FINAL REPORT

DEVELOPMENT OF TEST PROCEDURE FOR THE DESIGN OF BLACK BASE

by

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Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1976
VHTRC 76-R62

ABSTRACT

There is no standard design procedure available for black base mixes containing aggregates larger than 1" (25.4 mm).

This investigation dealt with the use of stability testing equipment similar to that used in the design of surface mixes and development of a compaction procedure for 6" (152.4 mm) diameter specimens. A compaction procedure was developed that could be used with slight modification to duplicate field densities. The trends of the VTM and VFA curves appear promising as an indicator of the proper asphalt content; however, the inherent variability of the stability measurement eliminates it as a design criterion.

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INTRODUCTION

Black base, which has been used in Virginia since 1947, is a dense-graded hot plant mix containing maximum sized aggregate larger than 1" (25.4 mm). Because of the large aggregate, the Marshall procedure cannot be utilized for the design of the mix and the designer must rely upon his experience.

This type of mix accounts for approximately 70% of the asphaltic concrete in new construction, therefore, it obviously is a major item in the overall cost of a pavement. Economy in the use of the mix can best be achieved if a laboratory mix design procedure is used to combine the aggregates and asphalt cement in proper proportions.

The Marshall procedure is used in Virginia to design all dense-graded mixes with maximum sized aggregate less than 1" (25.4 mm) and the district laboratories are geared to this design method. Any design method that could utilize any of the existing equipment would be advantageous. Included in the existing equipment is a 6" (150.4 mm) diameter stability testing head similar to the 4" (101.6 mm) head used in the Marshall procedure that was used in part of the evaluation of several black base mixes but for which there is no regular use procedure.

PURPOSE AND SCOPE

The purpose of this study was to examine a modified version of the Marshall design procedure for use with black base mixes containing aggregate larger than 1" (25.4 mm).

The primary objective of the study was accomplished by —

1. development and verification of a laboratory compaction procedure that approximated the compactive effort imparted to the mix in the field;

2. development of the familiar Marshall design curves for density, stability, voids, etc. by performing tests at several asphalt contents for each mix; and

3. performance of an analysis of variance using stability as the dependent variable and mixes and asphalt content levels as the independent variables to determine sources of variation.

MATERIALS

The sources of aggregates and job mix proportions employed were the same as those used by Freeman in a similar study.(1) The sources and proportions of the aggregates for each of the five B-3 base mixes(2) are listed in Table 1(1) and the gradations and asphalt contents are listed in Table 2.

Each of the five mixes had been placed on construction projects and cored for field density determinations by Freeman. These densities were used as a guide in establishing a compaction procedure in the present study.

Although the time interval between Freeman's study and the present one was approximately two years, it is believed that the aggregate did not change at the source except that for mix #1. In this mix the #5 traprock had less aggregate in the 1" to 1½" sieve range, although the original gradation specifying 22.5% between the 3/4" and 1½" sieves was met; therefore, the mix was finer than the #1 mix in Freeman's study.

Table 1

Materials and Mix Designs(1)

Mix #1 — Route 1, Fairfax County

30% #68 Traprock Vulcan Materials, Manassas, Virginia
25% #5 Traprock Vulcan Materials, Manassas, Virginia
10% Concrete Sand Lone Star Industries, Upper Marlboro, Maryland
35% #10 Screenings Vulcan Materials, Manassas, Virginia
4.5% AC-20

Mix #2 — Route 17, Fauquier County

50% #57 Granite Vulcan Materials, Occoquan, Virginia
30% Grade "B" Sand Massaponax Sand and Gravel, Fredericksburg, Virginia
20% #68 Gravel Massaponax Sand and Gravel, Fredericksburg, Virginia
4.4% AC-20

Mix #3 — Route 419, Roanoke County

60% #5 Limestone Rockydale Quarries, Roanoke, Virginia
30% Limestone Screenings Rockydale Quarries, Roanoke, Virginia
10% Natural Sand Martin's Property, Roanoke, Virginia
4.5% AC-20

Mix #4 — Route 50, Frederick County

25% #5 Limestone Stuart M. Perry, Inc., Winchester, Virginia
50% 3/4" Limestone Crusher Run Stuart M. Perry, Inc., Winchester, Virginia
25% #10 Limestone Stuart M. Perry, Inc., Winchester, Virginia
4.5% AC-20

Mix #5 — Route 340, Warren County

25% #5 Limestone Riverton Lime & Stone Co., Riverton, Virginia
45% #26 Limestone Crusher Run Riverton Lime & Stone Co., Riverton, Virginia
30% #10 Limestone Riverton Lime & Stone Co., Riverton, Virginia
4.5% AC-20

