Iowa State Highway Commission

MATERIALS DEPARTMENT

SPECIAL INVESTIGATIONS

Report of R - 232

# Study of Type 'A' Asphaltic Concrete Surface Mix Design

IOWA STATE HIGHWAY COMMISSION

DEPARTMENT OF MATERIALS

Special Investigations Section

Final Report for

Research Project R-232

# Study of Type 'A' Asphaltic Concrete Surface Mix Design

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## 1.0 INTRODUCTION

In some asphaltic concrete mixes asphalt absorption in field mixes is difficult to predict by the routine mix design tests presently being used. Latent or slow absorption in hot mixes is hard to compensate for in field control due to aggregate gradations being near maximum density. If critical asphalt need could be changed by increasing voids in the mineral aggregate so that more freedom could be exercised in compensating for the absorption, this may aid in design.

The voids in the mineral aggregate can be related to composite gradation of total aggregate in a mixture, i.e. if a composite gradation of aggregate is finer than that of maximum density curve, the V.M.A. will be greater than that of a mix of maximum density.

The typical gradation of Iowa Type 'A' mixes is finer than a gradation which is near the centerline of the specification at sieves larger than the No. 30 and coarser at the lower sieve sizes. The mixes of the typical gradation will have higher V.M.A. than those of the near centerline mixes. By studying properties of the mixes of the typical gradation and comparing them with those of the mixes of maximum density, it may aid in the modification and simplification of our present testing methods and specification requirements while still maintaining control of quality of the mix by controlling voids, stability, gradation and asphalt content.

## 2.0 PURPOSE

The overall objectives of the study are:

2.1 To study our present method for determining the asphalt absorption.

2.2 To correlate per cent air voids calculated from Measured Bulk Specific Gravity of aggregate with those obtained from undisturbed specimens by high pressure air meter.

2.3 To compare per cent air voids calculated from Measured Bulk Specific Gravity with those calculated from Calculated Bulk Specific Gravity.

2.4 To correlate per cent air voids obtained from undisturbed specimens with those obtained from disturbed (Hveem) specimens by high pressure air meter.

2.5 To correlate per cent air voids calculated from Measured Bulk Specific Gravity of aggregate with those obtained from disturbed (Hveem) specimens by high pressure air meter.

2.6 To correlate Solid Specific Gravity of a mixture calculated from the Iowa State Highway Commission's Effective Specific Gravity of aggregate with those obtained from undisturbed specimens by high pressure air meter.

2.7 To correlate Solid Specific Gravity of mixtures obtained from undisturbed specimens with those obtained from disturbed (Hveem) specimens by high pressure air meter.

2.8 To correlate Solid Specific Gravity of mixtures calculated from Measured Bulk Specific Gravity of aggregate with those obtained from disturbed (Hveem) specimens by high pressure air meter.

2.9 To study some aggregate gradation parameters.

2.10 To study the effect of gradation of total aggregate in a mixture to Hveem and Marshall Stability.

2.11 To compare Hveem with Marshall Stability.

2.12 To compare properties of 3/4 inch mixes with those of 3/8 inch mixes.

2.13 To compare properties of a mix of 50 blow Marshall Compaction with those of a mix of 75 blow Marshall Compaction.

2.14 To evaluate test results related to our present specification and to possibly recommend a modification of the specification.

3.0 MATERIALS

3.1 Five sources of crushed limestone were used in this study. Their sources and detailed description are shown in Table 1. Results of their Specific Gravity tests are shown in Table 3.

3.2 For the sand portion of the aggregate in the mixes, a single source of sand for all aggregate mixes was chosen to eliminate the effect of absorption change in the sand. The sand at West Des Moines (Concrete Material Company's plant) was selected for the study. Results of the Specific Gravity tests are shown in Table 3.

3.3 85 - 100 Pen. asphalt (AB7-110) was used for all mixes in this study.

## 4.0 LABORATORY PROCEDURE

4.1 Preparations of aggregates for mixes

The coarse aggregates were separated in the laboratory on all sieves from top size down to the number 8 sieve and each size was treated as individual portions for the design of composite gradation. All particles of the aggregates passing the number 8 sieve were treated as fine particles for design.

4.2 Design of per cent composition of the individual aggregates in mixes

The approximate centerline of the specifications was used as an ideal gradation. Each mix size was controlled to the ideal gradation down to and including the No. 4 sieve. (See Figures 1 to 10). Three designs based on per cent of individual portions of aggregates were made and their composite gradations were as follows:

4.2.1 Gradation 1. At the No. 8 and No. 16 sieves the curve was approximately 5 per cent higher than the ideal gradation or apparent middle 50 per cent of the specification limit. At sieve No's 50, 100 and 200 the curve was 6 per cent lower than that of the ideal gradation.

4.2.2 Gradation 2. The same as Gradation 1 except that the curve was only approximately 3 per cent lower than the middle 50 per cent curve at Sieve No's 50, 100 and 200.

4.2.3 Gradation 3. The gradation will approximately follow that of the middle 50 per cent of the specification limit. The gradations of the mixes of each stone are shown in Fig. 1 to Fig. 10, and the per cent composition for each gradation and stone is also shown in Table 2.

The final appropriate compositions of the individual aggregates in the mix shown in Table 2, were obtained by trial and error.

4.3 Testing

Nine specimens were made at each asphalt content. The specimens molded were 4" diameter by 2-1/2" high and compacted at 280 ± 5°F. One standard procedure of compaction was followed throughout the entire series, i.e. 50 Blow Marshall compaction except that 75 blow Marshall compaction was also used for the mixes of Cooney stone for comparative purposes. Three specimens were tested using the Hveem stabilometer. Three were tested by the Marshall Stability method. Specimens for the stability tests were kept at 140°F in a water bath for a predetermined uniform length of time, which was one-half hour as standard for the Marshall Test and the two hours for Hveem Stability Test.

Three specimens were tested in the high pressure air meter for air content and Solid Specific Gravity. The Hveem specimens were again tested in the high pressure air meter after the stability test. All nine specimens had been tested for their density prior to any testing treatment.

The asphalt contents used on each mix was of a wide enough range to give low V.M.A. filled with asphalt to a very high V.M.A. filled with asphalt and corresponding low voids in the total mix. This was in one per cent increments with possibly 1/2 per cent change introduced at a critical point that had to be determined during the progress of the project.

The results of the tests for the study are shown in Tables 4 to 15 and Fig. 11 to Fig. 22.

## 5.0 INTERPRETATION OF RESULTS

### 5.1 Asphalt Absorption

There are many test procedures for the determination of asphalt absorption of a compacted paving mixture, i.e., Absorption by Rice's Method, Absorption determined by Bulk - Impregnated Specific Gravity, Absorption by the Immersion Method, Absorption by Cross-Sectional Area Measurement etc., but no standard test or reliable method is currently available. In order to find the value of asphalt absorption, the Effective Specific Gravity of aggregate has to be found. The Effective Specific Gravity value obtained from various tests do not agree. Thus, the Iowa State Highway Commission has developed a method of calculation for the Effective Specific Gravity based on the assumption that the Effective Specific Gravity is to be the average between Bulk and Apparent Specific Gravity of the aggregate.

The equation for the determination of asphalt absorption is:

$$\mathcal{U}ac = \left( \frac{1}{Gb} - \frac{1}{Gv} \right) \cdot \gamma ac. \ 100 \qquad (1)$$

Where

$\mathcal{U}ac$ = asphalt absorbed in pounds per 100 pounds of dry aggregate

Gb = Bulk Specific Gravity of aggregate

Gv = Effective Specific Gravity of aggregate

= 1/2 (Ga + Gb) for I.S.H.C's

Ga = Apparent Specific Gravity of aggregate

$\gamma$ac = Specific Gravity of asphalt

The proof is shown in Appendix A.

The Effective Specific Gravity is also used for the determination of Maximum Theoretical Specific Gravity of paving mixtures, the equation is:

$$\text{Maximum Theoretical Specific Gravity} = \frac{100}{\frac{Pag}{Gv} + \frac{Pac}{\gamma ac}} \qquad (2)$$

Where

Pag = Per cent by weight of aggregate in the compacted paving misture

Pac = Per cent by weight of asphalt in the mixture

The method of determination of the Effective Specific Gravity of aggregate by I.S.H.C. implies that approximately fifty per cent of water permeable voids are filled with asphalt (See Appendix B). This is very good working average for the determination of asphalt absorption in a compacted paving mixture especially for mixtures containing limestone since it can be proven from the results of this study that the percentage of air voids calculated from the Bulk Specific Gravity of aggregate with allowance for asphalt absorption which is calculated by using I.S.H.C's Effective Specific Gravity is very close to those measured by the high pressure air meter. This will be discussed later in Section 5.2. The air voids measured by the high pressure air meter are correct. This is because all stones used in this study are relatively low absorptive stones and no large error is involved even though the air voids correction for the stones are ignored (The air voids correction was neglected for this study).

5.2 <u>Correlation between air voids calculated from Measured Bulk Specific Gravity of aggregate and air voids determined by high pressure air meter</u>.

The correlation is shown in Fig. 5.2

The estimating equation is:

$$y = 0.413 + 0.977\,x \qquad (3)$$

Where $y$ = Air Voids calculated from Measured Bulk Specific Gravity with allowance for asphalt absorption

$x$ = Air Voids measured by high pressure air meter

With correlation coefficient = 0.987

Standard error of estimate = 0.52

Coefficient of determination = 0.974

The correlation coefficient of 0.987 indicates that there is a good correlation between these two variables. The slope of the estimating line is very close to that of the line of equality (1.000), while the value of y - intercept is only 0.413. The standard error of estimate (0.52) indicates that we can expect about 68 per cent of the actual values to be within $\pm 0.52$ and about 95 per cent to be within $\pm 1.04$. From these statistical points of view, the conclusion can be drawn that the air voids calculated from the Measured Bulk Specific Gravity of aggregate with an allowance for asphalt absorption can be used instead of the value of air voids measured by the high pressure air meter with the precaution that:

1. For 3/4 inch mixes, the calculated air voids have to be more than 4.3%. From the Figure 5.2, if calculated air voids are equal to 4.3%, air voids by the air meter will be 4.0% with an error of $\pm 1.0$% approximately. This insures

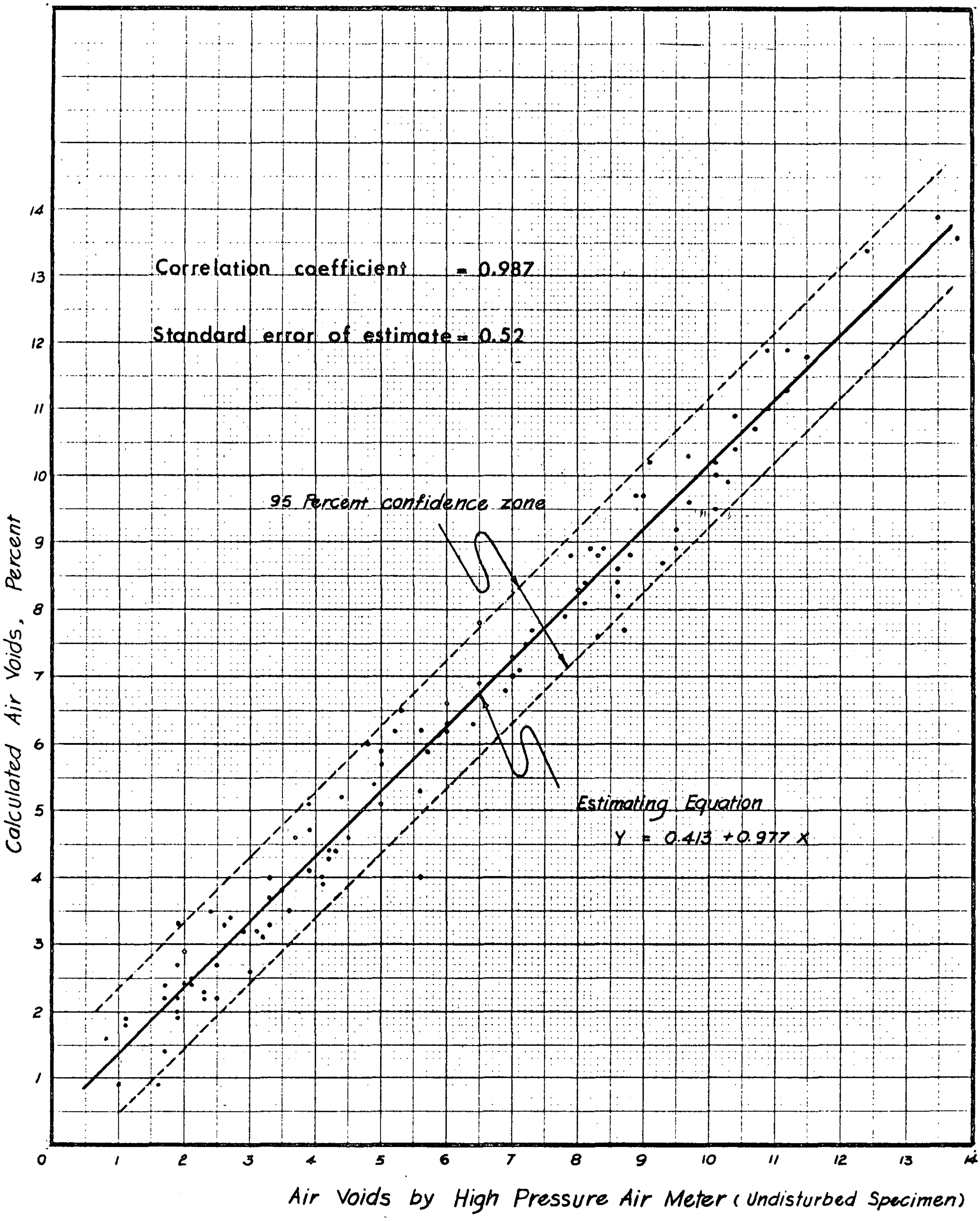


FIGURE 5.2 CORRELATION BETWEEN AIR VOIDS BY HIGH PRESSURE AIR METER AND CALCULATION

that the air voids in the compacted paving mixture will not be lower than 3.0% which will not cause flushing or bleeding of the pavement.

2. For 3/8 inch mixes, if minimum per cent air voids required are 4, as recommended by this report in Section 5.15, the calculated air voids have to be more than 5.3% due to the same reason as given in 1.

Air voids calculated from Bulk Specific Gravity of the aggregate with an allowance for asphalt absorption are closely related to the actual performance of the paving mixture under traffic conditions. This figure is also very close to that calculated from the Effective Specific Gravity which is the one currently in use.

In order to compare the methods of calculation on air voids of a compacted paving mixture by using the Bulk and Effective Gravities of aggregate, an equation of each method has to be found.

Bulk Specific Gravity of the compacted paving mixture = Gm.

| | | Calculation Based On | |
|---|---|---|---|
| No. | Properties of Mixture | Bulk Sp.Gr. (Gb) | Effective Sp.Gr. (Gv) |
| 1. | Volume occupied by aggregate | $\frac{Pag.\ Gm}{Gb}$ | $\frac{Pag.\ Gm}{Gv}$ |
| 2. | Volume of asphalt in mixture | $\frac{Pac.\ Gm}{\gamma ac.}$ | $\frac{Pac.\ Gm}{\gamma ac.}$ |
| 3. | Volume absorbed asphalt in aggregate | $\frac{\mu ac.}{100}\ Pag.\ Gm$ | - |
| 4. | Effective volume of asphalt | $\frac{Pac.\ Gm}{\gamma ac.} - \frac{\mu ac.\ Pag.\ Gm}{100}$ | $\frac{Pac.\ Gm}{\gamma ac.}$ |
| 5. | Void in mineral aggregate (V.M.A.) | $100 - \frac{Pag.\ Gm}{Gb}$ | $100 - \frac{Pag.\ Gm}{Gv}$ |
| 6. | Per cent Air Voids (V.M.A. - Eff. Vol. asphalt) | $100 - \frac{Pag.\ Gm}{Gb} - \frac{Pac.\ Gm.}{\gamma ac.} + \mu ac.\ Pag.\ Gm/100$ | $100 - \frac{Pag.\ Gm}{Gv} - Pac.\ Gm/\gamma ac.$ |

Difference of Air Voids = Air Voids by Effective Sp.Gr. - Air Voids by Bulk Sp.Gr.

$$= P_{ag} \cdot G_m (1/G_b - 1/G_v) - \mu_{ac} \cdot P_{ac} \cdot G_m/100$$
$$= P_{ag} \cdot G_m (1/G_b - 1/G_v - \mu_{ac}/100)$$
$$= P_{ag} \cdot G_m [(1/G_b - 1/G_v) - (1/G_b - 1/G_v) \cdot \gamma_{ac}]$$
$$= P_{ag} \cdot G_m [(1 - \gamma_{ac})(1/G_b - 1/G_v)] \qquad (4)$$

This value approaches zero, since $\gamma_{ac} \cong 1$, thus per cent air voids calculated from Bulk Specific Gravity is close to that calculated from the Effective Specific Gravity.

Furthermore, the air voids calculated from Apparent Specific Gravity are also compared to those calculated from the Bulk and the Effective Specific Gravity. The results are shown in Table 5.2.

TABLE 5.2 Comparison of the void properties of a compacted paving mixture by using various types of Specific Gravity of aggregate.

Bulk Sp. Gr. of compacted mixture = 2.36

Asphalt Content = 5 lbs. per 100 lbs.of mixture

Asphalt Absorption = 0.5 lbs. per 100 lbs.of aggregate

Asphalt Sp. Gr. = 1.02

| Method for Calculation Based On | Allowance for Asphalt Absorption | % V.M.A. | % Voids Filled with Asphalt | % Air Voids |
|---|---|---|---|---|
| Apparent Sp. Gr. 2.72 | No | 17.6 | 65.9 | 6.0 |
| Bulk Sp. Gr. 2.64 | No | 15.1 | 76.8 | 3.6 |
| Bulk Sp. Gr. 2.64 | Yes | 15.1 | 69.5 | 4.6 |
| Effective Sp. Gr. 2.68 (ISHC) | No | 16.3 | 71.2 | 4.7 |

From Table 5.2, neither the per cent air voids calculated from Bulk nor Apparent Specific Gravity without allowance of asphalt absorption are close to those calculated from Bulk Specific Gravity with allowance for asphalt absorption or Effective Specific Gravity of aggregate. The voids calculated from Apparent Specific Gravity include the volume of the air pockets between coated aggregate particles plus the voids of water permeable pore space within the aggregate particles which is not filled with asphalt( Vol. of air pocket + Vol. of water permeable pore space - Vol. of asphalt absorbed). This is not true since the air voids should be only the volume of the air pockets. The air voids calculated from the Bulk Specific Gravity without allowance for asphalt absorption is also in error, since some amount of asphalt has been absorbed into the aggregate particles and this value cannot be neglected, especially for mixes using highly absorptive stones. The value is equal to the actual per cent of voids in mineral aggregate subtracted from the total per cent volume of asphalt in the mixture (without correction for asphalt absorption), thus the value of the air voids calculated by this method is less than the actual one. Hence, either air voids calculated from Measured Bulk Specific Gravity with allowance of asphalt absorption or Effective Specific Gravity can be used and related to the pavement performance.

5.3 <u>Correlation between calculated air voids from Calculated Bulk Specific Gravity and Measured Bulk Specific Gravity of Aggregate</u>.

From Fig. 5.3.1, the correlation between Measured (I.S.H.C's) and Calculated Bulk Specific Gravity of Aggregate is found to be:

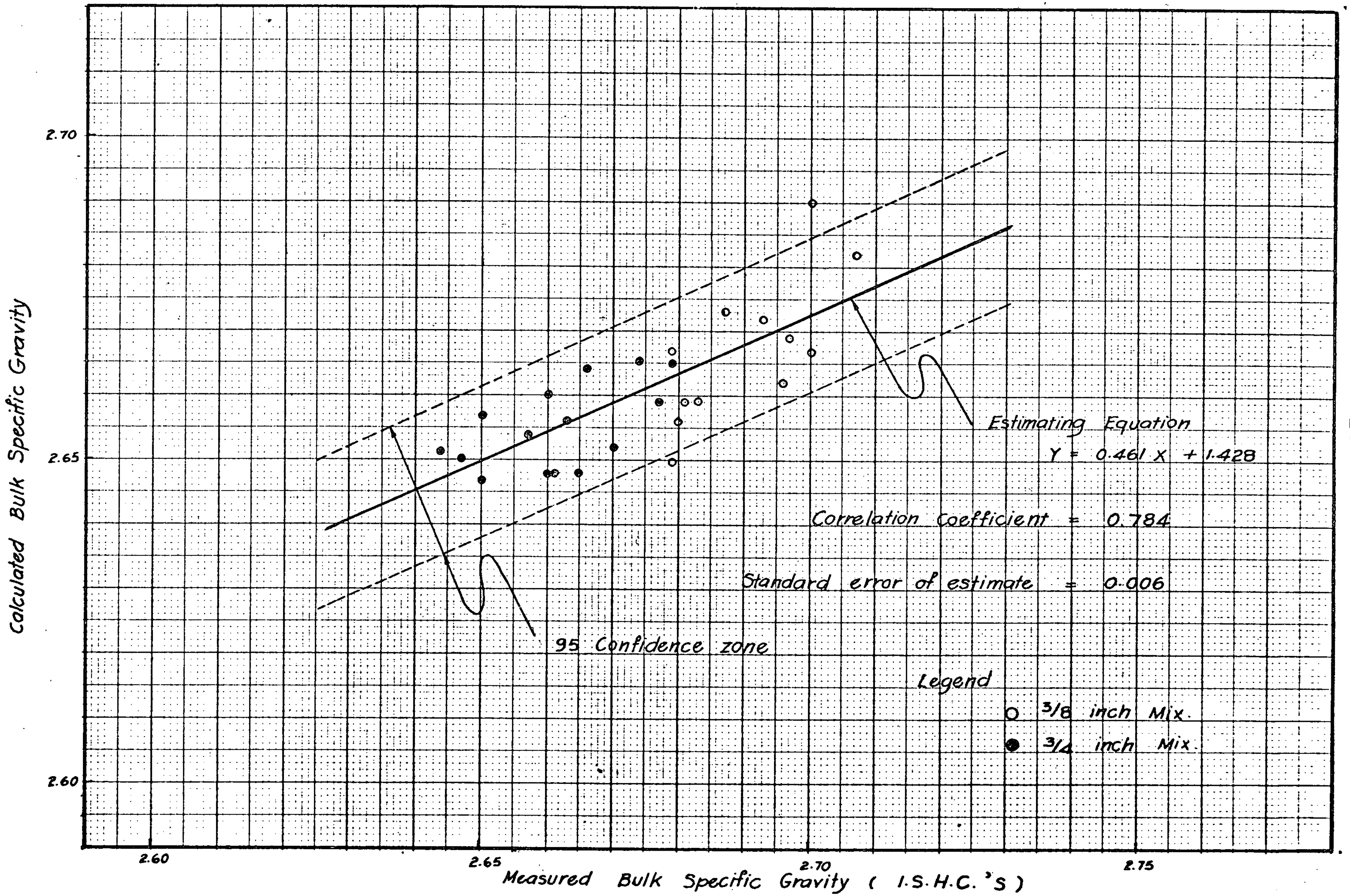


FIGURE 5.3.1 CORRELATION BETWEEN MEASURED AND CALCULATED BULK SPECIFIG GRAVITY OF AGGREGATE

$$y = 0.461\ x + 1.428$$

$$\text{or}\quad Gcb = 0.461\ Gmb + 1.428 \qquad (5)$$

where x, or Gmb = Measured Bulk Specific Gravity of aggregates. (See Appendix C)

Y, or Gcb = Calculated Bulk Specific Gravity of aggregate.

From the figure, it can be seen that Gmb is higher than Gcb when Gmb is more than approximately 2.65 and vice versa. It is obvious that the measured one is more effective than the calculated one since the air voids calculated from the Measured Bulk Specific Gravity is close to that measured by the high pressure air meter. This can be proved as follows:

From Section 5.2, the air voids calculated from Bulk Specific Gravity of Aggregate can be obtained by the equation:

$$\text{Air Voids (\%)} = 100 - \frac{Pag.Gm}{Gb} - \frac{Pac.Gm}{\gamma ac.} + \frac{\mu ac.Pag.Gm}{100}$$

Where Gb = Bulk Specific Gravity of Aggregate.

By using the correlated equation (5), the difference between air voids calculated from measured and calculated Bulk Specific Gravity of aggregate is:

% Voids calculated from <u>measured</u> Bulk Sp. Gr. $(Vv)_{Gmb}$ - % voids calculated from <u>calculated</u> Bulk Sp. Gr. $(Vv)_{Gmb}$

$$= \frac{Pag.Gm}{Gcb} - \frac{Pag.Gm}{Gmb}$$

$$= Pag.Gm.\left[\frac{1}{0.461\ Gmb + 1.428} - \frac{1}{Gmb}\right]$$

$$= Pag.Gm\left[\frac{Gmb - 0.461\ Gmb - 1.428}{Gmb\ (0.461\ Gmb + 1.428)}\right]$$

$$= Pag.Gm\left[\frac{(0.539\ Gmb - 1.428)}{Gmb\ (0.461\ Gmb + 1.428)}\right]$$

$$= Pag.Gm.K \qquad (6)$$

TABLE 5.3 K Value at Various Gmb:

| Gmb | $Kx10^{-4}$ |
|---|---|
| 2.50 | -124.78 |
| 2.55 | - 80.58 |
| 2.60 | - 38.95 |
| 2.65 | + 0.57 |
| 2.70 | + 37.83 |
| 2.75 | + 73.25 |

The value of K at various values of Gmb is also shown in Figure 5.3.2.

From the relationship $(Vv)_{Gmb} - (Vv)_{Gcb}$ = Pag. Gm. K; and Table 5.3. The air voids calculated from Calculated Bulk Specific Gravity when Measured Bulk Sp. Gr. is more than approximately 2.65 and vice versa.

The air voids calculated from Measured Bulk Specific Gravity can be well correlated to that measured by the high pressure air meter as shown in Fig. 5.2, with the estimating equation:

$$y = 0.413+0.977\ x \tag{7}$$

Where y = Air Voids calculated from Measured Bulk Sp.Gr.

x = Air voids measured by the high pressure air meter

so that the air voids calculated from Calculated Bulk Specific Gravity will be less than that measured by the high pressure air meter significantly at a high value of Measured Bulk Specific Gravity of aggregate, and vice versa. For example, assume:

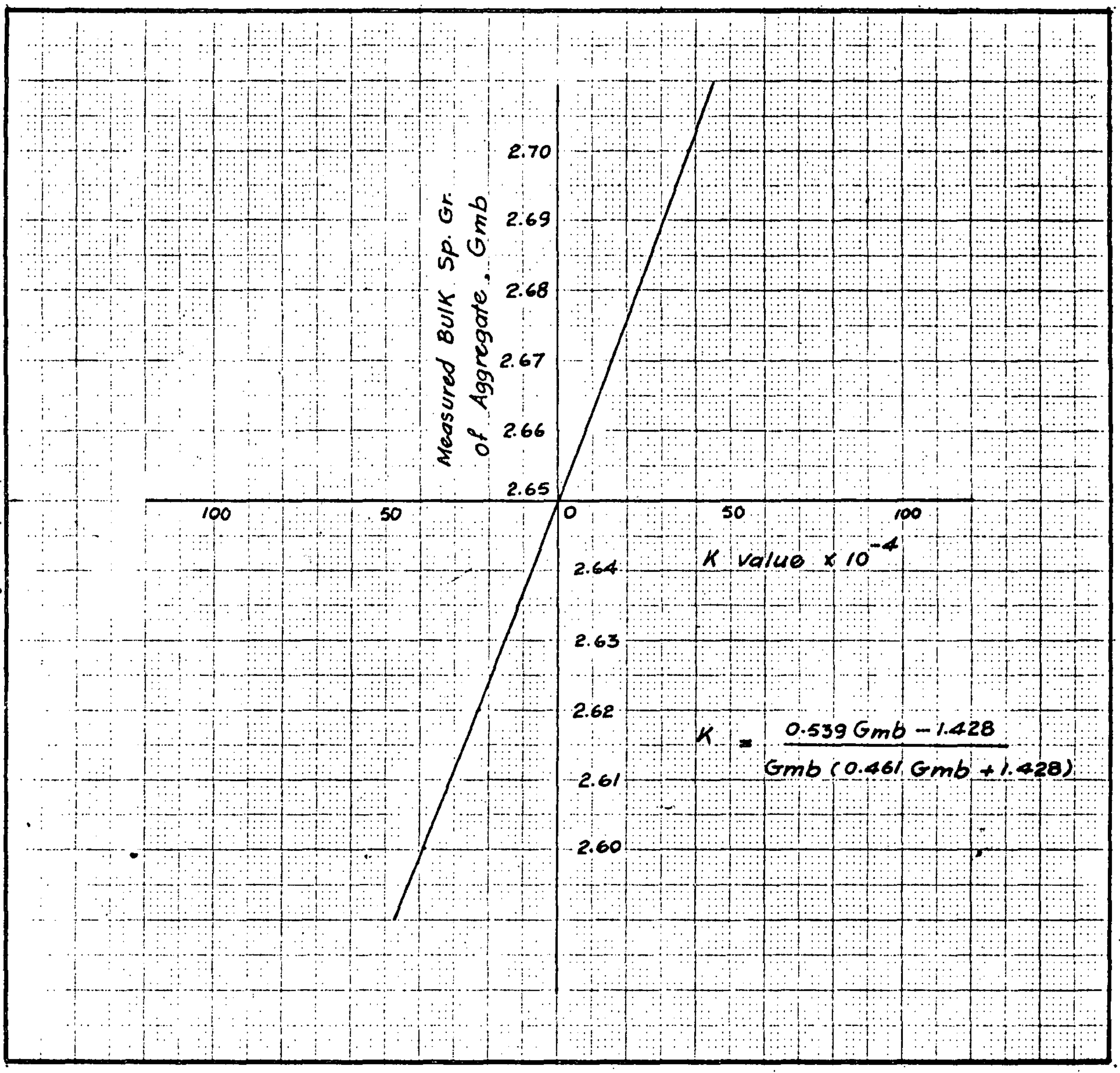


FIGURE 5.3.2 RELATIONSHIP BETWEEN CORRECTION FACTOR AND MEASURED BULK SPECIFIG GRAVITY ( I.S.H.C.'S) OF TOTAL AGGREGATE IN COMPACTED MIXTURE

Measured Bulk Specific Gravity = 2.70

Air Voids calculated from measured Bulk Specific Gravity with allowance for asphalt absorption = 5.0%

Per cent aggregate in the mixture = 95%

and Bulk Specific Gravity of the mixture = 2.40

From the equation: $(Vv)_{Gcb} = (Vv)_{Gmb} - Pag.\,Gmk$; the value of $(Vv)_{cb}$ can be found by substituting the value of $(Vv)_{Gmb}$, Pag., Gm, and k:

$$(Vv)_{Gcb} = 5.0 - 95 \times 2.4 \times 37.83 \times 10^{-4}$$

$$= 5.0 - 0.9$$

$$= \underline{4.1}$$

On comparing the air voids calculated from Measured Bulk Specific Gravity and Calculated Bulk Specific Gravity, the air voids calculated from Measured Bulk Specific Gravity is closer to that measured by the high pressure air meter than the calculated one. Further study is needed for the correlation between Measured Bulk Specific Gravity and Calculated Bulk Specific Gravity for the reason of obtaining more experimental data to verify Fig. 5.3.1.

