final

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report

SERVICE CORRELATION

OF THE

TRAFFIC SIMULATOR

by

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Bituminous Research Laboratory

Iowa Highway Research Board Project H.R. 100
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March, 1967

Iowa State University

Ames, Iowa

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A study was undertaken by the Bituminous Research Laboratory of the Engineering Research Institute at Iowa State University, under the sponsorship of the Iowa Highway Research Board, project HR 100, to ascertain the effects of a number of characteristics and properties of asphaltic concrete mixes upon the service behavior of the mixes as evaluated by the Traffic Simulator (1,2) and by field observations.

The study included: Investigations of the relations, of gradation, fraction and resistance to wear of aggregates; of stability, cohesion, per cent voids and asphalt content of a number of laboratory and field mixes to service behavior as indicated by the Traffic Simulator under various test conditions. Based upon the results of the tests and the relationships noted, tentative criteria for the Traffic Simulator test were devised, subject to verification by observations and measurements of field service behavior of the mixes.

Utilized in the study were the following: 30 laboratory design mixes prepared by and molded into test specimens by the Marshall method at the Iowa Highway Commission Laboratory; and 17 field mixes obtained from asphalt plants operating on highway construction projects in Iowa. The field mixes were compacted into test specimens, using both the Marshall and Kneading Compactor methods, by the Bituminous Research Laboratory. The field mixes represented the use of a variety of aggregates and application of the mixes for various road purposes and traffic characteristics.

Data concerning both laboratory and field mixes included: gradation of aggregates, Los Angeles Abrasion and loss on freezing and thawing of coarse aggregates, specific gravity of total aggregate, asphalt content, data on Iowa stability of the mixes all were supplied by the Iowa State Highway Commission Laboratory. The sources of the aggregates used in the respective paving contracts from which field samples were taken are shown in Table 1. All aggregates used in the mixes complied with specification requirements for the respective types of A or B asphaltic concrete (3,4). Asphalt cements used in all of the mixes were of an 85-100 penetration grade.

The tests conducted by the Bituminous Research Laboratory, in accordance with standard procedures, included: specific gravity of compacted mix; voids in compacted mix; Hveem stability and cohesion; Marshall stability and flow; and Traffic Simulator tests at both 100°F and 140°F. Additional Traffic Simulator tests were conducted on a selected group of specimens at 100, 110, 120, 130 and 140°F to determine the critical test temperature.

Field inspections were made of the roads from which samples were taken after one and two years of service. Cores were removed from some of these roads after one year of service for further tests.

Test Results

All data concerning aggregates and mixes, and results of tests performed are shown in Table 2. The laboratory design mixes are designated "L" prefixed by a number indicating the county in Iowa in which the mix was to be used. These numbers correspond to the official county numbers carried on Iowa automobile license plates. The field mixes corresponding to the respective laboratory design mixes are designated as "FM" or "FH" respectively, depending upon the Marshall or Kneading compaction method used in preparing the test specimens.

The Traffic Simulator results, shown in the table, are indicated as the number of passes that caused a displacement of 0.10 inch at a specimen test temperature of 140°F, unless otherwise specifically indicated.

Discussion of Results

It is recognized that the properties of an asphaltic concrete mix depend not only upon the characteristics or properties of its ingredients but also, and perhaps to a greater degree, upon the combination of its ingredients and the manner in which the mix is compacted. Consequently, any evaluation of the effects of the properties of an ingredient upon those of the mix must consider the interrelation of its properties with those of the other ingredients and their proportionate quantities in the mix.

Therefore, all pertinent factors were considered in evaluating the effects of ingredient properties, ingredient proportions, stability, cohesion and void content of a mix upon the resistance of a mix to displacement under a moving load, as measured by the Traffic Simulator.

Due to the variety of materials and mixes involved and the limited population of test specimens which precluded comprehensive statistical analysis, the evaluations were based upon arithmetical averages of pertinent results. Where wide deviation in results was noted, efforts were made to ascertain the cause.

Effect of Aggregate Resistance to Abrasion

The effect of the resistance to abrasion of a coarse aggregate (as measured by the Los Angeles Abrasion Test) upon the resistance of a mix to displacement (as measured by the Traffic Simulator) is shown in Fig. 1.

Upon completion of the Traffic Simulator tests the specimens were cut into sections and the extent of the degradation of the coarse aggregates noted. The results of these observations for the field mixes are shown in Table 3. Similar results were noted with the laboratory design mixes.

Generally the results indicate that as the resistance of an aggregate to abrasion decreases, from 29% to 35%, the resistance of a mix to displacement also decreases. As the resistance to abrasion decreases below 35%, 35 to 40% the resistance of a mix to displacement increases sharply. This behavior is no doubt related to the character and amount of degradation that occurs during compaction of the mix and under traffic, and the asphalt and void content of the mix.

Although results are not consistent, it may be noted from Table 3 that aggregates subject to average or larger amounts of degradation appear to indicate that mixes with 5% to 6% asphalt have generally higher resistance to displacement. Field inspections (Table 4) generally confirm this.

The effects of degradation of aggregates are interrelated with the asphalt and void contents of a mix and also with the amount of absorption of asphalt by the aggregate. It was observed during the Traffic Simulator tests that mixes containing low void contents and aggregates exhibiting small amounts of degradation and absorption of asphalt, developed excessive asphalt characteristics that had a lower resistance to displacement. On the other hand, mixes with comparatively high void contents and aggregates with average or above average degradation and absorption of asphalt resisted displacement much better, provided the asphalt content was not excessive. In the latter mixes the degraded particles apparently filled the available voids, and by absorption and increased surface area assimilated the asphalt during densification of the mix under a moving load. Field behavior under traffic appears to confirm these observations.

Field observations exposed some other important aspects of aggregate behavior in a mix under traffic that were not revealed by the Traffic Simulator using 2½ inch deep specimens. On curb elimination projects, where 1½ inch to 2 inch mats were laid on Portland cement concrete, aggregates with high resistance to wear properties, 29% to 32% L.A., tended to crush and crack under traffic and shell out ("pop out" of the surface of the pavement). They appeared to be literally pounded to pieces, leaving the surface open. Aggregates less resistant to wear appeared to strip and wear more. Thus the depth of the surfacing and rigidity of the base also have some influence upon the resistance of a mix to traffic wear and displacement.

Effect of Absorption of Asphalt by Aggregates

The amount of absorption of asphalt by the coarse aggregates used in the field mixes observed in sections of the test specimens after the Traffic Simulator test is shown in Table 3. The amount of absorption indicated is based upon the average amount noted during the examination of all mixes tested.

These results appear to indicate that coarse aggregates having an average or slightly higher amount of absorption of asphalt under normal mix design procedures yield a higher resistance to displacement under a moving load.

This is contrary to the generally accepted belief that aggregates exhibiting any absorption should be avoided. Again it must be recognized that this characteristic of an aggregate must be correlated with the gradation of the aggregates, the degradation of the aggregates during compaction and under traffic, the amount of fines, and the asphalt and void content of the mix. When such interrelations are properly balanced, a limited amount of absorption of asphalt by an aggregate may not be as detrimental as generally believed.

Effect of Aggregate Proportions

In evaluating the effects of aggregate proportions in a mix upon the resistance of a mix to displacement under a moving wheel load, the aggregate gradation of the mix was divided into three fractions: coarse aggregate as the portion retained on the No. 4 sieve; fine aggregate as the portion passing the No. 4 sieve and retained on the No. 200 sieve; and dust as the portion passing the No. 200 sieve.

The relationships between aggregate proportions and the resistance to displacement of the field mixes (compacted by the Marshall and Kneading

Compactor methods) are shown in Fig. 2. Those for the laboratory design mixes, compacted by the Marshall method and containing various amounts of asphalt, are shown in Fig. 3.

The effects of aggregate proportions on the resistance of a mix to displacement under a moving wheel load cannot be readily evaluated on the basis of a single fraction of the aggregate without considering other variables, such as character of the aggregate, proportions of other fractions, asphalt and void content of the mix and method of compaction.

The influence of the method of compaction, with its side factors of density of the mix and aggregate degradation, become evident in Fig. 2. Mixes compacted by the Kneading Compactor, which generally yield higher density, for the most part appear to possess higher resistance to displacement than those compacted by the Marshall method.

Although specific effects cannot be precisely determined, some general relationships are apparent in both the field and laboratory design mixes.

In the field mixes, in which the asphalt content varies between 4.5 and 6%, the combination of aggregates that appears to yield the higher resistance to displacement under a moving load, regardless of compaction method, is approximately as follows:

Coarse Aggregate	- 39 to 41%
Fine Aggregate	- 49 to 51%
Dust	- 8%

The effects of aggregate proportions upon the resistance of a mix to displacement under a wheel load, as indicated by the Traffic Simulator, with respect to various asphalt contents in the laboratory design mixes compacted by the Marshall method, are shown in Fig. 3. Although the curves are erratic due to other variables (such as character of aggregates and void contents in mixes) some general combinations of aggregates that yield comparatively high resistance to displacement may be selected.