Table 2

Mix Gradations

Mix	No. 1	No. 2	No. 3	No. 4	No. 5	B-3 Median
Route	Rt. 1	Rt. 17	Rt. 419	Rt. 50	Rt. 340	
Sieve	% Passing					
1½"	100	100	100	100	100	100
3/4"	79	79	73	77.5	80	79
No. 4	43	40	42	44	43	43
No. 8	32	32	28	31	31	31.5
No. 200	4	2	6	4.5	4	4

DEVELOPMENT OF COMPACTION PROCEDURE

Basic Assumption and Density Criteria

To permit use of the available 6"-diameter testing head and obtain proportionality with the 2.5" (63.5 mm) thick by 4" (101.6 mm) in diameter Marshall specimen, the laboratory specimen was made 3.75" (95.2 mm) x 6" (150.4 mm). It was a basic assumption, to facilitate implementation in the field design laboratories, that the necessary equipment should require a minimum capital outlay.

The criteria used to evaluate the acceptability of a laboratory compaction procedure were (1) that it be able to closely duplicate field densities, and (2) it be capable of producing specimens having limited variations in density. Freeman's study had established that the average laboratory density should vary from field densities by no more than ± 1.5 pcf (24 kg/m^3), and that the range within specimens should be no more than 1.7 pcf (27 kg/m^3). Freeman used the kneading compactor to fabricate the specimens and obtained an average laboratory density 0.7 pcf (11 kg/m^3) greater than the field density; however, the range of average density within specimens was 2.4 pcf (38 kg/m^3), and thus was unacceptable.

The mix yielding the greatest variability within specimens in Freeman's study, mix #4, was used in the present study to establish the compaction procedure, and then the remaining four mixes were checked with the procedure.

Procedures and Results

The aggregate was heated in an oven to 300°F (149°C) and mixed with asphalt cement at 275°F (135°C) for 2 minutes. The mix was then transferred to the mold and compacted at an average temperature of 270°F (132°C). All tools, molds and compaction equipment that contacted the mixture were preheated to prevent excessive cooling of the mix during compaction.

In the initial trial procedure a portable electric rammer with a vibrating frequency of 3,200 cycles per minute was utilized (Figure 1). The mix was put into the 6" (150.4 mm) mold in two layers and each layer was vibrated. Various vibration times were tried; however, the maximum density achieved was well below the field density and was unacceptable.

Figure 1. Compaction of specimen with vibratory rammer.

The double plunger compaction method was also tried. This technique involves compressing a hot bituminous mixture in a mold by applying pressure from both ends with a testing machine normally used to break concrete cylinders. The maximum pressure applied, 354 psi (2.44 MPa), resulted in a low density, so this method too was deemed unsatisfactory.

In the third trial procedure a combination of the vibratory rammer and double plunger technique was used. The specimens were compacted initially using the vibratory rammer in the procedure described previously, then, after maximum compaction was reached, the mold and mix were transferred to the compression testing machine and subjected to a pressure of up to 495 psi (3.41 MPa) by the double plunger technique. Although different combinations of vibration and compressive pressure were applied, satisfactory density was not obtained in any case. The fourth procedure utilized a drop hammer as specified in ASTM Standard Test Method D 1559-75, except that the 4" (101.6 mm) diameter foot was replaced with a 3" (76.2 mm) one (Figure 2). All of the mixture was placed into the mold (Figure 3) with care being exercised to prevent segregation. Fifty blows were applied by moving the drop hammer around the mold, always with the foot against the inner perimeter. This procedure imparted a kneading action similar to that of the California kneading compactor. Each foot position overlapped the previous one slightly. After 50 blows were applied, the mold was removed from the base plate and replaced in an inverted position. Fifty blows were then applied to the inverted face, the mold and specimen were cooled at air temperature, and the specimen was extracted from the mold with a jack assembly.

Eight specimens were made for each of five mixes to determine the within mix variability. Density and void determinations were obtained for each specimen, after which the specimen was sawed into equal top, middle, and bottom portions and density and void determinations again made. Figure 4 illustrates the typical aggregate particle distribution in the sawed sections.

The differences between field densities and voids and laboratory densities and voids are given in Table 3. Also, the ranges within specimens are listed. The initial mix (#4) was within the 1.5 pcf (24 kg/m^3) criteria mentioned previously for the difference between field and laboratory densities, and the 1.7 pcf (27 kg/m^3) criteria was acceptable for the within specimen range. Results for the remaining mixes revealed that the average laboratory density was considerably higher than the average field density. The gradation of mix #1 was slightly finer than the field gradation because of the difference in aggregates mentioned previously under "Materials"; therefore, for this mix the comparison of laboratory and field densities may be misleading.

