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Final Report

BITUMINOUS MIXTURES CONTAINING FLY ASH

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ABSTRACT

Mineral fillers of pulverized limestone and fly ash, high and low carbon, were compared. Specimens of asphaltic concrete, similar in all respects except for the fillers, were tested for (1) stability and flow by the Marshall method and (2) compressive strength, dry and after periods of immersion in water.

On the average, mixtures containing limestone dust gave the highest stabilities, followed in order by those containing high-carbon fly ash and low-carbon fly ash, although some characteristic other than carbon content seems to be responsible for differences in behavior of the fly-ash fillers.

Mixtures within the range of Michigan State Highway Department criteria and current practice can be prepared with any of the fillers studied, although those containing fly ash from some sources seem to be more critical with respect to mixture control requirements.

The compressive strengths of the mixtures were not materially affected by any of the fillers and all mixtures containing the several fillers were highly resistant to water action.

OBJECTIVE

This project has as its objective the determination of relative efficiencies of fly-ash fillers and asphaltic concrete paving mixtures.

INTRODUCTION

The specifications for dense-graded asphaltic concrete of the Michigan State Highway Department require the use of a fine mineral filler. Pulverized limestone is the most widely used material for this purpose, but fly ash is available in some areas and is acceptable if it meets certain requirements, including a carbon content between 7 and 12% by weight. These limits of carbon content were established some years ago and a large amount of fly ash conforming to them has been used from plants of The Detroit Edison Company. Two plants of the Company now produce fly ash containing considerably less than 7% carbon. It is the objective of this investigation to compare the characteristics of asphaltic concrete mixtures in which are used as fillers: (1) limestone dust, (2) low-carbon fly ash, and (3) high-carbon fly ash. The sources of fillers were as follows:

National Lime and Stone Co.	limestone
Waukesha Products Co.	limestone
The Detroit Edison Co.	fly ash
Marysville	(10.3% carbon)
The Detroit Edison Co.	fly ash
Conners Creek	(9.9% carbon)
The Detroit Edison Co.	fly ash
Trenton Channel	(2.9% carbon)
The Detroit Edison Co.	fly ash
St. Clair	(3.05% carbon)

SCOPE

Since the principle use of filler is in the dense-graded asphaltic concrete employed in surfaces constructed under Michigan State Highway Department specifications, the mixtures used in this study were prepared in accordance with these requirements. The typical composition is as follows:

Asphalt	5.5% by weight
Filler	6.0% by weight
Fine aggregate	33.5% by weight
Coarse aggregate	55.0% by weight

The current design is based on density-stability studies made a number of years ago and modified by experience on past construction of this type. This design conforms closely to the following criteria when tested by the Corps of Engineers Marshall stability method:*

Stability (Marshall)	1500 lb or above
Voids	3 to 5%
Flow (Marshall)	20 (max)
Percentage of voids of the aggregate filled with asphalt	75-85%

MATERIALS

With the exception of the two low-carbon fly ashes, all the materials used conform to Michigan State Highway specifications for use in dense-graded asphaltic concrete. In order to preserve uniformity, the coarse aggregate was divided into sizes and recombined for each batch of mixture to a typical gradation within the State specifications. Tests of the aggregates, fillers, and asphalt are given in Appendix A.

TESTS EMPLOYED

In addition to tests on the constituent materials, compacted mixtures were tested for (1) strength or "stability," (2) flow or deformation, and (3) strength retention after immersion in water. Details of specimen preparation and testing procedures are described in Appendix B.

For determinations (1) and (2), the Marshall method of specimen preparation and testing was used. In this method mixtures are prepared of identical composition except for the asphalt content which is varied in 0.5% steps from very lean to very rich. Cylindrical specimens are compacted by the prescribed procedure and the density of each is determined. From the known specific gravities and percentages of the constituent materials and the specific gravity of the compacted specimen, there are computed (1) the voids in the specimen, (2) the percentage of voids of the aggregate filled with asphalt, and (3) the weight per cubic foot of the compacted mixture. Each of these computed characteristics is plotted against asphalt content.

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*Described by Gayle McFadden and Walter C. Rickets, _Proceedings Assn. of Asphalt Paving Technologists_, _17_:92-113 (1948).

The compacted specimens are tested for "stability" or strength and "flow" or deformation in the Marshall apparatus. The specimen on edge is pressed between upper and lower testing heads conforming to the curvature of the specimen but spaced 3/4 in. apart, thus permitting deformation. An attachment permits measurement of deformation, recorded as "flow," as the load is applied at a standard rate. The "stability" of the specimen is the maximum load which the specimen will sustain, and the "flow" value is read as the amount of deformation at the instant the maximum load value is obtained. Curves of both stability and flow are plotted against asphalt content. These constitute two additional characteristic curves.

Mixtures were prepared and tested with three filler contents (4%, 6%, and 8%) by weight for each of the six fillers of this investigation. The five sets of characteristic curves and the data from which they were plotted for each of the six fillers are presented in Appendix C, Tables I through V and Figs. 1 through 30.

The relative resistance to water of the six fillers was determined by the immersion-compression test developed by the U. S. Bureau of Public Roads.* In this test, test specimens of the mixtures are prepared by double-plunger direct compression without tamping. The specimens are tested in unconfined compression at 77°F, three without exposure to water, three after 4 days' immersion in water, and three after 14 days' immersion in water. The compressive strength of the specimens after water immersion divided by the compressive strength of the specimens which are not exposed to water gives the percentage of retained strength or index of resistance.

SELECTION OF MIXTURES FOR COMPARISON

Asphaltic paving mixtures are so designed that when laid the pavement will contain some air voids. One in which the voids of the aggregates are entirely filled with asphalt will deform under heavy traffic and prove unsatisfactory. Thus, the Michigan State Highway Department designs its mixtures to contain 3 to 5% voids when compacted in the laboratory by the methods used in this study.

For the purpose of selecting comparable mixtures conforming to State Highway Department practice, compositions, compacting to 4% voids were chosen. From the characteristic void-asphalt (Appendix C) curves for mixtures containing 4, 6, and 8% of filler from each source, the asphalt content resulting in 4% voids (average of the 3-5% limits of the State Highway Department) was de-

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*"Standard Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures," ASTM, D1075-54.

termined. At this asphalt content the remaining properties (stability, flow, weight per cu ft, and percent aggregate voids filled with asphalt) were picked from the corresponding characteristic curves. The required amounts of asphalt to give 4% voids did not vary a great deal for the several fillers as will be noted in Table I.

The water-immersion tests were made on mixtures typical of Michigan State Highway Department practice with 6% filler and with the asphalt contents which would give 4% voids when compacted by the Marshall method. The asphalt contents were those of Table I, for 6% filler.

DISCUSSION OF TEST DATA

The following comments are based on the test characteristics of mixtures containing 4% voids and are identical in composition except for the variation in asphalt content needed to produce 4% voids and, also, for the sources of filler. The test characteristics of those mixtures containing 6% filler are considered most significant, since most Michigan State Highway Department mixtures carry close to this amount.

STABILITY

The Marshall test for stability is one of a number of arbitrary strength tests. It has been developed for dense-graded mixtures containing coarse aggregates and its use is rather widespread. Test results are not expressed in terms of shear or compressive stress, but are merely the maximum total load in pounds which a specimen is able to resist under the conditions of the specified test procedure. The criteria of satisfactory behavior of mixtures in this test are established by the observations on test tracks and highways. Exact duplication of test results is not possible.

As shown by Table I and Fig. 1, all mixtures containing the six fillers at 4% void content possess stabilities over 1500 lb, with the exception of that one with 8% of the low-carbon fly ash from the St. Clair plant. The stability of the mixture containing high-carbon fly ash from the Marysville plant is similar to those of the two limestone mixtures. The mixtures containing Conners Creek fly ash, also high carbon, is similar in stability to the two low-carbon fly-ash mixtures. The average of the stabilities of the high-carbon fly-ash mixtures is a little below the average of those containing limestone dust, and the stability of mixtures in which low carbon is used is lowest.

COMPRESSIVE STRENGTH

In discussing the strength or stability of the mixtures, attention should be directed to the unconfined compressive strengths of dry specimens which were determined in connection with the immersion-compression test series. The specimens were identical with those containing 6% filler in Table I, except that they contained somewhat higher percentages of voids. These test results are given in the first column of Table III.

Whereas in the Marshall stability test the specimen is partially confined, the specimens whose strengths are reported in Table III were entirely without lateral support. The unconfined compressive strength is often regarded as a valid criterion for design. In this study, the unconfined compressive strengths of all mixtures, regardless of the source and nature of the filler, were not significantly different, indicating that perhaps the mineral filler in the amounts used in such mixtures is less significant with respect to strength than the other components.

FLOW

Flow measurements are made as deformation progresses in the Marshall stability test. The deformation at maximum load is recorded. Plastic mixtures deform more and rigid mixtures deform less. A certain degree of plasticity is desired although no correlation exists between the laboratory results obtained on this test and the service behavior of a mixture. The Michigan State Highway Department practice is to design mixtures which have flow values of 20 or below. All the mixtures at 4% voids possessed flow values well under this limit as shown in Table II and Fig. 2.

UNIT WEIGHT

Figure 3 shows the unit weight of mixtures containing the six fillers at 4% voids. These weights do not vary greatly and are not significant in this study. They should be closely similar since the mixtures are compacted to the same percentage of solid density. The only variables are the minor variations in asphalt content and the specific gravities of the several fillers.

PERCENT VOIDS IN AGGREGATE FILLED WITH ASPHALT

The set of values, shown in Fig. 4, is of interest only in indicating that compaction to 4% voids, and with the typical 6% filler used by the Michigan State Highway Department, the aggregate voids are likely to be a trifle less than 75% filled with asphalt.

RESISTANCE TO WATER ACTION

When mixed with asphalt and stirred in water under the conditions of the water-asphalt preferential test, all the six fillers proved to be satisfactory.

For the water-immersion compression tests, mixtures were chosen which contain 6% filler and the appropriate asphalt content to compact to 4% voids by the Marshall method. These mixtures are identical with those whose Marshall stabilities and asphalt contents are shown in the middle columns of Table I. However, under the double-plunger compression method of compaction prescribed for the preparation of immersion-compression specimens, the voids could not be reduced to 4%. Rather, the average voids of the specimens were as follows:

Filler	Nature	Average Voids of Immersion-Compression Specimens, %
National Lime and Stone	Limestone	6.70
St. Clair	Low-carbon fly ash	6.02
Trenton Channel	Low-carbon fly ash	5.64
Conners Creek	High-Carbon fly ash	6.11
Marysville	High-carbon fly ash	5.39
Waukesha Products	Limestone	6.41

The higher percentage of voids above 4% is not of consequence. The two strength tests (Marshall stability and direct compression) are so different that they cannot be expected to produce comparable results. The higher percentage of voids might be expected to facilitate the penetration of water to the interior of the specimen and in this manner somewhat increase the severity of the test.

Actually the results of the compressive-strength tests of each series were remarkably uniform. They are shown in Table III and Figs. 5a and 5b. There is no significant decrease in strength in mixtures containing any one of the six fillers. The retention, after 14 days' immersion, of 75% of the dry strength has been suggested as indicating satisfactory resistance to water action. All mixtures were above this limit.

INTERRELATIONSHIPS

With increases in asphalt content beyond a certain point, the stability and voids of a mixture decrease and the flow increases. There are indications in this study that the balance between the minimum Marshall stability of 1500 lb, the asphalt content, minimum desired voids, and percentage of filler as expressed by the current Michigan State Highway Department practice may be somewhat critical when fly ash from some of the sources is used as filler.

For some reason, perhaps shape of the particles, mixtures containing 6% fly ash from St. Clair, Trenton Channel, and Conners Creek gave 1500-lb stability with 5.5% asphalt, and, at this point, contained 3.1, 3.5, and 3.1% voids, respectively. An increase in asphalt would reduce the stability below 1500 lb and also would reduce the voids below the design limit. The two limestone fillers and the Marysville fly ash tolerate 6%, or a little more, asphalt while still maintaining 1500-lb stability, although at this asphalt content the voids also would be critical. The following data, picked from the charts of Appendix C, indicate these relationships:

Approximate Maximum Asphalt Content, with Corresponding Voids to Give Marshall Stability of 1500 lb

Filler	4%		6%		8%	
	Asph. %	Voids %	Asph. %	Voids %	Asph. %	Voids %
National Lime and Stone	5.8	3.2	6.0+	2.6	6.4	2.9
St. Clair	5.8	3.0	5.5	3.1	4.6	4.2
Trenton Channel	6.0	3.0	5.5	3.5	5.5	3.2
Conners Creek	6.1	2.6	5.5	3.1	5.1	3.7
Marysville	6.5+	2.6	6.2	2.3	6.0	2.7
Waukesha Products	6.2	2.9	6.1	2.5	5.9	2.5

CONCLUSIONS

The following conclusions are based on this rather limited study designed to investigate the relative effects of certain fillers when used in a single, typical, dense-graded asphaltic concrete mixture.

1. The Marshall stabilities are somewhat affected by the fillers from the several sources. The limestone dusts gave highest stability values, followed in order by the high-carbon fly ash and the low-carbon fly ash. However, all the fillers do produce mixtures under current Michigan State Highway Department practices which possess stabilities of above the minimum design limit of 1500 lb.

2. In the unconfined compressive-strength test the source of filler was not a significant factor. Mixtures containing high-carbon fly ash and low-carbon fly ash possessed strength at least equal to those containing limestone dust.

3. Flow values of the mixtures determined by the Marshall test procedure show no significant difference attributable to the source of filler when other design criteria were satisfied.

4. All the mixtures tested, regardless of the source of filler, were satisfactory with respect to resistance to water action as determined by the immersion-compression test.

5. There were some indications that mixtures containing fly ash from three sources are more critical with respect to design relationships between asphalt content, voids, stability, and flow than are those containing the limestone dusts and the fourth (Marysville) fly ash.

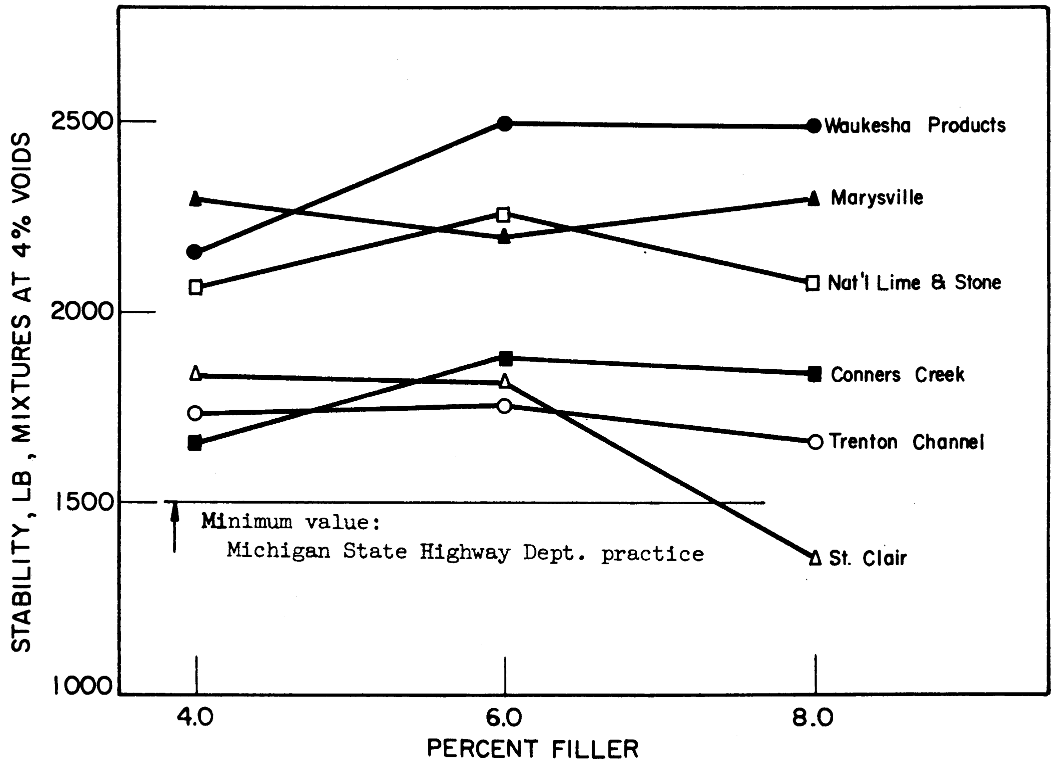

Fig. 1. Stabilities of mixtures at 4% voids.

TABLE I. STABILITIES OF MIXTURES AT 4% VOIDS, lb

Filler	Filler 4%	Asphalt %	Filler 6%	Asphalt %	Filler 8%	Asphalt %
National Lime and Stone	2060	5.4	2260	5.1	2080	5.25
St. Clair	1840	5.2	1820	4.9	1360	4.75
Trenton Channel	1740	5.3	1760	5.2	1660	5.15
Conners Creek	1660	5.2	1880	4.8	1840	4.9
Marysville	2300	5.25	2200	5.1	2300	5.1
Waukesha Products	2160	5.25	2500	5.0	2490	4.8
Average Stabilities of Mixtures at 4% Voids, lb						
2 limestones	2110		2380		2285	
2 high-carbon fly ash	1980		2040		2070	
2 low-carbon fly ash	1790		1790		1510	

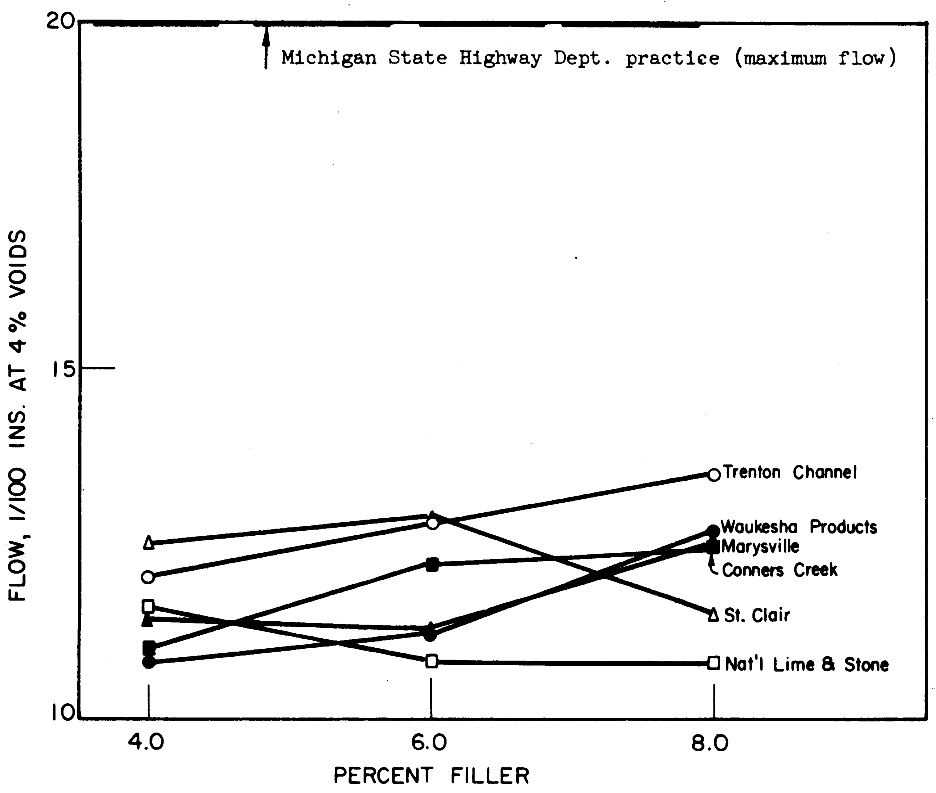

Fig. 2. Flow values of mixtures at 4% voids.

TABLE II. FLOW VALUES OF MIXTURES AT 4% VOIDS
(1/100 in.)

Filler	4%	6%	8%
National Lime and Stone	11.6	10.8	10.8
St. Clair	12.5	12.9	11.5
Trenton Channel	12.0	12.8	13.5
Conners Creek	11.0	12.2	12.4
Marysville	11.4	11.3	12.5
Waukesha Products	10.8	11.2	12.7

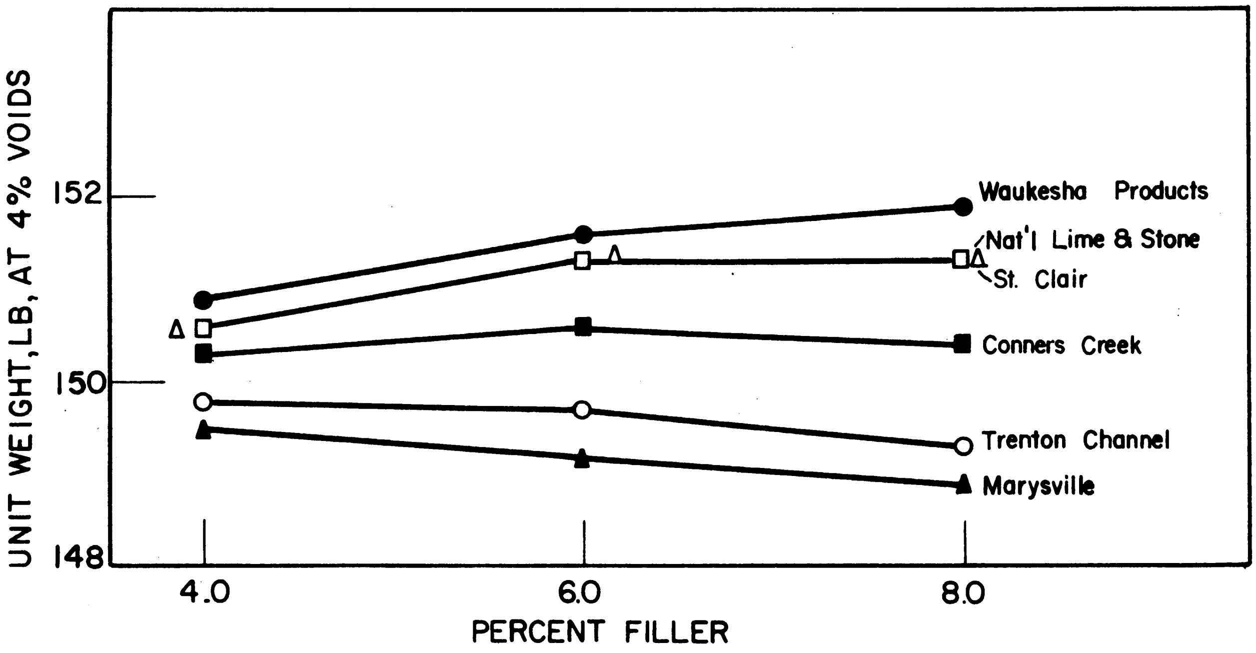

Fig. 3. Unit weight of mixtures at 4% voids.

