A LABORATORY EVALUATION OF SULPHUR-ASPHALT PAVING MIXTURES

FINAL REPORT

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ABSTRACT

A new asphalt paving material consisting of a mixture of poorly graded sand, asphalt cement and molten sulphur has been evaluated in the laboratory using Marshall test methods and materials readily available in Louisiana. Testing and evaluation included four sources of naturally occuring sands representing statewide availability, two asphalts (AC-20 and AC-40) and sulphur comprising 10 to 16 percent of the total weight of the mixture.

Results indicate that an acceptable highway paving material can be produced within the limits of mix design developed under previous tests conducted by Shell Canada Limited and the Texas A&M Research Foundation. Based on Marshall immersion tests, there are indications that sulphur-asphalt-sand mixtures may be slightly more sensitive to the action of water than are conventional asphaltic concrete mixes. In addition, the Marshall method of mix design and control may need further modification before being adopted for use on sulphur-asphalt paving mixtures.

INTRODUCTION

Louisiana's growing shortage of materials suitable for asphalt paving has led the Department of Highways to search for new materials and to extend the use of its native materials. One area of interest in this respect is in the shortage of aggregate, particularly those that can be used in asphaltic concrete mixtures. Aggregate deposits are being depleted at a rapid pace creating severe shortages in certain parts of the State. Many areas now require fairly long shipments which are often difficult to obtain and are costly.

A new material has been introduced by Shell Canada Limited (1)* which consists of a mixture of sulphur, asphalt, and sand (S-A-S) and is called "Thermopave." The material is reported to possess properties similar to asphaltic concrete, making it a possible alternative to this type of paving material. Molten sulphur is combined with varying percentages of hot asphalt and sand to produce the mixture. Paving grade asphalt cements are used along with native sands graded from coarse to fine.

The fact that inexpensive, poorly graded sands may be used in the "Thermopave" material makes it particularly attractive to Louisiana. These so called "marginal" sands are available in unlimited quantities throughout the State. Probably the largest quantities are available in creek and beach deposits which are normally gap-graded or single-sized materials. However, adequate supplies of underground sands are available at costs lower than coarse aggregates (gravel and shell) normally used in asphaltic concrete.

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*Underlined numbers in parenthesis refer to numbered references.

The "Thermopave" material was first introduced to the United States under the research program "Benefical Use of Sulphur in Sulphur-Asphalt Pavements" (2) conducted by the Texas A&M Research Foundation and co-sponsored by the Sulphur Institute and Bureau of Mines. Included in this program were extensive laboratory investigations of the material which supported the conclusion that S-A-S paving material made with inexpensive, poorly graded sands demonstrated properties at least equal to or better than conventional asphaltic concrete. In addition, it was determined that the S-A-S paving material could be produced for construction in a manner similar to conventional hot-mix production. However, a number of equipment modifications would be required which are still under development by Shell Canada Limited.

On the basis of this background and the potential for using the material in Louisiana, the Department of Highways in co-operation with the Federal Highway Administration authorized a Type B research study to investigate in the laboratory properties of various S-A-S mixes utilizing Louisiana sands, sulphur and asphalt.

PURPOSE AND SCOPE

Purpose: This study was initiated with a two-fold purpose in mind. First and most importantly, the study was undertaken to familiarize Department of Highways personnel with the S-A-S material and its physical properties. Second, the research effort was designed to verify results obtained by others using materials native to Louisiana.

Scope: The objectives of this research study were accomplished through a laboratory program of making, testing and evaluating specimens for Marshall properties. Four sources of sands representing statewide availability were evaluated using various combinations of asphalt cements (AC-20 and AC-40) and varying levels of elemental sulphur. In all, some 96 different combinations of S-A-S materials were included in the evaluation.

METHOD OF PROCEDURE

Materials: Four sand materials representing statewide availability were chosen for purposes of this study. Individual sources were (1) Holly Beach, a beach sand located in Southwestern Louisiana, (2) Acadian Sand Company, a sand pit source situated near Abbeville in South-central Louisiana, (3) Thompson Creek, a creek deposit north of Baton Rouge in Central Louisiana and (4) Anderson Pit, a pumped sand produced in the eastern part of the State.

Materials samples ranging from 400 to 500 lbs. were obtained from each location and were tested for gradation and physical properties. Results are presented for each source on Figure I and Table 1 in Appendix A. The sands represent a range of conditions from a gap graded beach sand to a uniformly graded concrete sand.

Asphalt cement types AC-20 and AC-40 conforming to Department of Highways Standard Specifications (4) were selected for use in this experiment. Asphalt AC-40 is the more commonly used of the two in base and surface course mixtures. The lower viscosity AC-20 asphalt is normally restricted to areas with low stability requirements such as shoulders and bases under concrete pavements. The physical properties of the asphalts used in this particular phase of testing are given in Table II (a) of Appendix A.

The final material used in the S-A-S mixture is elemental sulphur in powdered form supplied by Freeport Sulphur Company, Port Sulphur, Louisiana. Since the Department was unfamiliar with testing procedures to determine physical properties of sulphur, samples were submitted to the Sulphur Institute for their analysis. Resulting properties conformed to the requirements for the "Thermopave" material (2) and are listed in Table II (b).

<u>Laboratory Testing</u>: The "Thermopave" material tested by Shell Canada Limited (1) contained approximately 6 percent asphalt, 13.5 percent sulphur and 80.5 percent sand, each based on total weight of the mixture. This combination of materials was determined by preliminary tests in the laboratory and represented a mixture that yeilded desirable Marshall properties and provided an acceptable level of workability for field construction.

After extensive laboratory evaluation, Gallaway and Saylack (2) recommended that S-A-S paving mixtures be designed to conform to the following physical properties:

1)	Stability at 140^{o}F., pounds	1,200 min.
	Flow value, 0.01 inch	6 min.
	Air Voids, percent in mixture	15 max.
2)	Workability, inches slump	1-1/2 min. to 6 max.
3)	Stability after immersion, pounds	60 percent of initial stability, min.

They report that these criteria can normally be achieved when the sulphur content of the S-A-S mixture varies from about 10 to 20 percent by weight, the asphalt content from 4 to 8 percent by weight and the sand from 72-86 percent accordingly.

Using these findings as a basis for this research study and after conducting several preliminary tests, it was decided to test each of the sand sources and asphalt grades at sulphur levels of 10, 12, 13.5 and 16 percent by weight of the mixture and asphalt contents of 5, 6, and 7 percent by weight accordingly.

In order to conduct the required tests, several modifications to the Marshall method of preparing and testing specimens (ASTM DI559 and LDH TR305-74) had to be made. In addition, the S-A-S material behaves somewhat differently than conventional asphaltic concrete, and special handling procedures were found to be necessary to achieve desired results. The various modifications to equipment as well as procedures to fabricate and test Marshall specimens are described in the following paragraphs. These conform to recommended practices based on previous work at the Shell Canada Limited (1) and the Texas Transportation Institute (2) research laboratories.

A total of six briquette test specimens was prepared for each S-A-S combination in accordance with LDH TR 303-71, "Preparation of Hot Mix Samples for Laboratory Mix Design." Predetermined quantities of each sand material were oven dried and mixed with required amounts of asphalt and molten sulphur. In order to accommodate 7000-8000 gram batch sizes, a specially prepared mixing unit had to be provided as shown in Figure 2. The mixing sequence included precoating the sand with asphalt by mixing for approximately 30 seconds followed by blending and continued mixing of liquid sulphur for an additional 30 seconds. All S-A-S materials as well as containers, mixing blades, molds and handling equipment were preheated to 300°F prior to mixing.

The S-A-S mixture was quickly placed in mold assemblies designed especially to accommodate the material as indicated in Figure 3. The molds which were developed by Shell Canada's laboratory allowed for preparation of briquette specimens of the exact sizes (2-1/2 in. x 4 in.) needed for Marshall testing. Each specimen was compacted by two blows with a Marshall hammer on one side only. Unlike conventional asphaltic concrete, the S-A-S mixture has been found to require very little compactive effort to perform as a paving material. Deeme (3) reports that experience has shown that S-A-S pavement densities have veen found to generally range from 96 to 100 percent of the two blow Marshall specimen bulk densities.

The briquette specimens were allowed to cool for approximately four hours to room temperature and were extracted from the mold assemblies. It is important that the beiquettes be distrubed as little as possible to maintain the structuring effects of the sulphur. It has been shown that the molten sulphur occupies voids left by the asphalt coated sand and continues to restructure for a period of two or three days (1, 2, and 3).

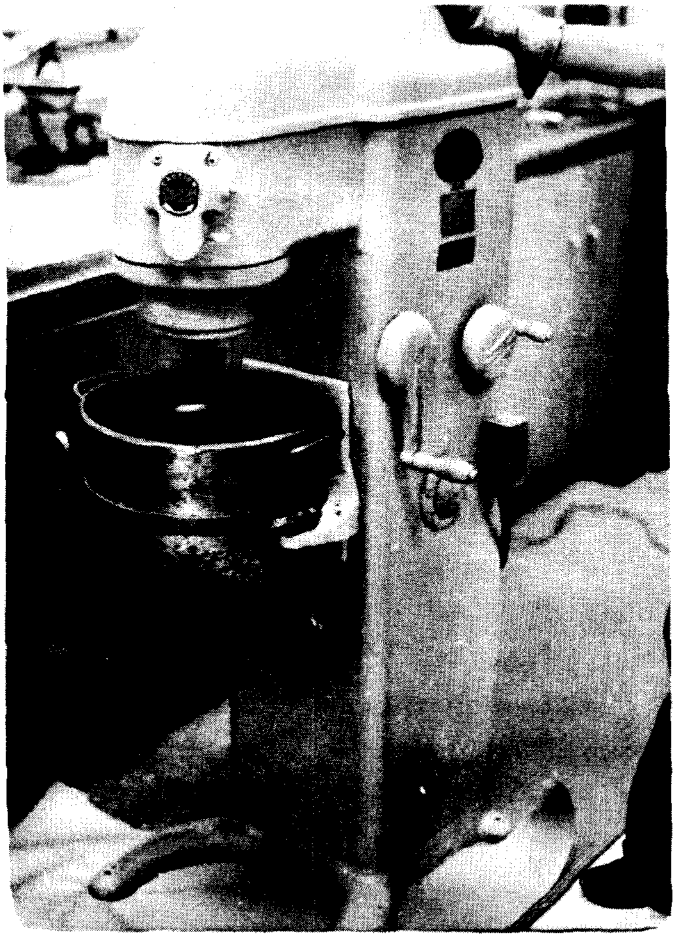

Figure 2: Laboratory Mixing Unit

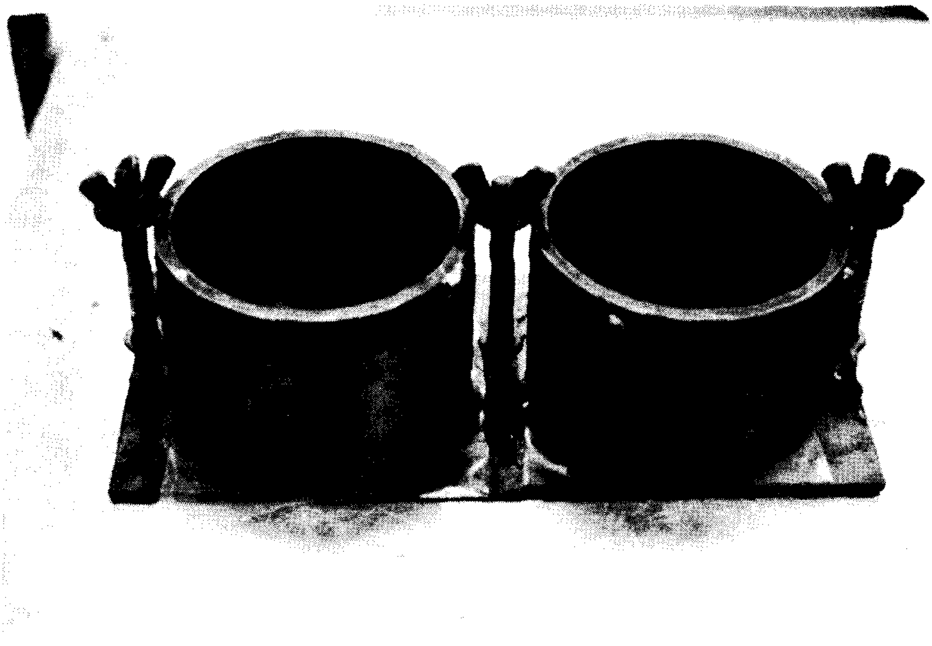

Figure 3: Mold Assembly for S-A-S Mixture

The six briquettes for each level of S-A-S were then stored in air at room temperature for 24 hours. Specific gravities were determined in accordance with LDH TR 304-66, "Determination of Specific Gravity of Compressed Bituminous Mixtures." Afterward, the test specimens were paried into two groups of three briquettes each according to like specific gravities. One set was maintained in air at room temperature for an additional 24 hours, and the other three specimens were immersed in a water bath at 140°F for a 24-hour period. The static immersion procedure has been adopted by the Department to determine the effects of water on compacted bituminous mixtures.

The Marshall test specimens were tested for physical properties 48 hours following their preparation and molding. Marshall stabilities and flow values were measured and recorded for both sets of briquettes. Test methods followed LDH TR 305-74, "The Stability and Flow of asphaltic Concrete Mixtures-Marshall Methods," and LDH TR 313-66, "Determining the Index of Retained Marshall Stability of Immersed Specimens." Retained stabilities reflect the comparison of average Marshall stabilities after immersion to average stabilities for air cured specimens. Similarly, percent water absorption and volumetric change (swell) were determined and reported.

As an additional part of information gained from this research effort an attempt was made to characterize workability of the various S-A-S mixes by estimating slump (inches). Although actual "slump" determinations were not conducted, experienced personnel estimated and recorded slump to the nearest inch. This information could be useful should the Department elect to enter into an experimental or demonstration project using the S-A-S material.

DISCUSSION OF RESULTS

Results obtained from the physical tests are presented for each sand source in Tables III through VI of Appendix B. From these data, corresponding properties essential to analysis were calculated and are given in Tables VII through X of Appendix B. Included are means or averages for the series of tests represented in addition to voids, VFA determinations, and average percentages for retained Marshall stability.

In order to facilitate analysis of the recorded data, graphical representations were prepared for each sand and asphalt type showing the influences of sulphur and asphalt contents on the various physical properties. The graphical relationships are indicated in Figures 4 through 7 in Appendix B for the Acadian Pit sand, Figures 8 through 11 for Anderson Pit sand, Figures 12 through 15 for Holly Beach sand, and Figures 16 through 19 for the Thompson Creek sand. Curves given in these figures were determined by attaching end points to values plotted for the extreme sulphur levels (10% and 16%) and extrapolating the midpoints (12% and 13.5% Sulphur) in order to produce a smooth line. This was felt to offer the best means of displaying the limited amount of data obtained from this research study.

The ensuing paragraphs contain a detailed discussion of each of the physical properties evaluated as well as other items affecting the findings of the research project.

Marshall Stability:

The effects of sulphur contents and asphalt percentages on Marshall stabilities are shown for each sand source on even-numbered Figures 4 through 19 of Appendix B. In all situations investigated, stability values increased significantly with the addition of greater amounts of sulphur. This generally confirms findings by others in earlier investigations (1, 2, and 3).

It can also be noted from these results that decreasing percentages of asphalts correspond to higher stability values. Taken alone, this might be interpreted to suggest that the range of asphalt contents used were somewhat high. However, as is the case with asphaltic concrete, asphalt contents cannot be based on stability alone. A substantial amount of asphalt is needed to adequately coat the aggregate material. The range of asphalt selected was based on an average coating thickness of five microns (.005 in.).

The ranges of Marshall stability values for each sand source meet and in most cases exceed the minimum requirements established by the Department's specifications (4). For conventional asphaltic concrete mixtures, a minimum of 1200 lb. Marshall stability is required for an average of four tests representing a normal day's production. This includes black base as well as surface course mixtures of the types comparable to the indicated S-A-S mixes.