Considering all factors involved, it appears that the following aggregate proportions with respect to asphalt contents would provide mixes of comparatively high resistance to displacement under a moving wheel load:

% Asphalt	4	5	6
% Coarse Aggregate	42-43	41	43
% Fine Aggregate	51-52	52	49
% Dust	6	7	8

These combinations conform quite well with those used in field mixes which exhibited good resistance to displacement under traffic in the field tests.

Effect of Voids in Compacted Mix

Shown in Fig. 4 is the effect of voids in the compacted mix upon its resistance to displacement under a moving wheel load, for the laboratory design mixes compacted by the Marshall method and the field mixes compacted by the Kneading Compactor and Marshall methods.

Generally, the resistance of the laboratory design mixes to displacement tends to increase as the void content increases up to 9%. Mixes containing 8 to 9% voids not only possess high resistance to displacement, they also show the most consistency in results with the least variation among specific mixes, regardless of other variables involved.

A similar trend is apparent with field mixes compacted by the Marshall method. The resistance of these mixes, however, were lower than those noted for their equivalent laboratory design mixes. This may be due to the necessity of reheating the field mix samples for preparation of test specimens.

Field mixes compacted by the Kneading Compactor exhibited higher resistance to displacement with the same void content than mixes compacted by the Marshall method.

These results appear to indicate that mixes with higher void contents provide higher resistance to displacement under a moving wheel load. This conclusion was confirmed by the service behavior of mixes under traffic after one to two years.

Effect of Asphalt Content

The influence of the asphalt content of a mix, within appropriate limits, upon its resistance to displacement under a moving load cannot be evaluated as an independent variable because it is so intimately interrelated with many other variables. Although the results of the individual test specimens vary widely for any particular asphalt content, the average of the results does exhibit a general trend (Fig. 5).

The resistance of the laboratory design mixes to displacement tends to decrease with increasing asphalt content, with little change between 5 and 6%. Conversely, field mixes tend to increase in resistance to displacement between 4½ and 5½% asphalt. This reversal of trend may possibly be caused by the reheating of field samples in the preparation of test specimens. Generally, specimens compacted by the Kneading Compactor had higher resistance to displacement than those compacted by the Marshall method.

Inspection of specimens sectioned after the Traffic Simulator test indicates that much of the wide variation of results among individual test specimens may be attributed to the absorptive and degradation characteristics of the coarse aggregates, and the voids in the mix.

Relation between Iowa State Highway Commission Stability and Resistance to Displacement

The stability of a mix, under the Iowa State Highway Commission procedure, is determined by the lateral pressure developed in the Hveem Stabilometer (3). In this procedure the test specimen is compacted by the Marshall method and subjected to test in the Hveem Stabilometer at 140^{o}F, dry and under a vertical load applied at the rate of 0.05 inch per minute. The lateral pressure developed under a load of 400 psi is reported as the stability of the specimen. A maximum of 60 psi is permitted for Type A mixes and 75 psi for Type B mixes (4). Lateral pressures of 40 to 50 psi are deemed desirable.

The relation between the Iowa State Highway Commission stability of a mix and its resistance to displacement as measured by the Traffic Simulator was not consistent. Traffic Simulator results for mixes having the same stability varied widely between 700 and 5000 passes. In many instances mixes that possessed stabilities in the desired range exhibited low resistance to displacement, while others having stabilities above the acceptable limits appeared to possess excellent resistance to displacement. These results clearly indicate that the stability of a mix, determined in this manner does not assure consistent service behavior under traffic. Field inspections of pavements laid using approved mixes confirm this (Table 4).

Relationships based upon the average of resistance to displacement results (Fig. 6) indicate that the resistance to displacement decreases, in both laboratory design and field mixes, as the stability value increases.

Relation between Hveem Stability and Resistance to Displacement

The field mixes were the only ones that were subjected to the Hveem stability test in accordance with prescribed procedure. The test specimens were compacted by the Kneading Compactor and Marshall methods. Here again the resistance to displacement results as measured by the Traffic Simulator varied considerably for mixes having similar stabilities. This also indicates that the Hveem stability does not yield adequate assurance that a mix will provide satisfactory service under traffic.

Due to the limited number of mixes and the variation of results a definite relation between Hveem stability and the resistance of a mix to displacement could not be determined. When results are averaged (Fig. 7) resistance to displacement appears to decrease between 20 to 40 stability value and then increase sharply for values up to 50. The same trend holds regardless of method of compaction.

Relation between Hveem Cohesion and Resistance to Displacement

Shown in Fig. 8 is the relation between Hveem cohesion and resistance to displacement of field mixes, compacted by the Marshall and Kneading Compactor methods, and based on the average of results.

The relationships are erratic and inconsistent, due probably to the limited number of mixes available and the variations in results. Note, however, that mixes compacted by the Kneading Compactor yielded considerably higher resistance to displacement for equal values of cohesion than those compacted by the Marshall method.

Relation between Marshall Stability And Resistance to Displacement

The relationships between the Marshall stability and the resistance of a mix to displacement as measured by the Traffic Simulator for field mixes, compacted by the Marshall and Kneading Compactor methods, and based on the average of results, are shown in Fig. 9.

Several trends are apparent for the mixes compacted by the Marshall method. The resistance of a mix to displacement appears to increase as Marshall stability increases. The results for individual mixes, however, vary more widely as Marshall stability increases.

Mixes compacted by the Kneading Compactor do not exhibit any trends, and results are erratic.

The range of results, shown in Fig. 9, clearly indicate that Marshall stability is not dependable in all cases, to assure adequate resistance of a mix to displacement in service under traffic.

Traffic Simulator Test Criteria

During the course of the study, a series of tests was conducted to determine the temperature that would provide a sharp differentiation in the behavior of mixes subjected to test in the Traffic Simulator. Tests were made with the temperature of the test specimens at 100, 110, 120, 130 and 140°F. The tests showed that the resistance of a mix to displacement remained fairly constant up to 120 to 130°F, above which the test temperature became more critical. A clear differentiation of the behavior of the mix was apparent at 140°F test specimen temperature.

During these tests the amount of displacement was also observed. It was found that a displacement of 0.10 inch with specimens at 140°F provided a critical point at which the behavior of mixes under a moving load could be evaluated.

Based upon the results of the many varied tests performed on laboratory design and field mixes during the investigation, the following conditions and criteria for the Traffic Simulator test were tentatively set, subject to adjustment after correlation with field service behavior:

Specimen test temperature, 140°F;

Equivalent wheel load, 80 psi;

Displacement of mix from original surface to bottom of rut created in the wheel track (measured at the center of the specimen), 0.10 inch

Resistance to displacement value given as the number of wheel passes required to cause a displacement of 0.10 inch at a specimen temperature of 140°F;

Criteria for laboratory design mixes -- when a resistance to displacement value of a mix is less than 1500 passes, the design of the mix should be reconsidered

Criteria for field mixes -- when a resistance to displacement value of a mix is less than 1000, the design of the mix should be reconsidered.

Correlation of Traffic Simulator Test Results With Field Service Behavior

The service behavior of 15 of the pavements laid during the summer of 1964, for which both laboratory design and field mix test data were available, was kept under periodic surveillance for two years. After one year in service, samples were cut from some of these pavements and subjected to further laboratory tests. Pavement conditions noted after one and two years in service were recorded and are shown in Table 4. All mixes used in these pavements met Iowa State Highway Commission specifications for the specific type of mix. However, they varied widely in their resistance to displacement as measured by the Traffic Simulator.

Tests made on the samples, taken from the wheel tracks of the pavement after one year of service under traffic, showed the results found in Table 4. In every case a material reduction in void content, a material reduction in Marshall stability with an increase in flow and a reduction in resistance to displacement was noted. This behavior may be attributed to traffic compaction.

Inspection of the condition of the pavements after one and two years of service disclosed the following:

1. Mixes that indicated comparatively high resistance to dis-

placement, as measured by the Traffic Simulator, showed practically no tendency to rutting or rippling in the wheel tracks. Those with resistance to displacement values slightly above the tentative criteria of 1000 passes indicated a slight tendency to rutting in the wheel tracks, while those with values below the tentative criteria generally showed excessive rutting. These observations of service behavior endorse and authenticate the tentative criteria set for resistance to displacement as measured by the Traffic Simulator, and the conclusion that stability is not an adequate control to assure satisfactory service behavior.

2. Extensive shelling, the crushing and popping out of coarse aggregate particles from the surface, and stripping of asphalt from coarse aggregates at the surface occurred in a number of the pavements. This behavior was not revealed to any significant extent by the Traffic Simulator. Analysis of this behavior (Table 4) indicates the following:

    (a) That mixes with lower asphalt content exhibit these tendencies to a greater degree than those with higher asphalt content.

    (b) That comparatively thin surfacings laid on rigid bases intensify the pounding effect of traffic on the coarse aggregates causing them to crack and subsequently pop out.

    (c) That the harder aggregates, having a higher resistance to wear, are subject to this action to a greater degree than softer aggregates with a lower resistance to wear.

