Gradation 1, composed entirely of Maryland sand fine aggregate and limestone dust. Figs. 20 through 25 are Marshall data for various combinations of Washington gravel coarse aggregate, Maryland sand fine aggregate, and limestone dust. Figs. 26 through 31 are Marshall data for various combinations of California granite coarse aggregate, Maryland sand fine aggregate, and lime-

TABLE 2

SUMMARY OF MARSHALL TEST PROPERTIES

Gradation Curve Number	Percent Fine Aggregate and Mineral Dust	Washington Gravel Coarse Aggregate			California Granite Coarse Aggregate		
		Opt. AC Content (%)[a]	Stability (lb)	Min. Agg. Voids (%)	Opt. AC Content (%)[a]	Stability (lb)	Min. Agg. Voids (%)
(*a*) NEW YORK TRAP ROCK FINE AGGREGATE							
1	100	9.3	2,550	24.2	9.3	2,550	24.2
2	75	6.8	2,500	19.4	6.8	3,070	19.0
3	65	6.4	2,260	18.3	6.3	2,810	18.5
4	55	5.6	2,100	16.6	5.8	2,780	17.6
5	45	5.2	1,860	15.6	5.6	2,760	17.5
6	35	4.9	1,510	15.1	5.5	2,580	17.0
7	25	5.4	1,260	15.5	6.1	1,780	18.4
(*b*) MARYLAND SAND FINE AGGREGATE							
1	100	6.6	1,510	18.8	6.6	1,510	18.8
2	75	5.7	1,570	15.8	5.7	1,800	16.1
3	65	4.9	1,565	14.6	5.2	1,900	15.2
4	55	4.6	1,580	14.3	4.7	2,140	14.5
5	45	4.4	1,335	13.6	4.9	1,915	15.0
6	35	4.5	1,090	13.5	5.3	2,010	15.6
7	25	4.9	840	14.4	5.8	1,400	18.5

[a] Based on dry weight of aggregate.

stone dust. Figs. 32 through 57 are parallel data for Hveem tests on these same materials.)

The optimum asphalt content was determined for each of these gradations and combinations of aggregates, in accordance with established procedures (*3*). Table 2 summarizes optimum asphalt contents, stability at optimum asphalt content, and minimum voids in the mineral aggregate as determined in Marshall tests for these mixes. Table 3 summarizes similar data from the Hveem tests. These data only are used to establish trends discussed in this paper. The detailed data of Figures 6 through 57 have been included, however, for use in further analyses by asphalt paving technologists.

STABILITY CHARACTERISTICS

One important property of an asphalt paving mix is stability, the ability to withstand repetitive traffic loadings without displacement. Both the Marshall and Hveem methods of mix design include a measurement of stability. Data derived

TABLE 3

SUMMARY OF HVEEM TEST PROPERTIES

Gradation Curve Number	Percent Fine Aggregate and Mineral Dust	Washington Gravel Coarse Aggregate			California Granite Coarse Aggregate		
		Opt. AC Content (%)[a]	Stability (lb)	Min. Agg. Voids (%)	Opt. AC Content (%)[a]	Stability (lb)	Min. Agg. Voids (%)
(*a*) NEW YORK TRAP ROCK FINE AGGREGATE							
1	100	8.1	52	23.2	8.1	52	23.2
2	75	6.4	55	20.2	6.4	57	20.0
3	65	5.8	55	18.3	6.0	58	19.0
4	55	5.3	56	17.0	5.3	58	17.6
5	45	4.7	54	15.7	4.7	58	17.2
6	35	4.7	40	15.0	5.3	49	17.3
7	25	4.5	35	15.2	5.3	43	18.6
(*b*) MARYLAND SAND FINE AGGREGATE							
1	100	6.4	30	17.5	6.4	30	17.5
2	75	4.9	38	15.0	5.2	38	15.5
3	65	4.3	44	13.3	4.7	45	15.3
4	55	3.9	46	13.0	4.4	49	14.1
5	45	3.8	44	12.4	4.6	48	15.1
6	35	3.6	39	12.5	4.7	45	15.1
7	25	3.9	32	12.9	4.6	36	18.4

[a] Based on dry weight of aggregate.

from this study provide a basis for establishing general trends in the variations of Marshall and Hveem stability with variations in proportions of coarse and fine aggregates. Such trends are shown for Marshall stability in Figure 2, where stability values are at the optimum asphalt content for the particular mix, determined as previously described.

It will be noted that all the curves show an increasing and then decreasing stability as the percentage of fine aggregate is increased from 25 to 100 percent. Combinations of the more angular crushed New York trap rock fine aggregate with both coarse aggregate types resulted in appreciably higher stability values than mixes containing the less angular, uncrushed Maryland sand fine aggregate.

Numerically, the increase in stability that could be attributed to use of the more angular trap rock fine aggregate amounted to approximately 500 to 1,000 lb for mixes containing more than 50 percent fine aggregate and filler. When less than about 50 percent of the trap rock fine aggregate was used, the effect of fine aggregate type became less pronounced, although it still remained quite significant with as little as 25 percent fine aggregate and limestone dust in the mix.

The influence of coarse aggregate type and quantity on Marshall stability at optimum asphalt content is also shown by the family of curves. The crushed, highly angular, California granite mixes were considerably higher in stability at optimum asphalt content than mixes containing the uncrushed less angular Washington gravel mixes.

These curves indicate that the influence of fine aggregate type on Marshall stability at optimum asphalt content was considerably greater than the influence of coarse aggregate type for mixes containing more than about 50 percent fine aggregate and mineral dust for the aggregates studied. When less than about 50 percent fine aggregate and mineral dust was used, the effect of fine aggregate type on Marshall stability at optimum asphalt content was roughly the same or

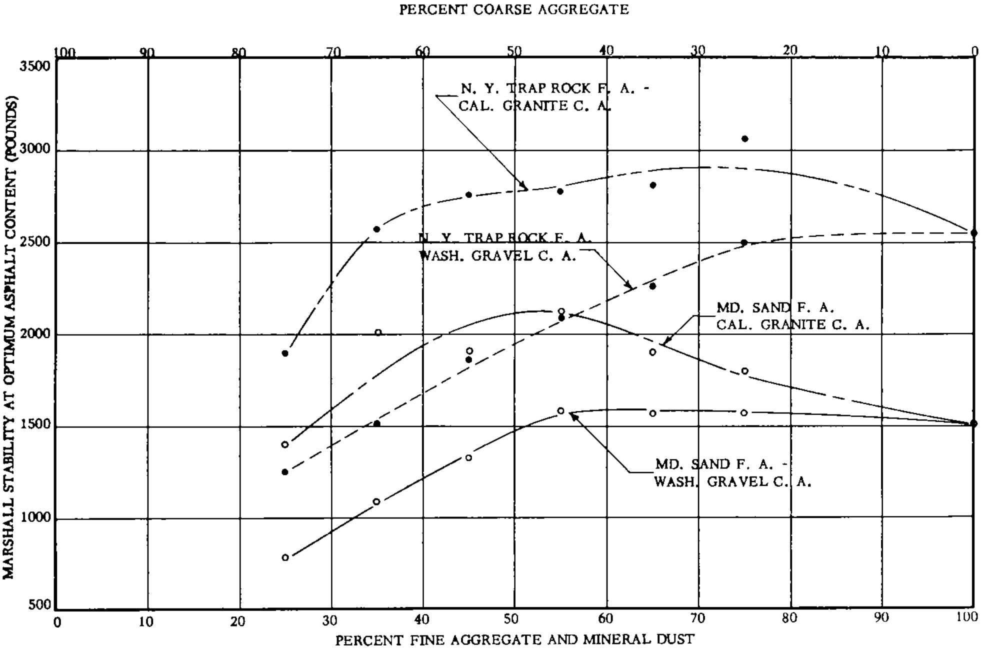


Figure 2. Marshall stability characteristics.

slightly less than that of coarse aggregate type.

A similar plot of Hveem stability values at optimum asphalt content for identical aggregates and gradations as used for the Marshall test series is shown in Figure 3. The curves for all mixtures show increasing and then decreasing Hveem stability values at optimum asphalt content as the fine aggregate and mineral dust fraction was varied from 25 to 100 percent.

Mixes containing the more angular New York trap rock fine aggregates produced Hveem stability values at optimum asphalt contents about 10 to 20 points higher than those containing the less angular Maryland sand fine aggregates, for fine aggregate and mineral dust concentrations greater than about 50 percent. Effect of fine aggregate type became less pronounced, but still remained significant, for mixes containing less than 50 percent fine aggregate and mineral dust.

The crushed and more angular California granite coarse aggregate mixes resulted in higher Hveem stability values than the uncrushed less angular Washington gravel coarse aggregate mixes for a given fine aggregate and filler.

AGGREGATE VOIDS CHARACTERISTICS

For a given aggregate, gradation, and compactive effort, as the asphalt content is increased in compacted bituminous mix specimens, aggregate voids decrease and then increase with further additions of asphalt. The effect of fine aggregate type and quantity upon aggregate voids may be shown by families of curves in which minimum percent aggregate voids values are plotted against the percent of fine aggregate and mineral dust for the various aggregate types.

Minimum aggregate voids values plotted in this manner reflect specimen density differences due to compactive efforts and methods. The development of aggregate voids data as described affords a means of comparing differences in the compaction methods used for the Marshall and Hveem test methods.

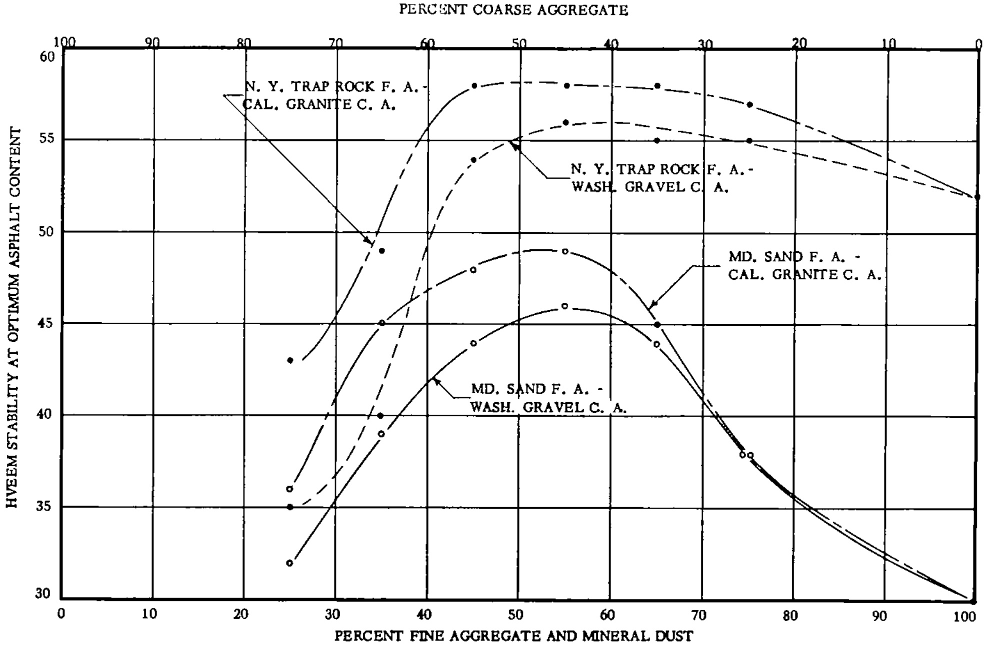


Figure 3. Hveem stability characteristics.

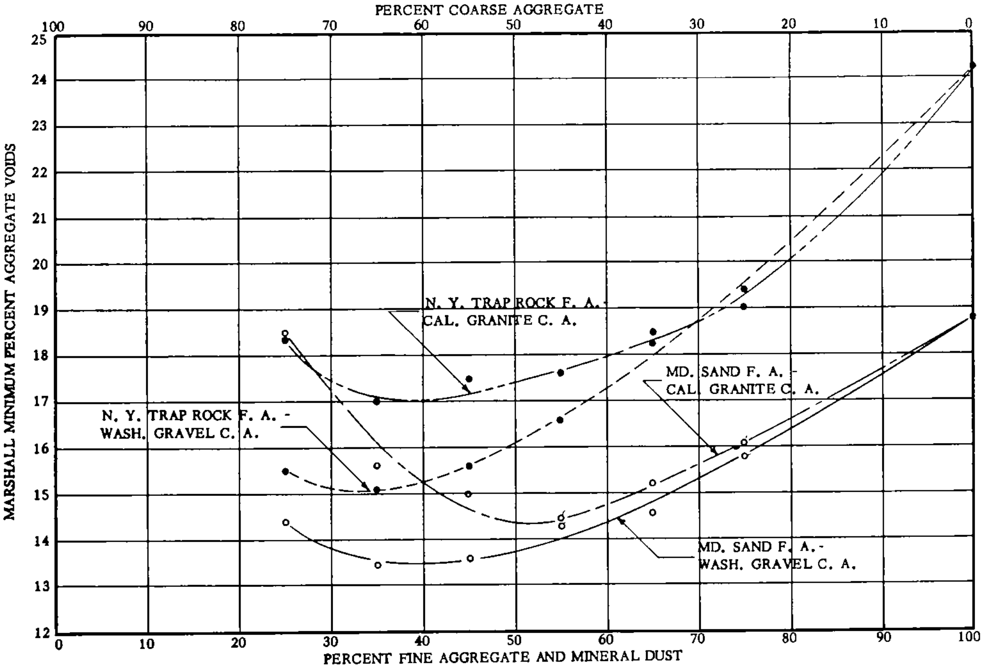


Figure 4. Marshall minimum aggregate voids characteristics.

Marshall Specimens

Figure 4 is a plot of minimum percent aggregate voids *vs* the different percentages of coarse aggregate, fine aggregate, and mineral dust, resulting from Marshall 50-blow compaction for the various aggregates used in the study. As the percentage of fine aggregate and filler was increased from 25 to 100 percent, minimum aggregate voids values decreased to a minimum and then increased.

Mixes containing the crushed, more angular New York trap rock fine aggregate had minimum percent aggregate voids values approximately 3 to 5 percent higher than the less angular Maryland sand mixes for fine aggregate, and mineral dust contents greater than about 55 percent for mix compositions containing both Washington gravel and California granite coarse aggregates. As the fine aggregate and mineral dust content was decreased below approximately 55 percent, the coarse aggregate type began to influence minimum percent aggregate voids values, and became a more significant factor in minimum percent aggregate voids. Results indicated that for the mixes containing 75 percent of the crushed California granite, fine aggregate type had no appreciable effect on minimum aggregate voids values. The curves also indicate that fine aggregate type has considerable influence on the percentages of coarse aggregate and fine aggregate and mineral dust required to produce minimum percent aggregate voids. Minimum percent aggregate voids were reached with greater amounts of the less angular Maryland sand fine aggregate than of the New York trap rock fine aggregate.

Hveem Specimens

Figure 5 is a plot of aggregate voids characteristics for Hveem specimens compacted by the triaxial kneading compaction method for the same aggregates and gradations used for the Marshall test series. Minimum aggregate voids values decreased to a minimum and then increased as the fine aggregate and min-

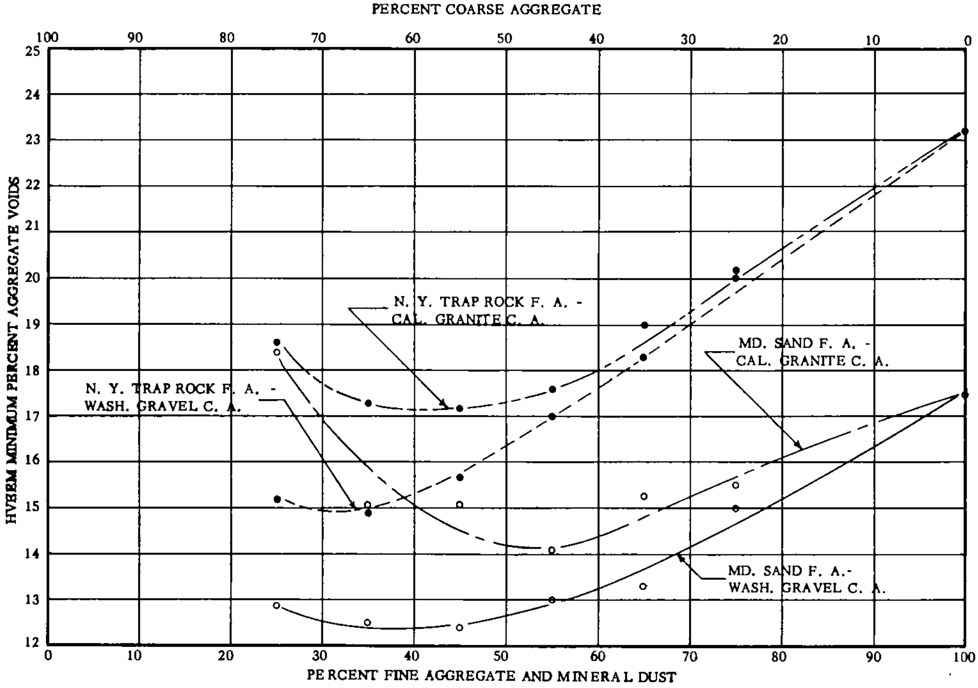


Figure 5. Hveem minimum aggregate voids characteristics.

eral dust fraction was increased from 25 to 100 percent. Use of the crushed, more angular trap rock fine aggregate generally resulted in higher minimum aggregate voids values than did the Maryland sand fine aggregate. The magnitude of difference of minimum aggregate voids varied, but generally was about 2 to 5 percent less for the mixes containing the Maryland sand fine aggregate compared to mixes containing the trap rock fine aggregate, except for mixes containing 65 percent or more California granite coarse aggregate. In this instance the effect of fine aggregate type was small. The effect of coarse aggregate type on minimum aggregate voids values became apparent when more than 25 percent was used. About 55 percent or more coarse aggregate was required before the effect of coarse aggregate type exceeded the effect of fine aggregate type on minimum aggregate voids.