The relationship of asphalt type (AC-20 or AC-40) to Marshall stability demonstrated by results obtained from the project indicates negligible differences in findings. Although it has been the Departments experience that the higher viscosity asphalt (AC-40) yields slightly higher stabilities in conventional hot mix, this cannot be concluded from results of this study due to insufficient data.

Another item of noteworthy mention is the fact that generally higher stabilities were obtained with the finer graded sands. The fairly one-sized, gap-graded sand from Holly Beach produced Marshall stabilities in the general range of 1500 to 3500 lbs. for the various combinations of asphalt and sulphur contents studied. The coarsest sand material evaluated, Anderson Pit, yielded stability values in the general range of 500 to 2500 lbs. which represented one of the lowest ranges of values obtained.

A matter of primary interest to the evaluation of test results is testing variance. Throughout the period of laboratory testing, it was noticed that individual Marshall stability values were varying excessively based on previous experience with asphaltic concrete specimens. Each group of briquettes was prepared from the same batch of S-A-S mixture and were all molded and tested in the same time frame. Consequently, any differences in stability results would be due to testing variance and not other material changes on related causes.

In order to demonstrate testing variance obtained during this study, Table XI has been prepared showing various statistical data for each of the four sand sources. Included are average ranges for batch-by-batch stability test results in addition to means and standard deviations indicative of magnitude and extent of variability.

TABLE XI

Statistical Comparison of Marshall Stability Test Results for Various Sand Sources

Source	Mean Marshall Stability (lbs.)	Avg. Range of Indiv. Test Results (lbs.)	Estimated Std. Dev. (lbs.)
Acadian Pit	1617	331	196
Anderson Pit	1671	435	257
Holly Beach	2327	652	385
Thompson Creek	1501	380	225

A recent survey of asphaltic concrete mixtures produced in the State of Louisiana during the past five years revealed that standard deviations for Marshall stability averaged approximately 300 lbs. (5). However, this value includes sampling as well as testing variance. In Louisiana mixtures, testing variance normally accounts for about 40 percent of the overall variation which would amount to 120 lbs. using the previously mentioned figure for standard deviation. Comparing this to the above listed values for the S-A-S mixtures, it would appear conclusive that testing results obtained under this study varied beyond limits normally experienced with asphaltic concrete. It is considered to be beyond the scope of this study to attempt to isolate the causes of this excessive variability. It could well be attributed to basic unfamiliarity with the S-A-S material rather than changes in the material itself. Probably more importantly, the Marshall method may not be suitable for designing and controlling S-A-S mixtures. Further revisions to equipment and testing procedures may be necessary to better accommodate this new material.

Marshall Flow:

The relationship of Marshall flow to varying percentages of asphalt and sulphur for each of the sands and asphalt types investigated is demonstrated on Figures 4 through 19 of Appendix B. Marshall flow, which is a measure of deformation during loading of the specimen, is another physical property important to characterization of the material.

Inspection of the various graphical representations shown fails to reveal any significant trends for Marshall flow within the ranges of sulphur and asphalt tried. In fact, practically all the flow values recorded are in the range of .04 to .08 inch which is not uncommon for conventional asphaltic concrete. Department of Highways specifications (4) require a flow limit of .15 inch maximum, and the range of values determined by this study are well within this figure.

Gallaway and Saylack (2) recommend designing S-A-S mixtures to produce minimum flow values of .06 inch. Due to the nature of sulphur, it is possible to produce mixes that are too brittle for flexible pavements which is the primary reason for minimum flow requirements. Again, from inspection of applicable figures in Appendix B, it can be seen that Marshall flows in excess of .06 inch are attainable within the ranges of asphalt and sulphur contents tested. In most cases, however, the .06 inch flow minimum requirement appears to be a borderline value and consequently could present considerable problems in field control.

Percent Air Voids:

Asphaltic concrete mix design requirements established by the Department call for percent air voids for laboratory-prepared specimens in the 3 to 7 percent range. Past experience has shown that asphaltic concrete mixes in this range exhibit qualities desirable in paving mixtures and are specifically impermeable.

Gallaway and Saylack (2) demonstrated that for a given air void content, the permeability of S-A-S mixtures is much less than for asphaltic concrete. For example, it was found that S-A-S mixes with 16 percent air voids have the same permeability as asphaltic concrete with 6 percent air voids. This was explained by the fact that most of the air voids in S-A-S mixes appear to be entrapped by the sulphur causing them to be sealed off from water penetration (1).

Based on considerable laboratory and field evaluation, Shell Canada Limited recommended that S-A-S mixes be designed for 15 percent air voids maximum (3). Results obtained from this research project (Figures 4 through 19, Appendix B) indicate that this requirement can be met for the various sands, asphalt type and percentages, and sulphur contents studied.

Further inspection of these relationships confirmed the fact that percentage air voids tend to decrease with additional amounts of sulphur. This is as expected since the sulpbur is forced to occupy voids remaining on the asphalt-aggregate mixture. Once hardened, the sulphur not only fills voids but serves as a structuring agent which in turn improves many properties of the mixture.

Voids Filled With Asphalt (VFA):

Although this is an important consideration in asphaltic concrete mix design, its effect on the performance of S-A-S mixes is questionable due to presence of the sulphur. The VFA determinations for this project are based on available air space in the Marshall specimen not occupied by mineral aggregate or sulphur. Although the data accurately represents the volumetric percent of air voids filled with asphalt, it should not be viewed in the same content as a design criteria for conventional mixes.

VFA relationships with asphalt and sulphur contents are given in Figures 4 through 19 of Appendix B. As one would probably expect, general increases in VFA were realized with increasing percentages of asphalt and sulphur. Due to data limitations on this particular project, it is not feasible to suggest levels for future design purposes.

Density:

Specimen densities are based on apparent specific gravity measurements made in accordance with LDH TR 304-66, "Determination of Specific Gravity of Compressed Bitiminous Mixtures." Figures 4 through 19 show the effects of asphalt and sulphur contents on specimen densities for the various sand sources and asphalt types.

Density measurements for Marshall briquettes varied from 120 to 135 lbs. per cu. ft. depending upon the source of sand used. Most of the data suggest that maximum densities for the various combinations of S-A-S were attainable in the ranges of asphalt and sulphur tested. This would indicate that the asphalt-sand materials are capable of retaining only limited amounts of liquid sulphur at elevated temperatures. Evidence of this was noted during the laboratory testing program whereby mixes containing excessive amounts of sulphur exhibited substantial drainage toward the bottom of the molds.

Shell Canada Limited (1, 3) has determined that laboratory densities obtained from two-blow compaction on one face of the specimen compare closely with pavement densities produced in the field. It is pointed out that the only compactive force applied to the S-A-S material during construction is from the vibrating screed on the paving machine. Unlike conventional asphaltic concrete, no rolling of the mix is needed after installation.

Marshall Immersion Properties (Percent Retained Stability, Absorption, and Swell):

To determine the effects of water on compacted bituminous mixtures, the Department has adopted method of test LDH TR 313-66, "Determining the Index of Retained Marshall Stability of Immersed Specimen." The testing procedure which involves static immersion of briquette specimens in a 140^{O}F water bath for 24 hours not only includes determinations for retained stability but also contains criteria for water absorption and volumetric swell. For conventional asphaltic concrete, adopted limits for approval are: Retained stability - 75 percent minimum; percent absorption - 1%; percent swell - 1%.

Marshall immersion test data for this research project are shown graphically in Figures 4 through 19 of Appendix B. Close inspection of the results presented indicates a general decline in retained stabilities with increasing percentages of sulphur. This relationship would suggest that S-A-S mixtures may be more water sensitive than conventional mixes. Even with this decline, however, it is pointed out that retained stability values for the most part were found to exceed the 75 percent minimum requirement mentioned previously. In fact, many individual results were in excess of 100 percent retained stability after immersion in the water bath.

Data representing percent water absorption in Figure 4 through 19 of Appendix B reflect values of considerably greater magnitude for S-A-S mixes than commonly incurred by conventional asphaltic concrete. Values shown range from 0 to 5 percent water absorption (by weight) with the largest grouping of data in the 1 to 4 percent range. As indicated previously, conventional mixes normally exhibit water absorption rates of less than 1 percent.

It would seem apparent that the cause for higher absorptions found in the S-A-S mixes is due to higher percentages of air voids as discussed previously. This finding is further supported by the fact that greater absorption percentages were obtained for the high VMA sands (Acadian Pit and Holly Beach) as opposed to the more uniformly graded sands (Anderson Pit and Thompson Creek) with lower VMA's. In addition, lower absorption are shown for increasing percentages of asphalt which serve to indicate that rate of absorption in a function of void availability.

Results obtained for volumetric swell (%) are also shown graphically for the various sand sources and asphalt types in Figures 4 through 19. Two of the sands (Anderson Pit and Thompson Creek) demonstrated no problem in producing swells less than one percent. The Holly Beach sand produced swells that were borderline from the standpoint of the one percent maximum requirement placed on conventional mixes while all the swell values shown for the Acadian Pit sand exceed one percent, ranging from 1 to 3 percent.

Reasons for the variation in swell results among the different sand sources evaluated are unknown to the writer. It is possible that the sources with higher swell properties contained small amounts of clay or other deleterious matter that caused the swelling to occur. Although such determinations are beyond the scope of this report, they would need to be investigated prior to placing the S-A-S material in a field construction project. This could be accomplished during the period of materials acceptance and mix design for a given project.

In view of the full range of Marshall immersion test data acquired under this research project, it would appear to be feasible to design S-A-S mixes that meet currently accepted criteria for percent retained stability and percent swell. However, water absorption requirements would have to be revised to allow for use of the material.

It should be repeatedly emphasized that the Marshall method may need further revision before it is adopted for design and construction control of S-A-S mixes. In addition, it may be unfair to compare properties of the S-A-S mixes with those established for asphaltic concrete. Final determinations will depend upon performance of the material in the actual field situation. Such should certainly be the next action by the Department in evaluating the applicability of S-A-S mixes to pavements in Louisiana.

CONCLUSIONS

The findings of this research study warrant the following conclusions with the provision that they are based upon limitations of the methods of test used, namely the Marshall method of asphaltic concrete mix design.

1. A material with suitable Marshall test properties can be prepared using various combinations of sulphur, asphalt and naturally occurring Louisiana sands. Typical mixtures consist of 10 to 16 percent sulphur, 5 to 7 percent asphalt, and 77-85 percent sand, all based on total weight of the mixture.

2. Findings by Shell Canada Limited (1, 3) and Texas A & M Research Foundation (2) that S-A-S mixtures produce generally higher Marshall stabilities than conventional asphaltic concrete were confirmed by the results of this study. The increase in stability is due to structuring effects caused by the addition of sulphur.

3. Testing variance for S-A-S mixtures exceeds that normally obtained for asphaltic concrete mixtures. This could be a result of a basic unfamiliarity with the material as well as a possible lack of applicability of the Marshall method for testing its physical properties.

4. S-A-S mixtures contain a much larger percentage of air voids and a correspondingly lower percentage of VFA than conventional asphaltic concrete mixtures. In order to facilitate design and control of S-A-S material for field construction, new criteria for voids and VFA will need to be established.

5. Marshall immersion tests indicate that water has a more pronounced effect on S-A-S mixes than with conventional mixtures. This was evidenced by loss in retained stability

with additional percentages of sulphur in the mix. However, for the most part, minimum established limits for percent strength retained were exceeded with the S-A-S mixtures suggesting that water should present no significant problem in terms of overall performance.

6. Paving mixtures with desired workability can be obtained within the percentages of sulphur, asphalt, and sand used on this study.

RECOMMENDATIONS

Based on the findings of this laboratory evaluation and in view of the Department of Highways need to expand its use of native materials in highway construction, it is recommended that a field demonstration test section be constructed using the S-A-S material. To permit this type of evaluation, a 1000 foot section of roadway within a typical asphaltic concrete pavement project would be desirable. Due to past experience with insufficient anti-skid characteristics of native sand materials, it is recommended that the S-A-S mixture be used for base and binder courses and not as a finished riding surface.

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APPENDICES

APPENDIX A

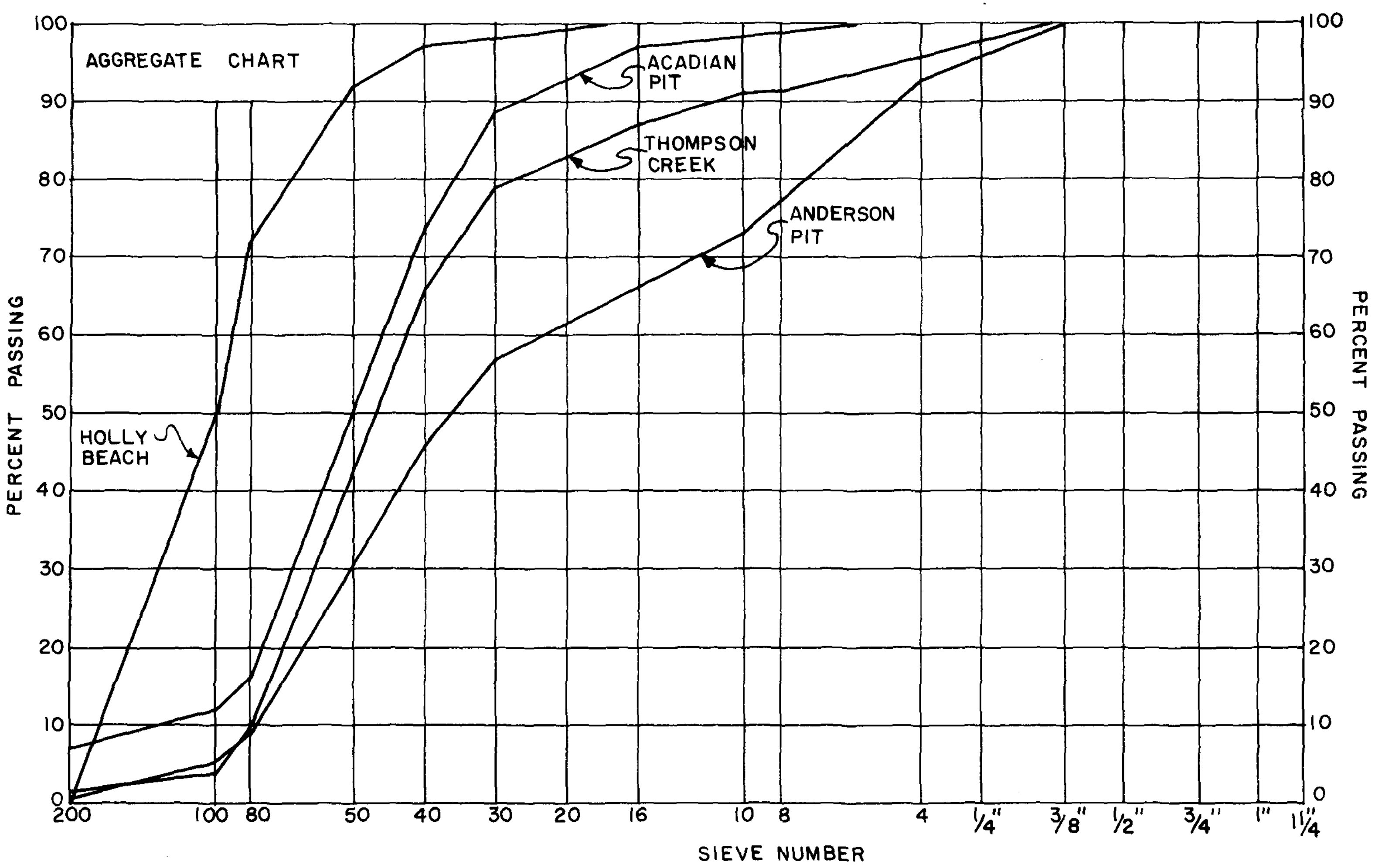

Figure 1: Aggregate Gradations for S-A-S Mixtures

TABLE I

MATERIALS TEST PROPERTIES OF VARIOUS SAND SOURCES

Percent Passing Individual Sieve Size (By Wt.)