### 5.4 Correlation between air voids obtained from undisturbed and disturbed (Hveem) Specimens by high pressure air meter.

The correlation is shown in Fig. 5.4. Per cent air voids from disturbed specimens are lower than those from undisturbed specimens. This is because during the Hveem stability test, vertical pressure was applied to the specimen and caused a new arrangement of the aggregate particles within the specimen. From calculated correlation, it is obvious that the higher the void content of the specimen, the higher the difference in air voids between

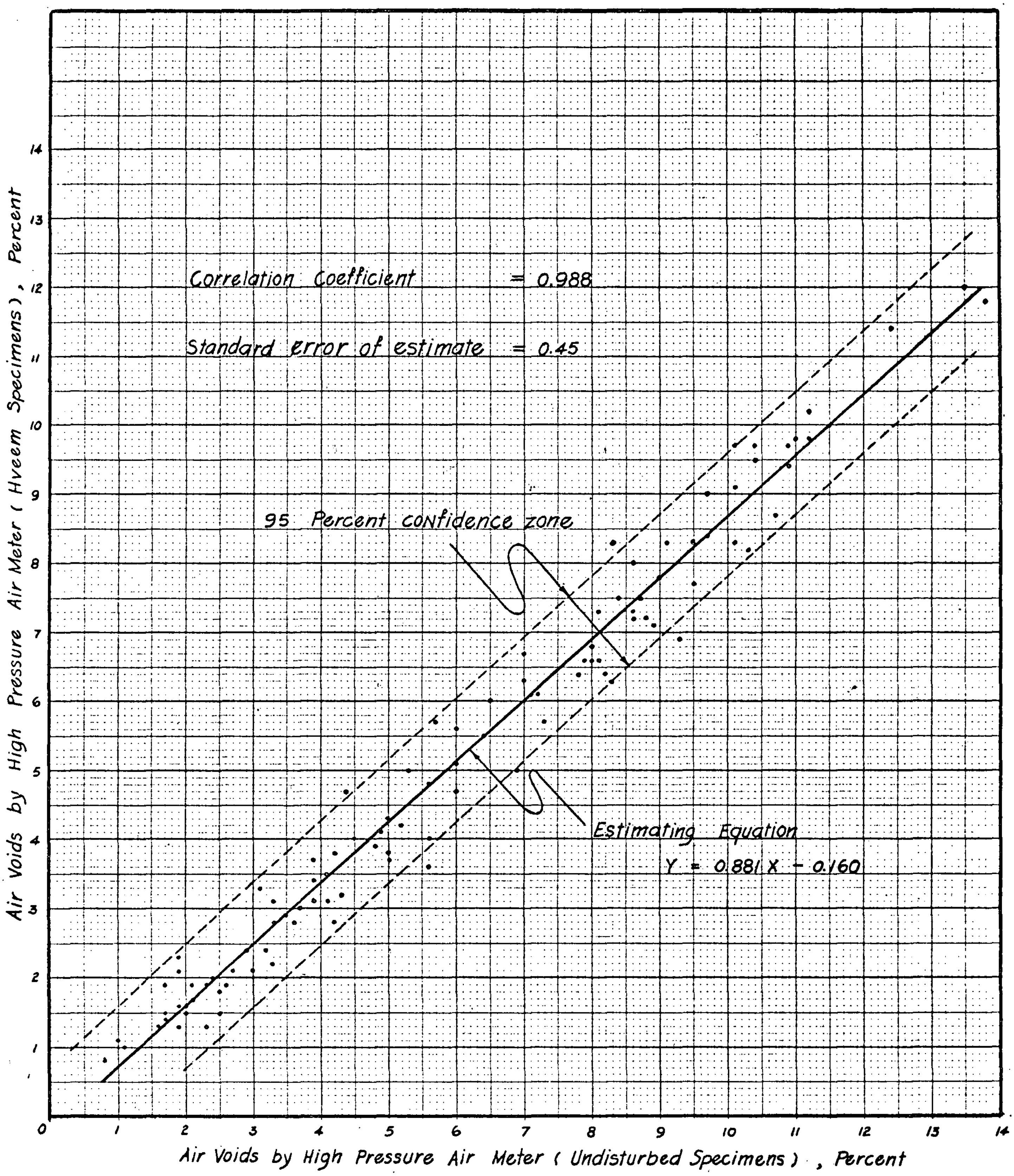


FIGURE 5.4 CORRELATION BETWEEN AIR VOIDS OBTAINED FROM UNDISTURBED AND DISTURBED ( HVEEM ) SPECIMENS BY HIGH PRESSURE AIR METER

undisturbed and disturbed specimens.

The statistical interpretation can be made the same way as given in 5.2. The correlation might be useful in case that Hveem stability and air voids by the high pressure air meter are requested. Normally 2 sets of specimens have to be prepared, one for the Hveem stability test and the other for the high pressure air meter test. By using the correlation, only one set of specimens will need to be prepared.

5.5 Correlation between air voids calculated from Measured Bulk Specific Gravity of aggregate and those obtained from disturbed (Hveem) specimens by high pressure air meter.

The correlation is shown in Fig. 5.5.

The interpretation of the results can be made almost the same as given in 5.4.

In order to check the correlation in Fig. 5.5, the estimating equation of Fig. 5.3 is substituted in that of Fig. 5.4, that is:

$$Vv\,(\text{Cal.}) = 0.977\ Vv.\ (\text{HM - und.}) + 0.413 \qquad (8)$$

$$Vv\ (\text{HM - Dist.}) = 0.881\ V_V\ (\text{HM - und.}) - 0.160 \quad (9)$$

Substituting the value of Vv (HM - und.) in (8)

$$Vv\,(\text{Cal.}) = 0.977\ Vv\ \frac{Vv\,(\text{HM - Dist.}) + 0.160}{0.881} + 0.413$$

$$Vv\,(\text{Cal.}) = 1.108967\ \ Vv\,(\text{HM - Dist.}) + 0.1774347 + 0.413$$

$$= 1.108967\ \ Vv\,(\text{HM - Dist.}) + 0.5904347$$

$$Vv\,(\text{HM - Dist.}) = 0.902\ Vv\,(\text{Cal.}) - 0.532 \qquad (10)$$

Where Cal. = Calculated, HM = High pressure air meter

Und. = Undisturbed specimen, Dist. = Disturbed specimen.

This equation is slightly different to that obtained in Fig. 5.5 due to the rounding error from equations (8) and (9). It is obvious that the one that is directly correlated (Fig. 5.5) is more precise than (10).

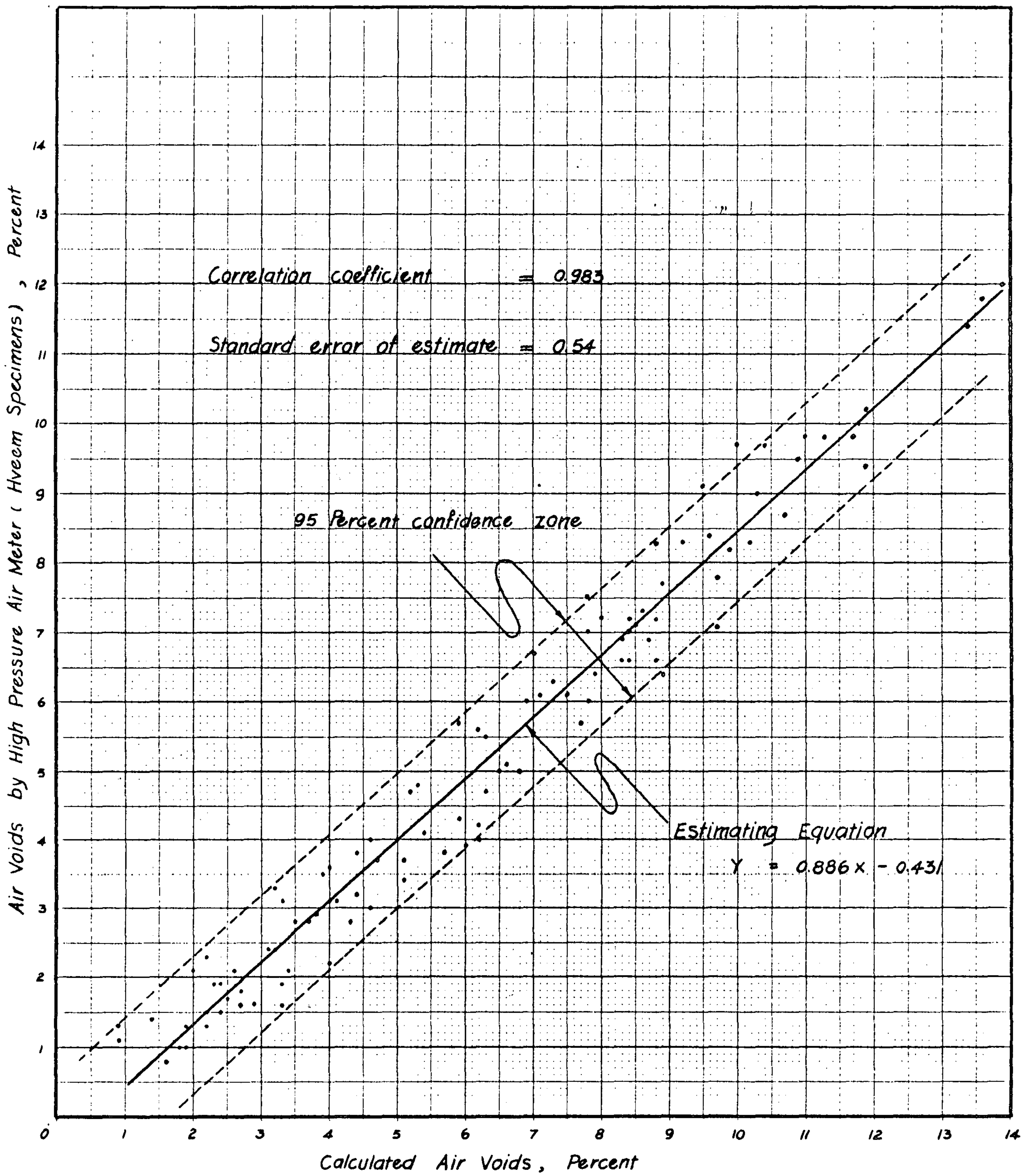


FIGURE 5.5 CORRELATION BETWEEN CALCULATED AIR VOIDS AND AIR VOIDS BY HIGH PRESSURE AIR METER ( HVEEM SPECIMENS )

5.6 Correlation between Maximum Theoretical Specific Gravity of compacted mixtures measured by high pressure air meter with those calculated from the I.S.H.C's Effective Specific Gravity of aggregate.

The Maximum Theoretical Specific Gravity of a compacted mixture can be determined by the equation shown in Section 5.1, i.e.

$$\text{Maximum Theoretical Specific Gravity} = \frac{100}{\dfrac{Pag}{Gv} + \dfrac{Pac}{\gamma ac}} \qquad (11)$$

The equation (11) can be written also in terms of total weight of the mix, aggregate and asphalt, i.e.

$$\text{Maximum Theoretical Specific Gravity} = \frac{Wmm}{\dfrac{Wag}{Gv} + \dfrac{Wac}{\gamma ac}} \qquad (12)$$

Where Wmm = Weight of total mix (Aggregate + Asphalt).
Wag = Weight of aggregate in the mix.
Wac = Weight of asphalt in the mix.

The Effective Specific Gravity of the aggregate (Gv) can be determined by the experiments which have been listed in Section 5.1 or the I.S.H.C's method of calculation and substituted in equation (11) or (12) in order to obtain the Maximum Theoretical Specific Gravity of the mix.

A direct way for the determination of the Maximum Theoretical Specific Gravity is by the high pressure air meter. The amount of the air voids measured by the air meter is subtracted from the bulk volume of the mix and the value obtained is the solid volume of the mix. In other words, the value of $\left(\dfrac{Wag}{Gv} + \dfrac{Wac}{\gamma ac}\right)$ which is the solid volume of the mix can be found directly from the air meter test and the Maximum Theoretical Specific Gravity may be obtained by the equation (12).

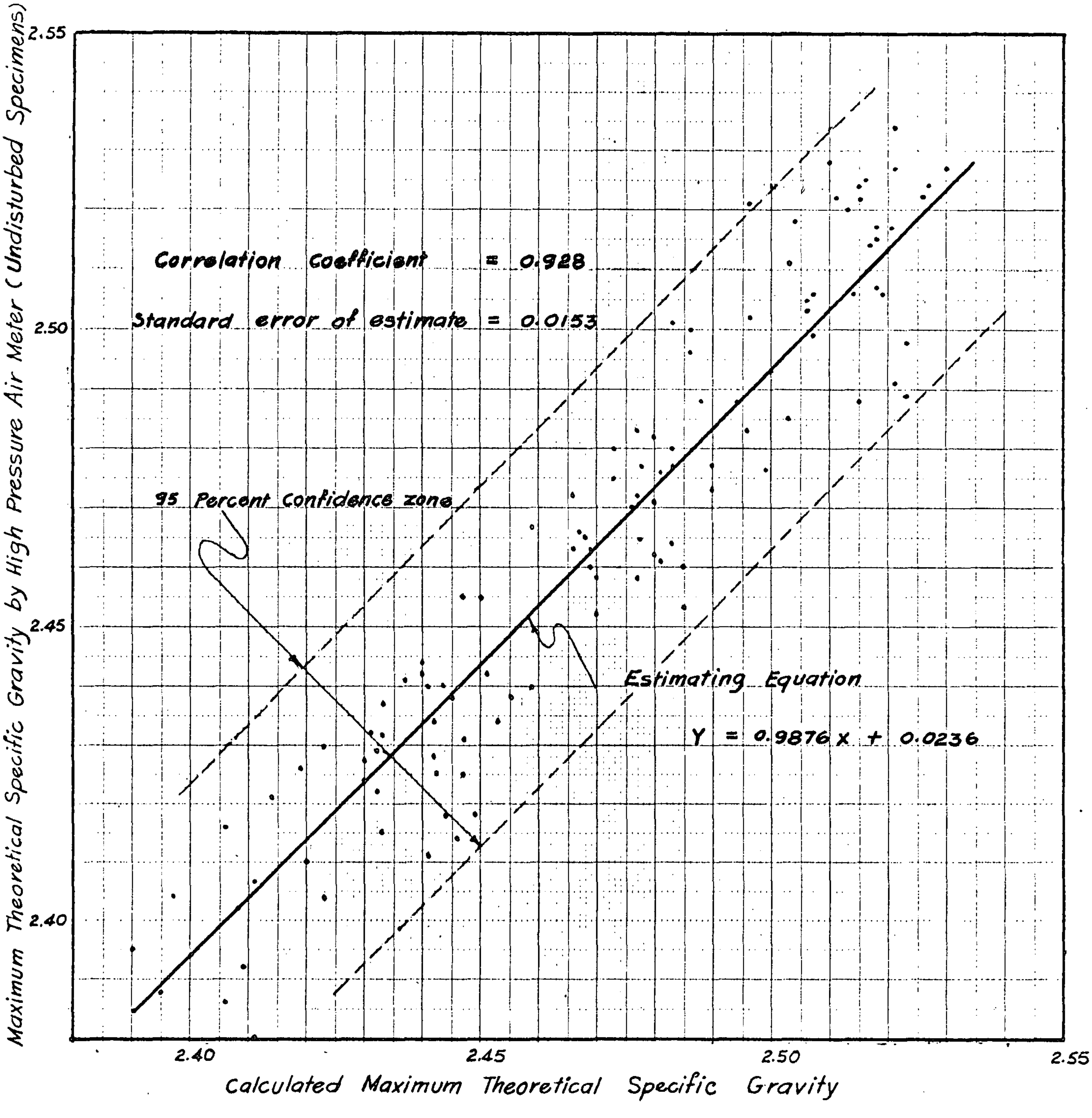


FIG. 5.6 CORRELATION BETWEEN MAXIMUM THEORETICAL SPECIFIG GRAVITY OF MIXTURES CALCULATED FROM I.S.H.C.'S EFFECTIVE SPECIFIG GRAVITY OF AGGREGATE WITH THOSE OBTAINED FROM UNDISTURBED SPECIMENS BY HIGH PRESSURE AIR METER

The Maximum Theoretical Specific Gravity of the mixes made in this study by the high pressure air meter is correlated with those calculated from the I.S.H.C's Effective Specific Gravity of aggregate. The results are shown in Fig. 5.6.

According to the statistical point of view, the correlation is very good and implies that the I.S.H.C's method of calculation is acceptable for the mixes using the relatively low absorptive stones used in this study. This is another way to prove that the I.S.H.C's Effective Specific Gravity of aggregate is a very good working average.

5.7 Correlation between Maximum Theoretical Specific Gravity of compacted mixtures obtained from undisturbed specimens with those obtained from disturbed (Hveem) specimens by high pressure air meter.

Actually the amount of the bulk volume and the air voids of the disturbed specimens are less than those of the undisturbed specimens due to the difference of the arrangement of the aggregate particles in the mixes while their weight is still the same. The Bulk Specific Gravity of the undisturbed specimen is then lower than that of the disturbed specimen.

Theoretically, if the air voids obtained from the disturbed specimen is subtracted from its actual volume in order to obtain its actual solid volume, the Maximum Theoretical Specific Gravity computed from the actual solid volume will be the same as obtained from the undisturbed

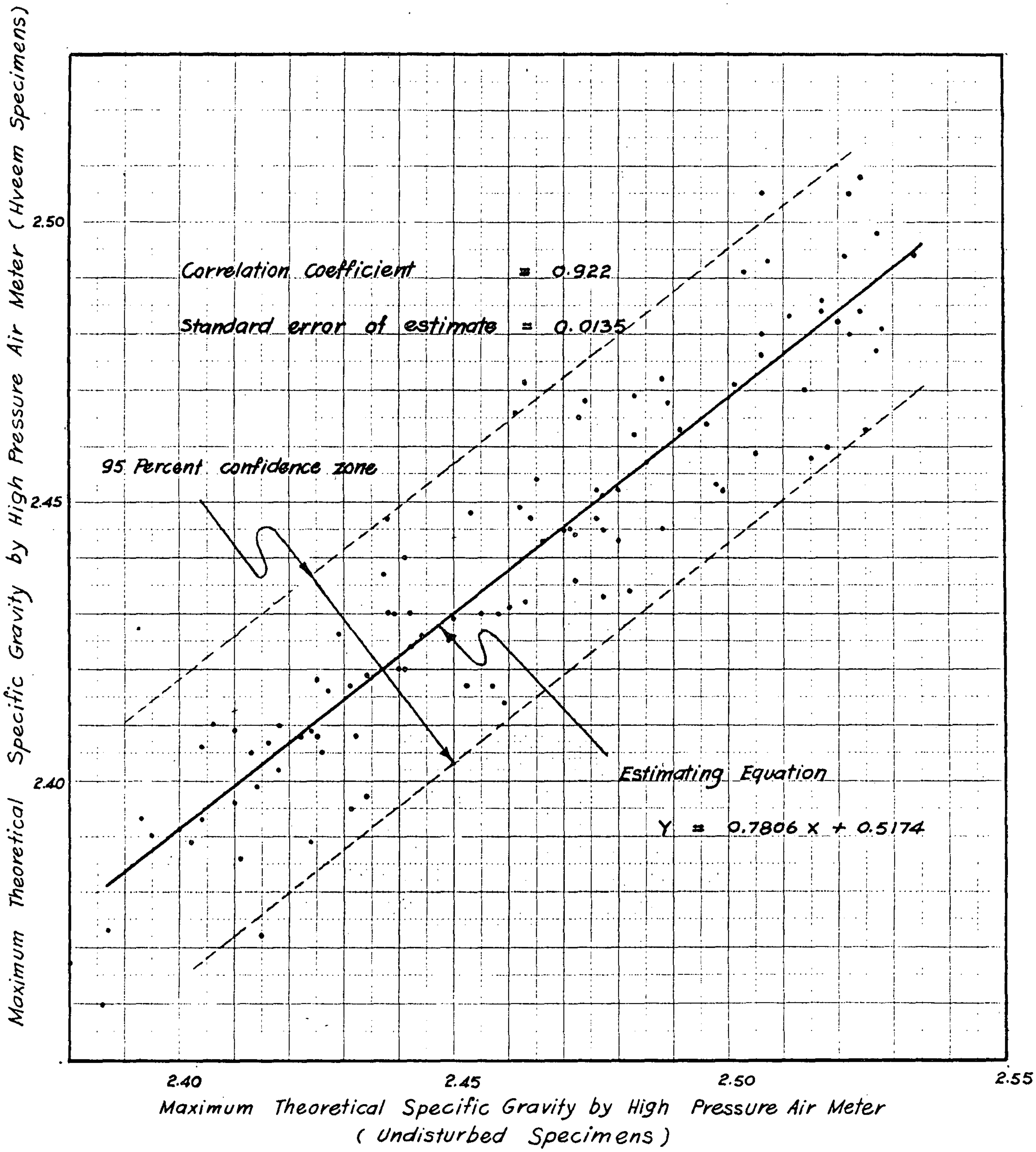


FIG. 5.7 CORRELATION BETWEEN MAXIMUM THEORETICAL SPECIFIG GRAVITY OF MIXTURES OBTAINED FROM UNDISTURBED SPECIMENS WITH THOSE OBTAINED FROM DISTURBED (HVEEM) SPECIMENS BY HIGH PRESSURE AIR METER.

specimen. In this study, the actual volume of the disturbed specimens were not determined and assumed to be the same as that of the undisturbed specimens. The Maximum Theoretical Specific Gravities obtained from the disturbed specimens are then lower than those obtained from the undisturbed specimens and cannot be used to represent the property of the mix. However, the correlation is still valid as one can predict the Maximum Theoretical Specific Gravity of an undisturbed specimen when the Maximum Theoretical Specific Gravity of a disturbed specimen (computed by ignoring volume changed) is known.

The results of the correlation is shown in Fig. 5.7, and the statistical interpretation can be made in the same way as given in the previous sections.

5.8 Correlation between Maximum Theoretical Specific Gravity obtained from disturbed specimens by high pressure air meter with those calculated from the I.S.H.C's Effective Specific Gravity of aggregate.

The correlation is shown in Fig. 5.8. The statistical interpretation can be made in the same way as given in Section 5.5.

5.9 Comparison of Composite Gradation

There are many ways to analyze or described gradation differences. The different methods devised to try to convey functions concerning gradation effects vary with the authors purpose or use of such aggregates.

For this study of asphaltic concrete surface mixes the author chose to compare the following methods of gradation

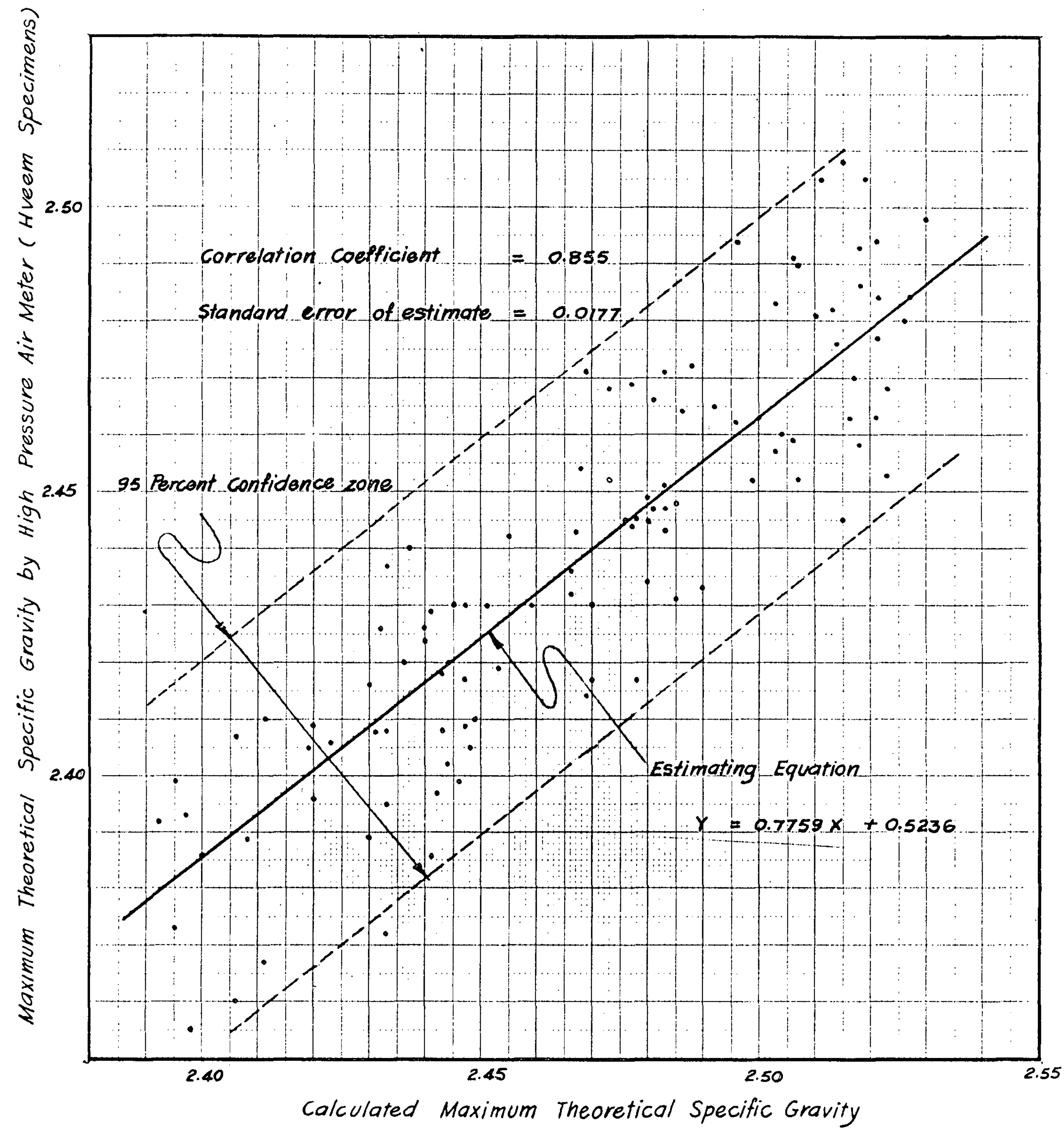


FIG. 5.8 CORRELATION BETWEEN MAXIMUM THEORETICAL SPECIFIG GRAVITY OF MIXTURES CALCULATED FROM I.S.H.C.'S EFFECTIVE SPECIFIG GRAVITY OF AGGREGATE WITH THOSE OBTAINED FROM DISTURBED (HVEEN) SPECIMENS BY HIGH PRESSURE AIR METER.

analysis. They are Hudson ($\bar{A}$), Relative Surface Area, Uniformity Coefficient, Fineness Modulus.

