Effect of Fillers on Asphaltic Concrete Mixes

LADIS H. CSANYI, RODNEY E. COX, and CHARLES R. TEAGLE
Respectively, Professor in Charge, Bituminous Research Laboratory, Iowa State University, and Captain and Major, U. S. Army Corps of Engineers

This study, attempts to determine the effects on a filler on the properties of asphaltic concrete mixes. Three different types of aggregates, crushed gravel, crushed hard limestone, and crushed soft limestone, were used in conjunction with two different types of fillers, crushed limestone dust and pulverized loess, in the preparation of a series of asphaltic concrete mixes. The mixes contained 0, 2½, 5, 7 and 10 percent minus 200-mesh filler and asphalt contents from 4 to 8 percent of an 85 to 100 penetration asphalt cement. The mixes were tested for Marshall, Hveem and Iowa stabilities; Hveem cohesion; voids in compacted specimens; and trafficability under a moving load in a traffic simulator. A supplementary series of tests was also made to ascertain the effects of small quantities of asbestos added to some of these mixes.

The results of the study indicate (a) that quantity type of filler used in conjunction with fixed quantities of binder have a material effect on the properties of mixes; (b) that the type of aggregate used in mixes containing the same quantities of filler and of binder has its effect on mix properties; (c) that some methods of test for properties of mixes are more sensitive to the effects of fillers than others; (d) that stability alone is not always a dependable criterion in determining mix behavior under moving loads; and (e) that certain quantities of asbestos in certain mixes have a beneficial effect on properties of mixes tested under moving loads.

THE EFFECT of fillers on the properties and behavior of hot-mixed asphaltic concrete mixes prepared by conventional mixing procedures has been fairly extensively studied in the past. Usually the studies have been limited to a specific type of filler with a specific type of aggregate. The purpose apparently has been to determine the optimum quantity of filler for the best results as far as the physical properties and service behavior of the mixes were concerned. The types, characteristics, and properties of the fillers, aggregates, and asphaltic binders varied widely in these studies. It has therefore been difficult to develop theories concerning the function and specific effects of fillers and to apply these theories to the behavior of specific mixes.

Two rather general theories, however, have emerged from the studies. One suggests that the filler, an inert mineral of relatively very fine particle size distribution, serves primarily to fill the voids in the fine aggregate or coarse and fine aggregate combinations. It thereby increases the density of the resulting compacted mix. Another theory suggests not only that the filler fills voids in the aggregate but also that some of the filler hardens and toughens the binder, making a denser, tougher mix because a portion of the fraction of the filler passing the 325-mesh sieve becomes suspended in the asphaltic binder.

The first therory is used extensively in designing asphaltic mixes to control aggregate blending to obtain the desired densities. Filler contents are kept rather low to avoid brittleness and cracking of mixes in service. Some of the minute particles of the filler enter the asphalt, particularly when mixes are prepared with softer asphalts

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and at the upper allowable mixing temperature limits. The latter theory seems to be more typical of actual conditions and may increase in importance with the trend toward control of viscosity of the binder during mixing.

Some difficulties have been found in interpreting and evaluating the results of the studies because of differences in use of the term "filler." This term is often used loosely to designate a mix material with a particle size distribution smaller than the aggregates. Sometimes filler has a particle size distribution from retained on the No. 4 sieve to passing the 200-mesh sieve. At other times all the filler passes the 200-mesh sieve. Specifications often define a filler, regardless of basic origin or chemical composition, as an inert mineral flour or dust having a specified particle size distribution from passing the No. 10 sieve down to passing the 200-mesh sieve. The AASHO filler specifications are much more specific in that gradation is limited to specified quantities passing the No. 30 sieve and passing the No. 200 sieve (1). Some of the studies have included a gradation of the filler. Seldom, however, has that portion of material passing the No. 200 sieve which adheres to the aggregates or are combined within them, as determined by the wash test, been reported. In some instances, especially where softer aggregates are used, this portion may amount to an appreciable quantity. Because the total fraction of all materials passing the No. 200 sieve contained in a mix is known to have a decided effect on mix properties, such totals should be available if realistic evaluations are to be made.

In this study, therefore, the filler will be restricted to the fraction of the mix materials passing the No. 200 sieve, either as part of the aggregate or of the so-called mineral filler.

Purpose and Scope

The purpose of this study was to ascertain the effects on the physical properties of asphaltic concrete mixes of various types and quantities of filler in combination with various types of aggregates.

Separate series of tests were conducted to determine the effect of small quantities of asbestos added to the mixes with the Ocheydan and Garner aggregate and with the limestone filler.

All mixes were tested for Marshall, Hveem, and Iowa stabilities, and voids in compacted specimens and other pertinent data were determined. The test specimens were also subjected to a trafficability test in a laboratory traffic simulator.

Test of Materials

The materials used in the investigation, except the loess and asbestos were obtained from hot-mix Type A asphalt concrete paving projects in the vicinity of Ocheydan, Garner, and Columbus Junction, Iowa. In the project on Iowa Route 9 near Ocheydan, the coarse aggregate being used was crushed gravel; in the project on US 69 near Garner, it was a hard crushed limestone; and in the project on US 218 near Columbus Junction it was a soft limestone.

The fine aggregate was a sand, and the mineral filler was a limestone dust available locally in each area. The loess used as a filler in this investigation was obtained from Carroll County, Iowa, through the courtesy of County Engineer M. L. Schmeiser. The asphaltic binder was an 85 to 100 penetration asphalt cement, and the asbestos was grade 7M06, furnished by the Canadian Johns-Manville Co. To simplify identification, the materials are designated by job source i.e., Ocheydan, Garner, and Columbus Junction. The physical properties of the separate materials are given in Tables 1, 2, 3, and 4.

The damp loess as received from the field was dried in pans on a thermostatically controlled hot plate at 500 F for 24 hr. After

TABLE 1

PHYSICAL PROPERTIES OF ASPHALT CEMENTS

Source	Penetration[a] 77/100/5	Flash Pt.[b] (° F)	Soft. Pt.[c] (° C)	Spec. Grav.[d] at 77 F	Ductility[e] at 77 F
Ocheydan	90	637	50	1.02	150+
Garner	89	602	46	1.03	150+
Columbus Jct.	91	665	48	0.994	150+

[a]By ASTM D-5. [b]By ASTM D-92. [c]By ASTM E-28.
[d]By ASTM D-70. [e]By ASTM D-113.

TABLE 2

PHYSICAL PROPERTIES OF AGGREGATES

Aggregate	Total Percent Passing										Spec. Grav.[a]		L.A. Abrasion[b] (%)	V.M.A.[c] (%)	Unit Wt.[d] (pcf)
	3/4 in.	5/8 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 40	No. 80	No. 100	No. 200	Apparent	Bulk			
Ocheydan:															
3/4 in.	100.0	86.5	55.6	19.6	—	—	—	—	—	2.7	2.73	2.70	25.2	40.9	98.4
3/8 in.	—	—	—	100.0	46.8	5.5	—	—	—	1.9	2.70	2.66	35.2	40.8	95.3
Sand	—	—	—	—	100.0	94.7	33.5	15.5	13.4	8.3	2.74	2.71	—	21.0	127.6
Garner:															
3/4 in.	100.0	92.4	69.8	23.0	3.3	1.4	1.3	—	1.0	0.7	2.79	2.75	25.0	40.5	102.0
3/8 in.	—	—	—	100.0	47.0	3.5	—	—	2.2	1.2	2.78	2.76	27.0	39.6	104.0
Sand	—	—	—	—	100.0	93.0	51.0	18.5	13.2	5.9	2.78	2.74	—	32.7	115.0
Columbus Jct.:															
3/4 in.	100.0	—	57.2	—	3.9	2.0	1.9	1.8	—	1.6	2.66	2.48	28.9	43.3	87.7
3/8 in.	—	—	100.0	99.5	33.6	3.4	1.5	1.4	—	1.2	2.63	2.45	25.6	41.5	87.4
Sand	—	—	—	—	100.0	73.1	21.2	3.9	—	1.1	2.61	2.43	—	31.8	111.4

[a] By ASTM C-127. [b] By ASTM C-131. [c] By ASTM C-30. [d] By ASTM C-29.

TABLE 3

PHYSICAL PROPERTIES OF MINERAL FILLERS

Filler	Total Percent Passing										
	No. 4	No. 8	No. 40	No. 80	No. 100	No. 200	No. 270	No. 325	No. 400	5 μ	1 μ
Ocheydan[a]:											
Dry sieve	100.0	99.5	93.0	69.9	62.6	45.4	—	—	—	—	—
Hydrometer	—	—	—	—	—	—	36.0	32.0	28.0	2.0	—
Garner[b]:											
Dry sieve	100.0	100.0	98.5	84.0	76.5	48.5	—	—	—	—	—
Hydrometer	—	—	—	—	—	—	38.0	34.0	29.5	5.0	2.0
Columbus Jct.[c]:											
Dry sieve	100.0	100.0	90.2	57.9	48.8	27.3	—	—	—	—	—
Hydrometer	—	—	—	—	—	—	25.2	20.0	16.2	3.9	2.2
Carroll Co. loess[d]:											
Dry sieve	100.0	99.4	69.9	53.6	50.2	46.0	—	—	—	—	—
Hydrometer	—	—	—	—	—	—	99.0	96.5	94.0	90.0	24.5

[a] Spec. grav., 2.65. [b] Spec. grav., 2.74. [c] Spec. grav., 2.68. [d] Spec. grav., 2.74.