	Acadian Pit	Anderson Pit	Holly Beach	Thompson Creek
3/8 inch	100	100	100	100
No. 4	100	93	100	95
No. 8	99	77	100	91
No. 10	98	73	100	91
No. 16	97	66	100	87
No. 30	89	57	98	79
No. 40	74	47	97	66
No. 50	50	29	92	41
No. 80	16	9	72	10
No. 100	12	5	48	4
No. 200	7	1	0	2

Specific Gravity	2.66	2.66	2.66	2.66
Loose Unit Wt. (#/ft^3)	86.9	102.8	86.3	96.0
Rodded Unit Wt. (#/ft^3)	97.4	109.6	96.5	103.2
% V M A	41	34	42	38

TABLE II

MATERIALS TEST PROPERTIES OF ASPHALTS AND SULPHUR

a) Asphalts:

Property	AC 20	AC 40
Kinematic Viscosity @ 275°F, Cs	442	682
Viscosity, Absolute @ 140°F, Poises	1900	4267
Penetration @ 77°F 100g., 5 sec.	80	48
Flash Point C.O.C., °F	630	650
Thin Film Oven Test Absolute Viscosity @ 140°F, Poises	2936	7147
Ductility of Residue @ 77°F, 5 cm./mm., cm.	100+	100+
Solubility in CS_2	99.95	99.94

b) Sulphur:*

Purity, dry basis	99.94%
Moisture	0.02%
Ash	0.01%
Carbon	0.04%
Acidity (as H_2SO_4)	0.005%

* Note - Sulphur Tests conducted by Freeport Sulphur Co., Research and Development Laboratory, Belle Chasse, Louisiana.

APPENDIX B

ABBREVIATIONS

AC = asphalt content (% by wt.)
SULFER = sulphur content (% by wt.)
SGC (i) = specific gravity - control specimen
THEO = theoretical specific gravity
SGI (i) = specific gravity - immersed specimen
STC (i) = Marshall stability - control specimen (lbs.)
FC (i) = Marshall flow - control specimen (0.1 in.)
STI (i) = Marshall stability - immersed specimen (lbs.)
FI (i) = Marshall flow - immersed specimen (.01 in.)
ABS = % water absorption by wt.
SWL = % volumetric swell
SLMP = estimated slump (in.)
MSGC = mean specific gravity - control specimens
MSTI = mean specific gravity - immersed specimens
MSTC = mean Marshall stability - control spemimens (lbs.)
MSTI = means Marshall stability - immersed speciments (lbs.)
MFC = means Marshall flow - control specimens (.01 in.)
MFI = means Marshall flow - immersed specimens (.01 in.)
STBRTD = % strength retained
PCTTH = % theoretical gravity
VOIDS = % air voids
VFA = % voids filled with asphalt

Table III: Marshall Test Properties - Acadian Pit Sand

Asphalt AC-20

ID=6

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	1.978	1.979	1.991	2.389	1.965	2.005	1.981	1217	1061	905	5	6	7	951	936	967	5	6	6	4.0	1.9	2
5	12.0	2.044	2.046	2.022	2.375	2.049	2.030	2.028	1373	1342	967	12	8	7	1092	936	826	12	10	7	3.2	1.7	2
5	13.5	2.083	2.049	2.067	2.365	2.091	2.063	2.048	2465	1888	2106	8	8	7	1716	1451	1326	8	9	9	3.2	3.1	2
5	16.0	2.101	2.102	2.107	2.347	2.091	2.100	2.121	2839	2824	2995	12	11	12	1997	2169	2231	12	12	13	2.3	1.7	3
6	10.0	2.036	2.006	2.011	2.356	2.006	2.028	2.021	998	640	671	6	6	7	686	764	780	7	6	6	3.7	2.3	2
6	12.0	2.067	2.061	2.037	2.341	2.052	2.063	2.047	1607	1576	1513	9	8	8	1014	983	1077	10	9	7	2.7	2.0	2
6	13.5	2.087	2.077	2.058	2.332	2.090	2.059	2.054	2543	2543	2346	5	3	4	1716	1544	1435	5	5	2	1.4	2.3	2
6	16.0	2.092	2.065	2.040	2.315	2.023	2.064	2.080	2964	2496	1404	7	7	5	1529	1703	2028	8	8	6	1.2	2.1	3
7	10.0	2.046	2.051	2.055	2.322	2.042	2.064	2.047	1061	1139	826	6	5	5	749	671	671	7	7	6	2.3	1.6	2
7	12.0	2.073	2.074	2.067	2.309	2.020	2.078	2.090	1092	1482	1431	6	7	8	655	1092	967	7	8	7	1.7	1.2	3
7	13.5	2.048	2.082	2.036	2.299	2.060	2.057	2.047	1607	1513	1108	5	4	5	1046	1014	998	6	7	5	1.7	1.2	4
7	16.0	2.021	2.030	2.030	2.283	2.033	2.041	2.007	1960	2028	1841	6	4	4	1139	1186	936	5	5	7	1.7	1.2	4

N=12

Asphalt AC-40

ID=5

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	1.959	1.964	1.942	2.392	1.989	1.961	1.937	1310	1326	764	6	5	8	1045	889	795	6	7	6	4.3	1.9	1
5	12.0	2.032	2.007	2.009	2.378	2.044	1.994	2.019	2153	1466	1872	5	5	8	1529	1061	1357	8	8	9	3.6	2.0	2
5	13.5	2.046	2.048	2.050	2.367	2.065	2.070	2.015	2340	2496	2184	6	7	5	1794	1960	1357	9	9	5	2.8	1.2	2
5	16.0	2.090	2.064	2.095	2.350	2.086	2.093	2.071	3026	2510	2906	8	7	8	2340	2418	2028	9	10	8	2.2	1.1	2
6	10.0	2.015	2.016	1.993	2.359	2.008	1.986	2.021	671	624	595	4	5	6	905	671	811	5	6	5	3.2	2.0	2
6	12.0	2.047	2.036	2.045	2.345	2.037	2.023	2.065	1960	1560	1716	8	9	7	1092	1077	1248	7	5	7	2.7	1.8	3
6	13.5	2.039	2.058	2.066	2.335	2.021	2.064	2.072	2184	2386	2417	6	5	6	1498	1747	1888	6	5	4	2.2	1.3	3
6	16.0	2.005	2.064	2.060	2.318	2.005	2.031	2.078	2153	2527	2340	6	7	6	1482	1591	1960	6	8	9	2.3	1.7	4
7	10.0	2.001	2.011	2.030	2.326	1.935	2.032	2.041	764	560	530	6	6	8	480	671	600	8	8	8	2.6	1.9	1
7	12.0	2.059	2.058	2.065	2.312	2.029	2.069	2.079	1388	1576	1357	8	8	8	718	1061	998	8	10	10	2.0	2.3	2
7	13.5	2.017	2.028	2.028	2.302	1.999	2.016	2.064	1560	1716	936	5	5	4	967	1092	1030	5	5	6	1.8	1.0	2
7	16.0	1.957	1.999	1.998	2.286	1.965	1.970	2.000	1482	1638	1560	5	6	4	983	1170	936	5	6	6	2.3	1.3	3

N=12

Table IV: Marshall Test Properties - Anderson Pit Sand

Asphalt AC-20

ID=8

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	2.103	2.124	2.120	2.389	2.115	2.107	2.122	2044	2106	2075	5	5	6	1700	1560	1279	7	6	6	1.6	.1	2
5	12.0	2.128	2.118	2.121	2.375	2.092	2.129	2.139	2637	2278	1326	10	10	7	1981	2402	2402	8	11	10	1.6	.2	2
5	13.5	2.089	2.137	2.130	2.365	2.096	2.145	2.114	2527	2543	2980	8	8	4	2527	2418	2511	6	7	5	1.5	.3	3
5	16.0	2.091	2.089	2.099	2.347	2.087	2.087	2.111	2714	2652	2793	5	5	5	2543	2558	2652	5	4	7	1.4	.3	4
6	10.0	2.122	2.095	2.094	2.356	2.126	2.110	2.080	1279	1077	1139	4	4	4	1092	1139	702	4	4	4	1.5	.2	3
6	12.0	2.122	2.097	2.087	2.341	2.138	2.110	2.067	1092	1513	1279	7	5	4	1248	1388	1061	5	7	4	1.4	.3	4
6	13.5	2.091	2.083	2.105	2.332	2.084	2.077	2.114	1960	1747	1934	7	5	5	1529	1607	1903	4	5	8	1.3	.3	5
6	16.0	2.097	2.097	2.101	2.315	2.087	2.097	2.114	2683	2122	2305	9	7	6	2012	2450	2230	7	5	4	1.2	.3	5
7	10.0	2.031	2.055	2.064	2.322	2.011	2.063	2.076	592	516	560	6	5	8	315	452	500	8	5	5	1.3	.0	4
7	12.0	2.078	2.079	2.078	2.309	2.066	2.070	2.093	890	827	764	5	5	7	749	548	936	5	8	5	1.1	.2	5
7	13.5	2.038	2.052	2.037	2.299	2.024	2.071	2.065	1030	1232	1077	5	5	5	921	1388	1170	5	6	7	0.8	.0	5
7	16.0	2.040	2.064	2.081	2.283	2.052	2.063	2.075	1404	1248	1451	5	6	6	1404	1373	1357	5	6	6	0.7	.0	5

N=12

Asphalt AC-40

ID=7

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	2.088	2.094	2.098	2.392	2.054	2.083	2.101	1388	1607	1451	6	6	7	1373	1435	1591	5	5	5	1.7	.2	2
5	12.0	2.131	2.140	2.153	2.378	2.124	2.145	2.156	2153	2980	2574	9	10	9	1997	2510	2169	9	9	9	1.5	.2	2
5	13.5	2.055	2.081	2.073	2.367	2.053	2.094	2.062	2451	2527	2683	6	6	7	1872	1560	1669	8	10	10	1.8	.4	4
5	16.0	2.072	2.085	2.103	2.350	2.071	2.097	2.098	2371	2777	2309	10	8	10	2293	2714	2371	9	8	8	2.5	.5	5
6	10.0	2.064	2.073	2.110	2.359	2.108	2.063	2.107	967	1170	983	5	4	6	1357	967	1232	5	6	5	1.3	.1	4
6	12.0	2.053	2.088	2.088	2.345	2.047	2.071	2.118	1108	1388	1326	7	7	5	1154	1014	1232	8	8	7	1.2	.0	5
6	13.5	2.028	2.049	2.063	2.335	2.016	2.051	2.074	1560	1888	1685	6	6	6	967	1716	1544	4	4	4	1.4	.0	5
6	16.0	2.086	2.105	2.086	2.318	2.078	2.105	2.102	2808	2714	2418	4	7	6	2261	2340	2636	5	5	8	1.0	.0	5
7	10.0	2.026	2.068	2.067	2.326	2.021	2.067	2.068	811	702	780	6	9	6	780	936	936	5	8	7	1.7	.1	5
7	12.0	1.983	2.078	2.065	2.312	1.987	2.009	2.078	811	1139	1186	5	5	5	671	780	983	5	5	9	1.4	.3	5
7	13.5	2.045	2.061	2.066	2.302	2.035	2.066	2.066	1108	1451	1201	5	4	4	1061	1123	1295	5	5	5	0.9	.2	5
7	16.0	2.073	2.092	2.089	2.286	2.059	2.098	2.102	1435	1643	1466	5	5	7	1342	1747	1825	5	7	6	0.5	.1	5

N=12

Table V: Marshall Test Properties - Holly Beach Sand

Asphalt AC-20

ID=4

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	1.950	1.978	1.945	2.389	1.978	1.977	1.929	1404	1591	1529	6	5	5	1638	1373	936	5	6	5	4.7	1.4	0
5	12.0	2.008	1.989	2.016	2.375	1.993	1.994	2.024	1872	952	1716	4	5	7	1373	1513	1716	5	7	10	4.2	1.0	0
5	13.5	2.049	2.042	2.005	2.365	2.049	2.035	2.012	3400	2885	1903	10	5	9	3130	2683	2168	9	10	7	3.2	1.0	0
5	16.0	2.047	2.089	2.093	2.347	2.051	2.098	2.067	2870	3430	4028	9	12	12	3080	4345	2948	10	15	11	2.3	0.7	0
6	10.0	2.009	1.994	1.994	2.356	2.031	2.018	1.950	1607	1264	1248	6	6	5	1872	1451	780	10	8	6	3.8	1.7	0
6	12.0	2.042	2.030	2.004	2.341	2.012	2.025	2.045	2169	1872	936	7	7	4	1810	1841	2028	8	8	6	2.8	0.9	0
6	13.5	2.052	2.058	2.063	2.332	2.027	2.070	2.065	3400	3573	3080	6	6	6	2824	2496	2465	5	6	7	2.3	0.5	0
6	16.0	2.022	2.050	2.045	2.315	2.011	2.037	2.075	3080	2839	3058	5	8	7	2621	3011	2964	4	6	6	2.0	0.5	0
7	10.0	1.956	1.960	1.927	2.332	2.007	1.945	1.919	1716	2278	2340	8	6	4	1919	2839	2527	7	6	7	2.0	1.5	0
7	12.0	1.991	1.997	1.987	2.309	2.002	1.986	1.989	2870	2170	2777	6	6	7	2278	2730	2356	8	6	6	1.6	0.0	0
7	13.5	1.979	1.991	1.991	2.299	1.944	2.020	1.992	2806	2215	1716	3	6	3	1716	1638	1466	5	7	3	2.6	1.0	0
7	16.0	2.007	1.988	1.995	2.283	1.950	2.018	2.009	2215	2730	3075	4	4	8	2059	2028	2059	7	5	7	2.1	0.9	0

N=12

Asphalt AC-40

ID=3

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
5	10.0	2.004	1.986	1.972	2.392	2.023	1.961	1.985	2199	1903	1420	4	6	6	1856	1154	1170	10	5	6	4.3	1.6	2
5	12.0	2.026	2.028	2.025	2.378	2.038	1.979	2.044	2386	2496	2511	11	6	7	2153	936	1700	9	7	13	3.8	1.1	2
5	13.5	2.016	2.033	2.017	2.367	2.012	2.028	2.022	3160	3110	2652	6	8	7	2839	3080	2059	8	9	7	3.2	1.0	3
5	16.0	2.048	2.043	2.034	2.350	2.000	2.055	2.073	3400	3475	3870	10	10	8	2730	3240	2808	10	8	9	2.6	0.8	3
6	10.0	1.961	1.979	1.979	2.359	1.955	1.987	1.971	1388	1170	1373	4	4	6	1045	1217	1014	8	7	7	4.4	1.6	2
6	12.0	2.013	1.991	2.018	2.345	1.974	2.024	2.023	2714	1997	2138	9	4	6	1810	2169	2153	6	5	5	3.2	1.2	2
6	13.5	2.011	2.014	2.008	2.335	1.992	2.021	2.023	3700	2964	2636	9	10	4	2527	2839	2824	8	5	10	2.8	0.6	3
6	16.0	1.971	1.971	2.016	2.318	1.961	1.962	2.031	3160	2777	3080	6	10	12	2434	2527	2230	7	9	12	2.2	0.7	4
7	10.0	1.981	1.977	1.971	2.326	1.994	1.972	1.965	936	1342	905	5	4	5	1170	905	842	5	5	7	3.6	1.5	0
7	12.0	1.979	2.002	1.988	2.312	1.966	2.006	2.005	2137	2059	1264	7	6	10	1794	1716	1872	8	6	7	3.1	0.9	0
7	13.5	2.023	1.992	1.939	2.302	2.001	1.989	1.953	2761	2542	2137	7	6	6	2637	2090	2496	5	6	6	2.5	1.0	0
7	16.0	1.991	1.942	1.921	2.286	1.965	1.963	1.929	3160	3180	3100	5	7	5	2558	2808	2450	4	5	4	2.2	1.0	0