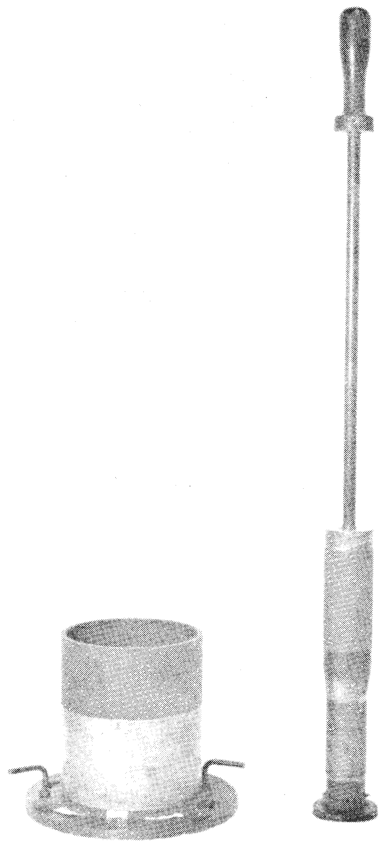

Figure 2. Drop hammer and mold assembly.

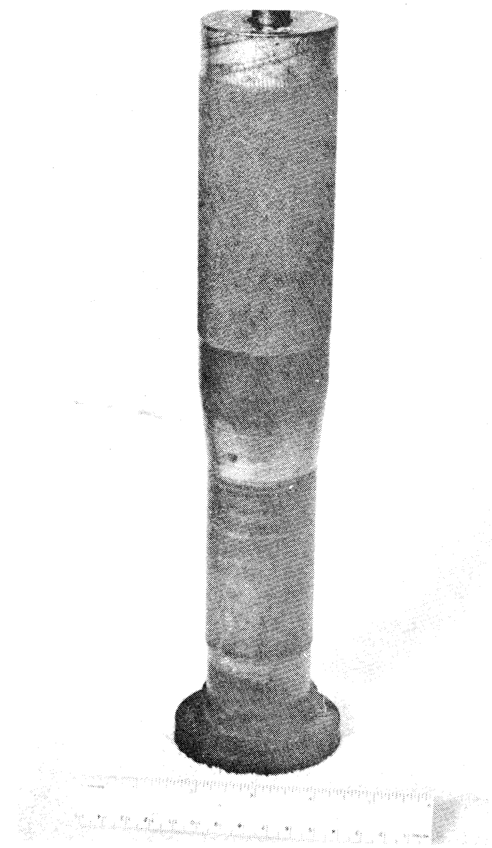

Figure 3. Mold assembly on compaction pedestal.

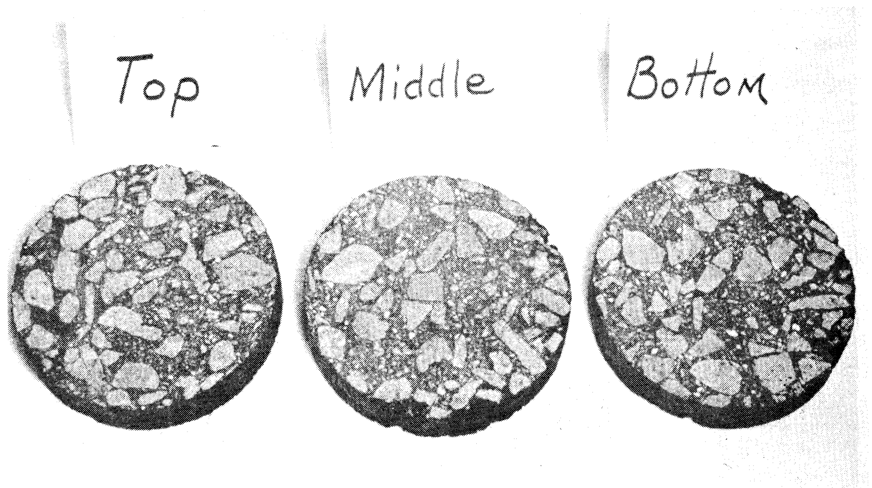

Figure 4. Sawed sections of specimen compacted with drop hammer.

Table 3

Comparison of Field and Lab (Drop Hammer) Densities and Voids

Mix	Field Density, pcf	Field VTM, %	Average Lab Density, pcf	Average Lab VTM, %	Within Specimen Density Range, pcf	Within Specimen VTM Range, %	Field Density & Lab Density Diff., pcf	Field VTM & Lab VTM Diff., %
1	156.7	6.1	159.2	4.4	1.5	0.9	+2.5	-1.7
2	142.4	8.6	146.7	6.1	3.6	2.5	+4.3	-2.5
3	152.5	6.3	156.2	3.8	1.0	0.6	+3.7	-2.5
4	147.5	8.4	148.4	7.0	1.6	1.0	+0.9	-1.4
5	150.2	5.5	152.7	4.5	1.5	0.9	+2.5	-1.0

Note: 1 pcf = 16.02 Kg/m^3

It appears that the compactive effort could be lessened somewhat by decreasing the number of blows; possibly to 40 blows on each side of the specimen.

