Performance of Asbestos-Asphalt Pavement Surface Courses with High Asphalt Contents

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The performance of eight asbestos-asphalt pavements and adjacent standard pavements placed in 1959 and 1960 in four cities is evaluated through core analyses, surface texture photographs, water permeability, and skid resistance tests.

Even with asphalt content increased 50 percent or more above standard optimum, the pavements containing asbestos fibers have remained stable under heavy traffic. Asphalt hardening has been greatly reduced, with penetration of recovered asphalt at two locations remaining within the range of original penetration grade. All these test pavements with high asphalt contents show superior resistance to incipient raveling compared with adjacent standard pavements. Simple mix design criteria have been established for asbestos-asphalt surface pavements based on superior performance of these test sections to date.

•FOUR YEARS AGO an investigation of asbestos-asphalt pavements was initiated by Johns-Manville Research and Engineering Center to study the effect of short asbestos fibers on the various physical properties of asphalt pavement. The type of asbestos used was Canadian chrysotile asbestos, which makes up more than 90 percent of the fiber used in the United States for all purposes. It is a nonproprietary product with at least nine producers in Canada. The fiber grade chosen for the evaluation was 7M06, a fiber used in a variety of asphalt building and industrial products for many years. Tables 1 and 2 give the asbestos fiber classification and physical properties of Canadian chrysotile fiber.

Results (1) of the wide variety of laboratory tests performed in the study were subsequently presented at the 1960 Highway Research Board annual meeting. Included in the early work were static load compression tests, which suggested that with asbestos included, asphalt could be increased above standard optimum by 40 to 50 percent. Based on the acknowledged fact that an asphalt pavement was weaker in static loading compared to dynamic loading, these test data were used as a basis for mix design recommendations for asphalt concrete with asphalt content increased from approximately 6 to 7.5 or 8 percent. In 1959 and early 1960, a number of cities placed test pavements following these recommendations, and in some instances increased asphalt content up to 9 percent or more by weight of total mix.

The following is a progress report on the performance of these early test pavements with high asphalt content compared to the adjacent standard pavements placed simultaneously. The performance data include photographs of the present pavement surfaces, core analyses, stability test data, and permeability and skid resistance test results. Tentative interpretations are made of the performance data and test results in light of past performance studies of asphalt pavements published by the industry. Only that phase of performance which relates to durability of the asphalt surface course

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is considered in this report. Excluded is the other important phase of performance which relates to structural design. The report includes all the test pavements with high asphalt contents placed before June 1960. In addition, the core analyses represent all the cores taken from these pavements to date.

For some time after June 1960, Johns-Manville paving recommendations deliberately limited the increase in asphalt content in order to study field performance of these high asphalt content pavements and thereby confirm the laboratory test data. During this "performance period," tests by the American Oil Company (2) using a full-scale traffic simulator demonstrated that under very heavy traffic, asphalt content in asbestos-asphalt concrete could be increased safely up to 50 percent above the standard optimum value. These tests supported the field performance results; in addition, they established quantitatively the relationship between fiber-to-asphalt ratio and critical temperature resistance.

Review of Literature

Before initiation of laboratory work on asbestos-asphalt pavements in 1959, a number of leading asphalt paving technologists were consulted to determine in what way they thought asphalt pavements could best be improved in performance.

There was general agreement that increasing asphalt content or film thickness of the binder between aggregate particles should improve pavement durability. Published reports confirmed this conclusion.

Reference to a few of these reports is pertinent and will establish a frame of reference for the report to follow.

In a performance study by Raschig and Doyle (3) in 1937, a qualitative correlation was found between penetration of recovered asphalt and condition of the pavement surface (i.e., raveling and cracking) as shown in Table 3.

In 1937, Hubbard and Gollomb (4), in their study of 29 pavements, reported the same general relationship with the critical range given as 20 to 30 penetration. Their interest in this was prompted by a survey in Ohio which showed that roads built with 50-60 grade asphalt went from good to poor quality in the age interval between 38 and 53 months, corresponding to a penetration of 32 and 25, respectively.

TABLE 1

ASBESTOS FIBER CLASSIFICATION

Quebec Standard Classification		Quebec Standard Test[a] Guaranteed Minimum Wt. (oz)			
Group	Item	½ In.	No. 4	No. 10	Pan
3	3R	2	8	4	2
4	4K	0	4	9	3
5	5R	0	0	10	6
6	6D	0	0	7	9
7	7D	0	0	5	11
	7F	0	0	4	12
	7H	0	0	3	13
	7K	0	0	2	14
	7M	0	0	1	15
	7R	0	0	0	16

[a] Canadian chrysotile asbestos classification.