N=12

Table VI: Marshall Test Properties - Thompson Creek Sand

Asphalt AC-20

ID=2

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
~~5~~	~~10.0~~	~~2.023~~	~~2.026~~	~~2.028~~	~~2.389~~	~~2.025~~	~~2.015~~	~~2.040~~	~~1081~~	~~1092~~	~~1279~~	~~5~~	~~7~~	~~7~~	~~1217~~	~~1170~~	~~1186~~	~~6~~	~~7~~	~~6~~	~~2.8~~	~~.7~~	~~0~~
5	12.0	2.058	2.070	2.072	2.375	2.050	2.088	2.069	1903	1919	2496	6	7	4	1872	1825	1326	7	5	4	2.3	.5	0
5	13.5	2.019	2.083	2.079	2.365	2.060	2.079	2.066	2746	3042	2028	5	8	5	2746	2059	1716	5	8	5	2.0	.2	0
~~5~~	~~16.0~~	~~2.035~~	~~2.021~~	~~2.110~~	~~2.347~~	~~2.072~~	~~2.042~~	~~2.054~~	~~2606~~	~~2621~~	~~2465~~	~~7~~	~~7~~	~~7~~	~~2028~~	~~1960~~	~~2059~~	~~9~~	~~8~~	~~9~~	~~1.8~~	~~.2~~	~~0~~
6	10.0	2.045	2.056	2.068	2.356	2.048	2.055	2.066	1139	967	640	3	6	6	952	890	858	4	5	5	2.1	.3	0
6	12.0	2.043	2.062	2.071	2.341	2.034	2.050	2.088	1716	1061	1560	6	5	5	1014	1123	1638	6	6	5	1.8	.1	0
~~6~~	~~16.0~~	~~2.038~~	~~2.058~~	~~2.025~~	~~2.315~~	~~2.027~~	~~2.060~~	~~2.049~~	~~2153~~	~~2246~~	~~1997~~	~~8~~	~~7~~	~~8~~	~~1903~~	~~1373~~	~~1700~~	~~8~~	~~7~~	~~8~~	~~1.7~~	~~.3~~	~~0~~
7	10.0	2.230	2.062	2.057	2.322	2.049	2.056	2.055	655	764	718	5	5	6	655	624	655	6	6	5	1.9	.5	2
7	12.0	2.039	2.052	2.037	2.309	2.042	2.055	2.062	655	874	733	8	6	6	1217	1201	1217	6	7	7	1.5	.3	3
~~7~~	~~13.5~~	~~2.063~~	~~2.000~~	~~1.989~~	~~2.299~~	~~2.052~~	~~2.027~~	~~1.988~~	~~1248~~	~~1279~~	~~936~~	~~5~~	~~5~~	~~6~~	~~1357~~	~~905~~	~~827~~	~~5~~	~~5~~	~~5~~	~~1.4~~	~~.0~~	~~5~~
7	16.0	2.064	2.070	2.081	2.283	2.062	2.078	2.075	1872	1685	1451	6	5	6	1716	1888	1576	5	6	6	0.9	.0	5

N=11

Asphalt AC-40

ID=1

AC	SULFR	SGC1	SGC2	SGC3	THEO	SGI1	SGI2	SGI3	STC1	STC2	STC3	FC1	FC2	FC3	STI1	STI2	STI3	FI1	FI2	FI3	ABS	SWL	SLMP
~~5~~	~~10.0~~	~~2.024~~	~~2.038~~	~~2.000~~	~~2.392~~	~~2.020~~	~~2.011~~	~~2.028~~	~~1076~~	~~811~~	~~500~~	~~5~~	~~5~~	~~6~~	~~1388~~	~~1560~~	~~1357~~	~~4~~	~~6~~	~~4~~	~~3.0~~	~~.4~~	~~2~~
5	12.0	2.065	2.044	2.061	2.378	2.067	2.053	2.049	1716	2355	1513	10	7	4	1794	2324	1888	9	7	8	2.4	.3	2
5	13.5	2.038	2.068	2.072	2.367	2.073	2.059	2.046	2652	2262	2215	10	7	6	2418	2512	2434	8	9	10	1.9	.2	3
~~5~~	~~16.0~~	~~2.036~~	~~2.056~~	~~2.023~~	~~2.350~~	~~2.055~~	~~2.038~~	~~2.017~~	~~1591~~	~~3080~~	~~3240~~	~~4~~	~~10~~	~~13~~	~~2683~~	~~2731~~	~~2793~~	~~7~~	~~10~~	~~10~~	~~1.9~~	~~.1~~	~~4~~
6	10.0	2.032	2.041	2.031	2.359	2.024	2.042	2.035	1123	796	470	6	5	8	1186	1139	1248	5	6	5	2.2	.1	2
6	12.0	1.980	1.985	2.045	2.345	1.959	1.992	2.059	1046	1310	1326	8	6	7	1077	1092	1326	9	7	6	2.0	.2	2
~~6~~	~~13.5~~	~~2.048~~	~~2.063~~	~~2.038~~	~~2.335~~	~~2.061~~	~~2.031~~	~~2.058~~	~~2106~~	~~2059~~	~~1643~~	~~5~~	~~7~~	~~6~~	~~2418~~	~~2184~~	~~2153~~	~~6~~	~~5~~	~~6~~	~~1.7~~	~~.2~~	~~4~~
6	16.0	1.968	1.969	2.006	2.318	1.947	1.980	2.007	2309	1981	1872	3	8	7	1903	1966	1825	5	4	9	1.8	.1	5
7	10.0	2.005	1.997	2.000	2.326	2.003	2.016	1.991	440	515	330	4	7	5	764	811	718	7	8	7	2.4	.6	4
~~7~~	~~12.0~~	~~1.957~~	~~1.993~~	~~1.965~~	~~2.312~~	~~1.955~~	~~1.984~~	~~2.033~~	~~733~~	~~552~~	~~967~~	~~5~~	~~5~~	~~5~~	~~764~~	~~811~~	~~1045~~	~~5~~	~~6~~	~~5~~	~~2.2~~	~~.6~~	~~5~~
7	13.5	2.024	2.033	2.060	2.302	2.018	2.047	2.053	1342	1498	1357	7	9	8	1279	1373	1186	7	7	9	1.4	.3	5
7	16.0	2.017	2.053	2.050	2.286	2.032	2.033	2.060	1529	1560	1466	8	9	6	1560	1544	1264	9	6	9	1.1	.2	5

N=12

Table VII: Calculated Physical Properties - Acadian Pit Sand

Asphalt AC-20

ID=6

AC	SULFR	THEO	ABS	SWL	SLPP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.389	4.0	1.9	2	1.983	1.984	1061	951	6	6	89.6	83.0	17.0	36.15
5	12.0	2.375	3.2	1.7	2	2.037	2.036	1227	951	9	10	77.5	85.8	14.2	41.05
5	13.5	2.365	3.2	3.1	2	2.066	2.067	2153	1498	8	9	69.6	87.4	12.6	44.32
5	16.0	2.347	2.3	1.7	3	2.103	2.104	2886	2132	12	12	73.9	89.6	10.4	49.54
6	10.0	2.356	3.7	2.3	2	2.018	2.018	770	743	6	6	96.5	85.7	14.3	45.12
6	12.0	2.341	2.7	2.0	2	2.055	2.054	1565	1025	8	9	65.5	87.8	12.2	49.53
6	13.5	2.332	1.4	2.3	2	2.067	2.068	2477	1565	4	4	63.2	88.6	11.4	51.37
6	16.0	2.315	1.2	2.1	3	2.052	2.056	2288	1753	6	7	76.6	88.6	11.4	51.18
7	10.0	2.322	2.3	1.6	2	2.051	2.051	1009	697	5	7	69.1	88.3	11.7	54.37
7	12.0	2.309	1.7	1.2	3	2.071	2.063	1342	905	7	7	67.4	89.7	10.3	57.74
7	13.5	2.299	1.7	1.2	4	2.055	2.055	1409	1019	5	6	72.3	89.4	10.6	56.85
7	16.0	2.283	1.7	1.2	4	2.027	2.027	1943	1087	5	6	55.9	88.8	11.2	55.16

N=12

Asphalt AC-40

ID=5

AC	SULFR	THEO	ABS	SWL	SLPP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.392	4.3	1.9	1	1.955	1.962	1133	910	6	6	80.3	81.7	18.3	34.15
5	12.0	2.378	3.6	2.0	2	2.016	2.019	1830	1316	6	8	71.9	84.8	15.2	39.17
5	13.5	2.367	2.8	1.2	2	2.048	2.050	2340	1704	6	8	72.8	86.5	13.5	42.41
5	16.0	2.350	2.2	1.1	2	2.083	2.083	2814	2262	8	9	80.4	88.6	11.4	47.01
6	10.0	2.359	3.2	2.0	2	2.008	2.005	630	796	5	5	126.3	85.1	14.9	43.98
6	12.0	2.345	2.7	1.8	3	2.043	2.042	1745	1139	8	6	65.3	87.1	12.9	47.99
6	13.5	2.335	2.2	1.3	3	2.054	2.052	2329	1711	6	5	73.5	88.0	12.0	49.93
6	16.0	2.318	2.3	1.7	4	2.043	2.038	2340	1678	6	8	71.7	88.1	11.9	50.00
7	10.0	2.326	2.6	1.9	1	2.014	2.003	618	584	7	8	94.5	86.6	13.4	50.53
7	12.0	2.312	2.0	2.3	2	2.061	2.059	1440	926	8	9	64.3	89.1	10.9	56.24
7	13.5	2.302	1.8	1.0	2	2.024	2.026	1404	1030	5	5	73.4	87.9	12.1	53.20
7	16.0	2.286	2.3	1.3	3	1.985	1.978	1560	1030	5	6	66.0	86.8	13.2	50.54

N=12

Table VIII: Calculated Physical Properties - Anderson Pit Sand

Asphalt AC-20

ID=8

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.389	1.6	.1	2	2.116	2.115	2075	1513	5	6	72.9	88.6	11.4	47.40
5	12.0	2.375	1.6	.2	2	2.122	2.120	2080	2262	9	10	108.7	89.3	10.7	49.05
5	13.5	2.365	1.5	.3	3	2.119	2.118	2683	2485	7	6	92.6	89.6	10.4	49.73
5	16.0	2.347	1.4	.3	4	2.093	2.095	2720	2584	5	5	95.0	89.2	10.8	48.47
6	10.0	2.356	1.5	.2	3	2.104	2.105	1165	978	4	4	83.9	89.3	10.7	53.39
6	12.0	2.341	1.4	.3	4	2.102	2.105	1295	1232	5	5	95.1	89.8	10.2	54.55
6	13.5	2.332	1.3	.3	5	2.093	2.092	1880	1680	6	6	89.4	89.8	10.2	54.45
6	16.0	2.315	1.2	.3	5	2.098	2.099	2371	2231	7	5	94.1	90.6	9.4	56.52
7	10.0	2.322	1.3	.0	4	2.050	2.050	556	422	6	6	75.9	88.3	11.7	54.35
7	12.0	2.309	1.1	.2	5	2.078	2.076	827	744	6	6	90.0	90.0	10.0	58.54
7	13.5	2.299	0.8	.0	5	2.042	2.053	1113	1160	5	6	104.2	88.8	11.2	55.34
7	16.0	2.283	0.7	.0	5	2.062	2.063	1368	1378	6	6	100.7	90.3	9.7	59.10

N=12

Asphalt AC-40

ID=7

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.392	1.7	.2	2	2.093	2.093	1482	1466	6	5	98.9	87.5	12.5	44.84
5	12.0	2.378	1.5	.2	2	2.141	2.142	2569	2225	9	9	86.6	90.0	10.0	50.96
5	13.5	2.367	1.8	.4	4	2.070	2.070	2554	1700	6	9	66.6	87.5	12.5	44.56
5	16.0	2.350	2.5	.5	5	2.087	2.089	2486	2459	9	8	98.9	88.8	11.2	47.49
6	10.0	2.359	1.3	.1	4	2.082	2.093	1040	1185	5	5	113.9	88.3	11.7	50.90
6	12.0	2.345	1.2	.0	5	2.076	2.079	1274	1133	6	8	88.9	88.5	11.5	51.26
6	13.5	2.335	1.4	.0	5	2.047	2.047	1711	1409	6	4	82.3	87.7	12.3	49.22
6	16.0	2.318	1.0	.0	5	2.092	2.095	2647	2412	6	6	91.1	90.3	9.7	55.68
7	10.0	2.326	1.7	.1	5	2.054	2.052	764	884	7	7	115.7	88.3	11.7	54.40
7	12.0	2.312	1.4	.3	5	2.042	2.025	1045	811	5	6	77.6	88.3	11.7	54.26
7	13.5	2.302	0.5	.2	5	2.057	2.056	1253	1160	4	5	92.6	89.4	10.6	56.87
7	16.0	2.286	0.5	.1	5	2.085	2.086	1515	1638	6	6	108.1	91.2	8.8	61.69

N=12

Table IX: Calculated Physical Properties - Holly Beach Sand

Asphalt AC-20

ID=4

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.389	4.7	1.4	0	1.958	1.961	1508	1316	5	5	87.3	82.0	18.0	34.56
5	12.0	2.375	4.2	1.0	0	2.004	2.004	1513	1534	5	7	101.4	84.4	15.6	38.41
5	13.5	2.365	3.2	1.0	0	2.032	2.032	2729	2660	8	9	97.5	85.9	14.1	41.16
5	16.0	2.347	2.3	0.7	0	2.076	2.072	3443	3458	11	12	100.4	88.5	11.5	46.70
6	10.0	2.356	3.8	1.7	0	1.999	2.000	1373	1368	6	8	99.6	84.8	15.2	43.38
6	12.0	2.341	2.8	0.9	0	2.025	2.027	1659	1893	6	7	114.1	86.5	13.5	46.63
6	13.5	2.332	2.3	0.5	0	2.058	2.054	3351	2595	6	6	77.4	88.3	11.7	50.61
6	16.0	2.315	2.0	0.5	0	2.039	2.041	2992	2865	7	5	95.8	88.1	11.9	49.95
7	10.0	2.332	2.0	1.5	0	1.948	1.957	2111	2428	6	7	115.0	83.5	16.5	44.52
7	12.0	2.309	1.6	0.0	0	1.992	1.992	2606	2455	6	7	94.2	86.3	13.7	49.70
7	13.5	2.299	2.6	1.0	0	1.987	1.985	2179	1607	4	5	73.7	86.4	13.6	49.82
7	16.0	2.283	2.1	0.9	0	1.997	1.992	2673	2049	5	6	76.7	87.5	12.5	52.06

N=12

Asphalt AC-40

ID=3

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.392	4.3	1.6	2	1.987	1.990	1841	1393	5	7	75.7	83.1	16.9	36.34
5	12.0	2.378	3.8	1.1	2	2.026	2.020	2464	1596	8	10	64.8	85.2	14.8	39.92
5	13.5	2.367	3.2	1.0	3	2.022	2.021	2974	2659	7.	8	89.4	85.4	14.6	40.20
5	16.0	2.350	2.6	0.8	3	2.042	2.043	3582	2926	9	9	81.7	86.9	13.1	43.07
6	10.0	2.359	4.4	1.6	2	1.973	1.971	1310	1092	5	7	83.4	83.6	16.4	41.20
6	12.0	2.345	3.2	1.2	2	2.007	2.007	2283	2044	6	5	89.5	85.6	14.4	44.81
6	13.5	2.335	2.8	0.6	3	2.011	2.012	3100	2730	8	8	88.1	86.1	13.9	45.73
6	16.0	2.318	2.2	0.7	4	1.986	1.985	3006	2397	9	9	79.7	85.7	14.3	44.72
7	10.0	2.326	3.6	1.5	0	1.976	1.977	1061	972	5	6	91.6	85.0	15.0	47.24
7	12.0	2.312	3.1	0.9	0	1.990	1.992	1820	1794	8	7	98.6	86.1	13.9	49.31
7	13.5	2.302	2.5	1.0	0	1.985	1.981	2480	2408	6	6	97.1	86.2	13.8	49.43
7	16.0	2.286	2.2	1.0	0	1.951	1.952	3147	2605	6	4	82.8	85.3	14.7	47.42