Trends in minimum aggregate voids values for the Marshall and Hveem specimens were quite similar for the aggregates and gradations used in the study. The most notable differences were as follows:

1. Triaxial kneading compaction used for the Hveem method resulted in higher densification of mixes which contained the less angular and smoother surface textured aggregate types, than did the Marshall method compaction.
2. The Marshall compaction method resulted in approximately the same or slightly higher densification of mixes which contained highly angular and rough surface textured aggregate types, than did the compaction used for the Hveem method.

OPTIMUM ASPHALT CONTENTS

Both the Marshall and Hveem methods of mix design include criteria for selection of optimum asphalt content. Results of optimum asphalt content determinations by the Hveem method indicated that in all instances the mixes containing the crushed New York trap rock fine aggregate required more asphalt than did mixes containing the less angular Maryland sand. This was true when the trap rock fine aggregate was used in combination with the California granite coarse aggregate and the Washington gravel coarse aggregate. Optimum asphalt contents determined by the Hveem method for the various combinations of New York trap rock fine aggregate and Washington gravel coarse aggregate averaged 1.2 percent higher than for combinations of Maryland sand fine aggregate and Washington gravel coarse aggregate. Hveem method optimum asphalt contents for the various combinations of New York trap rock fine aggregates and California granite coarse aggregates averaged 1.0 percent higher than for combinations of Maryland sand fine aggregates and California coarse aggregates.

Marshall method optimum asphalt contents were also higher in all instances for mixes containing New York trap rock fine aggregates than mixes containing Maryland sand fine aggregate regardless of the coarse aggregate type used. Optimum asphalt contents determined by the Marshall method for the various combinations of California granite coarse aggregate and New York trap rock fine aggregate averaged 1.0 percent higher than did the combinations of California granite coarse aggregate and Maryland sand fine aggregate. Marshall optimum asphalt contents for combinations of Washington gravel coarse aggregates and New York trap rock fine aggregates averaged 1.1 percent higher than combinations of Washington gravel coarse aggregates and Maryland sand fine aggregates.

Also of interest is the fact that for all aggregates and gradations used in the study, Marshall method optimum asphalt contents averaged approximately 0.6 percent higher than optimum asphalt contents determined by the Hveem method.

SUMMARY AND CONCLUSIONS

The type and quantity of fine aggregate used for asphaltic concrete paving mixes have pronounced effects on Marshall and Hveem test properties. For the aggregates and gradations included in this study, the following conclusions may be drawn:

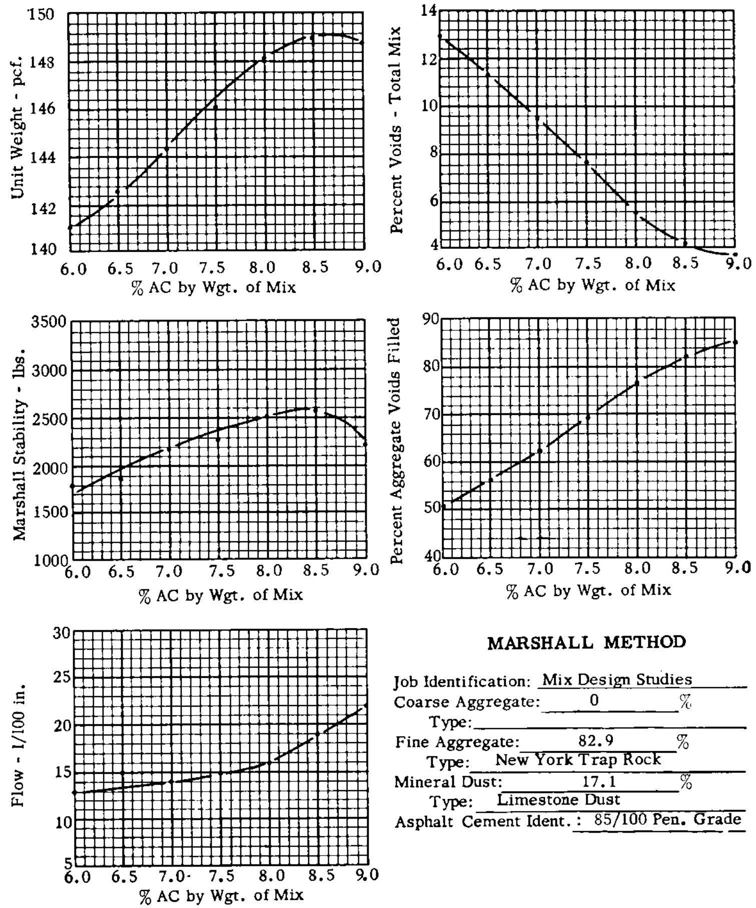
1. Increased angularity and roughness of surface texture of fine aggregates produced increased Marshall and Hveem stability values in asphaltic concrete mixes at optimum asphalt content.
2. Relative proportions of coarse and fine aggregate in asphaltic concrete mixes required to produce maximum Hveem or Marshall stability at optimum asphalt content appeared to be related to the angularity and surface texture of both coarse and fine aggregate fractions.
3. Increased angularity and roughness of surface texture of fine aggregate produced increased minimum percent aggregate voids in asphaltic concrete mixes compacted by the methods specified for the Marshall and Hveem methods.
4. Increased angularity and roughness of surface texture of the fine aggregate fractions used in asphaltic concrete mixes produced increased optimum asphalt contents determined in accordance with the criteria for selection of the optimum asphalt content for the Marshall and Hveem test methods.
5. Similar trends in optimum asphalt content, stability at optimum asphalt content, and minimum aggregate voids resulted for the Marshall and Hveem test methods as the types of fine and coarse aggregates were varied in asphaltic concrete mixes.

In conclusion, it is again pointed out that trends discussed in this paper represent only a small part of the information which can be derived from these laboratory data. It is hoped that asphalt paving technologists will familiarize themselves with details of these data and use them to good advantage in the design of asphalt paving mixes. The data presented here represent only one segment of a comprehensive study of factors influencing the behavior of asphalt paving mixes. Other segments of this study will be presented as developments suggest.

REFERENCES

1. RICHARDSON, C., "The Modern Asphalt Pavement." John Wiley & Sons, New York (1905).
2. GOETZ, W. H., AND LOTTMAN, R. P., "The Effect of Crushed Gravel Fine Aggregate on the Strength of Asphaltic Concrete Surfacing Mixtures." Circ. 63, Natl. Sand and Gravel Assn. (Mar. 1956).
3. "Mix Design Methods for Hot Mix Asphalt Paving." The Asphalt Inst.

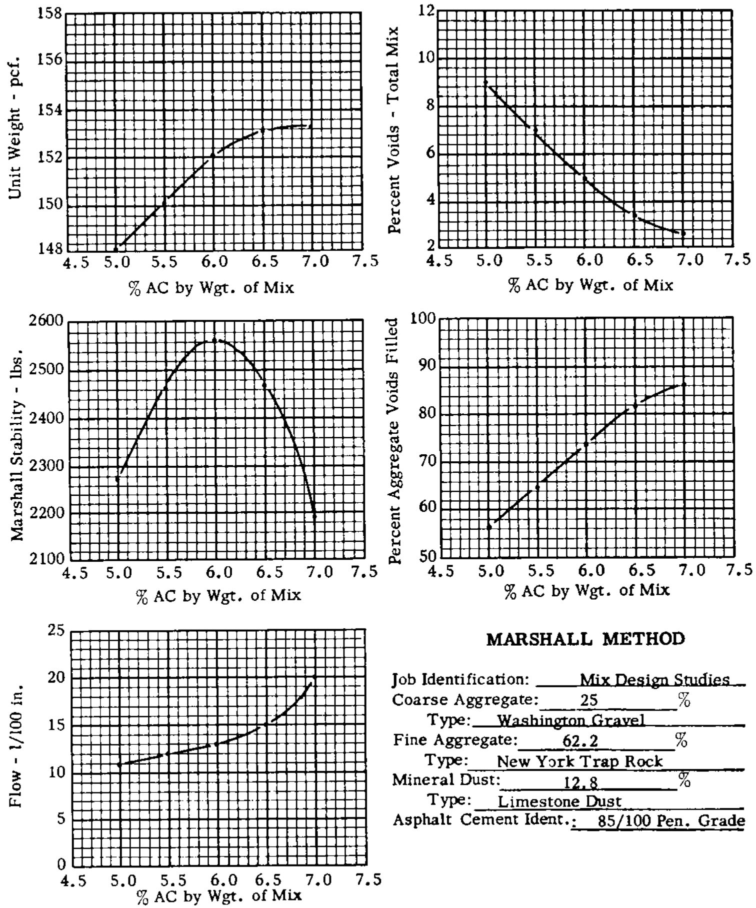
APPENDIX



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 0 %
Type:
Fine Aggregate: 82.9 %
Type: New York Trap Rock
Mineral Dust: 17.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

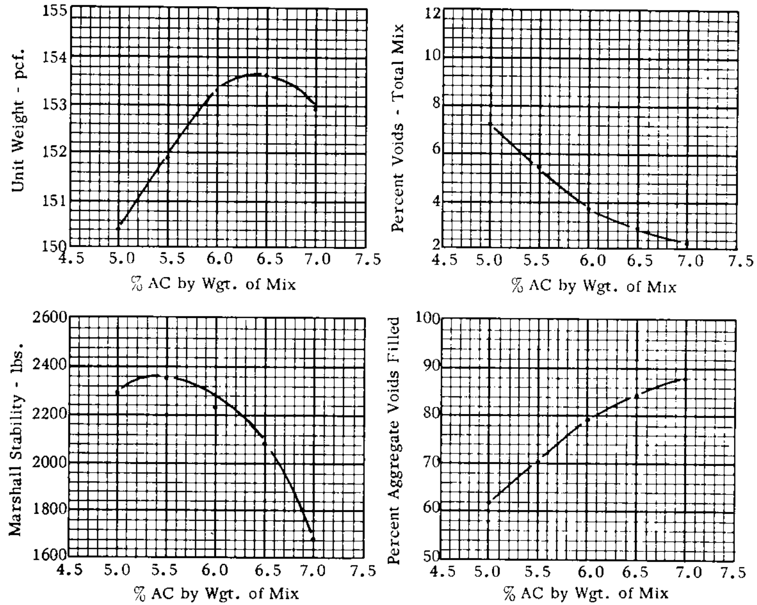
Figure 6.

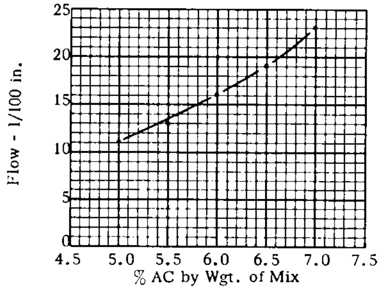


MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: Washington Gravel
Fine Aggregate: 62.2 %
Type: New York Trap Rock
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

Figure 7.

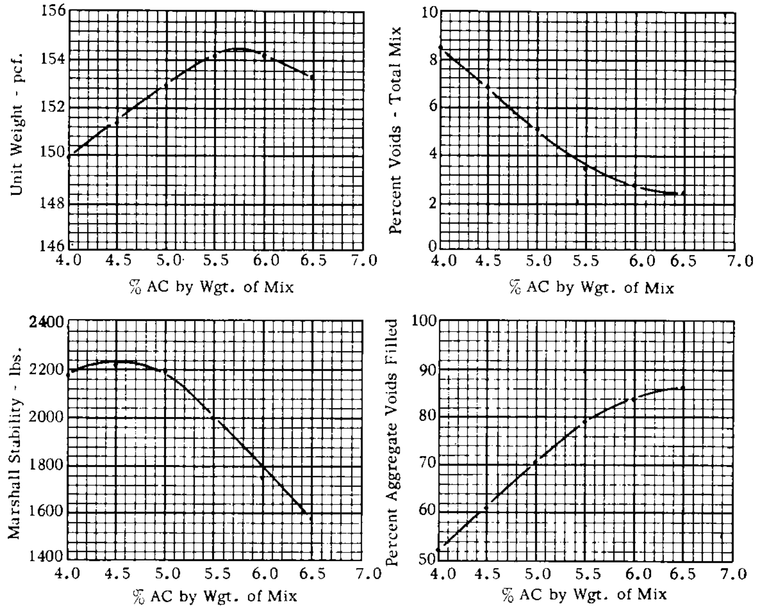


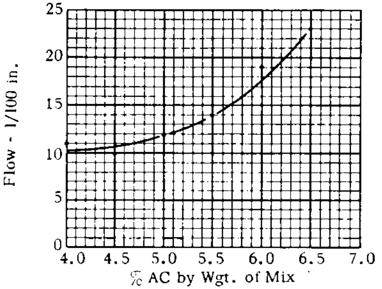


MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: Washington Gravel
Fine Aggregate: 53.9 %
Type: New York Trap Rock
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

Figure 8.

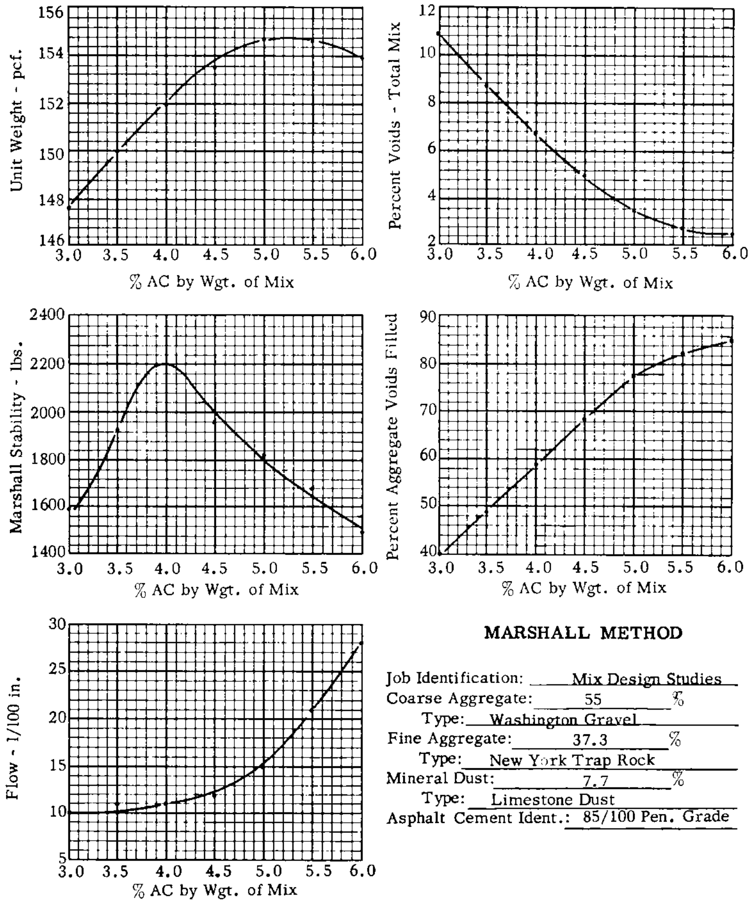




MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: Washington Gravel
Fine Aggregate: 45.6 %
Type: New York Trap Rock
Mineral Dust: 9.4 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

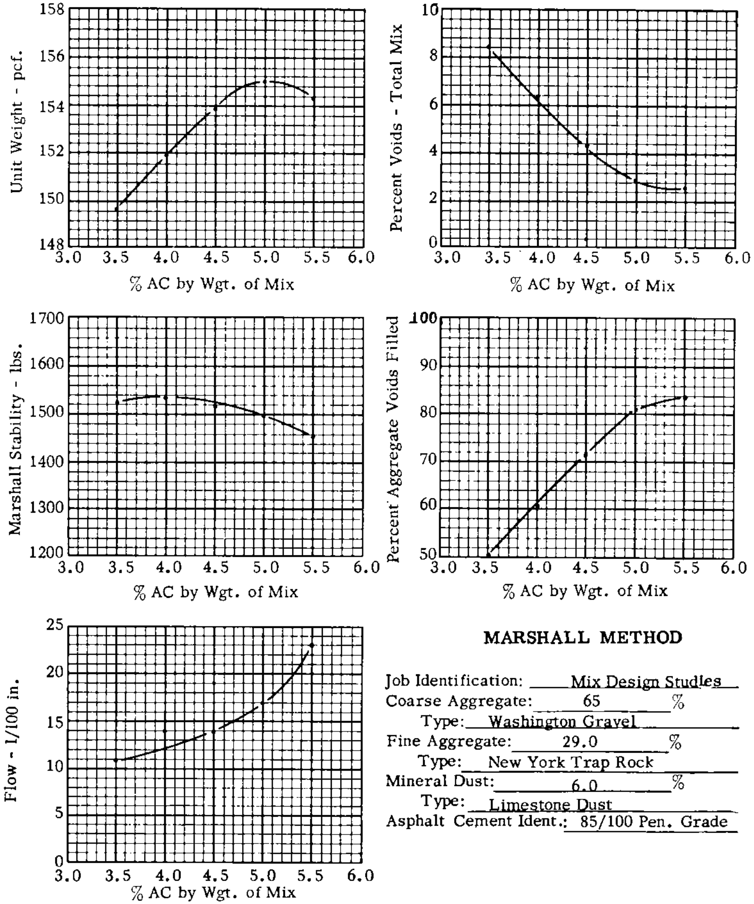
Figure 9.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: Washington Gravel
Fine Aggregate: 37.3 %
Type: New York Trap Rock
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