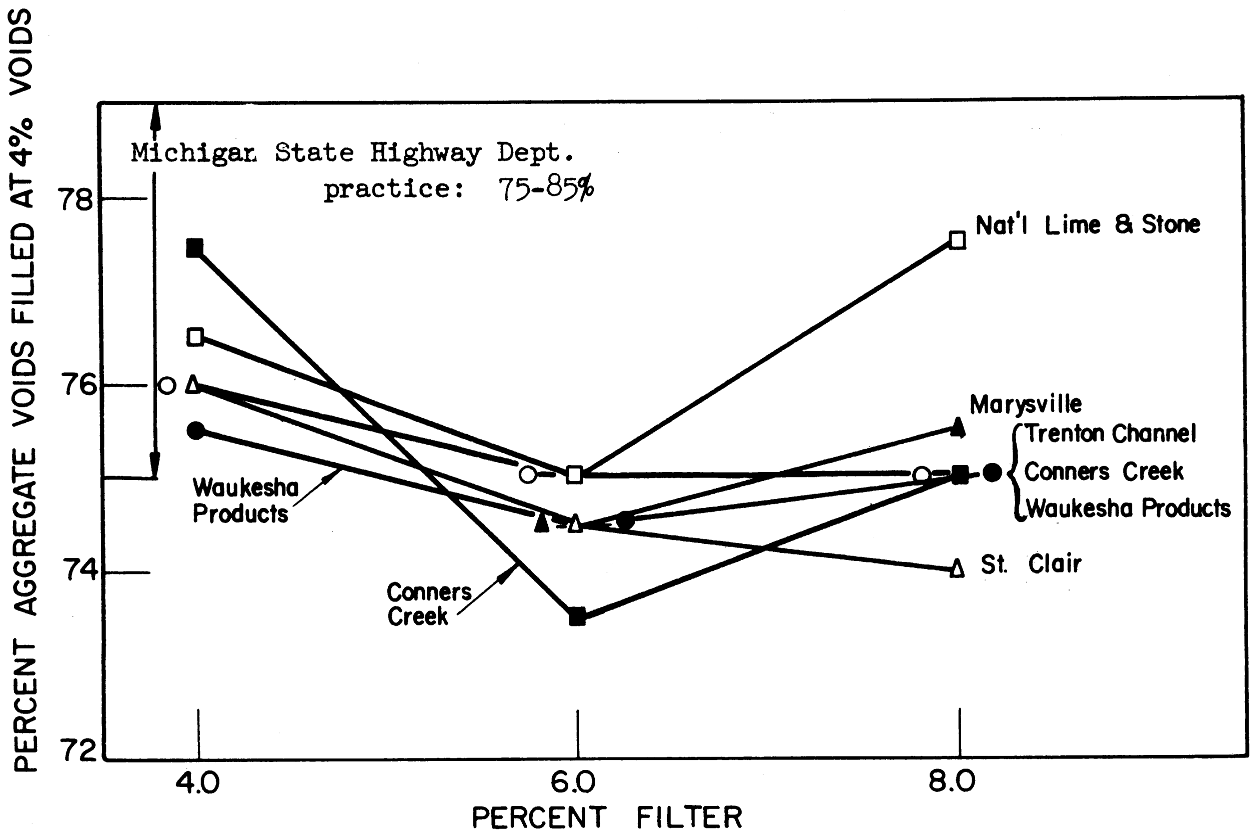

Fig. 4. Percent aggregate voids filled with asphalt at mixture voids of 4%.

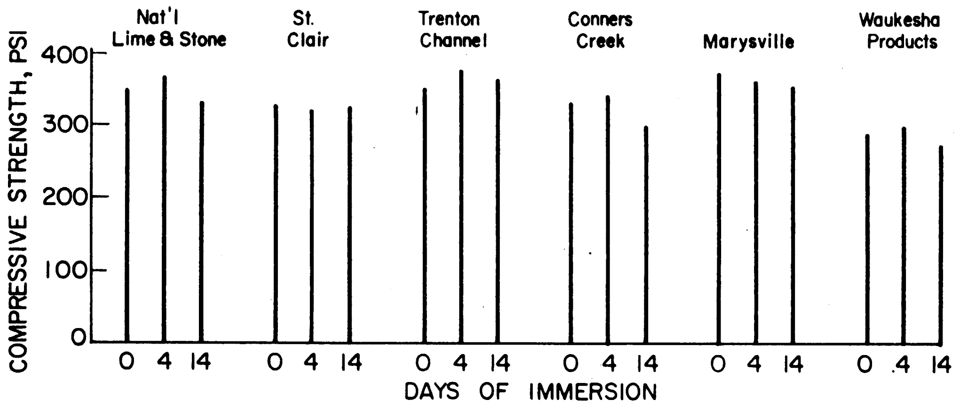

Fig. 5a. Strength of mixtures tested dry and after immersion.

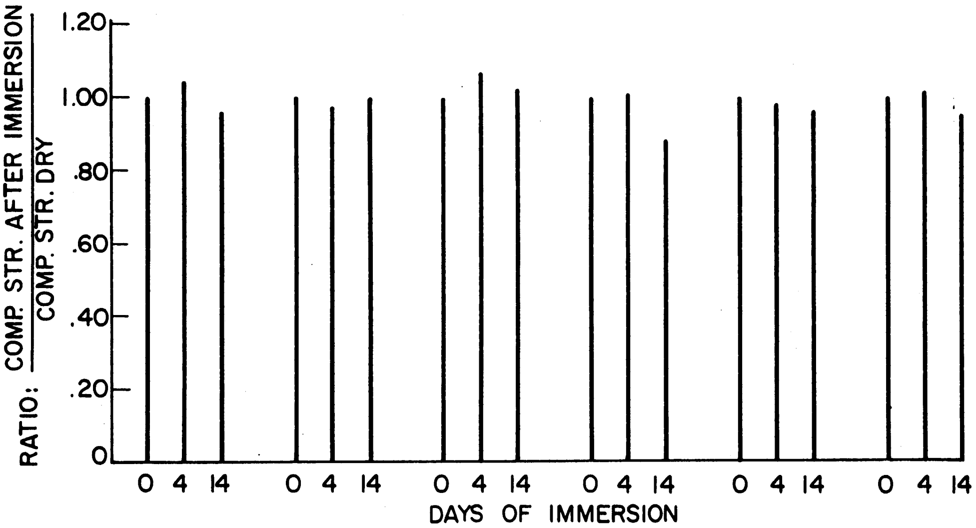

Fig. 5b. Ratio of strength of mixtures tested dry and after immersion.

TABLE III. COMPRESSIVE TESTS OF DRY AND IMMERSED SPECIMENS

Tested Filler	Compressive Strength, psi			Ratio of Str., Immersed and Dry		
	Dry	4-Day Immersion	14-Day Immersion	Dry	4-Day Immersion	14-Day Immersion
National Lime and Stone	349	365	336	1.00	1.05	0.96
St. Clair	328	323	327	1.00	0.98	1.00
Trenton Channel	355	379	367	1.00	1.07	1.03
Conners Creek	339	342	300	1.00	1.01	0.89
Marysville	375	366	359	1.00	0.98	0.96
Waukesha Products	292	299	277	1.00	1.02	0.95

APPENDIX A

MATERIALS

SOURCES OF MATERIALS

FILLER

The fly-ash fillers used in this investigation were the by-products of the combustion of powdered coal from The Detroit Edison Company plants at St. Clair, Trenton Channel, Conners Creek, and Marysville, Michigan.

The limestone fillers used were the standard products of the National Lime and Stone Company, Carey, Ohio, and the Waukesha Products Company, Waukesha, Wisconsin.

FINE AGGREGATE

The fine aggregates used were obtained from the Whittaker and Gooding pit in the vicinity of Ann Arbor, Michigan, and were being used as a fine aggregate in the production of bituminous concrete by the Ann Arbor Construction Company.

COARSE AGGREGATE

The coarse aggregate was crushed natural gravel from American Aggregates Corporation, Green Oaks, Michigan. It was furnished as coarse aggregates, meeting Michigan State Highway Department requirements for 25A coarse aggregate.

ASPHALT

The asphalt was a standard 85-100 penetration asphalt from the Lion Oil Company, Eldorado, Arkansas, and obtained from the Wayne County Road Commission from their supply on hand.

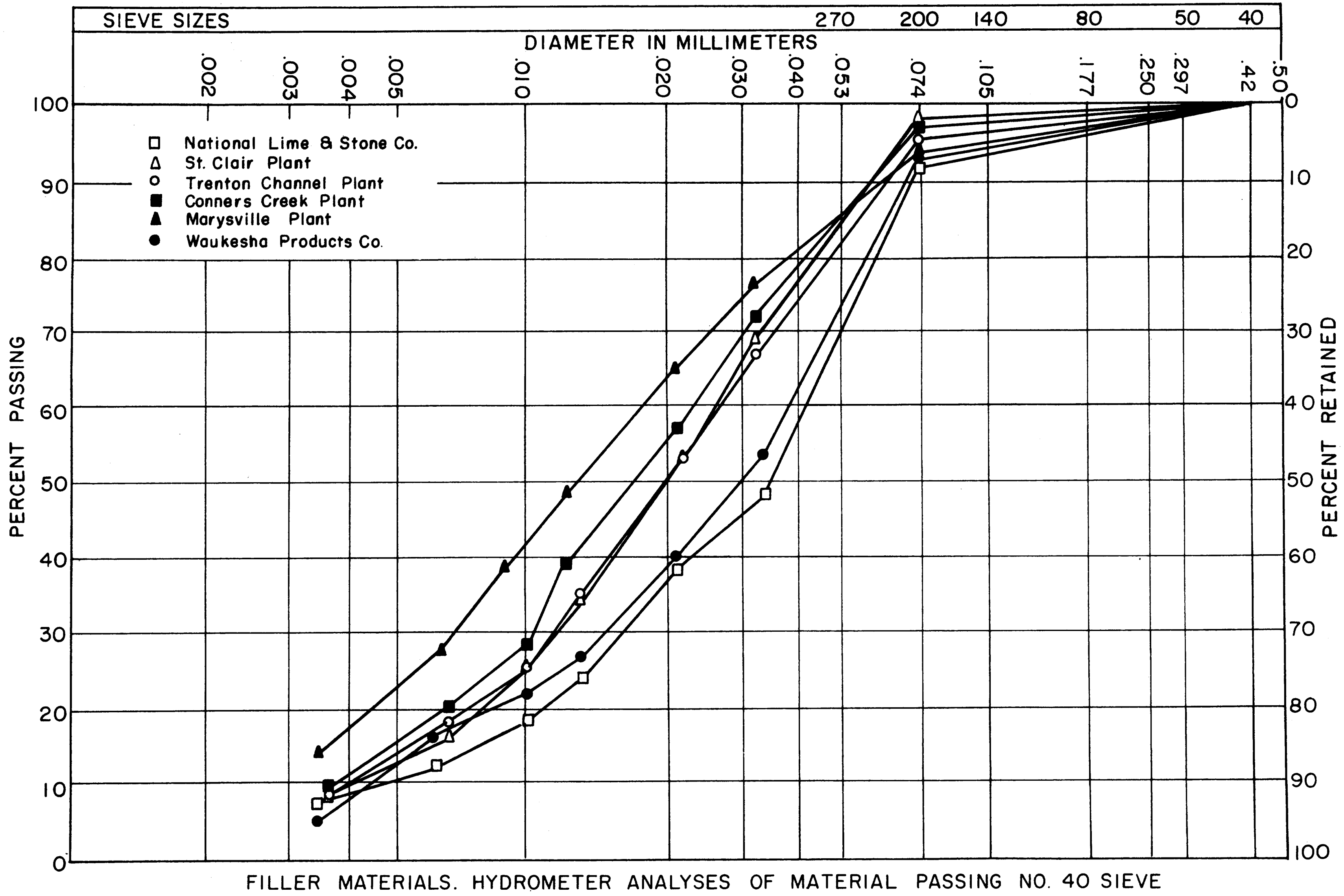

Fig. 1-A. Size distribution of filler materials (only that portion passing no. 200 sieve used in preparation of test mixtures).

TABLE I-A. TESTS OF FILLER MATERIALS

Fly Ash

Chemical Properties	St. Clair	Trenton Channel	Conners Creek	Marysville
	(percent by weight, water-free basis)			
Silicon Dioxide, SiO_2	39.1	46.0	40.7	44.5
Aluminum Oxide, Al_2O_3	25.0	27.7	21.9	--
Ferric Oxide, Fe_2O_3	23.1	17.0	21.9	--
Calcium Oxide, CaO	--	2.6	1.7	--
Magnesium Oxide, MgO	1.1	0.9	0.9	1.5
Sulfur Trioxide, SO_3	0.7	0.7	0.7	0.5
Loss on Ignition	3.05	2.9	9.9	10.3
Moisture	0.1	0.2	0.3	--
Specific Gravity	2.634	2.42	2.47	2.28
Water-Asphalt Preferential Test	Satisfactory	Satisfactory	Satisfactory	Satisfactory

Limestone Dusts

Chemical Properties	National Lime and Stone Co.	Waukesha Products Co.
Specific Gravity	2.83	2.83
Water-Asphalt Preferential Test	Satisfactory	Satisfactory

TABLE II-A. GRADATIONS OF AGGREGATES

Coarse Aggregate

Sieve	Gradation Used % Retained	 % Passing	Michigan State Highway Department Specifications % Passing
5/8 in.	0	100.0	100
1/2 in.	5.0	95.0	90-100
3/8 in.	41.2	53.8	--
No. 4	41.3	12.5	10-25
No. 10	12.5	0	0-10

Fine Aggregate

Sieve	Gradation Used	Michigan State Highway Department Specifications
Pass no. 4	0	100
Pass no. 4, ret'd no. 10	2.6	0-5
Pass no. 10, ret'd no. 40	25.6	5-35
Pass no. 40, ret'd no. 80	46.2	30-60
Pass no. 80, ret'd no. 200	25.6	15-35
Pass no. 200	0	0-5

TABLE III-A. ANALYSIS OF ASPHALT CEMENT

General Characteristics	Semi-solid
Specific Gravity at 25°C/25°C	1.018
Penetration at 25°C, 100 g, 5 sec	84
Flash Point, Cleveland Open Cup, C.	352
Loss on Heating at 163°C, 5 hr, 50 g, %	0.184
Penetration of Residue from Loss on Heating, 25°C, 100 g, 5 sec	73
Ductility at 25°C, cm	110+
Solubility in CCl_4, %	99.93
Oliensis Spot Test	Negative

APPENDIX B

TEST METHODS AND PROCEDURES

MARSHALL PROCEDURES FOR STABILITY AND FLOW TESTS

PREPARATION OF AGGREGATES

A sufficient quantity of aggregates, to make the required number of specimens, was air-dried to substantially constant weight and then separated into the required size ranges by means of mechanical sieving. To maintain uniformity of gradation of the test specimens, the separate size fractions were recombined by weight into individual batches of sufficient volume to mold three specimens, 4 inches in diameter by 2-1/2 inches compacted height.

PREPARATION OF MIXTURE AND COMPACTION OF SPECIMENS

The weighed aggregate fractions of each batch were heated to 300°F and thoroughly mixed dry by stirring with a spatula. The 12-quart-capacity mixing bowl of a Hobart mechanical mixer was then charged with the batch of heated aggregate and a crater formed in the dry blended mixture; the required amount of bitumen, at a temperature of 300°F, was then weighed into the mixture. Mixing of the aggregate and bitumen, using a wire, or bird-cage-type mixing paddle, was immediately started, and, after a mixing period of 1-1/2 minutes, the mixer was stopped and the mixture of fines and bitumen adhering to the sides of the bowl and to the paddle was scraped back into the mixing area, after which mixing was continued until a total mixing time of 3 minutes was completed. The mixture was then placed in a shallow pan, covered, and placed in the oven until the compaction temperature was attained. Compaction was accomplished, with the mix at a temperature of 280 ± 5°F, using standard Marshall test apparatus, with 50 blows applied with the compaction hammer on one side of the specimen, removing the base plate and collar, reversing the mold, reassembling, and applying the same number of blows to the opposite side of the specimen. After compaction, the mold containing the specimen was placed in cool water for a minimum of 2 minutes after which the sample was removed, by means of the sample extractor, from the mold and identified as to mix and specimen number. The specimens were allowed to cool to room temperature in air for approximately 24 hours, after which they were weighed in air and in water for specific-gravity determinations. In order to maintain close control, a maximum tolerance of 0.03, between the maximum and minimum range of specific gravities of the three specimens of each mix, was used and mixes not complying to this tolerance were repeated.

STABILITY AND FLOW DETERMINATION

The test specimens were brought to the test temperature of 140°F by immersing them in a water bath at 140°F for a period of one hour. Using the

Marshall-type specimen mold holder, breaking head, loading jack, proving ring assembly, and flow meter, specimens were subjected to load applications at a constant rate to produce a uniform vertical movement of 2 inches per minute until failure of the specimen occurred. The maximum reading of the dial in the proving ring assembly, converted to pounds, is the stability value for the individual specimen, and the flow meter reading, expressed in hundredths of an inch, is the flow, or deformation under stability loading, value of the specimen. The stability value varies directly with the thickness, or height, of the specimen. Therefore, it was necessary to correct the stability values for specimens of a thickness varying from the standard 2-1/2 inches. Flow values do not vary appreciably with change in thickness of the specimen and therefore no corrections were made for the flow value.

SELECTION OF MIXES

From the test results obtained, and the values computed, the average results of the three specimens for each filler, at each bitumen and filler content, were plotted and shown in Figs. 1 through 30, Appendix C. On the basis of these curves, the median of the standard void range, 3 to 5%, with 6% filler content was selected as the basis for determining the bitumen content for each of the six fillers.

WATER-IMMERSION AND UNCONFINED COMPRESSION-TEST PROCEDURES

Mixtures with bitumen contents as determined from the 4% void curves with 6% filler were used for the water-immersion test series.

PREPARATION OF AGGREGATES

A sufficient quantity of aggregates, to make the required number of specimens, was air-dried to substantially constant weight and then separated into the required size ranges by means of mechanical sieving. To maintain uniformity of gradation of the aggregates, the separate size fractions were recombined by weight into individual batches of sufficient size to mold one specimen, 4-1/2 inches in diameter by 4-1/2 inches compact height.

PREPARATION OF MIXTURE AND COMPACTION OF SPECIMENS

The weighed aggregate fractions of each batch were heated to 300°F and thoroughly mixed dry by stirring with a spatula. The 12-quart-capacity mixing bowl of a Hobart mechanical mixer was then charged with the batch of heated aggregate and a crater formed in the dry blended mixture; the required amount of bitumen, at a temperature of 300°F, was then weighed into the mixture. Mixing of the aggregate and bitumen, using a wire, or bird-cage-type mixing paddle, was immediately started, and, after a mixing period of 1-1/2 minutes, the mixer was stopped and the mixture of fines and bitumen adhering to the sides of the bowl and to the paddle was scraped back into the mixing area, after which mixing was continued until a total mixing time of 3 minutes was completed. The mixture was then placed in a shallow pan, covered, and placed in the oven until the compaction temperature was attained. Compaction was accomplished, with the mixture at a temperature of 280 ± 5°F, by placing it in a molding cylinder which, together with the top and bottom plunger, had been preheated in the oven maintained at the molding temperature. With the bottom plunger in place and the molding cylinder supported temporarily on brass bars, the mixture was spaded around the inside of the mold with a spatula to reduce surface "honeycomb." It was then compressed between the top and bottom plungers under an initial load of approximately 150 psi to set the mixture against the sides of the mold. The support bars were then removed to permit full double-plunger action and the full molding load of 3000 psi, or 48,000 lb, was applied and maintained for two minutes.

After removal from the mold, specimens were oven cured 24 hours at 140°F and thereafter brought to test temperature, 77°F, by storing in air at this temperature for approximately 18 hours.

COMPRESSION AND WATER-IMMERSION TESTS

Nine specimens for each of the six fillers were prepared, and, after determining the oven-dry weight, the surface-dry weight, and the weight in water for each specimen, the nine specimens were divided, at random, into groups of three specimens each. One group was immediately tested in axial compression without lateral support at a uniform rate of vertical deformation of 0.05 inch per minute per inch of height. The compressive strength for each specimen was computed in pounds per square inch by dividing the maximum vertical load obtained during deformation at the rate specified by the original cross-sectional area of the test specimen. The second group of specimens was immersed in distilled water for four days at 120°F, then transferred to a second water bath, maintained at 77°F, for a period of two hours. The compressive strength was then determined. The third group of specimens was immersed in distilled water for 14 days at 120°F, then transferred to a second water bath, maintained at 77°F, for a period of two hours. The compressive strength of the third group was then determined

RETAINED STRENGTH

The numerical index of resistance of the bituminous mixtures to the possible detrimental effect of water was determined by dividing the strength of the specimens after immersion by the strength of the specimens which have not been immersed.

WATER-ASPHALT PREFERENTIAL TEST[*]

This test is used to determine the relative affinity for water or bitumen of a mineral filler which is to be used in a bituminous mixture.

Fifty millileters of asphaltic oil (SC-3A), heated to 140°F, was placed in an eight-ounce sample bottle with wide mouth and screw cap. Ten grams of material passing no. 200 sieve was added to the bituminous material. The bottle was placed in a hot-water bath maintained at a temperature of 140°F and the mixture stirred for five minutes with a mechanical mixer, which revolved at a controlled speed of 1500 rpm. The mixer was equipped with a stirring apparatus containing paddles and a specially designed dispersion cup equipped with baffles. After five minutes, 100 ml of distilled water at 140°F was added and the mixture stirred for a second five-minute period.

After the sample was allowed to settle for approximately 24 hours the amount of clean dust in the bottom of the bottle was observed.