Hudson ($\bar{A}$) - The term for a factor which expresses the relative coarseness of an aggregate gradation in a single number. It is found by summing the percentages passing the 1-1/2 in., 3/4 in., 3/8 in., No. 4, No. 8, No. 30, No. 50, No. 100, and No. 200 sieves and dividing by 100.

Relative Surface Area - It is a value in terms of square feet of surface area per pound of an aggregate. It is found by summing the product of the percentages passing and the appropriate surface area - factors.

Uniformity Coefficient - It is a ratio of the particle diameter at the 60 per cent finer point to that at the 10 per cent finer point on the gradation curve.

Fineness Modulus (FM) - It is an empirical factor obtained by adding the total percentages of a sample of the aggregate retained on each of the No. 100, No. 50, No. 30, No. 16, No. 8, No. 4, 3/8 in., 3/4 in., 1-1/2 in., and larger increasing in the ratio of 2 to 1 and dividing by 100.

The gradation factors are shown in Table 5.9.1. It is felt that the relative surface area is more sensitive to the variation in the aggregate gradation through this research study than the Hudson ($\bar{A}$) or the Fineness Modulus.

TABLE 5.9.1 RESULTS OF THE AGGREGATE PARAMETERS STUDY

| Stone | Grada-tion | Hudson ($\overline{A}$) | | Rel.Surf.Area Sq.ft./lbs. | | Unif.Coeff. (approx.) | | Fineness Modulus | |
|---|---|---|---|---|---|---|---|---|---|
| | | 3/4" Mix | 3/8" Mix | 3/4" Mix | 3/8" Mix | 3/4" Mix | 3/8" Mix | 3/4" Mix | 3/8" Mix |
| Cooney | 1 | 4.746 | 5.595 | 25.8 | 37.8 | 23 | 18 | 5.254 | 4.405 |
| | 2 | 4.750 | 5.661 | 30.6 | 42.4 | 28 | 27 | 5.250 | 4.339 |
| | 3 | 4.765 | 5.704 | 38.5 | 47.9 | 58 | 37 | 5.235 | 4.296 |
| Ft. Dodge | 1 | 4.713 | 5.753 | 24.1 | 39.2 | 24 | 14 | 5.287 | 4.247 |
| | 2 | 4.712 | 5.810 | 27.7 | 46.8 | 30 | 31 | 5.288 | 4.190 |
| | 3 | 4.671 | 5.811 | 32.5 | 52.7 | 36 | 45 | 5.329 | 4.189 |
| Douds | 1 | 4.692 | 5.741 | 26.6 | 37.0 | 26 | 11 | 5.308 | 4.259 |
| | 2 | 4.692 | 5.844 | 30.3 | 45.8 | 30 | 23 | 5.308 | 4.156 |
| | 3 | 4.693 | 5.814 | 35.9 | 51.6 | 53 | 46 | 5.307 | 4.186 |
| Schildberg | 1 | 4.606 | 5.810 | 23.6 | 38.5 | 18 | 10 | 5.394 | 4.190 |
| | 2 | 4.656 | 5.805 | 29.2 | 44.7 | 26 | 21 | 5.344 | 4.195 |
| | 3 | 4.588 | 5.944 | 32.7 | 49.7 | 33 | 43 | 5.412 | 4.056 |
| Clarke | 1 | 4.728 | 5.648 | 27.0 | 34.3 | 28 | 11 | 5.272 | 4.352 |
| | 2 | 4.794 | 5.713 | 32.1 | 41.1 | 30 | 17 | 5.206 | 4.287 |
| | 3 | 4.643 | 5.669 | 34.7 | 46.4 | 37 | 32 | 5.357 | 4.331 |
| | S* | 4.675 | 5.755 | 36.1 | 51.1 | 59 | 48 | 5.325 | 4.245 |

* Apparently Ideal Centerline of Specification

TABLE 5.9.2 RELATIONSHIP BETWEEN MARSHALL STABILITY AND RELATIVE SURFACE-AREA OF AGGREGATE

| | | 3/4 inch Mix | | 3/8 inch Mix | |
|---|---|---|---|---|---|
| Stone | Gradation | Rel. Surf. Area Sq. ft./lbs. | Marshall Sta. in 100 lbs. @ 5% A.C. | Rel. Surf. Area Sq. ft./lbs. | Marshall Sta. in 100 lbs. @ 6% A.C. |
| Cooney | 1 | 25.8 | 12.5 | 37.8 | 17.5 |
| | 2 | 30.6 | 20.0 | 42.4 | 20.5 |
| | 3 | 38.5 | 23.0 | 47.9 | 23.0 |
| Ft. Dodge | 1 | 24.1 | 11.0 | 39.2 | 11.0 |
| | 2 | 27.7 | 17.5 | 46.8 | 19.0 |
| | 3 | 32.5 | 23.5 | 52.7 | 21.0 |
| Douds | 1 | 26.6 | 11.5 | 37.0 | 11.0 |
| | 2 | 30.3 | 15.5 | 45.8 | 19.0 |
| | 3 | 35.9 | 22.0 | 51.6 | 21.0 |
| Schildberg | 1 | 23.6 | 8.5 | 38.5 | 7.5 |
| | 2 | 29.2 | 14.0 | 44.7 | 13.5 |
| | 3 | 32.7 | 19.0 | 49.7 | 18.5 |
| Clark | 1 | 27.0 | 10.5 | 34.3 | 9.6 |
| | 2 | 32.1 | 17.0 | 41.1 | 16.0 |
| | 3 | 34.7 | 22.3 | 46.4 | 21.5 |

The value of the Uniformity Coefficient is approximate. This is because exact diameters of the particle at the 60 per cent finer point and the 10 per cent finer point can not be found from the gradation curve, then the coefficient is inadequately precise.

The relationships between the relative surface area of aggregate and the Marshall Stability of the mixes made in this study have been investigated as shown in Table 5.9.2 and Fig. 5.9.2. The average rate of increase of the Marshall Stability is approximately 100 lbs. per unit of increase of the surface area (lbs. per Sq. ft./lbs.) for both 3/4 and 3/8 inch mix based on 5 and 6 per cent asphalt respectively.

No relationship can be found between the relative surface area of aggregate and the Hveem Stability of the mix. The Hveem Stability is neither sensitive to the contents of sand and fine fraction of stone (-No. 8) which varied in the mixes of gradation 1, 2 and 3. This will be discussed later in 5.10.

It is obvious that the relative surface area is sufficiently sensitive to be an indicator to reflect the variation in aggregate gradation for this study.

## 5.10 Effect of gradation to Hveem Stability

Now the relationship between voids in mineral aggregate (V.M.A.) and aggregate gradation will be considered. The aggregates incorporated in mixes of low V.M.A. have a better gradation than those of high V.M.A. when their maximum size is the same. Three gradations have been investigated as described in the testing procedure. By studying all

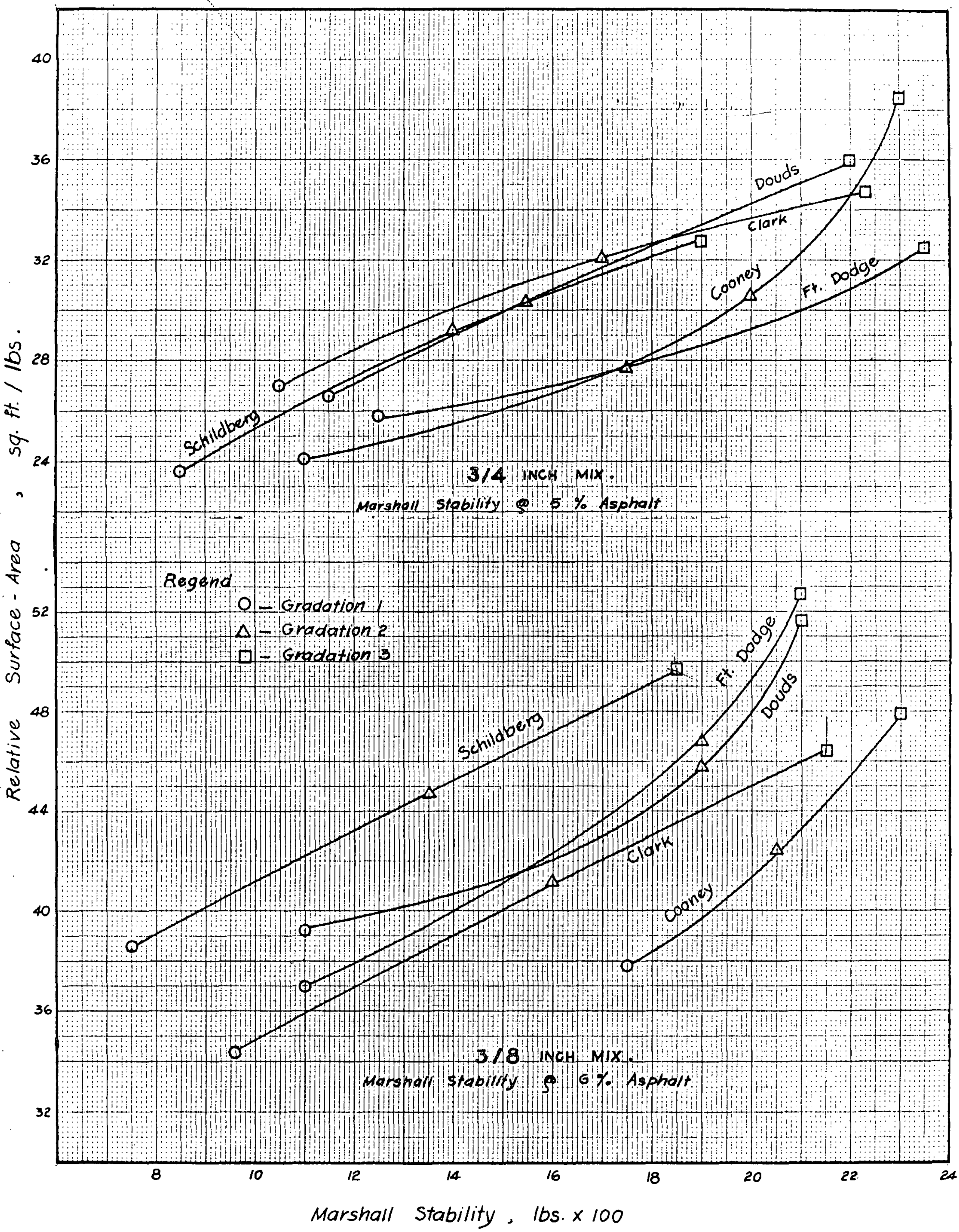


FIGURE 5.9.2 RELATIONSHIP BETWEEN MARSHALL STABILITY AND RELATIVE SURFACE - AREA OF AGGREGATE

available data, the general discussion can be made as follows:

5.10.1 The mix of Gradation 3 which is apparently nearest the ideal centerline of specification should give the best stability. This is because the mixes of Gradation 3 have less V.M.A. than the mixes of Gradations 1 and 2. But the results indicate that the above statement is not always true. For some of them give lower stability than those mixes of Gradations 1 and 2. The comparison is shown in Fig. 11 to Fig. 22. It appears that the Hveem stability is neither sensitive to the decrease of sand content nor the increase of fine fraction of stone (-No. 8).

5.10.2 The mix of Gradation 3 is slightly more sensitive in terms of Hveem stability when the asphalt content is varied from low to high.

5.10.3 It is quite difficult to give any disposition as to which stone is the best as far as the Hveem stability is concerned since the stability of mixes of the various stone studied fall within approximately the same range. For example at 5.0 and 5.5 per cent asphalt content, the average of the Hveem Stability for all mixes approximates 50 and 35 as shown in Figs. 11, 15, 17, 19, 21 and Figs. 16, 18, 20, 22 for 3/4 and 3/8 inch mixes respectively. This is because of no large difference in the properties of the stones used in this study. The table of Physical and Chemical properties of the stones are shown in Table 1.

5.11 <u>Effect of gradation on Marshall Stability.</u>

5.11.1 The mix of Gradation 3 gives the best stability consistently when compared to those of Gradations 1 and 2, as shown in Figs. 11, 15, 17, 19, 21 and Figs. 12, 16, 18

TABLE 5.11 RELATIONSHIP BETWEEN PER CENT V.M.A. AND MARSHALL STABILITY

| Stone | Test Properties | 3/4" Mix @ 5% Asphalt Gradation 1 | 2 | 3 | 3/8" Mix @ 6% Asphalt Gradation 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Cooney | V.M.A. | 17.3 | 16.1 | 15.1 | 16.7 | 15.8 | 15.9 |
| | *Stability | 12.5 | 20.0 | 23.0 | 17.5 | 20.5 | 23.0 |
| Ft. Dodge | V.M.A. | 16.7 | 15.4 | 13.4 | 19.1 | 16.5 | 16.0 |
| | *Stability | 11.0 | 17.5 | 23.5 | 11.0 | 19.0 | 21.0 |
| Douds | V.M.A. | 17.8 | 16.9 | 16.0 | 20.5 | 18.6 | 18.2 |
| | *Stability | 11.5 | 15.5 | 22.0 | 10.0 | 19.0 | 24.0 |
| Schildberg | V.M.A. | 19.4 | 18.5 | 18.4 | 22.9 | 22.4 | 21.7 |
| | *Stability | 8.5 | 14.0 | 19.0 | 7.5 | 13.5 | 18.5 |
| Clark | V.M.A. | 17.8 | 16.0 | 15.7 | 20.8 | 18.8 | 18.1 |
| | *Stability | 10.5 | 17.0 | 22.3 | 9.6 | 16.0 | 21.5 |

* Marshall Stability in 100 lbs.

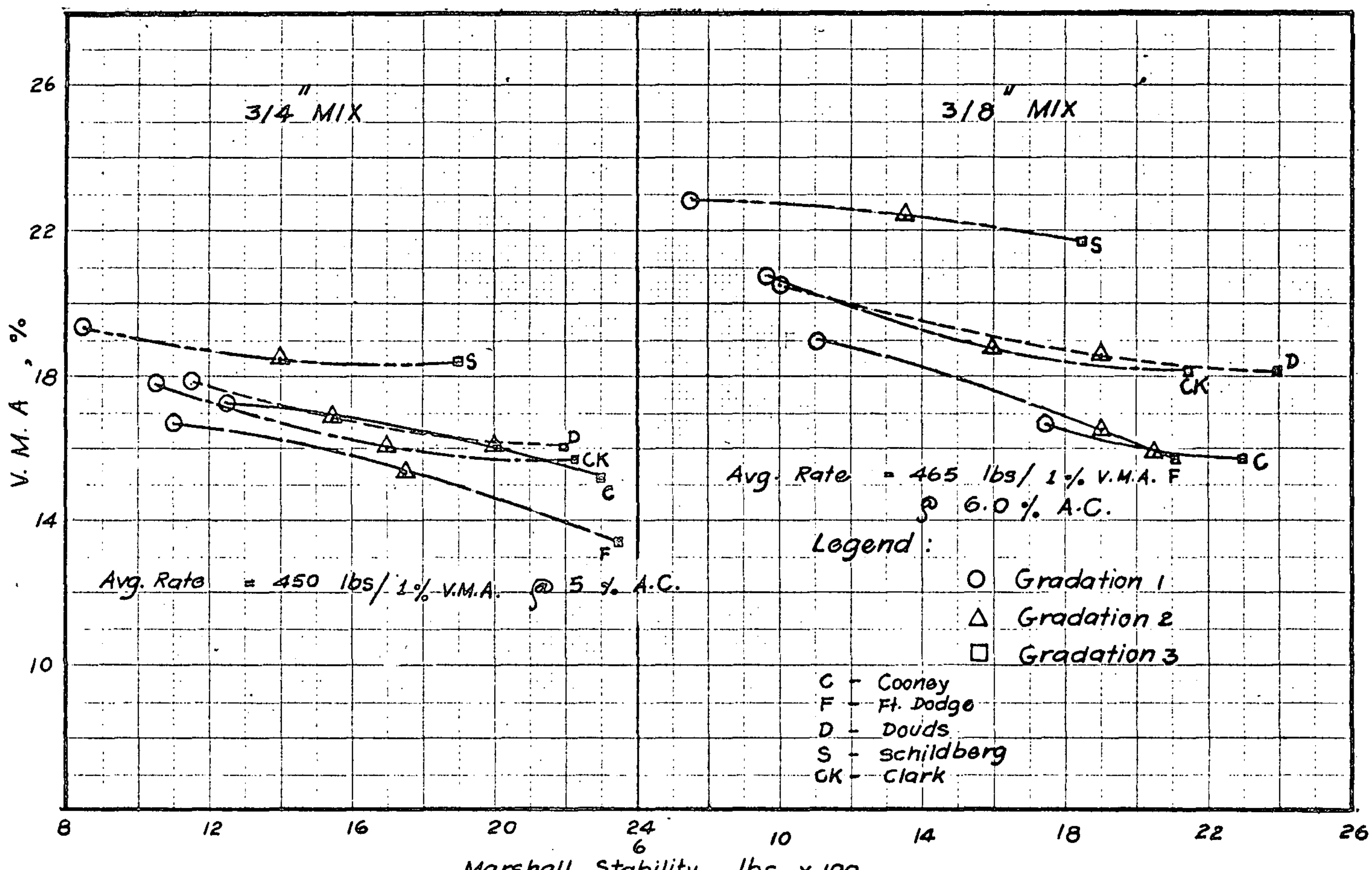


FIG. 5.11 VARIATION OF PERCENT V.M.A. WITH MARSHALL STABILITY

20, 22 for 3/4 inch mixes and 3/8 inch mixes respectively. The mixes containing a high per cent V.M.A. always has less Marshall Stability. Relationship of per cent V.M.A. and Marshall Stability are shown in Fig. 5.11 for both 3/4 and 3/8 inch mixes.

From Fig. 5.11, the average rate of increase is 450 and 465 lbs./per cent of decrease of V.M.A. based on 5 and 6 per cent asphalt content for 3/4 and 3/8 inch mixes respectively. The general conclusion can be drawn that per cent V.M.A. which is related to the gradations of total aggregates, affects the Marshall Stability significantly.

5.11.2 Marshall Stability of the mix of Gradation 3 is more sensitive than that of the mix of Gradations 1 and 2, while the rate of flow change per per cent asphalt change is apparently the same for all mixes.

5.12 Comparison between Hveem and Marshall Stability.

5.12.1 No direct correlation can be made between the two tests.

5.12.2 Increasing the V.M.A. caused by increasing the per cent of aggregate passing the No.'s 8, 16 and 30 sieves while decreasing the per cent of aggregate passing the No.'s 50, 100 and 200 sieves affect Marshall Stability significantly but not Hveem Stability.

5.12.3 The higher density of the mix gives higher Marshall stability consistently but is not consistent for Hveem stability.

5.12.4 The flow in the Marshall test of the mix of Gradation 3 is more sensitive than those of the mixes of

Gradations 1 & 2, while the number of displacement turns in the Hveem test of the mix of Gradations 1, 2 and 3 is apparently the same.

5.13 Comparison between 3/4 and 3/8 inch mixes.

5.13.1 There is no large difference between 3/4 and 3/8 inch mixes as far as the stability is concerned.

5.13.2 Per cent V.M.A. in 3/8 inch mixes are higher than those in 3/4 inch mixes. They are also higher in air void contents.

5.14 Comparison between 50 and 75 blow Marshall compaction.

5.14.1 A fifty per cent increase in compactive effort causes an increase of approximately one per cent in the unit weight of specimens for the 3/4 inch mixes with no significant increase indicated for the 3/8 inch mixes, as shown in Figs.11, 12, 13 and 14.

5.14.2 At the same asphalt content, approximately half a per cent decrease of air voids and V.M.A. was noticed when the compaction was increased from 50 blows to 75 blows for the 3/4 inch mixes, while approximately a one per cent decrease of air voids and two per cent decrease in V.M.A. for the 3/8 inch mixes as shown in Figs.11, 12, 13 and 14.

5.14.3 For the 3/4 inch mixes, the Marshall stability increased approximately 30 per cent from the mixes of 50 blows to those of 75 blows, when they are determined at 5 per cent asphalt content. For 3/8 inch mixes, the Marshall stability increased approximately 20 per cent for the mixes of Gradations 1 and 2 while only approximate 6 per cent for the mixes of Gradation 3, when they are determined at 5.5 per cent asphalt.

5.14.4 No significant change in Hveem stability of 50 and 75 blow mixes was indicated for either the 3/4 or the 3/8 inch mixes.

5.15 <u>The evaluation of the test results concerning our present specification.</u>

All data has been evaluated based on the assumption that for all the mixes, at least 4.5 per cent asphalt content is necessary to insure that the pavement will not crack due to an insufficient asphalt content. The air voids in the mixes should be more than 3 per cent in order to insure that flushing or bleeding will not occur when the pavement is used by normal traffic. Besides those assumptions, all mixes must have the Hveem horizontal pressure less than 60 p.s.i. at 400 p.s.i. vertical pressure. Evaluation is shown in Table 5.15.2 for 3/4 inch mixes and Table 5.15.3 for 3/8 inch mixes.

TABLE 5.15.1 I.S.H.C's Design Criteria

| Properties of Mix | Size of Mix 3/4 inch | Size of Mix 3/8 inch |
|---|---|---|
| Air Voids | 4-10 | 5-12 |
| Hveem Hor. P.S.I. @ 400 Vert. P.S.I. | Less than 60 | Less than 60 |
| Basic Asphalt Content | 5.25 | 6.25 |

5.15.1 Basic per cent asphalt content.

The per cent asphalt content selected for the mixes of each gradation and stones are compared as shown in Fig. 5.15, for both 3/4 and 3/8 inch mixes. From the figures, it can be seen that 5.0 and 5.5 per cent asphalt are good averages

TABLE 5.15.2 EVALUATION OF 3/4 INCH MIXES

| Stone | Gradation No. | Min. V.M.A. | % Voids @ 4.5 % A.C. | % A.C. @ Hveem Hor. P.S.I. = 60 | % A.C. @ % Voids = 3.0 | Range of % A.C. Selected | % Voids Corresponding to Range of % A.C. | Marshall Stability Corresponding to Range of % A.C. (lbs.) |
|---|---|---|---|---|---|---|---|---|
| Cooney | 1 | 16.6 | 8.3 | 6.3 | 6.3 | 4.5 - 6.3 | 8.3 - 3.0 | 1250 - 1230 |
| | 2 | 16.0 | 6.6 | 5.8 | 5.8 | 4.5 - 5.8 | 6.6 - 3.0 | 2020 - 1850 |
| | 3 | 15.1 | 5.4 | 5.6 | 5.5 | 4.5 - 5.5 | 5.4 - 3.0 | 2570 - 2100 |
| Ft. Dodge | 1 | 16.3 | 7.4 | 6.8 | 6.1 | 4.5 - 6.1 | 7.4 - 3.0 | 1070 - 1120 |
| | 2 | 15.2 | 6.2 | 5.2 | 5.5 | 4.5 - 5.2 | 6.2 - 3.8 | 1810 - 1750 |
| | 3 | 15.4 | 3.6 | 5.0 | 4.7 | 4.5 - 4.7 | 3.6 - 3.0 | 2530 - 2500 |
| Douds | 1 | ≅16.7 | 8.5 | 6.4 | 6.2 | 4.5 - 6.2 | 8.5 - 3.0 | 1100 - 1300 |
| | 2 | ≅16.1 | 7.3 | 6.5 | 6.2 | 4.5 - 6.0 | 7.3 - 3.0 | 1650 - 1500 |
| | 3 | 16.0 | 6.4 | 5.3 | 5.7 | 4.5 - 5.3 | 6.4 - 3.8 | 2350 - 2050 |
| Schildberg | 1 | ≅18.5 | 7.9 | 6.7 | 6.3 | 4.5 - 6.3 | 10.0 - 3.0 | 820 - 950 |
| | 2 | 17.3 | 7.4 | 7.0 | 5.9 | 4.5 - 5.9 | 7.4 - 3.0 | 1350 - 1400 |
| | 3 | 17.8 | 6.5 | 7.1 | 5.9 | 4.5 - 5.9 | 6.5 - 3.0 | 1950 - 1800 |
| Clarke | 1 | ≅17.1 | 8.5 | >7.0 | 6.5 | 4.5 - 6.5 | 8.5 - 3.0 | 1000 - 1300 |
| | 2 | ≅15.7 | 6.8 | 6.0 | 5.8 | 4.5 - 5.8 | 6.8 - 3.0 | 1700 - 1800 |
| | 3 | 15.6 | 6.2 | 6.0 | 5.6 | 4.5 - 5.6 | 6.2 - 3.0 | 2300 - 2000 |

TABLE 5.15.3 EVALUATION OF 3/8 INCH MIXES

| Stone | Gradation No. | Min. V.M.A. | % Voids @ 4.5 % A.C. | % A.C. @ Hveem Hor. P.S.I. = 60 | % A.C. @ % Voids = 3.0 | Range of % A.C. Selected | % Voids Corresponding to Range of % A.C. | Marshall Stability Corresponding to Range of % A.C. (lbs.) |
|---|---|---|---|---|---|---|---|---|
| Cooney | 1 | 16.7 | 9.2 | 6.3 | 6.3 | 4.5 - 6.3 | 9.2 - 3.0 | 1600 - 1700 |
| | 2 | 15.8 | 7.7 | 5.5 | 5.8 | 4.5 - 5.5 | 7.7 - 3.8 | 2550 - 2300 |
| | 3 | 15.8 | 8.2 | 5.5 | 5.8 | 4.5 - 5.5 | 8.2 - 3.8 | 3200 - 2750 |
| Ft. Dodge | 1 | 19.0 | 10.4 | 5.5 | 6.9 | 4.5 - 5.5 | 10.4 - 7.4 | 1200 - 1150 |
| | 2 | 16.4 | 8.7 | 5.9 | 6.0 | 4.5 - 5.9 | 8.7 - 3.2 | 1900 - 1950 |
| | 3 | 15.6 | 6.9 | 5.2 | 5.5 | 4.5 - 5.2 | 6.9 - 3.7 | 2800 - 2800 |
| Douds | 1 | ≅20.2 | 12.0 | 5.0 | ≅7.7 | 4.5 - 5.0 | 12.0 - 10.1 | 950 - 950 |
| | 2 | 18.5 | 10.2 | 5.9 | ≅6.8 | 4.5 - 5.9 | 10.2 - 5.5 | 1900 - 1950 |
| | 3 | 18.0 | 9.6 | 5.8 | ≅6.6 | 4.5 - 5.8 | 9.6 - 5.2 | 2350 - 2500 |
| Schildberg | 1 | 22.7 | 13.9 | 6.0 | ≅8.5 | 4.5 - 6.0 | 13.9 - 10.4 | 800 - 750 |
| | 2 | 22.0 | 13.6 | 7.7 | ≅8.2 | 4.5 - 7.7 | 13.6 - 5.0 | 1400 - 1200 |
| | 3 | 21.4 | 13.4 | 7.8 | ≅8.0 | 4.5 - 7.8 | 13.4 - 3.7 | 1850 - 1650 |
| Clarke | 1 | 20.7 | 12.0 | 5.7 | 7.9 | 4.5 - 5.7 | 12.0 - 8.9 | 950 - 950 |
| | 2 | ≅18.3 | 10.4 | 6.1 | 6.6 | 4.5 - 6.1 | 10.4 - 5.3 | 2050 - 1550 |
| | 3 | ≅18.0 | 10.7 | 5.5 | 6.5 | 4.5 - 5.1 | 10.7 - 6.8 | 2150 - 2250 |

for all mixes and stones used in this study for 3/4 and 3/8 inch mixes respectively. It must be kept in mind that all stones used in this study were low absorptive stones whose water absorption is less than one per cent.

5.15.2 Air Voids

The ranges of per cent air voids selected from Table 5.15.2 and Table 5.15.3 of all mixes have been compared as shown in Fig. 5.15 for both 3/4 and 3/8 inch mixes.

It is suggested that the most suitable range of per cent air voids should be 3 to 9 and 4 to 12 for 3/4 and 3/8 inch mixes respectively. Within the ranges selected, 4 to 6 and 5 to 7 per cent air voids are the most effective for all the mixes of 3/4 and 3/8 inch mixes respectively.