The variability of density within specimens was satisfactory with the exception of that for mix #2.

"MARSHALL" DESIGN CURVES

Figures 5 through 9 illustrate the changes in test values and mix properties brought about by varying the asphalt content. The values show the customary trend toward decreased voids in total mix (VTM),increased voids filled with asphalt (VFA),and increased flow with an increase in the asphalt content.

The maximum and minimum decreases of VTM was 2% and 1% per 1% asphalt content increase, respectively, for mixes #1 and #3; the corresponding values for VFA were 15% and 10%.

Mixes #1, #2, and #3 showed an increase in voids in mineral aggregate (VMA), with an increase in asphalt content; however, mixes #4 and #5 gave an optimum value.

The VTM, and possibly the VFA, would appear to be a useful property in the design of base mixes. It is not clear whether the VMA is a useful property, although it may be important to specify a minimum or maximum value for it.

The unit weight curves did not show an optimum value as expected and, therefore, would not be used in a design method.

All mixes showed a change of stability with varying the asphalt contents, but there was no definite trend. A minimum stability value would possibly be useful to ensure adequate strength of the mix, but it must be shown that there is a significant difference between minimum and maximum stability values if this parameter is to be useful for asphalt content design. This point is discussed in the following section of the report.

The general trend was for the flow to increase as the asphalt content was increased. Mix #2 showed an insignificant difference in maximum and minimum flow values of only 2%, and mix #4 showed an optimum (maximum) flow value at 4.75% asphalt content. The applicability of flow as a design criterion is uncertain.

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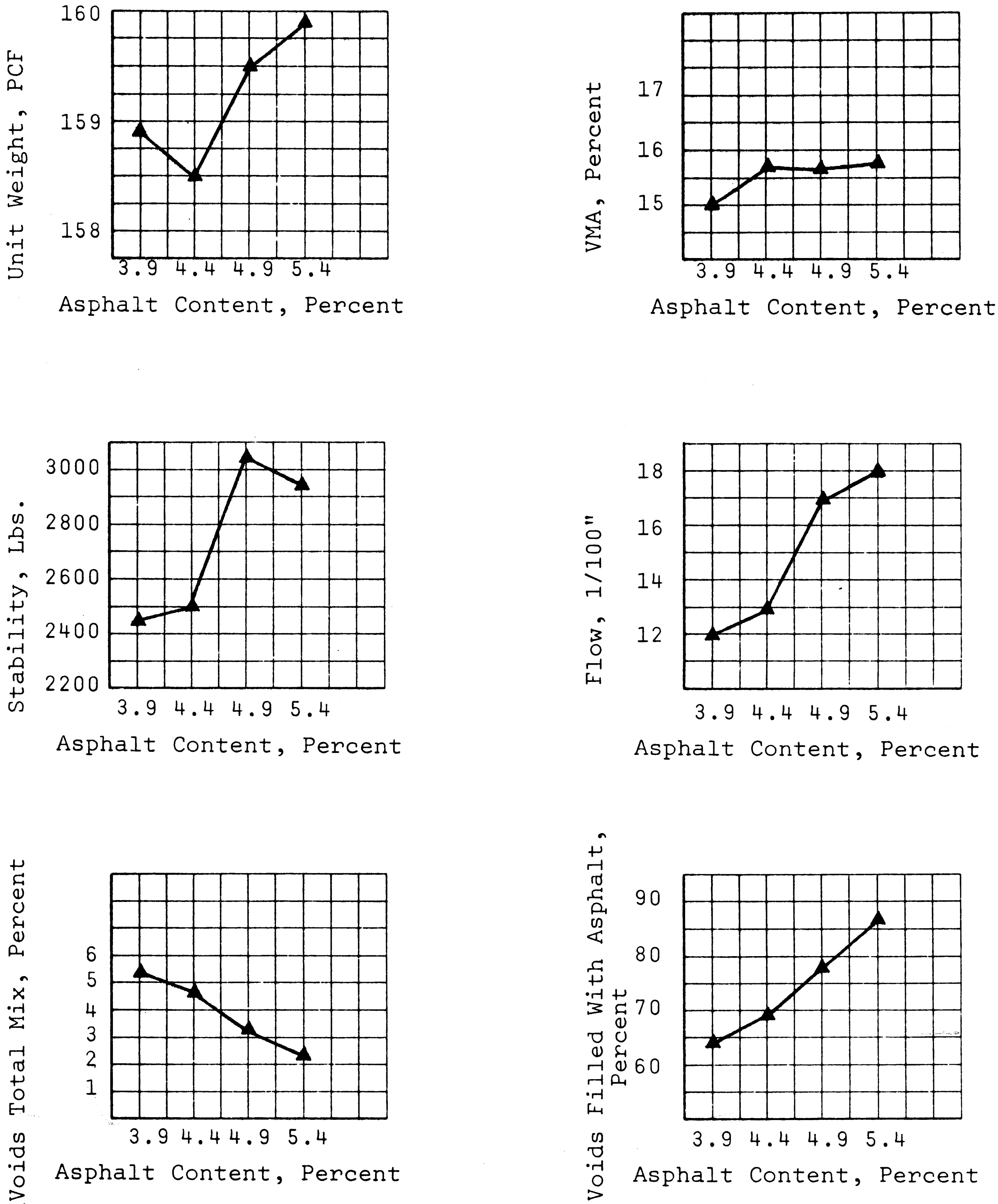