TABLE 2

PHYSICAL PROPERTIES OF CANADIAN CHRYSOTILE ASBESTOS

Property	Value
Specific gravity[1]	2.55
Fiber diameter[2] (in.)	0.000000706 to 0.00000118
No. of fibrils[1] in 1 in.	850,000 to 1,400,000
Tensile strength[1,2] (psi)	100,000 to 355,000

[1] Source: (15).
[2] Source: (16).

TABLE 3

CONDITION OF PAVEMENT SURFACE AND PENETRATION OF RECOVERED ASPHALT

No. of Pavements	Condition	Penetration[a]
8	Excellent	40
4	Good	29
5	Fair	20
12	Poor	14

[a] At 77 F recovered asphalt.

As a result, softer asphalts were specified for general use by Ohio, California, and, subsequently, most States during the 1940's. In 1939, Vokac (5) confirmed this but reported the critical range to be between 18 and 25 penetration.

One of the most comprehensive studies of durability of road asphalts was published in 1942 by Endersby, Stross, and Miles (6). In summarizing the work of others they reported:

> This experience is paralleled by that in Europe where it has been found that pavements tend to crack in the region of 20 penetration but are in good condition above 30...
>
> There is a climatic factor, since in Arizona bad results do not seem to follow until penetration drops below 15...Mere hardness cannot in itself be the sole cause of raveling and cracking ...However, the tendency of an asphalt to harden is one of the indispensable factors of any predictive formula, because the deleterious changes, whatever they may be, are always accompanied by hardening.

Endersby and his co-writers, in setting up a rating system, relied on "raveling resistance . . . as an index of durability" because "cracking is very much a function of the resilience of the subgrade and its resistance to depression under load." Applying their numerical rating system from 1 to 6 (with 1 being top rating) they found that, "raising asphalt content in this mix by one-fifth raises the grade 1 point, except of course, where the rating was already 1."

Recently, a report (7) prepared jointly by the U. S. Bureau of Public Roads Laboratory and the Maryland State Roads Commission was published describing the performance of wearing courses containing 85-100 penetration asphalt. The relationship found between initial air voids and 4-year loss in penetration is shown in Figure 1. Because of the rapid loss in penetration in pavements with high initial void contents, they

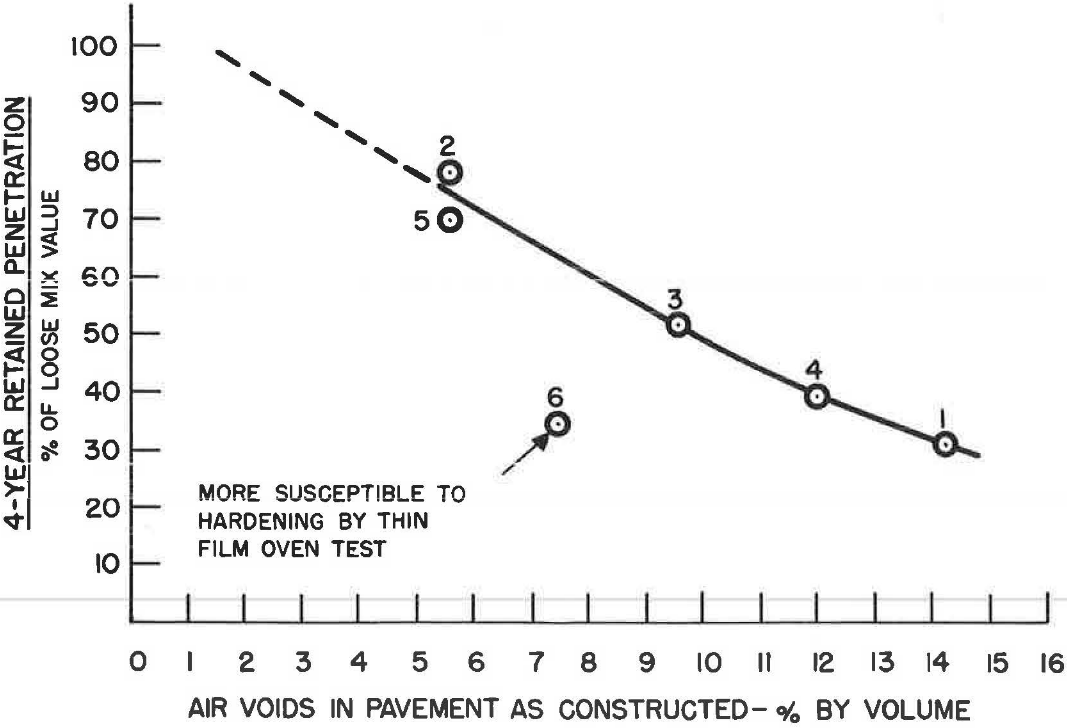


Figure 1. Effect of initial percentage of air voids in pavement (from 7).

recommend limiting initial void contents for heavy-duty pavements to approximately 7 percent maximum. The authors point out that "percentage of air voids is controlled primarily by asphalt content for a particular aggregate," and therefore, asphalt content could be adjusted in the field so as to obtain initial voids after compaction within prescribed limits. They also note that "asphalt ductility did not drop below 150 cm for the three test sections. . . with the lowest percentage of air voids." In the pavements with high initial voids after compaction under traffic, ductility is shown to be decreasing rapidly, whereas corresponding penetration is decreasing slowly. These data suggest that both ductility and penetration measurements are desirable in studying hardening of asphalt in pavement as related to performance.