If the mineral filler is of satisfactory quality it will remain in the bituminous material and the water will remain clear. If the dust is of a poor quality, showing a strong affinity for water, the dust will be concentrated in the bottom of the bottle having separated from the oil. If the dust is entirely satisfactory there will be 0% separation; if entirely unsatisfactory there will be 100% separation. A separation of up to an estimated 25%, based on the total sample is considered satisfactory for this test.

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[*] ST-35 method of test for water-asphalt preferential of mineral filler. W. S. Housel, _Applied Soil Mechanics, Laboratory Manual of Soil Testing Procedures_, 1948.

APPENDIX C

TEST DATA AND CHARACTERISTIC CURVES

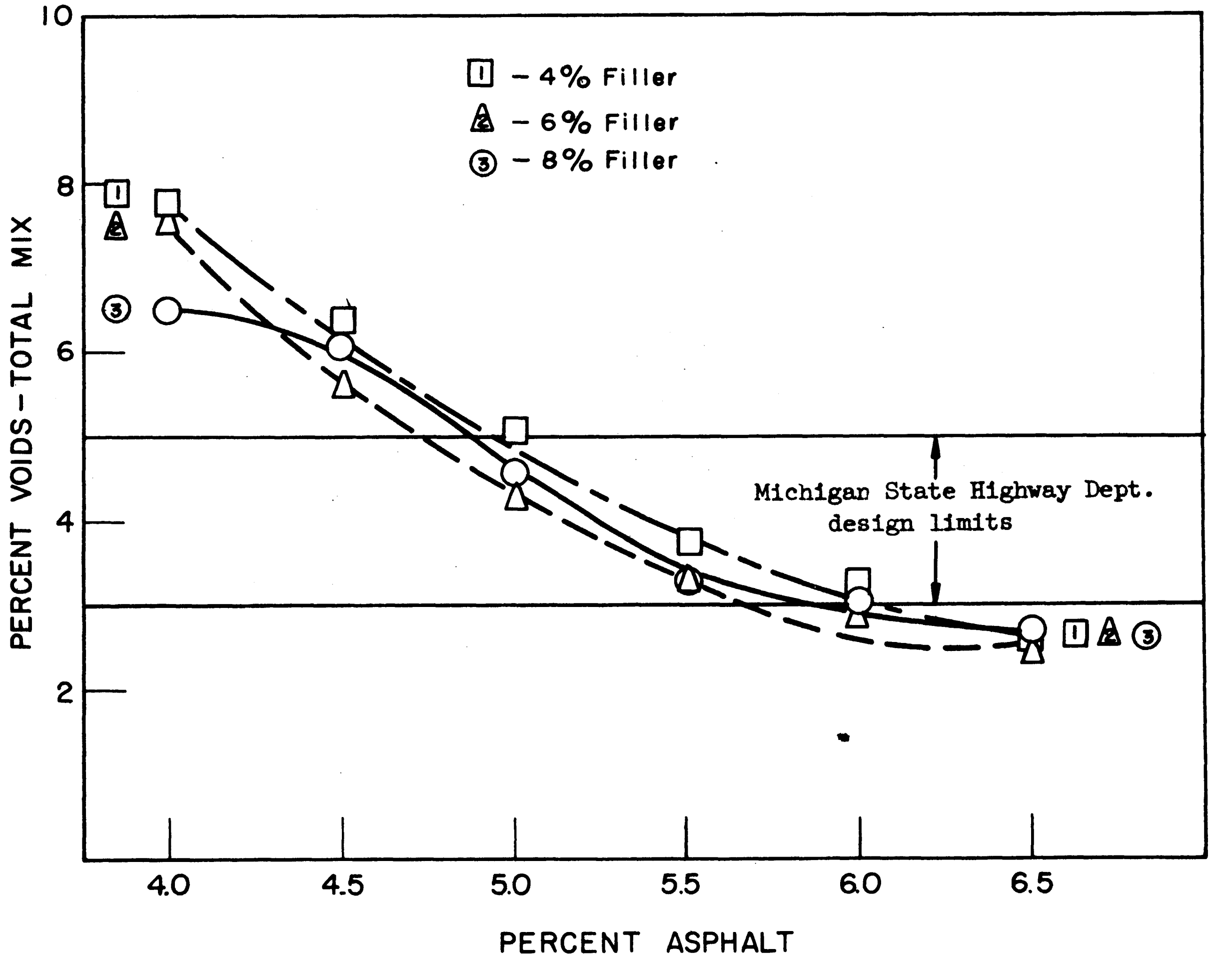

Fig. 1-C. Characteristic curves: % asphalt vs void in mix.

Filler: National Lime and Stone Co.

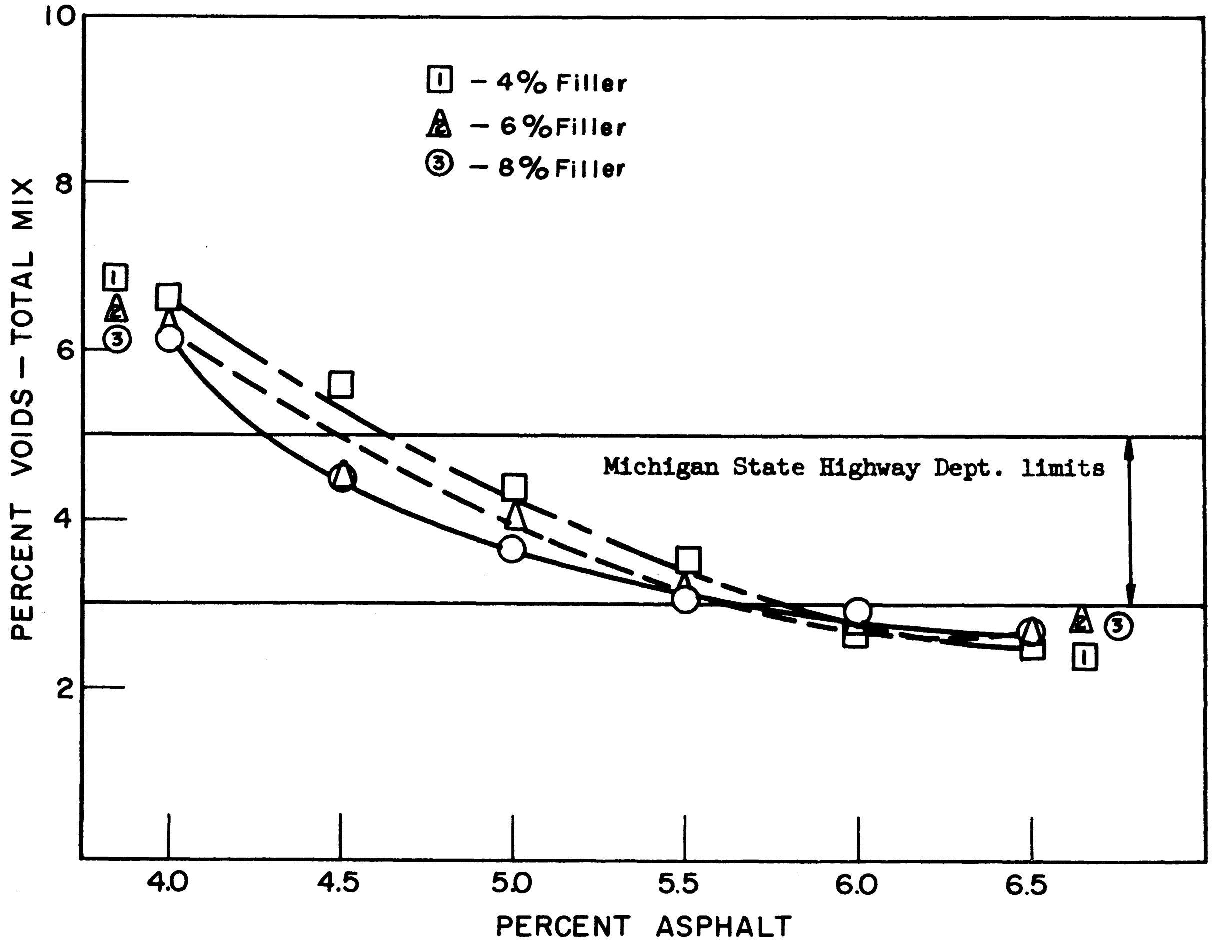

Fig. 2-C. Characteristic curves: % asphalt vs voids in mix.

Filler: St. Clair Plant

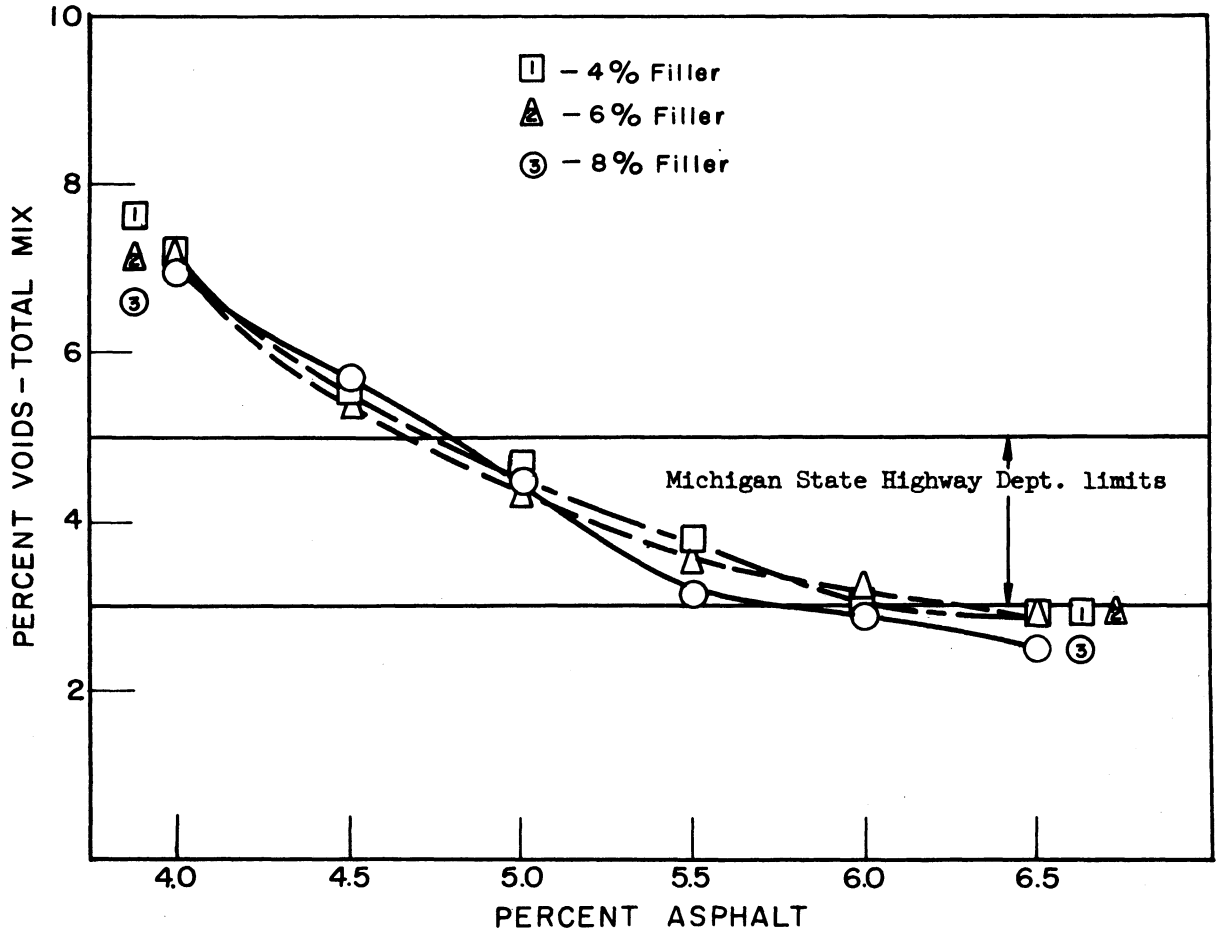

Fig. 3-C. Characteristic curves: % asphalt vs voids in mix.

Filler: Trenton Channel Plant

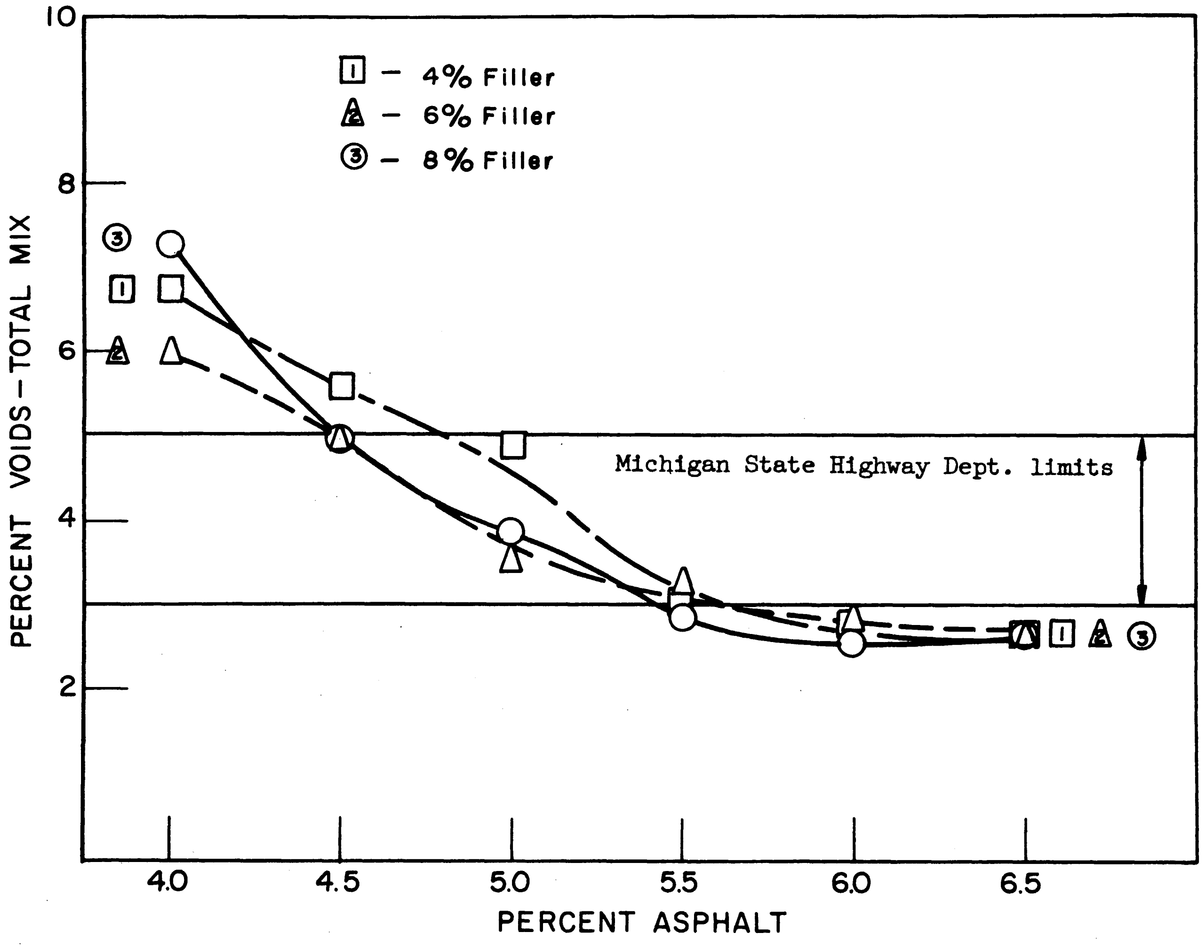

Fig. 4-C. Characteristic curves: % asphalt vs voids in mix.

Filler: Conners Creek Plant

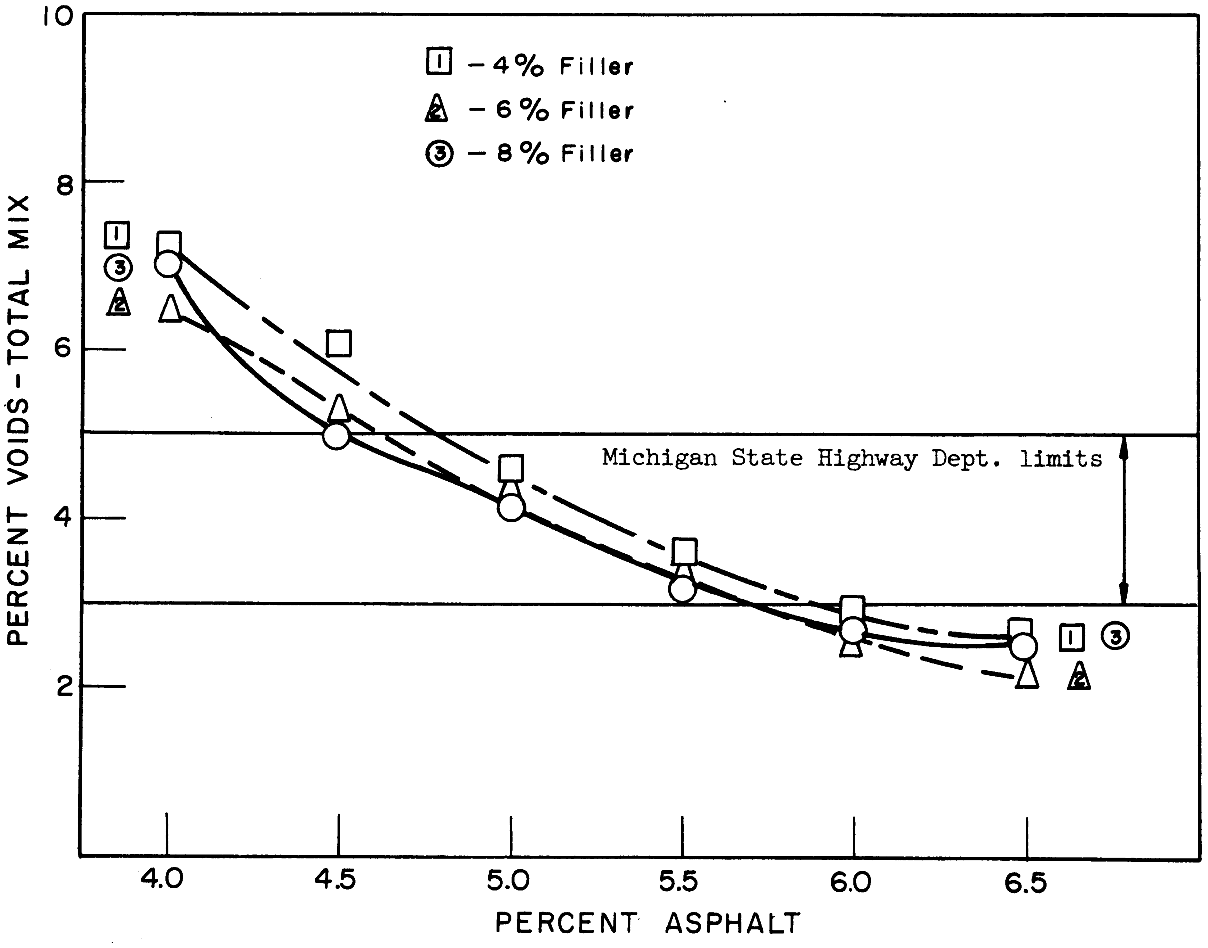

Fig. 5-C. Characteristic curves: % asphalt vs voids in mix.

Filler: Marysville Plant

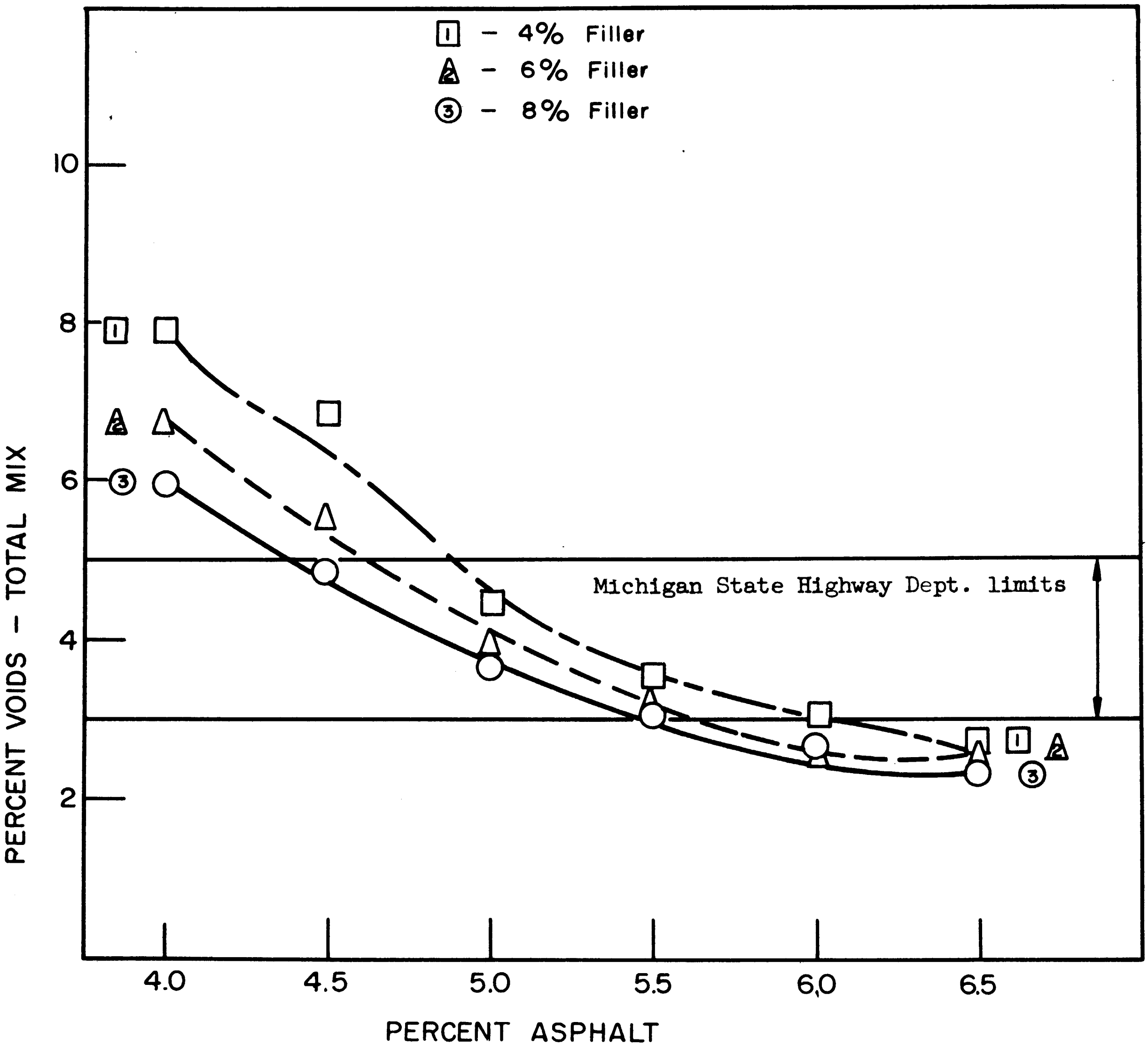

Fig. 6-C. Characteristic curves: % asphalt vs voids in mix.