Conclusions

Based upon an analysis of the results of the various tests performed upon a variety of laboratory design and field mixes and the inspections and observations made of the behavior of some of these mixes in service under traffic for a period of two years, the following conclusions may be drawn:

1. Stability, as measured by either the Marshall, Hveem, or Iowa State Highway Commission methods, is not adequate to assure the desired service behavior of a mix under traffic.
2. The Traffic Simulator test possesses the potentialities of serving as an auxiliary test for the evaluation of the behavior of a mix in service under traffic and as a quality control test for field mixes.
3. The tentative conditions and criteria set for the Traffic Simulator tests are tenable for evaluating the service performance of a mix.
4. Coarse aggregates possessing higher Los Angeles Abrasion Values, and which tend to degrade and absorb asphalt in limited amounts, tend to provide a mix with improved resistance to displacement under a moving wheel load.
5. Mixes containing 8 to 9% voids yield improved and most consistent resistance to displacement under a moving wheel load.

References

1. "Traffic Simulator for Checking Mix Behavior," L. H. Csanyi, H. P. Fung, Highway Research Record No. 51, Highway Research Board, 1964.

2. "Design and Operation of the Traffic Simulator," L. H. Csanyi, Final Report, Engineering Research Institute, Iowa State University, March, 1967.

3. Iowa State Highway Commission, Standard Specifications for Construction on Primary, Farm to Market and Secondary Roads, and Maintenance Work on the Primary Road System 1964, Sec. 4100.12, pg. 568.

4. Ibid Sec. 2303.02(1) pg. 267 and pg. 292.

Table 1. Materials used

Sample No.	County	Type aggregate	Quarry
ABC4-705	Adair	Fine Sand	Jefferson Qr., NW¼ 17-77-31 Adair Co.
S-462(9)		3/4" Cr. Stone	Jefferson Qr., NW¼ 17-77-31 Adair Co.
ABC4-797	Allamakee	Pit Run Sand	S. of New Albin SE¼ 10-100n-04w Allamakee Co.
FN-161(6)		Crusher Run	Johnson Qr., SW of Lansing, SW¼ 35-99n-04w Allamakee Co.
		Limestone	Johnson Qr., SW of Lansing, SW¼ 35-99n-04w Allamakee Co.
ABC4-905	Appenoose	Conc. Sand	Eddyville Plant, SW¼ 36-74-16 Mahaska Co.
FN-712		3/8" Dust Cr. Stone	Plano., NW¼ 27-70-19 Appanoose Co.
		3/4"-3/8" Cr. Stone	Plano., NW¼ 27-70-19 Appanoose Co.
FN-2(2)		3/8" Cr. Stone	Hallett-Gilmore City, NE¼ 36-92-31 Pocahontas Co.
		Coarse Sand	L. G. Everist-Hawarden, W½ NE¼ 27-95-48 Sioux Co.
		Fine Sand	Brower-Sargent Bluff, SW¼ NW¼ 6-87-47 Woodbury Co.

Table 2.

Mix No.	I.H.C. Mix No. ABC4	Aggregates: % +No. 4	% -No.4 +200	% -200	% loss F & T	L.A. Wear	Sp. Gr. Total Agg.	Laboratory & Field Mixes: % AC	Sp. Gr.	% Voids	I.H.C. Stab.	Hveem: Stab	Disp.	Cohes.	Marshall: Stab.	Flow	Trafficability: No Passes .10" Displacement 140°F
1L	381	44	47	9	4.3	29	2.66	5.5	2.28	6.8	60	--	--	--	--	--	1300
	382	"	"	"	"	"	"	6.5	2.30	4.6	70	--	--	--	--	--	400
1FM	705A	44	48	8	4.3	29	2.66	5.7	2.26	8.5	61	26	3.8	85	1120	10	1400
1FH	705B	"	"	"	"	"	"	"	2.29	7.3	--	43	3.3	199	1920	9	300
2L	79	40	52	8	3.3	30	2.68	4.5	2.31	7.4	53	--	--	--	--	--	1900
	80	"	"	"	"	"	"	5.5	2.33	5.1	62	--	--	--	--	--	1500
	81	"	"	"	"	"	"	6.5	2.32	4.1	--	--	--	--	--	--	400
3L	459	37	56	7	2.7	35	2.71	4.0	2.26	11.1	48	--	--	--	--	--	5000
	460	"	"	"	"	"	"	5.0	2.28	8.9	56	--	--	--	--	--	5000
	461	"	"	"	"	"	"	6.0	2.33	5.6	49	--	--	--	--	--	4600
3FM	797A	37	56	7	2.7	35	2.71	5.7	2.31	7.6	50	34	3.2	57	1520	9	1000
3FH	797B	"	"	"	"	"	"	"	2.39	4.4	--	40	2.8	204	2480	13	1000
3FM	1370A	31	62	7	--	--	--	5.5	2.25	5.9	67	37	3.2	72	1050	10	1100
3FH	1370B	"	"	"	--	--	--	"	2.34	2.1	--	26	2.9	99	1630	14	5000
4L	285	41	52	7	5.9	29	2.71	4.0	2.37	6.7	40	--	--	--	--	--	3900
	286	"	"	"	"	"	"	5.0	2.41	3.7	51	--	--	--	--	--	2800
	287	"	"	"	"	"	"	6.0	2.42	1.8	79	--	--	--	--	--	500
4FM	905A	42	50	8	5.9	29	2.71	5.0	2.32	10.0	60	35	3.3	95	1440	9	1100
4FH	905B	"	"	"	"	"	"	"	2.40	7.0	--	44	2.3	208	2830	12	5000
5L	502	44	49	7	5.2	28	2.67	4.0	2.24	10.6	54	--	--	--	--	--	1200
	503	"	"	"	"	"	"	5.0	2.30	6.8	41	--	--	--	--	--	500
	504	"	"	"	"	"	"	6.0	2.35	3.4	46	--	--	--	--	--	1300
6L	462	14	75	11	4.2	29	2.68	4.5	2.22	11.2	62	--	--	--	--	--	2300
	463	"	"	"	"	"	"	5.5	2.24	9.0	60	--	--	--	--	--	1000
	464	"	"	"	"	"	"	6.5	2.27	6.5	62	--	--	--	--	--	800
16L	497	44	48	8	0.5	27	2.77	4.0	2.35	9.3	41	--	--	--	--	--	3700
	498	"	"	"	"	"	"	5.0	2.43	4.8	45	--	--	--	--	--	1200
	499	"	"	"	"	"	"	6.0	2.43	3.3	59	--	--	--	--	--	1000
21L	87	39	55	6	1.4	32	2.66	4.0	2.27	9.0	48	--	--	--	--	--	5000
	88	"	"	"	"	"	"	5.0	2.32	5.5	51	--	--	--	--	--	1600
	89	"	"	"	"	"	"	6.0	2.34	3.3	72	--	--	--	--	--	800
22L	92	43	49	8	3.8	38	2.73	4.0	2.30	9.7	53	--	--	--	--	--	700
	93	"	"	"	"	"	"	5.0	2.34	6.7	66	--	--	--	--	--	700
	94	"	"	"	"	"	"	6.0	2.38	3.6	113	--	--	--	--	--	5000
22L	644	44	49	7	2.4	30	2.74	4.0	2.33	9.3	47	--	--	--	--	--	2100
	645	"	"	"	"	"	"	5.0	2.37	6.4	53	--	--	--	--	--	600
	646	"	"	"	"	"	"	6.0	2.41	3.3	68	--	--	--	--	--	4000
22L	112	42	50	8	3.8	38	2.72	4.0	2.29	9.9	43	--	--	--	--	--	3000
	113	"	"	"	"	"	"	5.0	2.35	6.0	47	--	--	--	--	--	1000
	114	"	"	"	"	"	"	6.0	2.37	3.7	107	--	--	--	--	--	5000
23L	104	41	52	7	0.9	30	2.76	4.0	2.28	11.5	51	--	--	--	--	--	3600
	105	"	"	"	"	"	"	5.0	2.31	9.0	59	--	--	--	--	--	2400
	106	"	"	"	"	"	"	6.0	2.37	5.0	83	--	--	--	--	--	5000
23FM	1201	43	49	8	--	--	--	5.25	2.31	8.0	53	40	4.24	75	1570	8	1300
23FH	1201	"	"	"	--	--	--	5.25	2.41	4.0	--	46	3.0	111	3270	13	1900
24L	1217	38	55	7	5.0	32	2.66	4.0	2.26	9.6	46	--	--	--	--	--	5000
	1218	"	"	"	"	"	"	5.0	2.28	7.5	40	--	--	--	--	--	1300
	1219	"	"	"	"	"	"	6.0	2.31	4.9	54	--	--	--	--	--	1900
28L	383	44	48	8	7.1	40	2.74	4.0	2.30	10.1	41	--	--	--	--	--	2700
	384	"	"	"	"	"	"	5.0	2.32	9.2	42	--	--	--	--	--	5000
	385	"	"	"	"	"	"	6.0	2.38	4.4	49	--	--	--	--	--	5000
28FM	1109	44	48	8	7.1	40	2.74	5.5	2.26	8.9	46	33	3.9	59	1110	8	2600
28FH	1109	"	"	"	"	"	"	5.5	2.39	3.6	--	41	3.5	172	2850	13	400
29L	321	45	47	8	4.9	38	2.65	4.0	2.32	6.8	52	--	--	--	--	--	2000
	322	"	"	"	"	"	"	5.0	2.35	4.2	56	--	--	--	--	--	700
	323	"	"	"	"	"	"	6.0	2.36	2.4	--	--	--	--	--	--	300
29FM	709	37	54	9	4.9	38	--	4.8	2.26	9.6	68	34	3.3	61	1230	8	500
29FH	709	"	"	"	"	"	--	4.8	2.37	5.2	--	46	2.5	207	2460	8	2000
31L	1220	43	50	7	4.4	38	2.76	4.0	2.31	10.4	42	--	--	--	--	--	5000
	1221	"	"	"	"	"	"	5.0	2.35	7.6	42	--	--	--	--	--	5000
	1222	"	"	"	"	"	"	6.0	2.39	4.6	48	--	--	--	--	--	5000