Some Factors Affecting Durability

It is not practical to review all the published work on durability as it relates specifically to bituminous surfacing. Basically, apart from structural performance, durability refers to (a) possible water susceptibility characteristics related to the mineral constituents, and (b) hardening of the asphalt binder. Data published by the Asphalt Institute indicate that in contrast to many fine mineral admixtures, asbestos has no detrimental effect on water susceptibility characteristics (8, 9). Unpublished results of many other laboratories confirm this fact.

Concerning hardening of asphalt, several test series have been performed on asbestos-asphalt mixes by the Chicago Testing Laboratory for Johns-Manville using the Shattuck oxidation test to measure high-temperature hardening during mixing, and aging tests to measure hardening under service conditions. The report on the Shattuck oxidation tests conducted on each of six asphalts produced from different crude oils mixed with 2.5 percent 7M06 chrysotile fiber and Ottawa silica sand concluded:

> The asbestos has no adverse effect upon the hardening of the asphalt during the mixing cycle...Asbestos can safely be used in bituminous paving mixtures without any adverse effects upon the asphalt cement. (Appendix A)

The report on "The Effect of Aging Upon the Properties of Asphalt Concrete Containing Asbestos" concluded:

> Based upon these test results, it is apparent that asbestos has no injurious effect upon the properties of the asphalt in hot mix bituminous concrete when subjected to one year of aging. (Appendix B)

TEST METHODS

Table 4 gives basic information to identify the various pavements described. Figures 2 through 5 show the exact locations of each of the mixes including the approximate location of the cores described in this report. Aggregate gradations are shown in Figure 6. Production and construction information are given in Table 5. Core and plant mix analyses made at the time of placement are given in Appendixes C and D and recent core analysis data are given in Tables 6 through 9.

The methods used by the Chicago Testing Laboratory are outlined as follows:

1. Bulk density -- ASTM test method D-1188.
2. Theoretical maximum specific gravity — Michigan solvent immersion method.
3. Asphalt extraction (bitumen content) — ASTM D-1097.
4. Asphalt recovery — Abson method (ASTM D-1856 - 61T).

The surface layers in the cores were cut from the base or binder layers so that a small amount of the surface mix remained with the binder or base layer to prevent "contamination" in the analyses.

Skid resistance tests on the Manville pavements in October 1960 employed the stopping distance method with a Wagner Stopmeter and fifth wheel. The tests were performed on wet pavements at 30 mph, using a standard passenger car. Details of the apparatus and test conditions are given in Appendix E.

TABLE 4
PAVEMENT IDENTIFICATION

Location		Mix No.[a]	Date Placed	Placed by	Estimated Traffic	
City	Street				Count per Day	% Heavy Trucks
Calgary	Alyth Freeway	1 2	June 1960	City Street Dept.	6,500	10 (est)
Dallas	Greenville		Nov. 1959	M. P. McInerney Co.	23,000	
	Ross Avenue	1 2			17,000	15 (est)
Manville	N. 13th	1 2	Sept. 1959	Jannarone Engineering Company	500 (est)	10 (est)
St. Louis	Manchester	1	Oct. 1959	Bridges Paving Co.	10,300	25
	(Tower Grove) Strodtman	2 3			500-1,000 (est)	Min. 10 (est)

[a] Identifies exact mix described in Appendixes.

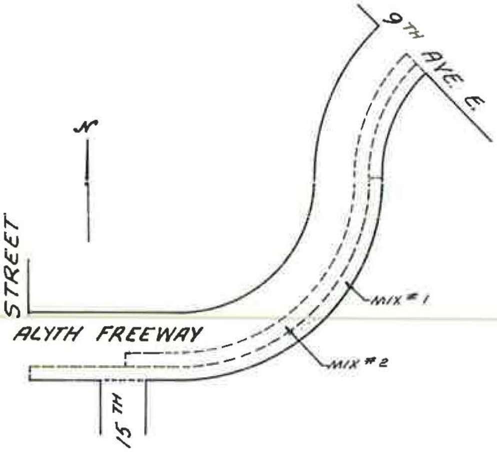


Figure 2. Mix locations, Calgary, Alberta.