N=12

Table X: Calculated Physical Properties - Thompson Creek Sand

Asphalt AC-20

ID=2

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.389	2.8	.7	0	2.026	2.027	1144	1191	6	6	104.1	84.8	15.2	39.28
5	12.0	2.375	2.3	.5	0	2.067	2.069	2106	1674	6	5	79.5	87.0	13.0	43.56
5	13.5	2.365	2.0	.2	0	2.060	2.068	2605	2174	6	6	83.5	87.1	12.9	43.67
5	16.0	2.347	1.8	.2	0	2.055	2.056	2564	2016	7	9	78.6	87.6	12.4	44.58
6	10.0	2.356	2.1	.3	0	2.056	2.056	915	900	5	5	98.4	87.3	12.7	48.53
6	12.0	2.341	1.8	.1	0	2.059	2.057	1446	1258	5	6	87.0	88.0	12.0	49.99
6	16.0	2.315	1.7	.3	0	2.040	2.045	2132	1659	8	8	77.8	88.1	11.9	49.97
7	10.0	2.322	1.9	.5	2	2.116	2.053	712	645	5	6	90.6	91.1	8.9	61.77
7	12.0	2.309	1.5	.3	3	2.043	2.053	754	1212	7	7	160.7	88.5	11.5	54.40
7	13.5	2.299	1.4	.0	5	2.017	2.022	1154	1030	5	5	89.3	87.7	12.3	52.71
7	16.0	2.283	0.9	.0	5	2.072	2.072	1669	1727	6	6	103.5	90.8	9.2	60.48

N=11

Asphalt AC-40

ID=1

AC	SULFR	THEO	ABS	SWL	SLMP	MSGC	MSGI	MSTC	MSTI	MFC	MFI	STBRTD	PCTTH	VOIDS	VFA
5	10.0	2.392	3.0	.4	2	2.021	2.020	796	1435	5	5	180.3	84.5	15.5	38.76
5	12.0	2.378	2.4	.3	2	2.057	2.056	1861	2002	7	8	107.6	86.5	13.5	42.52
5	13.5	2.367	1.9	.2	3	2.059	2.059	2376	2455	8	9	103.3	87.0	13.0	43.47
5	16.0	2.350	1.9	.1	4	2.038	2.037	2637	2736	9	9	103.8	86.7	13.3	42.66
6	10.0	2.359	2.2	.1	2	2.035	2.034	796	1191	6	5	149.6	86.3	13.7	46.39
6	12.0	2.345	2.0	.2	2	2.003	2.003	1227	1165	7	7	94.9	85.4	14.6	44.42
6	13.5	2.335	1.7	.2	4	2.050	2.050	1936	2252	6	6	116.3	87.8	12.[illegible]	49.47
6	16.0	2.318	1.8	.1	5	1.981	1.978	2054	1898	6	6	92.4	85.5	14.5	44.32
7	10.0	2.326	2.4	.6	4	2.001	2.003	428	764	5	7	178.5	86.0	14.0	49.27
7	12.0	2.312	2.2	.6	5	1.972	1.991	884	873	5	5	98.8	85.3	14.7	47.69
7	13.5	2.302	1.4	.3	5	2.039	2.039	1399	1279	8	8	91.4	88.6	11.4	54.86
7	16.0	2.286	1.1	.2	5	2.040	2.042	1518	1456	8	8	95.9	89.2	10.8	56.21