The most suitable range of air voids obtained from this study for 3/4 and 3/8 inch mixes are in substantial agreement with the present (Table 5.15.1). Hence, no comment will be made for the modification of our present specifications.

5.15.3 Stability

According to the evaluation of the mix which is based on the assumption that Hveem Horizontal pressure is less than 60 p.s.i.; within the range of per cent asphalt selected Marshall stability is varied widely due to the effect of aggregate gradation in the mixes. The mixes of Gradations 2 and 3 are suitable for all traffic conditions because Marshall Stability is higher than 1200 lbs. which is a minimum requirement for heavy duty traffic with the flow range of 8 to 16. The mix of gradation 1 sometimes has low Marshall stability and the mix cannot be used to

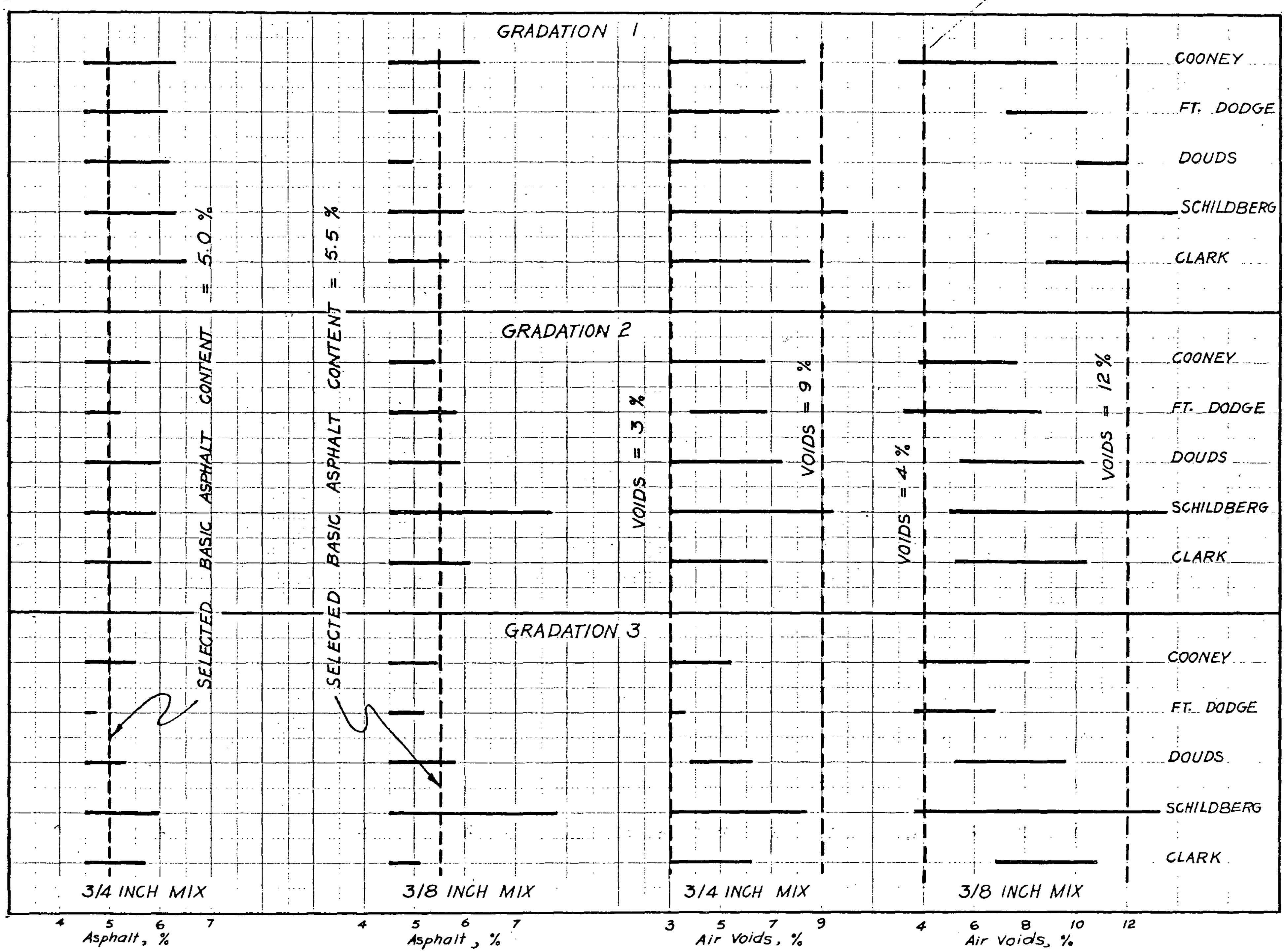


FIGURE 5.15 COMPARISON OF ASPHALT CONTENT AND AIR VOIDS RANGES WHICH SATISFIED TO THE HVEEM STABILITY ( HVEEM HOR. P.S.I. @ 400 VERT. P.S.I. < 60)

serve heavy duty traffic even though the Hveem Stability meets the requirements of the specification.

To insure that we have the best pavement, we possibly need a specification for Marshall Stability in addition to Hveem stability.

## 6.0 SUMMARY

1. Asphalt absorption calculated by using the I.S.H.C's Effective Specific Gravity is a good working average which can be used effectively for the mixes employing relatively low absorptive stone.

2. Good correlations were found between the following properties:

- Air voids calculated from Measured Bulk Specific Gravity of aggregate and air voids determined by high pressure air meter.
- Calculated air voids from Calculated Bulk Specific Gravity and Measured Bulk Specific Gravity of aggregates.
- Air voids obtained from undisturbed and disturbed (Hveem) specimens by high pressure air meter.
- Air voids calculated from Measured Bulk Specific Gravity of aggregates and air voids obtained from disturbed (Hveem) specimens by high pressure air meter.
- Maximum Theoretical Specific Gravity of compacted mixtures calculated from the I.S.H.C's Effective Specific Gravity of aggregates and those determined by high pressure air meter.
- Maximum Theoretical Specific Gravity of compacted mixtures obtained from undisturbed and disturbed specimens by high pressure air meter.

◦ Maximum Theoretical Specific Gravity of compacted mixtures calculated from the I.S.H.C's Effective Specific Gravity of aggregate and those obtained from undisturbed specimens by high pressure air meter.

3. The relative surface area of aggregate is a sufficiently sensitive indicator to reflect the variation in aggregate gradations used in this study.

4. No large difference in the Hveem Stability Test was noticed as the aggregate gradation changes in this study varied.

5. The greater the density of the mixture, the more the sensitivity of stability tests will be noticed.

6. V.M.A. in mixes is reflected directly in the Marshall Stability Test.

7. The higher density mixes gave higher Marshall Stability consistently but were not consistent for Hveem Stability.

8. No direct correlation in the changes in mixes used in this study can be found between the Hveem and the Marshall Stability.

9. V.M.A. in 3/8 inch mixes are higher than those in 3/4 inch mixes.

10. At the same asphalt content, the 3/8 inch mixes had a higher void content than the 3/4 inch mixes.

11. There is no large difference between 3/4 and 3/8 inch mixes as far as the stability, both Marshall and Hveem, is concerned.

12. Increase of the compactive effort apparently causes an increase in the density and the Marshall Stability of the mixes but does not significantly change the Hveem

Stability.

13. The range of air voids is recommended to be 3 to 9 and 4 to 12 per cent for 3/4 and 3/8 inch mixes respectively.

14. In addition to the Hveem stability requirement, the Marshall stability appears to be a good verification in design studies.

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## 8.0 ACKNOWLEDGEMENT

We wish to acknowledge the assistance of Testing Engineer, Bernard C. Brown, for his time spent in suggesting testing procedures and his aid in the preparation of this report to help make this research possible.

# APPENDIX A

To prove that: $\mathcal{M}ac = \left(\frac{1}{Gb} - \frac{1}{Gv}\right) . \gamma ac . 100$

Where $\mathcal{M}ac$ = Asphalt Absorption in lbs/100 lbs of aggregates.

Gb = Bulk Sp. Gr. of Aggregates.

Gv = Effective Sp. Gr. of Aggregates.

$\gamma ac$ = Asphalt Sp. Gr.

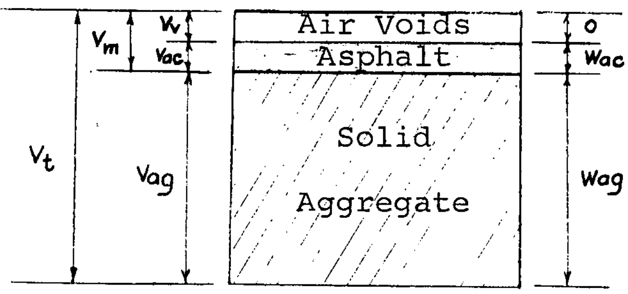



Fig. Graphical Representation of an Aggregate Particle.

Since: Bulk Sp. Gr. of Aggregate (Gb) $= \frac{Wag}{Vt}$

Apparent Sp. Gr. of Aggregate (Ga) $= \frac{Wag}{Vag}$

or $= \frac{Wag}{Vt - Vm}$

Effective Sp. Gr. of Aggregate (Gv) $= \frac{Wag}{Vt - Vac}$.

or $\frac{Wag}{Vag + Vv}$

Where Wag = Dry Weight of Aggregate

Vag = Solid volume of aggregate (excluding voids)

Vt = Total volume of aggregate (including voids)

Wac = Weight of asphalt absorbed in aggregate

Vac = Volume of asphalt absorbed in aggregate

Vm = Voids in aggregate

= Voids of water permeable pore space in aggregate

Vv = Voids which are not absorbed by asphalt

Since $\mu ac = \frac{Wac}{Wag} .100$

Then $\mu ac = \frac{\gamma ac \, . \, Vac}{Wag} .100$

$$= \frac{\gamma ac. \; Vac. \; Wag.}{Vt. \; (Vt - Vac)} \; . \; \frac{Vt. \; (Vt - Vac)}{Wag. \; Wag.} \; .100$$

$$= \frac{\gamma ac. [Vt - (Vt - Vac)] \; Wag.}{Vt. (vt - Vac)} \; . \frac{1}{Wag/_{Vt} . Wag/_{Vt} - Vac} \; .100$$

$$= \gamma ac \left[ \frac{Wag}{(Vt - Vac)} - \frac{Wag}{Vt} \right] . \frac{1}{(Wag/_{Vt}) \; . \; (Wag/_{Vt - Vac})} \; .100$$

$$= \gamma ac. \; (Gv - Gb) \; . \; \frac{1}{Gv. \; Gb.} \; .100$$

$$= \left( \frac{1}{Gb} - \frac{1}{Gv} \right) . \; \gamma ac. \; .100$$

## APPENDIX B

To prove that the method of calculation for the effective Specific Gravity of aggregate in compacted paving mixtures by the I.S.H.C. implies that approximately fifty per cent of the water permeable voids pore space is absorbed by asphalt.

According to A.S.T.M. C 127-59 (AASHO T85-60)

$$\text{Bulk Sp. Gr. of aggregate (Gb)} = \frac{A}{B-C} \tag{1}$$

$$\text{Bulk Sp. Gr. (Saturated Surface-Dry Basis) (Gbs)} = \frac{B}{B-C} \tag{2}$$

$$\text{Apparent Sp. Gr. (Ga)} = \frac{A}{A-C} \tag{3}$$

$$\text{and Per Cent of water absorption } (\mu w) = \frac{B-A}{A} \cdot 100 \tag{4}$$

Where: A = weight in grams of oven dry aggregate, in air

B = weight in grams of saturated surface-dry aggregate, in air

C = weight in grams of saturated surface-dry aggregates, in water

From (1) $$\frac{1}{Gb} = \frac{B-C}{A} \tag{5}$$

From (2) $$\frac{1}{Ga} = \frac{A-C}{A} \tag{6}$$

(5) - (6) $$\frac{1}{Gb} - \frac{1}{Ga} = \frac{B-C}{A} - \frac{A-C}{A} = \frac{B-A}{A}$$

Then: $$\mu w = \left(\frac{1}{Gb} - \frac{1}{Ga}\right) \cdot 100 \tag{7}$$

From Appendix A: $$\mu ac = \left(\frac{1}{Gb} - \frac{1}{Gv}\right) \cdot \gamma ac. \; 100 \tag{8}$$

Since, the effective Specific Gravity of aggregate is assumed to be an average of Bulk and Apparent Specific Gravity of aggregate, i.e.

$$Gv = 1/2\ (Ga + Gb)$$

Substituting Gv in (8)

then,

$$\mu ac = \frac{1}{Gb} - \frac{2}{(Ga + Gb)} \cdot \gamma ac.\ 100 \qquad (9)$$

Dividing (9) by (7)

$$\frac{\mu ac}{\mu w} = \frac{Ga \cdot \gamma ac}{(Ga + GB)}$$

$$\cong 0.50$$

## APPENDIX C

The Iowa State Highway Commission's Method for determination of Specific Gravity and absorption of aggregates.

### I <u>Specific Gravity and Absorption of Coarse Aggregate</u>

A. Scope

This method of test covers the procedure for determining the specific gravity and absorption of coarse aggregate by the pycnometer method.

B. Apparatus

1. Two quart pycnometer (Mason jar).
2. A constant temperature water bath capable of maintaining a temperature of 72 $\pm$ 1°F.
3. A balance having a capacity of 5000 grams and sensitive to 0.5 gram.
4. Drying table with overhead electric fan.
5. Ventilated oven capable of maintaining a temperature between 212 and 230°F.
6. Absorbent cloth.
7. Compressed air.
8. 6 quart pans.

C. Sample

A sample of at least 2.1 kg. of the aggregate shall be reconstituted for testing. The sample as received is separated into its individual sizes using the inch, 3/4, 1/2, 3/8 and No. 4 sieves. All of the material passing the No. 4 sieve shall be discarded. The sample is then reconstituted by building the gradation back to the original gradation of the material as received.

D. Test Procedure

1. After thoroughly washing the sample to remove dust or other coatings from the surfaces of the particles, immerse it in water for a period of not less than 16 hours. Remove the sample from the water, rewash it and then roll it in a large absorbent cloth. Place on the drying table and dry to a saturated surface dry condition, stirring and turning the particles so they will dry evenly. The weight of the sample in the saturated surface-dry condition shall then be obtained and recorded. This and all subsequent weights shall be determined to the nearest 0.5 gram.

Note: As coarse aggregates approach the saturated surface dry condition there is ordinarily a rather definite change in the appearance of the particles. The glossy wet appearance changes to a dull finish with less luster, but the outer surfaces of the particles are dry and the inner portions are completely saturated.

2. Place the sample in a previously calibrated two-quart pycnometer containing about 2 inches of water in the bottom. Nearly fill the jar using water from the constant temperature bath. Rinse the jar top and the pyc top and screw the pyc top onto the jar tightly enough so that it will not leak when the pyc is filled with water. Roll the pyc to remove all of the air. Refill with water and repeat the rolling until all of the air is released. Place the constant temperature tank until it reaches a constant temperature of 72 $\pm$ 1°F.

3. Remove the jar from the tank and using compressed air blow all of the water from under the lip of the jar ring and with an absorbent cloth dry the exterior surface of the pyc. Then weigh and record the weight of the pyc, plus the weight of the sample plus enough water at 72° to fill the pyc.
4. Pour the sample from pycnometer into a previously tared six quart pan. Pour off excess water exercising care not to lose any particles. Place in oven for 16 hours or until dry. Remove from oven and record weight.

E. Calculations

See Specific Gravity Terms and Formulas Numbers 4 - 8 as described in IV.

II <u>Specific Gravity and Absorption of Fine Aggregates</u>

A. Scope

This method of test covers the procedure for determining the specific gravity and absorption of fine aggregates.

B. Apparatus

1. One quart pycnometer (Mason jar with glass pyc top).
2. Constant temperature water bath capable of maintaining 72 $\pm$ 1 degree F.
3. A balance having a capacity of 5000 grams and sensitive to 0.5 gram.
4. Drying table with overhead electric fan.
5. Ventilated oven capable of maintaining a temperature between 212 and 230 degrees F.
6. Hot plate.

7. Six quart pans.
8. Compressed air.
9. Spatula.
10. Absorbent cloth.

C. Sample

A representative sample of at least 1.1 kg. of the aggregate shall be obtained by quartering.

D. Test Procedure

1. Keep the sample covered with water for not less than 16 hours. Pour off the excess water being careful not to lose any of the sample. Place the sample in a six quart pan and put on a hot plate. Care should be taken not to over dry the sample. Heat only enough to remove the excess free moisture. Stir sample while drying until it stops tracking in the bottom of the pan, then empty it on the drying table and dry to a saturated surface dry condition. Stir and mix the sample while drying to permit it to dry evenly. A spatula will be used to determine when the saturated surface dry condition has been reached. (The fine particles will not adhere to the spatula when it is S.S.Dry).

Obtain and record the weight of the saturated surface dry sample. This and all subsequent weights shall be determined to the nearest 0.5 gram.

2. Place the sample in a previously calibrated one quart pycnometer which has about 2 inches of water in the bottom. Fill the jar nearly full of water (water from the constant temperature bath). Rinse the top of the jar and the pyc top and then screw pyc top onto the jar tightly enough to make a water-tight seal. (When using ground glass pyc tops,

it is not necessary to tighten pyc top to a predetermined calibration mark to obtain the same volume each time). Fill pyc jar with water and roll to remove the entrapped air. Fill with water and repeat until all of the air has been released. Place the jar and its contents in the constant temperature tank until it reaches a constant uniform temperature of 72 ± 1°F.

3. Remove the jar from the tank and using compressed air blow all of the water from under the lip of the jar ring. With an absorbent cloth dry the exterior surface of the pyc. Obtain the weight of the pyc, plus the sample, plus enough water to fill the pyc.

4. Pour sample from the pycnometer into a six quart pan. Pour off excess water from pan after sample has settled, being careful not to lose any of the sample. Place the sample in the oven for 16 hours or until completely dry. Remove from oven and weigh.

E. Calculations

See Specific Gravity Terms and Formulas Numbers 4 - 8 as described in IV.

III <u>Specific Gravity and Absorption of Combined Aggregates</u>

A. Scope

This method covers the procedure for determining the specific gravity of combined aggregates by the pycnometer method. The method for determining the absorption of the combined aggregates is also covered.

B. Apparatus

1. Two quart pycnometer (Mason jar).
2. A constant temperature water bath capable of main-

taining a temperature of 72 ± 1°F.

3. A balance having a capacity of 5000 grams and sensitive to 0.5 gram.
4. Drying table with overhead electric fan.
5. Ventilated oven capable of maintaining a temperature between 212 and 230°F.
6. Aspirator
7. Hot plate
8. Four quart pans
9. Six quart pans
10. No. 8 sieve
11. No. 200 sieve
12. Seven quart stainless steel pan
13. Compressed air
14. Absorbent cloth
15. Spatula

C. Sample

A representative sample of at least 1500 gram of the aggregate shall be obtained by quartering or by reconstituting (building-up) the sample for testing.

D. Test Procedure

1. Wash the sample on the No. 200 sieve saving all of the wash water. Split the sample on the No. 8 sieve. For the coarse portion (+ No. 8) follow procedure No. I as explained in Method of Test for Specific Gravity and Absorption of Coarse Aggregate, and for the -No. 8 to +No. 200 material follow procedure No. II described under Method of Test for Specific Gravity and Absorption of Fine Aggregate.

2. Let the wash water stand undisturbed until all the -200 particles settle to the bottom of the 7 quart stainless steel pan. Siphon the water from the pan and put pan and sample in the oven to dry.
3. Place the coarse and fine portions of the sample in a previously calibrated two quart pycnometer in which the dried -200 material has been placed (after obtaining its weight). Cover material with water and place on the aspirator to remove any entrapped air. This procedure can be expedited by rolling the sample within the pycnometer. The jar is then filled nearly full of water. The top of the jar and the pyc top are rinsed with water. Screw the pyc top onto the jar tightly enough to form a seal so that it will not leak. Fill the jar with water and place it into the constant temperature water bath until a constant temperature of 72 $\pm$ 1°F is otbained.
5. Determine the total sample weight including fine, coarse (both saturated surface dry) and the -200 portion (oven dried).
6. Pour sample from pycnometer into a previously tared 6 quart pan. Let stand until all the particles settle to the bottom. Siphon the water from the pan exercising care not to lose any of the sample particles. Place sample in the oven for 16 hours or until dry. Remove from oven and weigh and record weight.
7. Calculations

    See "Specific Gravity Terms and Formulas" Numbers 4 - 9 as described in IV.

## IV Specific Gravity Terms and Formulas

1. Specific gravity is defined "The ratio of the weight of a given volume of a substance to the weight of an equal volume of another substance which is taken as the standard". Water at 72°F is the standard substance for determining the specific gravity of aggregates.

2. Pycnometer - A container of constant volume generally a one, two, or four quart Mason fruit jar with the top ground flat. A glass top which is ground smooth so that it will form a tight seal with the top of the jar when placed together and tightened with a metal jar ring. The pyc top has an opening to add water.

3. P = Weight in grams of the pycnometer full of water at 72°F.
   S = Weight in grams of sample in moisture condition required.
   W = Weight of sample used plus weight of pycnometer plus weight of enough water at 72°F to fill the pycnometer (all in grams).

4. Bulk Specific Gravity (Saturated Surface Dry)

$$= \frac{S}{P+S-W} = \frac{\text{saturated surface dry weight}}{\text{saturated surface dry volume}}$$

S in both numerator and denominator is the weight of the sample in a saturated surface dry condition.

5. Bulk Specific Gravity (Dry weight)

$$= \frac{S}{P+S-W} = \frac{\text{Dry Weight}}{\text{Saturated Surface Dry Volume}}$$

S in numerator is oven dry weight of sample.

S in denominator is saturated surface dry weight of sample.

This specific gravity is generally calculated when the saturated surface dry bulk specific gravity and absorption of the aggregate are known.

6. Apparent or Absolute Specific Gravity

$$= \frac{S}{P+S-W} = \frac{\text{Dry Weight}}{\text{Dry Volume}}$$

S in both numerator and denominator is the weight of the sample in an oven dry condition.

This specific gravity is also easily calculated when the saturated surface dry bulk specific gravity and the absorption of the aggregate are known.

7. Dry Absorption $= \frac{\text{Saturated Surface dry weight - oven dry weight}}{\text{Oven dry weight}} \times 100$

8. Saturated Surface Dry Absorption

$$= \frac{\text{Saturated surface dry weight - oven dry weight}}{\text{Saturated Surface dry weight}} \times 100$$

9. Dry Volume = Saturated surface dry volume - (Saturated surface dry weight - oven dry weight)

TABLE 1 DESCRIPTION OF STONES WITH SOME CHEMICAL AND PHYSICAL ANALYSIS

| Identification Number | Description of Stone (Producer and Location) | Particle Description | Petrography: Calcite-Grained: Fine | Med. | Coarse | Micro-Xlin: $CO_3^+$ | Quartz | Chemical Analysis: CaO % | MgO % | Insoluble % | % Loss | Physical Analysis: Wear % | F&T * Loss % | Bulk Sp.Gr.* (S.S.D) | Water Absorption * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AAT7-1258 | Cooney Constr.Co. @ Cooney Quarry SW 1/4 16-96-6 Allamakee County | Subangular, gray, dense to earthy, fine to medium grained, equidimensional calcite. Some of the particles are spotted with flaskes of clear calcite. | | | | | | | | | | 29.4 | 4.3 | 2.635 | 1.65 |
| AAT7-1255 -1257 | Ft. Dodge Limestone @ Ft. Dodge Mine SW 1/4 23,24-89-29, Webster Co. | Angular to subangular, light to dark gray, equidimensional to flat, oolitic to fine grained, dense, calcite. Particles are bounded by clean semi-flat surfaces or by dark, pitted stylolitic seams. Many particles spotted with clear calcite. | | | | | 0.6 | 53.8 | 1.6 | | | 27.8 | 0.7 | 2.653 | 0.80 |
| AAT7-1249 -1250 | Douds Stone Co. @ Wilson Quarry NW 1/4 11-74-8, Washington Co. | Angular, brownish-gray, dense, fine grained, non-fossiliferous calcite. Particles are bounded by clean conchoidal surfaces or by dark and pitted stylolitic seams. Most of the particles are equidimensional but a few are flat and elongate. | | | | | 4.9 | 52.5 | 0.4 | | | 25.3 | 3.5 | 2.665 | 1.00 |
| AAT7-1246 -1247 | Schildberg Constr. Co., @ Menlo Quarry SE 1/4 17-77-31 Adair County | Angular to sub-rounded, brown to gray, dense to earthy, fine grained, equidimensional to elongate calcite. The dense particles are bounded by clean conchoidal to flat surfaces. Most of the particles contain fossils which have been replaced by coarse grained, clear calcite. | 11.0 | 2.2 | 2.9 | | | 51.3 | 1.5 | 5.7 | | 24.6 | 3.6 | 2.641 | 1.06 |
| AAT7-1252 | Clark Limestone Co. @ Logan Quarry NE 1/4 19-79-42 Harrison County | Angular, gray, equidimensional, dense, fine grained calcite containing stringers of clear, coarse grained calcite. Particles are bounded by clean flat to sub-conchoidal surfaces. A few whole particles of dark gray chert are also present. | 16.4 | 1.7 | 3.6 | 76.8 | 1.5 | 52.7 | 1.3 | | 42.5 | 25.4 | 5.7 | 2.668 | 0.65 |

REMARKS: Per cent Wear and F. & T. Loss are according to AASHO T-96 (Los Angeles Abrasion) and I.S.H.C. - 4100.08 Method A of 1964 (Water-Alcohol Solution) respectively.

* Samples of 0.45 Power Grading of apparently ideal centerline of specification ( + No. 4 Sieve).