Table 2. (Continued)

Mix No.	I.H.C. Mix No. ABC4	Aggregates % +No. 4	% -No. 4 +200	% -200	% loss F & T	L.A. Wear	Sp. Gr. Total Agg	Laboratory & Field Mixes % AC	Sp. Gr.	% Voids	I.H.C. Stab.	Hveem Stab	Hveem Disp.	Hveem Cohes.	Marshall Stab.	Marshall Flow	Trafficability No Passes .10" Displacement 140°F
33L	143	43	50	7	3.0	30	2.70	4.0	2.35	7.4	43	--	--	--	--	--	1400
	144	"	"	"	"	"	"	5.0	2.38	4.8	52	--	--	--	--	--	900
	145	"	"	"	"	"	"	6.0	2.39	2.9	92	--	--	--	--	--	400
33FM	618	43	50	7	3.0	30	2.70	4.75	2.31	5.7	--	42	3.3	125	930	9	600
33FH	618	"	"	"	"	"	"	4.75	2.39	2.4	--	51	2.5	245	1960	13	600
33FM	2819	40	55	5	--	--	--	5.4	2.20	10.1	49	29	3.8	70	950	9	900
33FH	2819	"	"	"	--	--	--	5.4	2.27	8.1	--	33	3.1	142	1300	13	2200
45L	398	39	52	9	4.1	36	2.69	4.0	2.26	10.6	49	--	--	--	--	--	2800
	399	"	"	"	"	"	"	5.0	2.32	6.8	50	--	--	--	--	--	4400
	400	"	"	"	"	"	"	6.0	2.35	4.2	49	--	--	--	--	--	1700
48L	64	42	51	7	1.8	27	2.68	4.0	2.34	7.0	45	--	--	--	--	--	5000
	65	"	"	"	"	"	"	5.0	2.36	4.7	73	--	--	--	--	--	900
	66	"	"	"	"	"	"	6.0	2.37	2.8	--	--	--	--	--	--	300
52L	1288	43	51	6	4.7	30	2.69	4.0	2.34	7.4	45	--	--	--	--	--	4800
	1289	"	"	"	"	"	"	5.0	2.37	4.7	51	--	--	--	--	--	1600
	1290	"	"	"	"	"	"	6.0	2.38	2.9	81	--	--	--	--	--	300
52L	1291	43	49	8	1.8	32	2.68	4.0	2.31	8.3	45	--	--	--	--	--	5000
	1292	"	"	"	"	"	"	5.0	2.36	4.9	47	--	--	--	--	--	4400
	1293	"	"	"	"	"	"	6.0	2.36	3.9	55	--	--	--	--	--	4500
54L	535	40	53	7	--	--	2.64	4.0	2.21	11.0	49	--	--	--	--	--	3700
	536	"	"	"	--	--	"	5.0	2.26	7.6	54	--	--	--	--	--	1600
	537	"	"	"	--	--	"	6.0	2.29	5.0	69	--	--	--	--	--	1300
54L	1367	45	49	6	7.9	39	2.65	4.0	2.27	9.0	56	--	--	--	--	--	5000
	1368	"	"	"	"	"	"	5.0	2.31	6.1	41	--	--	--	--	--	5000
	1369	"	"	"	"	"	"	6.0	2.34	3.4	54	--	--	--	--	--	5000
54FM	2341	45	49	6	7.9	39	2.65	4.93	2.27	8.1	42	48	3.8	56	1630	10	3400
54FH	2341	"	"	"	"	"	"	4.93	2.32	6.1	--	46	3.8	103	2500	9	5000
55L	515	42	51	7	3.2	32	2.69	4.0	2.23	11.8	60	--	--	--	--	--	5000
	516	"	"	"	"	"	"	5.0	2.27	8.8	52	--	--	--	--	--	1700
	517	"	"	"	"	"	"	6.0	2.35	4.2	57	--	--	--	--	--	2300
55FM	1459	41	51	8	3.2	32	2.69	5.53	2.30	6.5	67	42	4.0	128	1510	13	700
55FH	1459	"	"	"	"	"	"	5.53	2.39	2.9	--	39	3.1	169	2500	16	1100
63L	115	45	47	8	2.1	31	2.70	4.0	2.28	9.7	45	--	--	--	--	--	5000
	116	"	"	"	"	"	"	5.0	2.33	6.2	46	--	--	--	--	--	3400
	117	"	"	"	"	"	"	6.0	2.35	3.9	91	--	--	--	--	--	700
70L	37	40	53	7	5.3	34	2.70	4.0	2.37	6.4	41	--	--	--	--	--	1700
	38	"	"	"	"	"	"	5.0	2.39	4.5	53	--	--	--	--	--	600
	39	"	"	"	"	"	"	6.0	2.39	3.4	102	--	--	--	--	--	300
70FM	444	40	53	7	5.3	34	2.70	4.27	2.35	5.0	65	37	3.4	92	1400	10	2000
70FH	444	"	"	"	"	"	"	4.27	2.42	3.7	--	33	2.2	182	1970	15	2600
87L	1694	44	48	8	8.0	29	2.68	4.0	2.28	9.6	55	--	--	--	--	--	1000
	1695	"	"	"	"	"	"	5.0	2.33	6.2	57	--	--	--	--	--	800
	1696	"	"	"	"	"	"	6.0	2.36	3.6	63	--	--	--	--	--	1000
87FM	2958	44	48	8	8.0	29	2.68	4.75	2.27	11.3	57	40	3.7	78	840	10	1100
87FH	2958	"	"	"	"	"	"	4.75	2.33	9.0	--	41	3.3	144	1660	12	5000
89L	532	42	52	6	4.9	38	2.69	4.0	2.34	7.3	55	--	--	--	--	--	3800
	533	"	"	"	"	"	"	5.0	2.39	3.9	55	--	--	--	--	--	1400
	534	"	"	"	"	"	"	6.0	2.40	2.1	80	--	--	--	--	--	600
89FM	1602	50	43	7	4.9	38	2.69	4.73	2.37	5.6	69	35	3.7	117	1300	12	2000
89FH	1602	"	"	"	"	"	"	4.73	2.43	3.2	--	36	2.7	175	2240	14	1700
93L	1714	40	53	7	5.9	29	2.69	4.0	2.32	8.1	39	--	--	--	--	--	3600
	1715	"	"	"	"	"	"	5.0	2.38	4.3	41	--	--	--	--	--	900
	1716	"	"	"	"	"	"	6.0	2.40	2.1	46	--	--	--	--	--	600
93FM	2299	40	53	7	5.9	29	2.69	4.75	2.36	5.2	--	37	3.7	86	1360	9	800
93FH	2299	"	"	"	"	"	"	4.75	2.42	2.9	--	38	3.4	123	1840	13	1500
97L	2296	38	55	7	4.6	27	2.68	3.8	2.25	11.0	42	--	--	--	--	--	5000
	2297	"	"	"	"	"	"	4.6	2.30	7.9	36	--	--	--	--	--	5000
	2298	"	"	"	"	"	"	5.75	2.35	4.2	44	--	--	--	--	--	5000
97FM	2629	35	52	7	4.6	27	2.68	5.20	2.28	8.1	--	42	3.7	103	990	10	1700
97FH	2629	"	"	"	"	"	"	5.20	2.34	5.6	--	44	3.3	137	1940	10	5000

Table 3. Absorption of Asphalt and Degradation of Coarse Aggregates after Traffic Simulator Test.