N=12

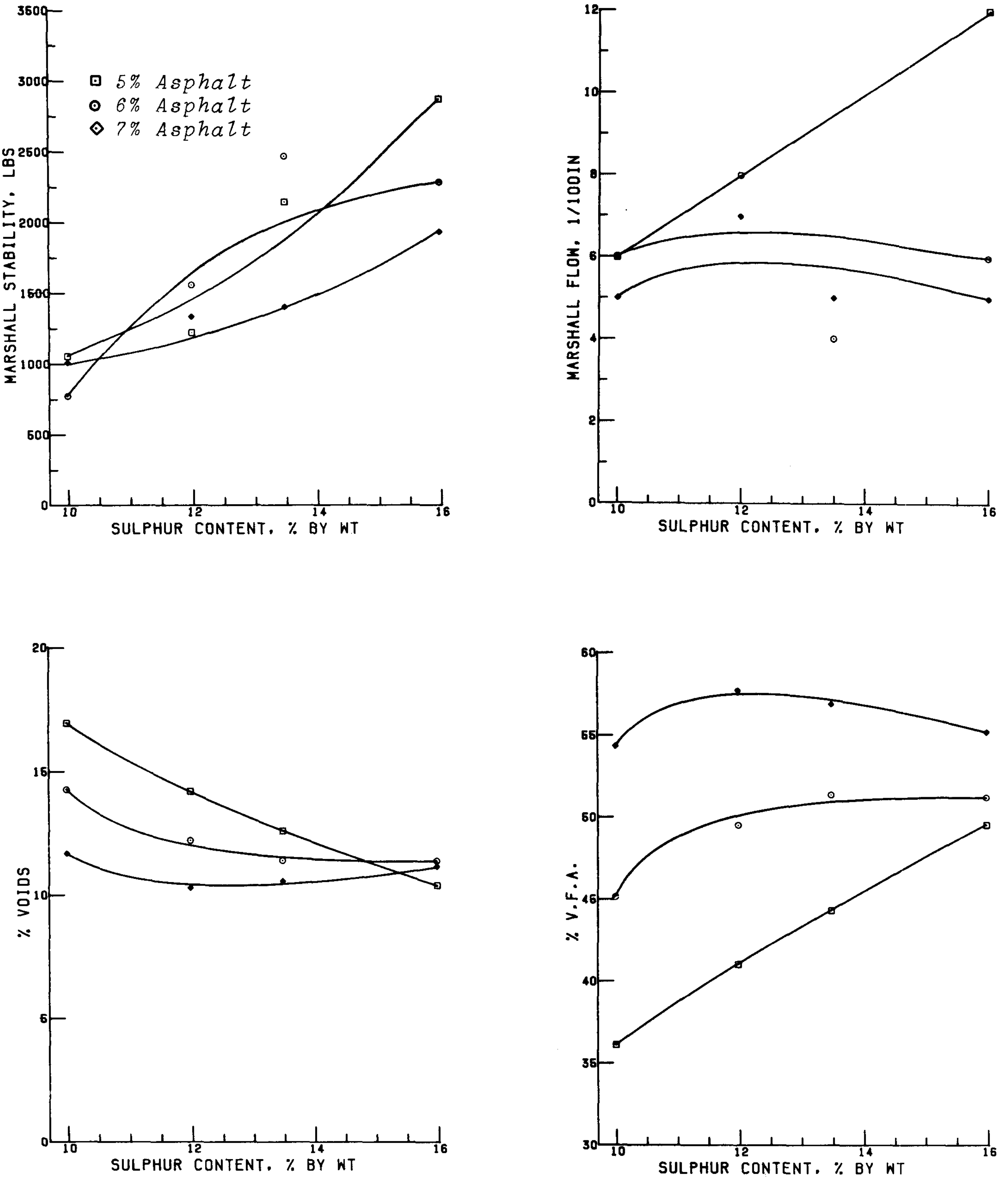

Figure 4: Marshall Test Properties - Acadian Pit Sand and Asphalt AC-20

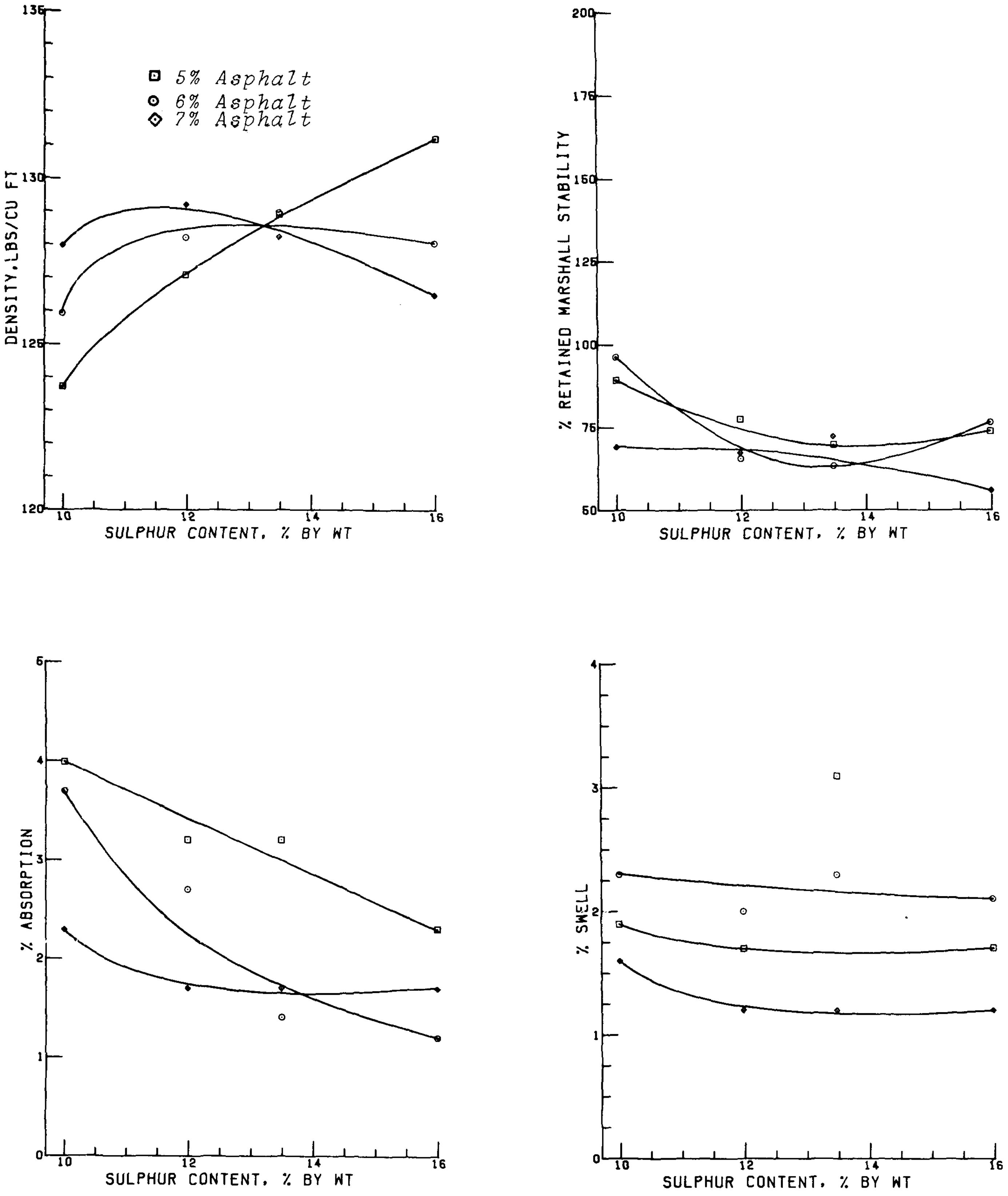

Figure 5: Marshall Test Properties - Acadian Pit Sand and Asphalt AC-20

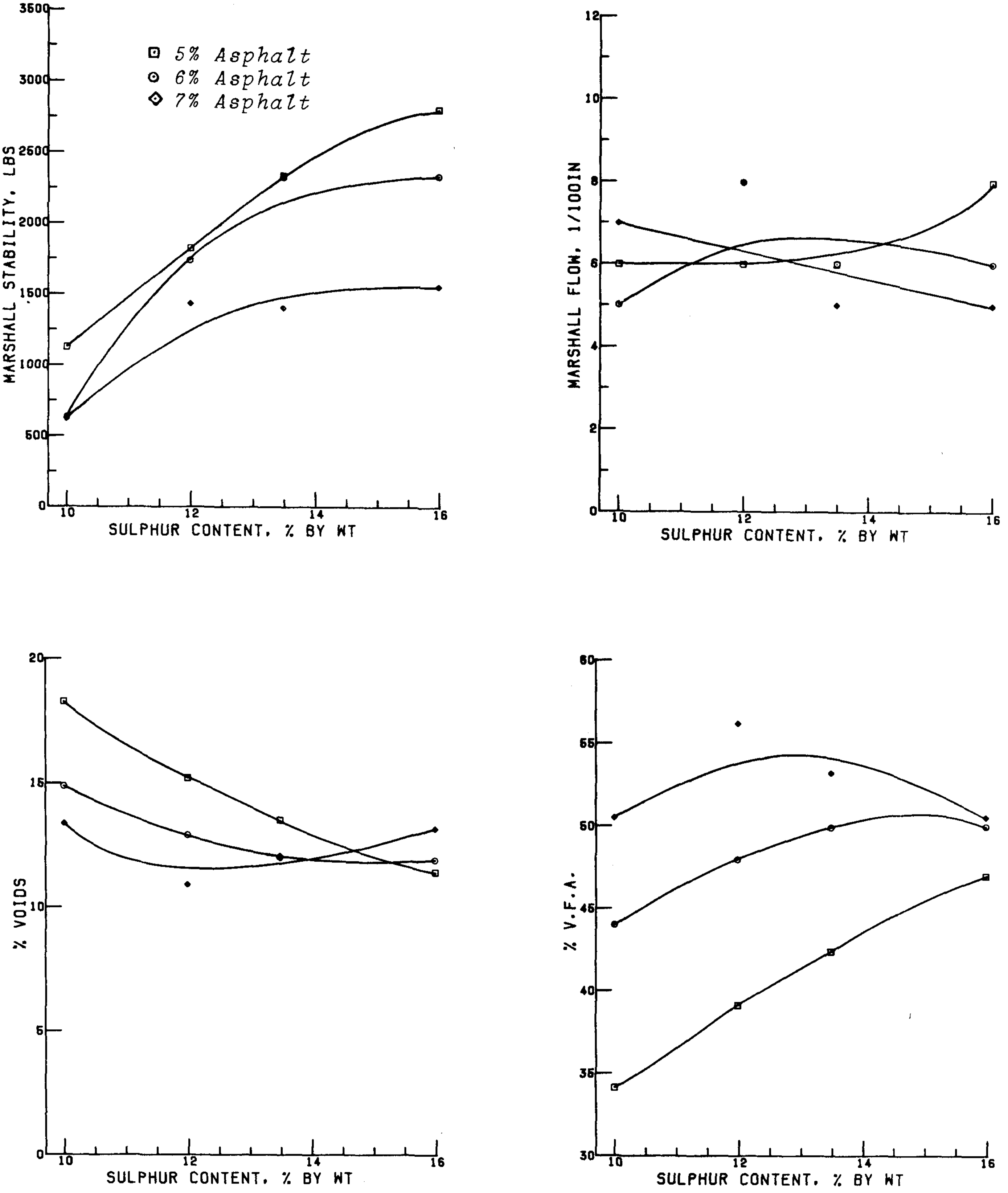

Figure 6: Marshall Test Properties - Acadian Pit Sand and Asphalt AC-40

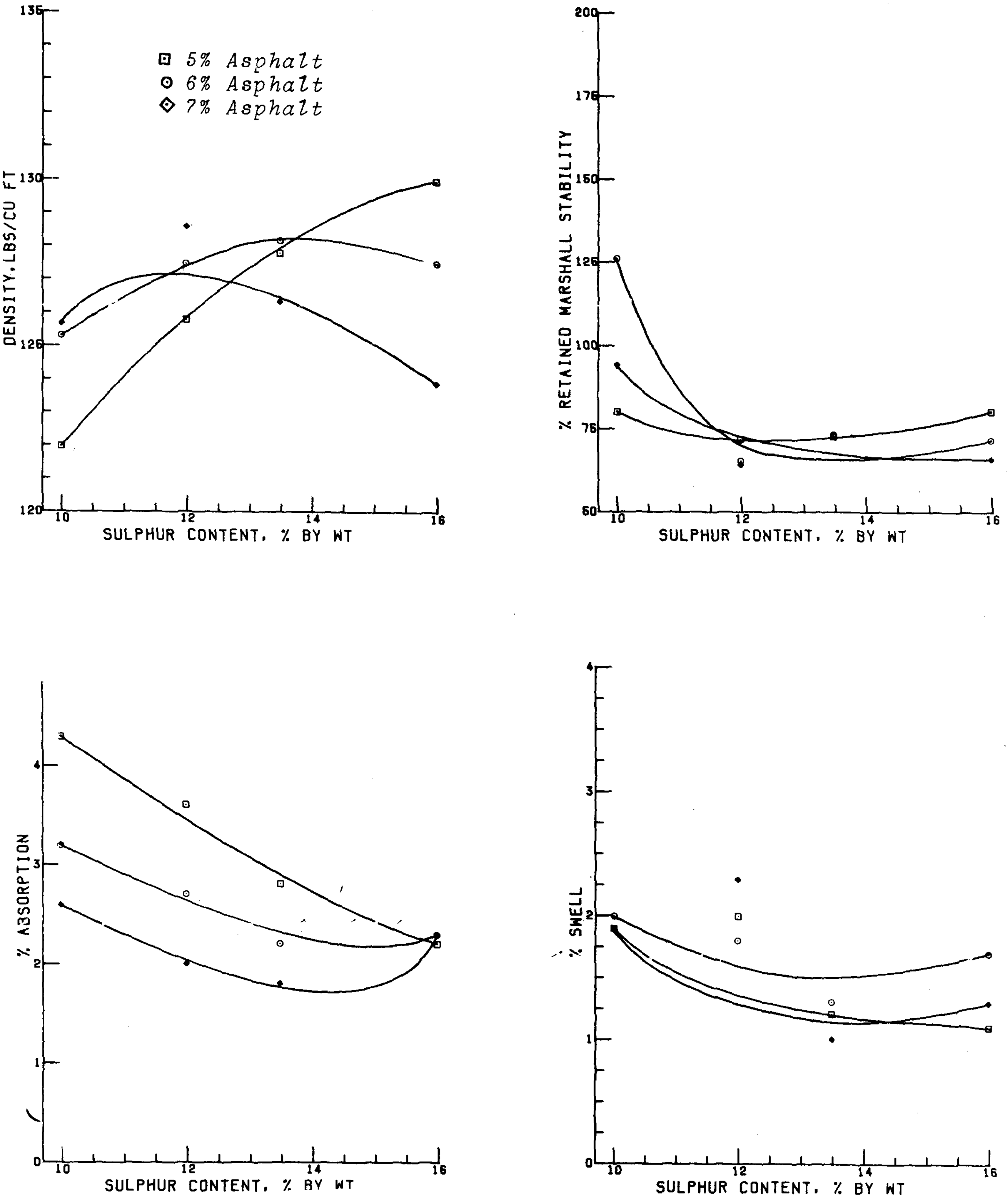

Figure 7: Marshall Test Properties - Acadian Pit Sand and Asphalt AC-40

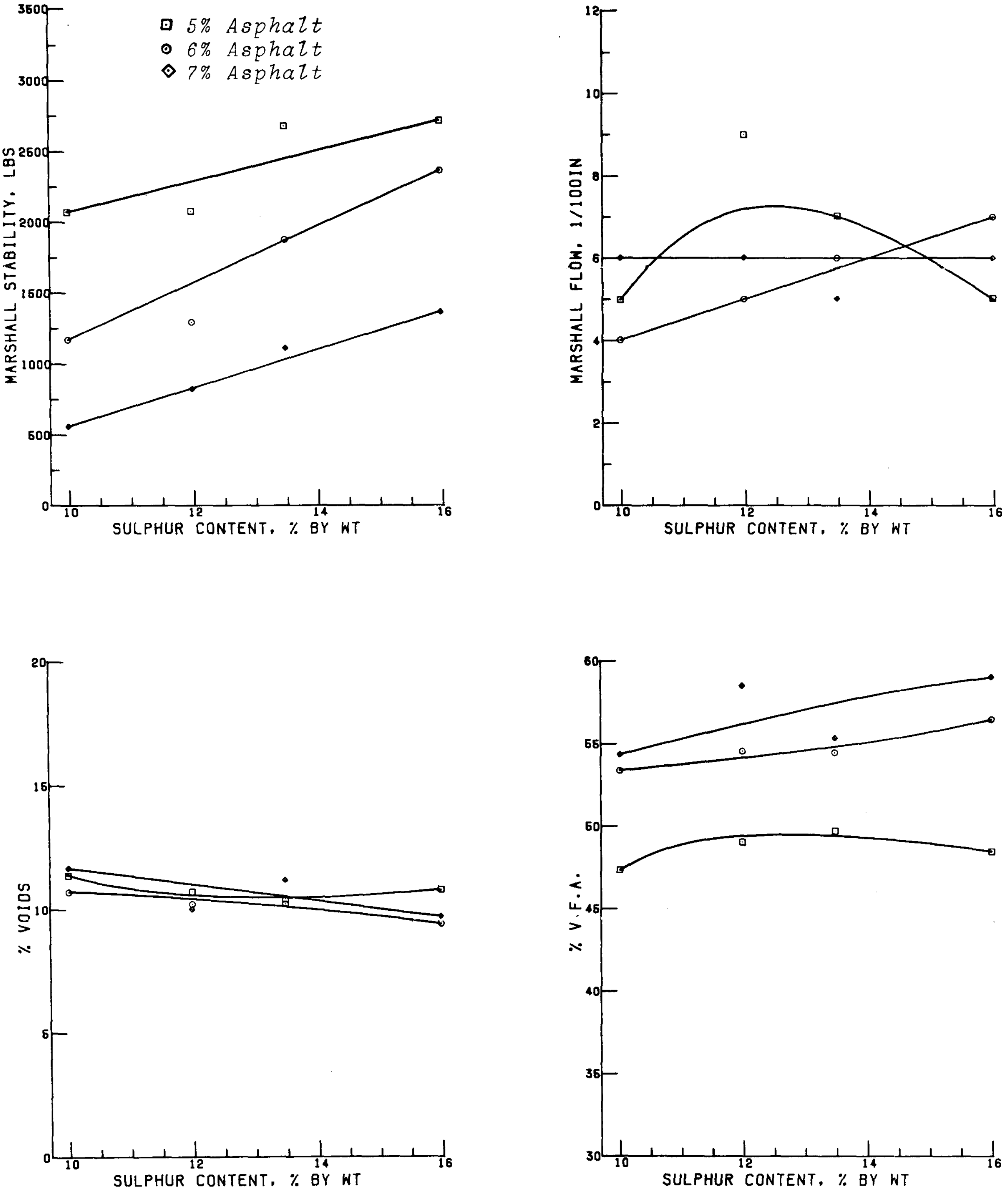

Figure 8: Marshall Test Properties - Anderson Pit Sand and Asphalt AC-20

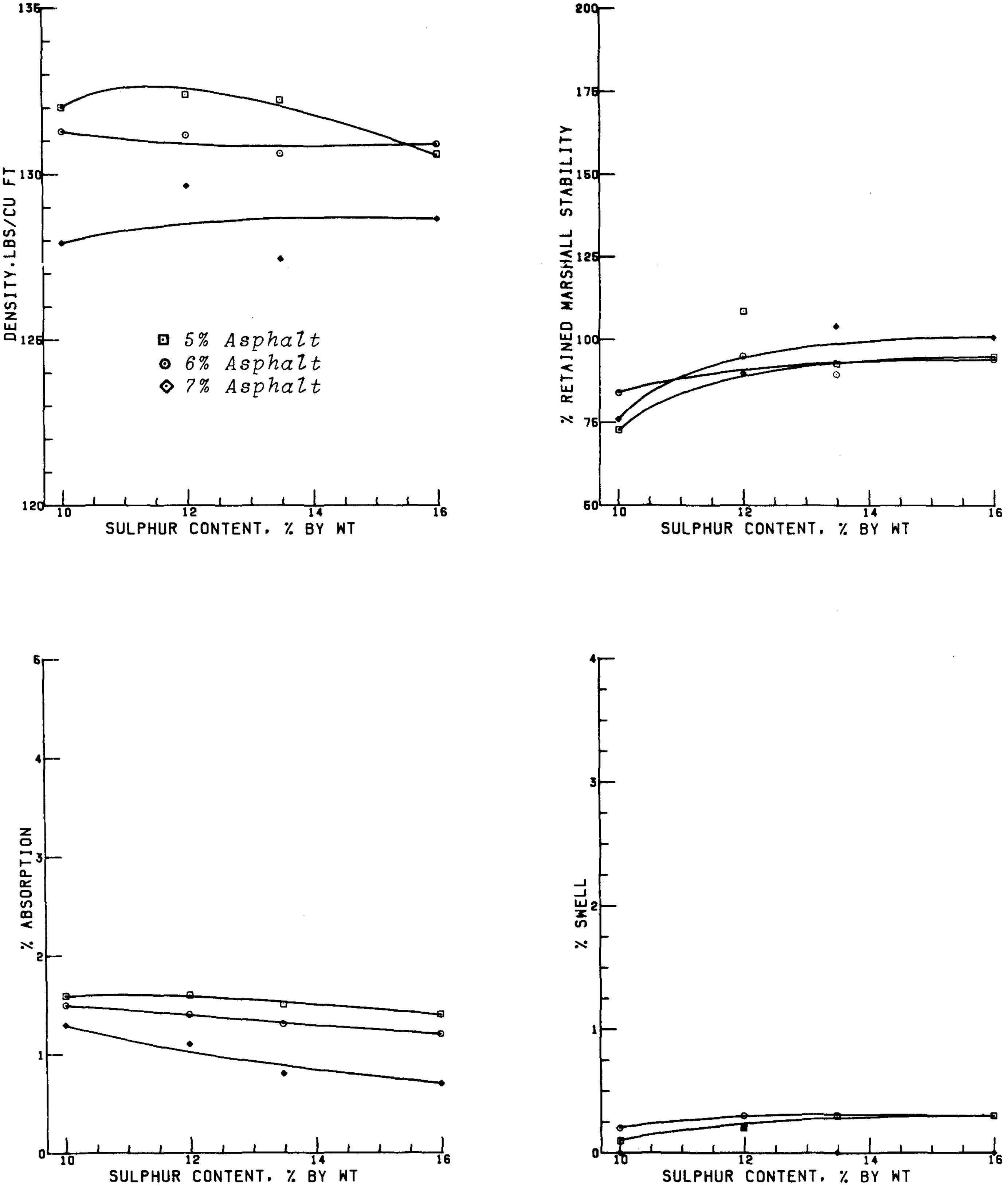