TABLE 4

PHYSICAL PROPERTIES OF CANADIAN CHRYSOTILE ASBESTOS 7M06

Properties	Values
Specific gravity	2.55
Fiber diameter (in.)	0.000000706 to 0.00000118
Fibrils in 1 in.	850,000 to 1,400,000
Tensile strength (psi)	100,000 to 355,000
Grading, Quebec standard test, minimum wt. (oz)	
1/2 mesh	0
4 mesh	0
10 mesh	1
Pan	15
Quebec standard classification	7M06 Medium bulk and absorption

heating, the loess was lumpy, hard, and dusty. The lumps when struck with a hammer shattered readily and appeared dry inside. The dried loess was then passed through a laboratory hammermill (Fig. 1) and converted to a mineral filler with less than 1 percent moisture and a particle size distribution as shown in Table 3. Raw loess can be converted to a mineral filler in quantities in excess of 25 tons per hour commerically and economically (2).

Composition of Mixes

To study the effect of fillers on the physical properties of mixes, mixes containing 0, 2.5, 5, 7, 7.5, and 10 percent filler were used. Job-mix formulas for each construction job using the coarse aggregates were obtained from the Iowa Highway Commission.

The percentages of each of the aggregates, the ¾- and ⅜-in. coarse aggregates and the sand given in the job-mix formula, were converted to weights to provide a 50-lb blend for these aggregates. The weights of the separate aggregates in the 50-lb blend were held constant for all mixes in each aggregate group. In preparing each of the mixes within a group, local mineral filler or loess was added to the fixed aggregate blend in quantities necessary to provide the minus No. 200 sieve filler content. The aggregates were washed to remove minus 200-mesh material for the zero percent filler content mixes. Aggregates were dry sieved to remove excess minus 200-mesh material for the 2.5 percent filler content mixes. The aggregate-filler composition for each mix was calculated on a basis of percentage of each mineral constituent by weight of

TABLE 5

PROPORTIONS OF MIX CONSTITUENTS USING VARIOUS AGGREGATES

Ocheydan						Garner						Columbus Junction					
-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Filler	Asphalt[a] (%)	-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Filler	Asphalt[a] (%)	-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Filler	Asphalt[a] (%)
						(a) Lime Filler											
0[c]	34.41	23.65	41.94	0	4.12	0[c]	27.18	25.00	47.82	0	4.20	0[c]	35.00	30.00	35.00	0	4.0
					4.62						4.70						4.5
					5.10						5.10						5.0
2½[d]	34.41	23.65	41.94	0	4.12	2½[d]	27.18	25.00	47.82	0	4.17	2½[d]	33.72	28.90	33.72	3.65	4.0
					5.10						5.15						5.0
					6.06						6.12						6.0
5	34.04	23.40	41.49	1.07	5.05	5	25.80	23.74	45.44	5.02	5.00	5	31.46	26.96	31.46	10.10	5.0
					6.00						6.00						6.0
					6.93						7.00						7.0
7	32.54	22.37	39.67	5.42	6.84	7	24.48	22.52	43.09	9.91	5.00	7½	29.86	25.59	29.86	14.67	5.0
					5.75						6.00						6.0
					6.65						7.00						7.0
10	30.42	20.91	37.07	11.60	6.24	10	21.44	19.72	37.74	21.10	5.00	10	24.56	21.05	24.56	29.81	6.0
					7.07						6.00						7.0
					7.88						7.00						8.0
						(b) Loess Filler											
2½[e]	33.44	22.99	40.80	2.77	4.01	2½[e]	26.53	24.40	46.68	2.39	4.00	2½[e]	33.43	28.66	33.43	4.46	4.0
					4.97						5.00						5.0
					6.00						6.00						6.0
5	32.11	22.08	39.14	6.67	4.99	5	26.05	23.94	45.80	4.18	5.00	—	—	—	—	—	—
					6.00						6.00						—
					7.00						7.00						—
7	30.77	21.15	38.02	10.06	5.00	7	24.91	22.92	43.85	8.32	5.00	7	30.83	26.42	30.83	11.90	5.0
					6.00						6.00						6.0
					7.00						7.00						7.0
10	28.95	19.90	35.30	15.85	6.00	10	22.20	20.43	39.08	18.30	6.00	10	29.18	25.00	29.18	16.66	6.0
					7.00						7.00						7.0
					8.00						8.00						8.0

[a] By wt of total mix. [b] By wt of total aggregate. [c] Aggregates wash sieved to remove all -200 material.
[d] Aggregates dry sieved to remove all but 2.5 percent of -200 material.
[e] Filler added to bring total -200 content, including dust on aggregates to desired percentage.

TABLE 6

MIX PROPORTIONS FOR VARIOUS AGGREGATES AND FILLERS WITH ASBESTOS

Ocheydan Agg., Lime Filler							Garner Agg., Lime Filler							Garner Agg., Loess Filler						
-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Lime	Asbestos[a] (%)	Asphalt[a] (%)	-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Lime	Asbestos[a] (%)	Asphalt[a] (%)	-200[a] (%)	Aggregate[b] (%) 3/4 in.	3/8 in.	Sand	Loess	Asbestos[a] (%)	Asphalt[a] (%)
5	34.0	23.4	41.5	1.1	0	5.0	5	25.8	23.7	45.5	5.0	0	5.0	5	26.0	24.0	45.8	4.2	0	5.0
					0	6.0						0	6.0						0	6.0
					0	6.9						0	7.0						0	7.0
5	34.0	23.4	41.5	1.1	1	5.0	5	25.8	23.7	45.5	5.0	1	4.9	5	26.0	24.0	45.8	4.2	1	5.0
					1	5.9						1	5.8						1	6.0
					1	6.9						1	6.7						1	7.0
5	34.0	23.4	41.5	1.1	2	5.0	5	25.8	23.7	45.5	5.0	2	4.8	5	26.0	24.0	45.8	4.2	2	5.0
					2	5.9						2	5.7						2	6.0
					2	6.8						2	6.6						2	7.0
5	34.0	23.4	41.5	1.1	3	4.9	5	25.8	23.7	45.5	5.0	3	4.8	5	26.0	24.0	45.8	4.2	3	5.0
					3	5.8						3	5.7						3	6.0
					3	6.7						3	6.5						3	6.6
7	32.5	22.4	39.7	5.4	0	4.9	7	24.5	22.5	43.1	9.9	0	5.0	7	24.9	22.9	43.9	8.3	0	5.0
					0	5.8						0	6.0						0	6.0
					0	6.7						0	7.0						0	7.0
10	30.4	20.9	37.1	11.6	0	5.4	10	21.4	19.7	37.8	21.1	0	5.0	10	22.2	20.4	39.1	18.3	0	5.0
					0	6.2						0	5.9						0	6.0
					0	7.0						0	6.8						0	7.0
					0	7.9						—	—						0	8.0

[a] By st of total mix. [b] By wt of total aggregate.

total aggregate-filler. Mixes for three different asphalt contents in each minus 200-mesh filler group were prepared (Table 5). The asphalt contents were based on total mix.

A brief study concerning the effect of small quantities of asbestos on the properties of the mixes was included in the over-all study. Asbestos in 1, 2, and 3 percent amounts was added to the Ocheydan-lime, Garner-lime, and Garner-loess mixes containing 5 percent minus 200-mesh material (Table 6).

PREPARATION OF MIXES

All of the mixes used were prepared in the same manner to assure comparative results. Each of the several aggregates used was weighed in quantities sufficient to provide a 50-lb batch having the correct proportions (Tables 5, 6). After being weighed, the

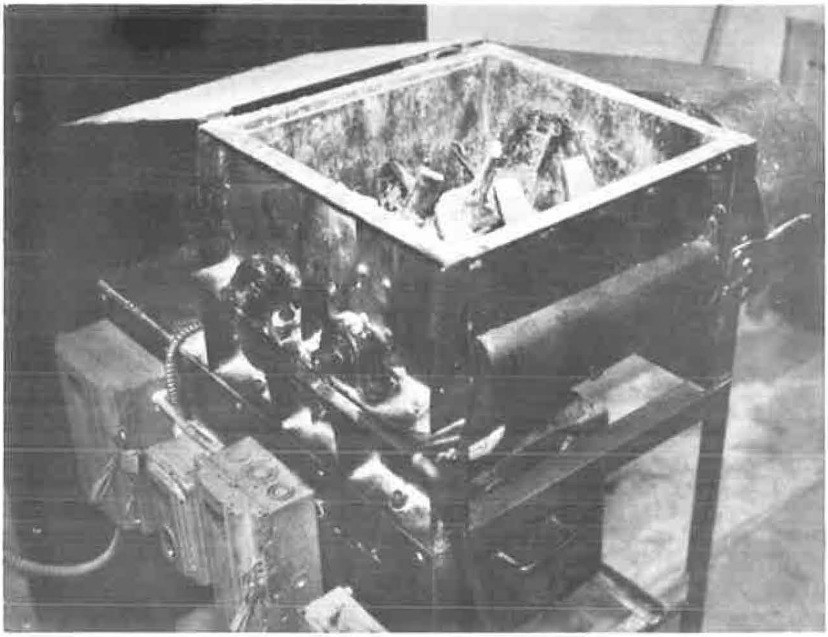


Figure 1. Laboratory twin shaft pugmill mixer.

aggregates were placed in pans with the coarse aggregate on the bottom. The fine aggregate and the filler were spread uniformly over the top. The loaded pans were covered and placed on a thermostatically controlled hot plate where they were heated overnight at 350 F to a uniform temperature of about 325 F.

After being heated, the proportioned aggregate and filler batch was placed in a preheated laboratory twin shaft pugmill mixer (Fig. 1). The aggregates were then dry mixed for 20 sec to assure uniform distribution of the ingredients, then the proper quantity of asphalt cement by weight at a temperature of 300 F was added and was mixed for 40 sec. The total mixing cycle was about 70 sec.

When mixing was completed, the asphaltic concrete was discharged into a pan which was immediately placed on a thermostatically controlled hot plate to keep the mix temperature between 250 and 275 F until the test specimens were molded.