Field Mixes

Resistance to Abrasion	Mix No.	Amount of Absorption of AC noted	Amount of Degradation Noted	Resistance to Displacement	
				Marshall Compaction	Kneading Compaction
27	97F	large	average	1700	5000
29	1F	average	small	1400	300
29	4F	small	small	1100	5000
29	87F	average	large	1100	5000
29	93F	small	average	800	1500
30	33F	small	small	600	600
32	55F	small	average	700	1100
34	70F	average	average	2000	2600
35	3F	large	average	1000	1000
38	89F	small	average	2000	1700
38	29F	large	average	500	2000
39	54F	large	large	3400	5000
40	28F	average	average	2600	400

Table 4. Service Behavior of Field Mixes

Mix No.	Mix Type	Paving	Traffic Volume	% Wear C.Agg	% AC	%-200	% Voids	Marshall Stab	Marshall Flow	Resist to Displace	Shelling	Stripping	Rutting	Surface	Remarks
1F	BII	Surfacing	--	29	5.7	8	8.5	1120	10	1400					
1965							--	--	--	--	--	--	--	--	--
1966							--	--	--	--	no	s	no	tight	no crack- very good cond.
3F	B	Ia 13 Surfacing	1270	35	5.7	7	7.6	1520	9	1000					
1965							*4.0	890	18	300	no	s	s,ow	tight	cond. good
1966							--	--	--	--	no	s	s,ow	tight	on Hill sur face open.
3F	A	Ia 9 Cb. Elim.	1390	35	5.5	7	5.9	1050	10	1100					
1965							5.6	560	14	100	m	m	s,bw	tight	reflection crack open wide
1966							--	--	--	--	m	m	¼" ow	tight	reflection crack open slight ripple
4F	A	Cb. Elim.	1830	29	5.0	8	10	1440	9	1100					
1965							4.4	1440	21	100	s	m	s,ow	tight	stripping heavy on curve
1966							--	--	--		m	m	1/8"bw	tight	
23F	A	Cb. Elim.	3670	33	5.25	8	8	1570	8	1900					
1965							6.1	1260	18	700	h	h	no	tight	
1966							--	--	--	--	h	h	no	tight	reflection cracks ¼" wide
28F	A	Cb. Elim.	1810	40	5.5	8	8.9	1110	8	2600					
1965							3.7	670	16	700	no	no	no	tight	condition ex.
1966							--	--	--	--	m	s	1/8"bw		reflection crack ½-1" wide
29F	A	Surfacing	1980	38	4.8	9	9.6	1230	8	500					
1965							4.3	890	15	200	m	m	1/8"ow	tight	segregation
1966							--	--	--	--	h	h	S	tight	segregation cracks
33F	A	Surfacing	1490	30	5.4	7	5.7	930	9	600					
1965							2.6	760	16	100	m	m	m, ow	open	segregation
1966							--	--	--	--	h	h	1/8"ow	open	crack in ow; mod. ripple transverse crack ½-1"
54F	A	Cb. Elim.	1160	39	4.9	6	8.1	1630	10	3400					
1965							8.1	890	12	300	h	h	no	tight	
1966							--	--	--	--	h	h	v.s.	tight	cond. good
55F	Bmod	Surfacing	2730	32	5.5	8	6.5	1510	13	700					
1965							--	--	--	--	--	--	--	--	
1966							--	--	--	--	s	s	ow	open	o.w. patched
70F	A	Cb. Elim.	1320	34	4.3	7	6	1400	10	2000					
1965							3.9	1230	18	500	s	m	no	tight	
1966							--	--	--	--	m	m	no	tight	reflection cracks
87F	A	Cb. Elim.	1300	29	4.75	8	11.3	840	10	1100					
1965							--	--	--	--	--	--	--	--	
1966							--	--	--	--	h	m	no	open	no cracks
89F	A	Cb. Elim.	1330	39	4.7	7	5.6	1300	12	2000					
1965							2.2	1220	15	200	s	no	no	tight	cond. excellent
1966							--	--	--	--	m	m	s	tight	cond. very good-slight reflection cm
93F	A	Surfacing	930	29	4.75	7	5.2	1360	9	800					
1965							2.4	1030	16	100	h	m	no	open	mix dry
1966							--	--	--	--	h	m	no	open	
97F	A	Surfacing	4020	27	5.2	7	8.1	990	10	1700					
1965							--	--	--	--	--	--	--	--	
1966							--	--	--	--	h	h	no	open	reflection crack bad

Note: no-none; s-slight; m-moderate; h-excessive effects noted. ow-outer wheel track; bw-both wheel tracks.

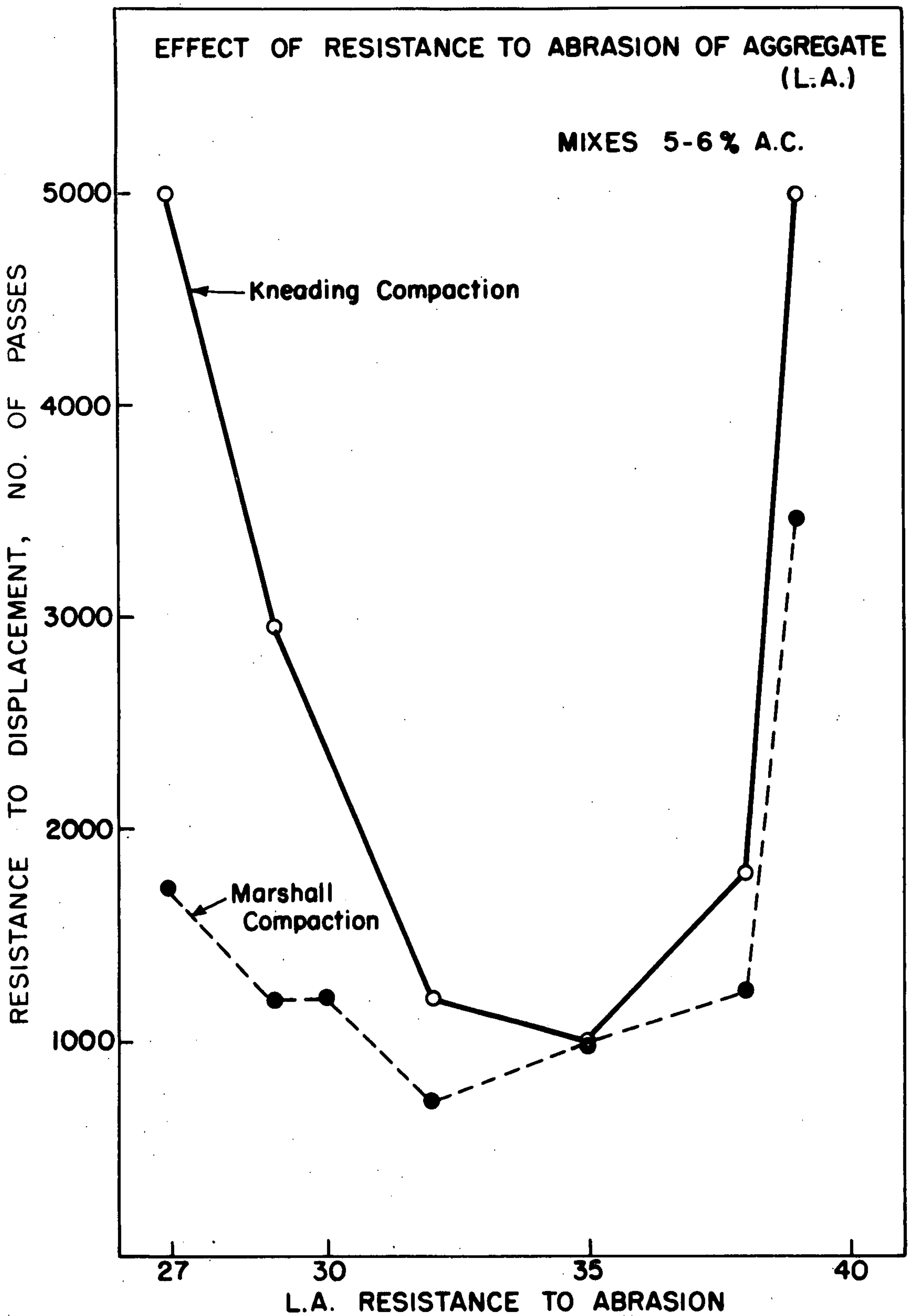

EFFECT OF RESISTANCE TO ABRASION OF AGGREGATE (L.A.)
MIXES 5-6% A.C.
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
Kneading Compaction
Marshall Compaction
27
30
35
40
L.A. RESISTANCE TO ABRASION

Figure 1.