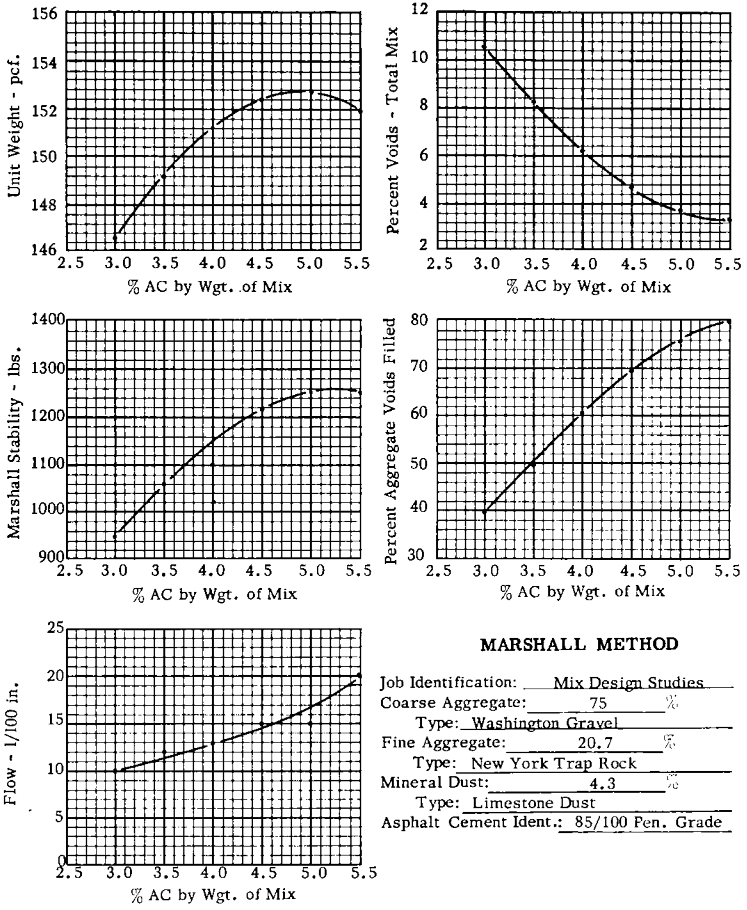
Figure 10.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: Washington Gravel
Fine Aggregate: 29.0 %
Type: New York Trap Rock
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

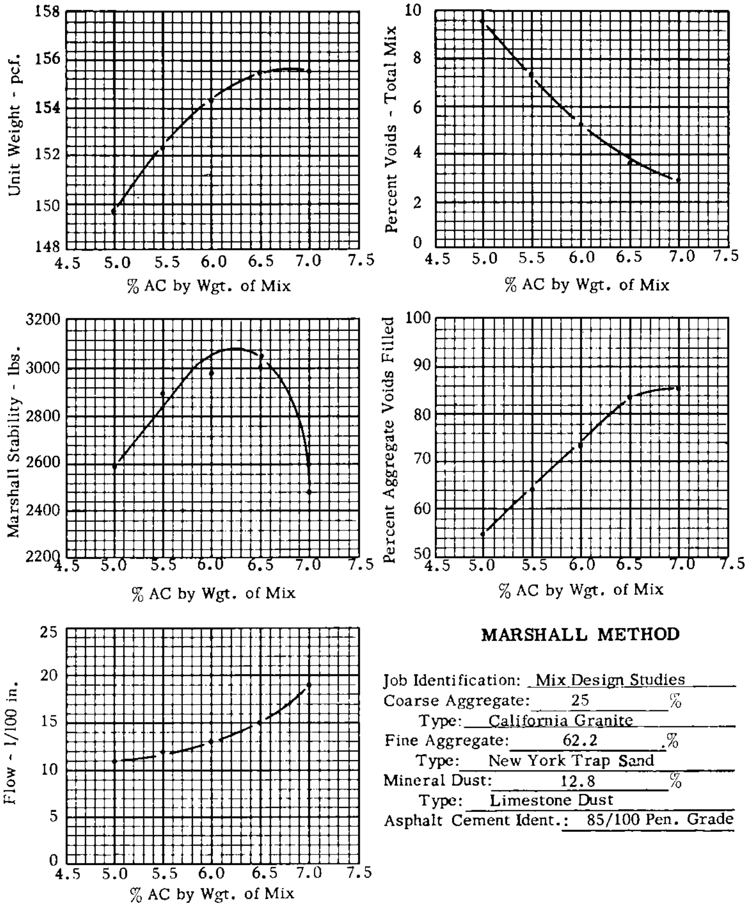
Figure 11.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: Washington Gravel
Fine Aggregate: 20.7 %
Type: New York Trap Rock
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

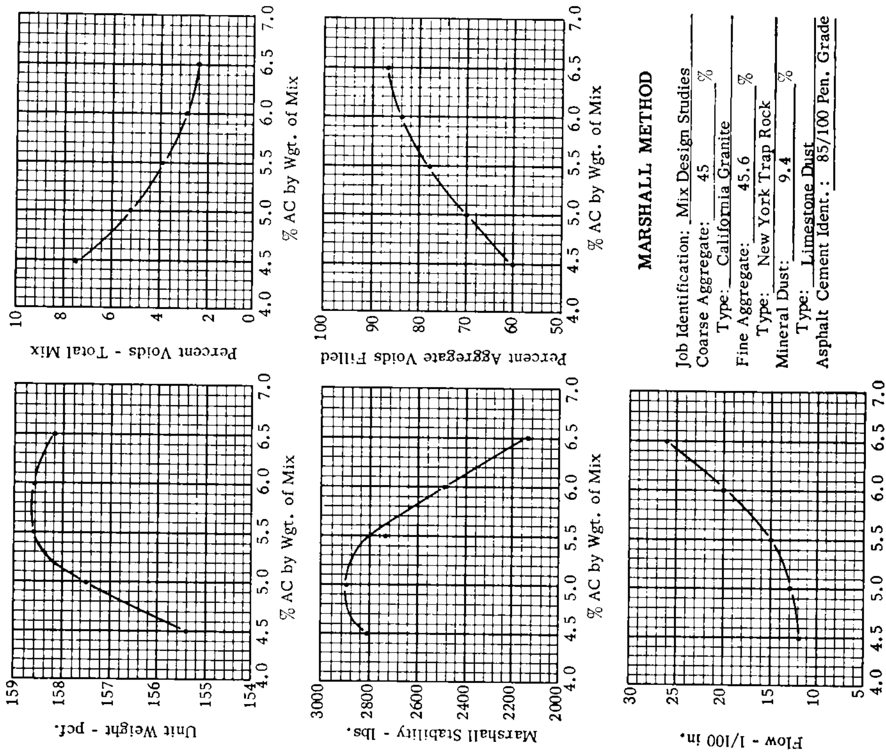
Figure 12.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: California Granite
Fine Aggregate: 62.2 %
Type: New York Trap Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

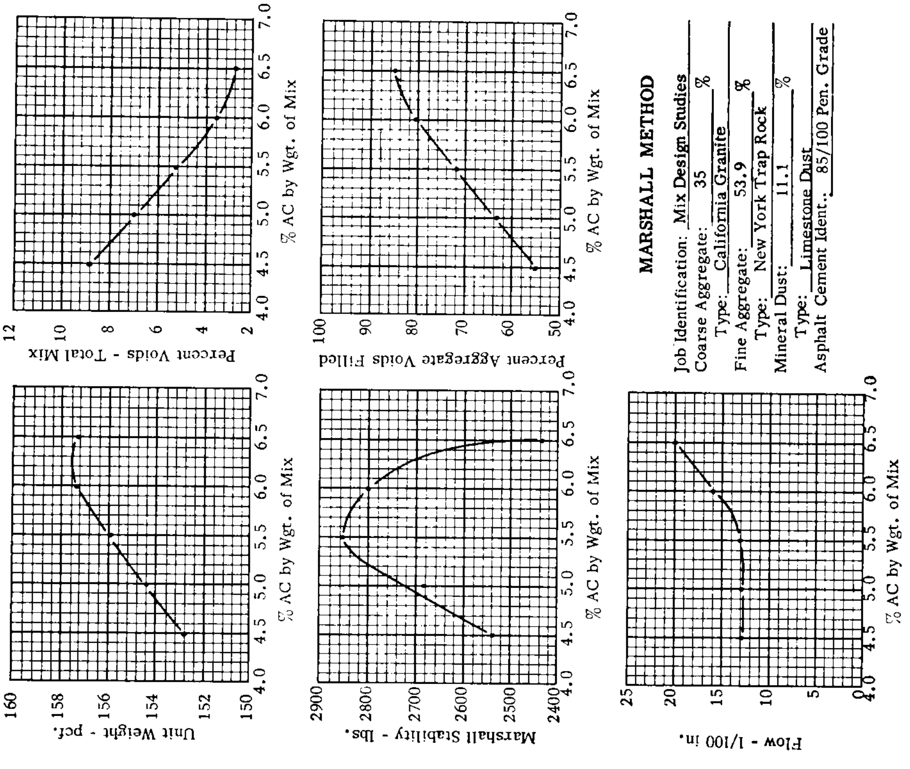
Figure 13.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: California Granite
Fine Aggregate: 45.6 %
Type: New York Trap Rock
Mineral Dust: 9.4 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

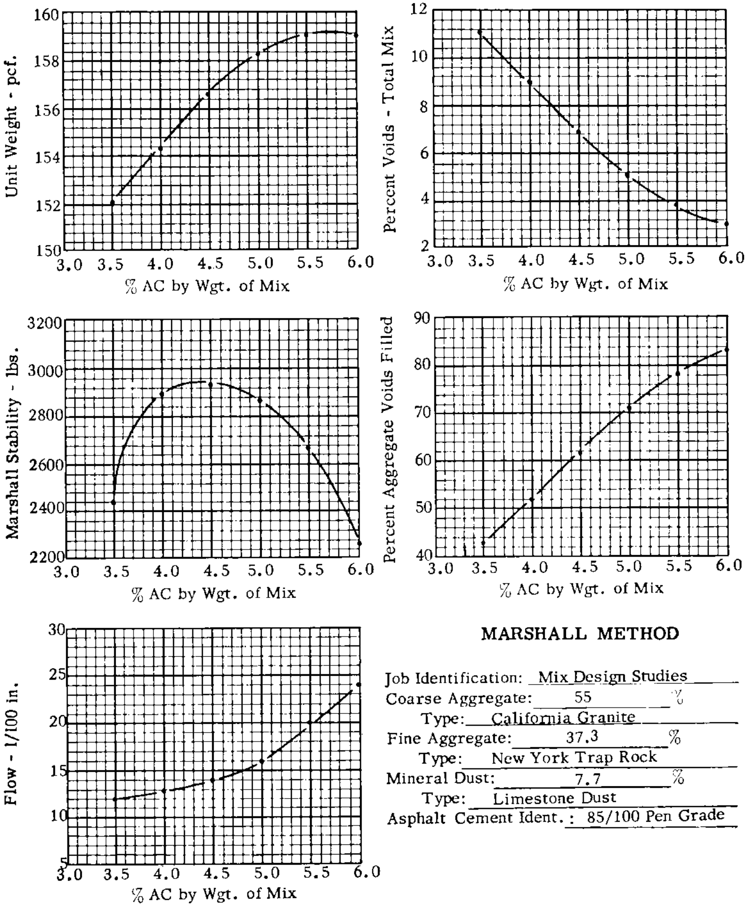
Figure 15.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: California Granite
Fine Aggregate: 53.9 %
Type: New York Trap Rock
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

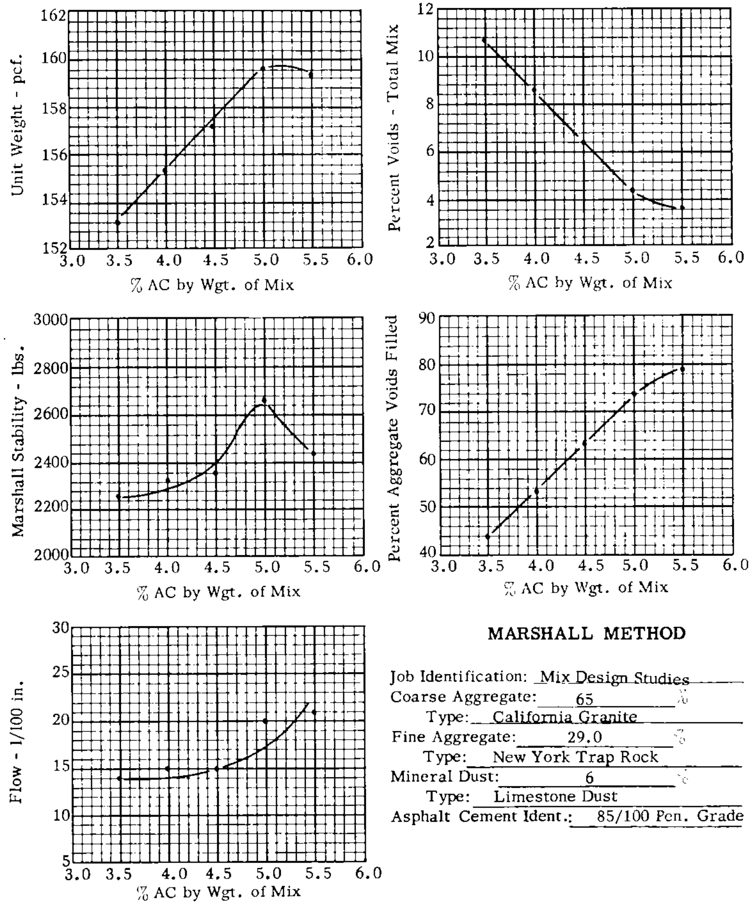
Figure 14.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: California Granite
Fine Aggregate: 37.3 %
Type: New York Trap Rock
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident. : 85/100 Pen Grade

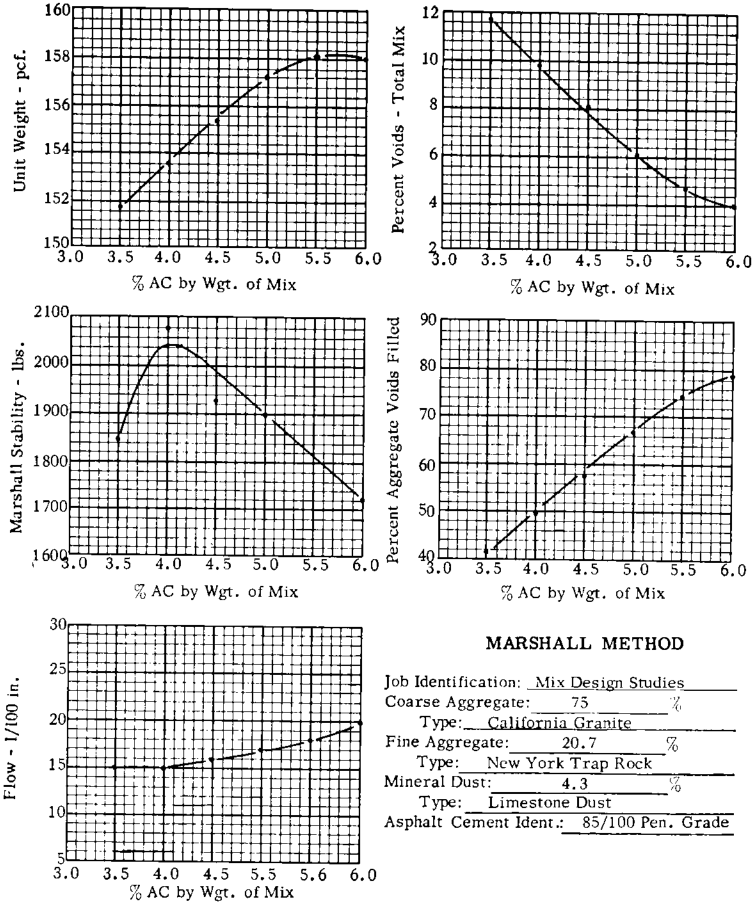
Figure 16.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: California Granite
Fine Aggregate: 29.0 %
Type: New York Trap Rock
Mineral Dust: 6 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

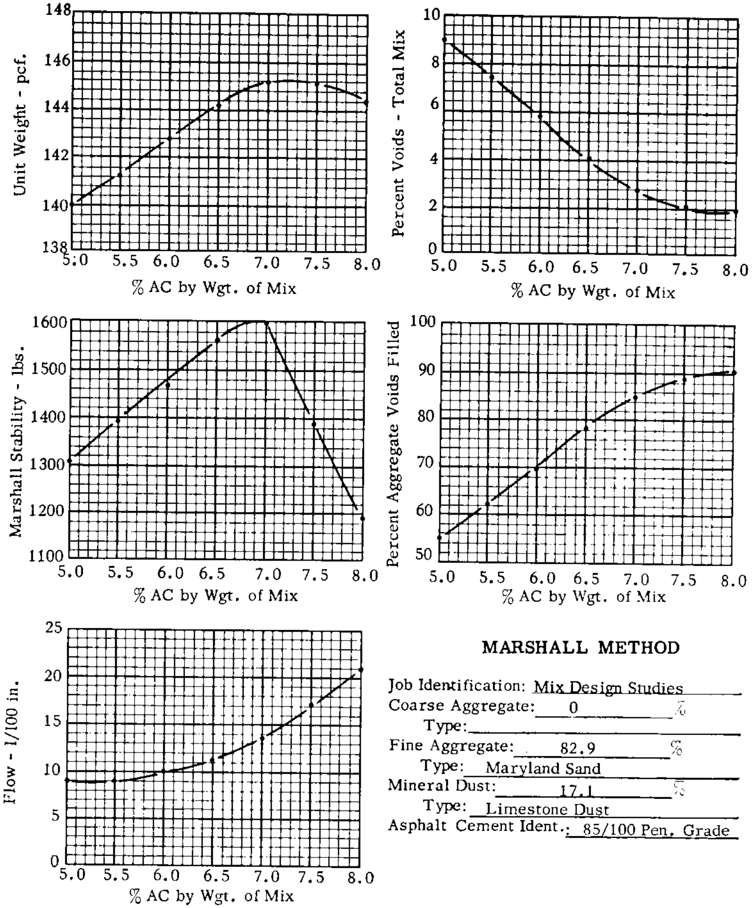
Figure 17.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: California Granite
Fine Aggregate: 20.7 %
Type: New York Trap Rock
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