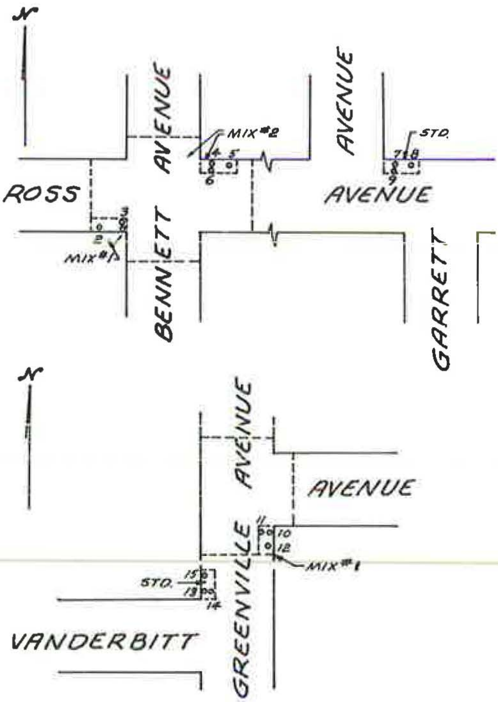


Figure 3. Mix locations, Dallas, Texas.

TABLE 5

PRODUCTION AND CONSTRUCTION DATA OF ASBESTOS SECTIONS

Location	Mix No.	Mixing Temp.[1] (°F)	Mixing Time (sec)		Paving Machine	Compaction Method	Placement Characteristics	Length (ft)	Average Width (ft)	Average Thickness (in.)		Type of Pavement	Type of Subbase Mix (State spec.)	Binder	Base, Subbase Underlying Pavement
			Dry	Wet						Design	Core				
Calgary	1		15	45	Barber-Greene	Steel wheel tandem	Flushed under roller	1,260	10	1½	1.58	New construction	HL III	1½-in. standard (without asbestos)	2 in. of ¾-in. gravel 17 in. of pit run gravel
	2		15	45	Barber-Greene		No flushing under roller, good placeability	1,082	10	1½	1.46 1.62 (std)				
Dallas	1	275-350	8	52	Blaw-Knox	Steel wheel roller-10 tons (3-wheel gallion Roll-O-Matic)	Good	90	46	2	1.33	Overlay	Type B	5-in. Type C (without asbestos)	Asphalt
	2		8	52	Blaw-Knox		Good	125	65	2	1.16 1.06 (std)				Concrete
Manville	1	300-325	60	wet mix	Barber-Greene	Steel wheel-tons	Slight flushing under roller[2]	271	20	1-1¼	1.32	New construction	SM	None	Penetration Macadam
	2	300-325	60	wet mix	Barber-Greene	Steel wheel-tons	Considerable flushing under roller[2]	242	20	1-1¼	1.35 1.05 (std)	New construction	SM	None	
St. Louis	1	325			Barber-Greene	Steel wheel roller—tons	Some flushing under roller	250	11	1½		Overlay		None	Paving brick
	2	325			--	Steel wheel roller—tons	Some flushing under roller	125	11	1½		Overlay		None	Paving brick
	3	325			--	Steel wheel roller—tons	Some flushing under roller, good placeability								

[1] Same mixing temperature used in both standard and asbestos pavements at each location.
[2] Mix as well as standard showed considerable tearing of mat; rolling eliminated tear cracks.

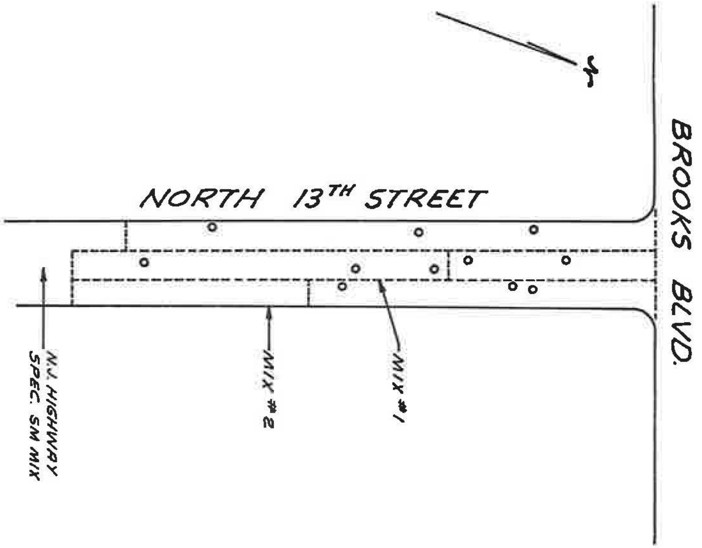


Figure 4. Mix locations, Manville, N. J.