Figure 9: Marshall Test Properties - Anderson Pit Sand and Asphalt AC-20

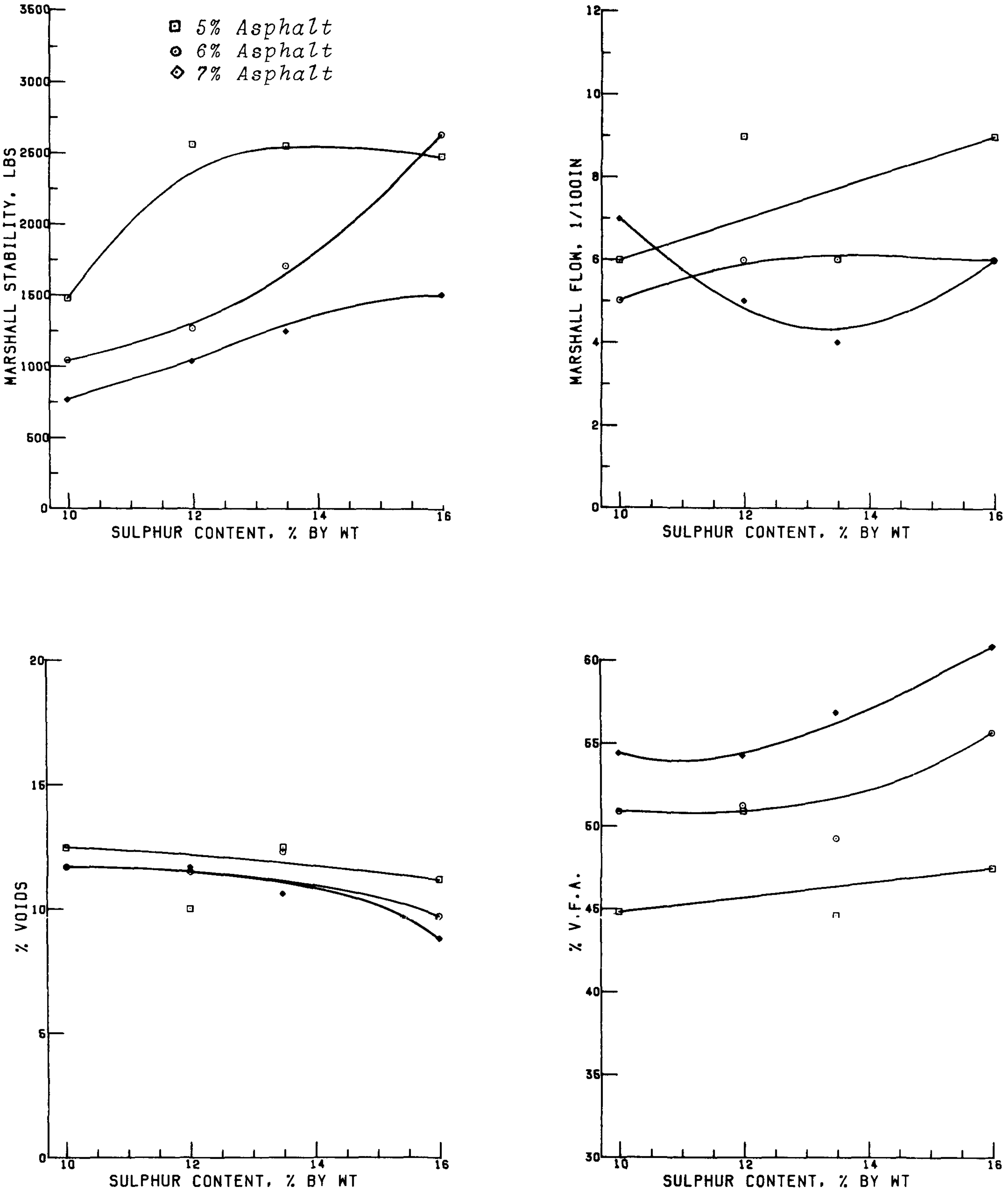

Figure 10: Marshall Test Properties - Anderson Pit Sand and Asphalt AC-40

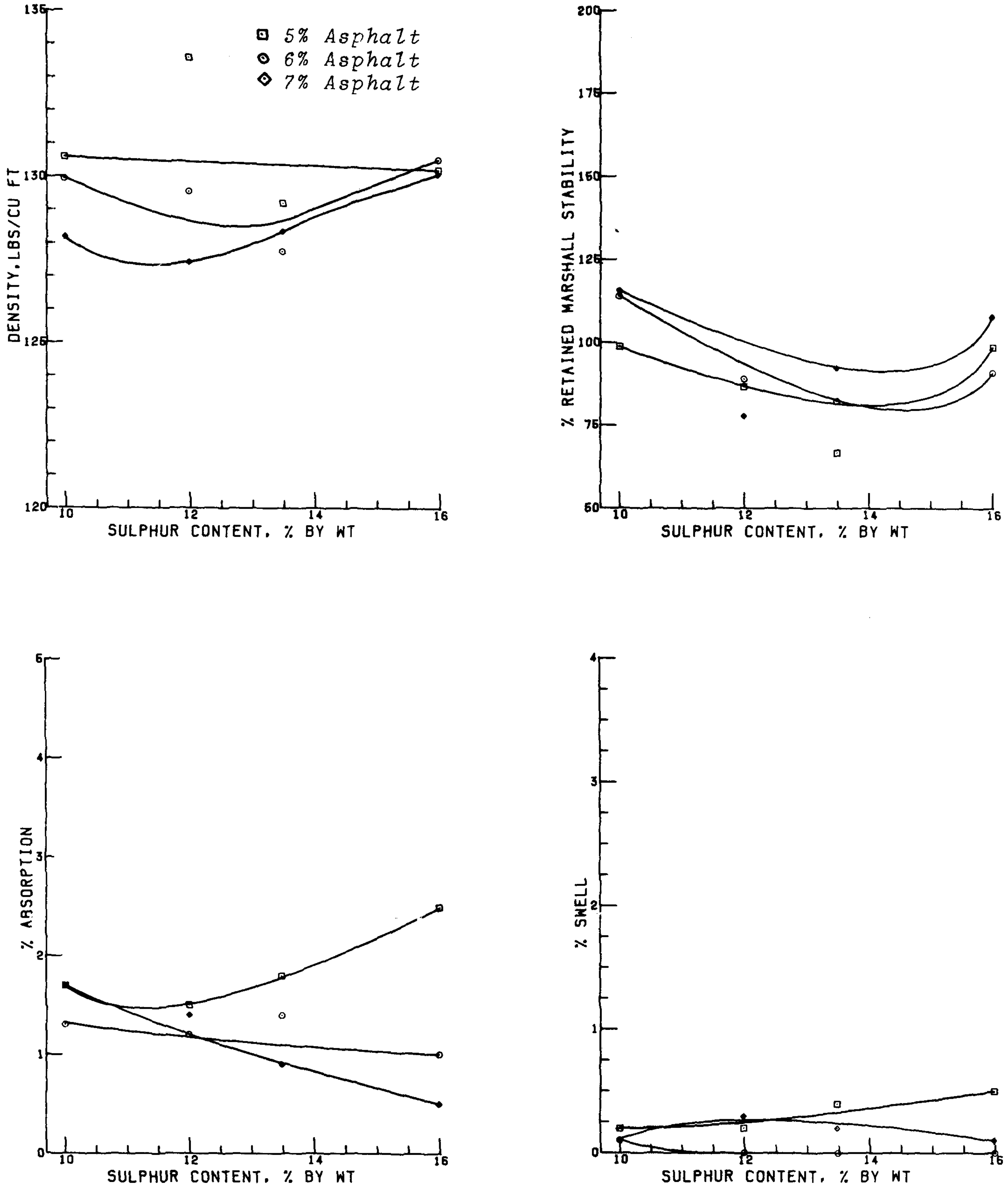

Figure 11: Marshall Test Properties - Anderson Pit Sand and Asphalt AC-40

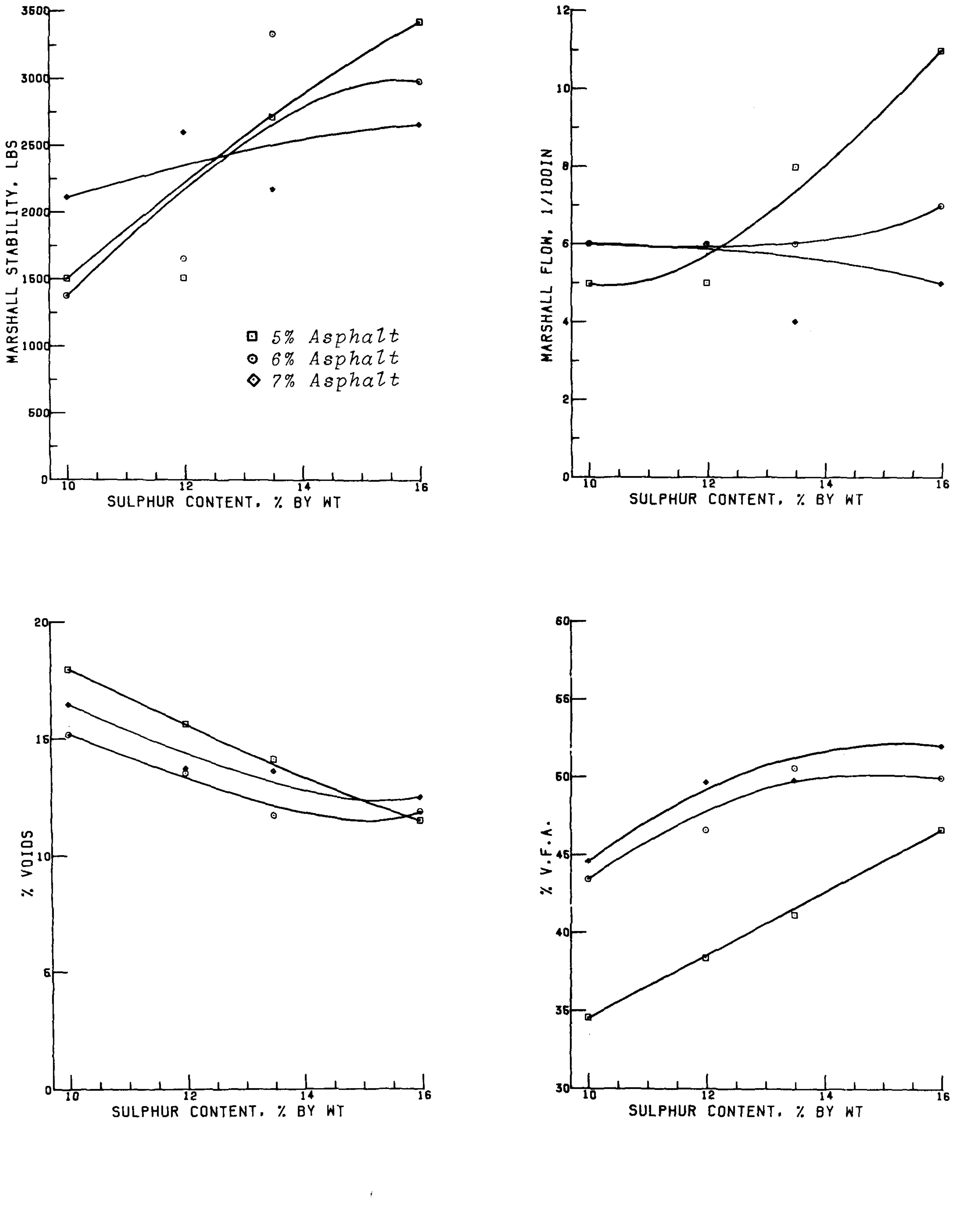

Figure 12: Marshall Test Properties - Holly Beach Sand and Ashpalt AC-20

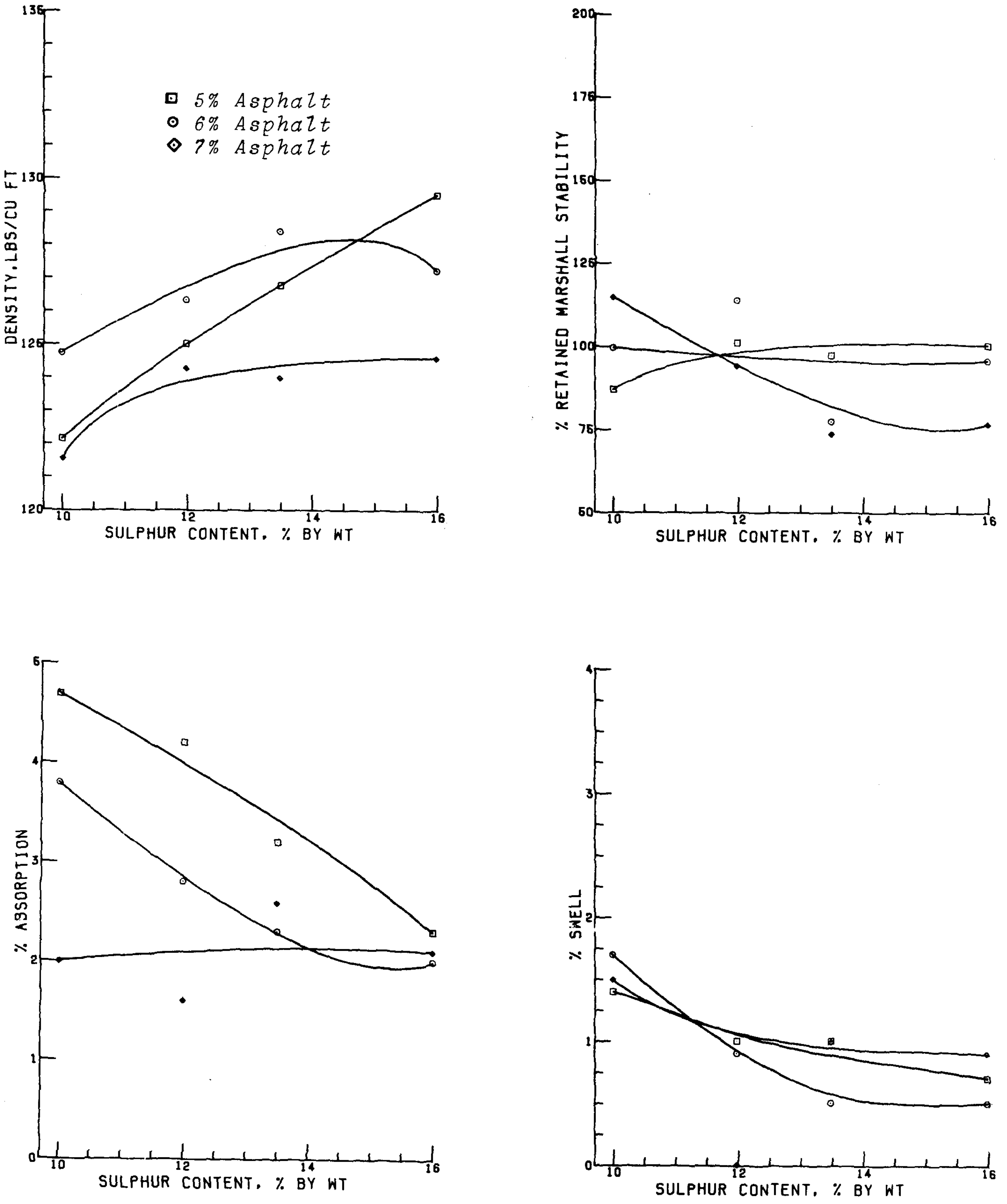

Figure 13: Marshall Test Properties - Holly Beach Sand and Asphalt AC-20

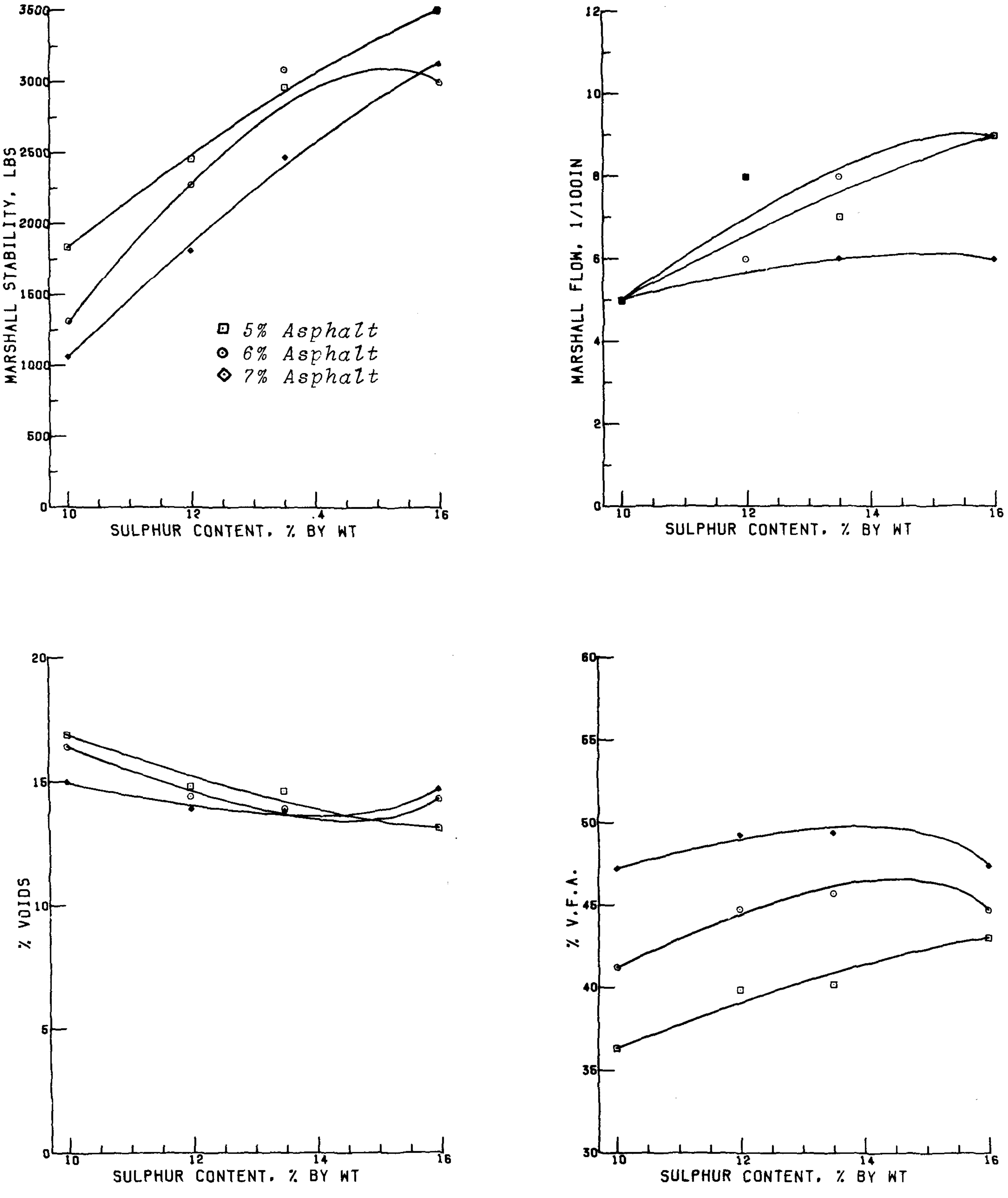

Figure 14: Marshall Test Properties - Holly Beach Sand and Asphalt AC-40