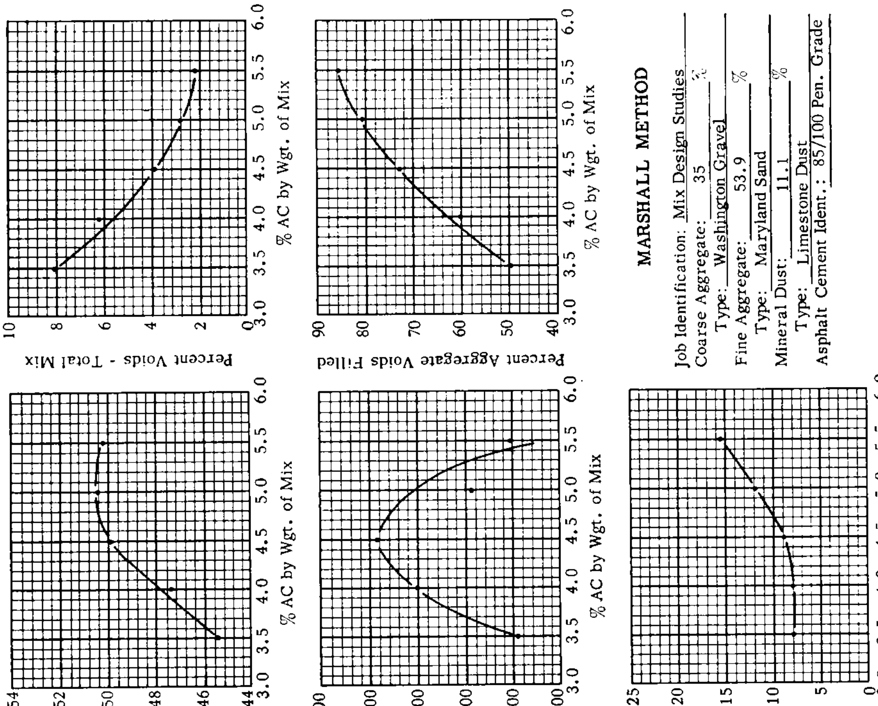
Figure 18.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 0 %
Type:
Fine Aggregate: 82.9 %
Type: Maryland Sand
Mineral Dust: 17.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

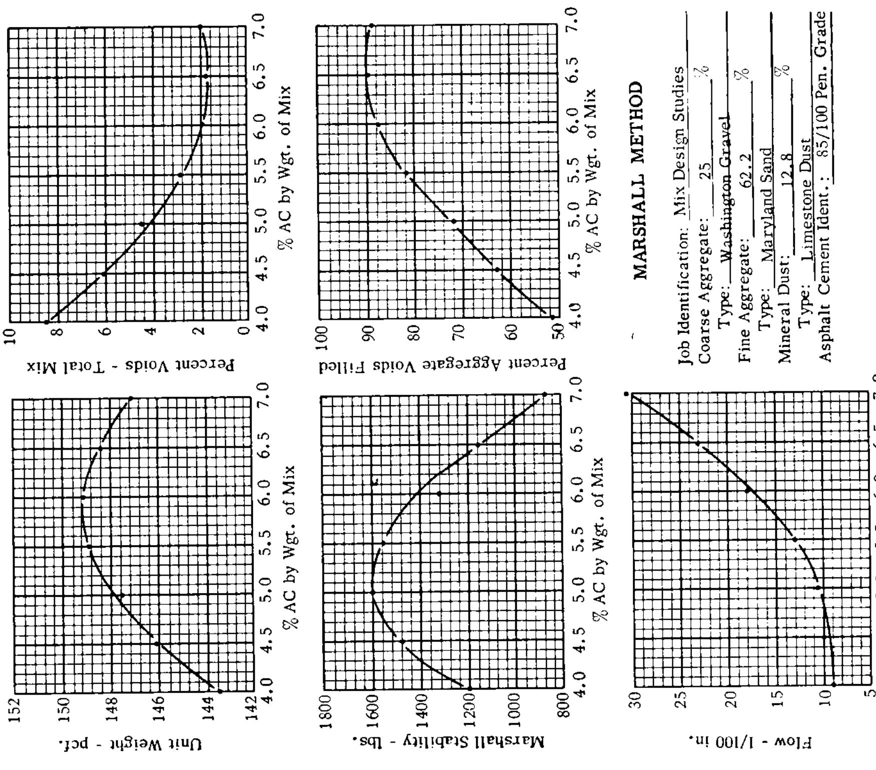
Figure 19.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: Washington Gravel
Fine Aggregate: 53.9 %
Type: Maryland Sand
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

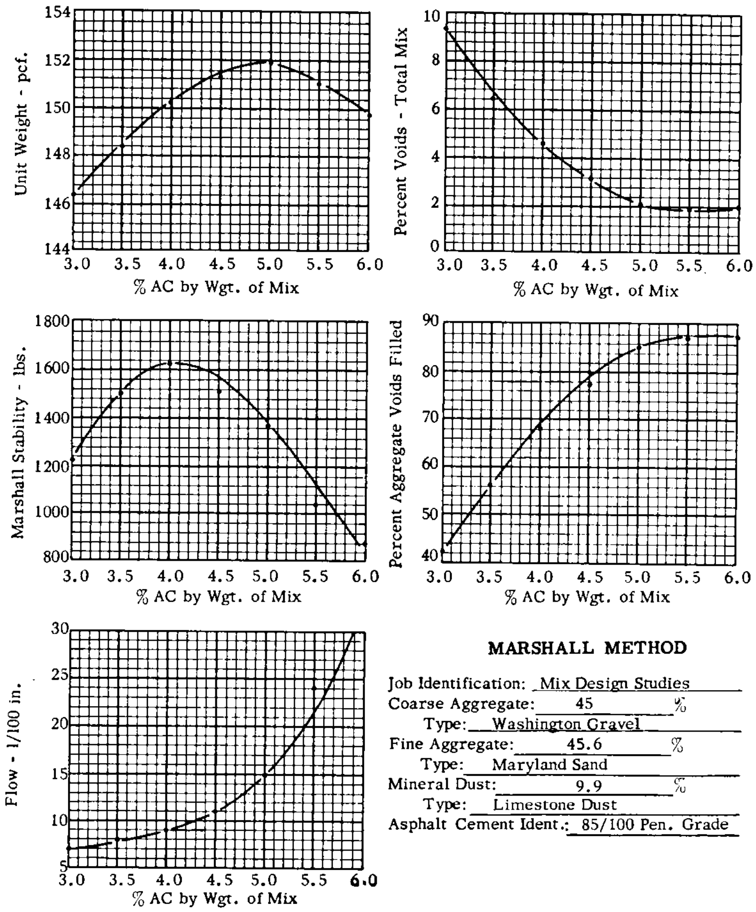
Figure 21.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: Washington Gravel
Fine Aggregate: 62.2 %
Type: Maryland Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

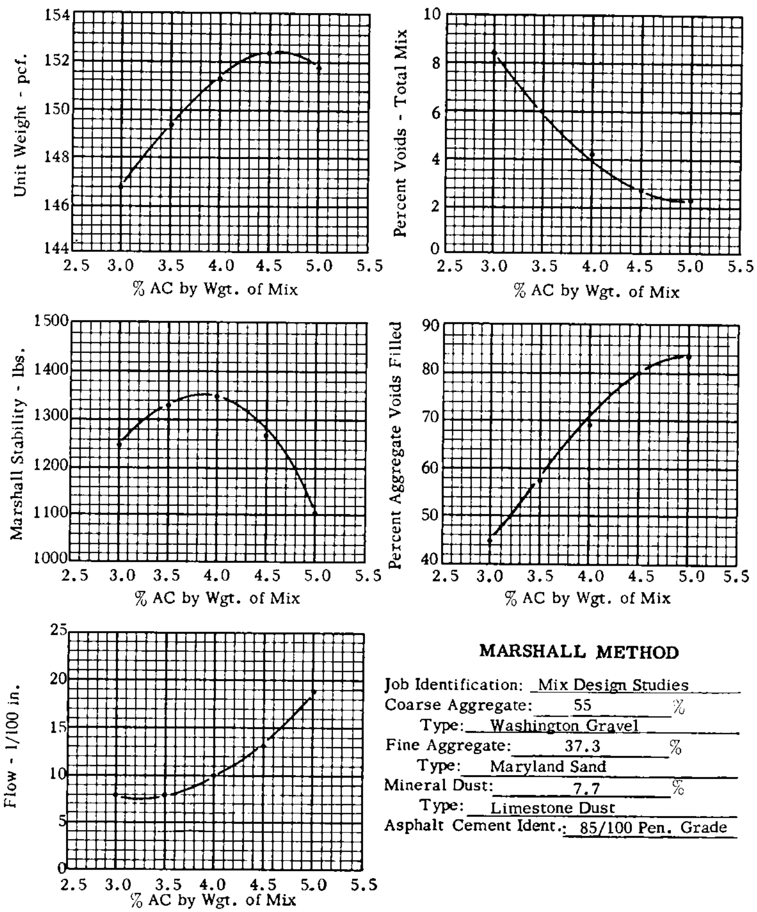
Figure 20.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: Washington Gravel
Fine Aggregate: 45.6 %
Type: Maryland Sand
Mineral Dust: 9.9 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

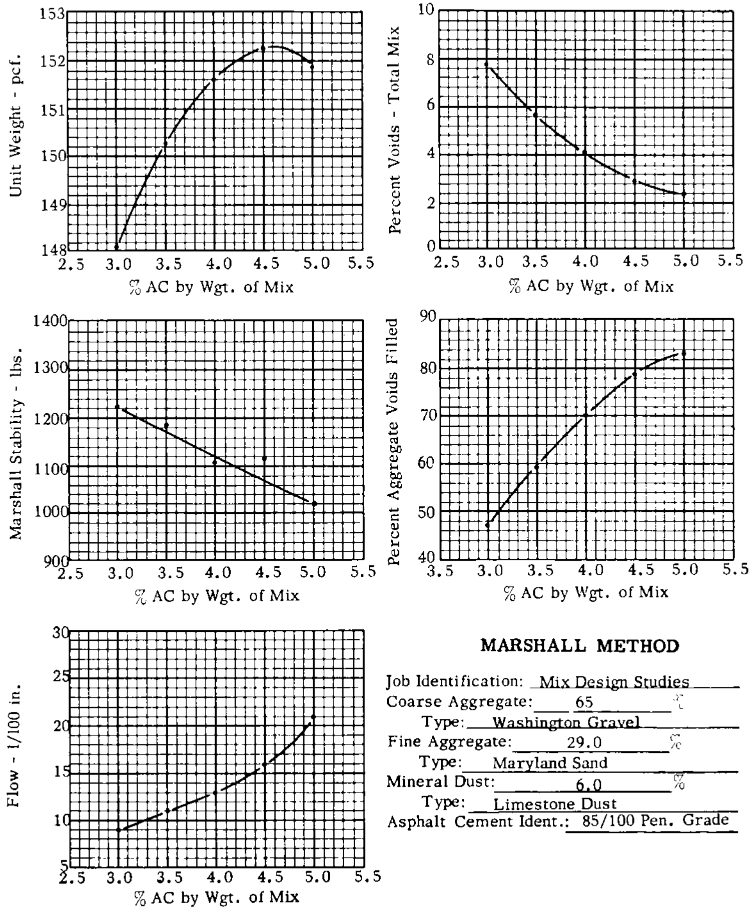
Figure 22.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: Washington Gravel
Fine Aggregate: 37.3 %
Type: Maryland Sand
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

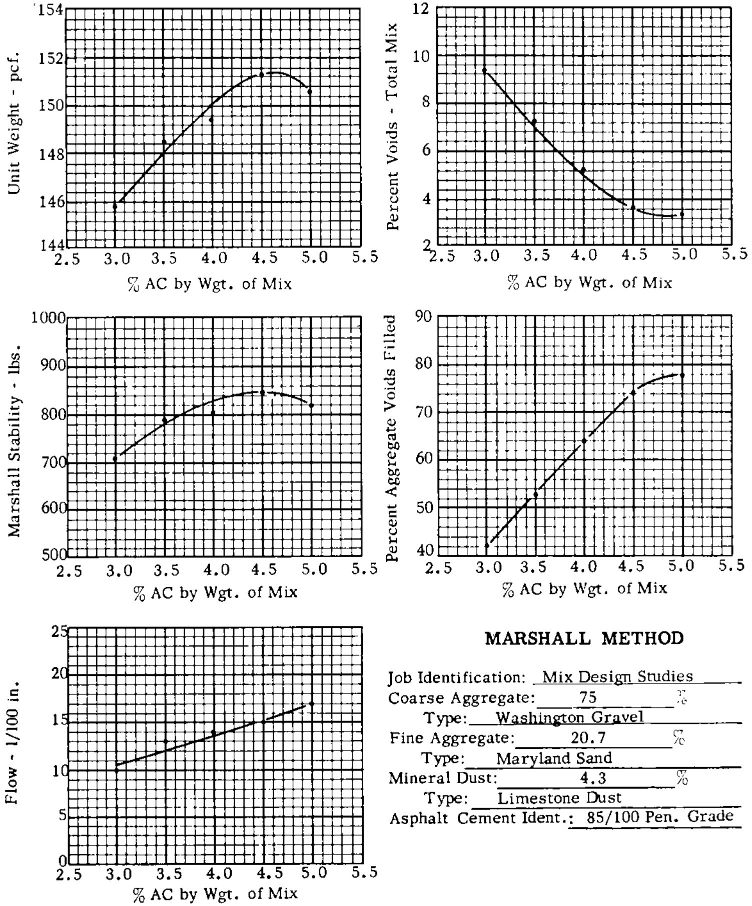
Figure 23.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: Washington Gravel
Fine Aggregate: 29.0 %
Type: Maryland Sand
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

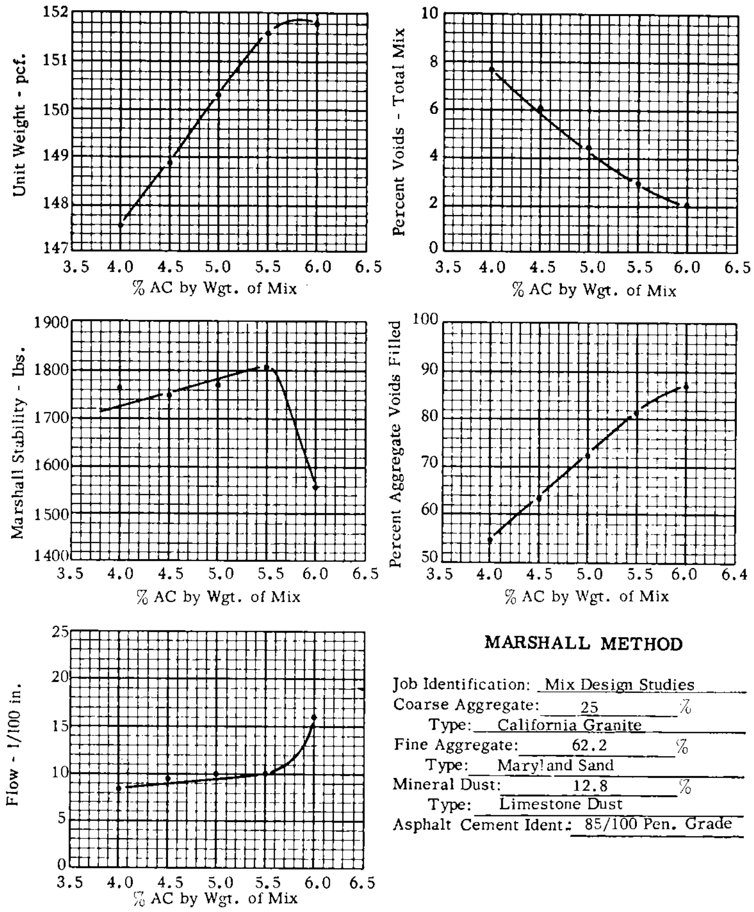
Figure 24.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: Washington Gravel
Fine Aggregate: 20.7 %
Type: Maryland Sand
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

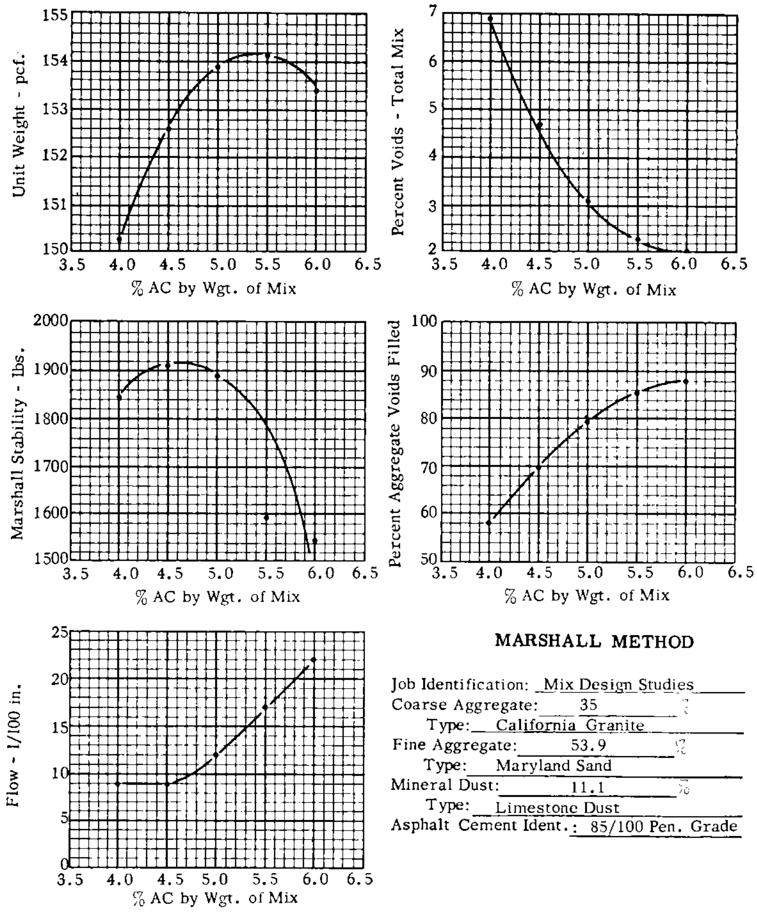
Figure 25.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: California Granite
Fine Aggregate: 62.2 %
Type: Maryland Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