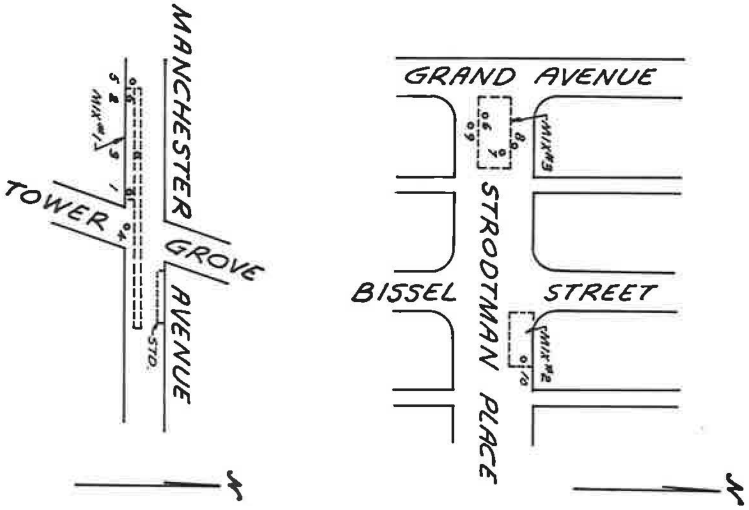


Figure 5. Mix locations, St. Louis, Mo.

TABLE 6

CALGARY, ALBERTA, CORE ANALYSES, CTL REPORTS 11537 AND 10364-69

Location (set)	Core No.	Specific Gravity at 77 F	Theoretical Maximum Specific Gravity	Air Voids (%)	Surface Course Thick. (in.)	Designed Composition		Recovered Bitumen (%)	Recovered Asphalt		
						Asbestos	Asphalt		Pen. at 77 F, 100/5	Duct. at 77 F, 5/60 cm	Ash (%)
1	10364	2.34	2.39	2.1	1.50	3-7M	6.9-9.2	8.0	111	150+	1.9
	10365	2.35	2.39	1.7	1.63						
	10366	2.34	2.39	2.1	2.00						
	10367	2.37	2.48	4.5	1.75	-	-	5.3	51	150+	1.7
	10368	2.33	2.48	6.0	1.63						
	10369	2.39	2.48	3.6	1.63						
2	1	2.36	2.48	4.8	2.13	0	5.0	4.7	48	150+	1.1
	2	2.41	2.46	2.0	1.38	0	5.0	4.8	63	150+	1.6
	3	2.35	2.38	1.3	1.25	3-7M	7.0	7.4	78	150+	0.6
	4	2.41	2.46	2.0	1.38	0	5.0	5.0	58	150+	1.0
	5	2.35	2.38	1.3	1.63	3-7M	7.0	7.0	83	150+	1.0
	6	2.32	2.38	2.5	1.50	3-7M	7.0	7.4	79	150+	0.3
	7	2.35	2.39	1.7	1.50	3-7M	7.0	7.1	67	150+	1.3
	8	2.34	2.39	2.1	1.50	3-7M	7.0	7.2	65	150+	0.9
	9	2.34	2.38	1.7	1.38	3-7M	7.0	7.1	62	150+	1.2