Figure 5. Asphalt content vs. #1 mix properties.
Note: Field asphalt content = 4.4%.

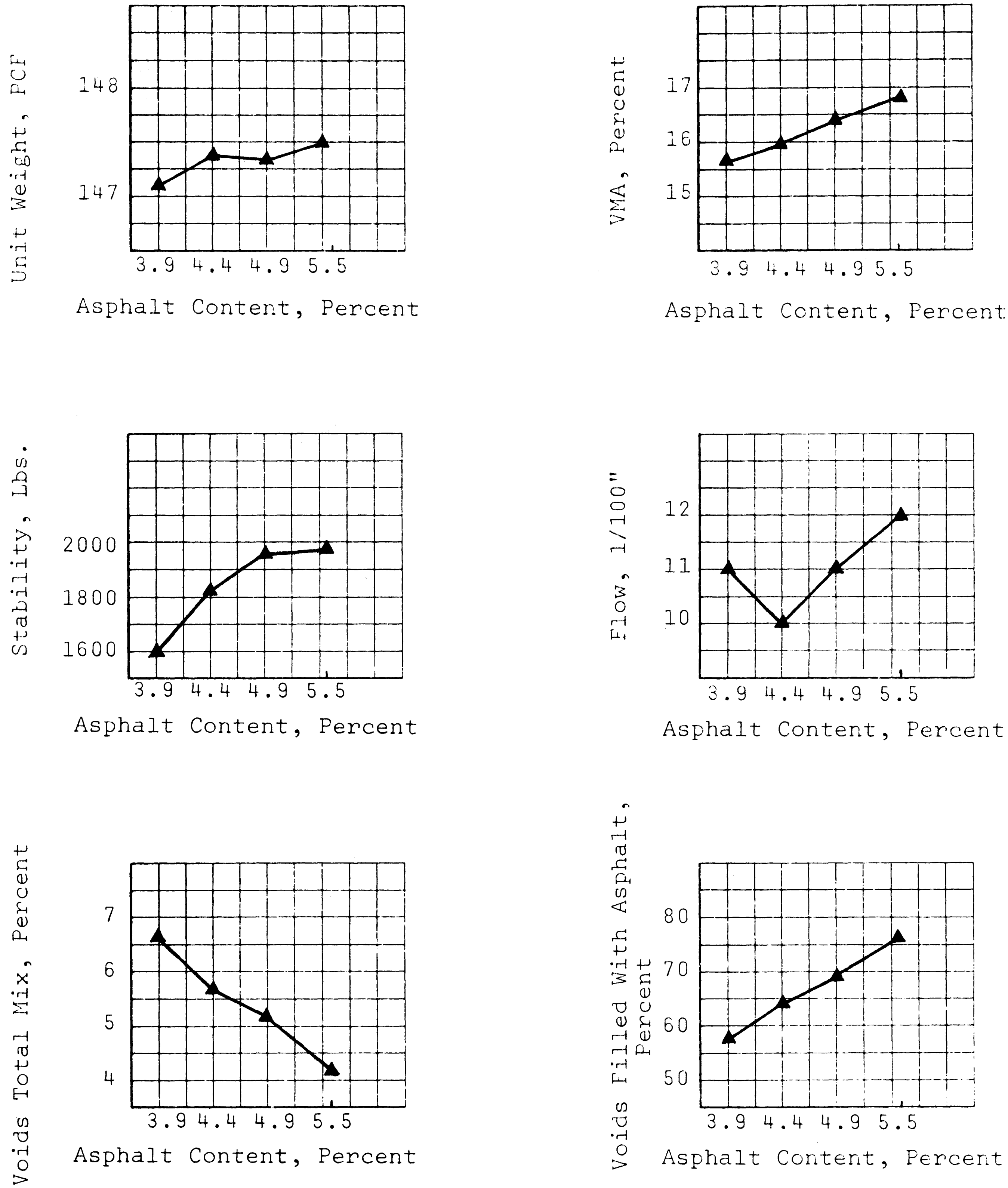

Figure 6. Asphalt content vs. #2 mix properties.
Note: Field asphalt content = 4.4%.