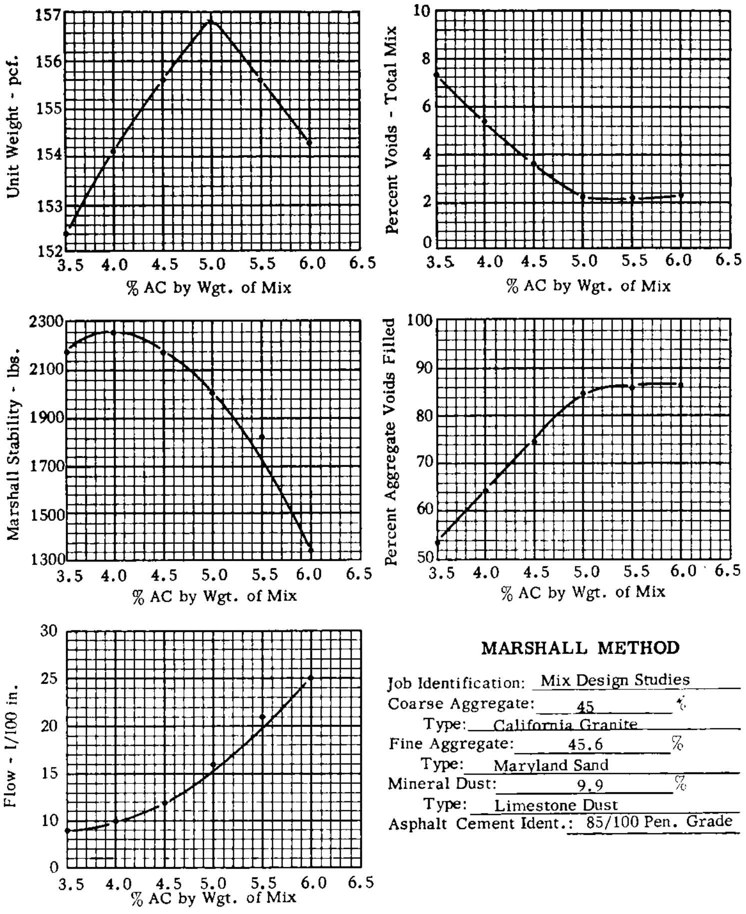
Figure 26.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: California Granite
Fine Aggregate: 53.9 %
Type: Maryland Sand
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

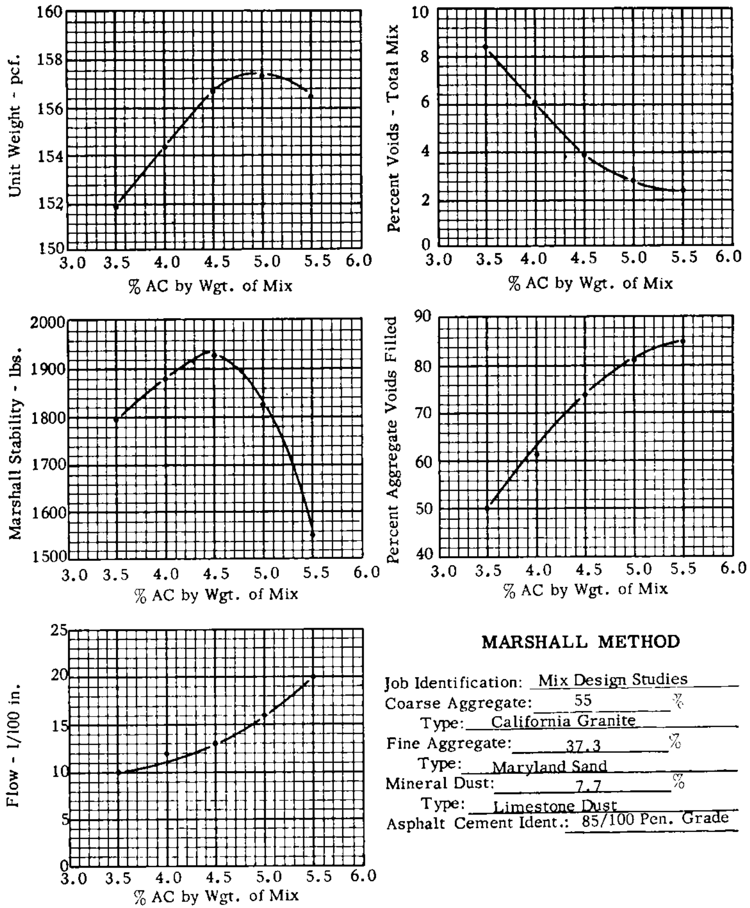
Figure 27.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: California Granite
Fine Aggregate: 45.6 %
Type: Maryland Sand
Mineral Dust: 9.9 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

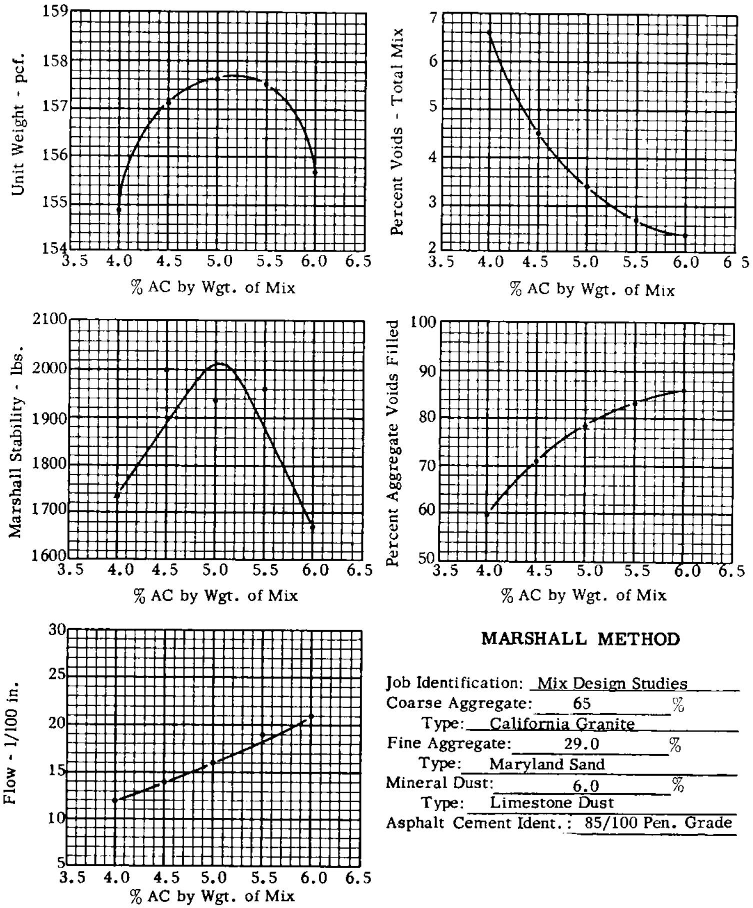
Figure 28.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: California Granite
Fine Aggregate: 37.3 %
Type: Maryland Sand
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

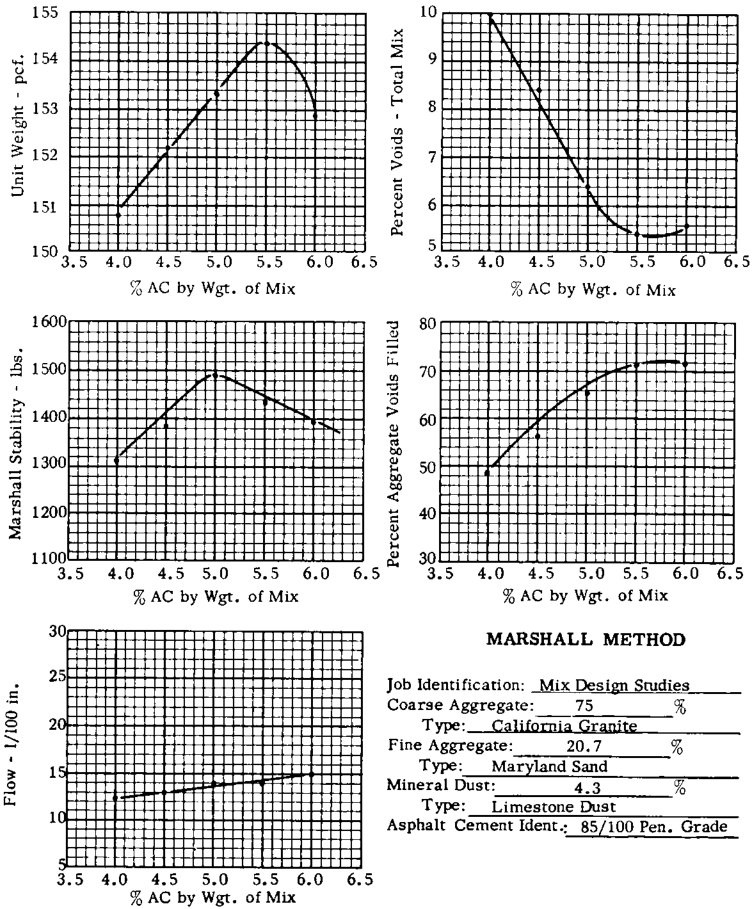
Figure 29.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: California Granite
Fine Aggregate: 29.0 %
Type: Maryland Sand
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

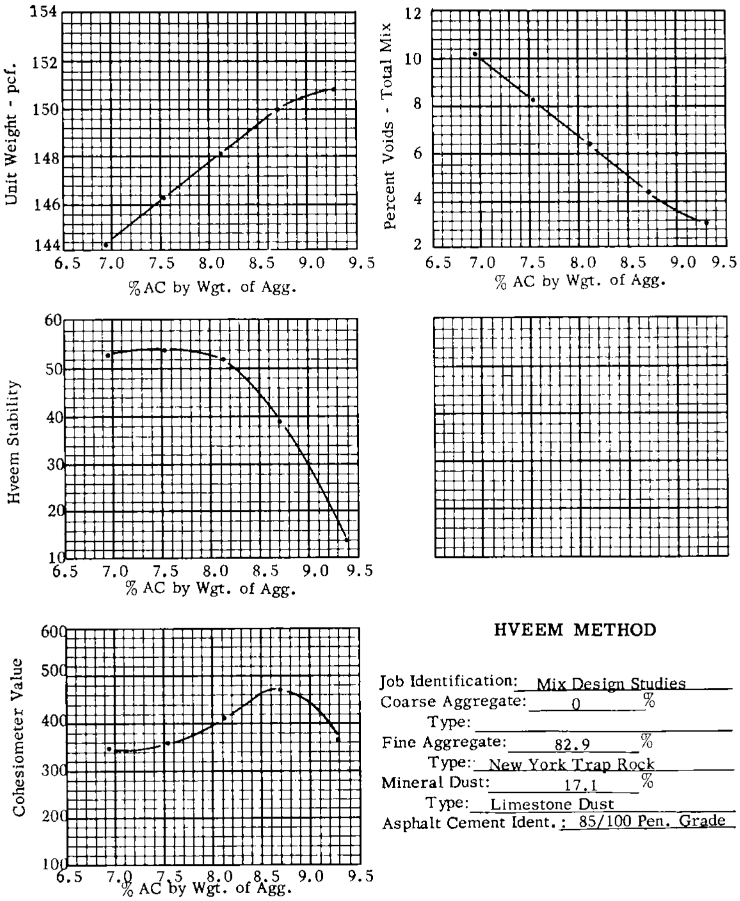
Figure 30.



MARSHALL METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: California Granite
Fine Aggregate: 20.7 %
Type: Maryland Sand
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

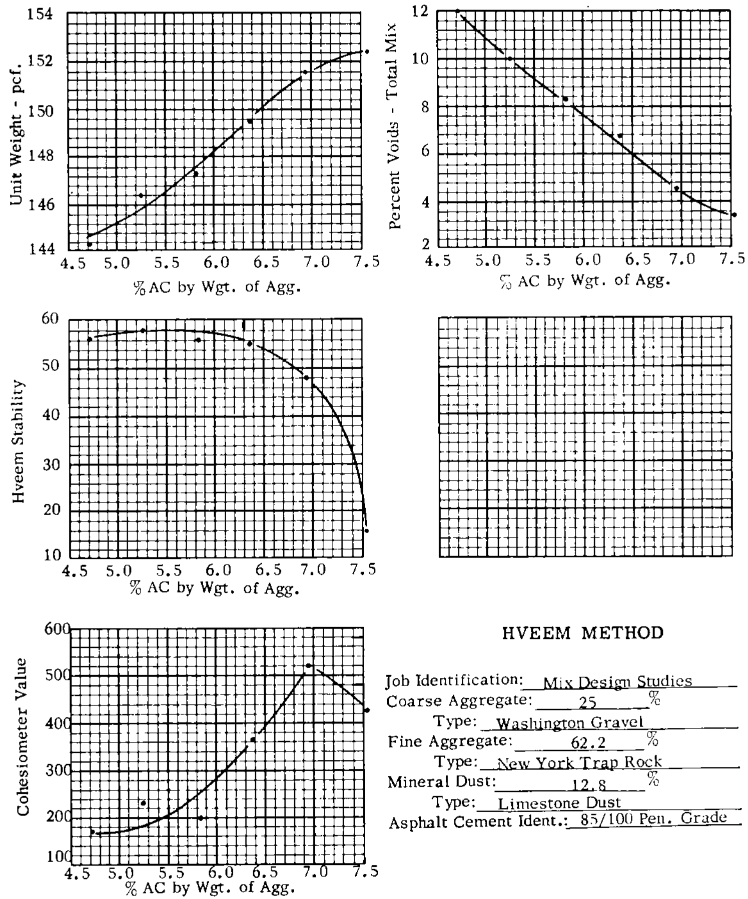
Figure 31.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 0 %
Type:
Fine Aggregate: 82.9 %
Type: New York Trap Rock
Mineral Dust: 17.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

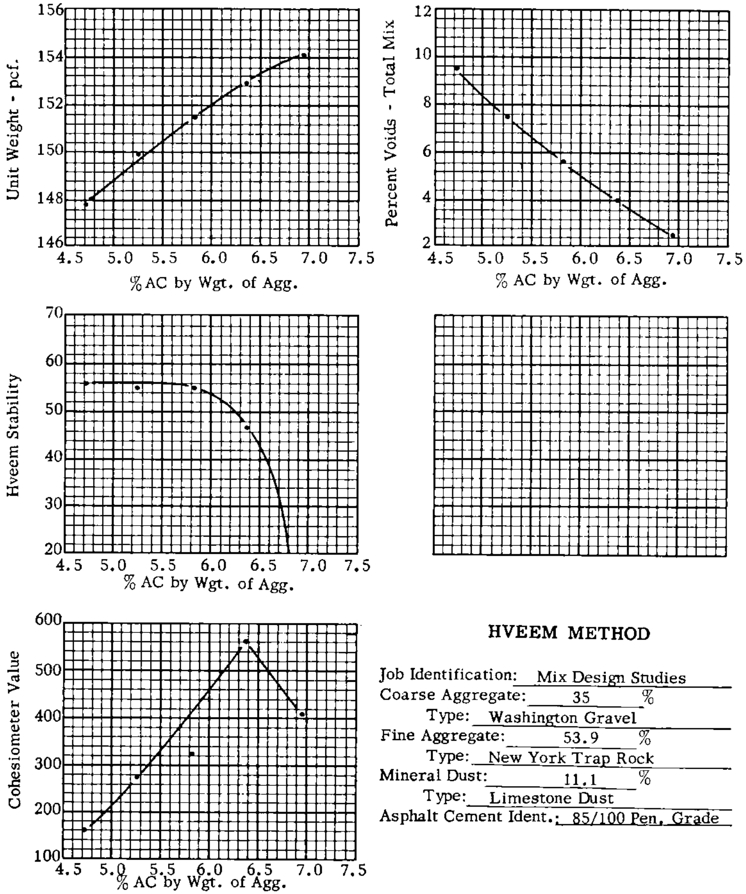
Figure 32.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: Washington Gravel
Fine Aggregate: 62.2 %
Type: New York Trap Rock
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

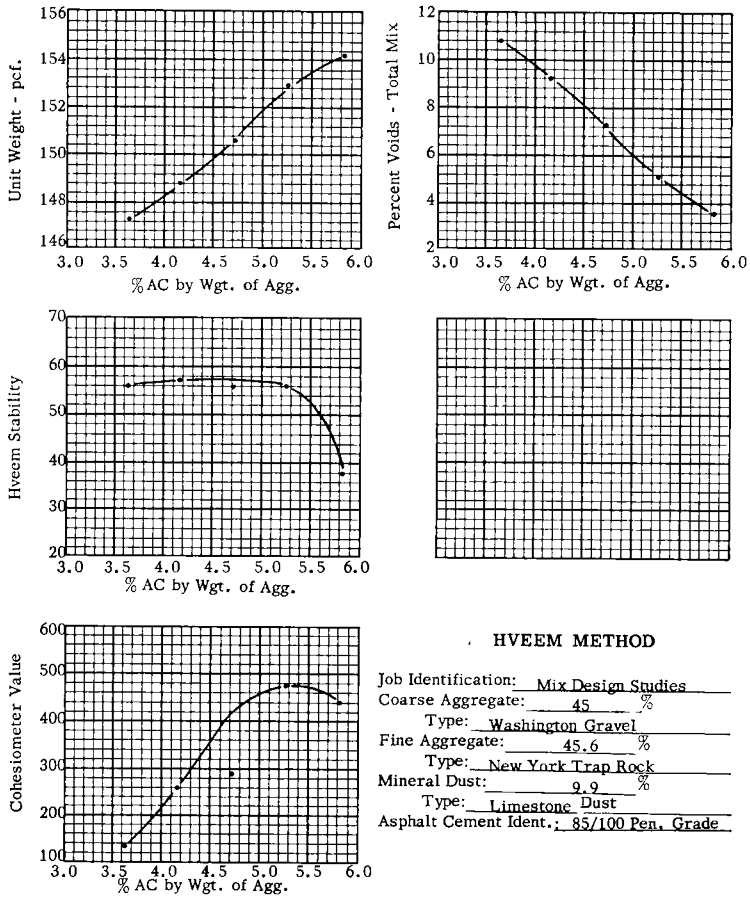
Figure 33.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: Washington Gravel
Fine Aggregate: 53.9 %
Type: New York Trap Rock
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