Preparation of Test Specimens

Specimens were prepared for the Marshall stability, flow, percent voids, and percent voids filled with asphalt tests; for the Hveem stability, cohesiometer, both wet and dry, and percent voids in compacted specimen tests; and for the Iowa stability, both wet and dry tests. Additional specimens of each mix were prepared for extraction of asphalt and aggregate gradation checks and for the traffic simulator test.

The Marshall test specimens were prepared by standard procedure in a mechanical compactor (3). The specimens, compacted with 50 blows on each side, were 4 in. in diameter and approximately 2.5 in. high.

For the purpose of this investigation a modification was made in the standard Hveem procedure for compaction (3). The Hveem test specimens were compacted by the static load method rather than by the kneading compactor method for comparison with the Iowa State Highway Commission Stability Test which utilizes the static load method. Therefore, Hveem and Iowa stability and cohesiometer test specimens were compacted as follows: Approximately 1,200 gm of the mix at a temperature between 250 and 275 F were weighed out and placed in a 4-in. diameter mold preheated to 150 F. This mold is so constructed that a double plunger action is effected on the sample under load. Compaction of the specimen is in a static load compression machine capable of a uniform head speed. The specimen is loaded at a rate of 0.05 in./min until a load of 3,000 psi is reached. This load is maintained for 3 min and then released, thus completing the compaction of the specimen.

TESTING OF SPECIMENS

All specimens were allowed to cure in air at a temperature of about 75 F for 24 hr before testing.

Marshall Tests

The Marshall tests for stability, flow, percent voids in compacted specimen, and percent voids filled with asphalt were conducted in accordance with standard procedure (3). Before being tested for stability the specimens were submerged in a water bath at 140 F for 20 to 30 min.

Hveem Tests

The Hveem stability tests conformed to standard procedure (3). The test is outlined here for comparison with the Iowa stability test procedure.

Before being tested for Hveem stability the specimens are placed in an oven at 140 F for at least 1 hr. The specimen is then placed in the Hveem stabilometer, which in turn is placed in a compression test machine. The specimen is given an initial lateral pressure of 5 as indicated on the stabilometer; then the test load is applied at a rate of 0.05 in./min. Readings of the stabilometer gage are recorded at test loads of 500, 1,000, and at each subsequent 1,000 lb thereafter, up to a maximum of 6,000 lb. After attaining 6,000 lb, the load on the specimen is immediately reduced to 1,000 lb. The stabilometer gage is adjusted to 5 again. The dial gage on the pump is adjusted to zero, and the pump handle is turned at a rate of 2 turns per sec until a reading of 100 is obtained on the stabilometer gage. The number of turns required is recorded.

The Hveem stability value is then determined from

$$S = \frac{\dfrac{22.2}{(P_h)(D_2)}}{P_v - P_h} + 0.222 \qquad (1)$$

in which

S = relative stability;
D_2 = displacement of specimen;
P_v = vertical pressure at 5,000 lb total load (400 psi); and
P_h = transmitted lateral pressure corresponding to P_v of 5,000 lb.

The computed value is recorded as Hveem stability-dry. A value of 35 or greater is deemed desirable for Iowa Type A mixes. The stabilometer gage reading at 5,000 lb total was recorded as Iowa stability-dry.

The Hveem cohesiometer tests were conducted according to standard procedure (3). The specimens were heated in an oven at 140 F for about 1 hr before testing. The cohesiometer value was determined by

$$C = \frac{L}{0.08H - 0.178H^2} \qquad (2)$$

in which

C = cohesiometer value;
L = weight in gm causing failure; and
H = height of specimen in in.

In Iowa Type A mixes, a value for C of 50 or greater is considered desirable according to Hveem criteria. The cohesiometer values were recorded as cohesiometer-dry.

Iowa Tests

Preparation, compaction, and curing of test specimens for the Iowa highway tests followed the same procedure as that for the modified Hveem tests.

The test specimens are first immersed in a water bath at 140 F for at least 1 hr. The specimens are then tested by the procedure of the Iowa Highway Commission. The wet-heated specimen is placed in the Hveem stabilometer, which then is set in a compression test machine capable of maintaining a uniform rate of loading. An initial lateral pressure of 5, as indicated on the stabilometer gage, is placed on the specimen, followed by the test load at a rate of 0.05 in./min. Readings on the stabilometer gage are recorded at test loads of 500, 1,000 and each subsequent 1,000 lb thereafter, up to a maximum of 6,000 lb. Up to this point the test procedure is the same as that of the standard Hveem.

The stabilometer gage reading at 5,000 lb vertical load, 400 psi, is the Iowa stability value. A value of 60 or less is deemed desirable for Iowa Type A mixes. These results are recorded at Iowa stability-wet. These tests were extended to acquire data necessary to calculate Hveem stability values, recorded as Hveem stability-wet.

Cohesiometer.—Cohesiometer tests were also conducted on the Iowa specimens in the same manner as for the Hveem specimens except that these specimens were heated in a water bath at 140 F rather than in an oven. These cohesiometer values are listed as cohesiometer-wet.

Extraction Tests

As a check on mix proportions, a representative sample of each mix was extracted in a rotarex extractor in accordance with standard ASTM rotarex procedure (ASTM Designation 1097) (4) with CCl_4 as the solvent. These tests confirmed that all mixes were in compliance with their respective designated proportions.

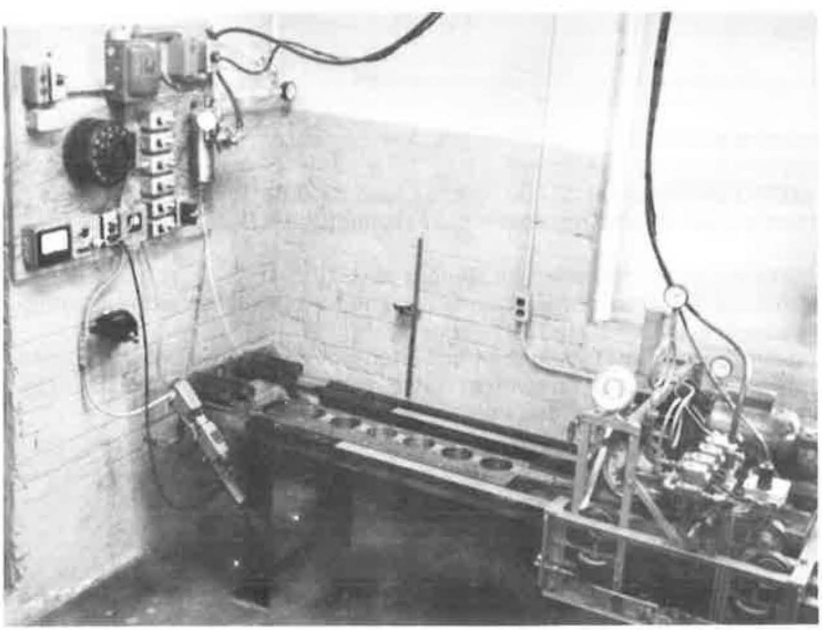


Figure 2. Iowa State University traffic simulator.

Traffic Simulator Tests

Trafficability tests were conducted on a compacted specimen of each mix by a traffic simulator designed and built by the Bituminous Research Laboratory of Iowa State University (Fig. 2). In the traffic simulator, Marshall and Hveem compacted test specimens, heated to and maintained at a temperature of 100 F in the machine, are subjected to a forward driving wheel load equivalent to an 80-psi tire pressure. The drive wheel, 8 in. in diameter and $1\frac{1}{2}$ in. wide, fitted with a soft, solid rubber tire travels over the specimen surface at about 4 mph. Measurements on the surface of the specimen along the wheel track are taken initially and after each 1, 000 passes of the wheel up to 5, 000 wheel passes. Displacement of the surface of the specimen is then calculated and recorded in 0. 001 in. at 1, 000, 3, 000, and 5, 000 passes.

ANALYSIS OF TEST RESULTS

A number of variables, such as aggregates, fillers, test procedures, and the filler and asphalt contents in the mixes, were involved in the investigation. The effect of any one of the variables on the properties of the mixes may be analyzed and evaluated and compared with the effect of any other variable.

The analysis of results in this discussion, however, is limited to the effect of the fillers on the properties of the mix, because this was the primary purpose of the study. Therefore, an analysis is presented of the effect of fillers on the stability, void content, cohesion, and trafficability of the mixes. Each value given is the result of averaging the test results obtained from three Marshall compacted specimens, and from five static load Hveem and Iowa highway compacted specimens.

Effect of Fillers on Stability of Mixes

Marshall Stability—Dynamic Compaction. —In mixes containing 5 percent asphalt and lime filler, stability dropped sharply at 5 percent filler content for both the Ocheydan gravel and Garner hard limestone aggregates (Fig. 3). The loss in stability at this point may be attributed either to the relationship between filler and asphalt or to the orientation of particles or to both. The stability increased with increase in lime filler content above

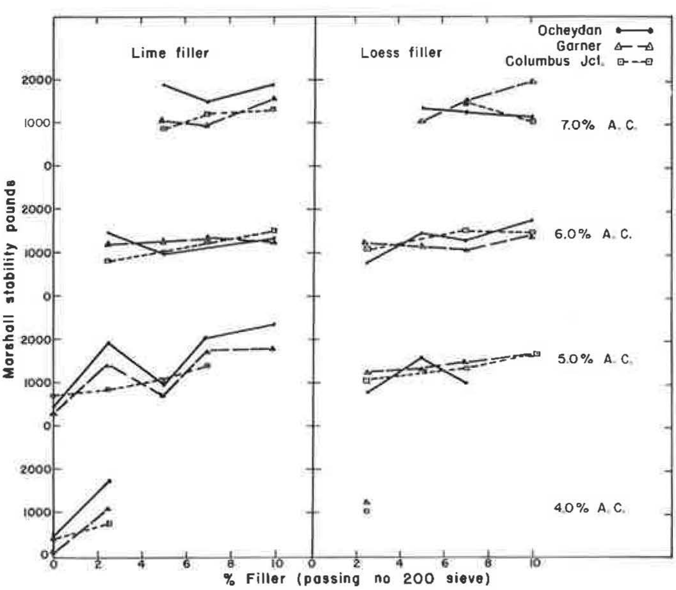


Figure 3.