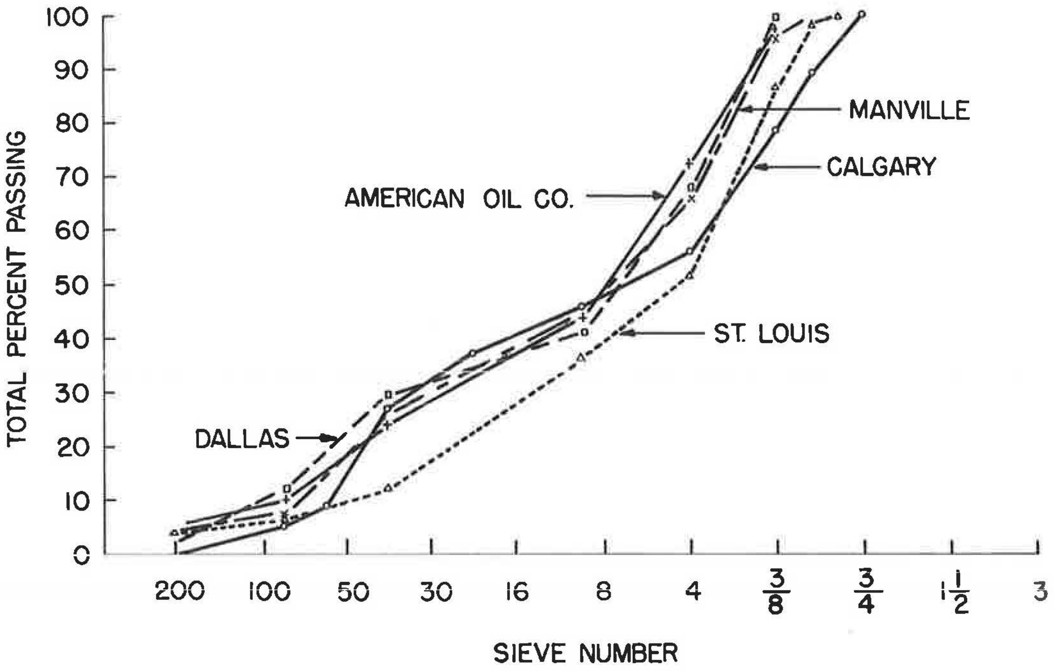


Figure 6. Aggregate gradation from core analyses.

TABLE 7

DALLAS, TEXAS, CORE ANALYSES, CTL REPORTS 04406-11 AND 11428

Location	Core No.	Specific Gravity at 77 F	Theoretical Maximum Specific Gravity	Air Voids (%)	Surface Course Thick. (in.)	Designed Composition		Recovered Bitumen (%)	Recovered Asphalt		
						Asbestos	Asphalt		Pen. at 77 F, 100/5	Duct. at 77 F, 5/60 cm	Ash (%)
Ross Ave. (1962)	1	2.35	2.38	1.2	1.25	1.7-7M	7.5	6.5	40	93	1.2
	2	2.28	2.38	4.2	1.13						
	3	2.32	2.38	2.5	1.62						
	4	2.33	2.37	1.7	1.25	2.6-7M	7.5	6.9	40	98	1.7
	5	2.33	2.37	1.7	1.25						
	6	2.33	2.37	1.7	1.00						
	7	2.32	2.46	5.7	1.25	0	5.0	5.0	25	12	1.7
	8	2.33	2.46	5.3	1.25						
	9	2.33	2.46	5.3	1.25						
Ross Ave. (1961)	1	2.36	-	-	-	2.6-7M	7.5	6.9	37	49	1.5
	2	2.29	-	-	-	2.6-7M	7.5	6.8			
	3	2.36	-	-	-	2.6-7M	7.5	7.3	38	45	2.5
	4	2.32	-	-	-	2.6-7M	7.5	-	-	-	-
	5	2.36	-	-	-	2.6-7M	7.5	7.6	40	40	1.9
	6	2.37	-	-	-	2.6-7M	7.5	7.5			
Greenville Ave.	10	2.32	2.41	3.7	1.50	2.0-7M	6.5	6.3	33	23	0.7
	11	2.32	2.41	3.7	1.50						
	12	2.32	2.41	3.7	1.75						
	13	2.24	2.47	9.3	0.50	0	5.0	4.5	33	34	1.8
	14	2.34	2.47	5.3	1.63						
	15	2.30	2.47	6.9	0.50						

TABLE 8

MANVILLE, N. J., CORE ANALYSES, CTL REPORT 11297

Core No.	Specific Gravity at 77 F	Theoretical Maximum Specific Gravity	Air Voids (%)	Surface Course Thick. (in.)	Designed Composition		Recovered Bitumen (%)	Recovered Asphalt		
					Asbestos	Asphalt		Pen. at 77 F, 100/5	Duct. at 77 F, 5/60 cm	Ash (%)
78	2.40	2.45	2.0	1.25	3.0-7M	9.5	9.1	55	126	1.1
79	2.41	2.45	1.6	1.50						
81	2.37	2.45	3.3	1.50						
84	2.42	2.45	1.2	1.25						
87	2.38	2.45	2.9	1.25						
80	2.40	2.48	3.2	1.00	2.0-7M	8.0	8.7	41	97	1.5
82	2.42	2.48	2.4	1.25						
83	2.45	2.48	1.2	1.38						
85	2.46	2.48	0.8	1.50						
86	2.45	2.48	1.2	1.50						
88	2.31	2.59	10.8	0.88	0	6.0	5.2	22	19	1.2
89	2.42	2.59	6.6	1.00						
90	2.41	2.59	6.9	1.50						
91	2.43	2.59	6.2	0.75						
92	2.34	2.59	9.6	0.75						