Filler: Waukesha Products Co.

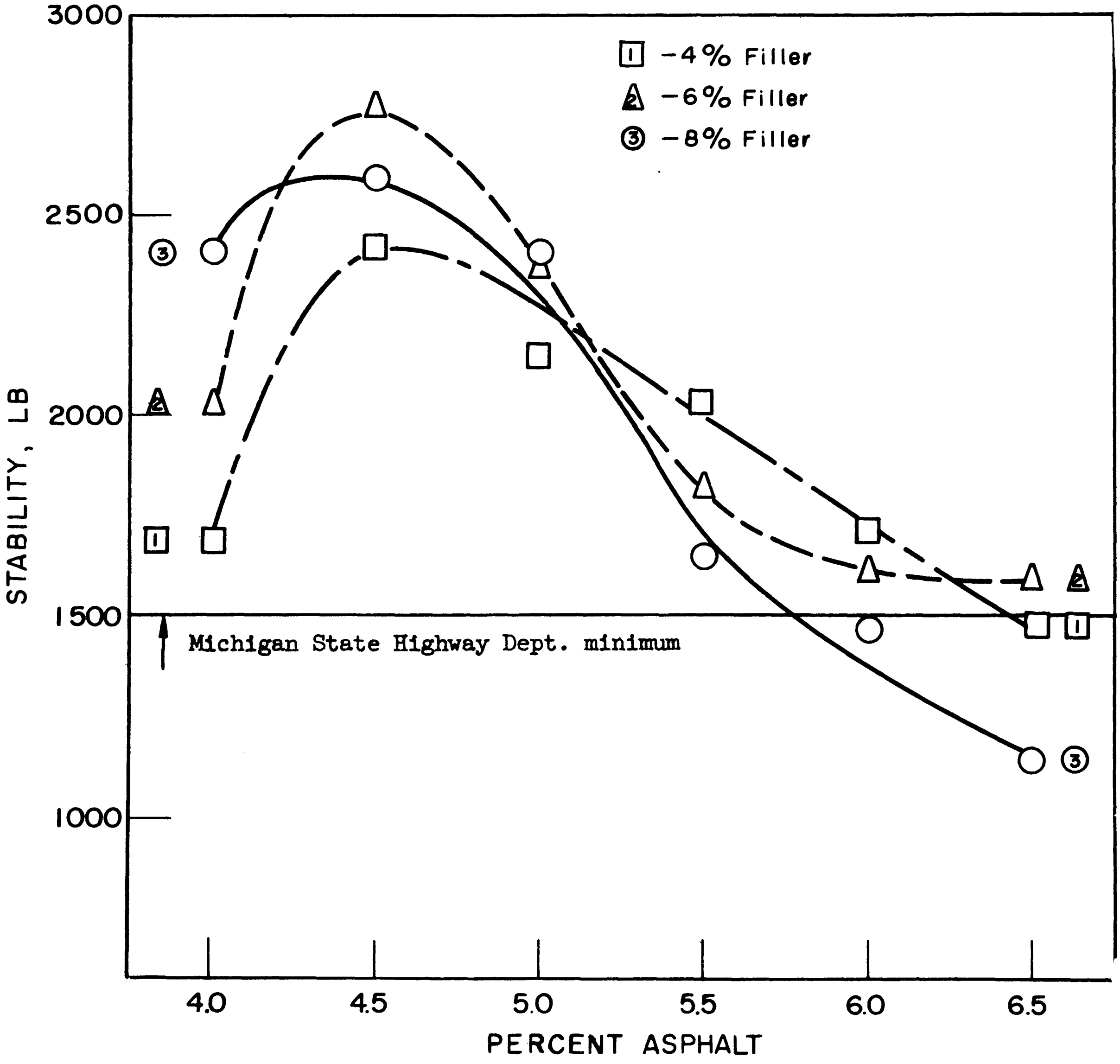

Fig. 7-C. Characteristic curves: % asphalt vs stability.

Filler: National Lime and Stone Co.

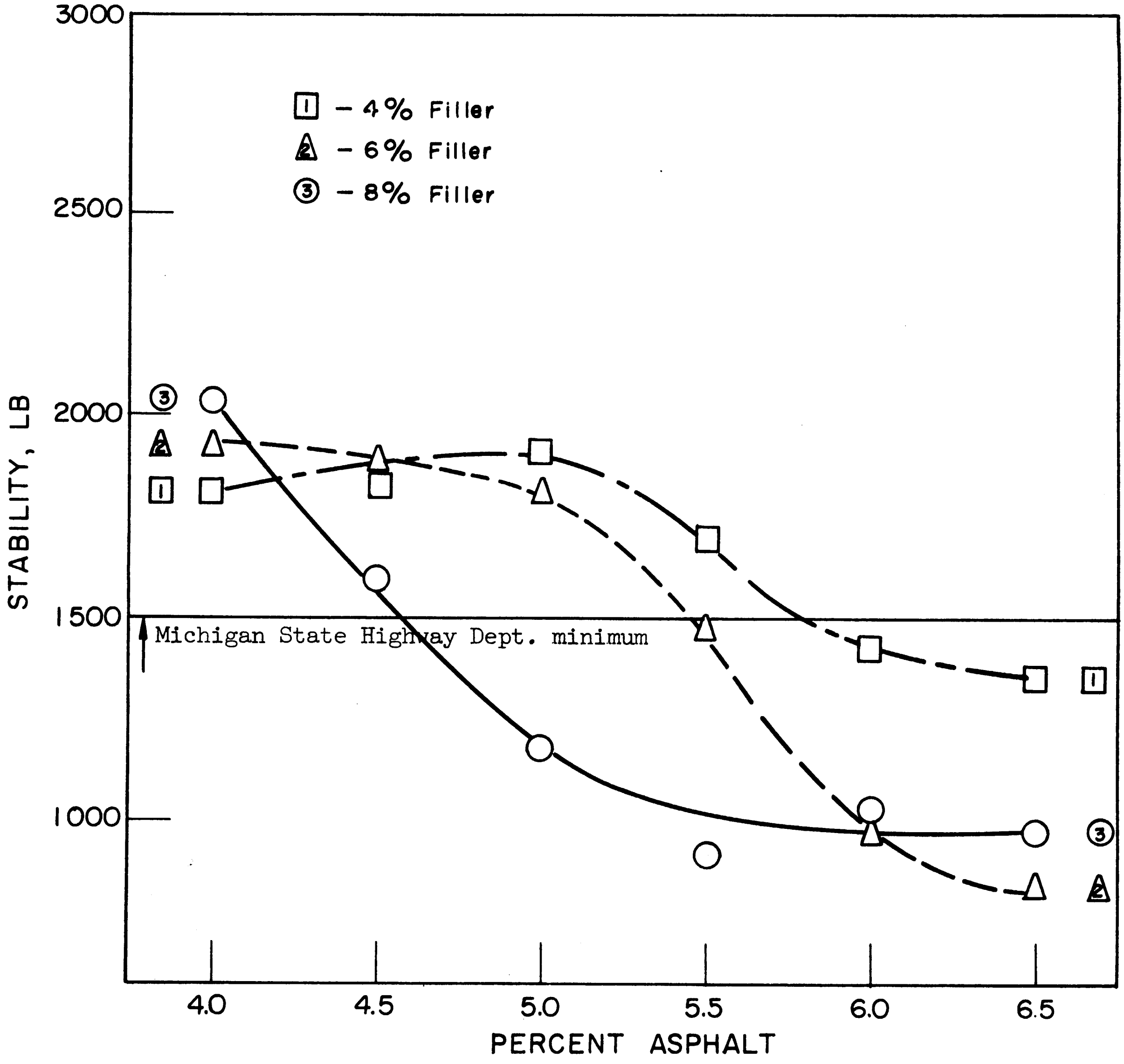

Fig. 8-C. Characteristic curves: % asphalt vs stability.

Filler: St. Clair Plant

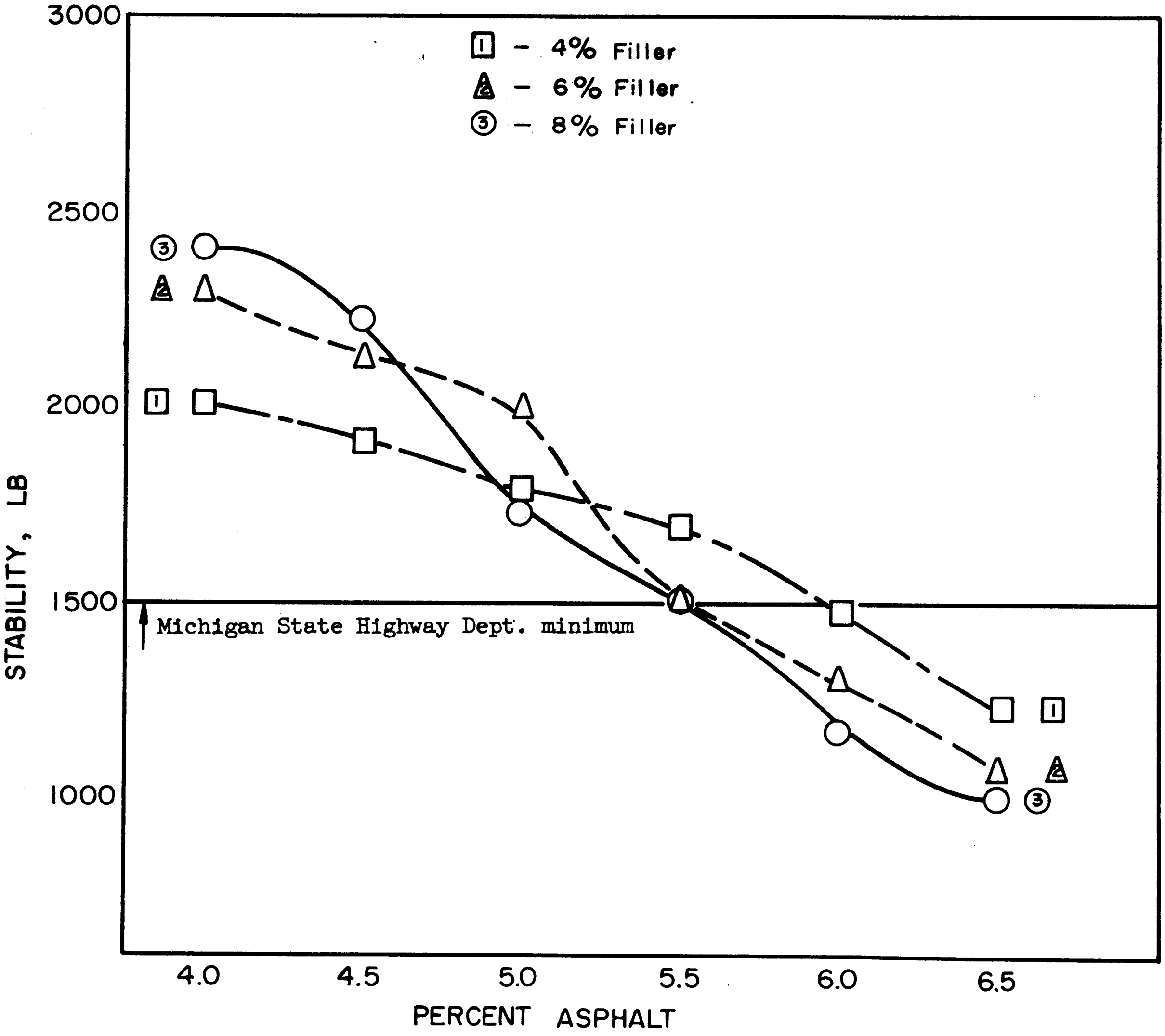

Fig. 9-C. Characteristic curves: % asphalt vs stability.

Filler: Trenton Channel Plant

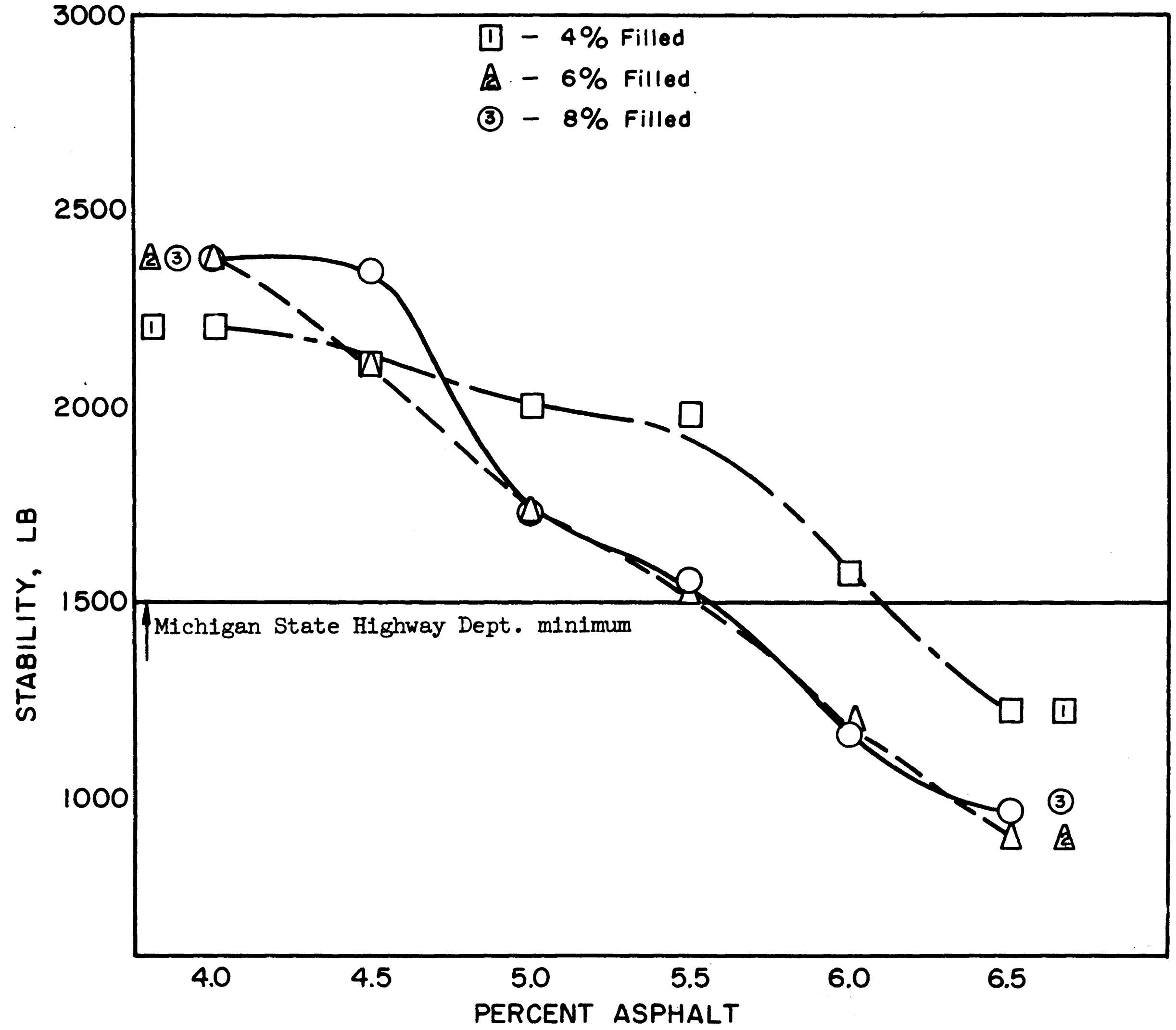

Fig. 10-C. Characteristic curves: % asphalt vs stability.

Filler: Conners Creek Plant

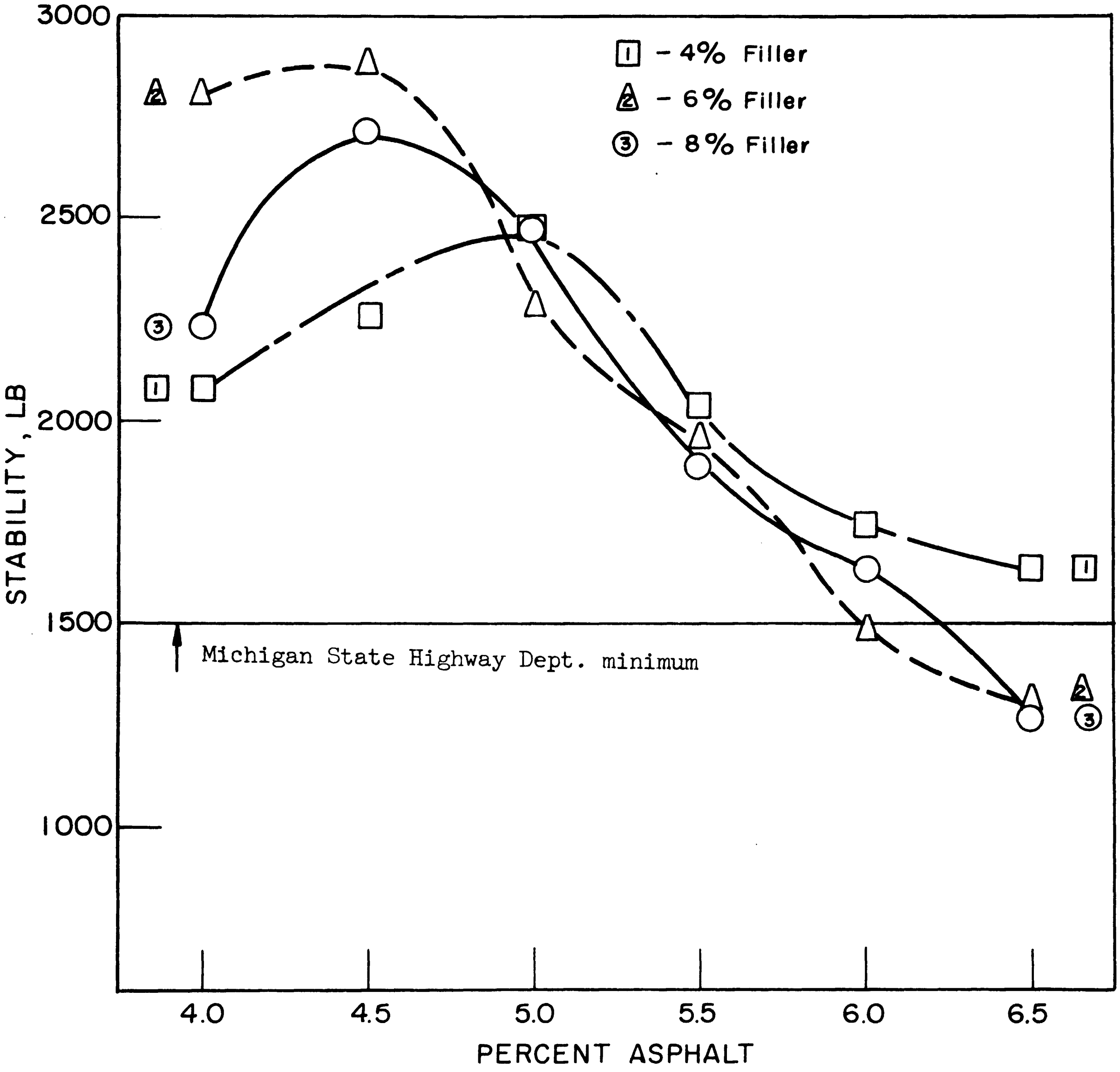

Fig. 11-C. Characteristic curves: % asphalt vs stability.

Filler: Marysville Plant

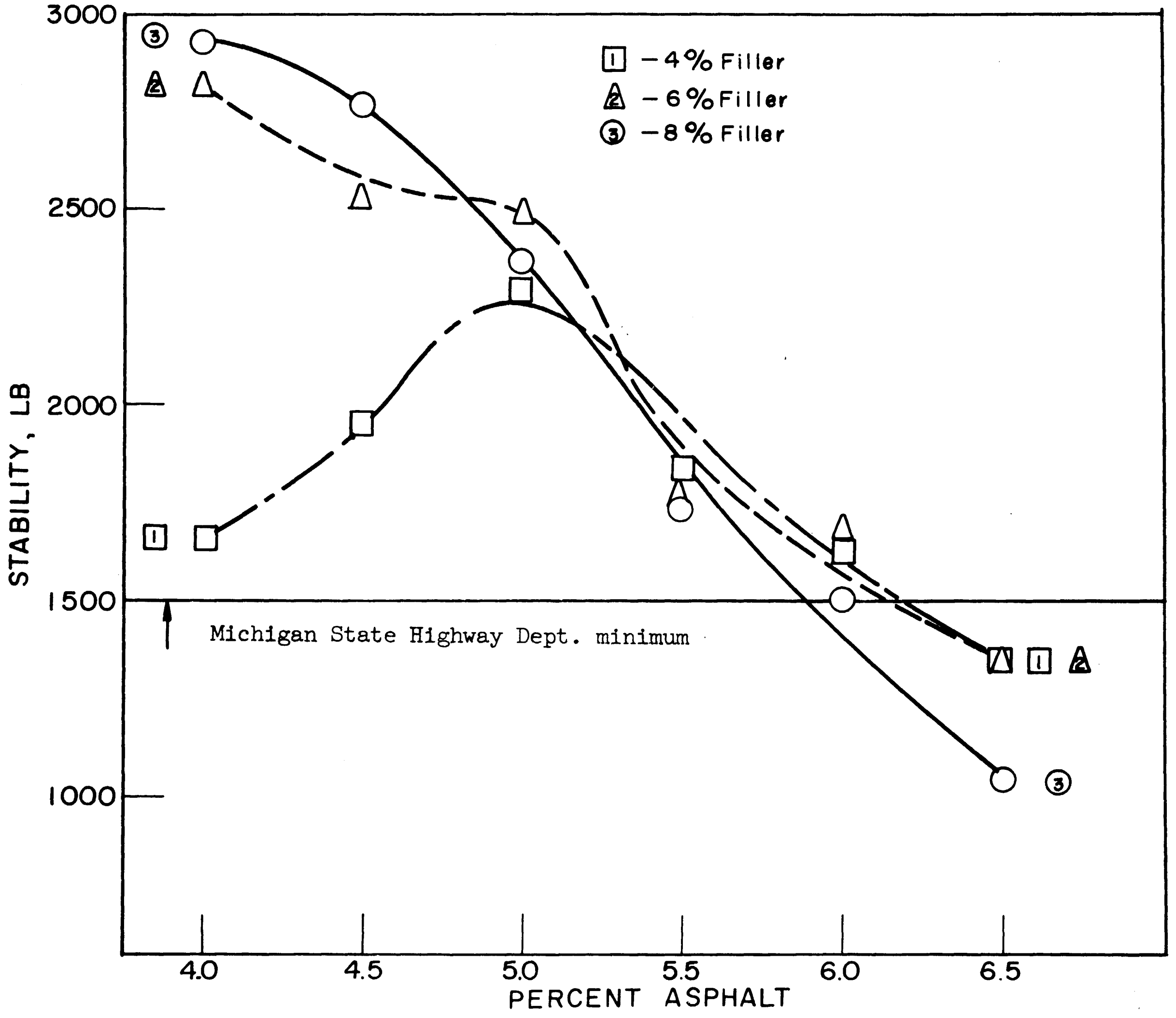

Fig. 12-C. Characteristic curves: % asphalt vs stability.