5 percent. An entirely different trend was shown in mixes containing 5 percent asphalt with pulverized loess as a filler. Ocheydan mixes attained their maximum stability at 5 percent filler content, and Garner and Columbus Junction mixes increased in stability with increase in filler content (Fig. 3). Loess filler appeared to have a smaller effect on stability than lime fillers over a range of filler content. This might be attributed to the interrelationship of the type of filler and the asphalt.

Mixes with lime as a filler and with 6 percent asphalt varied less in stability than those with 5 percent asphalt. The Ocheydan mixes dropped in stability at 5 percent filler content. The Garner mixes attained their maximum stability at 7 percent filler content, and the Columbus Junction mixes showed a steady increase in stability with increase in filler content. The effect of the lime filler with regard to type of aggregate was at a minimum at 7 percent filler content, as indicated by a 250-lb difference only in stability for all aggregate mixes (Fig. 3). When pulverized loess was used as a filler, Ocheydan and Garner mixes showed a slight loss of stability at 7 percent filler. The Columbus Junction mixes attained their maximum stability at this point. The change in stability over the range of loess filler content was somewhat wider than that for lime filler. The stabilities of the loess mixes are slightly higher than those of the lime filler mixes (Fig. 3).

Both the Ocheydan and Garner mixes with 7 percent asphalt had their lowest stability at 7 percent lime filler content. The Columbus Junction mixes increased in stability with increase in lime filler content. But mixes with pulverized loess as the filler gave different results. The Ocheydan mixes showed a slight loss in stability with increase of filler above 5 percent. The Garner mixes showed a sharp increase in stability above 5 percent filler content. And the Columbus Junction mixes dropped sharply in stability above 7 percent filler content (Fig. 3).

A general statement about the effect of the quantity of filler in a mix on its Marshall stability cannot be made. Character of aggregate, type of filler, and asphalt content all must be considered.

Some conclusions from the results of the Marshall stability test procedure are:

1. The quantity of lime filler in a mix had a minimal effect on Marshall stability when the mix contained 6 percent asphalt, regardless of the type of aggregate.
2. The quantity of pulverized loess in a mix had a less effect on Marshall stability than the quantity of lime filler regardless of asphalt content and type of aggregate. This was probably due to the closer interrelationship of the loess filler and the asphalt.
3. The Marshall stability of mixes with soft limestone aggregate increased with increase in filler content regardless of type of filler or asphalt content. This may have been due to a higher degree of degradation from dynamic compaction in this type of aggregate than in the harder aggregates which gave denser specimens for equivalent asphalt and filler contents.
4. Mixes containing loess filler are not as sensitive to increase in asphalt contents as are those with lime fillers. This may be because the loess absorbed or became suspended in the asphalt. Additional studies being conducted appear to favor the latter.

Hveem Stability—Static Compaction. —The Ocheydan aggregate mixes with lime as a filler and with 5 percent asphalt increased in Hveem stability materially with increasing filler content (Fig. 4), perhaps because the increased quantity of filler generates greater internal friction in the mix in relation with the gravelly character of the aggregate. The Garner mixes attained their maximum stability at 5 percent filler, then dropped sharply in stability at 7 percent filler, only to recover again sharply at 10 percent filler content. This behavior may be attributed to the asphalt-filler relationship acting on the internal friction of the mix. There seems to be no direct relationship between this behavior and the void content and the cohesion of these mixes. In the Columbus Junction mixes the quantity of filler between $2\frac{1}{2}$ and 7 percent seemed to have little or no effect on the stability. In mixes with loess as a filler, the Ocheydan mixes increased in stability with increase in filler content much the same as those containing lime as a filler, and for probably the same reason. The Garner mix attained its peak stability at 10 percent filler with considerably lower stabilities at 5 and 7 percent filler content.

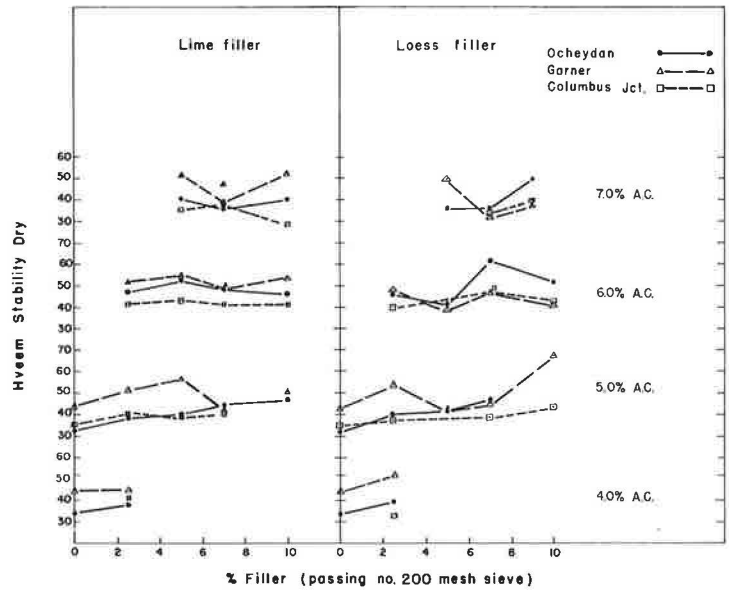


Figure 4.

This behavior does not correlate with void content but does to some degree with cohesion. The highest cohesion is attained at 10 percent filler content. Possibly the intimate relationship between loess filler and the asphalt may be responsible for this behavior. In the Columbus Junction mixes the quantity of filler in the mix seemed to have no effect on stability.

At 6 percent asphalt, Ocheydan mixes with lime filler attained their peak stability at 5 percent filler and then decreased in stability with increase in filler content. The Garner mixes also attained their maximum stability at 5 percent filler, then dropped at 7 percent and recovered stability at 10 percent filler content. The Columbus Junction mixes also reached a maximum stability at 5 percent filler content and then fell off in stability with increased filler; however, the effect of filler content on stability was relatively small. At 6 percent asphalt content the stabilities of all mixes with lime filler were generally higher than similar mixes containing 5 percent asphalt, and the effect of the filler was not quite so marked. When loess was used as a filler, all mixes attained their maximum stability at 7 percent loess filler content, regardless of aggregate type. In the Ocheydan mixes it appears that an interrelation between filler and asphalt occurs which yields peak stability at a sacrifice of cohesion. The Garner and Columbus Junction mixes attained peak stability with high cohesion at 7 percent filler. The shift of peak stability from 5 percent lime filler to 7 percent loess filler might have been caused by the finer gradation of the loess and a more intimate relation between the loess and the asphalt.

The Ocheydan and Garner mixes with lime as a filler and with 7 percent asphalt had their lowest stability at 7 percent filler, with relatively high stabilities at 5 and 10 percent filler. The Columbus Junction mixes, however, showed peak stability at 7 percent filler. All mixes, regardless of type of aggregate, had about the same stability at 7 percent filler content. This group of mixes clearly exhibits the effect of the relationship of filler and asphalt content in a mix. With loess as filler, all mixes behaved much the same with lowest stability at 7 percent filler content. Here also, as in the lime filler mixes, the mixes with loess as a filler have nearly the same stability.

As with Marshall stability, a general statement about the effect of the quantity or type of filler in a mix on its Hveem stability cannot be made. However, the effect of the filler on the properties of mixes differed materially when measured by the Marshall and the Hveem methods of determining stability. This is no doubt due to the differing methods of compaction of specimens and methods of test.

Some conclusions from the results of the Hveem stability test procedure are:

1. Most mixes with lime filler attained their highest stability at 5 percent filler content and those with loess, at 7 percent filler content.
2. The quantity of filler contained in a mix had the least effect on the mixes with 6 percent asphalt, regardless of aggregate type. This was also noted in the Marshall test.
3. All mixes generally, regardless of filler content, met minimum Hveem stability criteria.
4. Loess fillers gave excellent stability values and lime fillers showed better results at lower filler contents, but in the higher percentages loess gave the better stability values (4).

Iowa Stability—Static Compaction. —A value of 60 psi is used as a maximum for acceptable mixes in the Iowa stability—static compaction test. Consequently, the lower the test value the better the stability of the mix (Fig. 5).

In mixes containing 5 percent asphalt and lime as a filler, the stabilities of the Ocheydan and Garner mixes fluctuated slightly but tended toward increasing stability with increasing filler content. The stabilities were generally greater with the peak at 5 percent filler, however, the effect of filler content on stability was small. The stability of the Columbus Junction mixes was considerably lower than that of the other mixes and the quantity of filler had practically no effect. When loess was used as a filler, the stability of the Ocheydan mixes improved with increase of filler from $2\frac{1}{2}$ to 7 percent. That of the Garner mixes fluctuated markedly and showed a sharp loss at 5 percent, an equally sharp gain at 7 percent, and another sharp loss at 10 percent of filler content. This behavior of the Garner mixes seems to correlate with the void content of the test specimens. Because the specimens were tested for stability after immersion in hot water, absorption of moisture by the specimen and its effect on the loess filler may be responsible for this behavior. The quantity of filler up to 7 percent had little effect on the stability of the Columbus Junction mixes; however, at 10 percent filler content stability showed a decided improvement.