TABLE: 2 PERCENTAGE OF BLENDING AGGREGATE FOR EACH DESIRED GRADATION

| Description of Aggregate | Particle Size (Sieve Size) | Identification No. | Per cent Aggregate (by weight) Gradation 1 3/4in.Mix | Gradation 1 3/8in.Mix | Gradation 2 3/4in.Mix | Gradation 2 3/8in.Mix | Gradation 3 3/4in.Mix | Gradation 3 3/8in.Mix |
|---|---|---|---|---|---|---|---|---|
| Cooney Stone | 3/4in.-1/2in. | AAT7-1258 | 11.0 | - | 11.0 | - | 11.0 | - |
| | 1/2in.-3/8in. | " | 10.5 | - | 10.5 | - | 10.5 | - |
| | 3/8in.-No. 4 | " | 20.9 | 15.3 | 21.0 | 15.5 | 21.3 | 15.9 |
| | No. 4 -No. 8 | " | 7.3 | 19.7 | 8.0 | 19.5 | 15.2 | 22.7 |
| | -No. 8 | " | 12.3 | 25.0 | 18.9 | 33.0 | 27.4 | 40.4 |
| Sand | +No. 8 | AAT8-9 | 4.0 | 4.2 | 3.2 | 3.4 | 1.5 | 2.2 |
| | -No. 8 | " | 34.0 | 35.8 | 27.4 | 28.6 | 13.1 | 18.8 |
| Ft. Dodge Stone | 3/4in.-1/2 in. | AAT7-1256 | 11.0 | - | 11.0 | - | 11.0 | - |
| | 1/2in.-3/8 in. | " | 10.5 | - | 10.5 | - | 10.5 | - |
| | 3/8in.-No. 4 | AAT7-1257 | 20.9 | 15.3 | 21.3 | 15.8 | 21.2 | 15.7 |
| | No. 4 -No. 8 | " | 7.6 | 19.7 | 8.7 | 20.7 | 16.3 | 27.7 |
| | -No. 8 | AAT7-1255 | 11.4 | 20.0 | 17.5 | 30.0 | 25.2 | 36.6 |
| Sand | +No. 8 | AAT8-9 | 4.0 | 4.7 | 3.3 | 3.5 | 1.7 | 2.1 |
| | -No. 8 | " | 34.6 | 40.3 | 27.7 | 30.0 | 14.1 | 17.9 |
| Schildberg Stone | 3/4in.-1/2in. | AAT7-1246 | 11.0 | - | 11.0 | - | 11.0 | - |
| | 1/2in.-3/8in. | " | 10.5 | - | 10.5 | - | 10.5 | - |
| | 3/8in.-No. 4 | " | 20.9 | 15.6 | 21.0 | 15.7 | 21.3 | 15.8 |
| | No. 4 -No. 8 | " | 6.2 | 12.0 | 6.1 | 13.5 | 12.7 | 18.3 |
| | -No. 8 | AAT7-1247 | 14.4 | 23.4 | 22.2 | 37.0 | 30.0 | 47.0 |
| Sand | +No. 8 | AAT8-9 | 3.9 | - | 3.1 | - | 1.5 | - |
| | -No. 8 | " | 33.1 | - | 26.1 | - | 13.0 | - |
| Sand | - | AAT8-25 | - | 49.0 | - | 33.8 | - | 18.9 |
| Douds Stone | 3/4in.-1/2in. | AAT7-1249 | 11.0 | - | 11.0 | - | 11.0 | - |
| | 1/2in.-3/8in. | " | 10.5 | - | 10.5 | - | 10.5 | - |
| | 3/8in.-No. 4 | " | 21.2 | 15.6 | 21.3 | 15.8 | 21.4 | 15.9 |
| | No. 4 -No. 8 | " | 6.9 | 12.7 | 7.7 | 13.1 | 10.6 | 18.8 |
| | -No. 8 | AAT7-1250 | 17.0 | 26.2 | 25.7 | 42.5 | 38.6 | 55.0 |
| Sand | - | AAT8-25 | 33.4 | 45.5 | 23.8 | 28.6 | 7.9 | 10.3 |
| Clark Stone | 3/4in.-1/2in. | AAT7-1252 | 11.0 | - | 11.0 | - | 11.0 | - |
| | 1/2in.-3/8in. | " | 10.5 | - | 10.5 | - | 10.5 | - |
| | 3/8in.-No. 4 | " | 21.3 | 15.9 | 21.3 | 15.7 | 21.4 | 15.8 |
| | No. 4 -No. 8 | " | 6.4 | 14.9 | 7.1 | 14.3 | 13.1 | 20.2 |
| | -No. 8 | " | 12.2 | 18.7 | 19.4 | 31.5 | 27.0 | 39.0 |
| Sand | - | AAT8-25 | 38.6 | - | 30.7 | - | 17.0 | - |
| Sand | - | AAT8-40 | - | 50.5 | - | 38.5 | - | 25.0 |

TABLE 3 RESULTS OF SPECIFIC GRAVITY STUDY

| Aggregate | Description of Particle | Bulk Sp. Gr. (S.S.D.) | Bulk Sp. Gr. (Dry) | *Calc.Bulk Sp. Gr. (Dry) | Apparent Sp. Gr. | Water Absorption (%) |
|---|---|---|---|---|---|---|
| Cooney Stone | 3/4" - 1/2" | 2.628 | 2.585 | - | 2.701 | 1.64 |
| | 1/2" - 3/8" | 2.640 | 2.605 | - | 2.699 | 1.33 |
| | 3/8" - #4 | 2.668 | 2.646 | - | 2.704 | 0.81 |
| | #4 - #8 | 2.678 | 2.662 | - | 2.706 | 0.61 |
| | - #8 | 2.744 | 2.743 | - | 2.746 | 0.04 |
| | Gradation No. 1 - 3/4" Mix | 2.663 | 2.644 | 2.651 | 2.698 | 0.76 |
| | " " 2 - " " | 2.675 | 2.663 | 2.656 | 2.697 | 0.47 |
| | " " 3 - " " | 2.679 | 2.666 | 2.664 | 2.700 | 0.47 |
| | Gradation No. 1 - 3/8" " | 2.632 | 2.652 | 2.676 | 2.676 | 0.50 |
| | " " 2 " " | 2.670 | 2.654 | 2.683 | 2.699 | 0.64 |
| | " " 3 " " | 2.693 | 2.675 | 2.690 | 2.724 | 0.67 |
| Ft. Dodge Stone | 3/4" - 1/2" | 2.641 | 2.616 | - | 2.683 | 0.96 |
| | 1/2" - 3/8" | 2.664 | 2.647 | - | 2.694 | 0.66 |
| | 3/8" - #4 | 2.653 | 2.633 | - | 2.688 | 0.79 |
| | #4 - #8 | 2.650 | 2.625 | - | 2.694 | 0.98 |
| | -#8 | 2.726 | 2.723 | - | 2.730 | 0.09 |
| | Gradation No. 1 - 3/4" Mix | 2.666 | 2.650 | 2.647 | 2.691 | 0.58 |
| | " " 2 - " " | 2.671 | 2.657 | 2.654 | 2.694 | 0.52 |
| | " " 3 - " " | 2.662 | 2.650 | 2.657 | 2.683 | 0.45 |
| | Gradation No. 1 - 3/8" Mix | 2.685 | 2.677 | 2.659 | 2.699 | 0.30 |
| | " " 2 " " | 2.684 | 2.679 | 2.665 | 2.693 | 0.20 |
| | " " 3 " " | 2.699 | 2.679 | 2.667 | 2.715 | 0.35 |
| Shildberg Stone | 3/4" - 1/2" | 2.642 | 2.617 | - | 2.652 | 0.50 |
| | 1/2" - 3/8" | 2.646 | 2.620 | - | 2.688 | 0.96 |
| | 3/8" - #4 | 2.656 | 2.635 | - | 2.692 | 0.81 |
| | #4 - #8 | 2.671 | 2.648 | - | 2.711 | 0.87 |
| | -#8 | 2.702 | 2.689 | - | 2.726 | 0.50 |
| | Gradation No. 1 - 3/4" Mix | 2.675 | 2.665 | 2.648 | 2.693 | 0.39 |
| | " " 2 " " | 2.659 | 2.647 | 2.650 | 2.677 | 0.41 |
| | " " 3 - " " | 2.680 | 2.670 | 2.652 | 2.697 | 0.37 |
| | Gradation No. 1 - 3/8" Mix | 2.688 | 2.683 | 2.659 | 2.696 | 0.17 |
| | " " 2 - " " | 2.699 | 2.697 | 2.664 | 2.704 | 0.10 |
| | " 3 - " " | 2.704 | 2.700 | 2.667 | 2.713 | 0.17 |
| Douds Stone | 3/4" - 1/2" | 2.656 | 2.626 | - | 2.708 | 1.16 |
| | 1/2" - 3/8" | 2.665 | 2.640 | - | 2.708 | 0.96 |
| | 3/8" - #4 | 2.674 | 2.644 | - | 2.691 | 0.65 |
| | #4 - #8 | 2.690 | 2.672 | - | 2.720 | 0.66 |
| | -#8 | 2.722 | 2.717 | - | 2.732 | 0.20 |
| | Gradation No. 1 - 3/4" Mix | 2.671 | 2.660 | 2.660 | 2.689 | 0.33 |
| | " " 2 - " " | 2.688 | 2.679 | 2.665 | 2.704 | 0.35 |
| | " " 3 - " " | 2.693 | 2.687 | 2.673 | 2.670 | 0.20 |
| | Gradation No. 1 - 3/8" Mix | 2.697 | 2.693 | 2.672 | 2.705 | 0.15 |
| | " " 2 - " " | 2.709 | 2.707 | 2.682 | 2.712 | 0.10 |
| | " " 3 - " " | 2.705 | 2.700 | 2.690 | 2.715 | 0.20 |
| Clark Stone | 3/4" - 1/2" | 2.636 | 2.599 | - | 2.698 | 1.40 |
| | 1/2" - 3/8" | 2.655 | 2.629 | - | 2.699 | 1.00 |
| | 3/8" - #4 | 2.663 | 2.643 | - | 2.697 | 0.76 |
| | #4 - #8 | 2.669 | 2.674 | - | 2.706 | 0.82 |
| | -#8 | 2.674 | 2.672 | - | 2.679 | 0.10 |
| | Gradation No. 1 - 3/4" Mix | 2.670 | 2.660 | 2.648 | 2.688 | 0.40 |
| | " " 2 - " " | 2.676 | 2.661 | 2.648 | 2.702 | 0.57 |
| | " " 3 - " " | 2.685 | 2.674 | 2.665 | 2.704 | 0.40 |
| | Gradation No. 1 - 3/8" Mix | 2.692 | 2.680 | 2.656 | 2.688 | 0.10 |
| | " " 2 - " " | 2.687 | 2.681 | 2.659 | 2.697 | 0.22 |
| | " " 3 - " " | 2.700 | 2.696 | 2.662 | 2.708 | 0.16 |
| Sand (AAT8-9) | + No. 8 | 2.677 | 2.651 | - | 2.721 | 0.97 |
| | - No. 8 | 2.662 | 2.655 | - | 2.675 | 0.29 |
| Sand (AAT8-25) | + No. 8 and - No. 8 (comb.) | 2.667 | 2.656 | - | 2.685 | 0.40 |
| Sand (AAT8-40) | " " | 2.664 | 2.649 | - | 2.689 | 0.56 |

$$\text{* Calculated Bulk Sp. Gr. of Blended Aggregate} = \frac{P_1 + P_2 + P_2 + \ldots\ldots\ldots}{P_1/G_1 + P_2/G_2 + P_3/G_3 + \ldots\ldots}$$

Where $P_1, P_2, P_3, \ldots\ldots$ = Per cent by weight of individual aggregate in blended aggregate

$G_1, G_2, G_3, \ldots\ldots$ = Bulk Sp. Gr. of individual aggregate corresponding to $P_1, P_2, P_3, \ldots\ldots$

TABLE 4 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF COONEY STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 6.5 | 4 | 5 | 6 | 7 | 4 | 5 | 6 |
| Avg. Bulk Sp. Gr. of Specimen | 2.271 | 2.300 | 2.343 | 2.361 | 2.305 | 2.356 | 2.378 | 2.366 | 2.329 | 2.383 | 2.393 |
| Density of Specimen, Pcf. | 141.7 | 143.5 | 146.2 | 147.3 | 143.8 | 147.0 | 148.4 | 147.6 | 145.3 | 148.7 | 149.3 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.511 | 2.473 | 2.437 | 2.420 | 2.518 | 2.481 | 2.444 | 2.409 | 2.521 | 2.483 | 2.447 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.522 | 2.474 | 2.441 | 2.410 | 2.517 | 2.476 | 2.440 | 2.392 | 2.534 | 2.501 | 2.455 |
| Max. Sp. Gr. (Hveem Spe.) | 2.505 | 2.468 | 2.440 | 2.396 | 2.486 | 2.447 | 2.420 | 2.393 | 2.494 | 2.471 | 2.430 |
| Calc. Asph. Abs., % of Agg. | 0.39 | --- | --- | --- | 0.24 | --- | --- | --- | 0.24 | --- | --- |
| Effective Asph., % by Wt. | 3.64 | 4.65 | 5.65 | 6.16 | 3.78 | 4.78 | 5.79 | 6.79 | 3.78 | 4.78 | 5.79 |
| Effective Asph., % by Vol. | 8.0 | 10.4 | 12.8 | 14.1 | 8.5 | 10.9 | 13.4 | 15.6 | 8.5 | 11.1 | 13.4 |
| Vol. Occupied by Agg., % | 82.5 | 82.6 | 83.3 | 83.5 | 83.1 | 84.0 | 83.9 | 82.6 | 83.9 | 84.9 | 84.4 |
| Voids in Mineral Agg., % | 17.5 | 17.4 | 16.7 | 16.5 | 16.9 | 16.0 | 16.1 | 17.4 | 16.1 | 15.1 | 15.6 |
| Voids Filled With Asph., % | 45.7 | 59.8 | 76.6 | 85.5 | 50.3 | 68.1 | 83.2 | 89.7 | 52.8 | 73.5 | 85.9 |
| Calc. Air Voids, % | 9.5 | 7.0 | 3.9 | 2.4 | 8.4 | 5.1 | 2.7 | 1.8 | 7.6 | 4.0 | 2.2 |
| Air Voids (Air Meter Spe.), % | 10.1 | 7.0 | 4.1 | 2.0 | 8.6 | 5.0 | 2.5 | 1.1 | 8.3 | 5.6 | 2.5 |
| Air Voids (Hveem Spe.), % | 9.1 | 6.7 | 3.5 | 1.5 | 7.2 | 3.7 | 1.8 | 1.0 | 6.3 | 3.6 | 1.5 |
| Hveem Hor. PSI @ 400 Vert. PSI | 44 | 45 | 55 | 68 | 40 | 48 | 67 | 112 | 43 | 48 | 87 |
| Displacement, Turns | 2.58 | 2.60 | 2.70 | 2.55 | 2.42 | 2.45 | 2.40 | 2.57 | 2.52 | 2.62 | 2.55 |
| Hveem Stability | 41.0 | 39.9 | 34.0 | 29.9 | 45.1 | 39.9 | 31.3 | 26.6 | 42.2 | 38.3 | 23.8 |
| Marshall Stability, lbs. | 1240 | 1173 | 1193 | 1327 | 2000 | 2020 | 1807 | 1273 | 2777 | 2277 | 1943 |
| Flow, 1/100 inch | 9.7 | 10.0 | 10.0 | 12.0 | 11.0 | 10.3 | 12.0 | 19.0 | 10.0 | 12.0 | 17.7 |

TABLE 5 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF COONEY STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | | Gradation 3 at Percent Asphalt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5 | 6 | 7 | 4.5 | 5 | 6 | 7 | 4.5 | 5 | 6 | 7 |
| Avg. Bulk Sp. Gr. of Specimen | 2.258 | 2.315 | 2.350 | 2.363 | 2.303 | 2.348 | 2.378 | 2.376 | 2.307 | 2.363 | 2.392 | 2.385 |
| Density of Specimen, Pcf. | 140.9 | 144.5 | 146.6 | 147.5 | 143.7 | 146.5 | 148.4 | 148.3 | 144.0 | 147.5 | 149.3 | 148.8 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.486 | 2.468 | 2.432 | 2.397 | 2.496 | 2.477 | 2.441 | 2.406 | 2.515 | 2.496 | 2.459 | 2.423 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.496 | 2.465 | 2.429 | 2.404 | 2.521 | 2.483 | 2.450 | 2.416 | 2.524 | 2.483 | 2.439 | 2.404 |
| Max. Sp. Gr. (Hveem Spe.) | 2.464 | 2.454 | 2.426 | 2.393 | 2.494 | 2.469 | 2.429 | 2.407 | 2.508 | 2.462 | 2.430 | 2.406 |
| Calc. Asph. Abs., % of Agg. | 0.17 | --- | --- | --- | 0.32 | --- | --- | --- | 0.34 | --- | --- | --- |
| Effective Asph., % by Wt. | 4.34 | 4.85 | 5.85 | 6.58 | 4.21 | 4.71 | 5.72 | 6.85 | 4.19 | 4.69 | 5.70 | 6.70 |
| Effective Asph., % by Vol. | 9.5 | 10.9 | 13.4 | 15.7 | 9.4 | 10.7 | 13.2 | 15.8 | 9.4 | 10.7 | 13.2 | 15.5 |
| Vol. Occupied by Agg., % | 81.3 | 82.9 | 83.3 | 82.9 | 82.9 | 84.0 | 84.2 | 83.3 | 82.4 | 83.9 | 84.1 | 82.9 |
| Voids in Mineral Agg., % | 18.7 | 17.1 | 16.7 | 17.1 | 17.1 | 16.0 | 15.8 | 16.7 | 17.6 | 16.1 | 15.9 | 17.1 |
| Voids Filled With Asph., % | 50.8 | 63.7 | 8.02 | 91.8 | 55.0 | 66.9 | 83.5 | 94.6 | 53.4 | 66.5 | 83.0 | 90.6 |
| Calc. Air Voids, % | 9.2 | 6.2 | 3.3 | 1.4 | 7.7 | 5.3 | 2.6 | 0.9 | 8.2 | 5.4 | 2.7 | 1.6 |
| Air Voids (Air Meter Spe.), % | 9.5 | 6.0 | 3.3 | 1.7 | 8.7 | 5.6 | 3.0 | 1.6 | 8.6 | 4.9 | 1.9 | 0.8 |
| Air Voids (Hveem Spe.), % | 8.3 | 5.6 | 3.1 | 1.4 | 7.5 | 4.8 | 2.1 | 1.3 | 8.0 | 4.1 | 1.6 | 0.8 |
| Hveem Hor. PSI @ 400 Vert. PSI | 55 | 49 | 50 | 93 | 47 | 48 | 75 | -- | 42 | 45 | 89 | -- |
| Displacement, Turns | 2.38 | 2.43 | 2.40 | 2.55 | 2.37 | 2.50 | 2.48 | --- | 2.38 | 2.50 | 2.55 | --- |
| Hveem Stability | 36.7 | 39.5 | 39.2 | 23.2 | 41.0 | 39.4 | 27.8 | --- | 44.2 | 41.0 | 23.3 | --- |
| Marshall Stability, lbs. | 1603 | 1770 | 1670 | 1447 | 2567 | 2507 | 2047 | 1557 | 3213 | 3340 | 2217 | 1663 |
| Flow, 1/100 inch | 10.0 | 8.0 | 9.3 | 14.3 | 9.3 | 10.0 | 13.0 | 18.3 | 10.3 | 10.7 | 16.0 | 22.3 |

TABLE 6 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF COONEY STONE

WITH 75 BLOWS MARSHALL COMPACTION

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 4 | 5 | 6 | 4 | 5 | 6 |
| Avg. Bulk Sp. Gr. of Specimen | 2.291 | 2.349 | 2.378 | 2.333 | 2.390 | 2.394 | 2.354 | 2.414 | 2.405 |
| Density of Specimen, Pcf. | 143.0 | 146.6 | 148.4 | 145.6 | 149.1 | 149.4 | 146.9 | 150.6 | 150.1 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.511 | 2.473 | 2.437 | 2.518 | 2.481 | 2.444 | 2.521 | 2.483 | 2.447 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.519 | 2.465 | 2.421 | 2.512 | 2.470 | 2.428 | 2.516 | 2.467 | 2.437 |
| Max. Sp. Gr. (Hveem Spe.) | 2.471 | 2.438 | 2.416 | 2.470 | 2.450 | 2.425 | 2.490 | 2.474 | 2.432 |
| Calc. Asph. Abs., % of Agg. | 0.39 | --- | --- | 0.24 | --- | --- | 0.24 | --- | --- |
| Effective Asph., % by Wt. | 3.64 | 4.64 | 5.64 | 3.78 | 4.78 | 5.78 | 3.78 | 4.78 | 5.78 |
| Effective Asph., % by Vol. | 8.1 | 10.6 | 13.0 | 8.6 | 11.1 | 13.4 | 8.6 | 11.2 | 13.5 |
| Vol. Occupied by Agg., % | 83.2 | 84.4 | 84.5 | 84.1 | 85.3 | 84.5 | 84.8 | 86.0 | 84.8 |
| Voids in Mineral Agg., % | 16.8 | 15.6 | 15.5 | 15.9 | 14.7 | 15.5 | 15.2 | 14.0 | 15.2 |
| Voids Filled With Asph., % | 48.2 | 67.9 | 83.8 | 54.1 | 75.5 | 86.5 | 56.6 | 80.0 | 88.9 |
| Calc. Air Voids, % | 8.7 | 5.0 | 2.5 | 7.3 | 3.6 | 2.2 | 6.6 | 2.8 | 1.7 |
| Air Voids (Air Meter Spe.), % | 9.1 | 4.7 | 1.9 | 7.1 | 3.2 | 1.4 | 6.4 | 2.1 | 1.3 |
| Air Voids (Hveem Spe.), % | 7.3 | 3.7 | 1.5 | 5.6 | 2.4 | 1.3 | 5.3 | 2.5 | 1.1 |
| Hveem Hor. PSI @ 400 Vert. PSI | 45 | 47 | 61 | 41 | 40 | 69 | 44 | 47 | 97 |
| Displacement, Turns | 260 | 267 | 265 | 275 | 258 | 267 | 270 | 263 | 260 |
| Hveem Stability | 40.2 | 38.4 | 31.8 | 41.2 | 43.8 | 28.4 | 40.0 | 38.3 | 21.0 |
| Marshall Stability, lbs. | 1480 | 1667 | 1593 | 2360 | 2607 | 1940 | 3543 | 2827 | 2027 |
| Flow, 1/100 inch | 9.3 | 7.7 | 11.7 | 10.0 | 9.7 | 14.7 | 11.3 | 12.7 | 19.0 |

TABLE 7 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF COONEY STONE

WITH 75 BLOWS MARSHALL COMPACTION

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 |
| Avg. Bulk Sp. Gr. of Specimen | 2.253 | 2.317 | 2.349 | 2.326 | 2.383 | 2.383 | 2.333 | 2.402 | 2.395 |
| Density of Specimen, Pcf. | 140.6 | 144.6 | 144.6 | 145.1 | 148.7 | 148.7 | 145.6 | 149.9 | 149.4 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.486 | 2.450 | 2.414 | 2.496 | 2.459 | 2.423 | 2.515 | 2.478 | 2.441 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.500 | 2.455 | 2.421 | 2.512 | 2.466 | 2.429 | 2.521 | 2.464 | 2.428 |
| Max. Sp. Gr. (Hveem Spe.) | 2.467 | 2.447 | 2.421 | 2.448 | 2.427 | 2.403 | 2.440 | 2.449 | 2.418 |
| Calc. Asph. Abs., % of Agg. | 0.17 | --- | --- | 0.32 | --- | --- | 0.34 | --- | --- |
| Effective Asph., % by Wt. | 4.34 | 5.35 | 6.35 | 4.21 | 5.22 | 6.22 | 4.19 | 5.20 | 6.20 |
| Effective Asph., % by Vol. | 9.5 | 12.0 | 14.5 | 9.5 | 12.1 | 14.4 | 9.5 | 12.1 | 14.4 |
| Vol. Occupied by Agg., % | 81.1 | 82.6 | 82.8 | 83.7 | 84.8 | 84.0 | 83.3 | 84.9 | 83.7 |
| Voids in Mineral Agg., % | 18.9 | 17.4 | 17.2 | 16.3 | 15.2 | 16.0 | 16.7 | 15.1 | 16.3 |
| Voids Filled With Asph., % | 50.3 | 69.0 | 84.3 | 58.3 | 79.6 | 90.0 | 56.9 | 80.1 | 88.3 |
| Calc. Air Voids, % | 9.4 | 5.4 | 2.7 | 6.8 | 3.1 | 1.6 | 7.2 | 3.0 | 1.9 |
| Air Voids (Air Meter Spe.), % | 7.0 | 3.0 | 1.6 | 10.3 | 6.0 | 3.3 | 7.5 | 2.5 | 1.4 |
| Air Voids (Hveem Spe.), % | 5.7 | 2.6 | 1.6 | 7.9 | 4.6 | 2.3 | 4.5 | 2.0 | 1.0 |
| Hveem Hor. PSI @ 400 Vert. PSI | 57 | 52 | 85 | 52 | 47 | 29 | 57 | 63 | 97 |
| Displacement, Turns | 212 | 232 | 287 | 252 | 248 | 242 | 215 | 230 | 218 |
| Hveem Stability | 38.3 | 39.0 | 22.2 | 36.9 | 40.1 | 34.5 | 38.0 | 34.0 | 24.1 |
| Marshall Stability, lbs. | 3127 | 2790 | 2073 | 1833 | 1910 | 1810 | 3473 | 3247 | 2230 |
| Flow, 1/100 inch | 8.3 | 9.3 | 10.3 | 9.7 | 10.7 | 13.7 | 10.7 | 12.7 | 17.7 |

TABLE 8 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF FORT DODGE STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 6.5 | 4 | 5 | 6 | 4 | 5 | 6 |
| Avg. Bulk Sp. Gr. of Specimen | 2.287 | 2.318 | 2.361 | 2.365 | 2.306 | 2.367 | 2.393 | 2.356 | 2.415 | 2.411 |
| Density of Specimen, Pcf. | 142.7 | 144.6 | 147.3 | 147.6 | 143.9 | 147.7 | 149.3 | 147.0 | 150.7 | 150.4 |
| Calc. Max. Theo Sp.Gr. (ISHC) | 2.510 | 2.473 | 2.436 | 2.419 | 2.514 | 2.477 | 2.440 | 2.506 | 2.469 | 2.433 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.528 | 2.480 | 2.441 | 2.426 | 2.506 | 2.472 | 2.442 | 2.503 | 2.463 | 2.437 |
| Max. Sp. Gr. (Hveem Spe.) | 2.481 | 2.452 | 2.420 | 2.405 | 2.476 | 2.444 | 2.424 | 2.491 | 2.471 | 2.437 |
| Calc. Asph. Abs., % of Agg. | 0.20 | -- | -- | -- | 0.26 | -- | -- | 0.23 | -- | -- |
| Effective Asph., % by Wt. | 3.73 | 4.74 | 5.75 | 6.25 | 3.76 | 4.77 | 5.77 | 3.79 | 4.79 | 5.80 |
| Effective Asph., % by Vol. | 8.3 | 10.6 | 13.2 | 14.3 | 8.4 | 11.0 | 13.4 | 8.7 | 11.2 | 13.6 |
| Vol. Occupied by Agg., % | 82.8 | 83.1 | 83.7 | 83.4 | 83.3 | 84.6 | 84.7 | 85.4 | 86.6 | 85.5 |
| Voids in Mineral Agg., % | 17.2 | 16.9 | 16.3 | 16.6 | 16.7 | 15.4 | 15.3 | 14.6 | 13.4 | 14.5 |
| Voids Filled With Asph., % | 48.3 | 62.7 | 81.0 | 86.1 | 50.3 | 71.4 | 87.6 | 59.6 | 83.6 | 93.8 |
| Calc. Air Voids, % | 8.9 | 6.3 | 3.1 | 2.3 | 8.3 | 4.4 | 1.9 | 5.9 | 2.2 | 0.9 |
| Air Voids (Air Meter Spe.), % | 9.5 | 6.4 | 3.2 | 2.3 | 8.0 | 4.3 | 1.9 | 5.7 | 1.9 | 1.0 |
| Air Voids (Hveem Spe.), % | 7.7 | 5.5 | 2.4 | 1.9 | 6.8 | 3.2 | 1.3 | 5.7 | 2.3 | 1.1 |
| Hveem Hor. PSI @ 400 Vert. PSI | 43 | 43 | 48 | 57 | 46 | 58 | 77 | 33 | 57 | 110 |
| Displacement, Turns | 2.55 | 2.50 | 2.52 | 2.63 | 2.42 | 2.33 | 2.33 | 2.62 | 2.35 | 2.45 |
| Hveem Stability | 42.0 | 42.2 | 39.2 | 33.5 | 41.0 | 35.8 | 28.4 | 48.3 | 36.0 | 19.3 |
| Marshall Stability, lbs. | 1033 | 1107 | 1103 | 1140 | 1833 | 1737 | 1653 | 2617 | 2393 | 1840 |
| Flow, 1/100 inch | 8.3 | 7.3 | 7.3 | 12.0 | 8.7 | 8.7 | 13.3 | 11.0 | 13.3 | 17.0 |

TABLE 9 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF FORT DODGE STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 | 4.5 | 5.0 | 5.5 | 6.5 |
| Avg. Bulk Sp. Gr. of Specimen | 2.252 | 2.278 | 2.329 | 2.286 | 2.367 | 2.377 | 2.344 | 2.397 | 2.397 | 2.396 |
| Density of Specimen, Pcf. | 140.5 | 142.1 | 145.3 | 142.6 | 147.7 | 148.3 | 146.3 | 149.6 | 149.6 | 149.5 |
| Calc. Max. Theo Sp.Gr. (ISHC) | 2.506 | 2.469 | 2.433 | 2.504 | 2.467 | 2.431 | 2.518 | 2.499 | 2.480 | 2.443 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.505 | 2.459 | 2.431 | 2.518 | 2.466 | 2.432 | 2.507 | 2.476 | 2.462 | 2.425 |
| Max. Sp. Gr. (Hveem Spe.) | 2.459 | 2.414 | 2.395 | 2.460 | 2.443 | 2.408 | 2.493 | 2.452 | 2.449 | 2.418 |
| Calc. Asph. Abs., % of Agg. | 0.16 | --- | --- | 0.10 | --- | --- | 0.18 | --- | --- | - -- |
| Effective Asph., % by Wt. | 4.35 | 5.36 | 6.36 | 4.41 | 5.41 | 6.41 | 4.34 | 4.84 | 5.34 | 6.34 |
| Effective Asph., % by Vol. | 9.5 | 11.9 | 14.4 | 9.8 | 12.5 | 14.8 | 9.9 | 13.3 | 12.4 | 14.8 |
| Vol. Occupied by Agg., % | 80.3 | 80.4 | 81.3 | 81.5 | 83.5 | 83.0 | 83.2 | 84.7 | 84.2 | 83.3 |
| Voids in Mineral Agg., % | 19.7 | 19.6 | 18.7 | 18.5 | 16.5 | 17.0 | 16.8 | 15.3 | 15.8 | 16.7 |
| Voids Filled With Asph., % | 48.2 | 60.7 | 77.0 | 53.0 | 75.8 | 87.1 | 58.9 | 73.9 | 78.5 | 88.6 |
| Calc. Air Voids, % | 10.2 | 7.7 | 4.3 | 8.7 | 4.0 | 2.2 | 6.9 | 4.0 | 3.4 | 1.9 |
| Air Voids (Air Meter Spe.), % | 10.1 | 7.3 | 4.2 | 9.3 | 4.1 | 2.3 | 6.5 | 3.3 | 2.7 | 1.1 |
| Air Voids (Hveem Spe.), % | 8.3 | 5.7 | 2.8 | 6.9 | 3.1 | 1.3 | 6.0 | 2.2 | 2.1 | 1.0 |
| Hveem Hor. PSI @ 400 Vert. PSI | 51 | 66 | 66 | 54 | 53 | 91 | 37 | 57 | 66 | -- |
| Displacement, Turns | 2.43 | 2.38 | 2.47 | 2.33 | 2.37 | 2.50 | 2.42 | 2.15 | 2.33 | --- |
| Hveem Stability | 38.3 | 33.0 | 31.3 | 37.7 | 38.0 | 23.1 | 47.0 | 38.0 | 32.4 | --- |
| Marshall Stability, lbs. | 1227 | 1047 | 1127 | 1913 | 2100 | 1520 | 2803 | 3060 | 2450 | 1843 |
| Flow, 1/100 inch | 9.0 | 11.7 | 11.7 | 8.0 | 9.0 | 17.3 | 9.7 | 9.7 | 11.7 | 19.0 |