Filler: Waukesha Products Co.

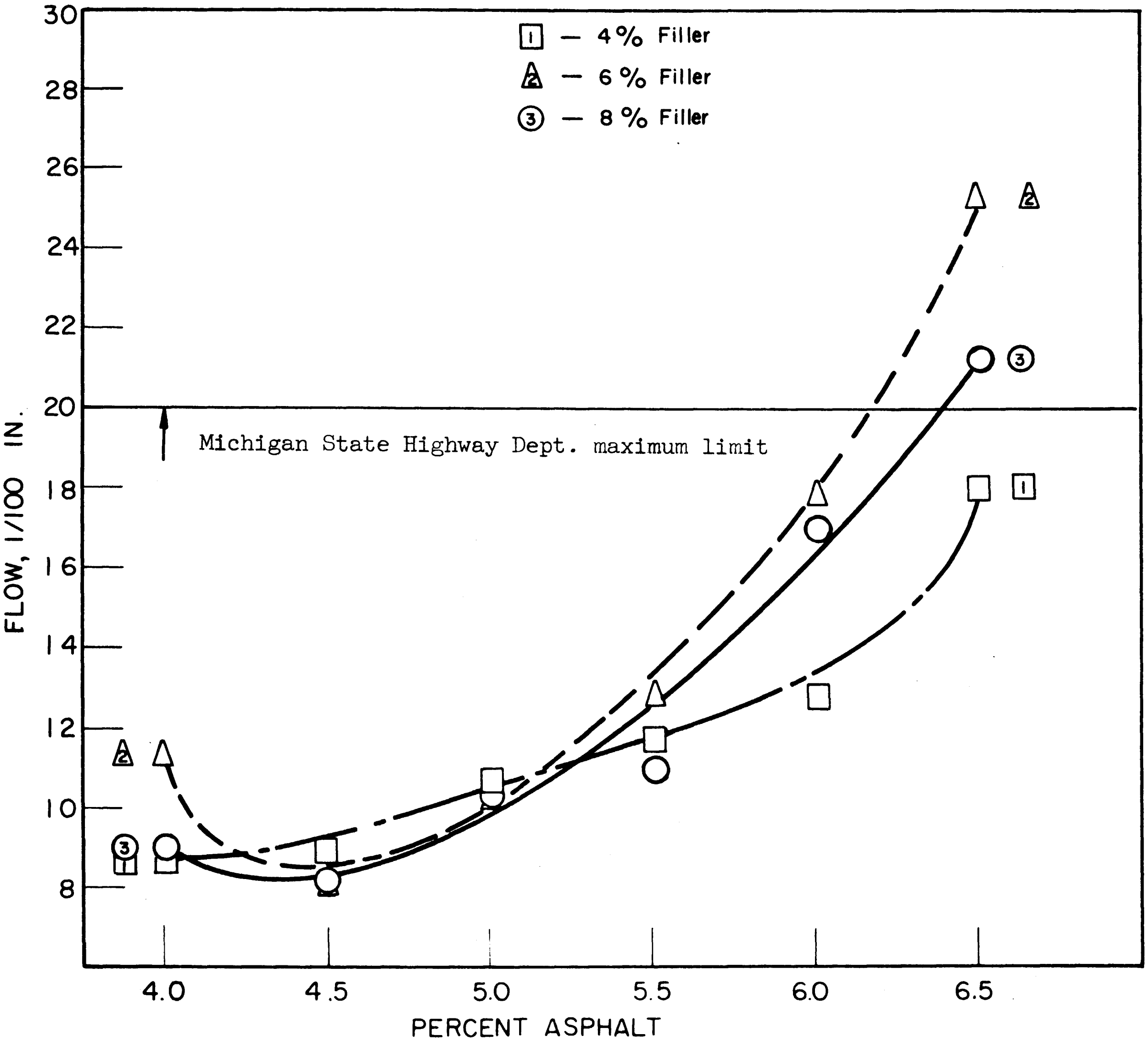

Fig. 13-C. Characteristic curves: % asphalt vs flow.

Filler: National Lime and Stone Co.

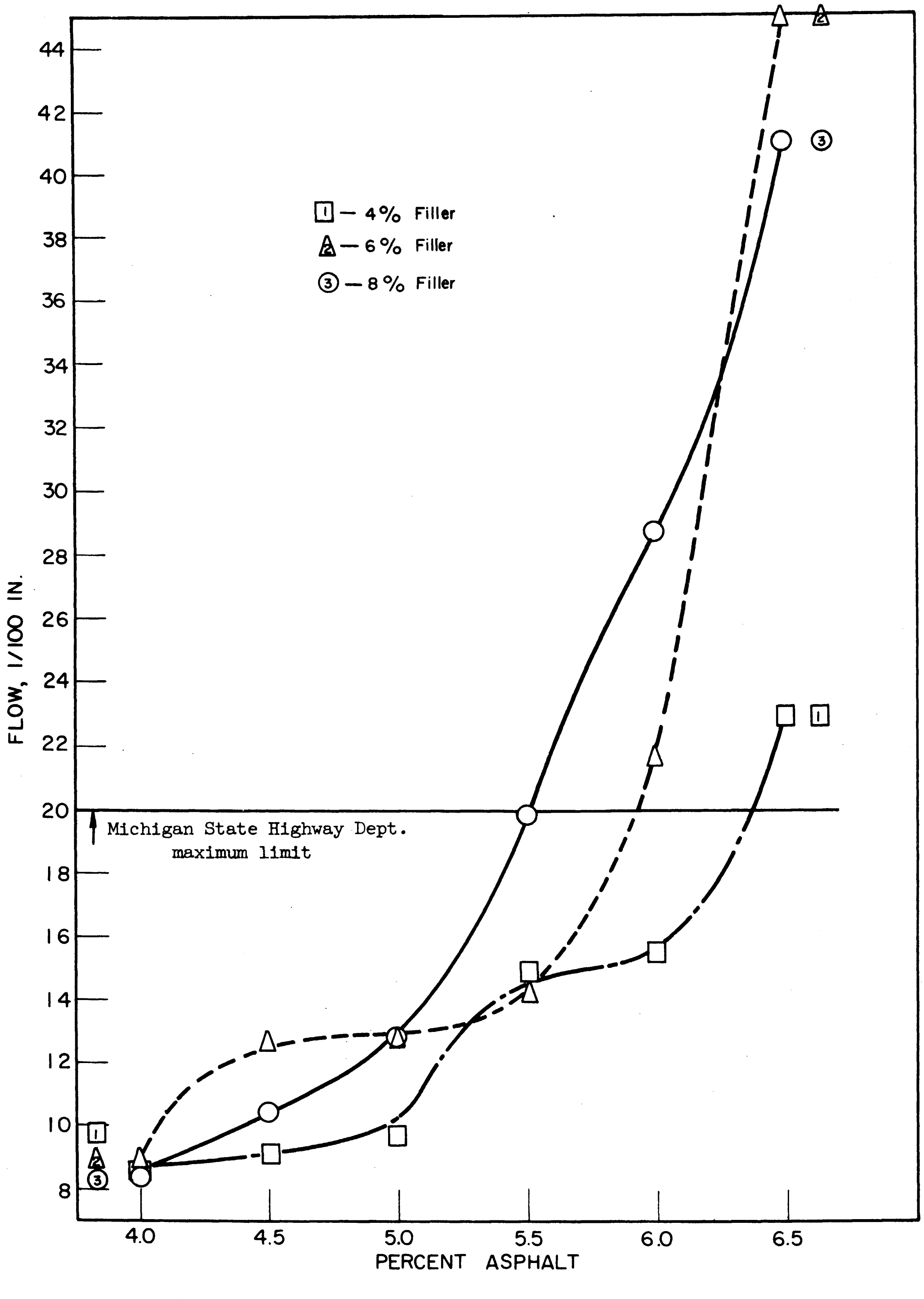

Fig. 14-C. Characteristic curves: % asphalt vs flow.

Filler: St. Clair Plant

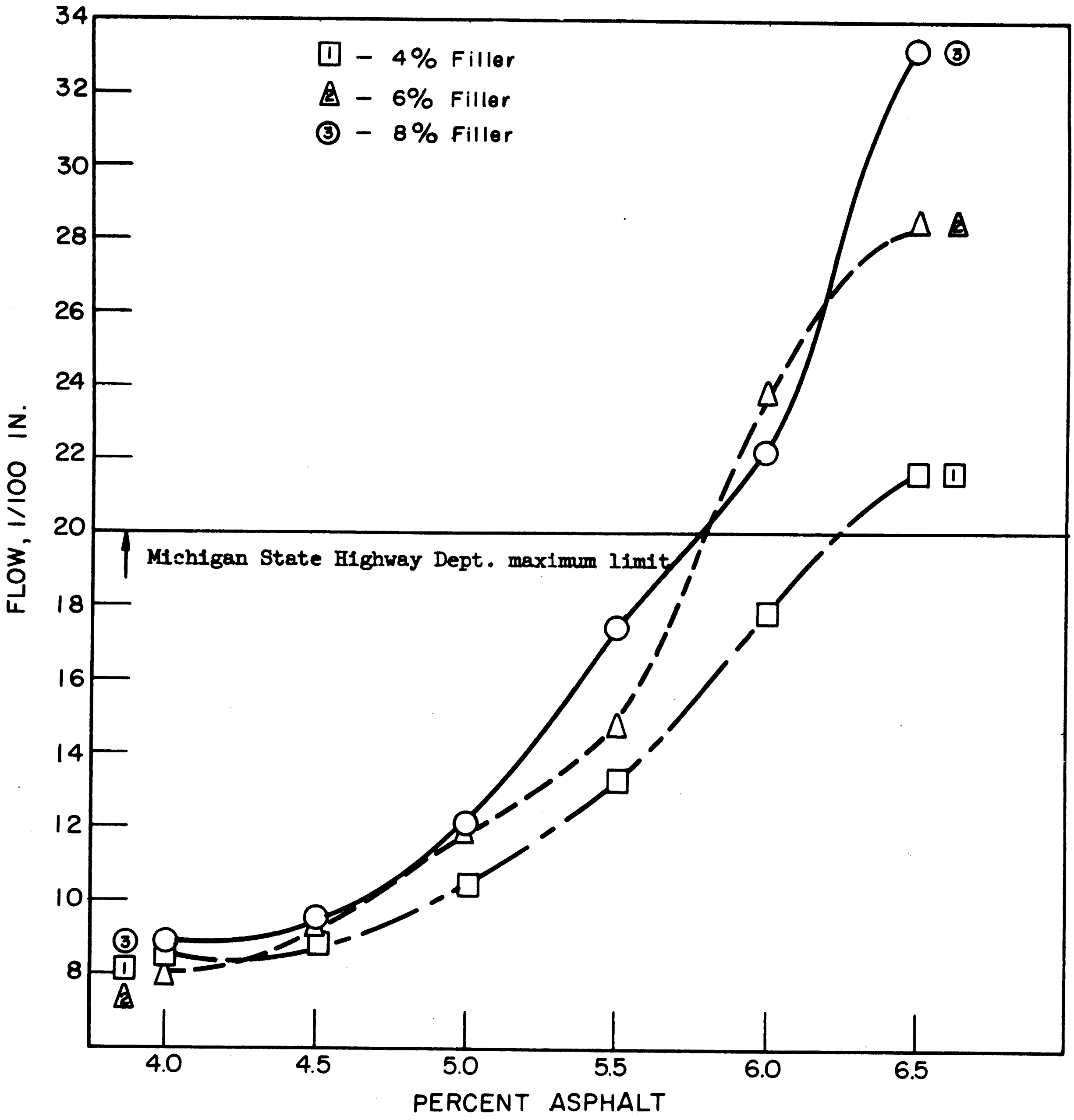

Fig. 15-C. Characteristic curves: % asphalt vs flow.

Filler: Trenton Channel Plant

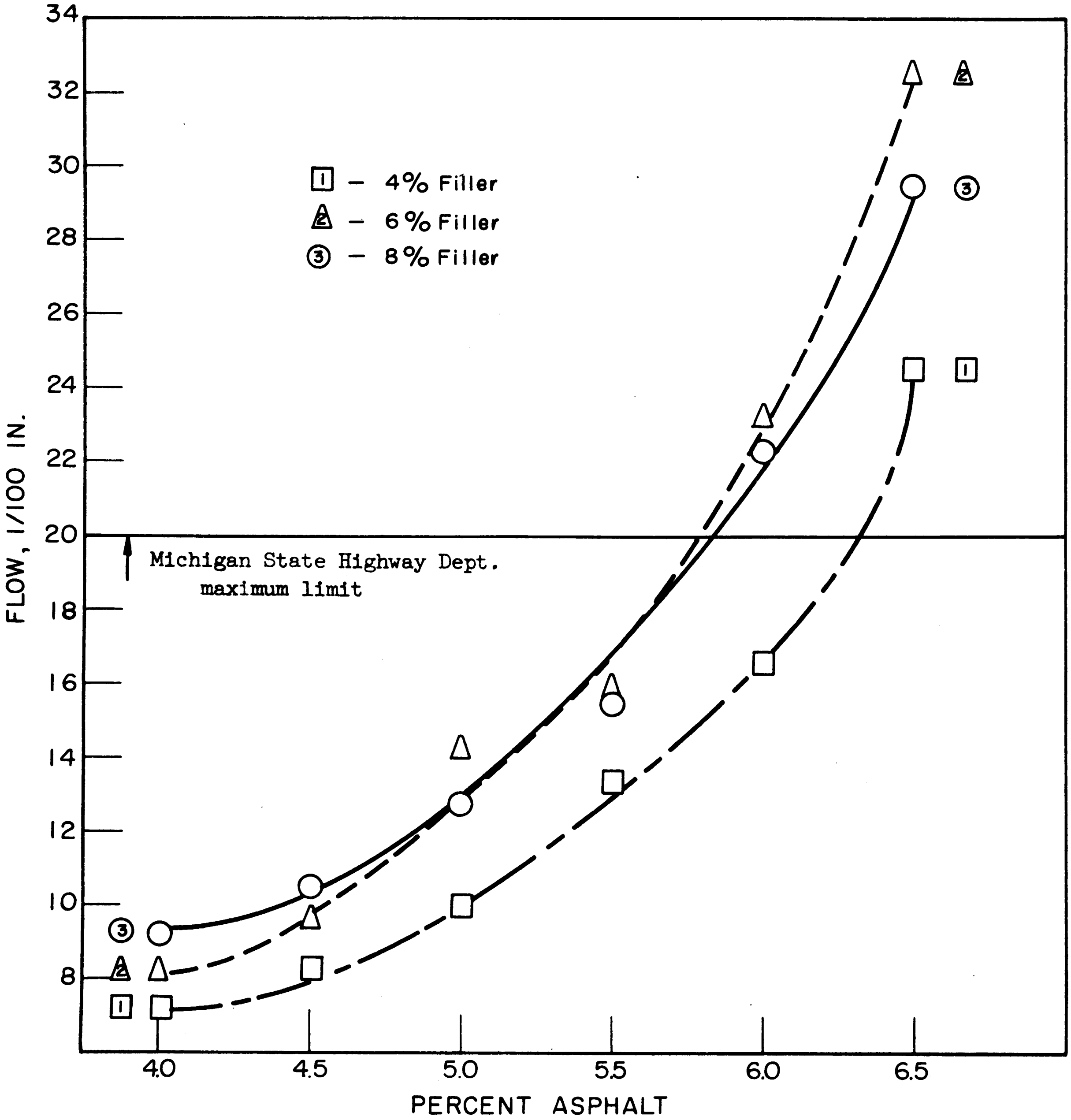

Fig. 16-C. Characteristic curves: % asphalt vs flow.

Filler: Conners Creek Plant

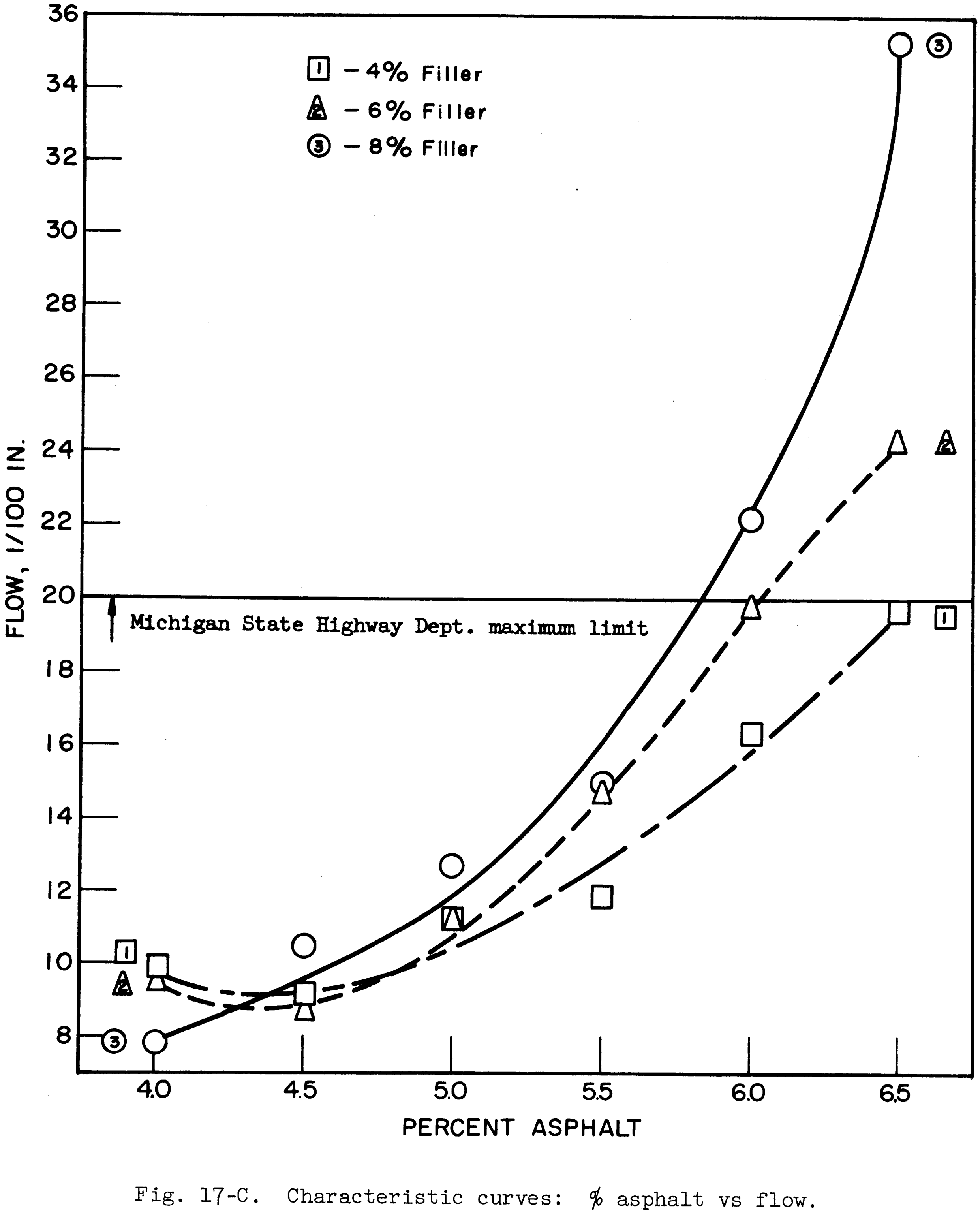

Fig. 17-C. Characteristic curves: % asphalt vs flow.