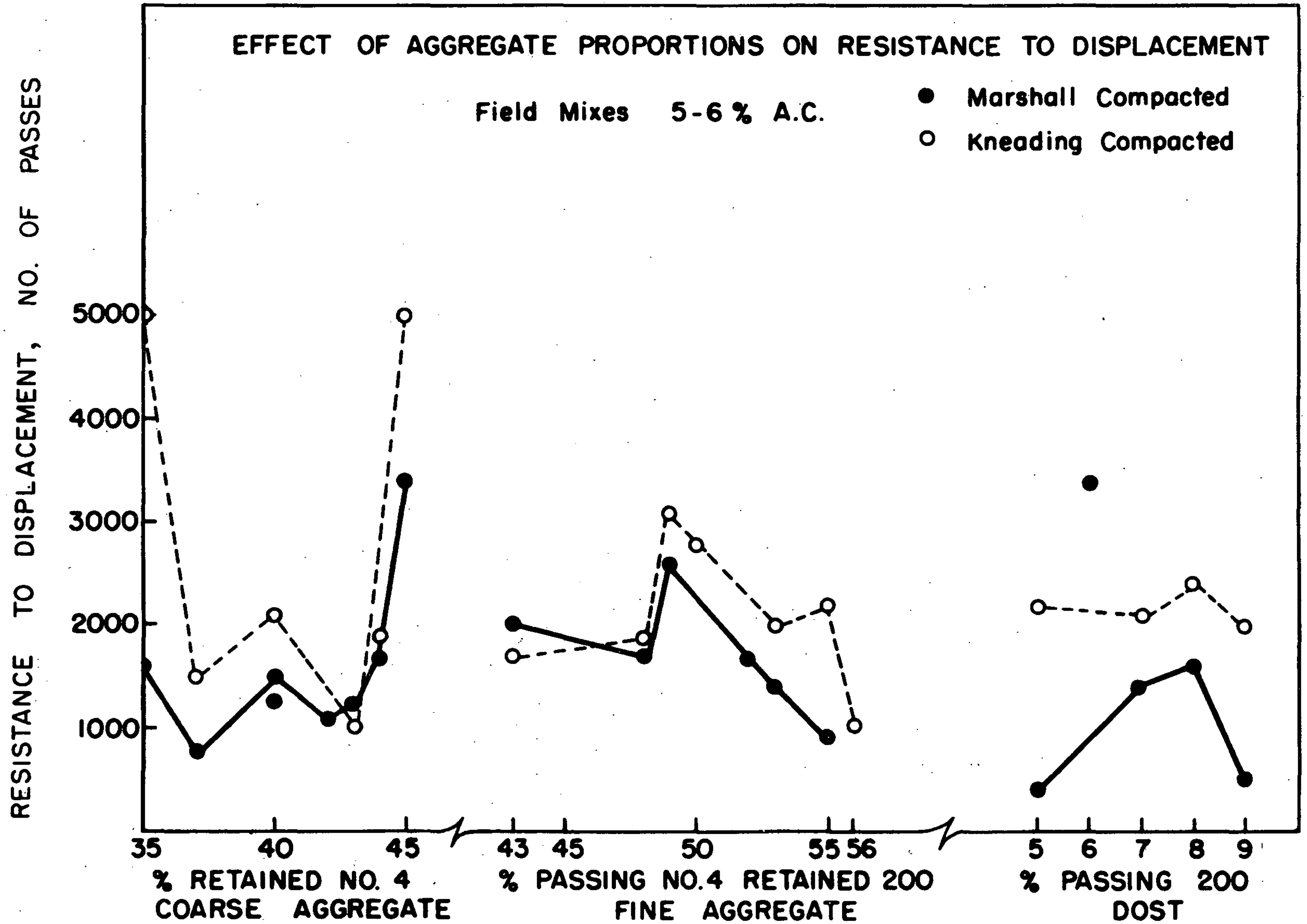

EFFECT OF AGGREGATE PROPORTIONS ON RESISTANCE TO DISPLACEMENT
Field Mixes 5-6 % A.C.
Marshall Compacted
Kneading Compacted
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
35
40
45
43
45
50
55
56
5
6
7
8
9
% RETAINED NO. 4
COARSE AGGREGATE
% PASSING NO.4 RETAINED 200
FINE AGGREGATE
% PASSING 200
DOST

Figure 2.

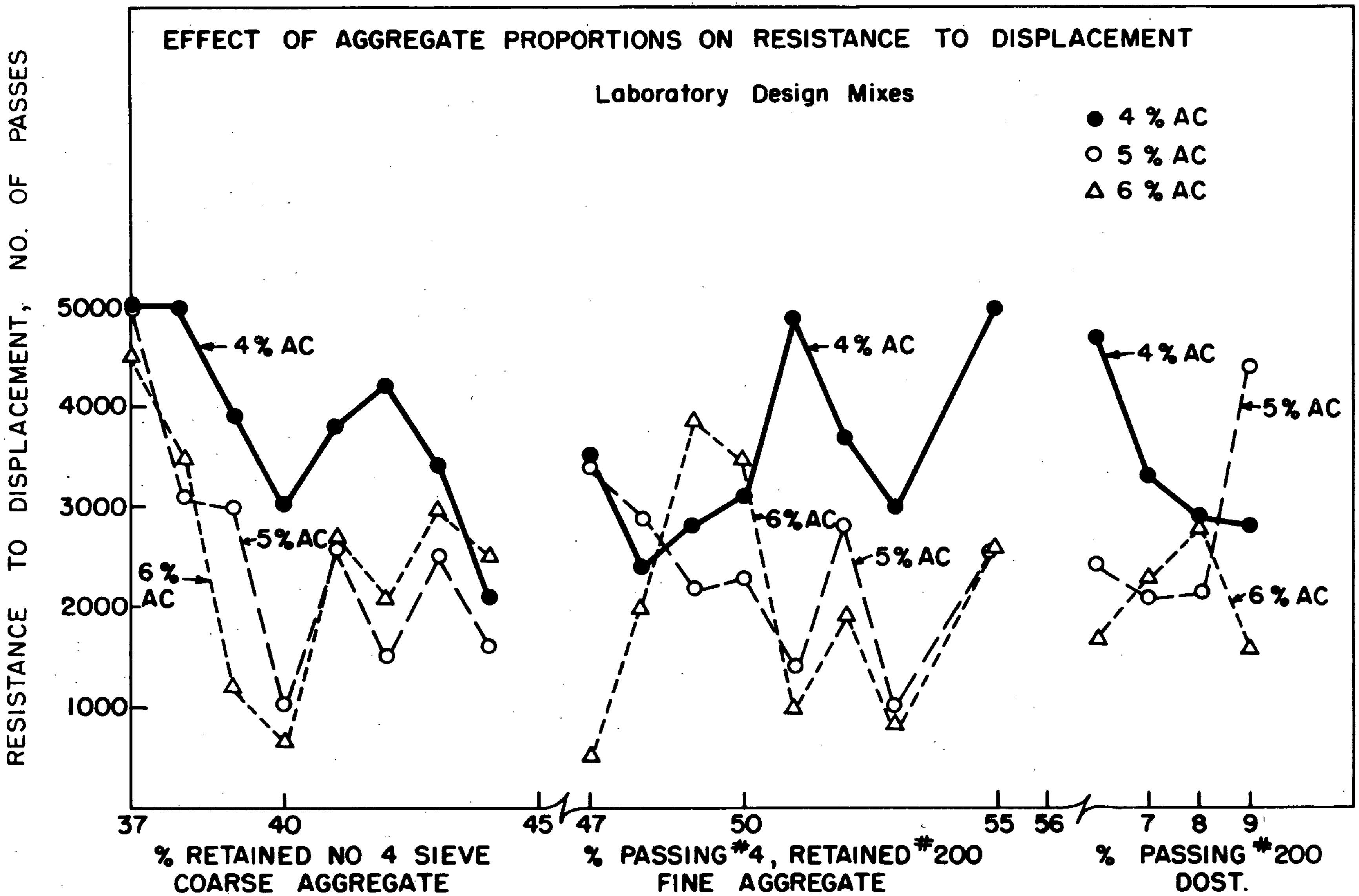

EFFECT OF AGGREGATE PROPORTIONS ON RESISTANCE TO DISPLACEMENT
Laboratory Design Mixes
● 4 % AC
○ 5 % AC
△ 6 % AC
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
4% AC
5%AC
6 % AC
4% AC
6%AC
5%AC
4 % AC
5% AC
6 % AC
37
40
45
47
50
55
56
7
8
9
% RETAINED NO 4 SIEVE
COARSE AGGREGATE
% PASSING #4, RETAINED #200
FINE AGGREGATE
% PASSING #200
DOST.

Figure 3.