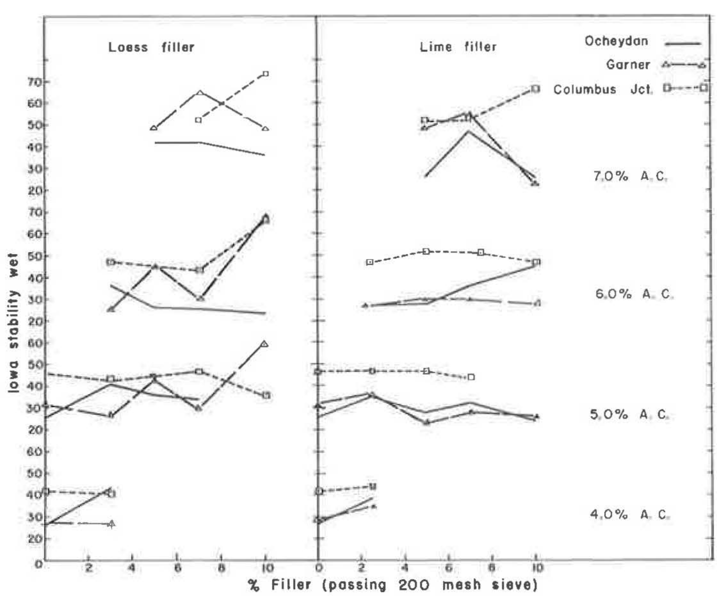


Figure 5.

In mixes with 6 percent asphalt and lime as a filler the quantity of filler in a mix had no effect on the stability of the Garner and Columbus Junction mixes. The loss in stability was sharp, however, with filler contents in excess of 5 percent in the Ocheydan mixes. When loess was used as a filler, the Ocheydan mixes improved in stability somewhat with filler contents in excess of 5 percent. The Garner mixes fluctuated widely in stability with increase in filler; stability dropped at 5 percent, recovered at 7 percent, and dropped to an unacceptable level at 10 percent filler contents. The Columbus Junction mixes were little affected by filler contents up to 7 percent, and then dropped sharply to an unacceptable level at 10 percent. The behavior noted in this group of mixes seems to be related almost directly to the voids in the test specimens.

In the 7 percent asphalt and lime filler mixes, the Ocheydan and Garner mixes lost stability from 5 to 7 percent regained stability sharply at 10 percent filler content. The Columbus Junction mixes had relatively low stability at 5 and 7 percent filler contents and dropped sharply to unacceptable values with 10 percent lime filler. There is no correlation with voids in test specimens. With loess as a filler, the Ocheydan mixes improved slightly in stability with increase in filler content; the Garner mixes lost stability at 5 to 7 percent and recovered it at 10 percent filler content. The Columbus Junction mixes lost stability from 7 to 10 percent filler content and dropped to unacceptable values at 10 percent loess filler content.

Effect of Filler Content on Stability in General. —The test results indicate that no general statement concerning the effect of fillers on the stability of an asphaltic concrete mix can be made. The effect of the filler on stability of a mix varies with the method of test used to determine stability, the character of the aggregates, and the quantity of asphalt contained in the mix.

The effect of the filler in mixes containing the same aggregate and same quantity of asphalt on stability as measured by the different methods was inconsistent and frequently showed a direct reversal of stability between methods. A test method often was quite sensitive to the variation in filler content with some mixes and was least sensitive with others.

The effect of fillers also varied with asphalt content of a mix. The amount of variation depended on the method used to determine stability. The least variation noted, regardless of method of test, was in mixes containing 6 percent asphalt. In such mixes the effect of the filler on stability seemed to be minimal.

The type of aggregate contained in a mix also had a definite bearing on the effect of a filler on stability. The effect of a filler was much greater in mixes containing hard aggregates, such as the Ocheydan and Garner. The filler usually had little effect with a softer aggregate, such as the Columbus Junction.

Effect of Fillers on Void Contents

Dynamic Compaction—Marshall Method. —Void contents of the test specimens (Fig. 6) compacted by the Marshall method of dynamic compaction were determined by standard procedures (5). The results were analyzed on the basis of type and quantity of filler, type of aggregate, and quantity of asphalt contained in the mix. The results indicated that the voids in the compacted specimens decreased with increased quantity of asphalt, regardless of type or quantity of filler or type of aggregate.

In mixes using lime as the filler a rather unusual effect was observed. The Ocheydan mixes showed an increase in voids at 5 percent filler and a decrease at 7 and 10 percent filler content in mixes containing 5 and 6 percent asphalt. At 7 percent asphalt the lowest void content appeared at 7 percent filler with an increase in voids at 10 percent filler content. In the Garner mixes with 5 percent asphalt, the voids increased similarly at 5 percent filler and decreased at 7 percent, and again increased at 10 percent filler content. At 6 and 7 percent asphalt contents the lowest voids were at 5 percent filler, followed by a relatively sharp increase in voids with increased filler content. The Columbus Junction mixes with 5 percent asphalt increased in voids up to 5 percent filler, then decreased with additional filler content. At 6 and 7 percent asphalt content the voids decreased with filler up to 7 percent and then increased at 10 percent filler.

When loess was used as a filler, the Ocheydan mixes attained their lowest void content at 5 percent filler and then increased sharply with additional filler, regardless of

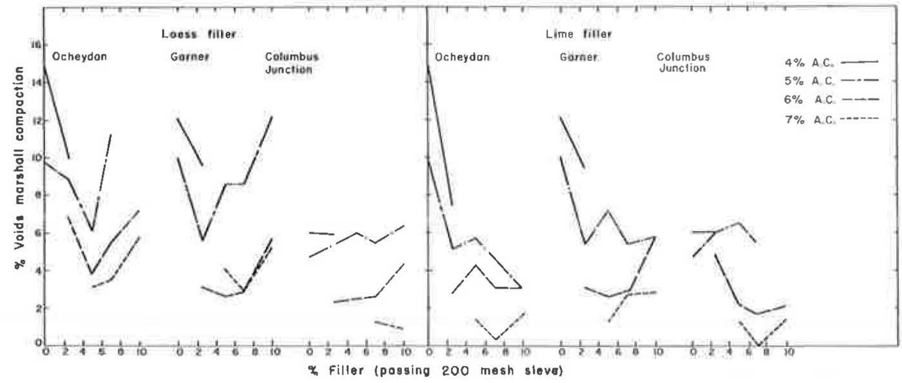


Figure 6.

asphalt content. The Garner mixes with 5 percent asphalt increased in voids with increase in filler content. At 6 percent asphalt the lowest void content was at 5 percent filler and at 7 percent asphalt, at 7 percent filler content. In the Columbus Junction mixes with 6 and 7 percent asphalt, voids increased with increase in filler content.

Static Compaction. —The voids in specimens compacted by static means (Fig. 7) were determined in the same manner as for those compacted by dynamic means (5).

With lime as a filler, the specimens of Ocheydan mixes compacted by the static method behaved much the same as those compacted by dynamic means. The rise in voids at 5 percent filler was followed by a decrease with increase in filler. The behavior of Garner and Columbus Junction mixes varied only slightly. The Garner mixes attained their lowest voids at 5 percent filler; the Columbus Junction mixes attained theirs at 7 percent. The method of compaction had slight effect on these mixes, because much the same trends in void contents with filler content were noted.

When loess was the filler in the Ocheydan mixes with 5 percent asphalt, the lowest void content was at 5 percent filler. At 6 percent asphalt the greatest void content was at 5 percent filler, followed by a decrease in voids with increase in filler content. In the Garner mixes the voids increased rather sharply with increase in filler content. In the Columbus Junction mixes with 5 percent asphalt the voids increased up to 7 percent filler, then decreased at 10 percent filler content. At 6 percent asphalt, voids increased with the increase in amount of filler.

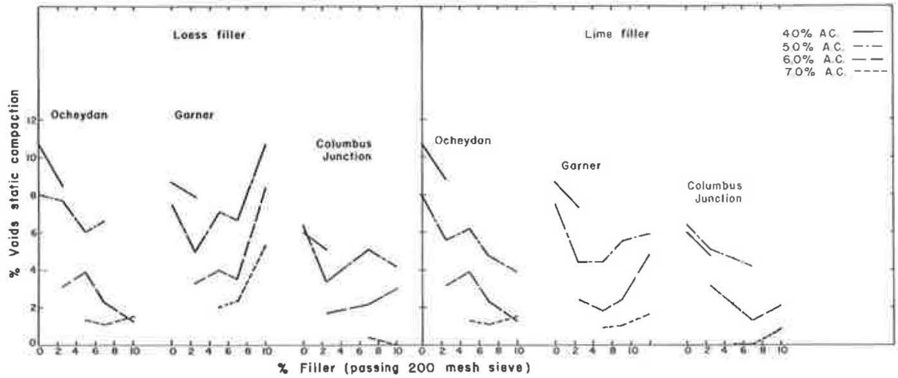


Figure 7.

General Effect of Fillers on Voids.—No specific trends were shown. The void content of a compacted specimen, however, was affected by its asphalt content to a greater degree than by either the type or quantity of filler. Often the method of compacting specimens had only slight effect on void content. Mixes with loess as a filler usually had higher void contents than similar lime mixes. This may be due to the method of determining voids or to a closer relation between filler and asphalt in which more of the loess, because of its finer particle size or mineral properties, becomes suspended in the asphalt.

Effect of Fillers on Cohesion

Only the statically compacted specimens were tested by the Hveem cohesiometer. In the test, normal procedures were followed for specimens heated in an oven at 140 F to determine dry cohesion. Other specimens were immersed in a water bath at 140 F to determine wet cohesion (Fig. 8). According to Hveem cohesiometer criteria, cohesion values above 50 are desirable for high-type asphaltic concrete mixes.