TABLE 9

ST. LOUIS, MO., CORE ANALYSES, CTL REPORTS 07347 AND 08191-4

Location	Core No.	Specific Gravity at 77 F	Theoretical Maximum Specific Gravity	Air Voids (%)	Surface Course Thick. (in.)	Designed Composition		Recovered Bitumen (%)	Recovered Asphalt		
						Asbestos	Asphalt		Pen. at 77 F, 100/5	Duct. at 77 F, 5/60 cm	Ash (%)
Manchester Ave. (Tower Grove)	1	2.37	2.45	3.2	-	1.2-7M 0.6-4T	9.3	8.3		110+	2.2
	2	2.37	2.43	2.5	-	1.2-7M 0.6-4T	9.3	8.9	68	110+	1.9
	3	2.40	2.46	2.4	-	1.2-7M	9.3	8.6	60	110+	1.9
	4	2.42	2.56	5.5	-	0	6.1	5.8	54	110+	1.9
	5	2.39	2.46	2.8	-	1.4-7M 0.6-4T	9.3	8.2	60	110+	1.5
	15	2.54	2.61	2.7	-	0	6.1	5.9	40	150+	2.2
Strodtman Place	6	2.29	2.41	5.0	-	3.0-7M	11.0	9.4	48	110+	1.1
	7	2.31	2.43	4.9	-	3.0-7M	11.0	9.8	51	110+	1.4
	8	2.30	2.43	5.3	-	3.0-7M	11.0	9.3	55	110+	1.6
	9	2.30	2.41	4.6	-	3.0-7M	11.0	9.8	52	110+	2.3
	10	2.37	2.47	4.1	-	2.0-7M	9.5	8.2	48	110+	2.1
	11	2.40	2.58	7.0	-	0	6.14	5.9	25	14	2.4
	12	2.44	2.58	5.4	-	0	6.14	6.0	31	101	2.0
	14	2.41	2.57	6.2	-	0	6.14	6.1	29	64	0.9

A modification of the California water permeability test was used for measuring surface tightness of pavements in St. Louis and Manville three years after placement. The modification, as described in Appendix F, enables the solution to be forced into a 6-in. diameter area of pavement under pressures up to approximately 24 in. of water. The area of penetration, solution, time, and type of measurement are approximately the same as those used in the California permeability test.

TEST RESULTS

Visual Performance

Considering performance of the surface courses apart from structural characteristics of the pavement section, appearance is the simplest and most widely used method of evaluation. Specifically, it indicates the following:

1. Surface Toughness. — Resistance to differential wear or disintegration of the fine aggregate phase and "popping out" of coarse aggregate.

2. Stability. — Flushing or plastic displacement (rutting or shoving, etc.).

The pavements discussed in this report have been in service for $2\frac{1}{2}$ to 3 years which is normally considered sufficient time to evaluate stability. In this period of time there are very noticeable differences in the surface toughness of the asbestos-modified pavements compared to the standard, although the standard pavements have satisfactory surface characteristics in most cases.

Surface Texture. — In three of the four cities, close-up photographs of the pavement surfaces have been obtained with the cooperation of sponsoring agencies (Figs. 7 through 12). At all locations, the standard pavements already show varying amounts of incipient raveling in the form of disintegration or wearing away of the fine aggregate phase, leaving the coarse aggregate projecting out above the fine aggregate phase and exposing coarse aggregate which was originally situated beneath the wearing surface. This is most pronounced in those pavements with medium traffic, where traffic densification has been least (Strodtman Avenue in St. Louis and North 13th Street, Manville) (Figs. 9, 10 and 12). The asbestos mixes with high asphalt contents show no visible evidence of surface disintegration but the Dallas pavements with the lowest asphalt content do show slight wear.

In the standard Calgary pavement with 100-120 penetration asphalt without asbestos, visible abrasion of the fine aggregate phase and exposure of the stone under heavy traffic are occurring after two years (Fig. 7b) even though penetration and ductility of the recovered asphalt are more than adequate by standard criteria. The same is true of the standard pavement (with 60-70 penetration asphalt) in St. Louis on Manchester Avenue (Fig. 11a). This differential abrasion is perhaps not severe enough to be called raveling. Nevertheless, the short asbestos fibers with the high asphalt contents appear to have prevented this abrasion of the fine aggregate phase to date in both the St. Louis and Calgary pavements (Figs. 7c and 11b). In contrast, on Strodtman Avenue the raveling evident in the standard pavement (Fig. 12b) can be explained in terms of hardness of the asphalt (Fig. 16d).