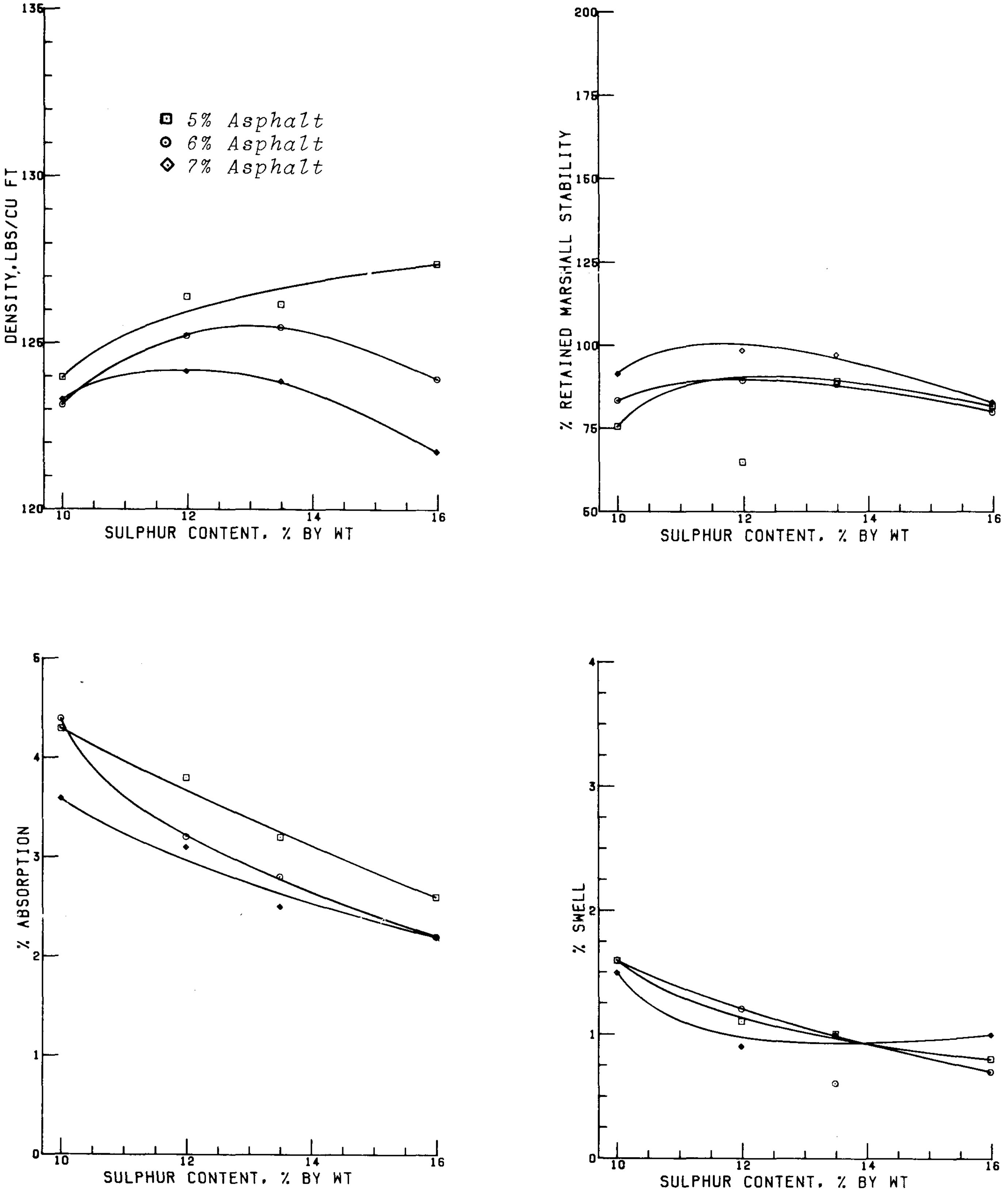

Figure 15: Marshall Test Properties - Holly Beach Sand and Asphalt AC-40

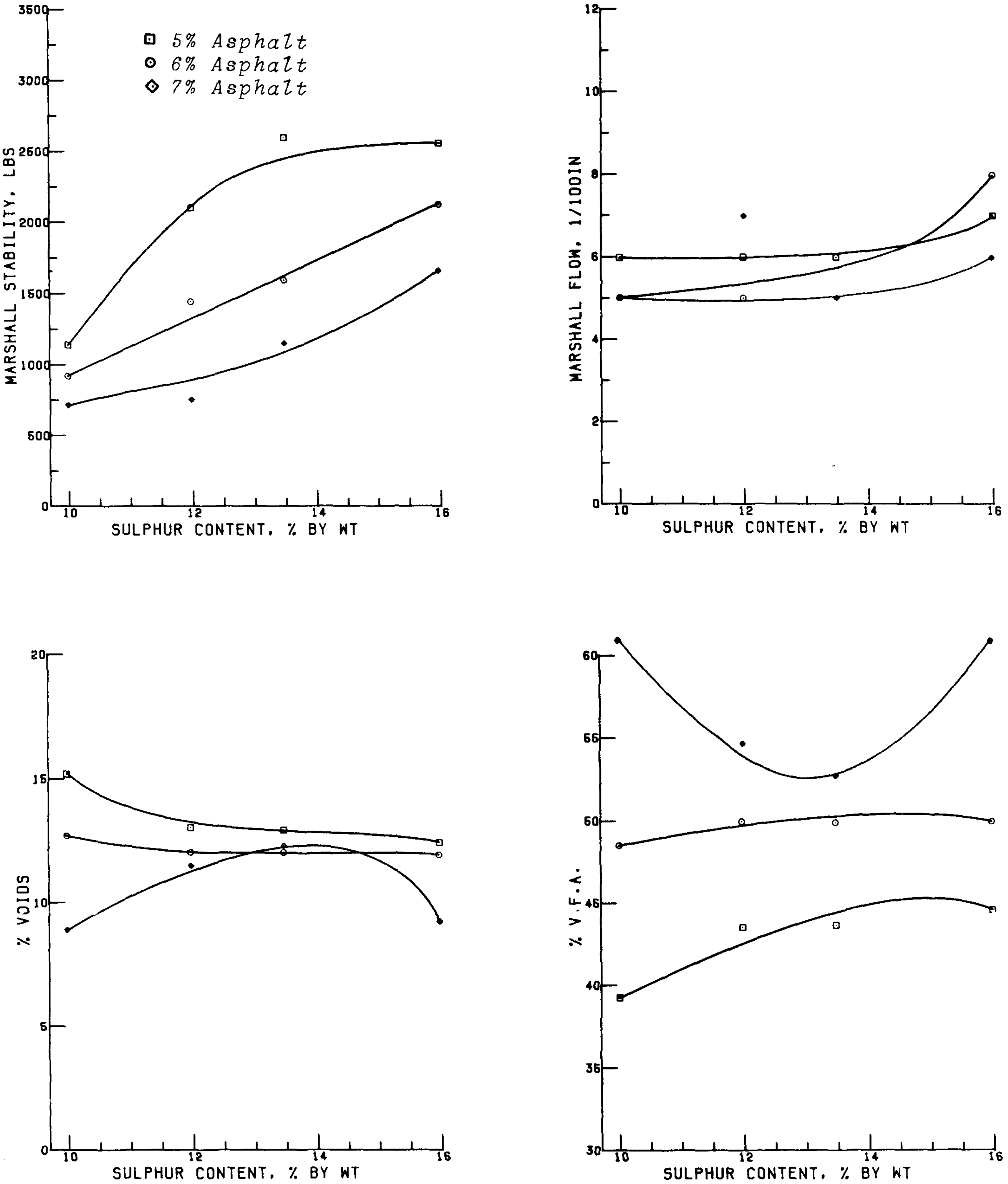

Figure 16: Marshall Test Properties - Thompson Creek Sand and Asphalt AC-20

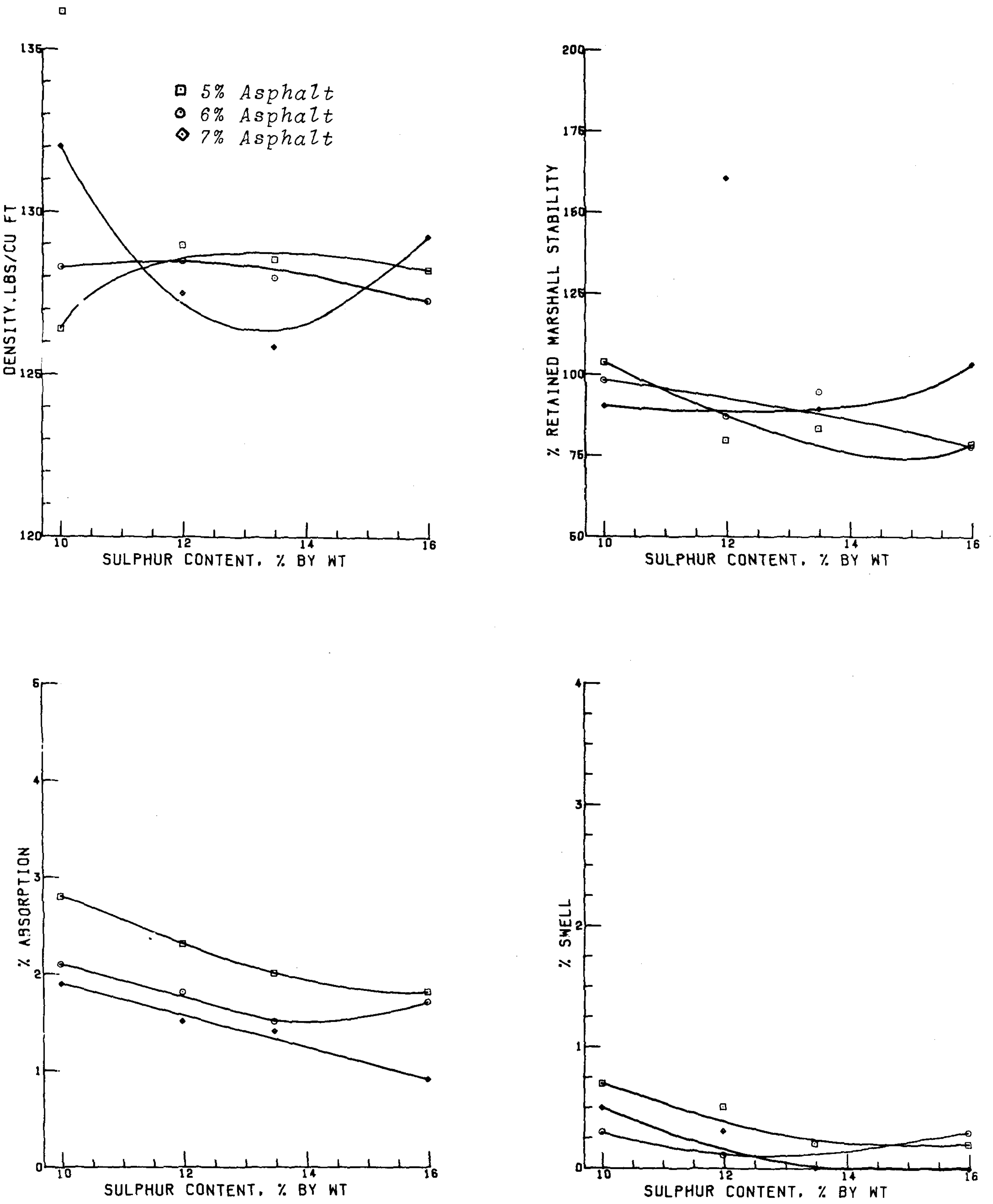

Figure 17: Marshall Test Properties - Thompson Creek Sand and Asphalt AC-20

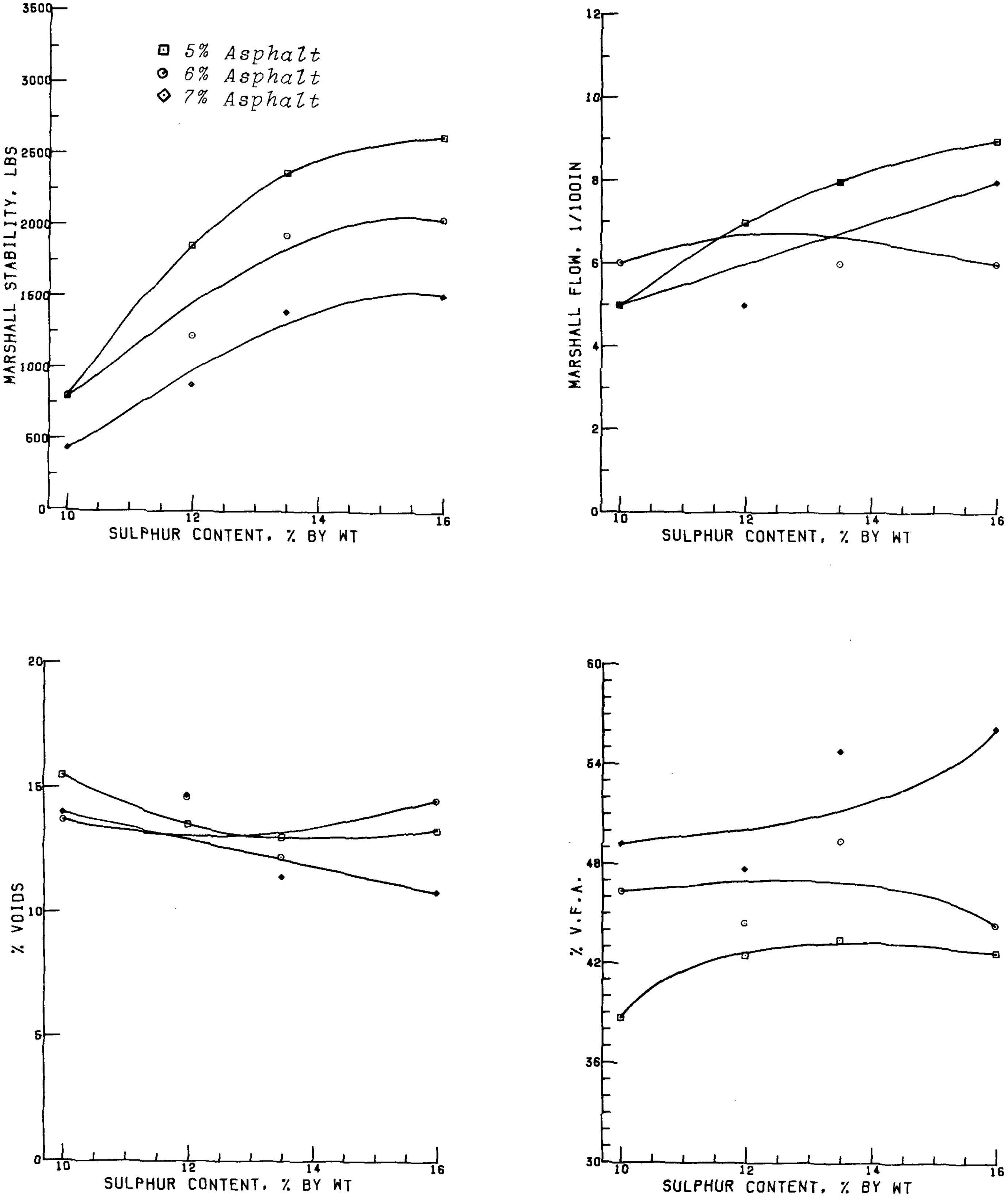

Figure 18: Marshall Test Properties - Thompson Creek Sand and Asphalt AC-40

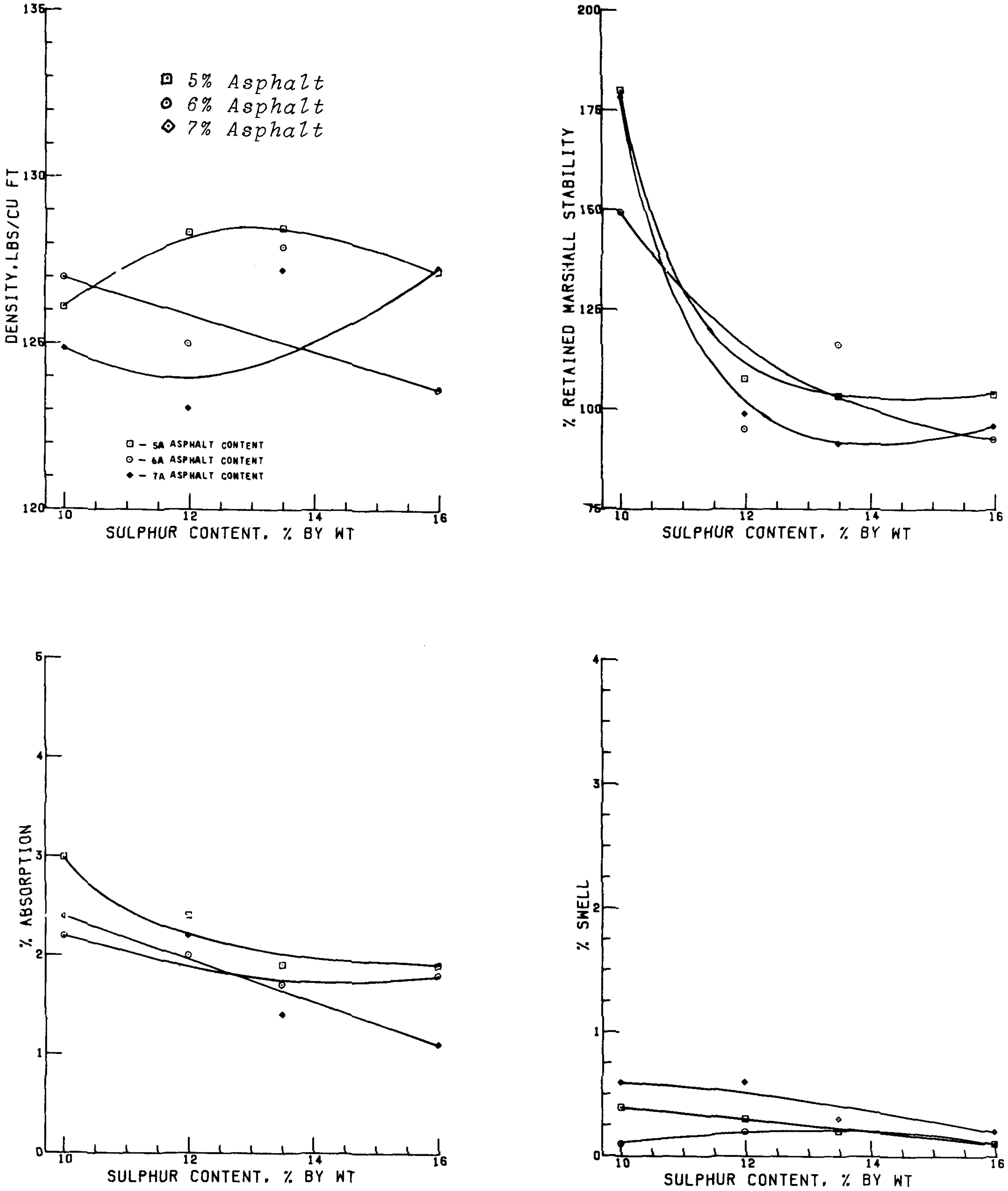

Figure 19: Marshall Test Properties - Thompson Creek Sand and Asphalt AC-40