When lime was the filler, the Ocheydan mixes had their lowest cohesion at 5 percent filler which then increased sharply with increase in filler content. The Garner mixes with 5 percent filler also were lowest in cohesion, which increased gradually with additional filler except for the mix containing 7 percent asphalt which increased rather sharply. The Columbus Junction mixes at 5 and 6 percent asphalt increased in cohesion with increase in filler up to 7 percent filler content and then decreased with the further increase of filler; but mixes with 7 percent asphalt had their lowest cohesion at 7 percent filler. Regardless of the variations in cohesion, all mixes had cohesion values well above the 50 minimum criteria. No correlation between cohesion, stability, and voids was found. The lime filler seemed to exert its greatest effect on the Ocheydan mixes and the least on the Garner mixes.

When loess was the filler, Ocheydan mixes with 5 percent asphalt attained their highest cohesion with 5 percent filler, and then decreased in cohesion with additional filler. At 6 percent asphalt the cohesion increased with increase in filler content. The Garner mixes, regardless of asphalt content, increased in cohesion sharply from 5 to 7 percent filler and then increased gradually in cohesion with additions of filler up to 10 percent. The Columbus Junction mixes with 6 percent asphalt increased in cohesion with increase in filler, and those with 5 percent asphalt developed an unusually high cohesion value of 920 with 7 percent filler. Loess as a filler did not have as much effect on the cohesion of the Ocheydan and Garner mixes as did the lime, however, its effect on the Columbus Junction mixes was extraordinary. The cohesion values of all mixes with loess were above the minimum.

Filler itself generally has no effect on cohesion. However, there is a define relationship between filler and asphalt that has a decided effect on the cohesion of a mix.

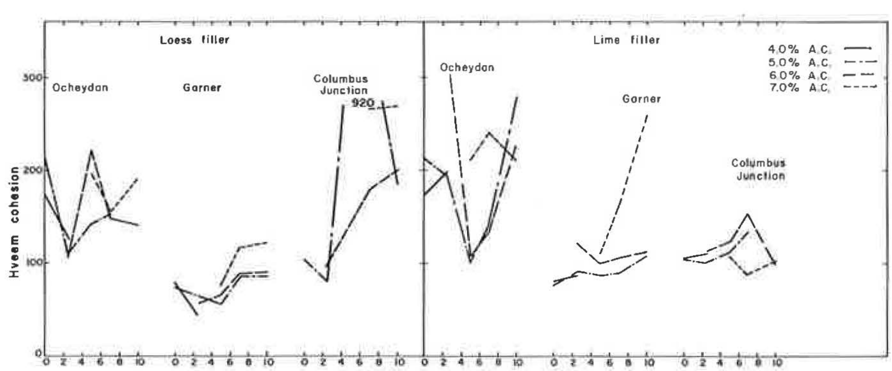


Figure 8.

The filler combined with asphalt evidently modifies the physical properties of the asphalt which then acts as the cementing agent to make it stronger, tougher, and more adhesive. A separate study has been undertaken to explore the extent of the relationship between filler and asphalt to seek an explanation of its effect not only on cohesion but also on voids and stability. Wet cohesion values were generally higher than dry cohesion values for most mixes.

Effect of Filler on Trafficability

Compacted specimens of all mixes were tested in the traffic simulator to compare their resistance to displacement under moving loads (Fig. 9). In the traffic simulator tests, the displacement in excess of 0.125 or $\frac{1}{8}$ in. of a mix, after 5,000 passes by the wheel load, seems to indicate that the mix may not resist rutting or channelizing under heavy traffic volumes.

In mixes with lime as filler, the dynamically compacted specimens of Ocheydan and Garner mixes with 5 percent asphalt improve in trafficability with increase in filler content, attaining the arbitrary criteria of maximum displacement of $\frac{1}{8}$ in. for 500 passes with filler contents of 5 percent and greater. In similar mixes statically compacted, the behavior is much the same as noted for mixes dynamically compacted, except that a slight loss in resistance to traffic occurs with 10 percent filler content. The Columbus Junction mixes all showed excellent trafficability, well within the criteria, regardless of filler content or method of compaction. At 6 percent asphalt the dynamically compacted mixes varied widely in behavior. The Ocheydan mixes improved in trafficability with increase in filler content up to 7 percent and met criteria at 5 percent. At greater than 7 percent filler the mixes went above the limit. The Garner mixes failed to meet criteria in mixes containing less than 10 percent filler. All Columbus Junction mixes met trafficability criteria. In statically compacted mixes all those up to 7 percent filler met the criteria. At greater than 7 percent filler, the Ocheydan and Garner mixes tended to show distress under traffic. At 7 percent asphalt all Ocheydan and Garner mixes failed to meet criteria, regardless of filler content or method of compaction, although these mixes met stability requirements for high-type pavements. All Columbus Junction mixes met trafficability criteria.

The specimens from dynamically compacted Ocheydan and Columbus Junction mixes with loess as a filler and with 5 percent asphalt are within trafficability criteria with

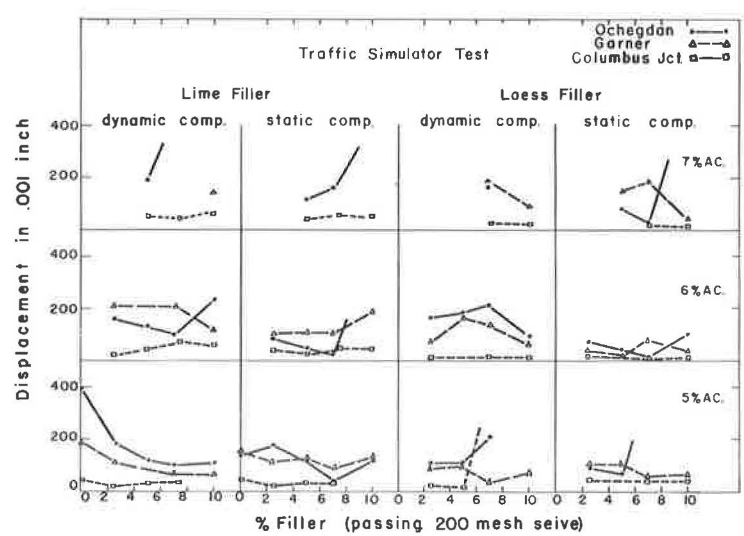


Figure 9.

filler contents up to 5 percent, but above that they lose trafficability sharply. The Garner mixes met criteria, with best results at 7 percent filler content. In mixes statically compacted, both the Garner and Columbus Junction mixes met criteria over the entire range of filler content. The Ocheydan mixes with more than 5 percent loess filler failed. At 6 percent asphalt, dynamically compacted, only the Ocheydan mix with 10 percent filler met criteria. The Garner mixes with 7 percent filler and more, and the Columbus Junction mixes over the full range of filler content, met criteria. All statically compacted mixes met criteria over the entire range of filler content. At 7 percent asphalt, all dynamically compacted Ocheydan mixes failed to meet criteria. The Garner mix with 10 percent filler and all Columbus Junction mixes with 7 percent or more of filler met criteria. The same statically compacted Ocheydan mixes with 5 and 7 percent filler met the criteria, as did the statically compacted Garner mixes with 5 and 10 percent filler and the statically compacted Columbus Junction mixes with more than 7 percent filler. The statically compacted mixes with loess showed a better resistance to traffic than similiar mixes with lime over the range of asphalt content.

No direct relationship between either type of quantity of filler and trafficability is evident from these test results. The degree of resistance to traffic seemed to depend largely on asphalt content and method of compaction. Generally, lower asphalt contents and static compaction yielded the higher resistance to displacement in the harder aggregate mixes. Surprisingly, the softer Columbus Junction aggregate mixes displayed the best resistance to traffic displacement, regardless of asphalt or filler content and method of compaction. No direct correlation of trafficability with void content or with stability of mixes is evident. Many mixes with high stability failed to meet trafficability criteria. Several mixes with comparatively low stability showed excellent resistance to displacement under a moving wheel load. This confirms field observations that mixes of apparently adequate stability show considerable distress by rutting or channeling in the wheel tracks of pavements carrying heavy traffic.

Effect of Asbestos as Additive

A special study was undertaken to ascertain some of the effects on mix properties of the addition of small quantities of asbestos (6). The mixes used in this phase of the investigation included the Ocheydan aggregate with 5 percent lime as the filler, the Garner aggregate with 5 percent lime and with 5 percent loess as the filler and with 5, 6, and 7 percent asphalt contents. Other mixes with 7 and 10 percent filler were used only for comparison (Table 6). Test mixes were prepared with the basic proportions and 1, 2, and 3 percent asbestos by weight with 5, 6, and 7 percent asphalt content. The mixes were tested for Marshall, Hveem, and Iowa stability, voids in compacted specimens, Hveem cohesion, and trafficability in the traffic simulator in the manner described previously (Figs. 10, 11, 12, and 13).

Effect of Asbestos on Stability. —The Marshall stabilities of the Garner-lime mixes were materially improved by the addition of asbestos, with 3 percent addition making the greatest improvement. In the Garner-loess mixes no improvement in Marshall stability was secured with the addition of 1 or 2 percent asbestos, but stability increased greatly when 3 percent asbestos was added. The addition of asbestos increased the stabilities of the Ocheydan-lime mixes containing 5 and 6 percent asphalt, but markedly reduced the stability of mixes with 7 percent asphalt.

The results of the test indicate that addition of asbestos lowered the Hveem stabilities of the Garner-lime mixes. The Hveem stabilities of the Garner-loess and the Ocheydan-lime mixes were materially improved by the addition of asbestos, and the 2 percent addition provided the greatest increase.

The Iowa stability of the Garner-lime mixes was adversely affected by the addition of 2 to 3 percent asbestos in mixes containing 6 percent or less of asphalt, but was materially improved by addition to mixes containing 7 percent asphalt. The addition of asbestos to the Garner-loess mixes generally improved their stabilities. The Iowa stabilities of the Ocheydan-lime mixes were adversely affected by the addition of 1 percent asbestos, and addition of greater amounts had little or no beneficial effects.