Filler: Marysville Plant

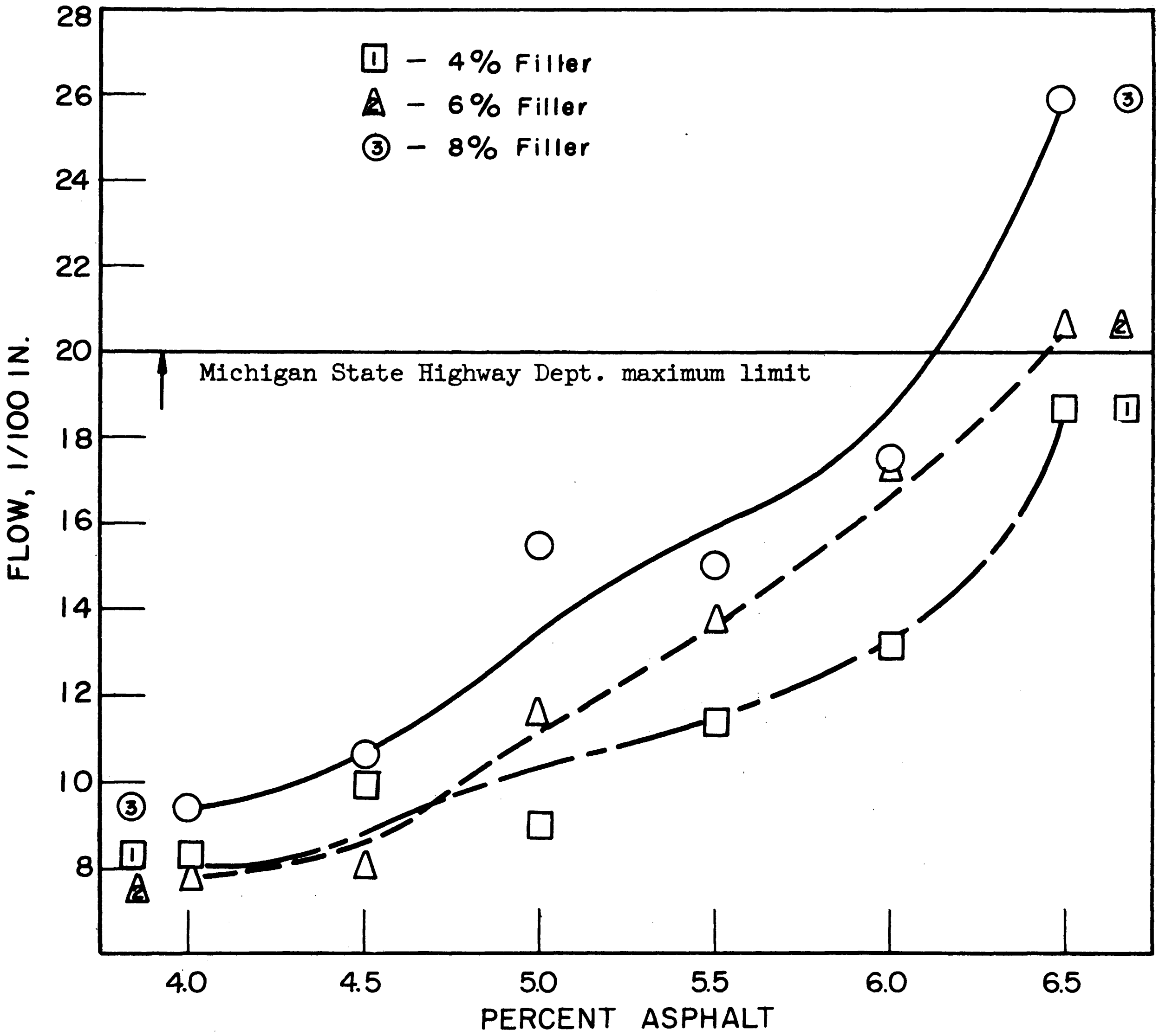

Fig. 18-C. Characteristic curves: % asphalt vs flow.

Filler: Waukesha Products Co.

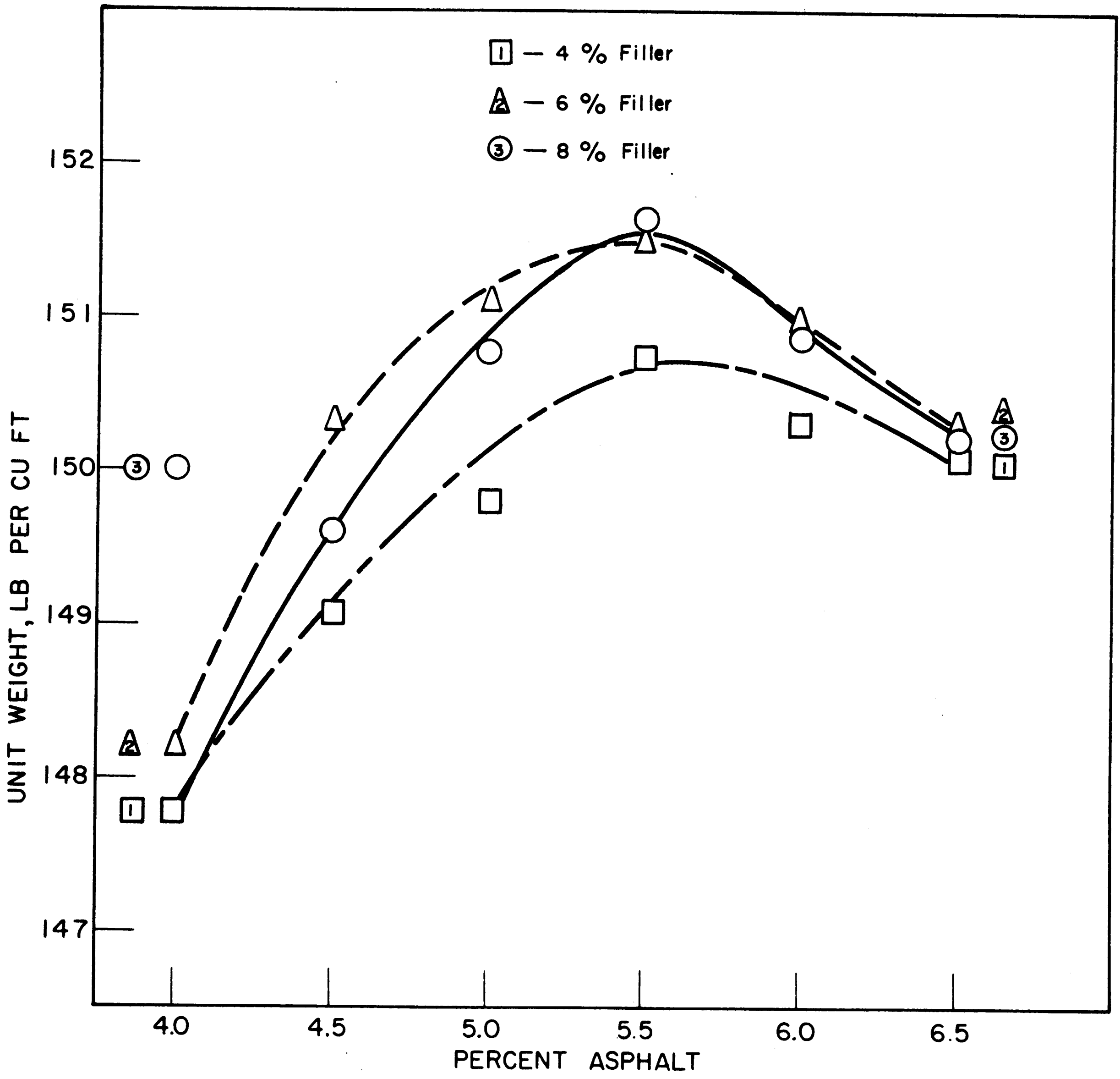

Fig. 19-C. Characteristic curves: % asphalt vs unit weight.

Filler: National Lime and Stone Co.

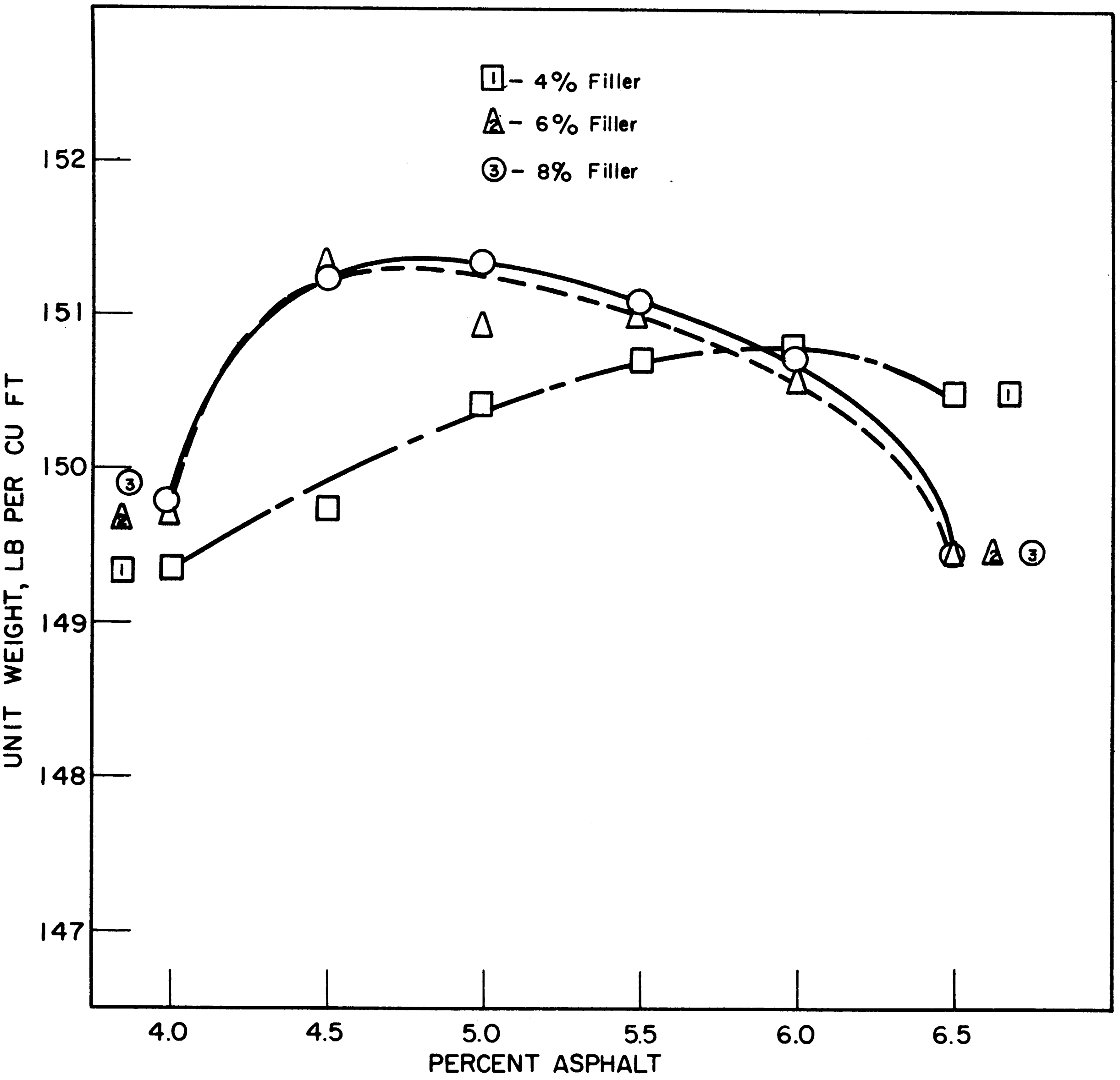

Fig. 20-C. Characteristic curves: % asphalt vs unit weight.

Filler: St. Clair Plant

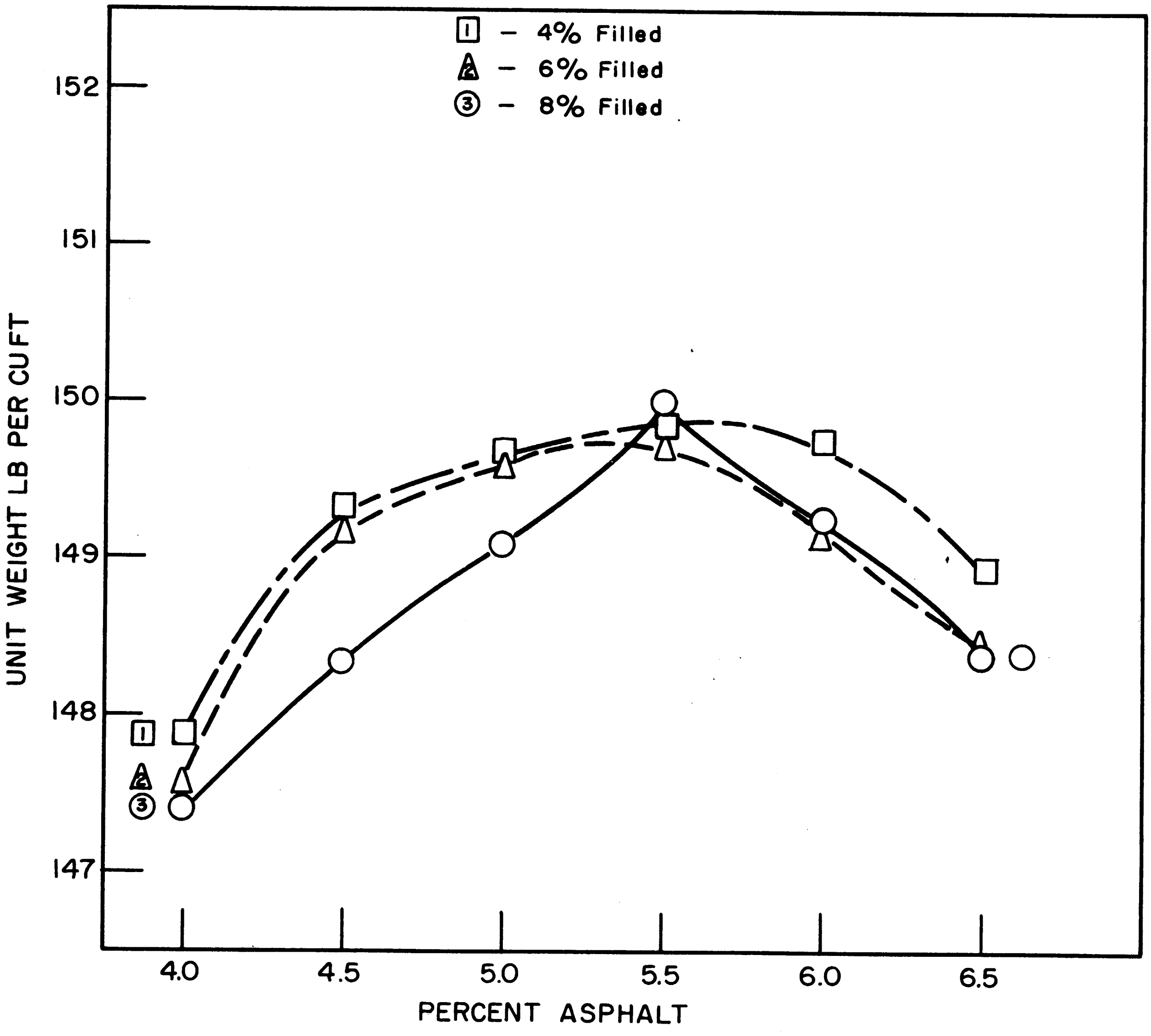

Fig. 21-C. Characteristic curves: % asphalt vs unit weight.

Filler: Trenton Channel Plant

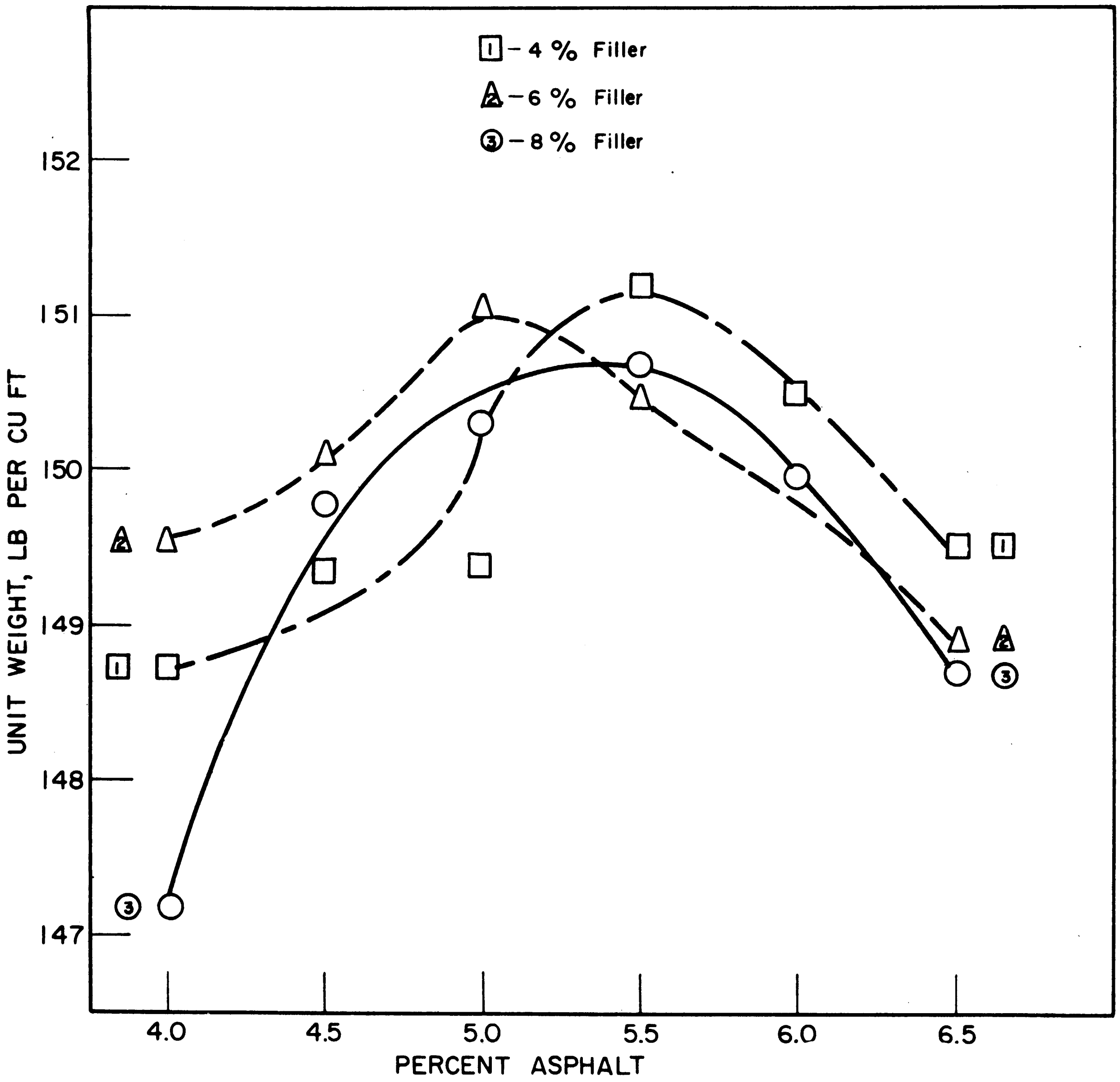

Fig. 22-C. Characteristic curves: % asphalt vs unit weight.

Filler: Conners Creek Plant

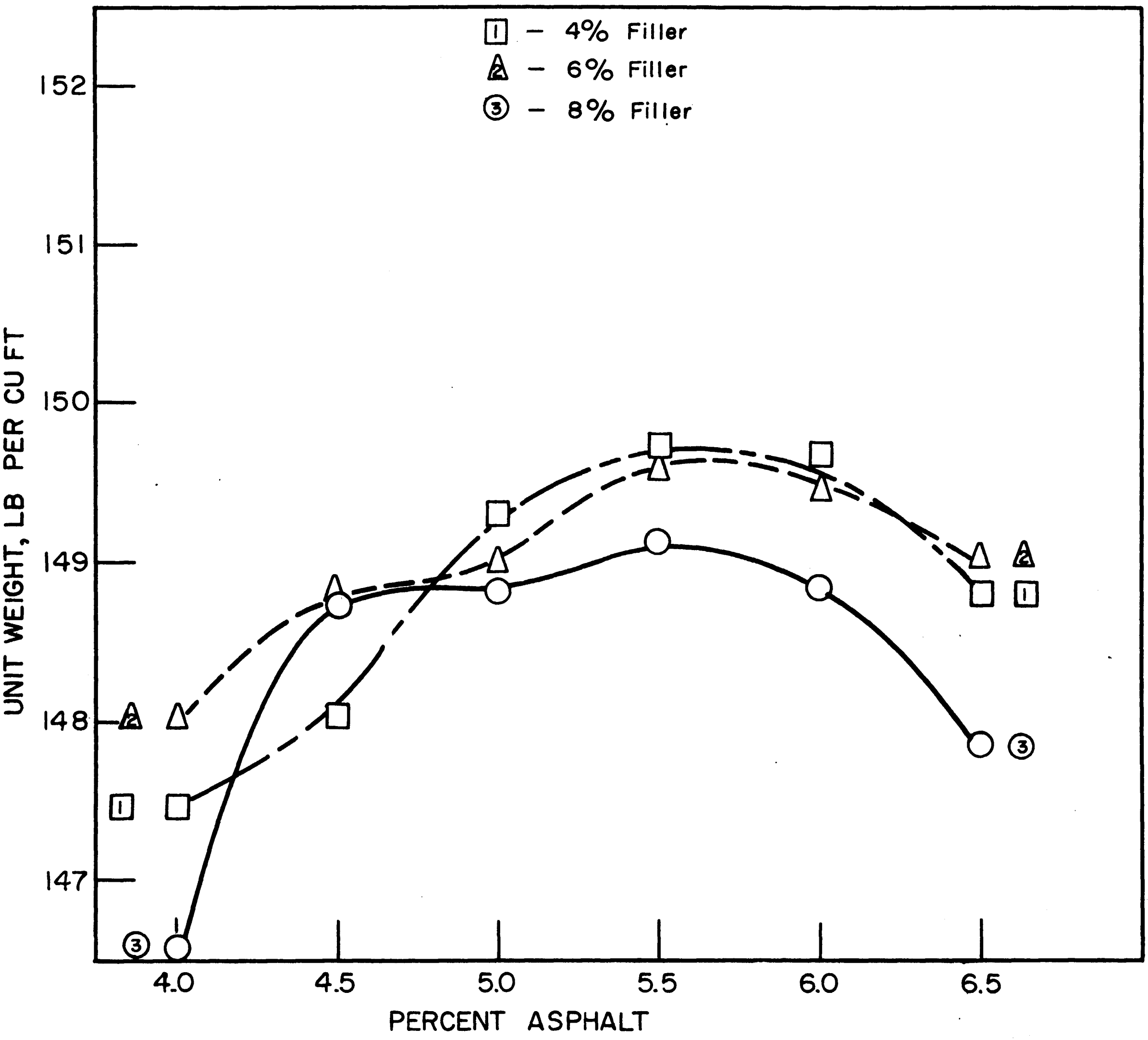

Fig. 23-C. Characteristic curves: % asphalt vs unit weight.