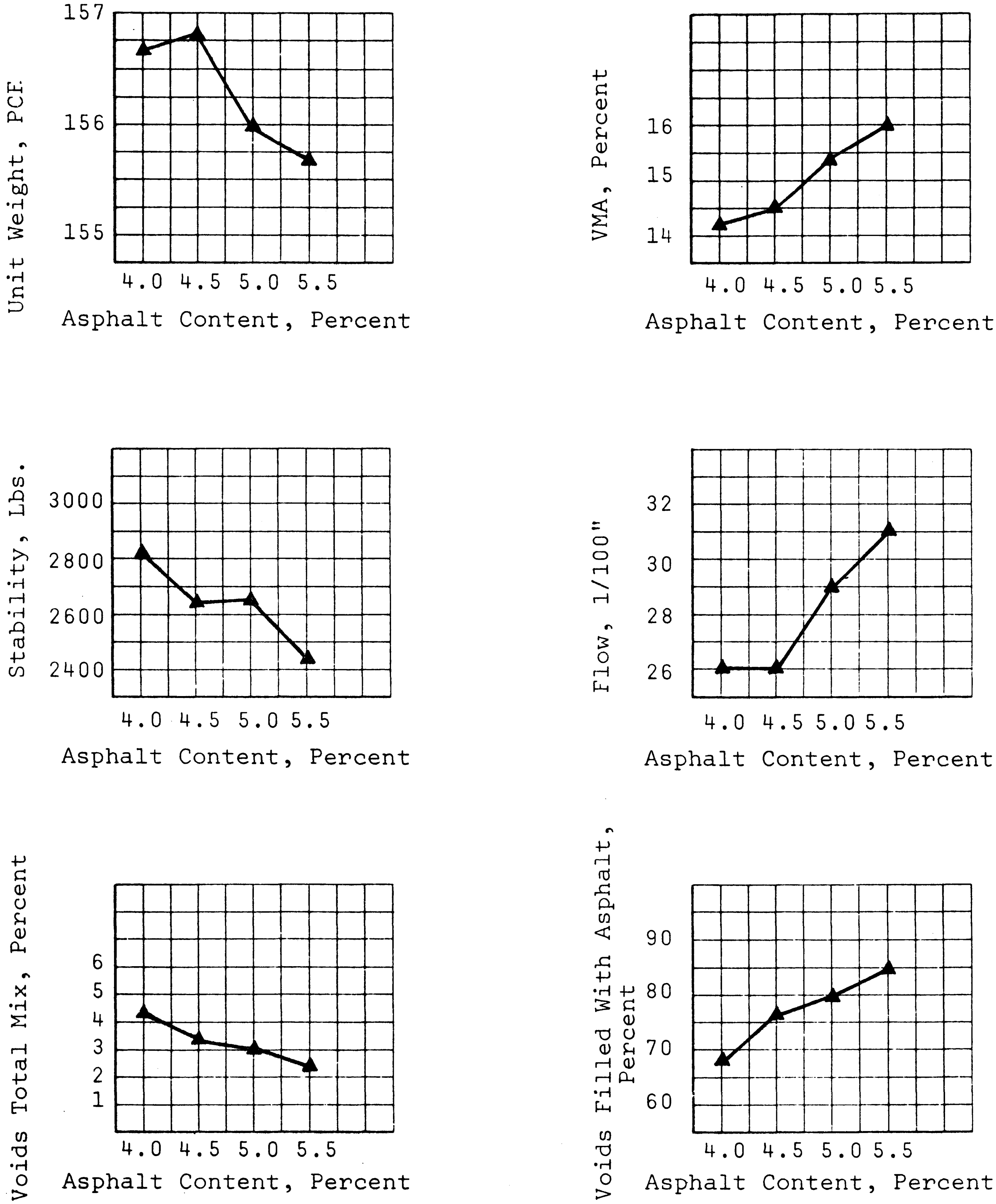

Figure 7. Asphalt content vs. #3 mix properties.
Note: Field asphalt content = 4.5%.