The test results clearly indicate that the method of determining the stability of a mix had a decided bearing on the evaluation of the effect of the quantity of asbestos added to a mix.

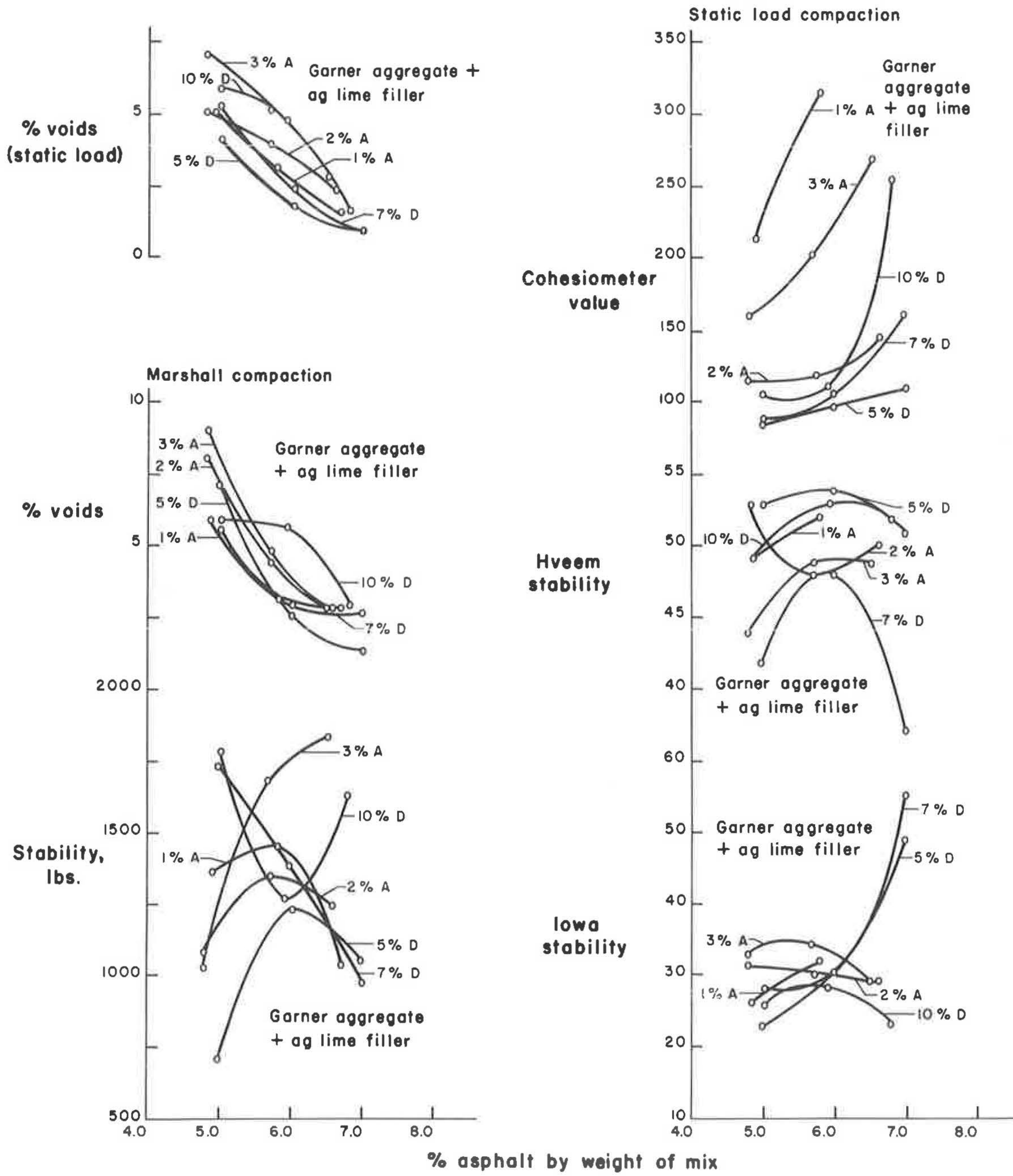
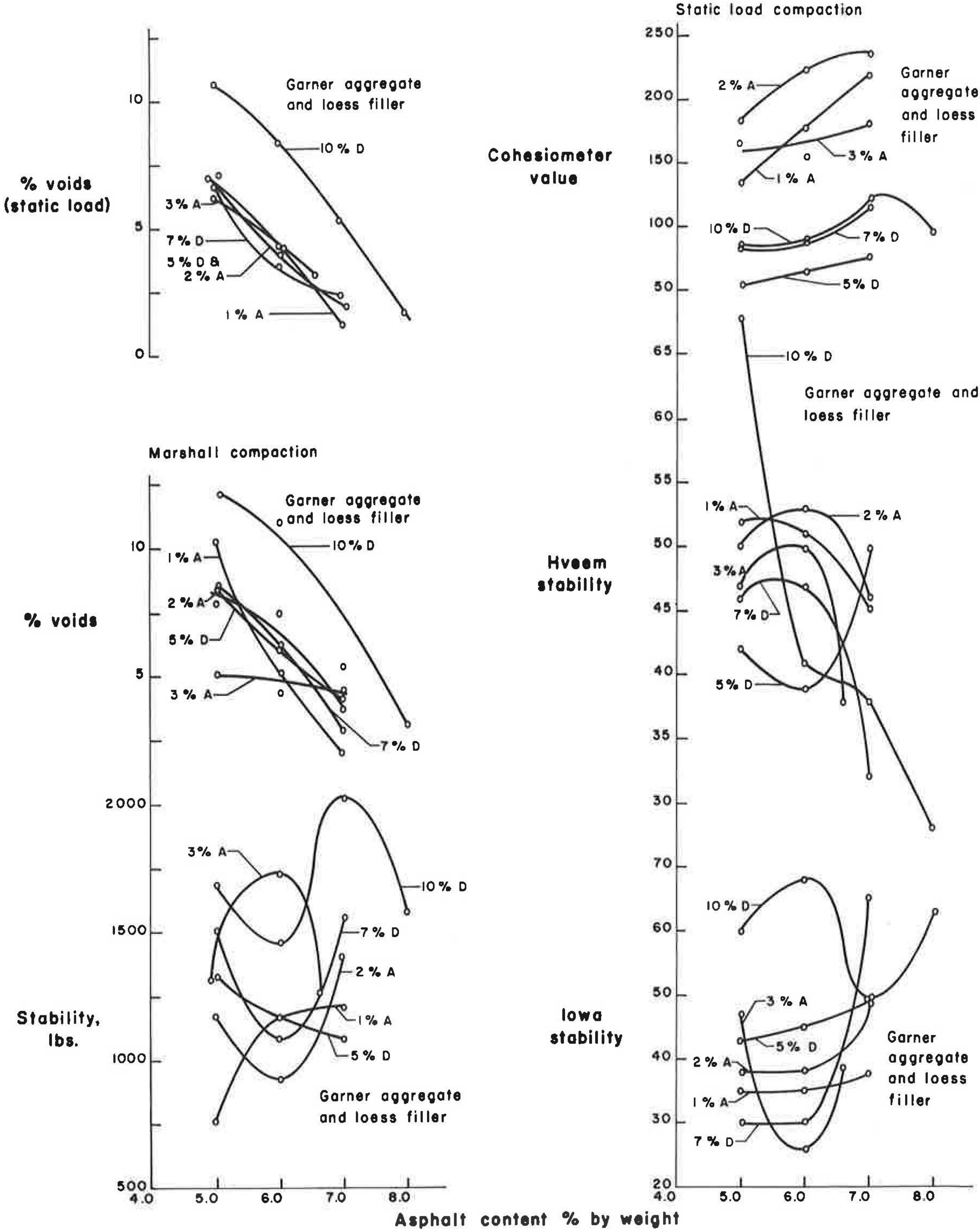
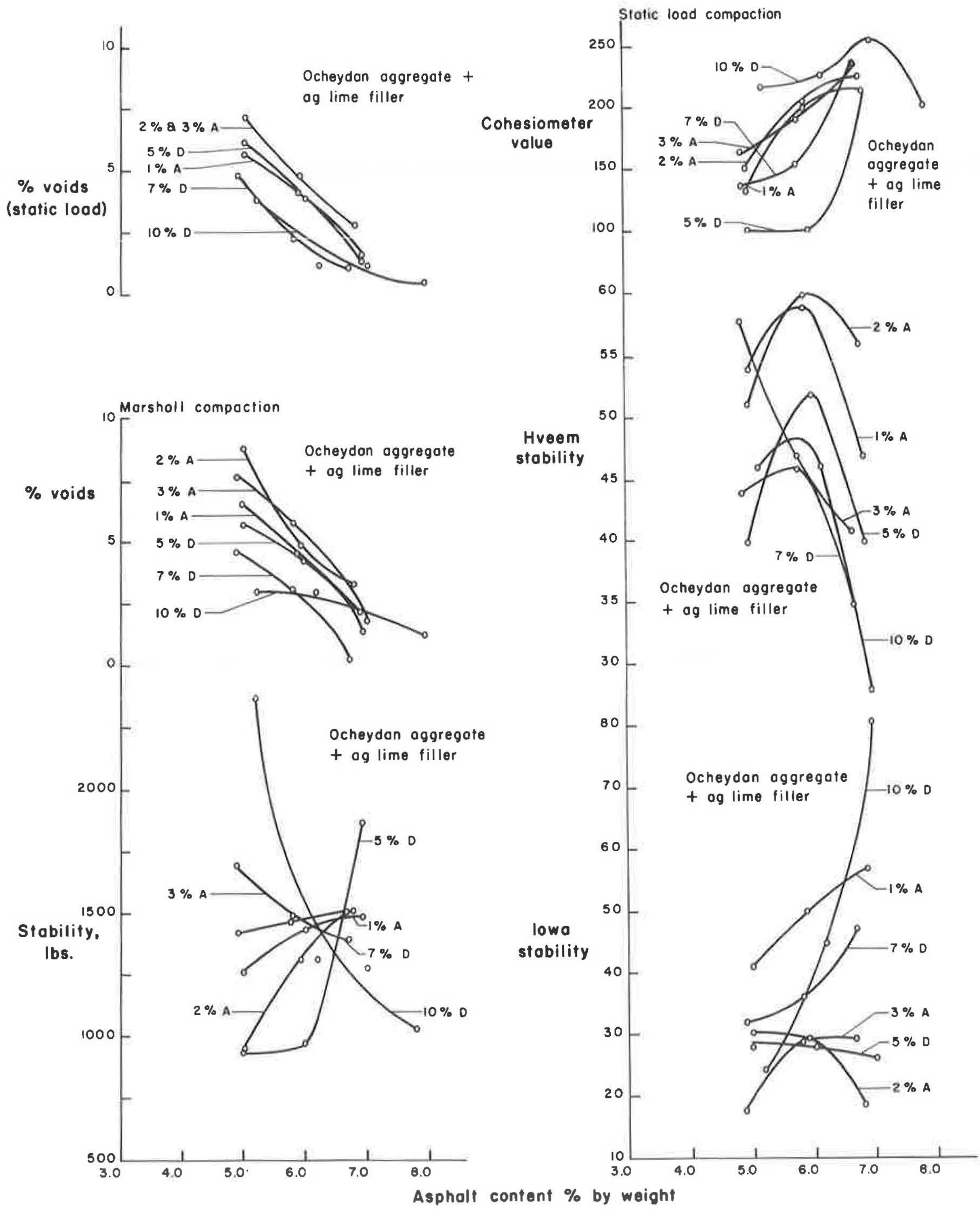