TABLE 10 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF DOUDS STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 6.5 | 4 | 5 | 6 | 4 | 5 | 6 |
| Avg. Bulk Sp. Gr. of Specimen | 2.273 | 2.296 | 2.354 | 2.370 | 2.319 | 2.339 | 2.385 | 2.311 | 2.376 | 2.396 |
| Density of Specimen, Pcf. | 141.8 | 143.3 | 146.9 | 147.8 | 144.7 | 146.0 | 148.0 | 144.2 | 148.3 | 149.5 |
| Calc. Max. Theo Sp.Gr. (ISHC) | 2.513 | 2.476 | 2.440 | 2.420 | 2.527 | 2.490 | 2.453 | 2.530 | 2.492 | 2.455 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.520 | 2.470 | 2.444 | 2.410 | 2.524 | 2.477 | 2.434 | 2.527 | 2.473 | 2.438 |
| Max. Sp. Gr. (Hveem Spe.) | 2.482 | 2.445 | 2.426 | 2.409 | 2.484 | 2.433 | 2.419 | 2.498 | 2.465 | 2.442 |
| Calc. Asph. Abs., % of Agg. | 0.20 | --- | --- | --- | 0.32 | --- | --- | 0.10 | --- | --- |
| Effective Asph., % by Wt. | 3.81 | 4.82 | 5.82 | 6.33 | 3.79 | 4.79 | 5.79 | 3.91 | 4.91 | 5.91 |
| Effective Asph., % by Vol. | 8.4 | 10.7 | 13.3 | 14.6 | 8.5 | 10.9 | 13.4 | 8.8 | 11.3 | 13.8 |
| Vol. Occupied by Agg., % | 82.0 | 82.0 | 83.2 | 83.3 | 83.1 | 82.9 | 83.7 | 82.6 | 84.0 | 83.8 |
| Voids in Mineral Agg., % | 18.0 | 18.0 | 16.8 | 16.7 | 16.9 | 17.1 | 16.3 | 17.4 | 16.0 | 16.2 |
| Voids Filled With Asph., % | 46.7 | 59.4 | 79.2 | 87.4 | 50.3 | 63.7 | 82.2 | 50.6 | 70.6 | 85.2 |
| Calc. Air Voids, % | 9.6 | 7.3 | 3.5 | 2.2 | 8.4 | 6.2 | 2.9 | 8.6 | 4.7 | 2.4 |
| Air Voids (Air Meter Spe.), % | 9.7 | 7.0 | 3.6 | 1.7 | 8.1 | 5.6 | 2.0 | 8.6 | 3.9 | 1.7 |
| Air Voids (Hveem Spe.), % | 8.4 | 6.3 | 2.8 | 1.5 | 6.6 | 4.0 | 1.6 | 7.3 | 3.7 | 1.9 |
| Hveem Hor. PSI @ 400 Vert. PSI | 51 | 54 | 47 | 75 | 40 | 48 | 54 | 45 | 55 | 75 |
| Displacement, Turns | 2.47 | 2.57 | 2.52 | 2.42 | 2.55 | 2.60 | 2.60 | 2.68 | 2.57 | 2.63 |
| Hveem Stability | 38.0 | 35.3 | 39.5 | 28.2 | 44.0 | 38.5 | 35.2 | 39.3 | 34.7 | 26.5 |
| Marshall Stability, lbs. | 1107 | 1013 | 1330 | 1273 | 1873 | 1440 | 1607 | 2460 | 2197 | 1807 |
| Flow, 1/100 inch | 10.7 | 8.7 | 10.7 | 13.7 | 10.3 | 11.7 | 13.3 | 10.3 | 12.0 | 18.3 |

TABLE 11 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF DOUDS STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 |
| Avg. Bulk Sp. Gr. of Specimen | 2.217 | 2.259 | 2.296 | 2.264 | 2.324 | 2.362 | 2.278 | 2.331 | 2.367 |
| Density of Specimen, Pcf. | 138.2 | 140.9 | 143.2 | 141.3 | 145.0 | 147.4 | 142.1 | 145.5 | 147.7 |
| Calc. Max. Theo Sp.Gr. (ISHC) | 2.515 | 2.478 | 2.441 | 2.523 | 2.485 | 2.449 | 2.523 | 2.485 | 2.448 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.488 | 2.457 | 2.411 | 2.489 | 2.453 | 2.418 | 2.498 | 2.460 | 2.413 |
| Max. Sp. Gr. (Hveem Spe.) | 2.445 | 2.417 | 2.386 | 2.468 | 2.448 | 2.410 | 2.453 | 2.431 | 2.405 |
| Calc. Asph. Abs., % of Agg. | 0.08 | --- | --- | 0.03 | --- | --- | 0.11 | --- | --- |
| Effective Asph., % by Wt. | 4.43 | 5.43 | 6.43 | 4.47 | 5.47 | 6.47 | 4.40 | 5.40 | 6.41 |
| Effective Asph., % by Vol. | 9.5 | 11.9 | 14.3 | 9.9 | 12.4 | 14.9 | 9.7 | 12.2 | 14.7 |
| Vol. Occupied by Agg., % | 78.6 | 79.3 | 79.7 | 79.9 | 81.1 | 81.6 | 80.6 | 81.6 | 82.0 |
| Voids in Mineral Agg., % | 21.4 | 20.7 | 20.3 | 20.1 | 18.9 | 18.4 | 19.4 | 18.4 | 18.0 |
| Voids Filled With Asph., % | 44.4 | 57.5 | 70.4 | 49.3 | 65.6 | 81.0 | 50.0 | 66.3 | 81.7 |
| Calc. Air Voids, % | 11.9 | 8.8 | 6.0 | 10.2 | 6.5 | 3.5 | 9.7 | 6.2 | 3.3 |
| Air Voids (Air Meter Spe.), % | 10.9 | 7.9 | 4.8 | 9.1 | 5.3 | 2.4 | 8.9 | 5.2 | 1.9 |
| Air Voids (Hveem Spe.), % | 9.4 | 6.6 | 3.9 | 8.3 | 5.0 | 2.0 | 7.1 | 4.2 | 1.6 |
| Hveem Hor. PSI @ 400 Vert. PSI | 61 | 61 | 56 | 57 | 54 | 70 | 55 | 55 | 78 |
| Displacement, Turns | 2.40 | 2.42 | 2.43 | 2.40 | 2.37 | 2.57 | 2.27 | 2.33 | 2.37 |
| Hveem Stability | 33.8 | 33.8 | 35.8 | 35.5 | 37.2 | 28.8 | 37.6 | 37.2 | 27.6 |
| Marshall Stability, lbs. | 996 | 960 | 993 | 1920 | 2040 | 1663 | 2377 | 2527 | 1993 |
| Flow, 1/100 inch | 9.0 | 8.3 | 9.7 | 10.0 | 9.3 | 12.3 | 9.7 | 10.3 | 13.7 |

TABLE 12 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF SCHILDBERG STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | | Gradation 3 at Percent Asphalt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5.5 | 6.5 | 7.5 | 4.5 | 5.5 | 6.5 | 7.5 | 4.5 | 5.5 | 6.5 | 7.5 |
| Avg. Bulk Sp. Gr. of Specimen | 2.158 | 2.181 | 2.217 | 2.238 | 2.174 | 2.207 | 2.239 | 2.269 | 2.183 | 2.228 | 2.256 | 2.287 |
| Density of Specimen, Pcf. | 134.7 | 136.1 | 138.3 | 139.5 | 135.7 | 137.7 | 139.7 | 141.7 | 136.2 | 139.0 | 140.8 | 142.9 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.507 | 2.470 | 2.433 | 2.398 | 2.516 | 2.478 | 2.442 | 2.406 | 2.521 | 2.483 | 2.446 | 2.411 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.499 | 2.452 | 2.415 | 2.377 | 2.525 | 2.477 | 2.434 | 2.386 | 2.491 | 2.464 | 2.414 | 2.379 |
| Max. Sp. Gr. (Hveem Spe.) | 2.452 | 2.417 | 2.372 | 2.355 | 2.463 | 2.445 | 2.397 | 2.360 | 2.463 | 2.447 | 2.399 | 2.367 |
| Calc. Asph. Abs., % of Agg. | 0.09 | --- | --- | --- | 0.04 | --- | --- | --- | 0.08 | --- | --- | --- |
| Effective Asph., % by Wt. | 4.42 | 5.42 | 6.42 | 7.43 | 4.46 | 5.47 | 6.47 | 7.46 | 4.42 | 5.43 | 6.43 | 7.45 |
| Effective Asph., % by Vol. | 9.3 | 11.5 | 13.8 | 16.2 | 9.4 | 11.7 | 14.1 | 16.5 | 9.4 | 11.7 | 14.1 | 16.6 |
| Vol. Occupied by Agg., % | 76.8 | 76.8 | 77.3 | 77.2 | 77.0 | 77.3 | 77.6 | 77.8 | 77.2 | 78.0 | 78.1 | 78.3 |
| Voids in Mineral Agg., % | 23.2 | 23.2 | 22.7 | 22.8 | 23.0 | 22.7 | 22.4 | 22.2 | 22.8 | 22.0 | 21.9 | 21.7 |
| Voids Filled With Asph., % | 40.1 | 49.6 | 60.8 | 71.1 | 40.9 | 51.5 | 62.9 | 74.3 | 41.2 | 53.2 | 64.4 | 76.5 |
| Calc. Air Voids, % | 13.9 | 11.7 | 8.9 | 6.6 | 13.6 | 11.0 | 8.3 | 5.7 | 13.4 | 10.3 | 7.8 | 5.1 |
| Air Voids (Air Meter Spe.), % | 13.5 | 11.0 | 8.2 | 6.0 | 13.8 | 10.9 | 8.0 | 5.0 | 12.4 | 9.7 | 6.5 | 3.9 |
| Air Voids (Hveem Spe.), % | 12.0 | 9.8 | 6.4 | 5.1 | 11.8 | 9.7 | 6.6 | 3.8 | 11.4 | 9.0 | 6.0 | 3.4 |
| Hveem Hor. PSI @ 400 Vert. PSI | 52 | 58 | 63 | 65 | 54 | 59 | 57 | 56 | 50 | 52 | 52 | 57 |
| Displacement, Turns | 2.60 | 2.55 | 2.55 | 2.45 | 2.53 | 2.50 | 2.42 | 2.52 | 2.48 | 2.47 | 2.47 | 2.45 |
| Hveem Stability | 36.2 | 34.2 | 31.7 | 31.8 | 35.8 | 33.8 | 35.3 | 35.0 | 38.3 | 37.3 | 37.3 | 35.1 |
| Marshall Stability, lbs. | 813 | 720 | 700 | 777 | 1387 | 1353 | 1233 | 1323 | 1840 | 1987 | 1730 | 1880 |
| Flow, 1/100 inch | 7.3 | 8.0 | 9.3 | 10.7 | 8.7 | 8.3 | 9.3 | 11.0 | 9.0 | 9.7 | 10.0 | 12.3 |

TABLE 13 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF SCHILDBERG STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | | Gradation 2 at Percent Asphalt | | | | Gradation 3 at Percent Asphalt | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 4 | 5 | 6 | 7 | 4 | 5 | 6 | 7 |
| Avg. Bulk Sp. Gr. of Specimen | 2.231 | 2.259 | 2.298 | 2.332 | 2.248 | 2.265 | 2.324 | 2.348 | 2.271 | 2.288 | 2.336 | 2.333 |
| Density of Specimen, Pcf. | 139.2 | 141.0 | 143.4 | 145.5 | 140.3 | 141.3 | 145.0 | 146.6 | 141.7 | 142.8 | 145.8 | 145.6 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.517 | 2.480 | 2.444 | 2.408 | 2.503 | 2.466 | 2.430 | 2.395 | 2.521 | 2.483 | 2.447 | 2.411 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.514 | 2.471 | 2.418 | 2.402 | 2.511 | 2.472 | 2.427 | 2.390 | 2.527 | 2.480 | 2.424 | 2.406 |
| Max. Sp. Gr. (Hveem Spe.) | 2.470 | 2.445 | 2.402 | 2.389 | 2.483 | 2.436 | 2.416 | 2.399 | 2.477 | 2.443 | 2.409 | 2.410 |
| Calc. Asph. Abs., % of Agg. | 0.20 | --- | --- | --- | 0.22 | --- | --- | --- | 0.19 | --- | --- | --- |
| Effective Asph., % by Wt. | 3.81 | 4.82 | 5.82 | 6.83 | 3.80 | 4.80 | 5.80 | 6.81 | 3.82 | 4.83 | 5.83 | 6.84 |
| Effective Asph., % by Vol. | 8.3 | 10.6 | 13.0 | 15.4 | 8.3 | 10.6 | 13.1 | 15.5 | 8.4 | 10.7 | 13.2 | 15.5 |
| Vol. Occupied by Agg., % | 80.4 | 80.5 | 81.1 | 81.4 | 81.5 | 81.3 | 82.5 | 82.5 | 81.7 | 81.4 | 82.2 | 81.3 |
| Voids in Mineral Agg., % | 19.6 | 19.5 | 18.9 | 18.6 | 19.2 | 18.7 | 17.5 | 17.5 | 18.3 | 18.6 | 17.8 | 18.7 |
| Voids Filled With Asph., % | 42.3 | 54.4 | 68.8 | 82.8 | 43.2 | 56.7 | 74.9 | 88.6 | 45.9 | 57.5 | 74.2 | 82.9 |
| Calc. Air Voids, % | 11.3 | 8.9 | 5.9 | 3.2 | 10.9 | 8.1 | 4.4 | 2.0 | 9.9 | 7.9 | 4.6 | 3.2 |
| Air Voids (Air Meter Spe.), % | 11.2 | 8.4 | 5.0 | 2.9 | 10.4 | 8.1 | 4.2 | 1.9 | 10.3 | 7.8 | 3.7 | 3.1 |
| Air Voids (Hveem Spe.), % | 9.8 | 7.5 | 4.3 | 2.4 | 9.5 | 7.3 | 3.8 | 2.1 | 8.2 | 6.4 | 3.0 | 3.3 |
| Hveem Hor. PSI @ 400 Vert. PSI | 48 | 48 | 53 | 65 | 47 | 55 | 49 | 60 | 46 | 48 | 49 | 58 |
| Displacement, Turns | 2.55 | 2.52 | 2.48 | 2.65 | 2.35 | 2.62 | 2.35 | 2.72 | 2.45 | 2.38 | 2.52 | 2.57 |
| Hveem Stability | 39.0 | 39.2 | 36.8 | 30.2 | 41.1 | 34.8 | 40.2 | 31.6 | 41.0 | 40.5 | 38.6 | 33.7 |
| Marshall Stability, lbs. | 873 | 773 | 843 | 1127 | 1380 | 980 | 1380 | 1420 | 2030 | 1777 | 1720 | 1700 |
| Flow, 1/100 inch | 10.7 | 10.0 | 9.7 | 9.3 | 9.3 | 10.3 | 9.3 | 14.0 | 10.3 | 10.7 | 11.7 | 12.3 |

TABLE 14 SUMMARY OF TEST PROPERTIES OF 3/4 INCH MIX OF CLARK STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 4 | 5 | 6 | 4 | 5 | 6 |
| Avg. Bulk Sp. Gr. of Specimen | 2.261 | 2.300 | 2.345 | 2.298 | 2.352 | 2.386 | 2.303 | 2.372 | 2.389 |
| Density of Specimen, Pcf. | 141.1 | 143.5 | 146.3 | 143.4 | 146.8 | 148.9 | 143.7 | 148.0 | 149.1 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.521 | 2.483 | 2.447 | 2.519 | 2.481 | 2.445 | 2.526 | 2.488 | 2.451 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.517 | 2.477 | 2.431 | 2.506 | 2.461 | 2.438 | 2.522 | 2.488 | 2.442 |
| Max. Sp. Gr. (Hveem Spe.) | 2.484 | 2.451 | 2.417 | 2.505 | 2.466 | 2.430 | 2.480 | 2.472 | 2.430 |
| Calc. Asph. Abs., % of Agg. | 0.20 | --- | --- | 0.29 | --- | --- | 0.21 | --- | --- |
| Effective Asph., % by Wt. | 3.84 | 4.84 | 5.82 | 3.73 | 4.74 | 5.74 | 3.81 | 4.81 | 5.81 |
| Effective Asph., % by Vol. | 8.4 | 10.8 | 13.3 | 8.3 | 10.8 | 13.3 | 8.5 | 11.0 | 13.5 |
| Vol. Occupied by Agg., % | 81.6 | 82.1 | 82.9 | 82.9 | 84.0 | 84.3 | 82.7 | 84.3 | 84.0 |
| Voids in Mineral Agg., % | 18.4 | 17.9 | 17.1 | 17.1 | 16.0 | 15.7 | 17.3 | 15.7 | 16.0 |
| Voids Filled With Asph., % | 45.7 | 60.3 | 77.8 | 48.5 | 67.5 | 84.7 | 49.1 | 70.7 | 84.4 |
| Calc. Air Voids, % | 10.0 | 7.1 | 3.8 | 8.8 | 5.2 | 2.4 | 8.8 | 4.6 | 2.5 |
| Air Voids (Air Meter Spe.), % | 10.1 | 7.1 | 3.5 | 8.3 | 4.4 | 2.1 | 8.8 | 4.5 | 2.1 |
| Air Voids (Hveem Spe.), % | 9.0 | 6.1 | 2.9 | 8.3 | 4.7 | 1.9 | 7.2 | 4.0 | 1.7 |
| Hveem Hor. PSI @ 400 Vert. PSI | 49 | 48 | 48 | 41 | 40 | 58 | 43 | 43 | 58 |
| Displacement, Turns | 2.45 | 2.50 | 2.62 | 2.58 | 2.60 | 2.60 | 2.55 | 2.60 | 2.53 |
| Hveem Stability | 39.2 | 39.1 | 38.3 | 43.0 | 43.5 | 33.4 | 42.0 | 41.5 | 34.0 |
| Marshall Stability, lbs. | 1013 | 1040 | 1173 | 1747 | 1703 | 1800 | 2220 | 2253 | 1823 |
| Flow, 1/100 inch | 9.3 | 9.3 | 9.0 | 9.0 | 10.0 | 12.7 | 11.0 | 12.7 | 15.3 |

TABLE 15 SUMMARY OF TEST PROPERTIES OF 3/8 INCH MIX OF CLARK STONE

| Description of Test Properties | Gradation 1 at Percent Asphalt | | | Gradation 2 at Percent Asphalt | | | Gradation 3 at Percent Asphalt | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 | 4.5 | 5.5 | 6.5 |
| Avg. Bulk Sp. Gr. of Specimen | 2.207 | 2.241 | 2.277 | 2.246 | 2.283 | 2.342 | 2.247 | 2.312 | 2.362 |
| Density of Specimen, Pcf. | 137.7 | 139.8 | 142.1 | 140.2 | 142.5 | 146.1 | 140.2 | 144.3 | 147.4 |
| Calc. Max. Theo. Sp.Gr. (ISHC) | 2.503 | 2.466 | 2.430 | 2.507 | 2.470 | 2.433 | 2.518 | 2.480 | 2.443 |
| Max. Sp. Gr. (Air Meter Spe.) | 2.485 | 2.463 | 2.424 | 2.506 | 2.458 | 2.422 | 2.515 | 2.482 | 2.425 |
| Max. Sp. Gr. (Hveem Spe.) | 2.457 | 2.432 | 2.389 | 2.490 | 2.430 | 2.408 | 2.458 | 2.434 | 2.408 |
| Calc. Asph. Abs., % of Agg. | 0.06 | --- | --- | 0.11 | --- | --- | 0.08 | --- | --- |
| Effective Asph., % by Wt. | 4.44 | 5.45 | 6.45 | 4.40 | 5.40 | 6.40 | 4.43 | 5.43 | 6.43 |
| Effective Asph., % by Vol. | 9.5 | 11.9 | 14.3 | 9.6 | 12.0 | 14.6 | 9.7 | 12.2 | 14.8 |
| Vol. Occupied by Agg., % | 78.6 | 79.0 | 79.4 | 80.0 | 80.5 | 81.7 | 79.6 | 81.0 | 81.9 |
| Voids in Mineral Agg., % | 21.4 | 21.0 | 20.6 | 20.0 | 19.5 | 18.3 | 20.4 | 19.0 | 18.1 |
| Voids Filled With Asph., % | 44.4 | 56.7 | 69.4 | 48.0 | 61.5 | 79.9 | 47.5 | 64.2 | 81.8 |
| Calc. Air Voids, % | 11.9 | 9.7 | 6.3 | 10.4 | 7.5 | 3.7 | 10.7 | 6.8 | 3.3 |
| Air Voids (Air Meter Spe.), % | 11.2 | 9.0 | 6.0 | 10.4 | 7.2 | 3.3 | 10.7 | 6.9 | 2.6 |
| Air Voids (Hveem Spe.), % | 10.2 | 7.8 | 4.7 | 9.7 | 6.1 | 2.8 | 8.7 | 5.0 | 1.9 |
| Hveem Hor. PSI @ 400 Vert. PSI | 57 | 60 | 61 | 52 | 57 | 62 | 61 | 58 | 86 |
| Displacement, Turns | 275 | 245 | 240 | 235 | 238 | 240 | 228 | 227 | 228 |
| Hveem Stability | | | | | | | | | |
| Marshall Stability, lbs. | 977 | 920 | 807 | 2040 | 1550 | 1660 | 2130 | 2250 | 1870 |
| Flow, 1/100 inch | 10.0 | 9.0 | 10.3 | 9.0 | 10.0 | 10.3 | 10.0 | 10.3 | 12.7 |