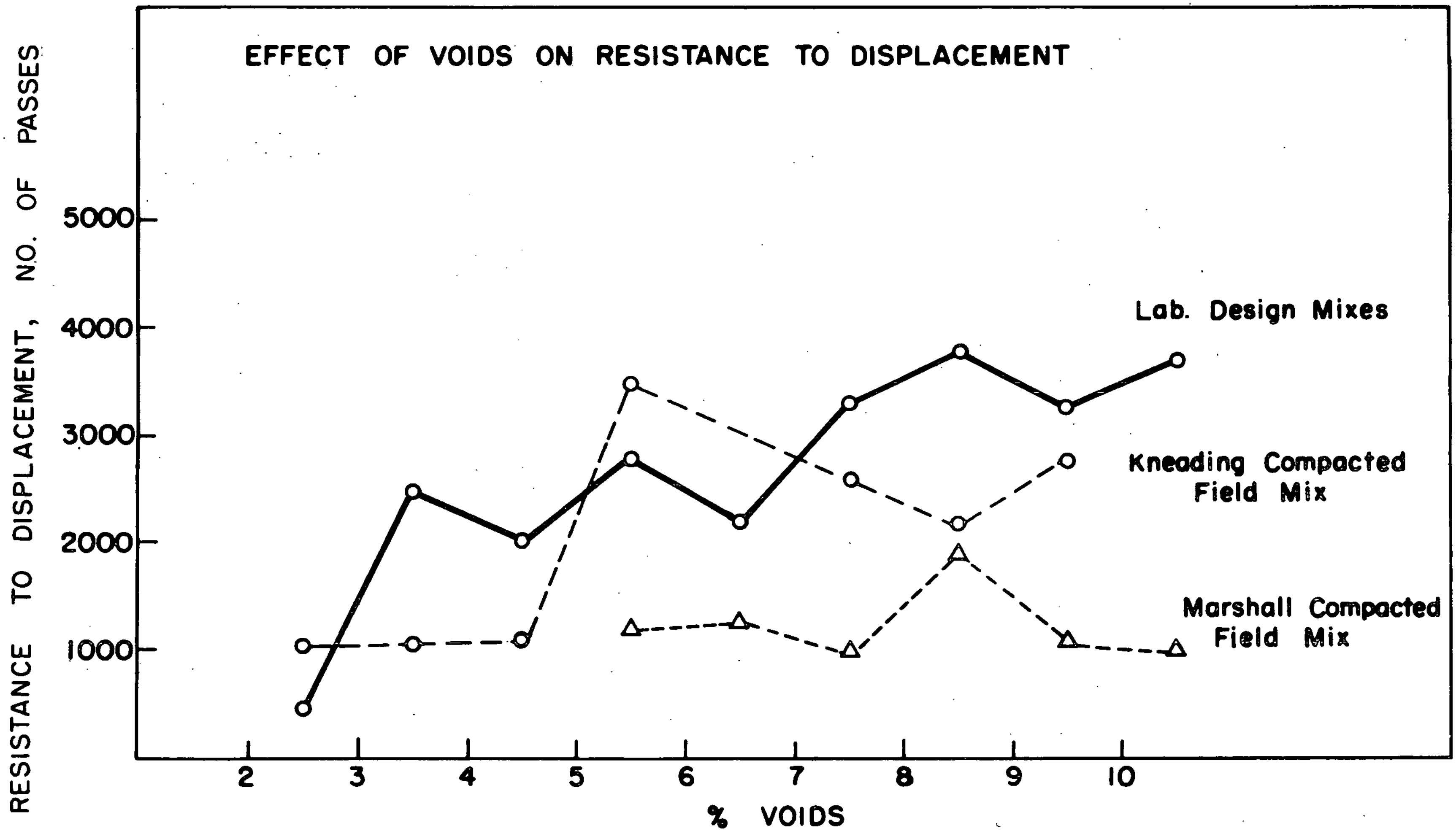
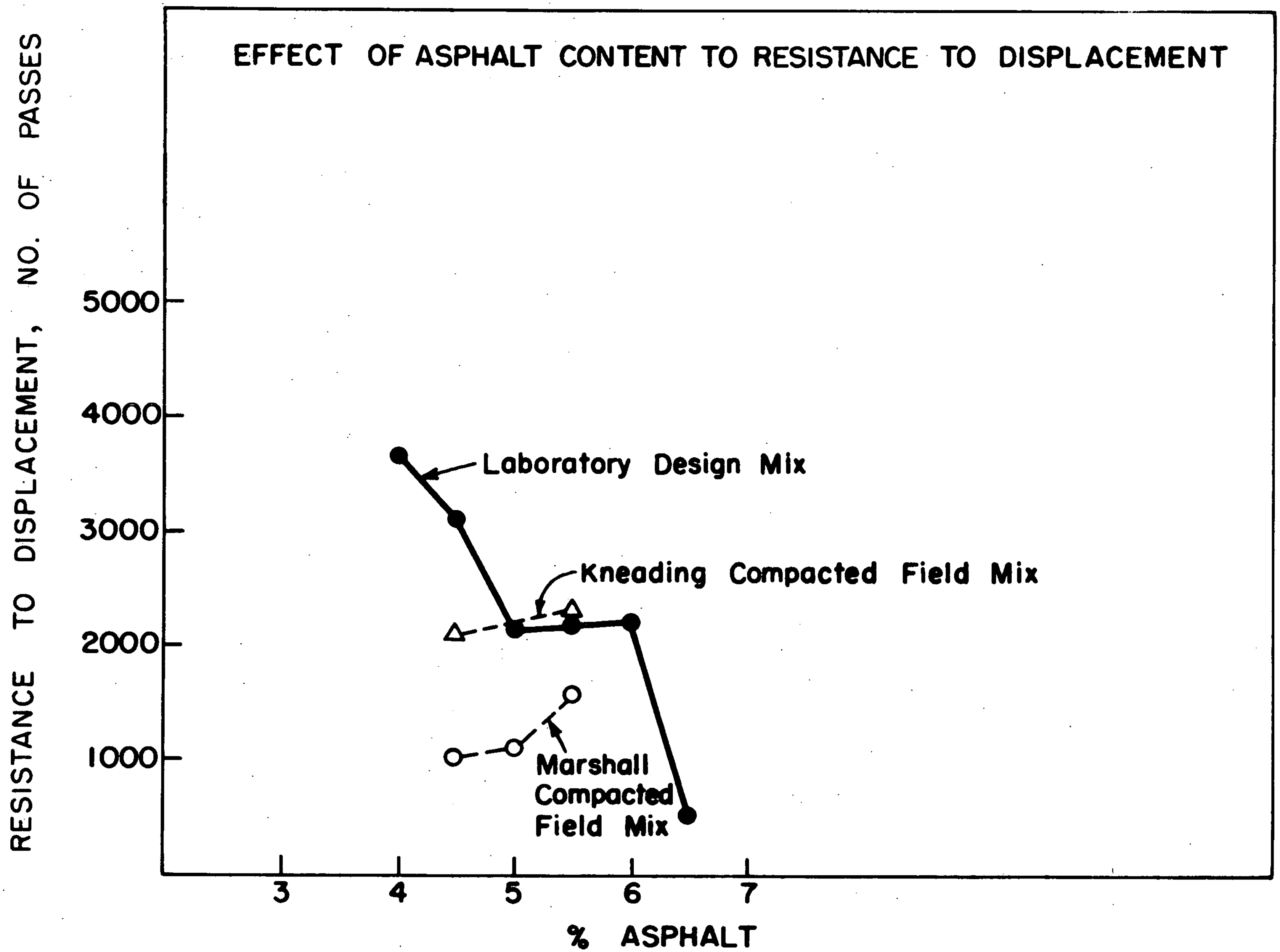

EFFECT OF VOIDS ON RESISTANCE TO DISPLACEMENT
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
2
3
4
5
6
7
8
9
10
% VOIDS
Lab. Design Mixes
Kneading Compacted Field Mix
Marshall Compacted Field Mix

Figure 4.



EFFECT OF ASPHALT CONTENT TO RESISTANCE TO DISPLACEMENT
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
Laboratory Design Mix
Kneading Compacted Field Mix
Marshall Compacted Field Mix
3
4
5
6
7
% ASPHALT

Figure 5.

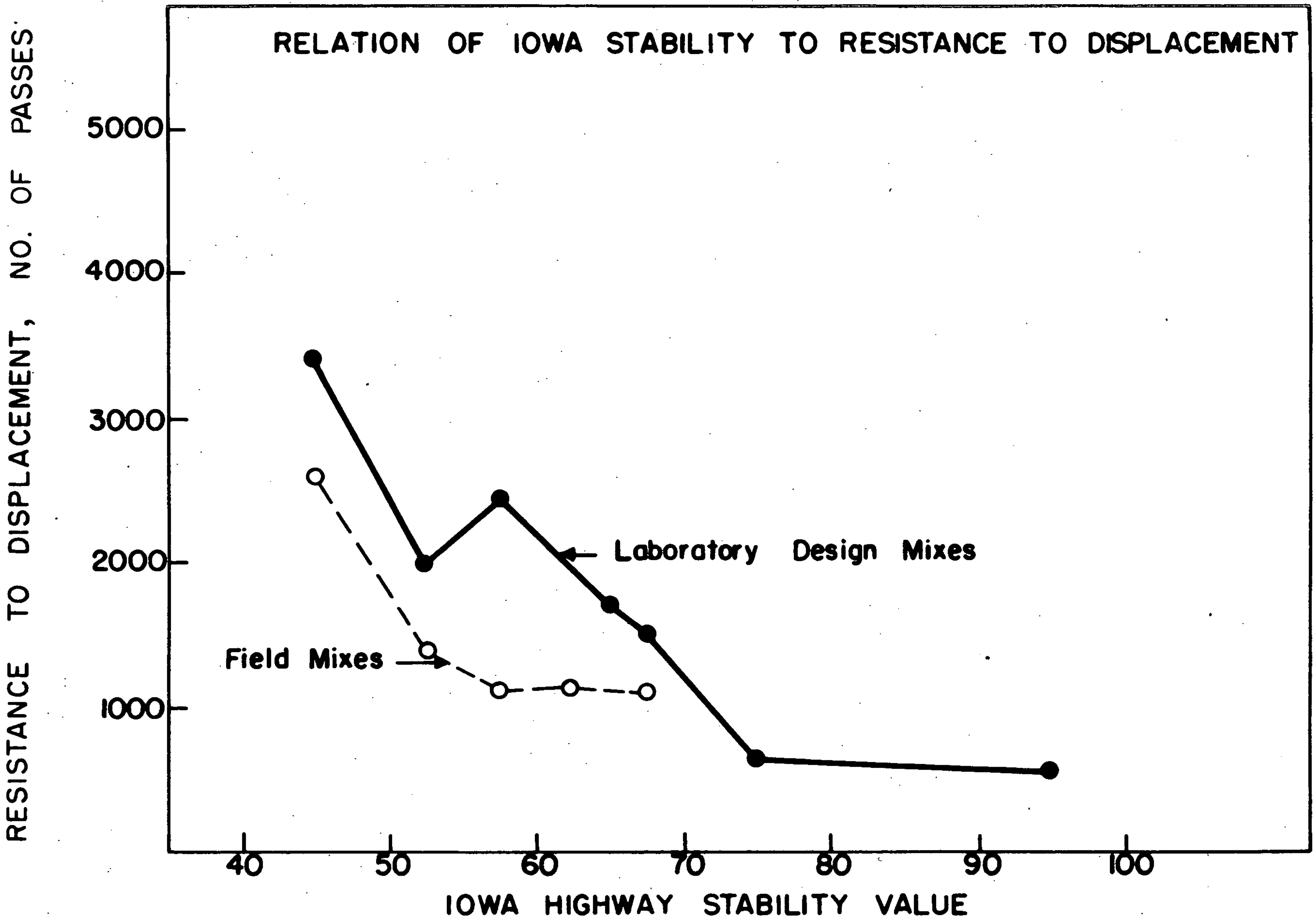

RELATION OF IOWA STABILITY TO RESISTANCE TO DISPLACEMENT
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
Laboratory Design Mixes
Field Mixes
40
50
60
70
80
90
100
IOWA HIGHWAY STABILITY VALUE

Figure 6.