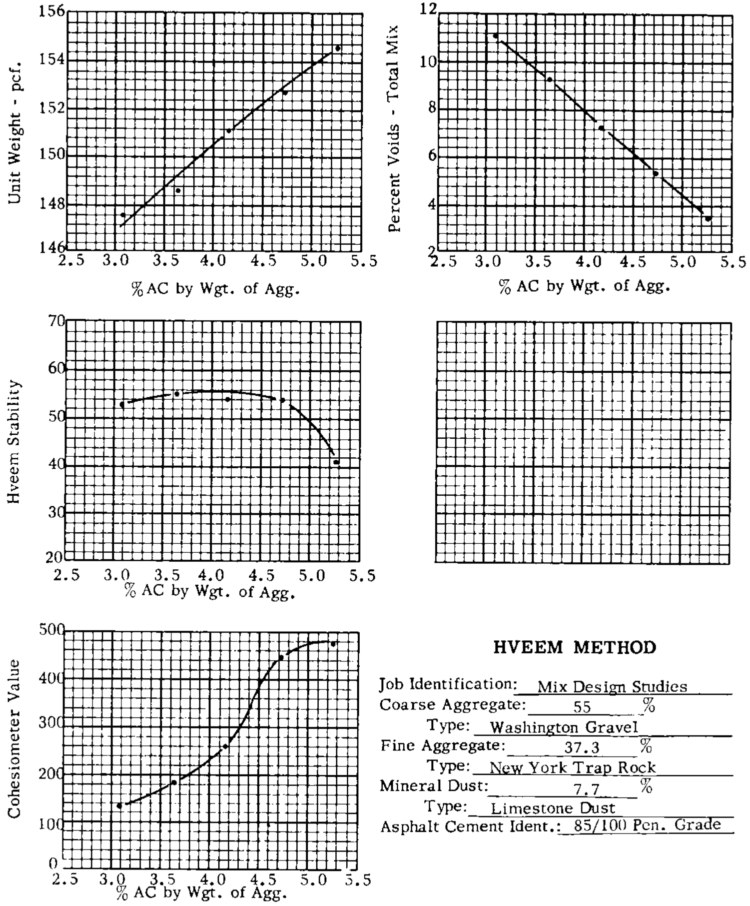
Figure 34.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: Washington Gravel
Fine Aggregate: 45.6 %
Type: New York Trap Rock
Mineral Dust: 9.9 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

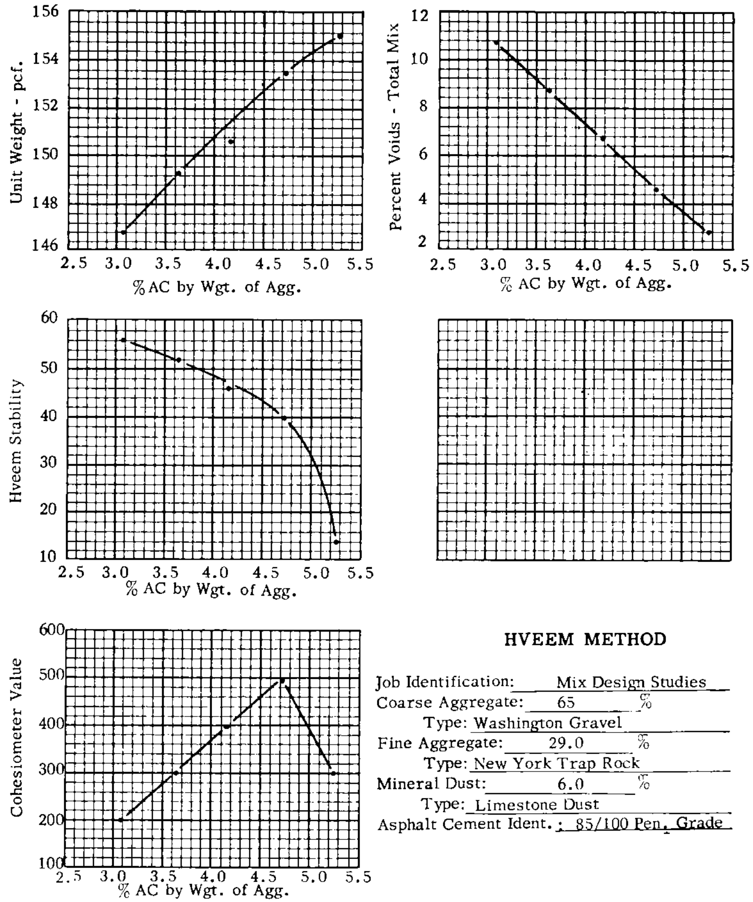
Figure 35.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: Washington Gravel
Fine Aggregate: 37.3 %
Type: New York Trap Rock
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

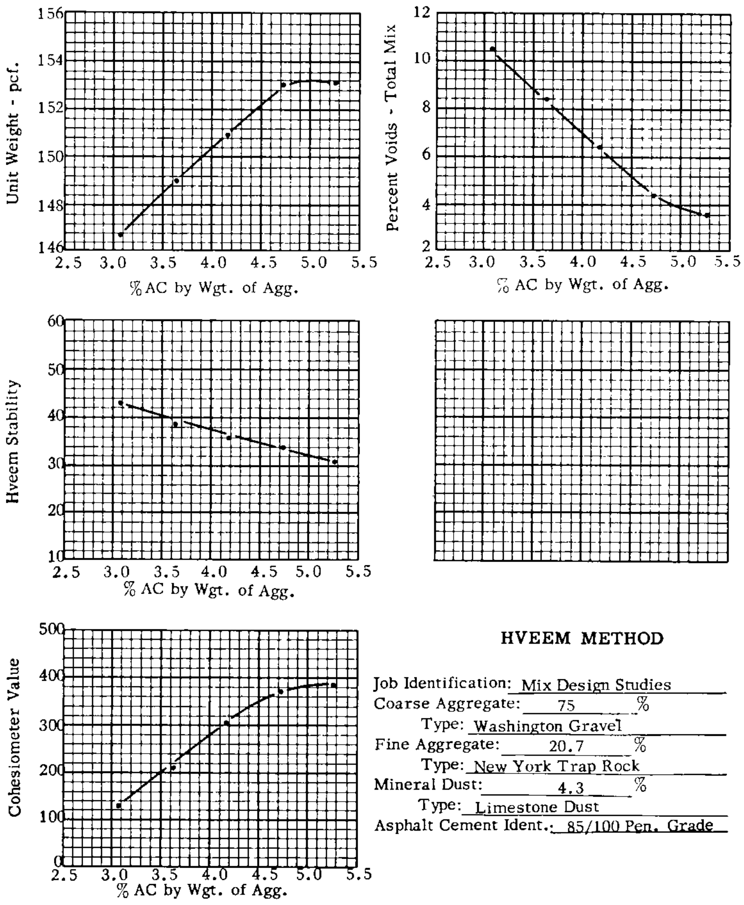
Figure 36.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: Washington Gravel
Fine Aggregate: 29.0 %
Type: New York Trap Rock
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident. : 85/100 Pen. Grade

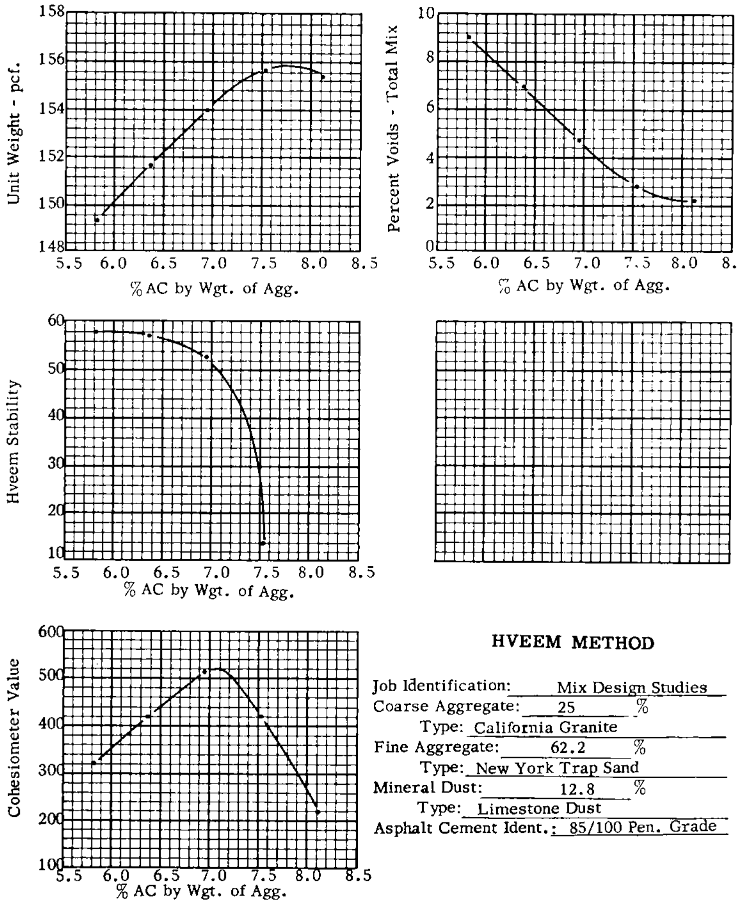
Figure 37.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: Washington Gravel
Fine Aggregate: 20.7 %
Type: New York Trap Rock
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

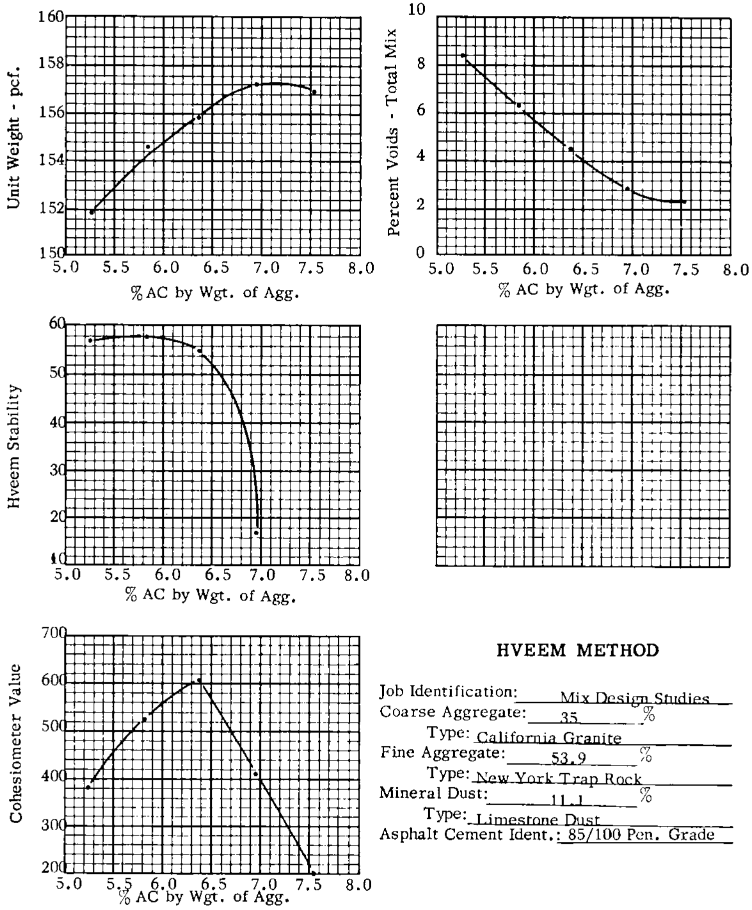
Figure 38.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: California Granite
Fine Aggregate: 62.2 %
Type: New York Trap Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

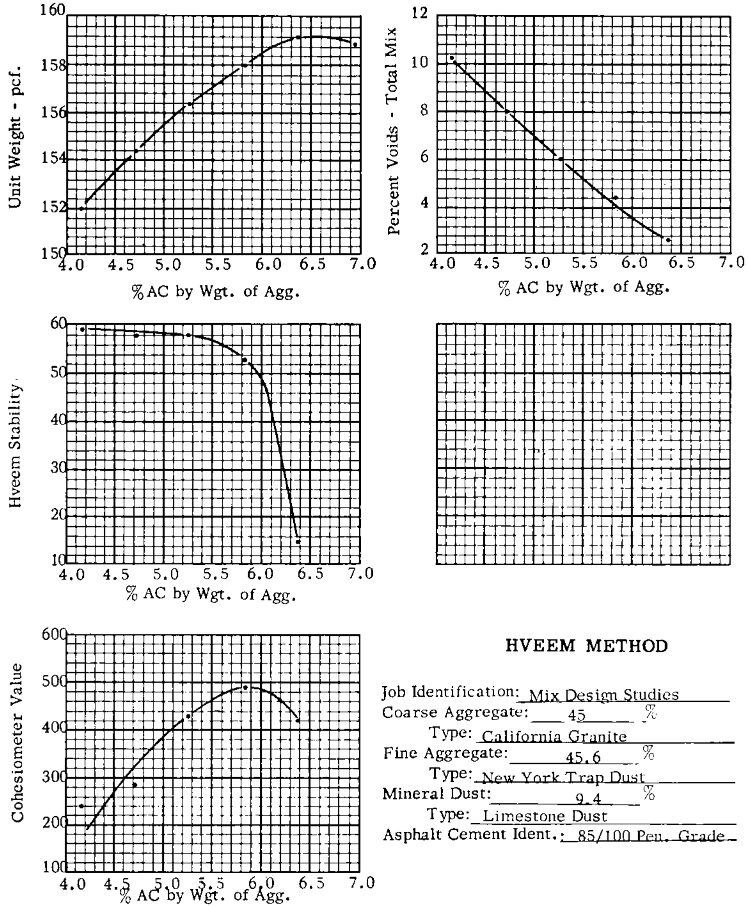
Figure 39.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: California Granite
Fine Aggregate: 53.9 %
Type: New York Trap Rock
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

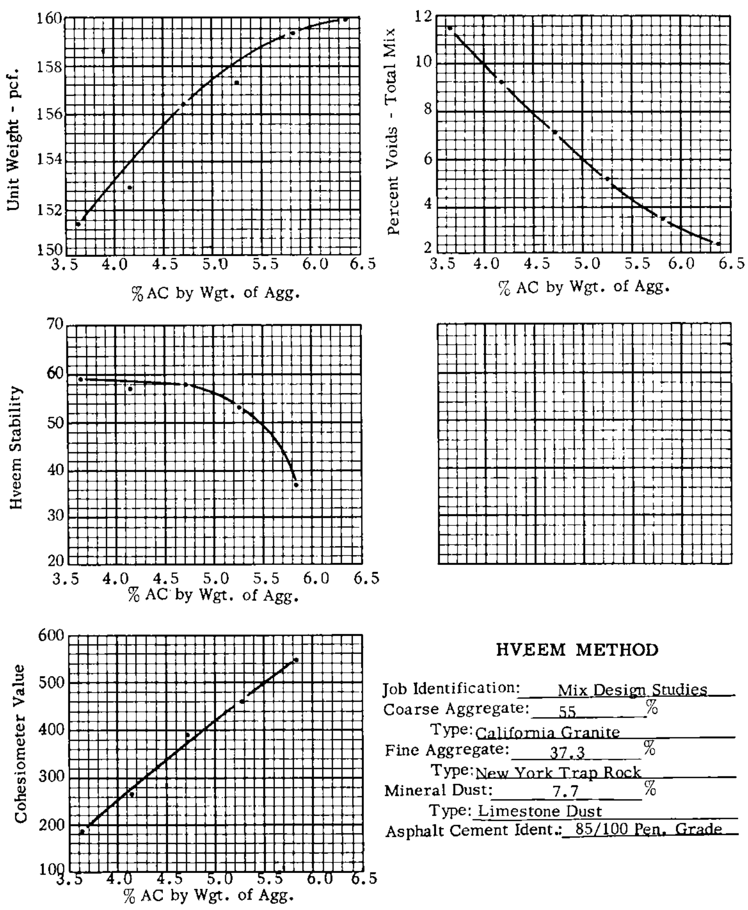
Figure 40.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: California Granite
Fine Aggregate: 45.6 %
Type: New York Trap Dust
Mineral Dust: 9.4 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

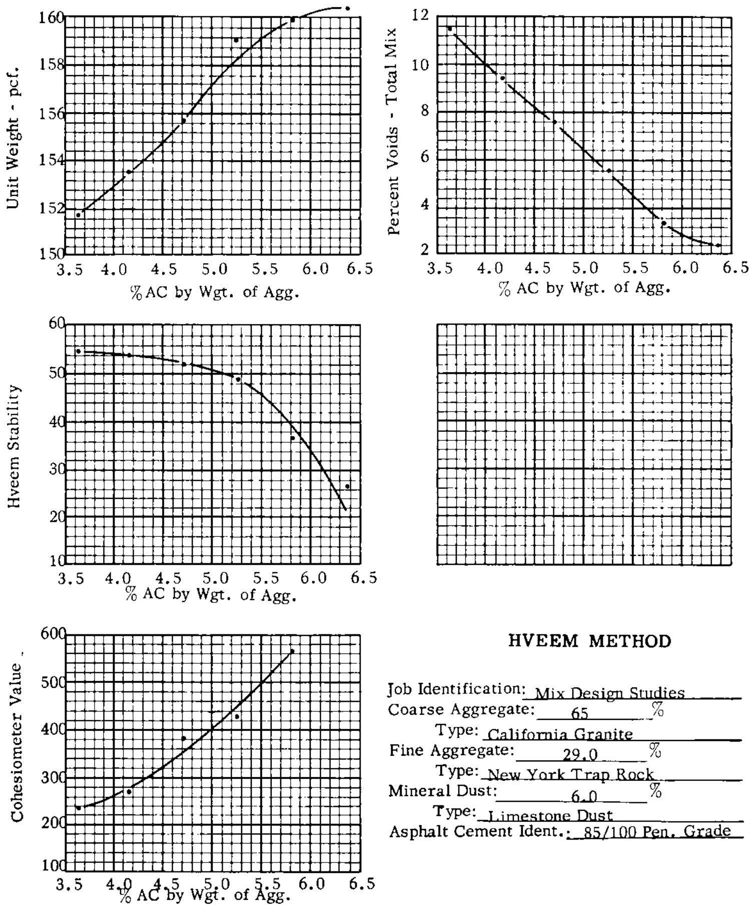
Figure 41.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: California Granite
Fine Aggregate: 37.3 %
Type: New York Trap Rock
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