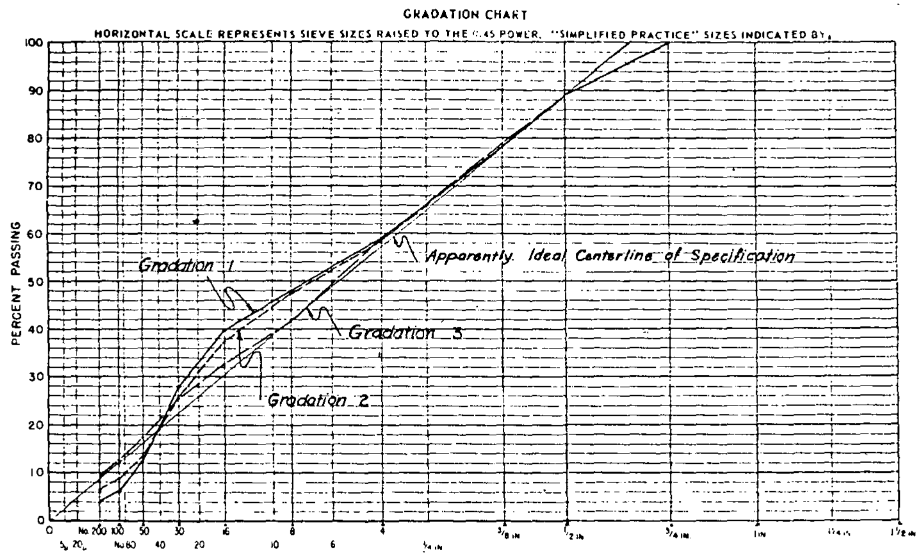



FIG. 1 AGGREGATE GRADATION CURVES OF 3/4" MIX OF COONEY STONE

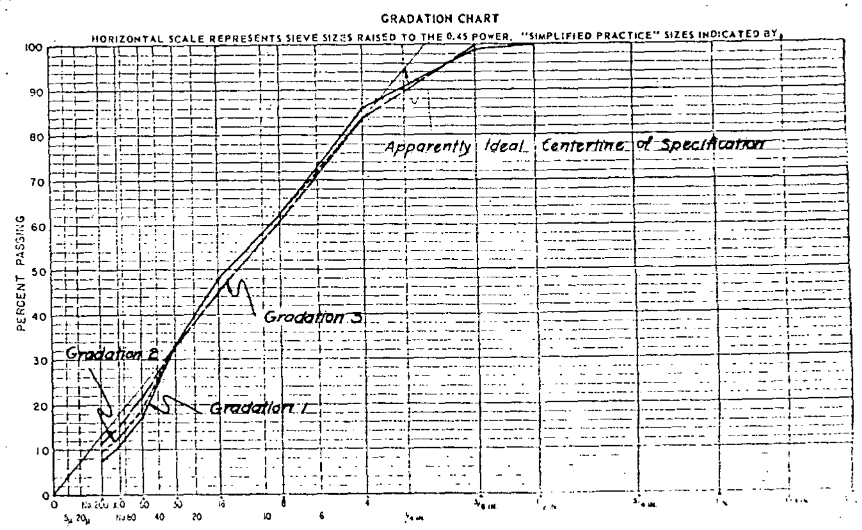



FIG. 2 AGGREGATE GRADATION CURVES OF 3/8" MIX OF COONEY STONE

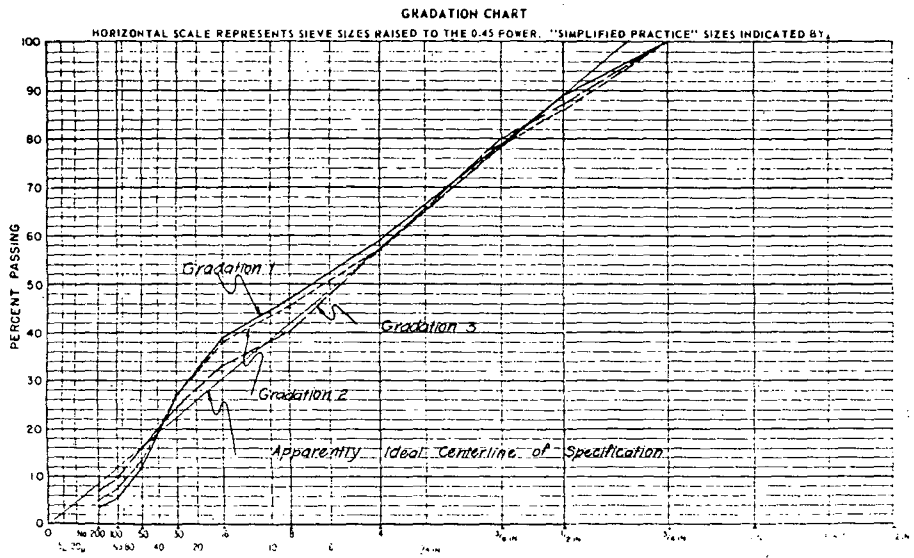



FIG. 3 AGGREGATE GRADATION CURVES OF 3/4" MIX OF FT. DODGE STONE

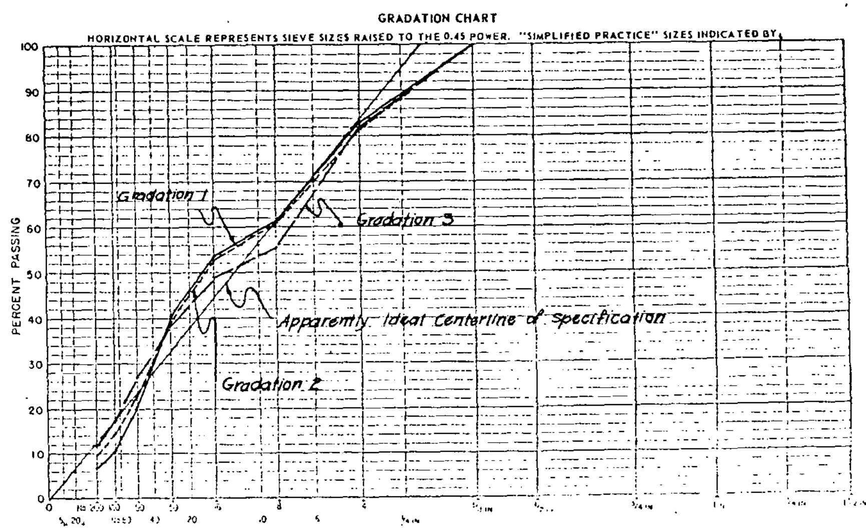



FIG. 4 AGGREGATE GRADATION CURVES OF 3/8" MIX OF FT. DODGE STONE

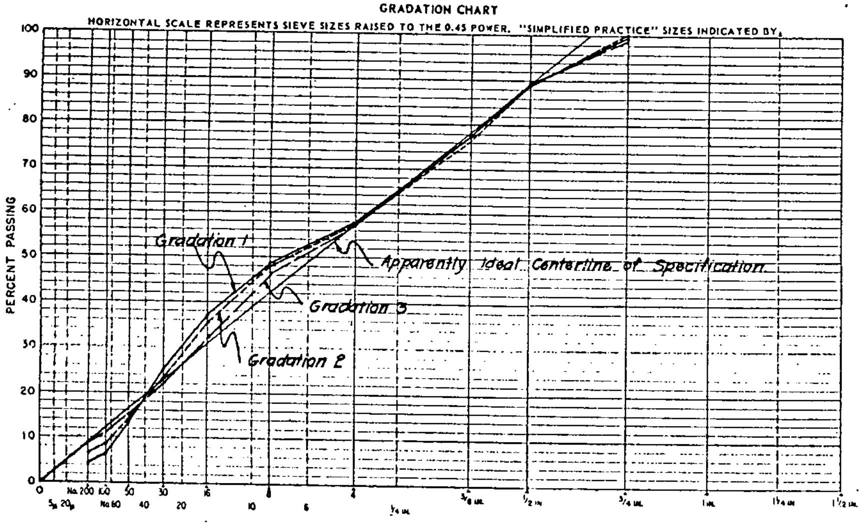



FIG. 5 AGGREGATE GRADATION CURVES OF 3/4" MIX OF DOUDS STONE

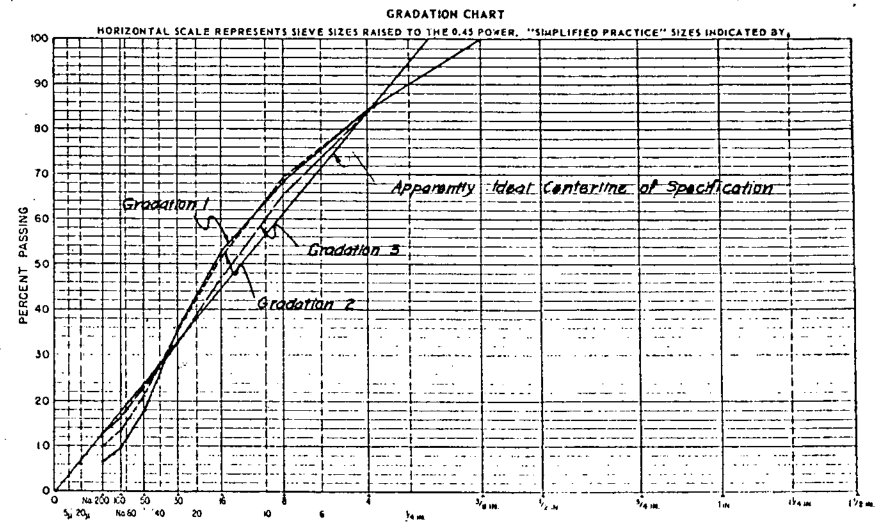



FIG. 6 AGGREGATE GRADATION CURVES OF 3/8" MIX OF DOUDS STONE

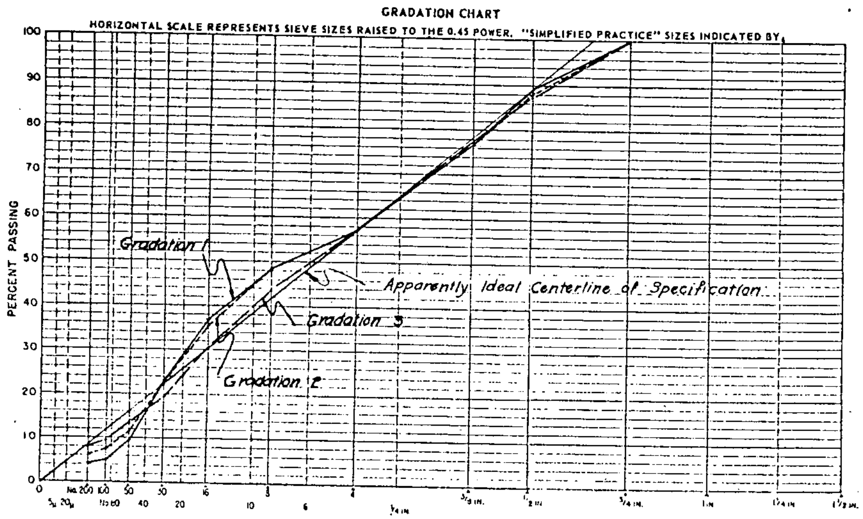



FIG. 7 AGGREGATE GRADATION CURVES OF 3/4" MIX OF SCHILDBERG STONE

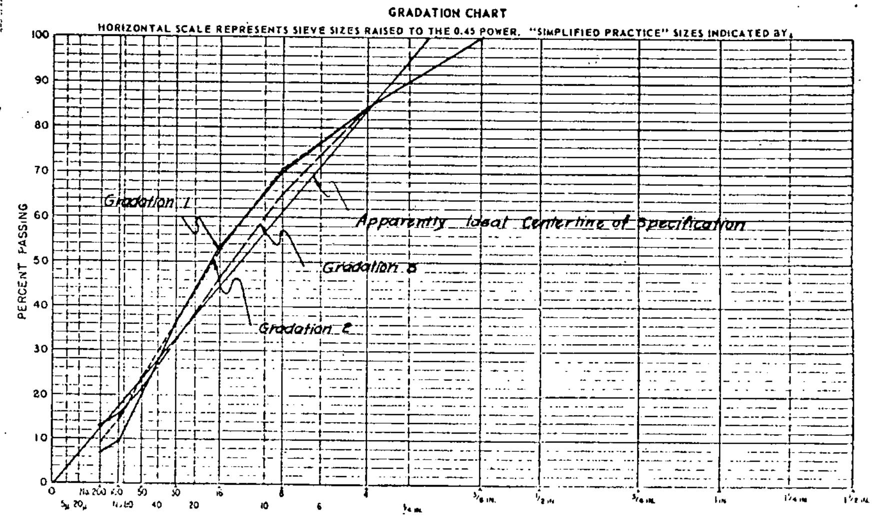



FIG. 8 AGGREGATE GRADATION CURVES OF 3/8" MIX OF SCHILDBERG STONE

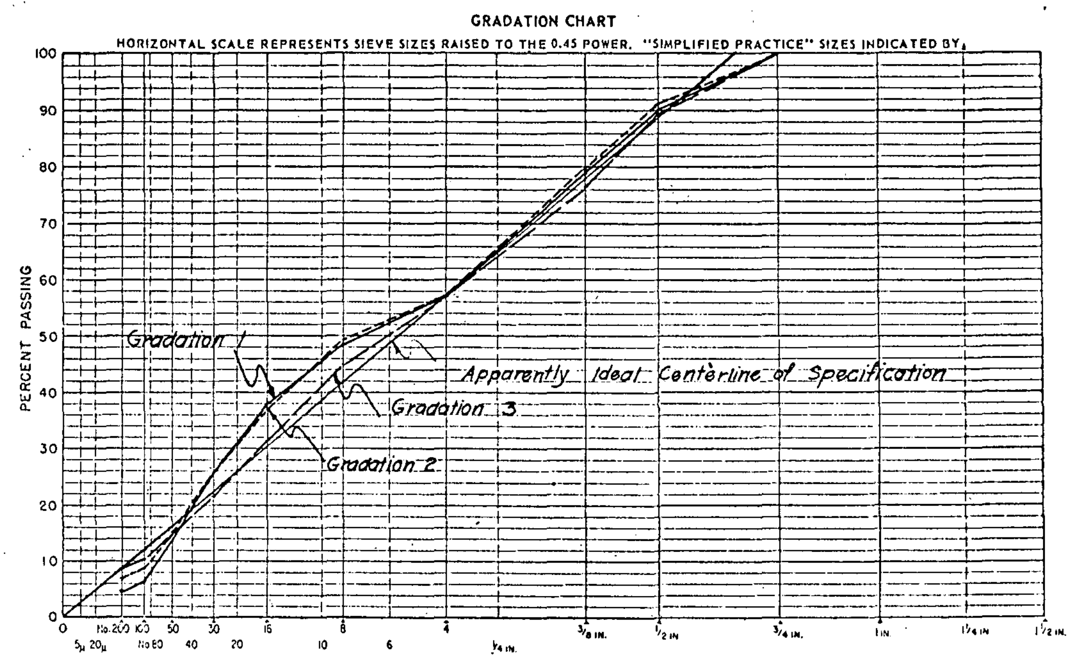



FIG. 9 AGGREGATE GRADATION CURVES OF 3/4" MIX OF CLARK STONE

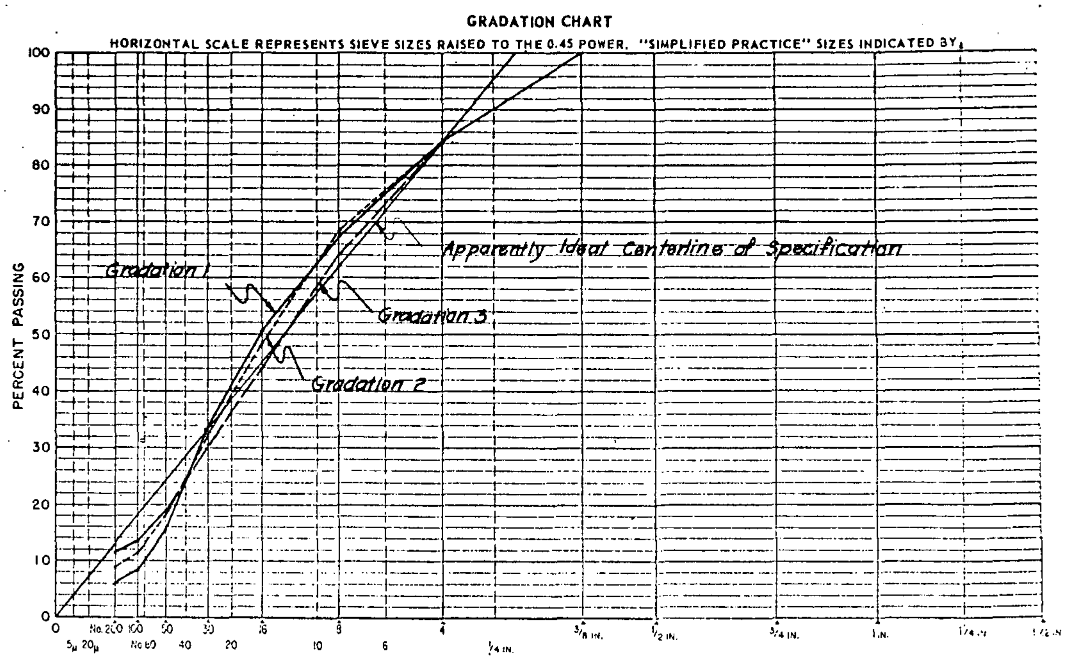



FIG. 10 AGGREGATE GRADATION CURVES OF 3/8" MIX OF CLARK STONE

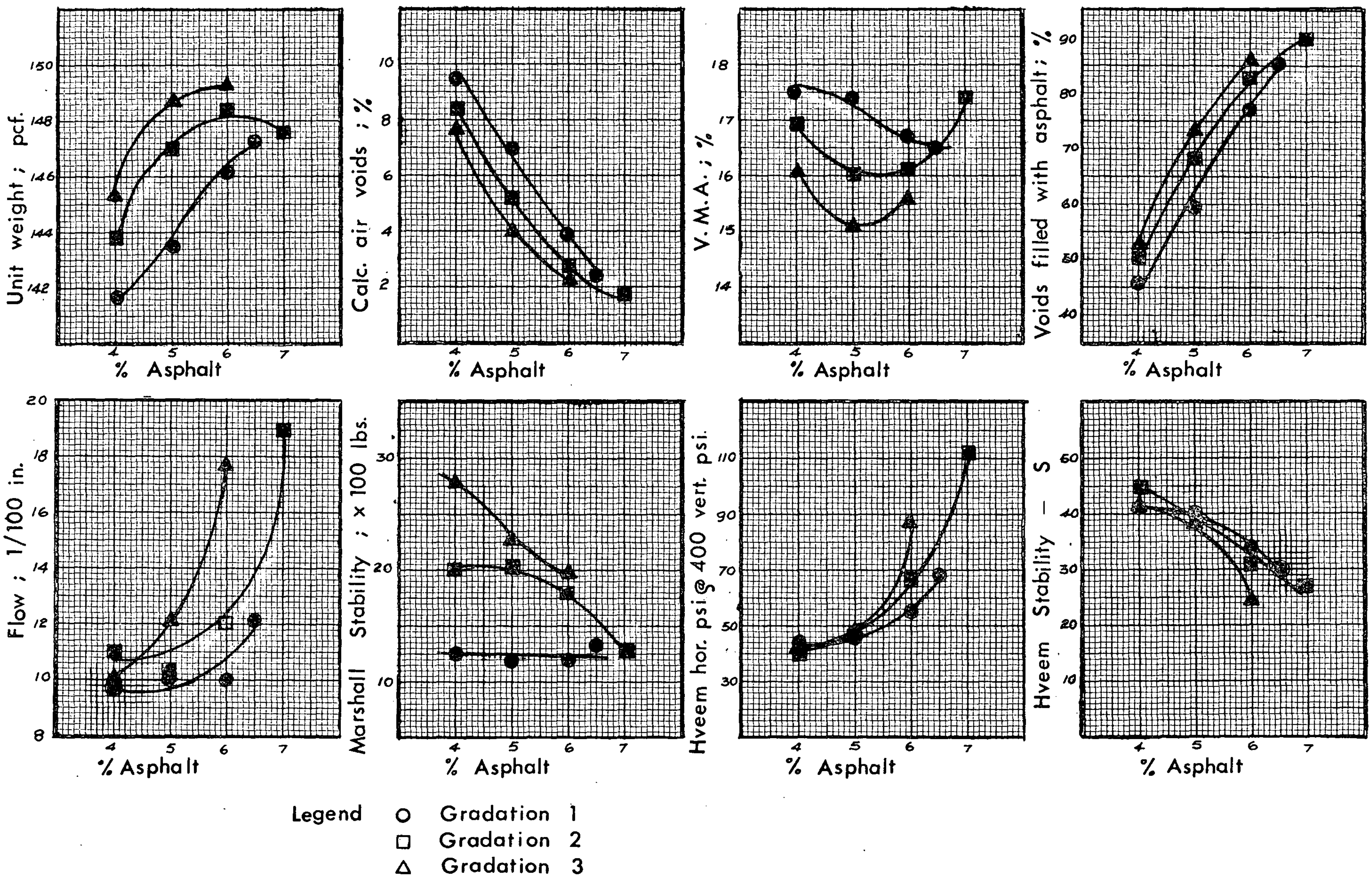
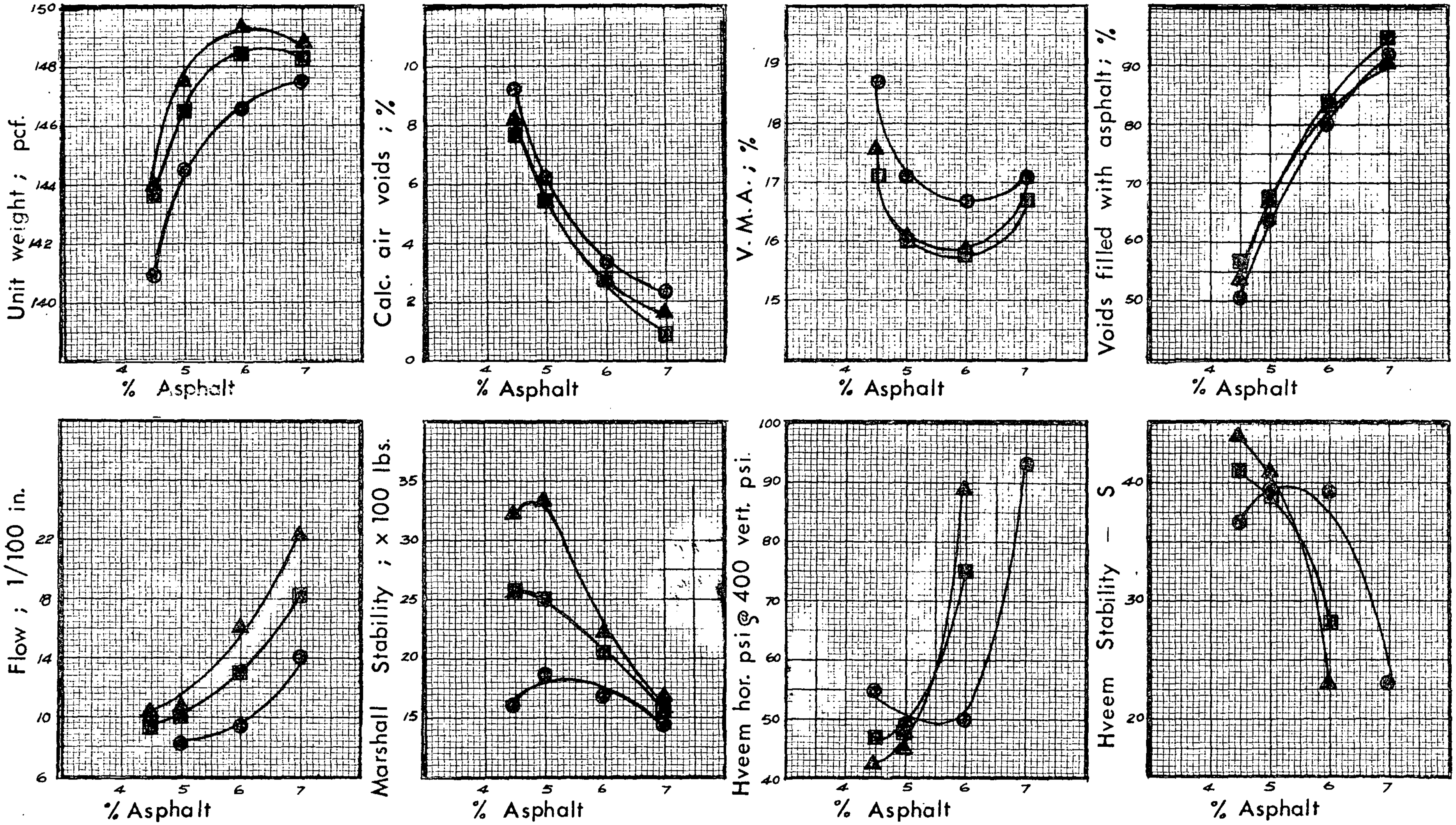



FIG. 11 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF COONEY STONE




Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 12 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF COONEY STONE

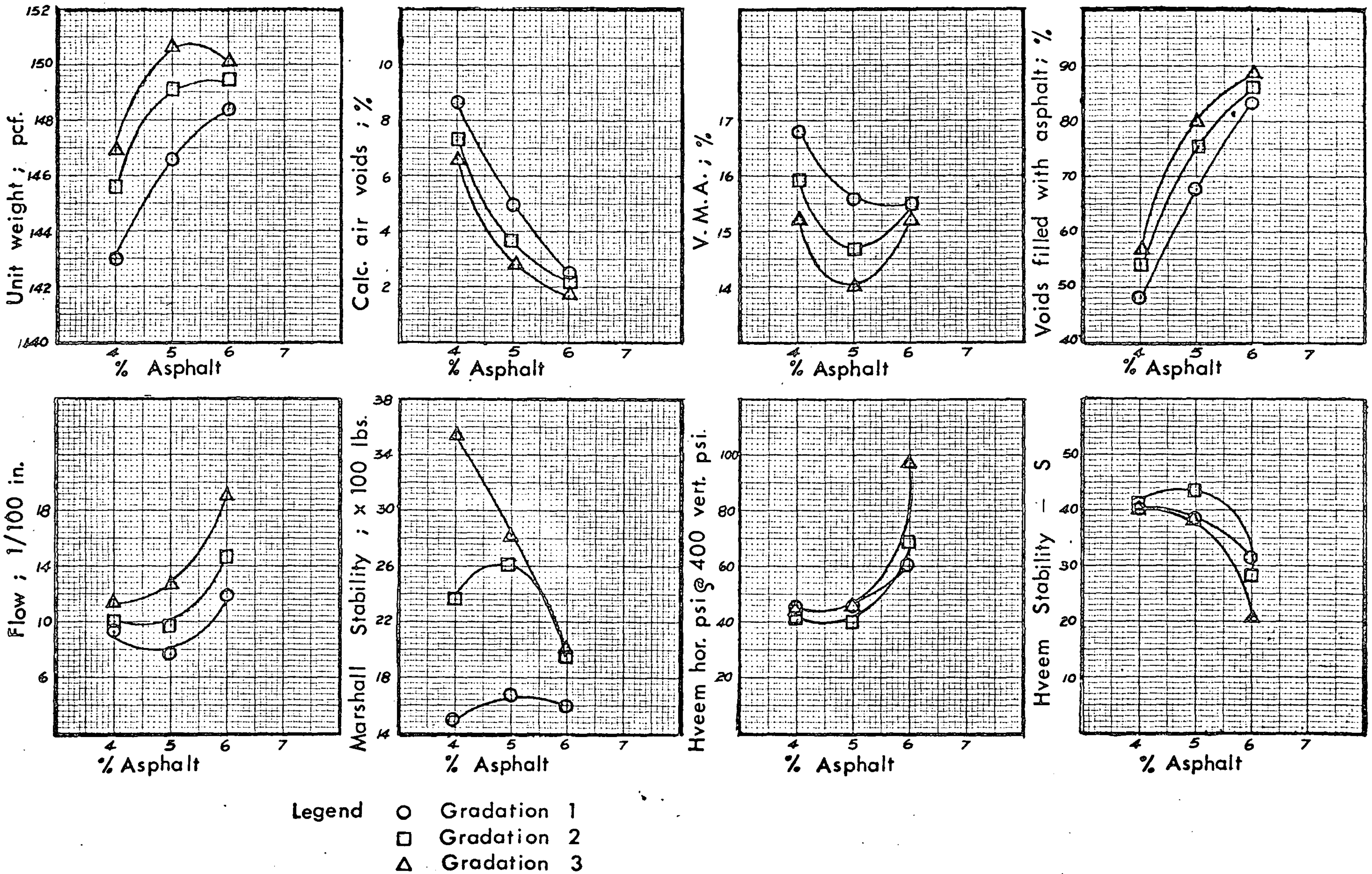
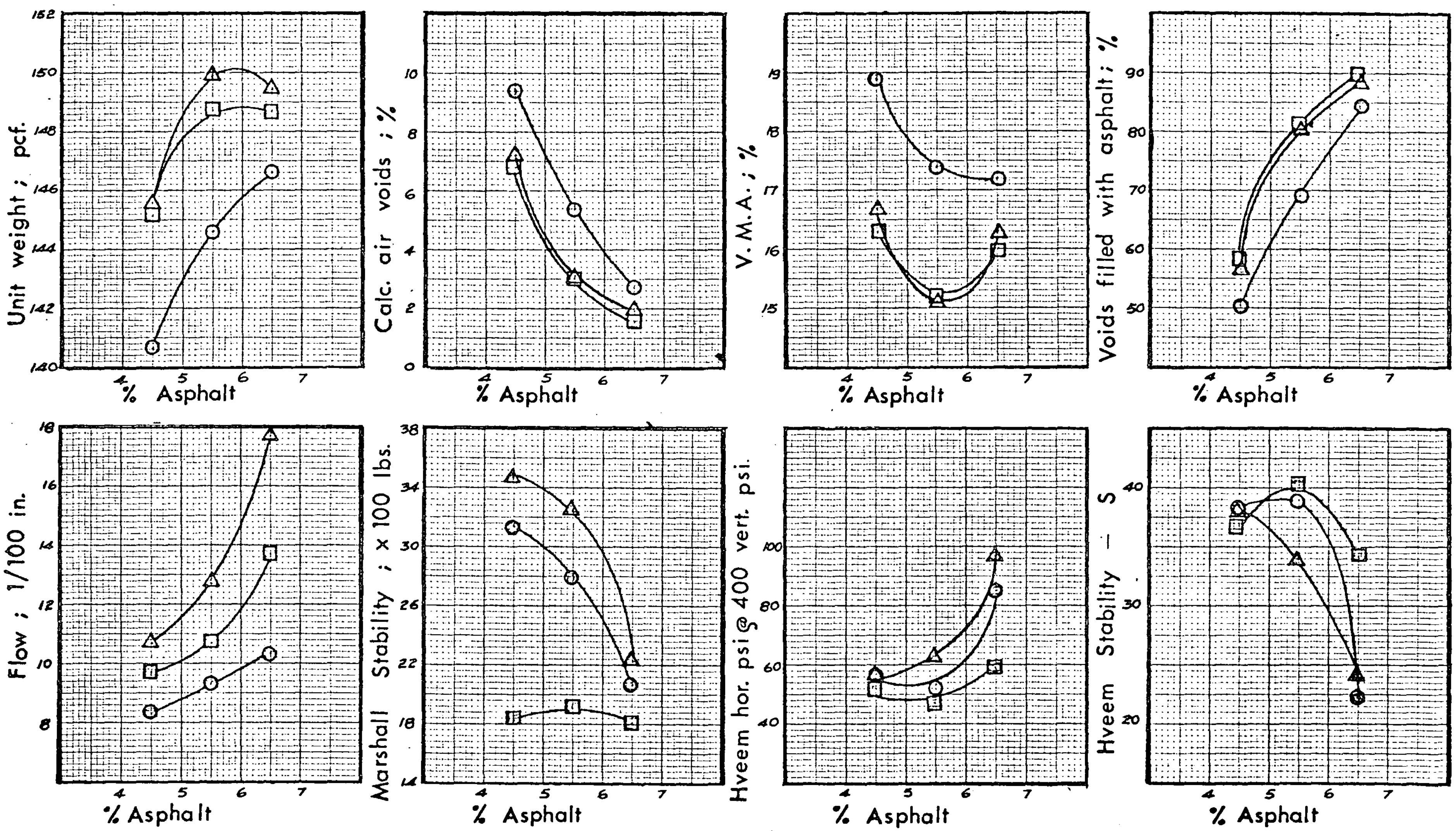
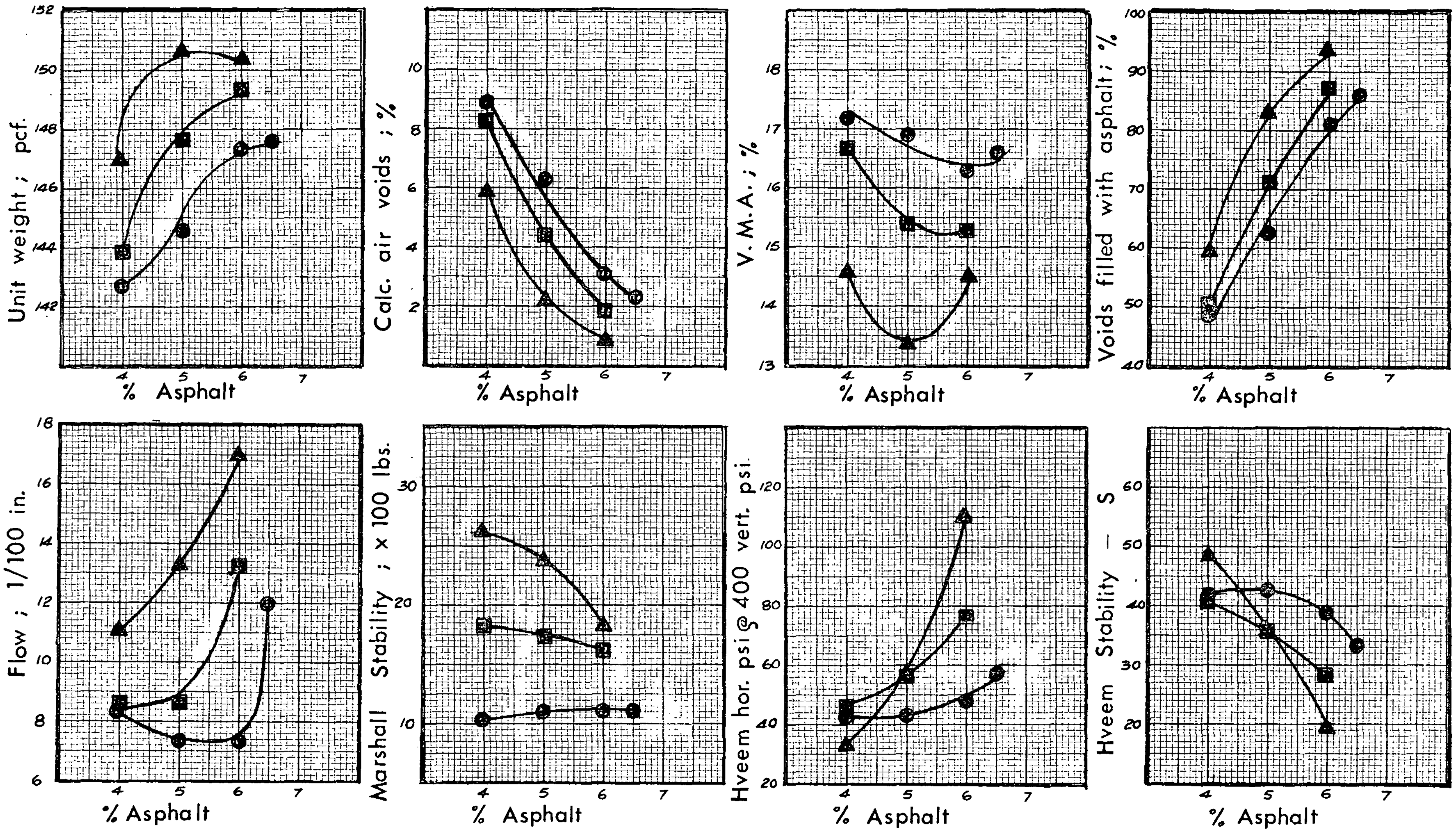