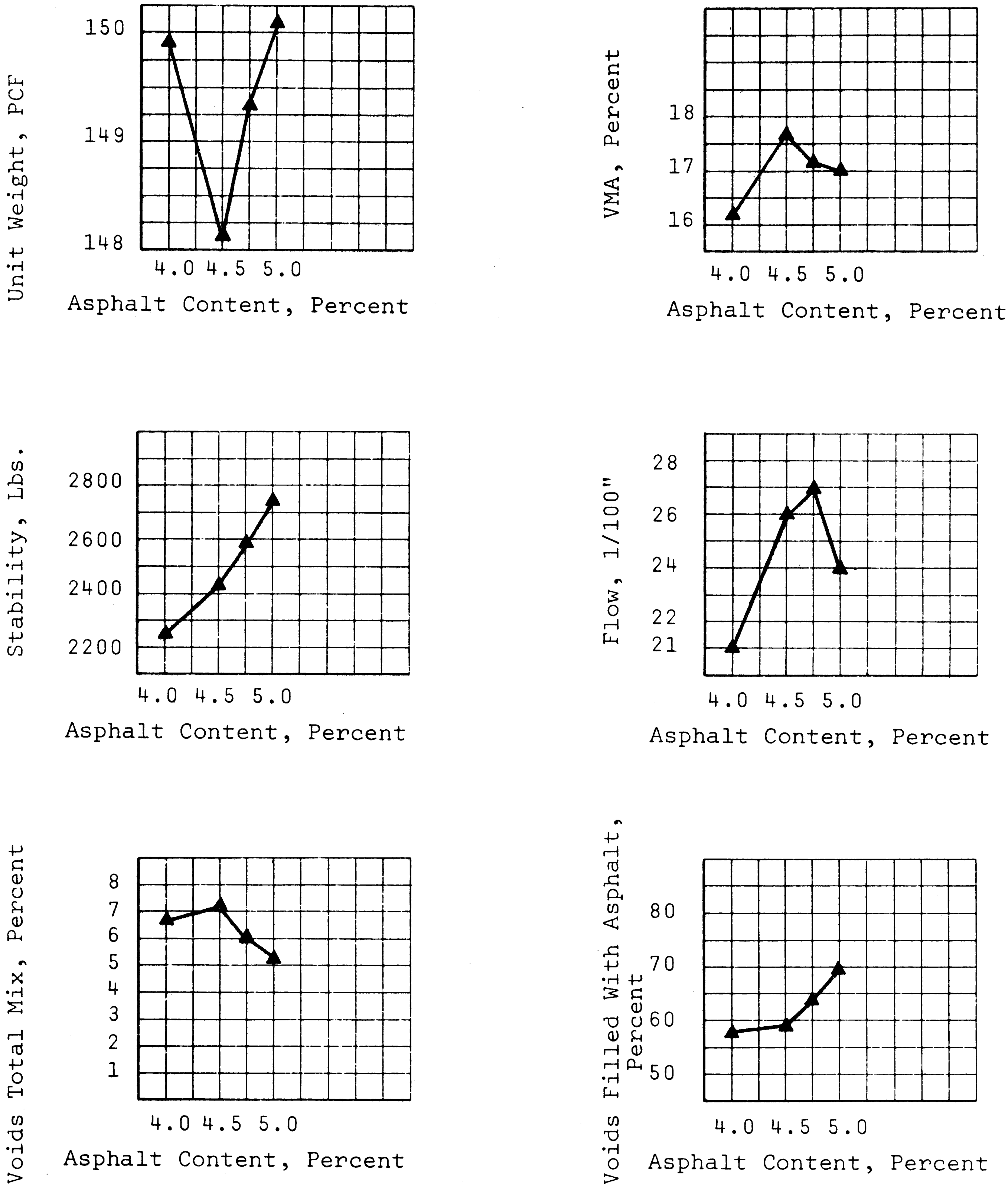

Figure 8. Asphalt content vs. #4 mix properties.
Note: Field asphalt content = 4.5%.