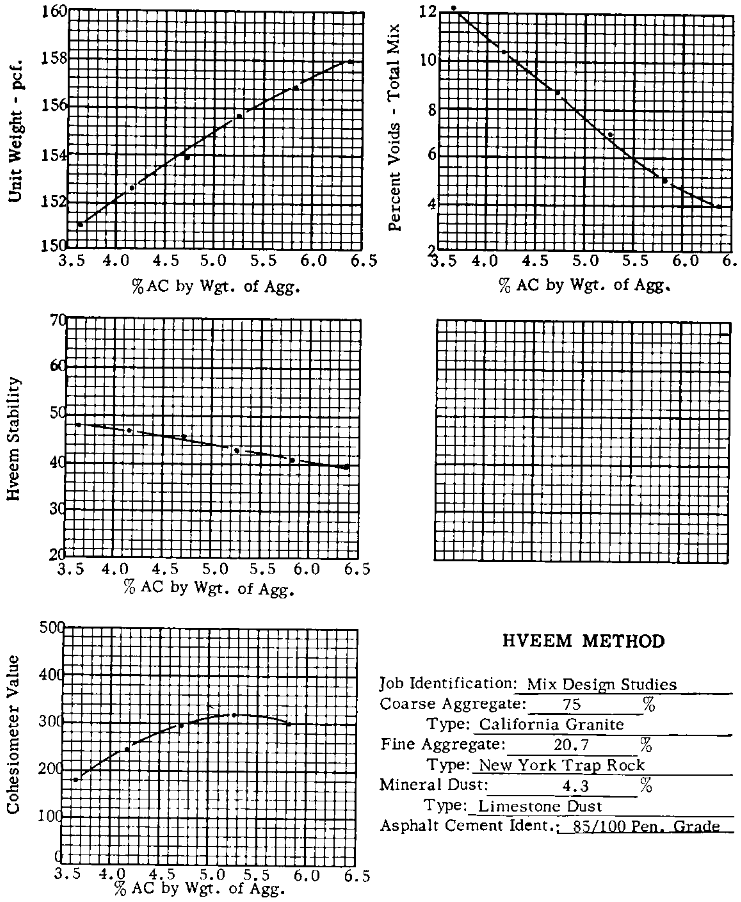
Figure 42.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: California Granite
Fine Aggregate: 29.0 %
Type: New York Trap Rock
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

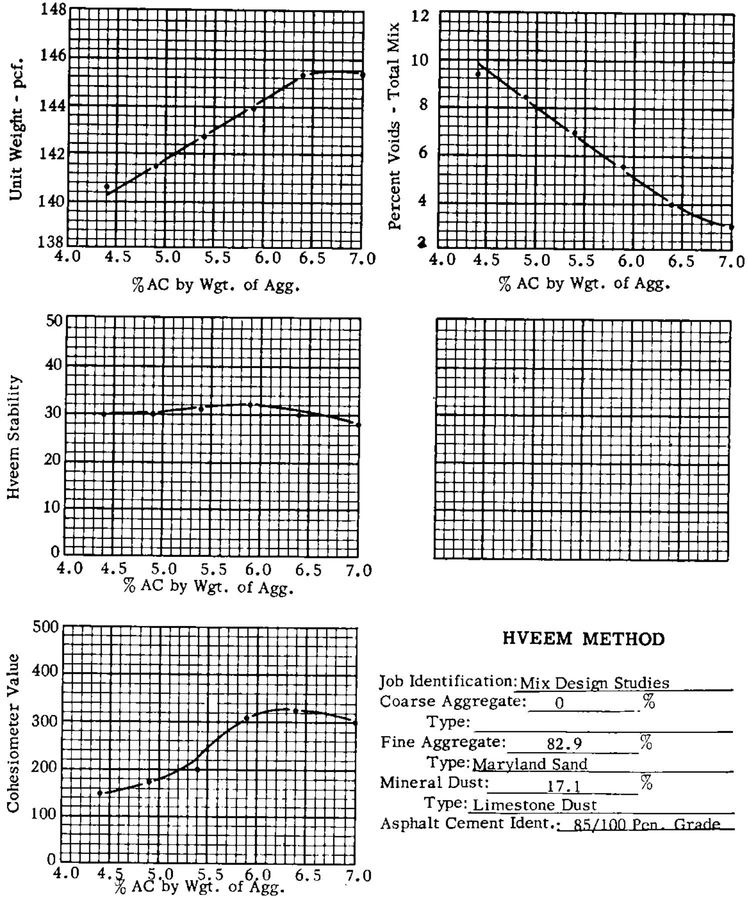
Figure 43.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: California Granite
Fine Aggregate: 20.7 %
Type: New York Trap Rock
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

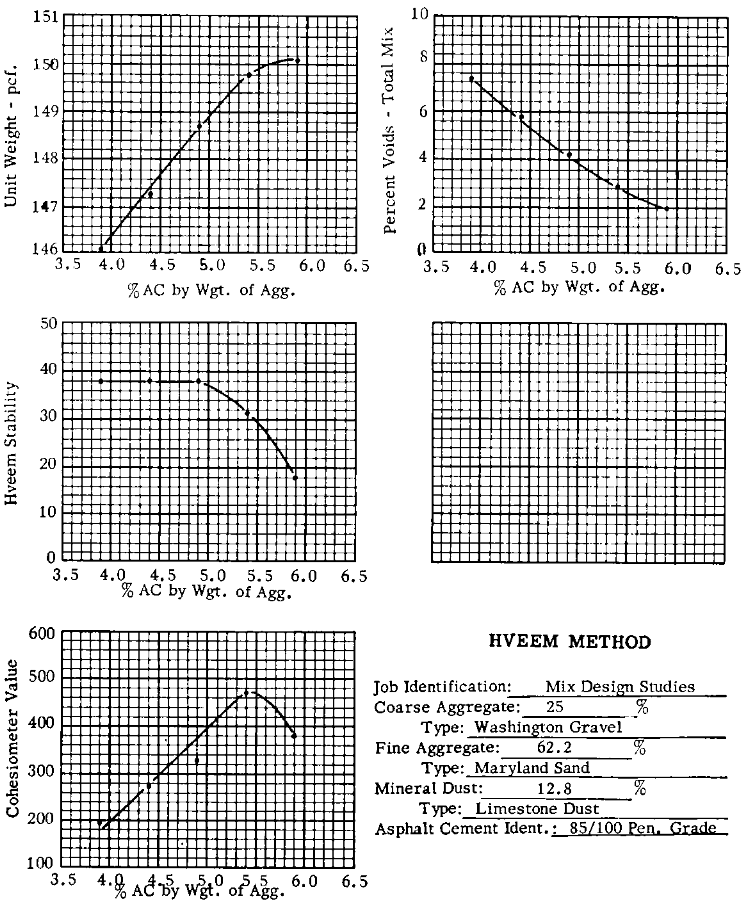
Figure 44.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 0 %
Type:
Fine Aggregate: 82.9 %
Type: Maryland Sand
Mineral Dust: 17.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

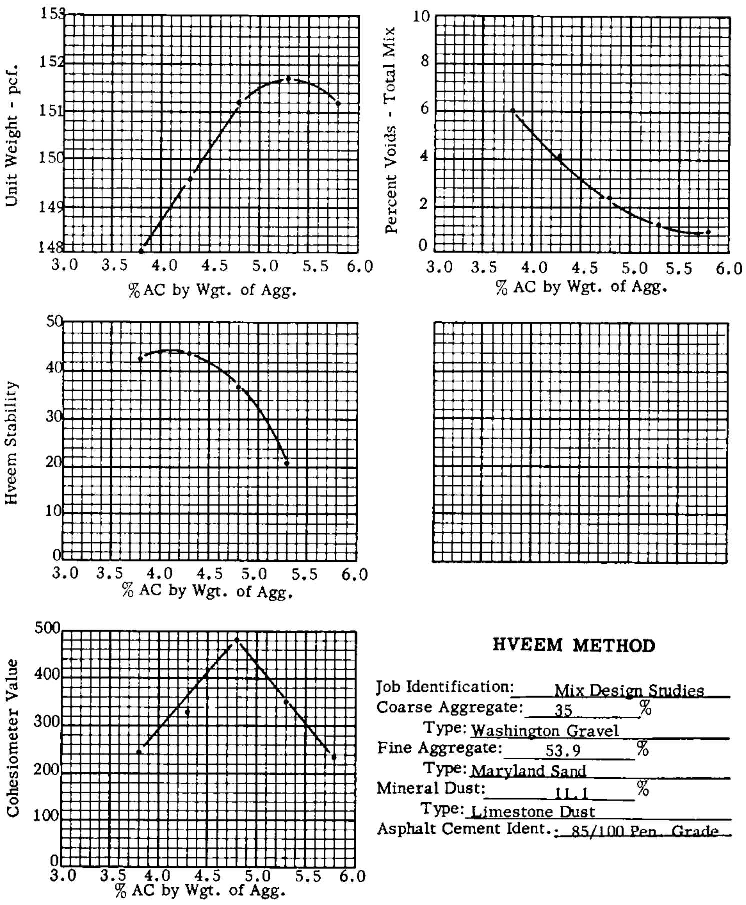
Figure 45.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: Washington Gravel
Fine Aggregate: 62.2 %
Type: Maryland Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

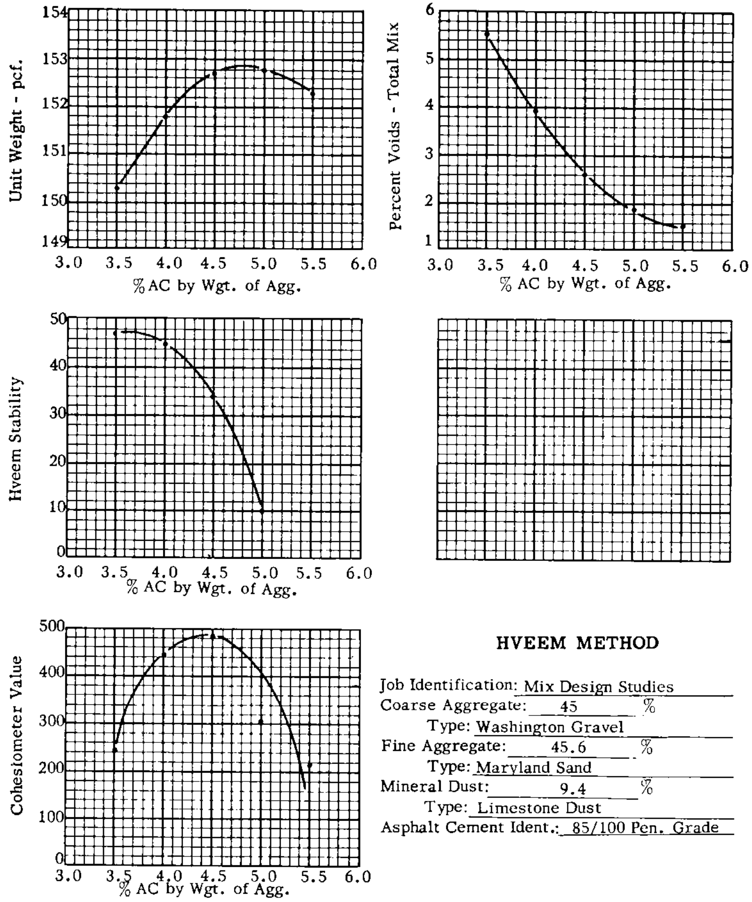
Figure 46.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: Washington Gravel
Fine Aggregate: 53.9 %
Type: Maryland Sand
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

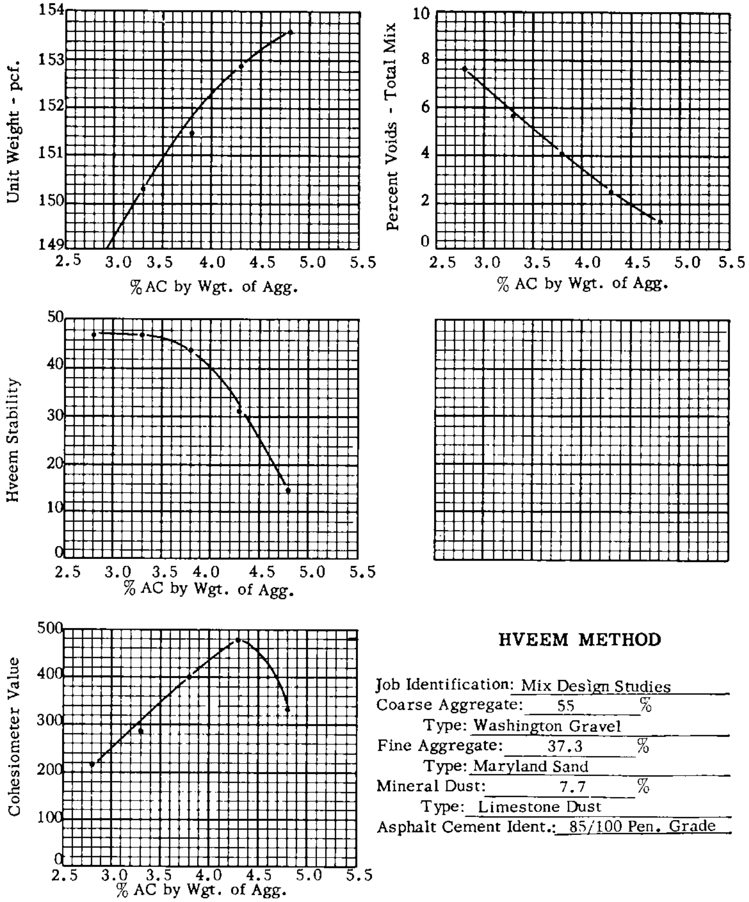
Figure 47.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: Washington Gravel
Fine Aggregate: 45.6 %
Type: Maryland Sand
Mineral Dust: 9.4 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

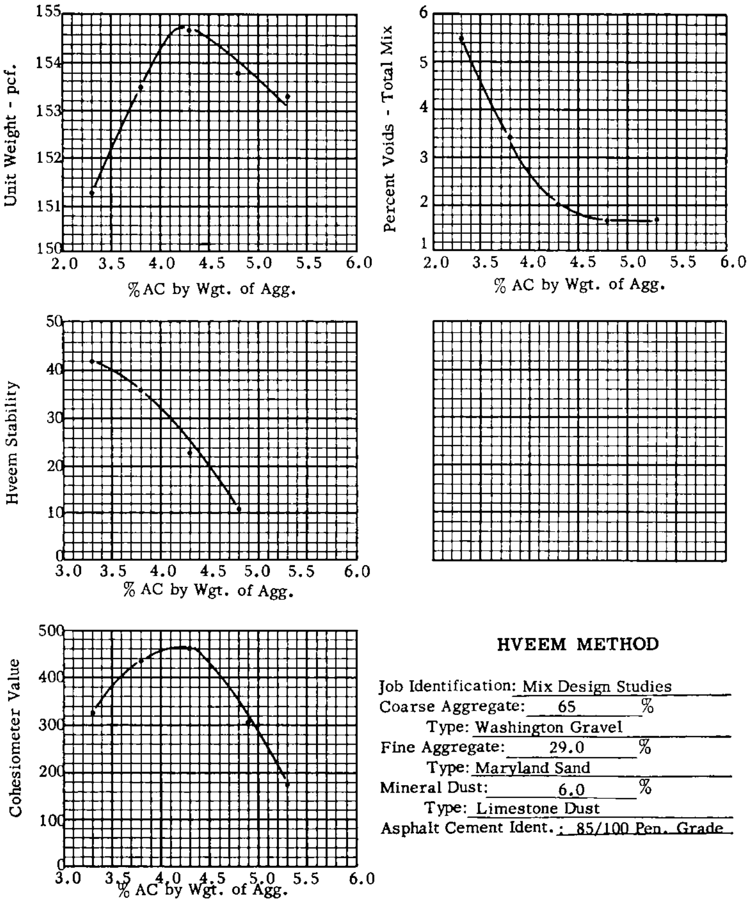
Figure 48.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: Washington Gravel
Fine Aggregate: 37.3 %
Type: Maryland Sand
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

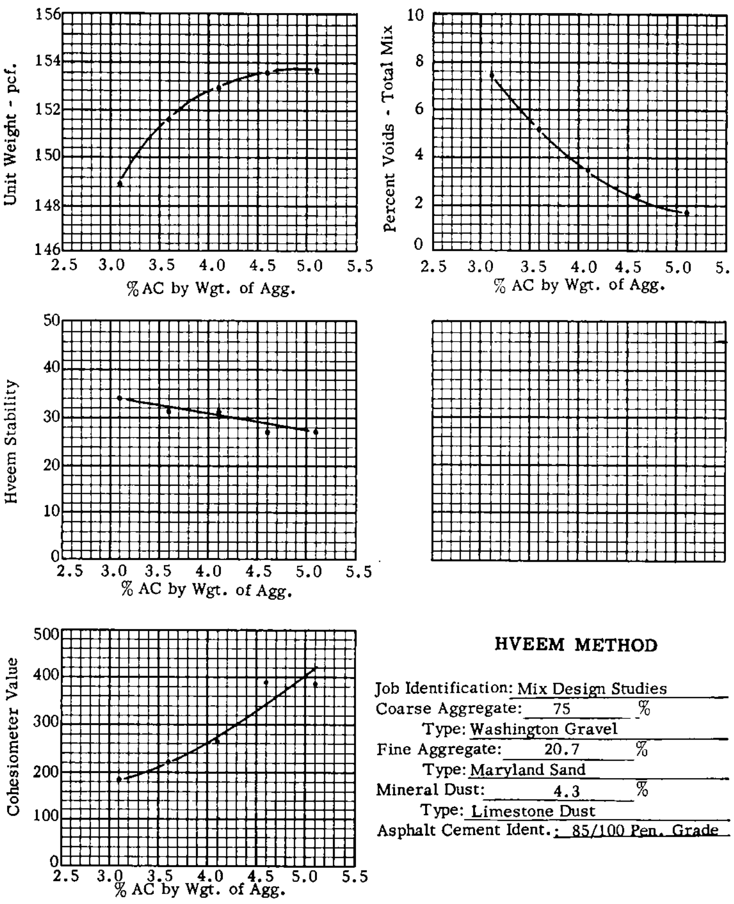
Figure 49.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: Washington Gravel
Fine Aggregate: 29.0 %
Type: Maryland Sand
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