FIG. 13 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF COONEY STONE WITH 75 BLOW MARSHALL COMPACTION



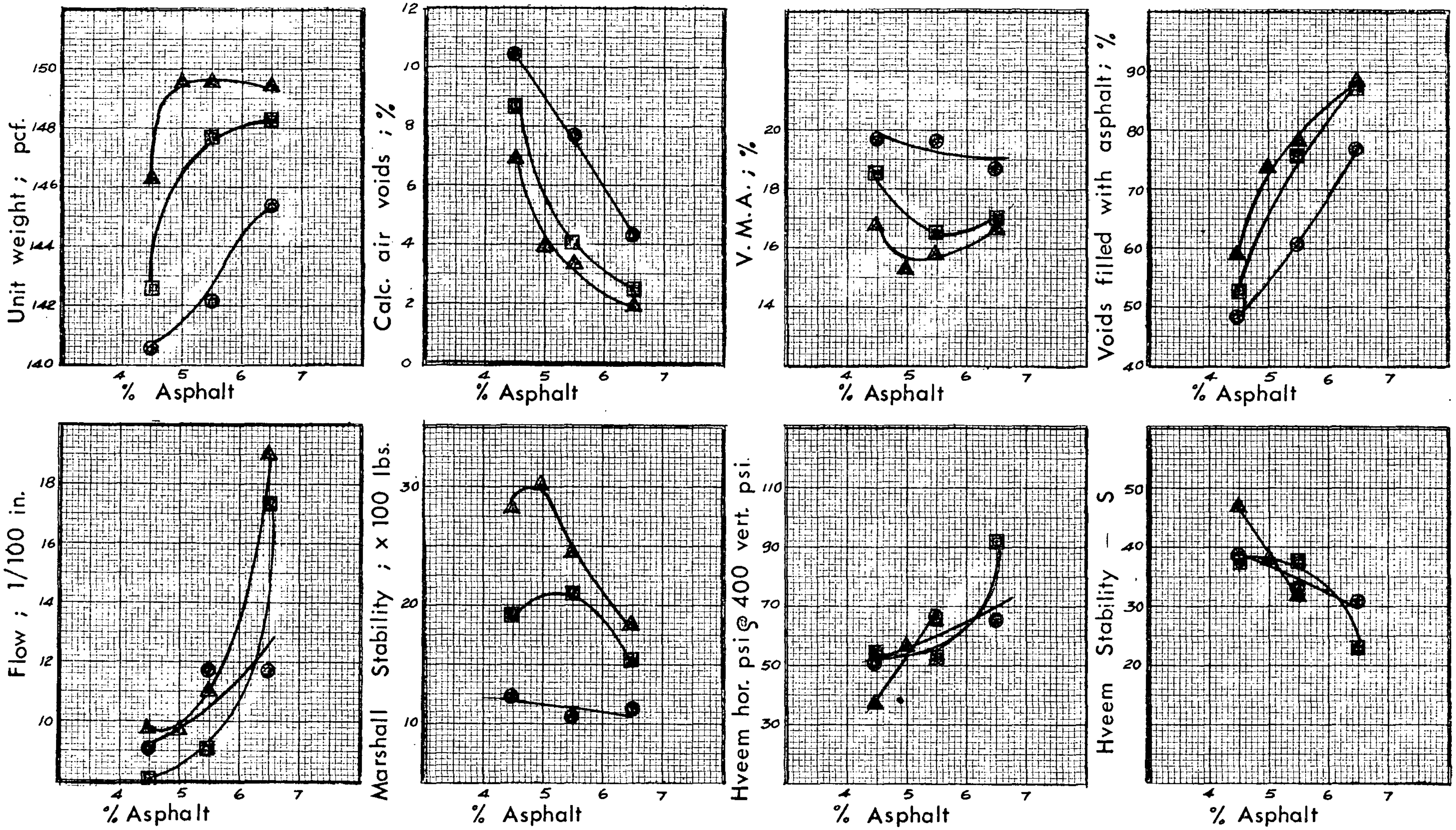

Legend
○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 14 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF COONEY STONE WITH 75 BLOW MARSHALL COMPACTION



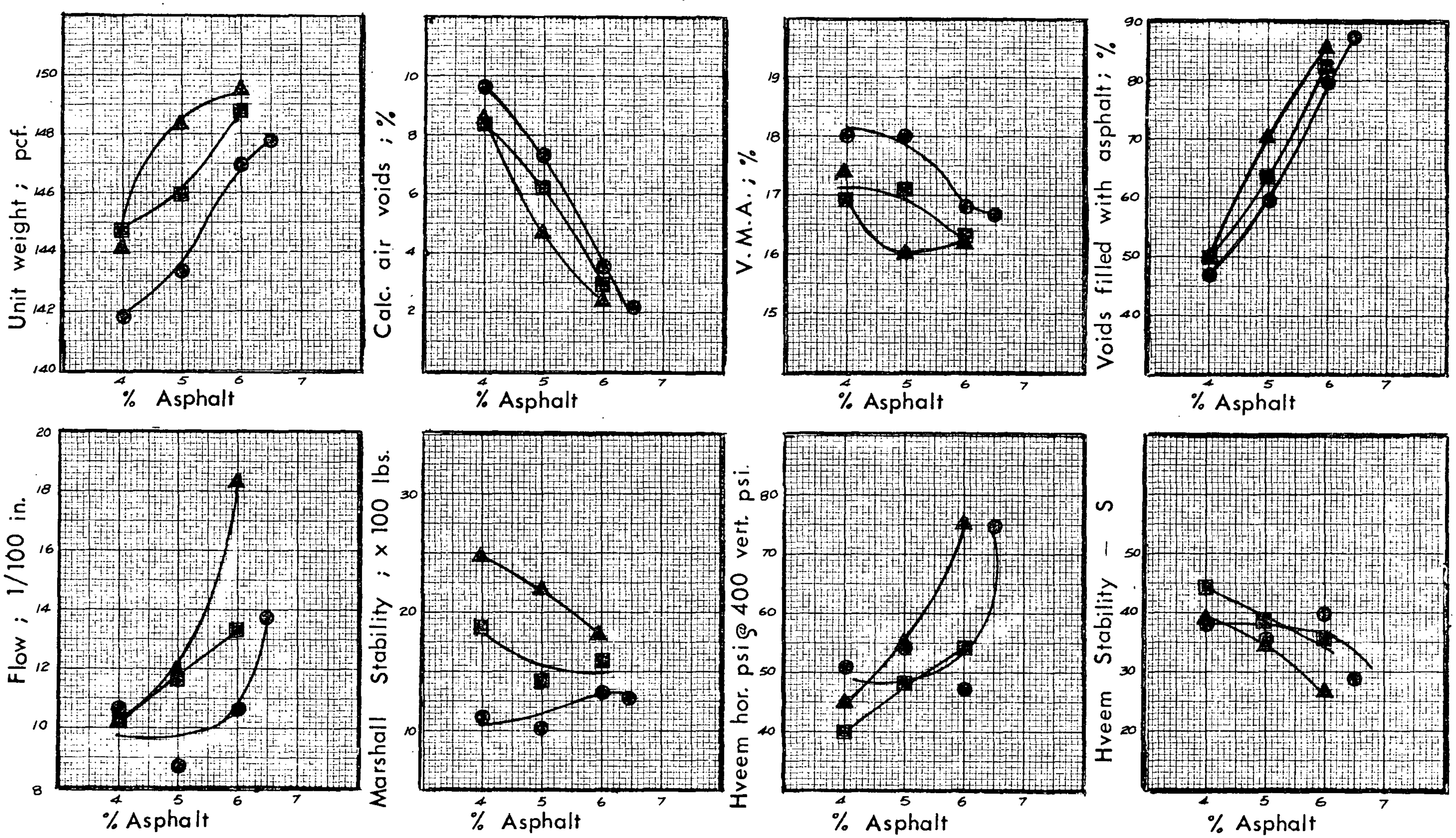

Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 15 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF FT. DODGE STONE



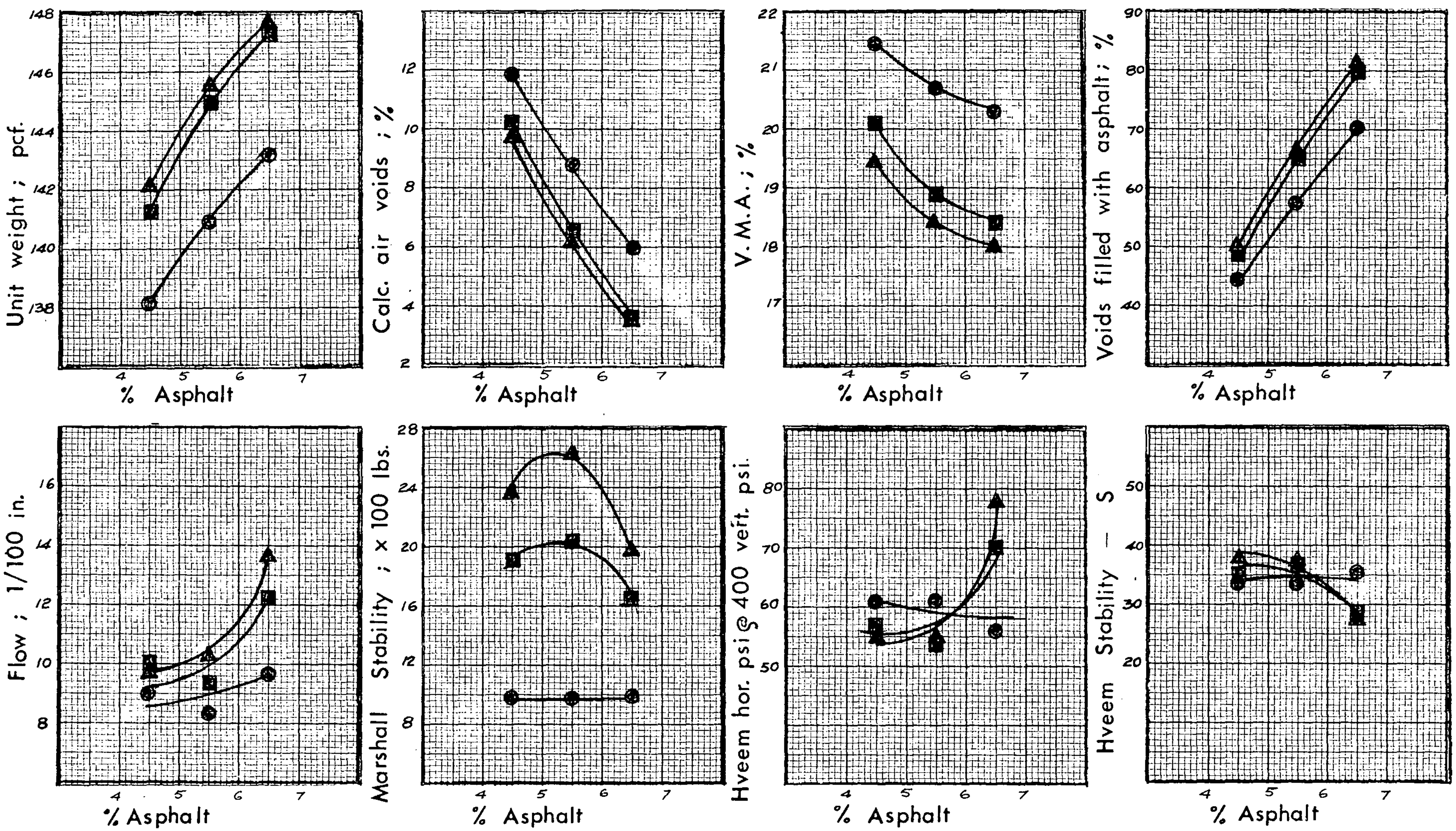

Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 16 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF FT. DODGE STONE



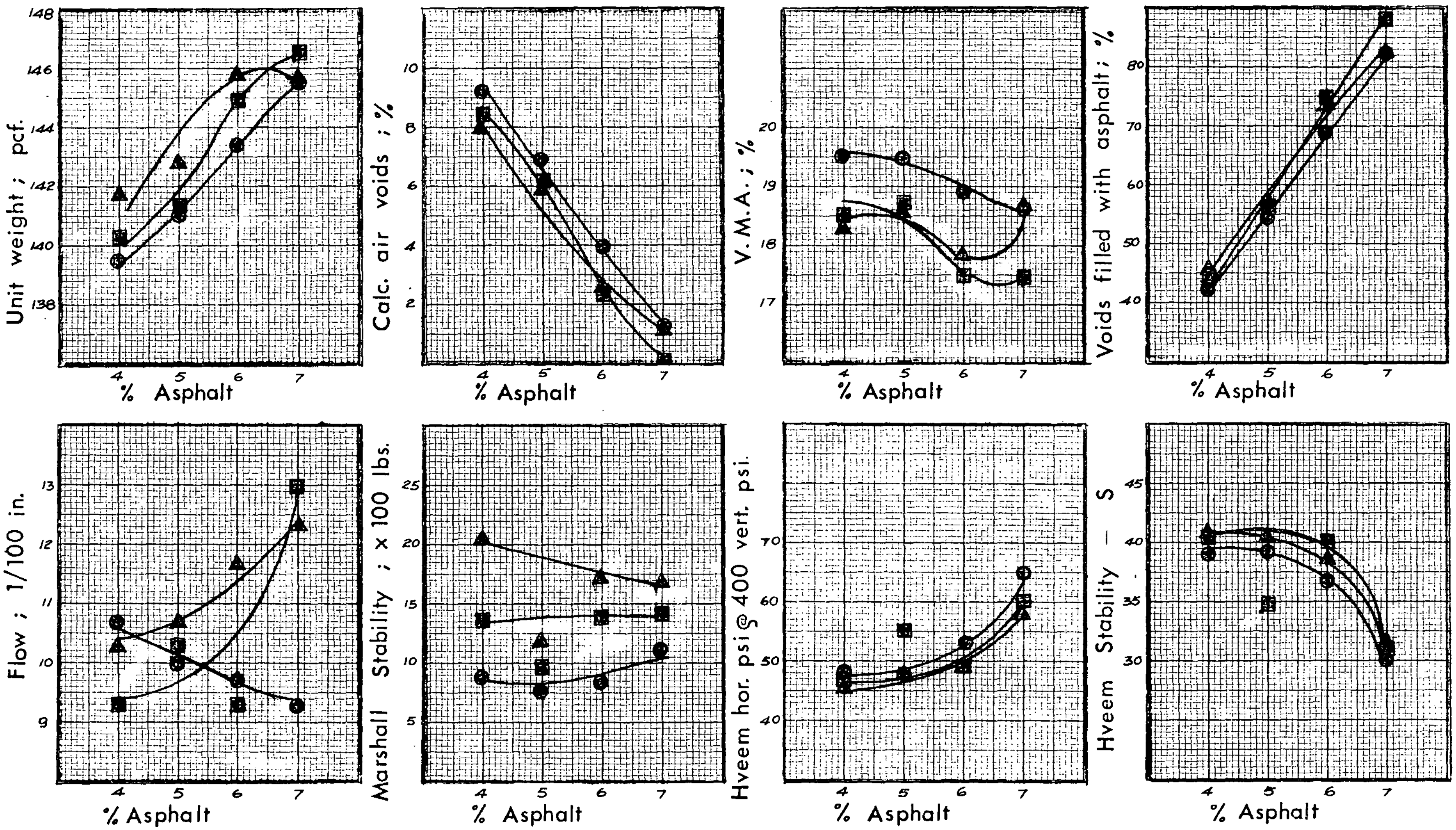

Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 17 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF DOUDS STONE



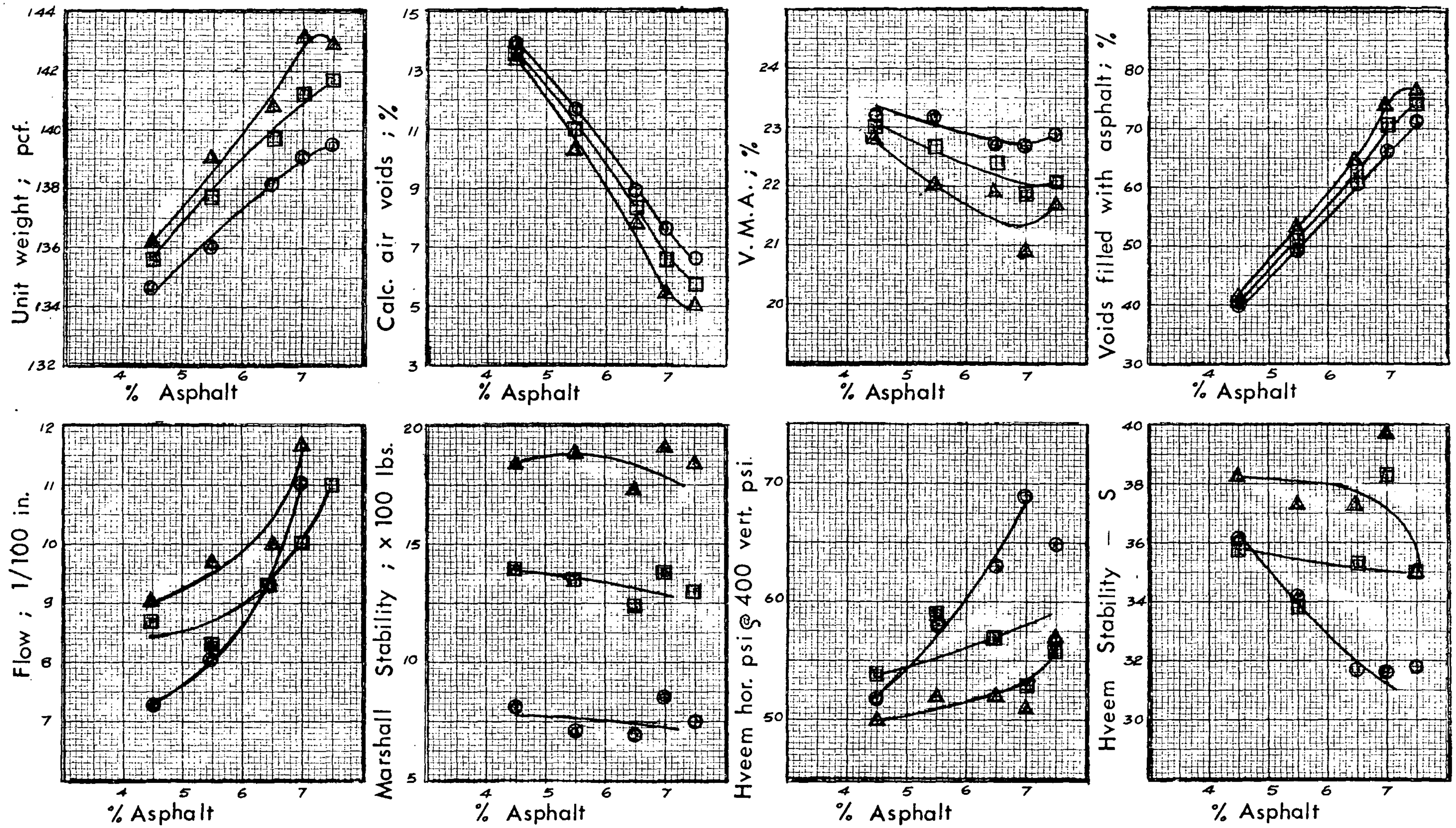

Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 18 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF DOUDS STONE




Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 19 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF SCHILDBERG STONE




Legend ○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 20 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF SCHILDBERG STONE

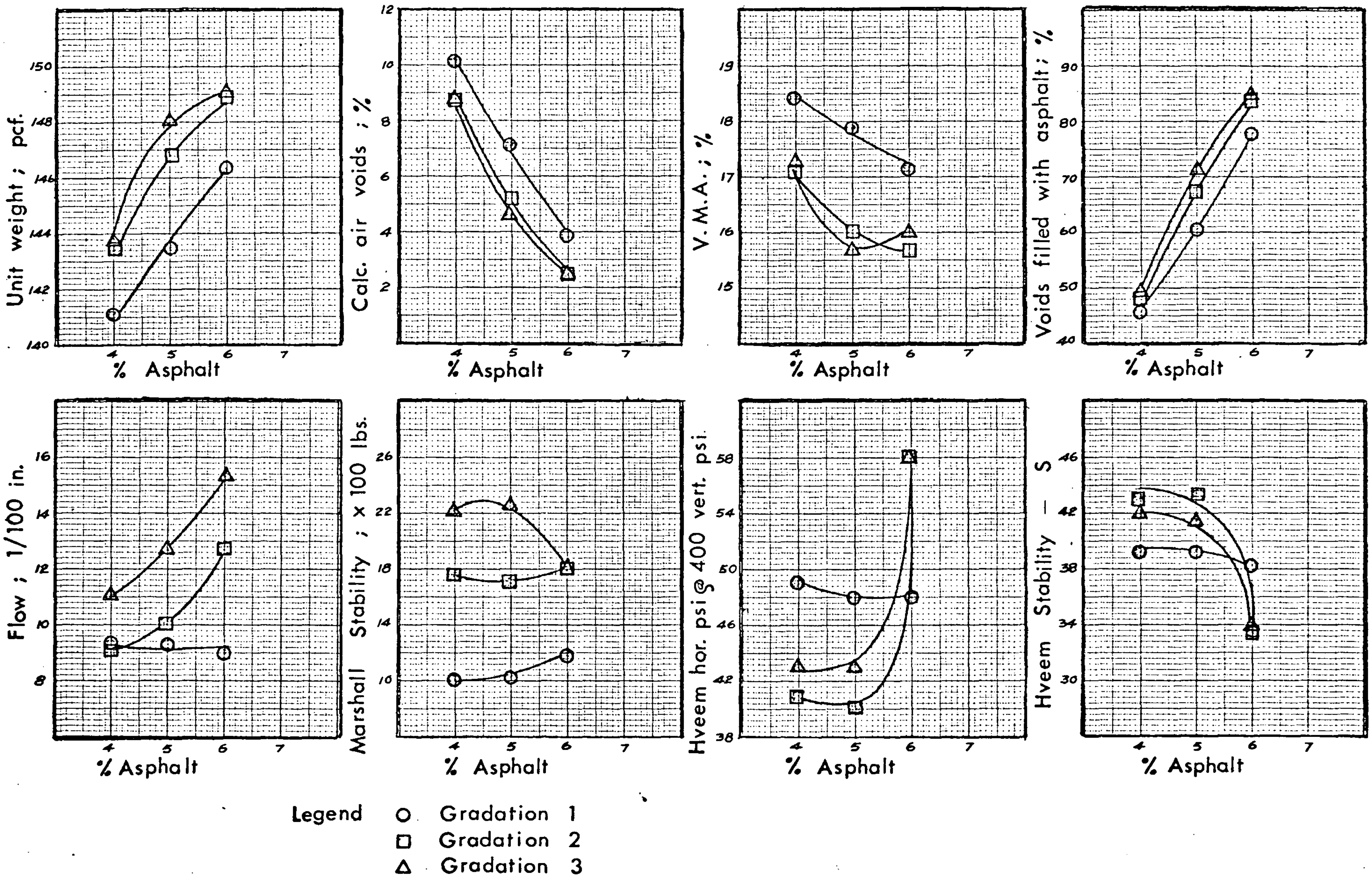
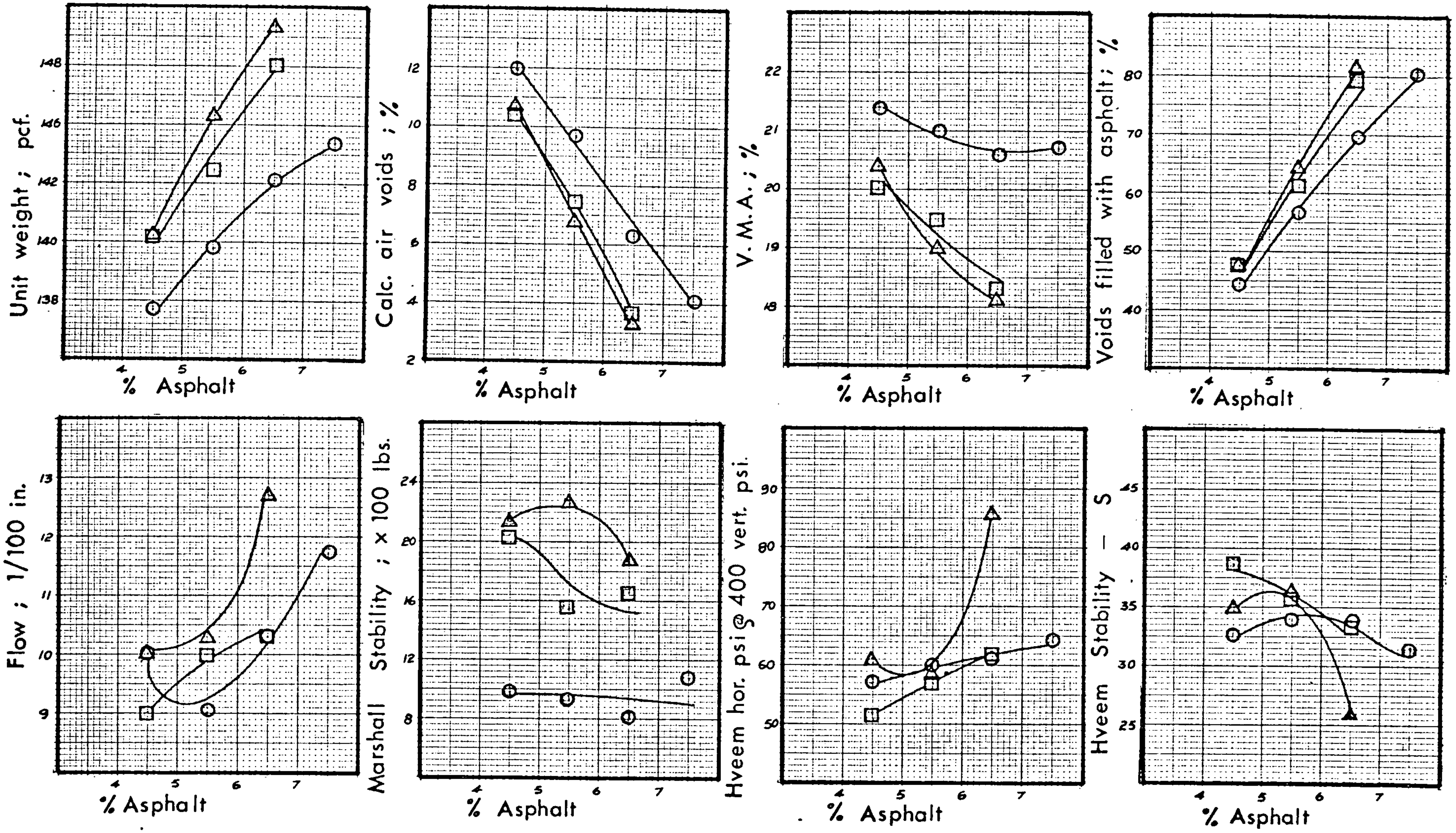



FIG. 21 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/4 INCH MIX OF CLARK STONE




Legend
○ Gradation 1
□ Gradation 2
△ Gradation 3

FIG. 22 EFFECT OF AGGREGATE GRADATIONS ON TEST PROPERTIES OF 3/8 INCH MIX OF CLARK STONE