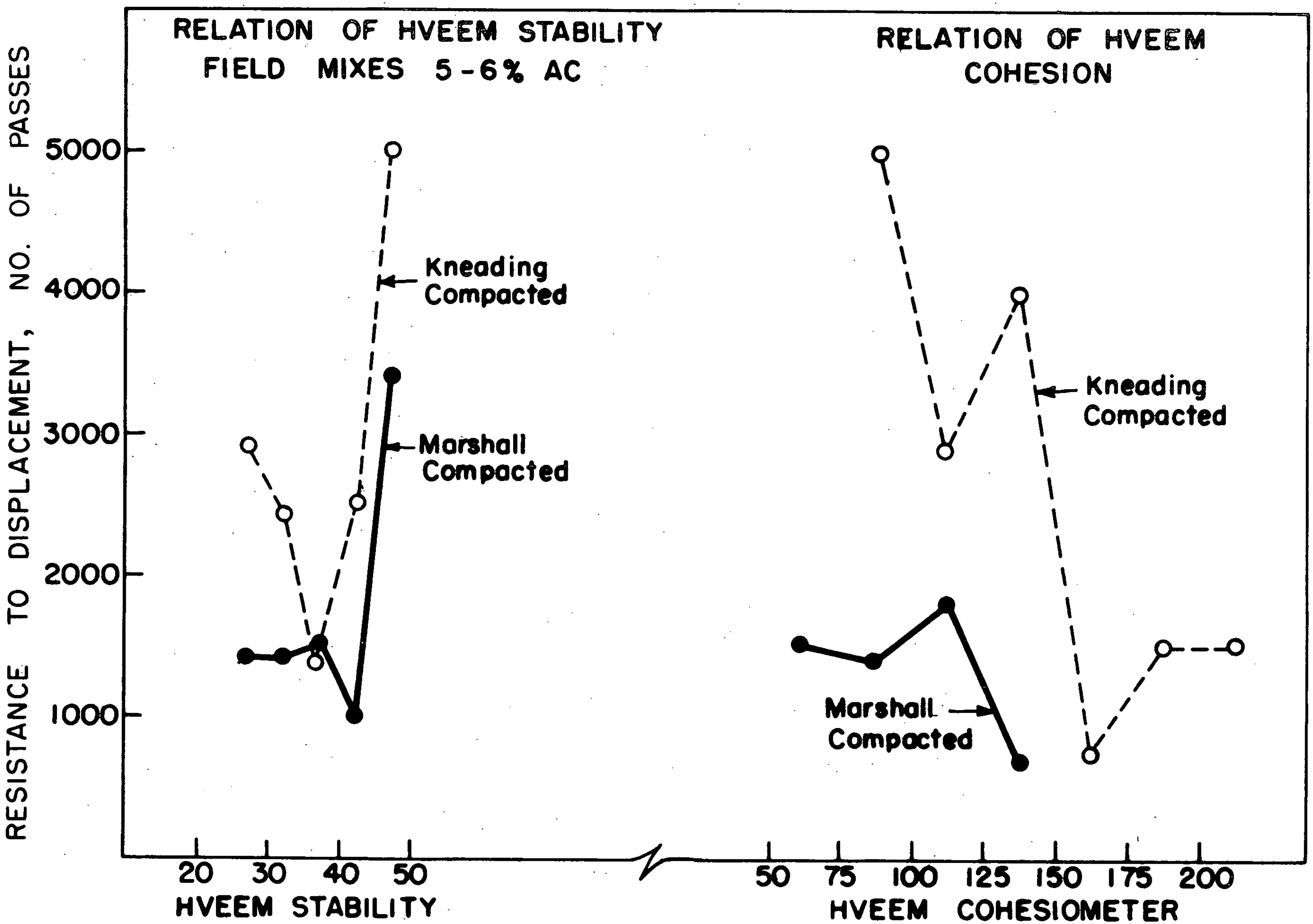


Figure 7.

Figure 8.

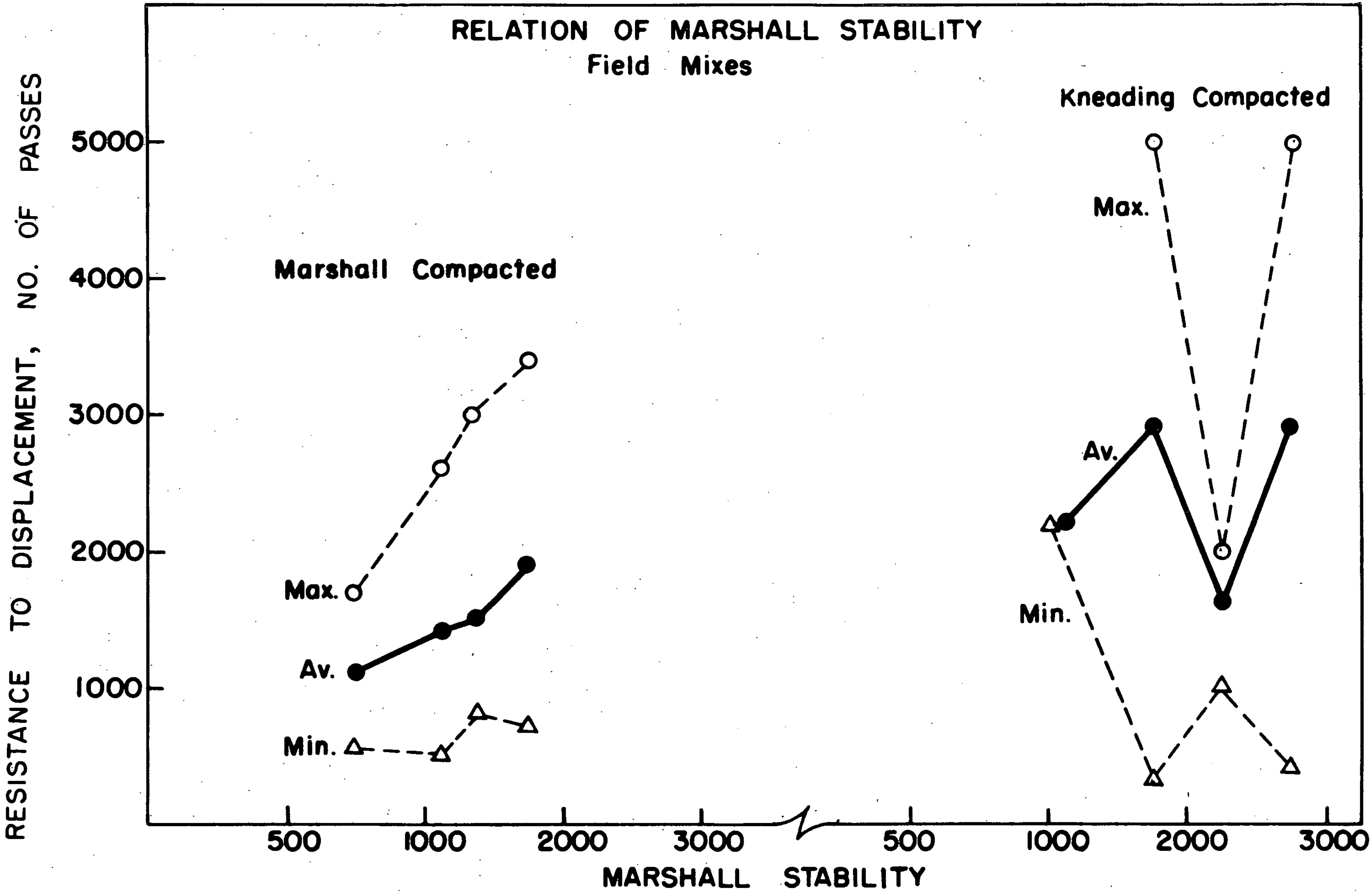

RELATION OF MARSHALL STABILITY
Field Mixes
Marshall Compacted
Kneading Compacted
Max.
Av.
Min.
Max.
Av.
Min.
RESISTANCE TO DISPLACEMENT, NO. OF PASSES
5000
4000
3000
2000
1000
500
1000
2000
3000
500
1000
2000
3000
MARSHALL STABILITY

Figure 9.