Filler: Marysville Plant

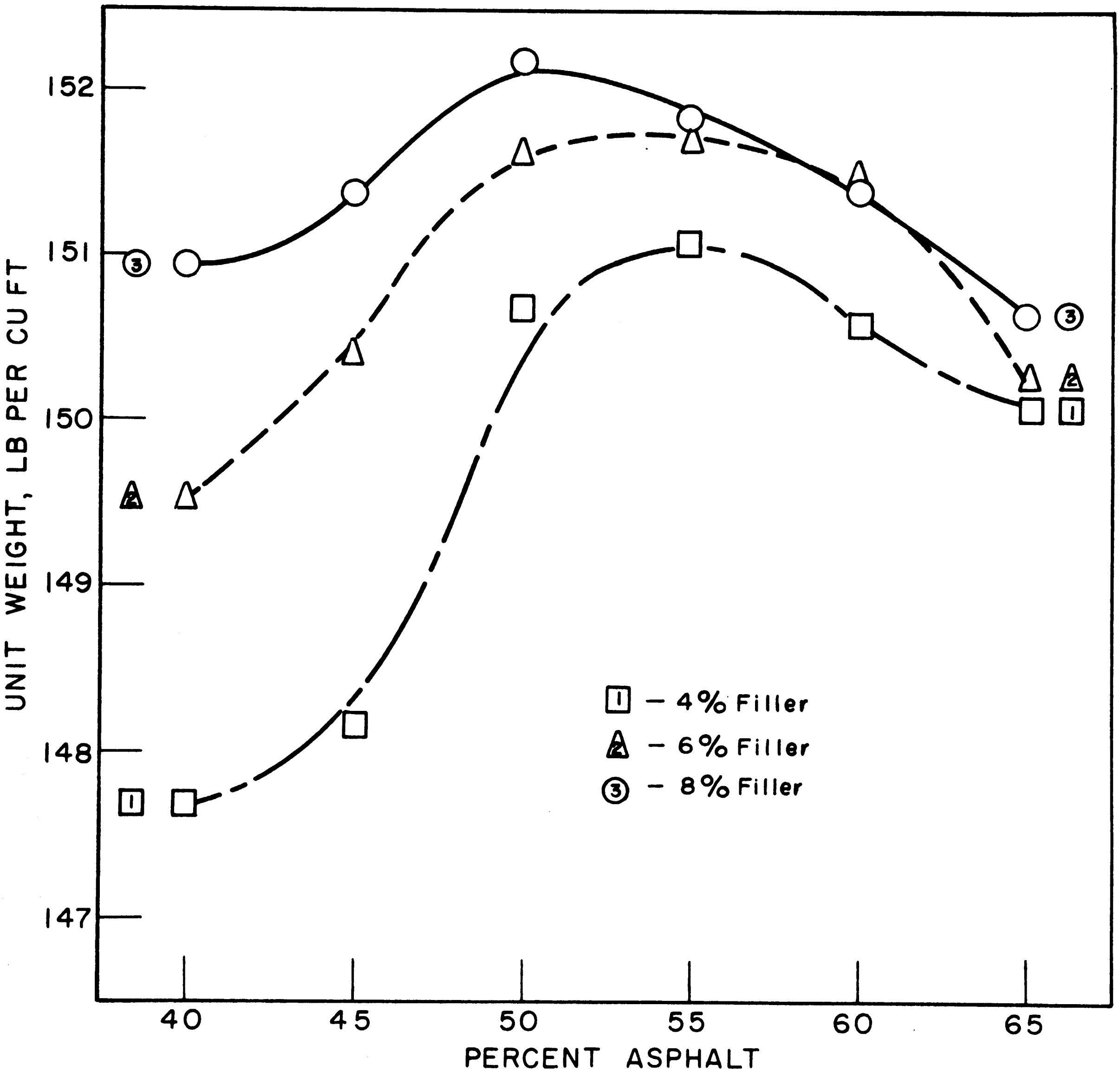

Fig. 24-C. Characteristic curves: % asphalt vs unit weight.

Filler: Waukesha Products Co.

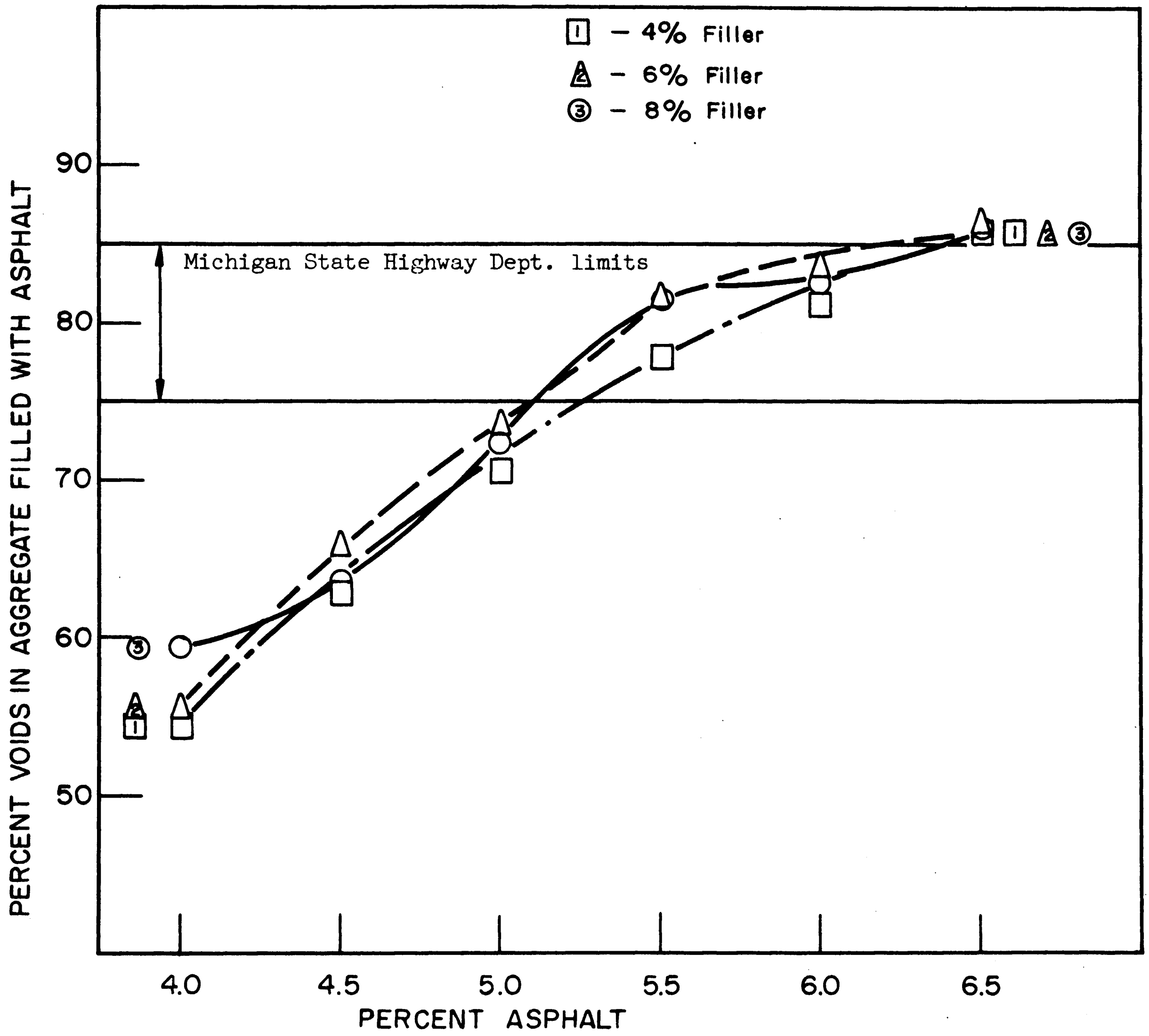

Fig. 25-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: National Lime and Stone Co.

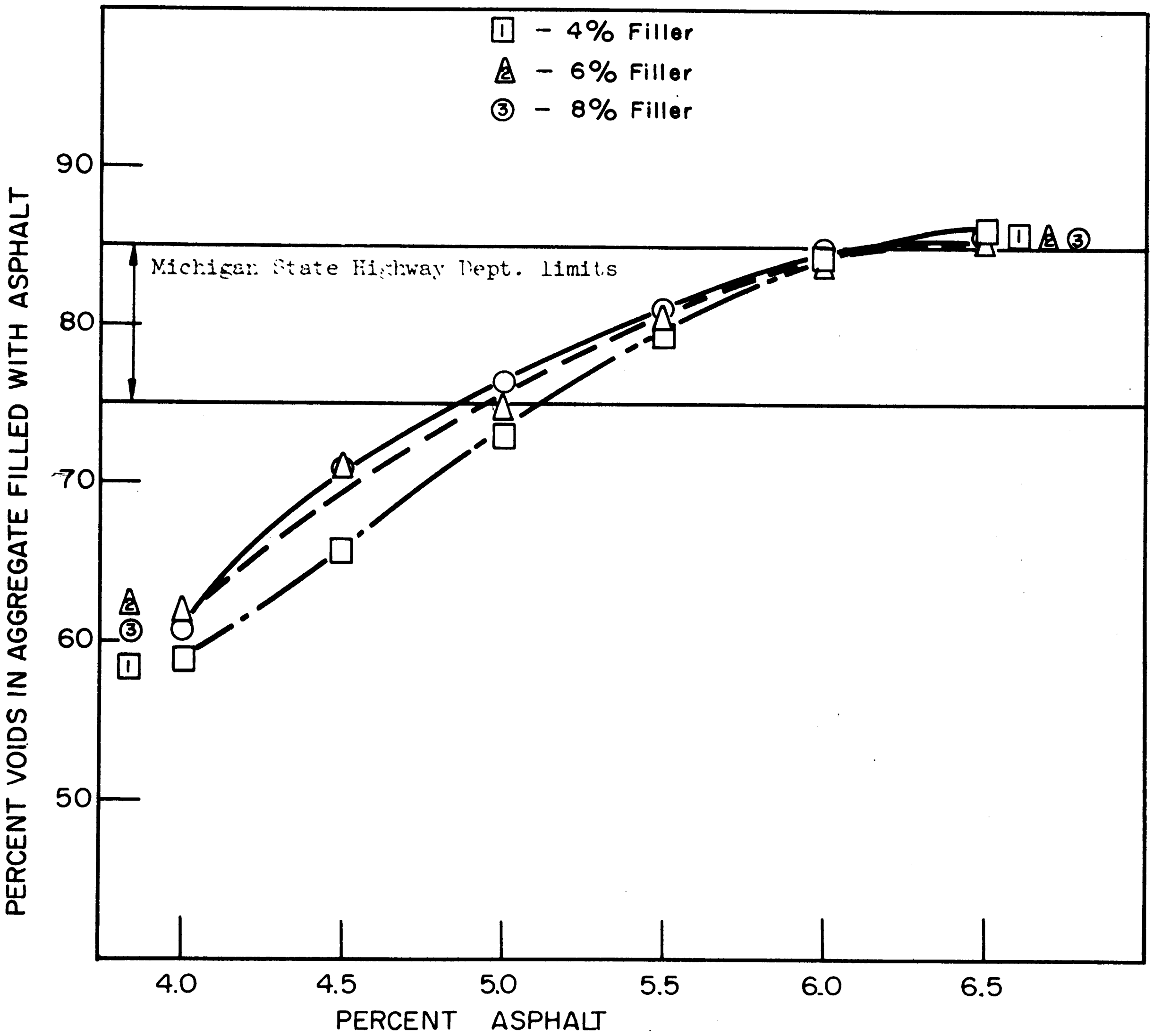

Fig. 26-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: St. Clair Plant

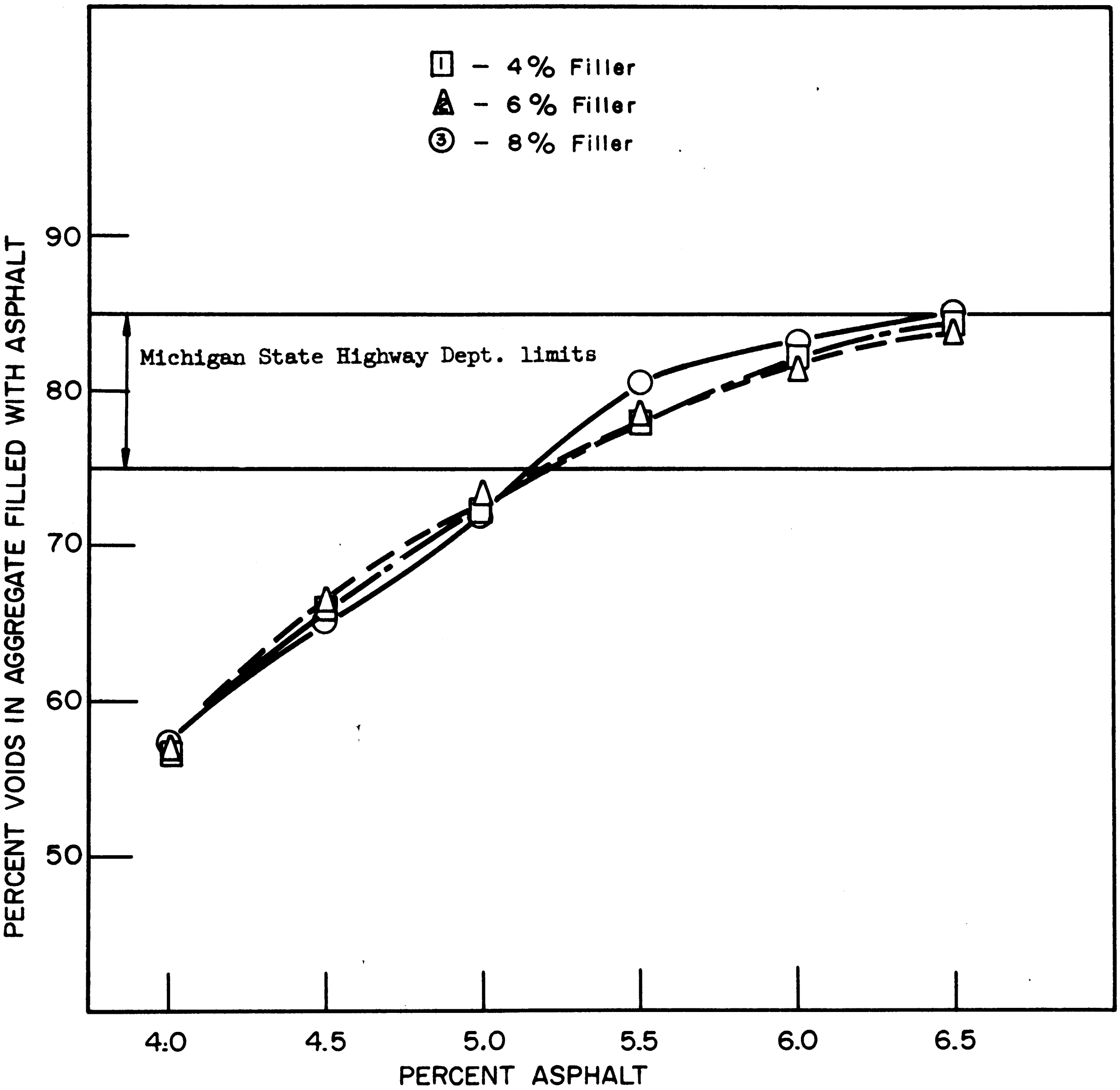

Fig. 27-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: Trenton Channel Plant

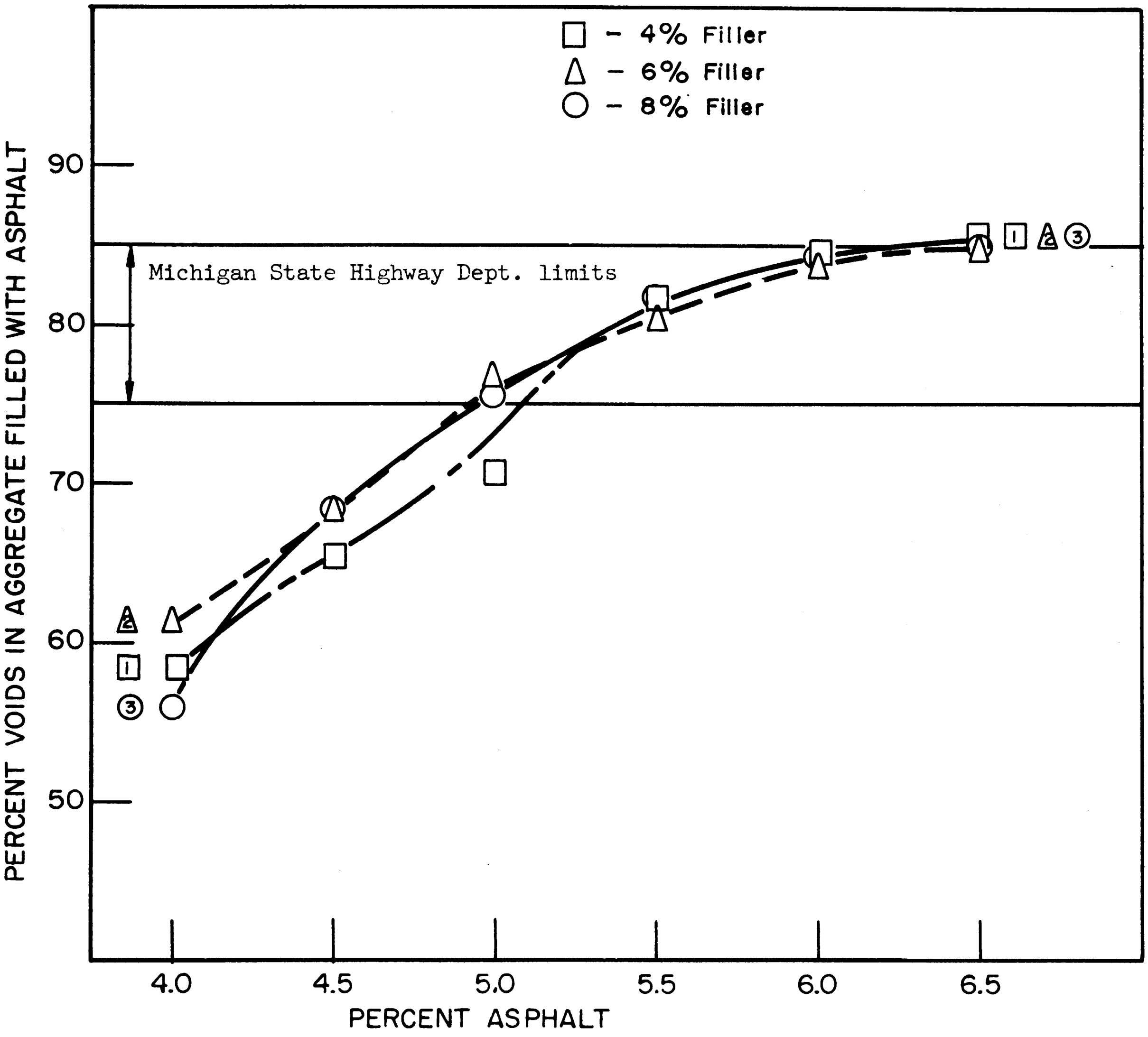

Fig. 28-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: Conners Creek Plant