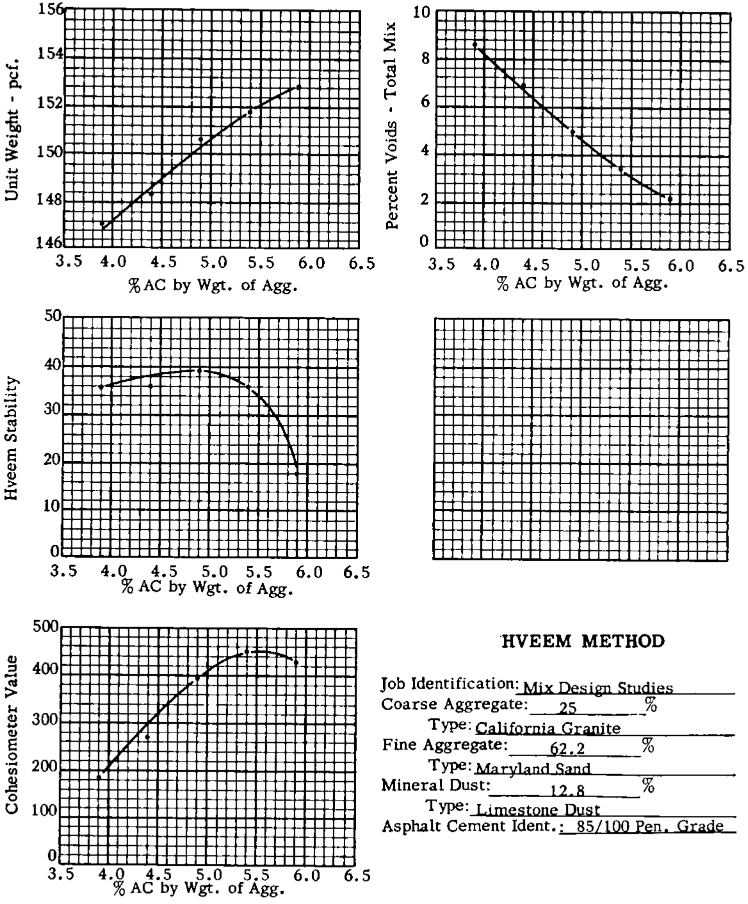
Figure 50.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: Washington Gravel
Fine Aggregate: 20.7 %
Type: Maryland Sand
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

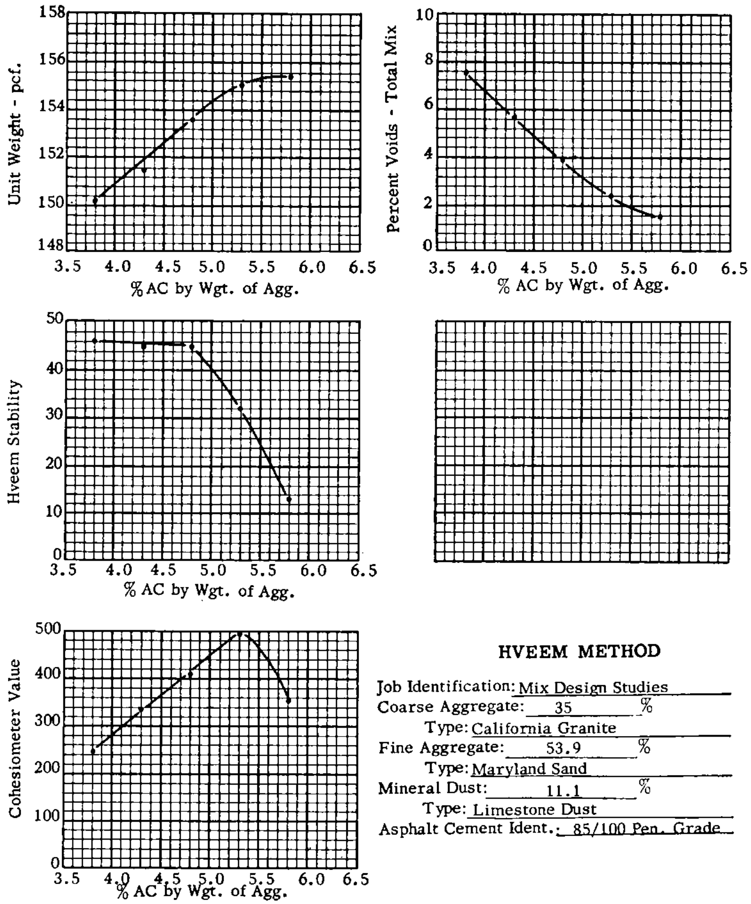
Figure 51.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 25 %
Type: California Granite
Fine Aggregate: 62.2 %
Type: Maryland Sand
Mineral Dust: 12.8 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

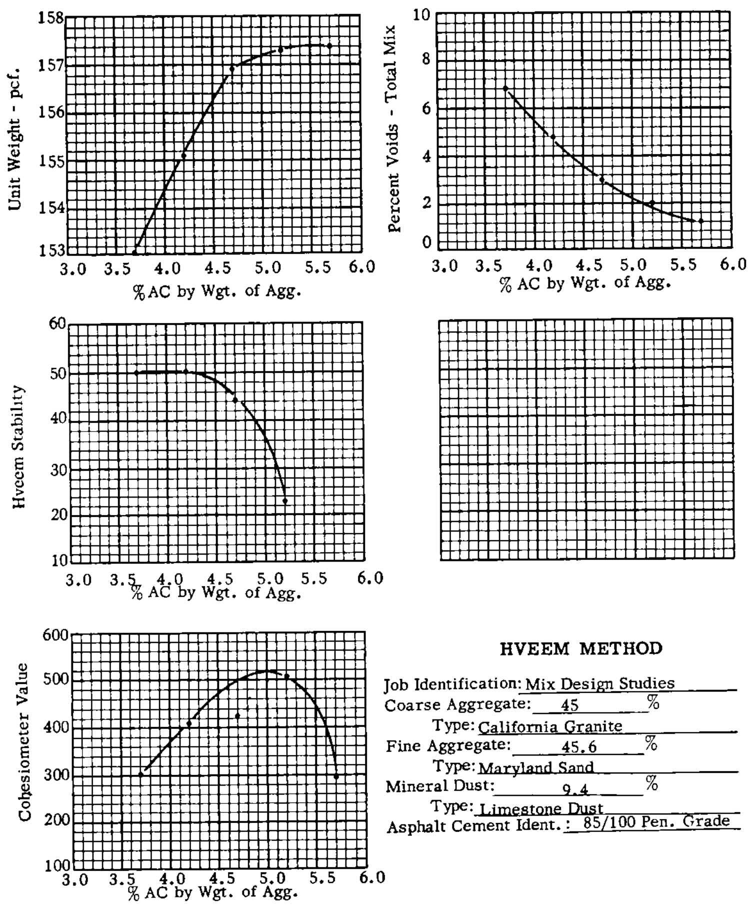
Figure 52.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 35 %
Type: California Granite
Fine Aggregate: 53.9 %
Type: Maryland Sand
Mineral Dust: 11.1 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

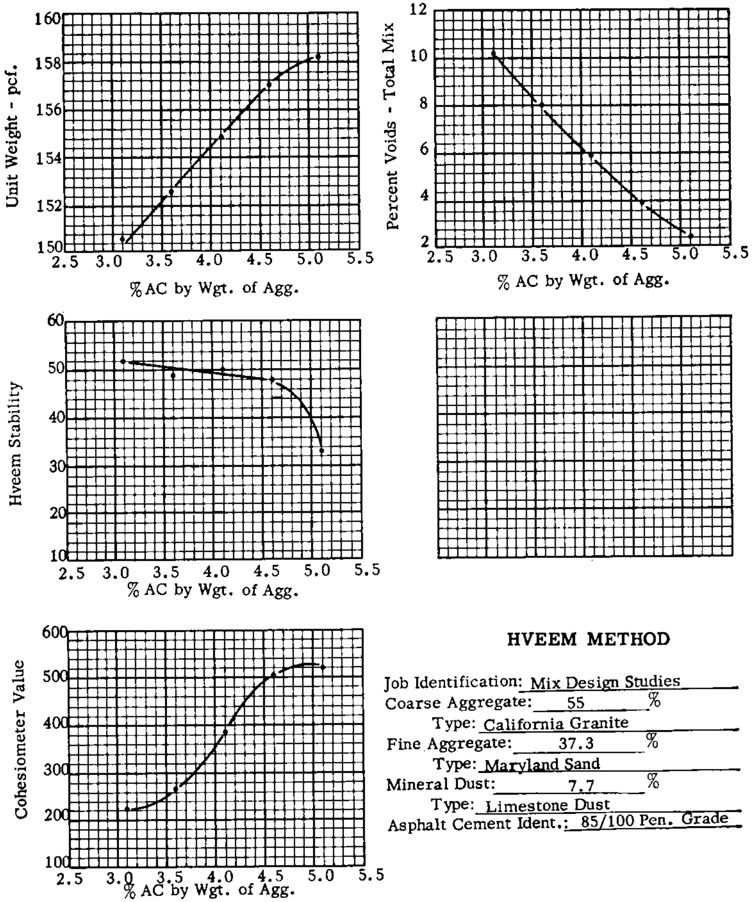
Figure 53.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 45 %
Type: California Granite
Fine Aggregate: 45.6 %
Type: Maryland Sand
Mineral Dust: 9.4 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

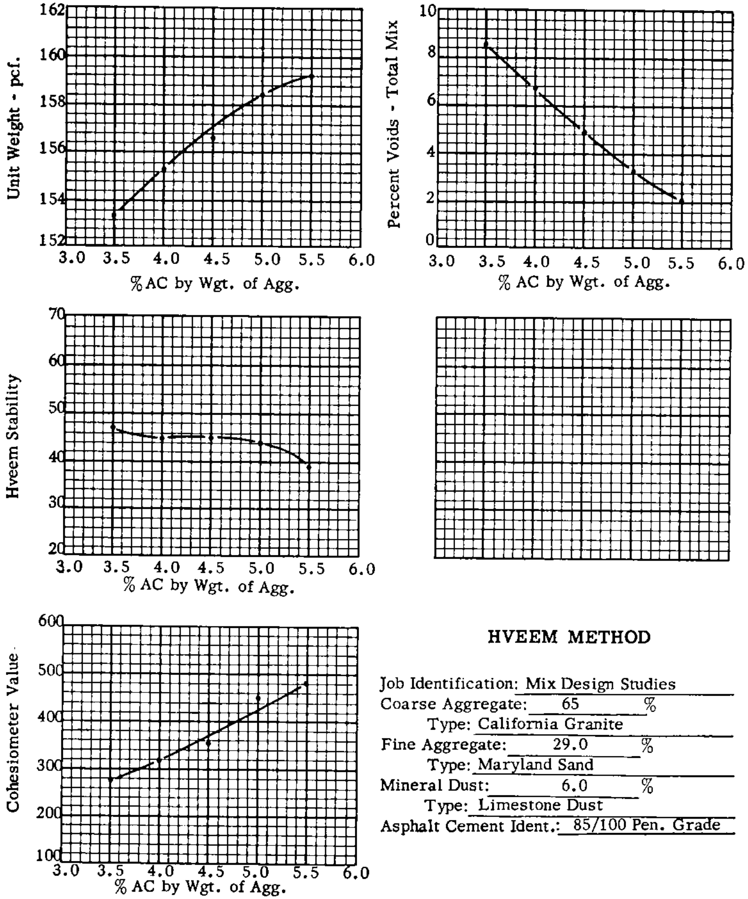
Figure 54.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 55 %
Type: California Granite
Fine Aggregate: 37.3 %
Type: Maryland Sand
Mineral Dust: 7.7 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

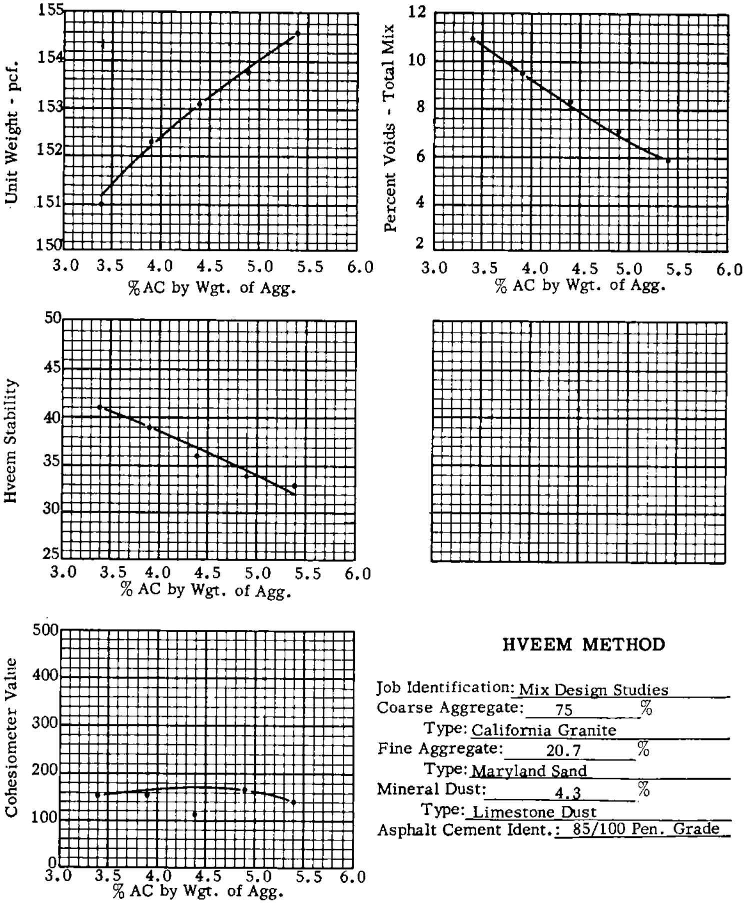
Figure 55.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 65 %
Type: California Granite
Fine Aggregate: 29.0 %
Type: Maryland Sand
Mineral Dust: 6.0 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

Figure 56.



HVEEM METHOD

Job Identification: Mix Design Studies
Coarse Aggregate: 75 %
Type: California Granite
Fine Aggregate: 20.7 %
Type: Maryland Sand
Mineral Dust: 4.3 %
Type: Limestone Dust
Asphalt Cement Ident.: 85/100 Pen. Grade

Figure 57.

DISCUSSION

J. A. Lefebvre, *Research Department, Imperial Oil Limited, Sarnia, Ont.* — It is gratifying to observe that, in general, the conclusions drawn by the authors are the same as those arrived at by the writer in a similar paper presented at the 1957 meeting of the Association of Asphalt Paving Technologists. Of particular interest is the fact that the Hveem procedure, which the writer had not included in his study, shows the same general trends as the Marshall procedure regarding stability and voids characteristics. Nevertheless, the effect of variations in percentage of coarse aggregate on Marshall stability, as illustrated by Figure 2 of the authors' paper, is less pronounced than that found by the writer. For three cases out of the four illustrated in the authors' Figure 2, there is little or no tendency for a well-defined peak to occur at some definite percentage of coarse aggregate.

The writer believes that this happens because the authors have not divided from each other the separate roles of coarse aggregate and mineral dust insofar as their influence on Marshall stability is concerned. The authors state: "The ratio of mineral dust to fine aggregate was constant throughout the study." It should be clearly recognized, however, that this means that as far as the mixture as a whole is concerned, every time the proportion of fine aggregate was altered, the percentage of mineral dust in the mixture was also changed. Consequently, as the percentage of coarse aggregate was increased from that of Grading No. 1 to that of Grading No. 7, for example, the percentage of the total mix passing No. 200 sieve was decreased from 17.1 to 4.3 percent.

It is a well known fact that, within limits, an increase in either percentage of coarse aggregate or percentage of mineral dust will increase the Marshall stability value of a paving mixture. Consequently, for the mixes tested by the authors, the increase in stability ordinarily expected from an increase in percentage of coarse aggregate was wholly or partially cancelled by the reduction in stability associated with the decrease in the fraction passing No. 200 sieve that occurred at the same time. It is believed that this is the reason that well-defined peaks do not occur in three of the stability curves in the authors' Figure 2 as the percentage of coarse aggregate was varied.

Griffith and Kallas, *Closure* — The authors wish to express their appreciation for Mr. Lefebvre's pertinent remarks. They certainly agree that changes in the quantity of mineral dust have significant effects on Marshall stability values and that it is possible that changes in mineral dust quantities could wholly or partially cancel changes in stability that might result from changes in the relative proportions of coarse and fine aggregate.

The method of varying aggregate gradations used for these studies was designed to result in mineral dust contents comparable to amounts commonly used in practice for various aggregate gradations. Thus, the gradation of the fine aggregate fraction, including the mineral dust, was maintained constant.

Recognizing the possible effects of quantity of mineral dust on the properties of asphalt paving mixes, additional studies using these same aggregates and mineral dust are being made by The Asphalt Institute.