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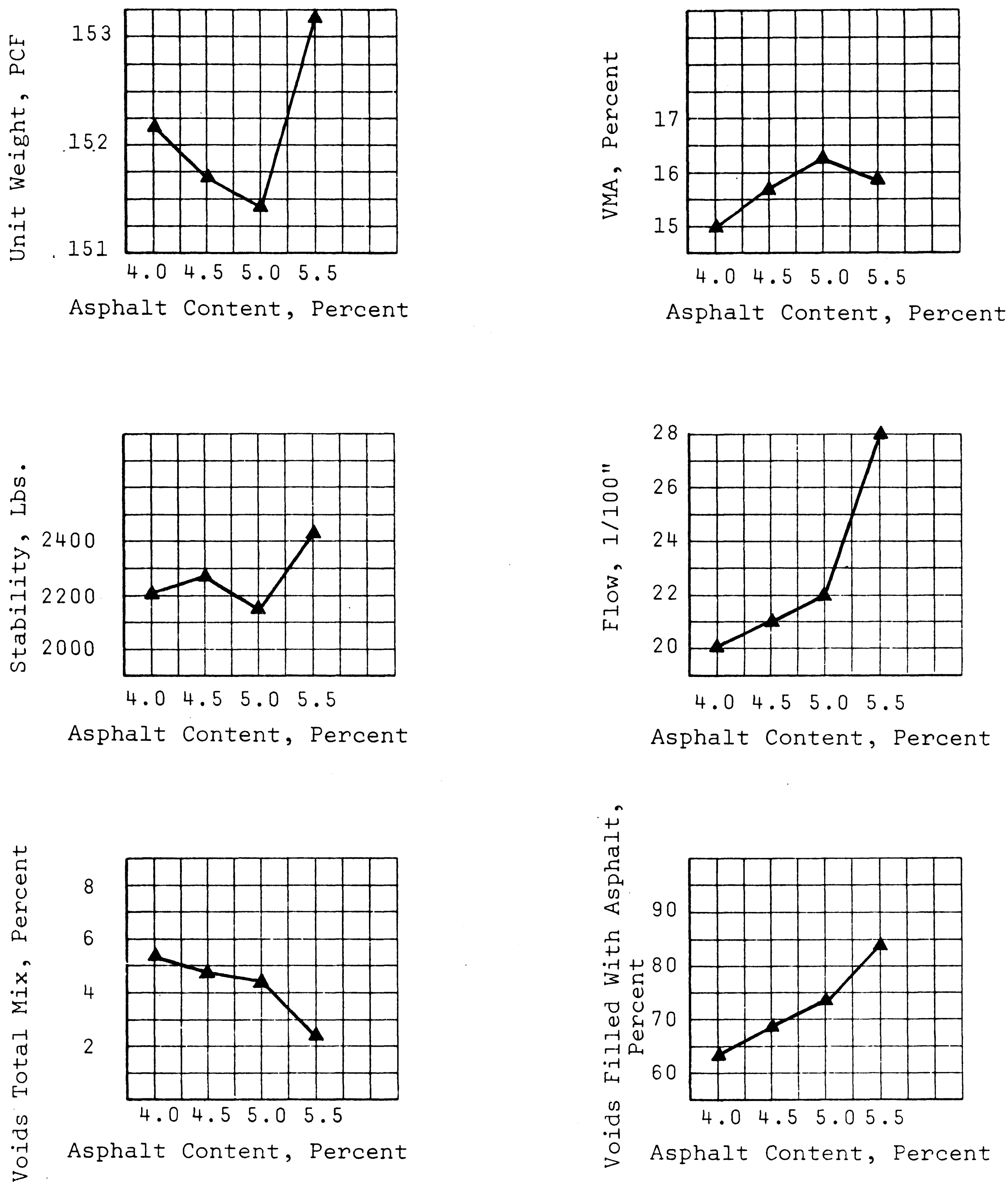

Figure 9. Asphalt content vs. #5 mix properties.
Note: Field asphalt content = 4.5%.

ANALYSIS OF VARIANCE

Sources of variation in stability were determined by an analysis of variance using stability as the dependent variable and mixes and asphalt contents as the independent variables. Table 4 lists the results.

Table 4

Analysis of Variance Results

Computation Steps	Mixes	Asphalt Content Levels	Interaction	Error
Degrees of Freedom	4	3	12	40
Mean Square	1,542,752	210,027	108,790	80,472
F-ratio	19.2	2.6	1.4	
Significance at 95% C.L.	Yes	No	No	
Component of Variance	121310	8200	9439	80,472
Standard Deviation	348	91	97	284

There was a significant difference between mixes but no significant difference between asphalt contents at the 95% confidence limits. Therefore, it is likely that the stability test would not indicate an optimum asphalt content for a particular mix if only three specimens are tested for each asphalt content. To obtain significant differences in stability values, eight specimens would be required at each asphalt content, which is probably impractical.

The component of variance and standard deviation results revealed that the majority of the variability was attributed to mix type. The standard deviation of a similar group of specimens, i.e. identical asphalt content and mix type, was 284 lbs. (error term).

CONCLUSIONS

1. A compaction procedure using a modified Marshall drop hammer will produce satisfactory laboratory specimens if slight modifications are performed in the compaction procedure, such as reducing the number of blows.

2. The trends of some void properties resulting from variations in asphalt content appear to be useful in mix design.

3. The stability parameter is too variable, using a practicable sample size, to indicate changes resulting from variations in the asphalt content.

RECOMMENDATIONS

It is recommended that an indirect tensile test be investigated as a possible replacement for the stability measurement; and, if the test can be used successfully, that additional data should be collected from field mixes to establish design criteria based on voids and strength.

REFERENCES

1. Freeman, J. R., Jr., "Final Report — Development of a Base Mix Design Procedure," Virginia Highway & Transportation Research Council, Charlottesville, Virginia, July 1974.

2. "Road and Bridge Specifications," Virginia Department of Highways & Transportation, Richmond, Virginia, July 1, 1974.