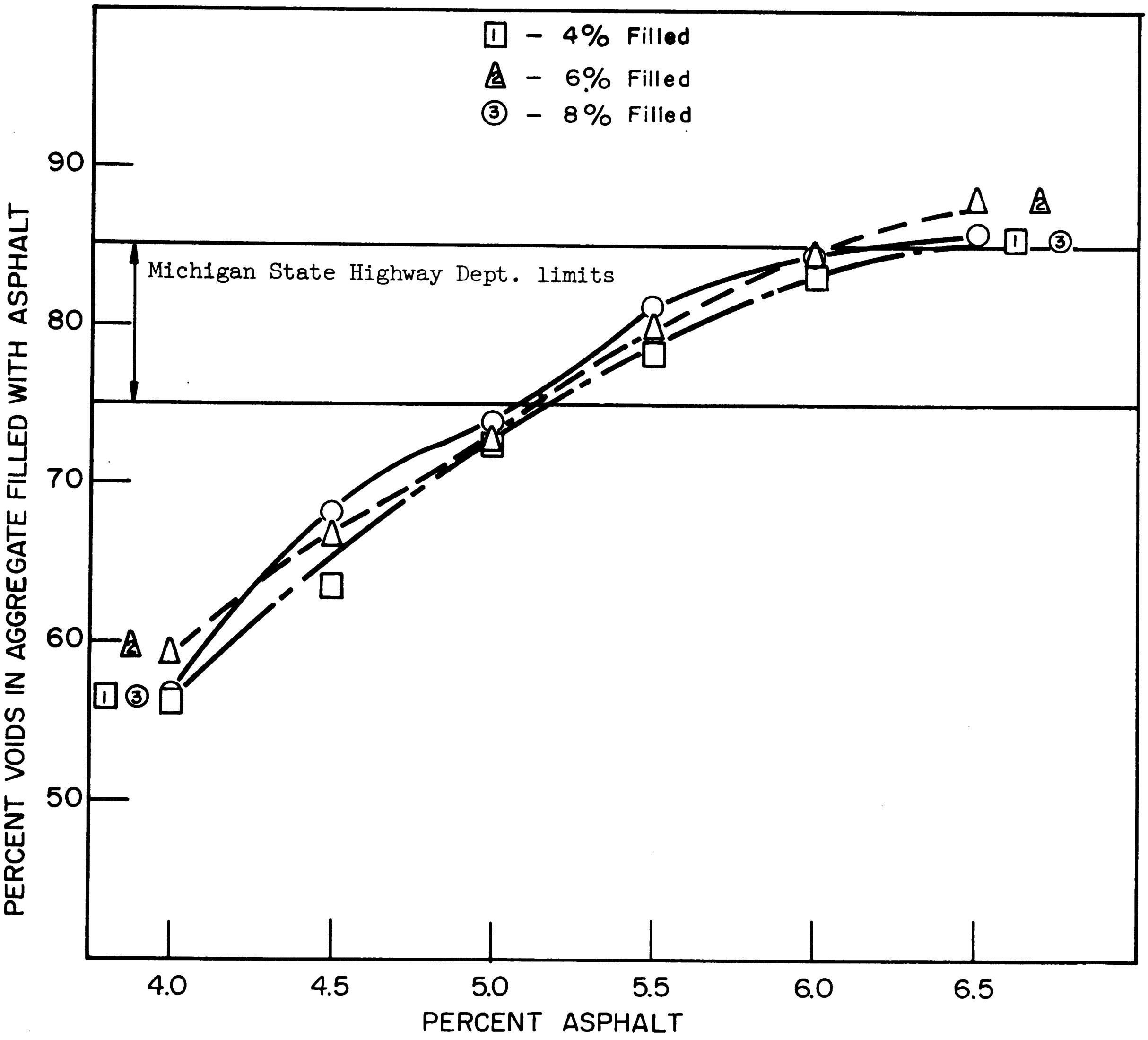

Fig. 29-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: Marysville Plant

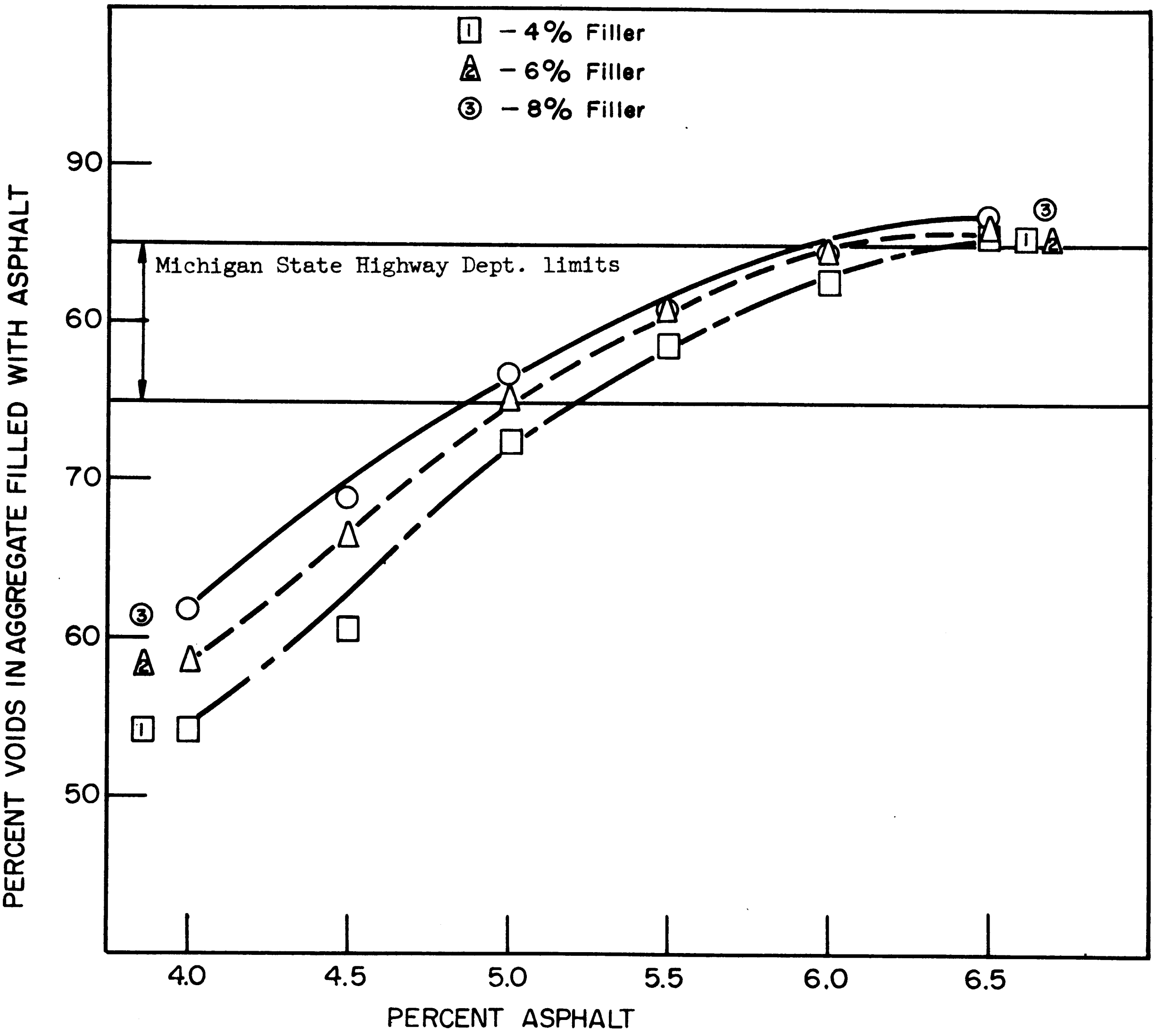

Fig. 30-C. Characteristic curves: % asphalt vs % aggregate voids filled.

Filler: Waukesha Products Co.

TABLE I-C

DATA FOR CHARACTERISTIC CURVES
Filler: National Lime and Stone Company

Mix Number	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Thickness of Specimen, in.	2.521	2.521	2.50	2.50	2.479	2.458	2.541	2.50	2.50	2.50	2.50	2.50	2.50	2.521	2.50	2.50	2.479	2.50
Specific Gravity	2.367	2.389	2.401	2.416	2.409	2.406	2.375	2.409	2.422	2.428	2.420	2.409	2.404	2.396	2.416	2.430	2.418	2.408
Unit Weight, lb/cu ft	147.72	149.07	149.82	150.76	150.32	150.13	148.22	150.34	151.12	151.53	150.99	150.30	150.00	149.51	150.78	151.65	150.87	150.24
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833	2.833
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.272	2.282	2.281	2.283	2.264	2.250	2.280	2.301	2.301	2.295	2.275	2.252	2.308	2.288	2.295	2.297	2.272	2.251
Theoretical Maximum Density of Mix	2.567	2.548	2.528	2.509	2.489	2.470	2.569	2.550	2.530	2.510	2.491	2.471	2.571	2.551	2.532	2.512	2.493	2.473
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.741	2.742	2.742	2.742	2.742	2.743	2.744	2.744	2.744	2.744	2.744	2.744	2.746	2.746	2.747	2.746	2.746	2.746
Voids in Mineral Aggregate	17.10	16.78	16.82	16.74	17.42	17.99	16.90	16.14	16.16	16.36	17.11	17.92	15.95	16.67	16.44	16.36	17.25	18.01
Voids, % — Total Mix	7.78	6.33	5.03	3.72	3.23	2.60	7.54	5.52	4.28	3.29	2.86	2.51	6.49	6.08	4.57	3.28	3.02	2.64
Total Voids Filled with Asphalt, %	54.50	62.96	70.08	77.83	81.49	85.51	55.33	65.88	73.52	80.16	83.34	85.99	59.28	63.62	72.22	80.18	82.50	85.32
Marshall Stability (corrected), lb	1685	2420	2148	2030	1698	1741	2020	2769	2369	1819	1606	1592	2410	2587	2400	1656	1468	1144
Flow: 0.01 in.	8.7	9.1	10.7	11.8	12.8	18.0	11.3	8.0	10.2	12.7	17.7	25.2	9.0	8.2	10.2	11.0	17.0	21.3

TABLE II-C

DATA FOR CHARACTERISTIC CURVES

Filler: St. Clair Plant

Mix Number	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218
Thickness of Specimen, in.	2.541	2.541	2.50	2.50	2.50	2.50	2.541	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Specific Gravity	2.393	2.399	2.411	2.415	2.416	2.403	2.399	2.425	2.419	2.420	2.413	2.395	2.400	2.424	2.425	2.421	2.415	2.395
Unit Weight, lb/cu ft	149.34	149.72	150.43	150.70	150.76	149.97	149.70	151.34	150.93	151.03	150.57	149.45	149.78	151.24	151.34	151.09	150.72	149.45
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634	2.634
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.297	2.291	2.291	2.282	2.271	2.247	2.303	2.316	2.298	2.287	2.268	2.240	2.304	2.315	2.304	2.288	2.270	2.239
Theoretical Maximum Density of Mix	2.561	2.541	2.521	2.502	2.483	2.464	2.559	2.539	2.520	2.500	2.481	2.461	2.557	2.537	2.518	2.498	2.479	2.459
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.734	2.733	2.734	2.734	2.733	2.734	2.731	2.732	2.732	2.731	2.731	2.731	2.729	2.729	2.729	2.729	2.729	2.728
Voids in Mineral Aggregate	15.97	16.16	16.20	16.53	16.90	17.80	15.66	15.23	15.90	16.26	16.94	17.99	15.56	15.18	15.56	16.15	16.81	17.91
Voids, % — Total Mix	6.53	5.58	4.31	3.48	2.70	2.46	6.28	4.48	4.02	3.19	2.74	2.68	6.13	4.47	3.68	3.07	2.90	2.60
Total Voids Filled with Asphalt, %	58.95	65.59	73.15	78.94	84.08	86.19	60.15	70.57	74.71	80.43	83.86	85.13	60.62	70.56	76.41	81.05	84.75	85.47
Marshall Stability (corrected), lb	1801	1823	1914	1686	1422	1350	1930	1867	1811	1462	974	838	2033	1586	1175	913	1028	979
Flow: 0.01 in.	8.7	9.2	9.8	14.8	15.5	23.0	8.8	12.7	12.8	14.2	21.7	44.8	8.4	10.5	12.8	19.8	28.7	41.0

TABLE III-C

DATA FOR CHARACTERISTIC CURVES
Filler: Trenton Channel Plant

Mix Number	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318
Thickness of Specimen, in.	2.552	2.531	2.541	2.511	2.50	2.511	2.542	2.552	2.511	2.50	2.521	2.542	2.563	2.521	2.521	2.521	2.521	2.532
Specific Gravity	2.370	2.393	2.398	2.402	2.399	2.387	2.365	2.391	2.398	2.399	2.390	2.379	2.362	2.377	2.389	2.404	2.392	2.382
Unit Weight, lb/cu ft	147.88	149.31	149.65	149.86	149.74	148.92	147.55	149.18	149.60	149.72	149.15	148.44	147.40	148.35	149.08	150.00	149.23	148.65
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.275	2.285	2.279	2.270	2.256	2.232	2.270	2.283	2.278	2.267	2.247	2.226	2.268	2.271	2.270	2.272	2.248	2.228
Theoretical Maximum Density of Mix	2.552	2.532	2.513	2.494	2.475	2.456	2.546	2.527	2.507	2.488	2.469	2.449	2.539	2.520	2.501	2.481	2.462	2.443
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.723	2.723	2.724	2.723	2.723	2.724	2.716	2.716	2.716	2.716	2.715	2.715	2.708	2.708	2.708	2.708	2.707	2.707
Voids in Mineral Aggregate, %	16.46	16.08	16.36	16.66	17.16	18.07	16.42	15.94	16.13	16.54	17.25	18.07	16.26	16.16	16.20	16.11	16.96	17.72
Voids, % — Total Mix	7.14	5.50	4.57	3.71	3.05	2.85	7.12	5.39	4.37	3.59	3.20	2.87	6.97	5.66	4.48	3.12	2.87	2.49
Total Voids Filled with Asphalt, %	56.68	65.81	72.07	77.85	82.31	84.28	56.63	66.30	73.02	78.35	81.54	84.16	57.15	65.04	72.42	80.70	83.12	85.96
Marshall Stability (corrected), lb	2039	1906	1789	1695	1474	1238	2287	2127	1986	1510	1313	1068	2409	2223	1738	1513	1171	1007
Flow: 0.01 in.	8.5	8.8	10.4	13.3	17.8	21.6	8.0	9.2	11.9	14.7	23.7	28.4	8.9	9.5	12.0	17.5	22.2	33.2

TABLE IV-C

DATA FOR CHARACTERISTIC CURVES

Filler: Conners Creek Plant

Mix Number	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418
Thic'ness of Specimen, in.	2.563	2.521	2.521	2.50	2.50	2.50	2.50	2.521	2.50	2.438	2.521	2.50	2.563	2.541	2.50	2.50	2.50	2.50
Specific Gravity	2.383	2.393	2.394	2.423	2.411	2.396	2.396	2.405	2.420	2.411	2.404	2.386	2.358	2.400	2.409	2.415	2.403	2.383
Unit Weight, lb/cu ft	148.70	149.34	149.37	151.17	150.47	149.49	149.53	150.07	151.03	150.45	150.03	148.87	147.16	149.76	150.30	150.67	149.95	148.68
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.47
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.288	2.286	2.274	2.289	2.267	2.240	2.301	2.297	2.300	2.278	2.260	2.231	2.264	2.292	2.288	2.282	2.259	2.228
Theoretical Maximum Density of Mix	2.554	2.534	2.515	2.496	2.477	2.458	2.549	2.530	2.510	2.491	2.472	2.452	2.544	2.524	2.505	2.486	2.467	2.447
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.726	2.726	2.726	2.726	2.725	2.726	2.720	2.720	2.720	2.719	2.719	2.719	2.713	2.713	2.714	2.713	2.713	2.713
Voids in Mineral Aggregate, %	16.07	16.15	16.58	16.02	16.82	17.83	15.42	15.53	15.45	16.21	16.87	17.96	16.55	15.53	15.69	15.88	16.73	17.88
Voids, % — Total Mix	6.73	5.55	4.82	2.94	2.65	2.54	5.99	4.94	3.57	3.21	2.74	2.70	7.30	4.91	3.84	2.87	2.59	2.63
Total Voids Filled with Asphalt, %	58.43	65.62	70.94	81.67	84.28	85.78	61.16	68.18	76.94	80.32	83.83	84.92	55.99	68.40	75.54	81.95	84.54	85.01
Marshall Stability (corrected), lb	2208	2106	1996	1978	1567	1231	2380	2108	1736	1527	1191	914	2368	2366	1731	1561	1175	970
Flow: 0.01 in.	7.2	8.2	10.0	13.4	16.6	24.5	8.2	9.6	14.3	15.8	23.2	32.5	9.2	10.5	12.8	15.5	22.3	29.5

TABLE V-C

DATA FOR CHARACTERISTIC CURVES
Filler: Marysville Plant

Mix Number	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518
Thickness of Specimen, in.	2.563	2.563	2.50	2.50	2.50	2.521	2.563	2.563	2.541	2.521	2.50	2.521	2.563	2.541	2.563	2.541	2.521	2.563
Specific Gravity	2.363	2.372	2.393	2.399	2.398	2.385	2.372	2.385	2.388	2.398	2.395	2.388	2.349	2.383	2.385	2.390	2.385	2.369
Unit Weight, lb/cu ft	147.45	148.03	149.32	149.70	149.66	148.84	148.04	148.82	148.99	149.61	149.45	149.03	146.58	148.72	148.82	149.14	148.84	147.83
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.269	2.266	2.273	2.267	2.255	2.230	2.277	2.278	2.269	2.266	2.251	2.233	2.255	2.276	2.266	2.258	2.242	2.215
Theoretical Maximum Density of Mix	2.546	2.526	2.506	2.488	2.469	2.450	2.536	2.517	2.498	2.478	2.459	2.440	2.527	2.507	2.488	2.469	2.450	2.431
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.716	2.715	2.715	2.716	2.715	2.716	2.704	2.705	2.704	2.704	2.704	2.703	2.693	2.692	2.693	2.692	2.692	2.691
Voids in Mineral Aggregate, %	16.47	16.55	16.27	16.53	16.96	17.88	15.78	15.79	16.10	16.30	16.74	17.38	16.26	15.44	15.87	16.11	16.71	17.69
Voids, % — Total Mix	7.19	6.08	4.51	3.58	2.86	2.64	6.44	5.24	4.41	3.24	2.60	2.12	7.05	4.94	4.14	3.20	2.64	2.55
Total Voids Filled with Asphalt, %	56.38	63.31	72.28	78.34	83.16	85.22	59.13	66.81	72.66	79.99	84.46	87.84	56.72	68.09	73.92	80.14	84.18	85.59
Marshall Stability (corrected), lb	2077	2250	2469	2033	1739	1637	2801	2874	2263	1955	1478	1305	2224	2713	2469	1893	1634	1269
Flow: 0.01 in.	9.7	9.0	11.2	11.8	16.3	19.7	9.5	8.8	11.2	14.7	19.7	24.3	7.8	10.5	12.7	15.0	22.2	35.3

TABLE VI-C

DATA FOR CHARACTERISTIC CURVES
Filler: Waukesha Products Company

Mix Number	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618
Thickness of Specimen, in.	2.563	2.541	2.50	2.50	2.50	2.458	2.521	2.50	2.50	2.50	2.458	2.50	2.50	2.50	2.50	2.50	2.479	2.458
Specific Gravity	2.366	2.374	2.415	2.421	2.413	2.405	2.396	2.410	2.430	2.431	2.427	2.407	2.419	2.426	2.439	2.433	2.426	2.414
Unit Weight, lb/cu ft	147.66	148.16	150.68	151.07	150.59	150.07	149.51	150.40	151.63	151.69	151.46	150.22	150.93	151.38	152.17	151.84	151.38	150.65
Stone, % by weight	57.2	56.8	56.5	56.2	55.9	55.6	55.9	55.6	55.3	55.0	54.7	54.4	54.7	54.4	54.0	53.7	53.4	53.1
Sand, % by weight	34.8	34.7	34.5	34.3	34.1	33.9	34.1	33.9	33.7	33.5	33.3	33.1	33.3	33.1	33.0	32.8	32.6	32.4
Filler, % by weight	4.0	4.0	4.0	4.0	4.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	8.0	8.0	8.0
Asphalt, % by weight	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5	4.0	4.5	5.0	5.5	6.0	6.5
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.272	2.267	2.294	2.288	2.269	2.249	2.300	2.302	2.308	2.297	2.282	2.251	2.322	2.317	2.317	2.300	2.280	2.258
Theoretical Maximum Density of Mix	2.568	2.548	2.528	2.509	2.489	2.470	2.569	2.550	2.530	2.510	2.491	2.471	2.571	2.550	2.531	2.511	2.492	2.472
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.742	2.742	2.742	2.742	2.742	2.743	2.744	2.744	2.744	2.744	2.744	2.744	2.745	2.745	2.746	2.746	2.745	2.745
Voids in Mineral Aggregate, %	17.15	17.31	16.34	16.56	17.26	18.02	16.18	16.11	15.88	16.28	16.85	17.98	15.42	15.59	15.63	16.25	16.93	17.76
Voids, % — Total Mix	7.85	6.82	4.48	3.51	3.04	2.63	6.73	5.48	3.95	3.15	2.56	2.58	5.92	4.86	3.64	3.10	2.65	2.33
Total Voids Filled with Asphalt, %	54.23	60.63	72.57	78.85	82.42	85.40	58.32	66.06	75.17	80.71	84.87	85.67	61.60	68.79	76.67	80.96	84.38	86.86
Marshall Stability (corrected), lb	1651	1949	2297	1839	1631	1358	2807	2516	2497	1758	1674	1350	2933	2766	2372	1739	1504	1055
Flow: 0.01 in.	8.2	10.0	9.0	11.3	13.2	18.7	7.8	7.9	11.5	13.7	17.4	20.6	9.4	10.6	15.5	15.0	17.5	25.9

APPENDIX D

DATA FROM IMMERSION-COMPRESSION TESTS

TABLE I-D

MIX PROPORTIONS AND TEST RESULTS OF WATER-IMMERSION TESTS

Specifications	Filler																	
	National Lime and Stone Co.			St. Clair Plant			Trenton Channel Plant			Conners Creek Plant			Marysville Plant			Waukesha Products Co.		
Mix Number	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Thickness of Specimen, in.	4.50	4.479	4.479	4.479	4.458	4.375	4.458	4.479	4.479	4.50	4.50	4.50	4.50	4.50	4.50	4.479	4.50	4.50
Specific Gravity	2.359	2.354	2.354	2.368	2.372	2.374	2.360	2.358	2.356	2.363	2.363	2.364	2.355	2.364	2.357	2.370	2.369	2.362
Unit Weight, lb/cu ft	147.16	146.89	146.77	147.74	147.99	148.12	147.28	147.14	147.01	147.47	147.43	147.50	146.95	147.51	146.60	147.89	147.85	147.53
Stone, % by weight	55.2	55.2	55.2	55.3	55.3	55.3	55.2	55.2	55.2	55.4	55.4	55.4	55.2	55.2	55.2	55.3	55.3	55.3
Sand, % by weight	33.7	33.7	33.7	33.8	33.8	33.8	33.6	33.6	33.6	33.8	33.8	33.8	33.7	33.7	33.7	33.7	33.7	33.7
Filler, % by weight	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Asphalt, % by weight	5.1	5.1	5.1	4.9	4.9	4.9	5.2	5.2	5.2	4.8	4.8	4.8	5.1	5.1	5.1	5.0	5.0	5.0
Specific Gravity (apparent)																		
Stone	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766	2.766
Sand	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694	2.694
Filler	2.833	2.833	2.833	2.634	2.634	2.634	2.42	2.42	2.42	2.47	2.47	2.47	2.28	2.28	2.28	2.83	2.83	2.83
Asphalt	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
Specific Gravity Compacted Aggregate	2.319	2.234	2.234	2.252	2.255	2.258	2.238	2.235	2.234	2.250	2.249	2.250	2.235	2.243	2.237	2.252	2.251	2.246
Theoretical Maximum Density of Mix	2.525	2.525	2.525	2.523	2.523	2.523	2.499	2.499	2.499	2.517	2.517	2.517	2.493	2.493	2.493	2.530	2.530	2.530
Theoretical Maximum Density of Total Mineral Aggregate, Void Free	2.744	2.744	2.744	2.731	2.731	2.731	2.716	2.716	2.716	2.719	2.719	2.719	2.704	2.704	2.704	2.744	2.744	2.744
Voids in Mineral Aggregate, %	15.48	18.60	18.60	17.55	17.42	17.33	17.61	17.70	17.76	17.25	17.28	17.24	17.36	17.04	17.27	17.94	17.95	18.14
Voids, % — Total Mix	6.56	6.74	6.79	6.15	6.00	5.92	5.55	5.64	5.72	6.11	6.13	6.09	5.54	5.18	5.45	6.32	6.35	6.55
Total Voids Filled with Asphalt, %	64.33	63.52	63.48	64.94	65.91	65.85	68.48	68.11	67.79	64.61	64.50	64.65	68.06	69.59	68.46	64.80	64.71	63.95
Water Immersion: Dry Strength, psi	349			328			355			339			375			292		
Water Immersion: 4-Day Immersion, psi		365			323			379			342			366			299	
Water Immersion: 14-Day Immersion, psi			335.7			327			367			300			359			277
Retained Strength, %		104.6	96.2		98.4	99.7		106.7	103.4		100.8	88.5		97.7	95.8		102.4	94.9