Static load compaction
% voids (static load)
Garner aggregate + ag lime filler
3 % A
10 % D
2 % A
1 % A
5 % D
7 % D
Marshall compaction
% voids
Garner aggregate + ag lime filler
3 % A
2 % A
5 % D
1 % A
10 % D
7 % D
Stability, lbs.
Garner aggregate + ag lime filler
3 % A
10 % D
1 % A
2 % A
5 % D
7 % D
Cohesiometer value
Garner aggregate + ag lime filler
1 % A
3 % A
10 % D
7 % D
2 % A
5 % D
Hveem stability
5 % D
10 % D
1 % A
2 % A
3 % A
7 % D
Garner aggregate + ag lime filler
Iowa stability
Garner aggregate + ag lime filler
7 % D
5 % D
3 % A
1 % A
2 % A
10 % D
% asphalt by weight of mix

Figure 10.



Garner aggregate and loess filler
% voids (static load)
10 % D
3 % A
7 % D
5 % D & 2 % A
1 % A
Marshall compaction
% voids
Stability, lbs.
Static load compaction
Cohesiometer value
Hveem stability
Iowa stability
2 % A
5 % D
Asphalt content % by weight

Figure 11.



Static load compaction
Ocheydan aggregate + ag lime filler
2 % & 3 % A
5 % D
1 % A
7 % D
10 % D
% voids (static load)
Cohesiometer value
10 % D
7 % D
3 % A
2 % A
1 % A
5 % D
Marshall compaction
% voids
2 % A
3 % A
1% A
5 % D
7 % D
10 % D
Hveem stability
2 % A
1 % A
3 % A
5 % D
7 % D
10 % D
Stability, lbs.
5 % D
3 % A
1% A
7 % D
2 % A
10 % D
Iowa stability
10 % D
1 % A
7 % D
3 % A
5 % D
2 % A
Asphalt content % by weight

Figure 12.

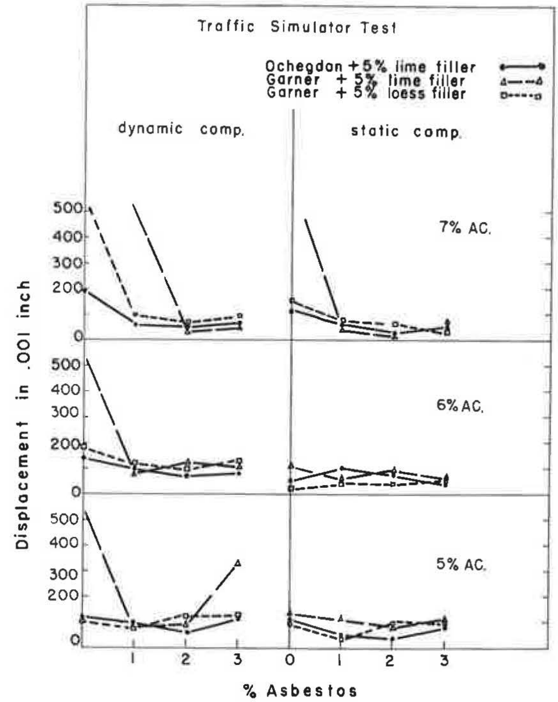


Figure 13.

Effect of Asbestos on Voids. — In the Garner-lime mixes, dynamically compacted, addition of 1 percent asbestos reduced voids in mixes having 6 percent or less of asphalt, but 2 and 3 percent asbestos increased voids, regardless of asphalt content. In the same statically compacted mixes, voids increased with addition of asbestos.

In the dynamically compacted specimens of Garner-loess mixes, the addition of 1 percent asbestos reduced voids in the mixes with 5 percent or more asphalt, but 2 percent asbestos had no effect. The addition of 3 percent asbestos reduced voids in mixes having 6 percent or less asphalt. The statically compacted specimens of the same mixes showed little change in voids with added asbestos.

The addition of asbestos to the dynamically compacted specimens from Ocheydan-lime mixes increased voids. Those statically compacted showed very little change in voids.

In general, the addition of asbestos had only minor effect on the void content of a mix, regardless of the method of compaction or type of materials in the mix.

Effect of Asbestos on Cohesion. —In all mixes tested the addition of asbestos produced a material increase in the cohesion of the mix. The addition of 1 percent asbestos in the Garner-lime mixes and the addition of 2 percent asbestos in the Garner-loess and Ocheydan-lime mixes yielded the greatest improvements.

Effect of Asbestos on Trafficability. —In general, the addition of asbestos improved the trafficability of all mixes tested. The extent of the improvement varied with the method of compaction and with the asphalt content of the mix (Fig. 13). The addition of 2 percent asbestos appeared to give the best results with most mixes tested and the greatest improvement in mixes with 7 percent asphalt.

CONCLUSIONS

From the evaluation and analysis of test results obtained in the course of this investigation, the following conclusions were drawn:

1. A general statement concerning the effect of fillers on the several properties of an asphaltic concrete, such as stability, voids in compacted specimens, cohesion, and trafficability, cannot be made. However, the specific effect of a filler on mixes having the same aggregates and asphalt content can be determined.

2. The effect of fillers on the stability of a mix varies with the method used to determine its stability, the asphalt content, and the characteristics of the aggregates used in the mix.

3. Different methods of determining stability indicate different patterns of the effect of fillers on the stability of a mix, because the methods differ in their sensitivity to the quantity of filler present in a mix.

4. Fillers have a more marked effect on the stability of mixes containing hard aggregates than on those containing softer aggregates.

5. There is a definite intimate relationship between filler and asphalt in a mix. This relationship has a marked effect on stability and cohesion. The asphalt-filler combination appears to modify the properties of the asphalt acting as the cementing agent of the aggregates, making it apparently stronger, tougher, and more adhesive at optimum conditions. The relationship between filler and asphalt, particularly as to form and degree prevalent in mixes, should be studied further.

6. The quantity of filler has the least effect on stability in mixes containing about 6 percent asphalt, regardless of method of test.

7. The void content of a mix is affected to a higher degree by the asphalt content than by the type or quantity of filler contained in a mix.

8. Pulverized loess as a filler yields higher void contents than equal quantities of lime dust.

9. The cohesion of a mix generally increases with increase of filler above 5 percent.

10. The trafficability of a mix generally improves with increase of filler up to an optimum around 7 percent, provided the amount of filler is consistent with asphalt content.

11. Mixes using softer aggregates tend to be displaced under traffic less than mixes with harder aggregates.

12. Pulverized loess can be used effectively as a filler in high-type asphaltic mixes when mixes are properly designed.

13. The addition of asbestos to a mix has varied effects on the stability and voids of mixes containing various aggregates, and therefore, each mix must be evaluated independently.

14. The addition of asbestos to a mix has a decided beneficial effect on cohesion and trafficability.

15. In the design of mixes for heavily traveled roads some consideration must be given to the trafficability of the mix, because there seems to be no correlation between stability and trafficability.

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REFERENCES

1. American Association of State Highway Officials, "Standard Specifications for Highway Materials." Part I, p. 59 (1958).
2. Csanyi, L. H., "Bituminous Mixes Prepared with Ungraded Local Aggregates." Joint publ., Iowa Highway Res. Board Bull. 19, and Iowa State Univ. Eng. Exp. Sta., Bull. 190, p. 61 (1960).
3. Martin, J. R., and Wallace, H. A., "Design and Construction of Asphalt Pavements." McGraw Hill, New York (1958).
4. Cox, R. E., "Effect of Loess Filler Upon Bituminous Concrete Containing Iowa Aggregates." Master's thesis, Iowa State Univ. (1962).
5. "Mix Design Methods for Hot Mix Asphalt Paving." Asphalt Inst. Man. Ser. 2 (1960).
6. Teagle, C. R., "Effect of Asbestos on Asphalt Mixes Containing Iowa Aggregates." Master's thesis, Iowa State Univ. (1962).
7. "Symposium on Mineral Fillers for Bituminous Mixes." HRB Bull. 329 (1962).
8. Lee, Dah yinn, "Function of Fillers in Bituminous Mixes." Doctorate thesis, Iowa State Univ. (1964).