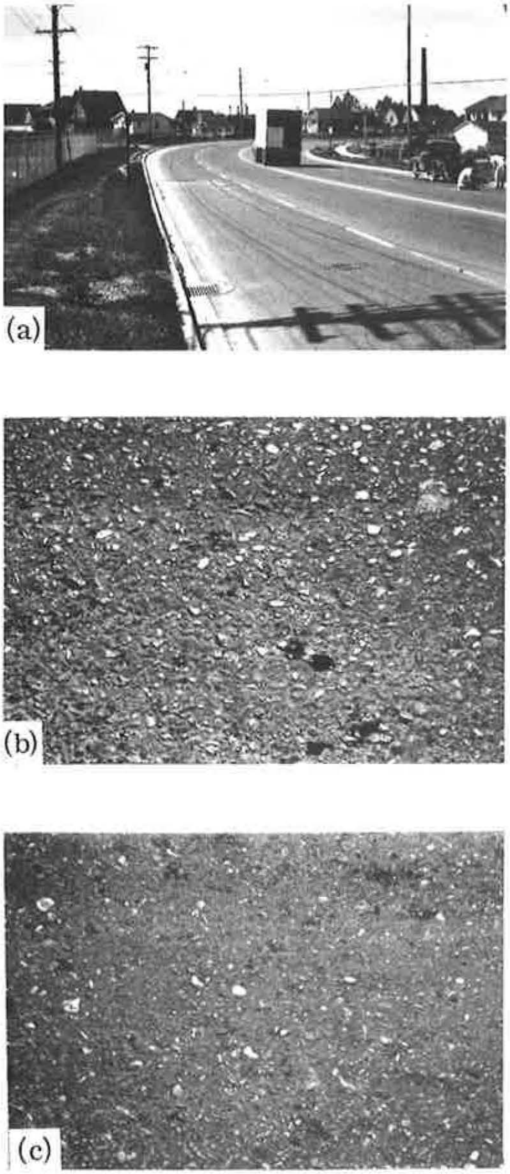


Figure 7. Alyth Freeway, Calgary, Alberta, July 1962: (a) looking south (map in Fig. 2); (b) standard pavement 5.5 percent asphalt content; (c) modification of standard mix by addition of 3 percent 7M06 asbestos and 7 to 9 percent asphalt content.

Pavement Cracks. — Figures 13 and 14 show the asbestos pavements in Manville and St. Louis, respectively; the first being a joint cracking, the second apparently a

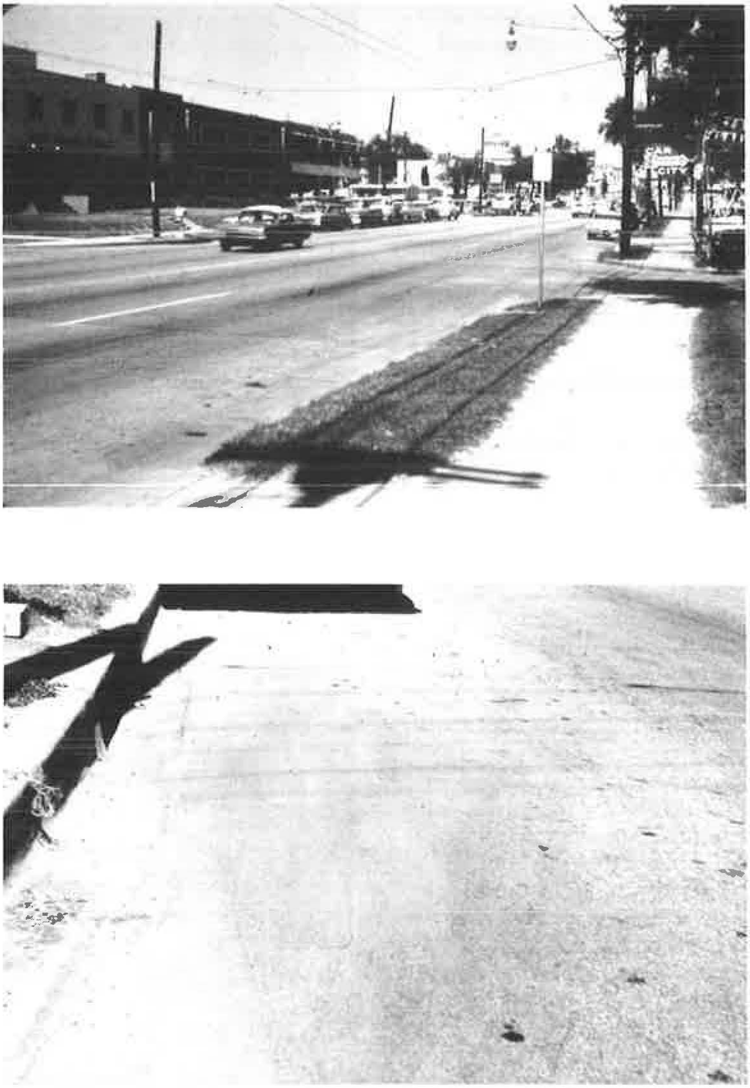


Figure 8. Ross Avenue, Dallas, Texas, August 1962: (top) intersection with Bennett Avenue (map in Fig. 3) with standard mix 5.0 percent asphalt content in foreground and asbestos-modified pavement with 7.5 percent asphalt content at intersection; (bottom) asbestos pavement with 7.5 percent asphalt content at bus stop, opposite corner.

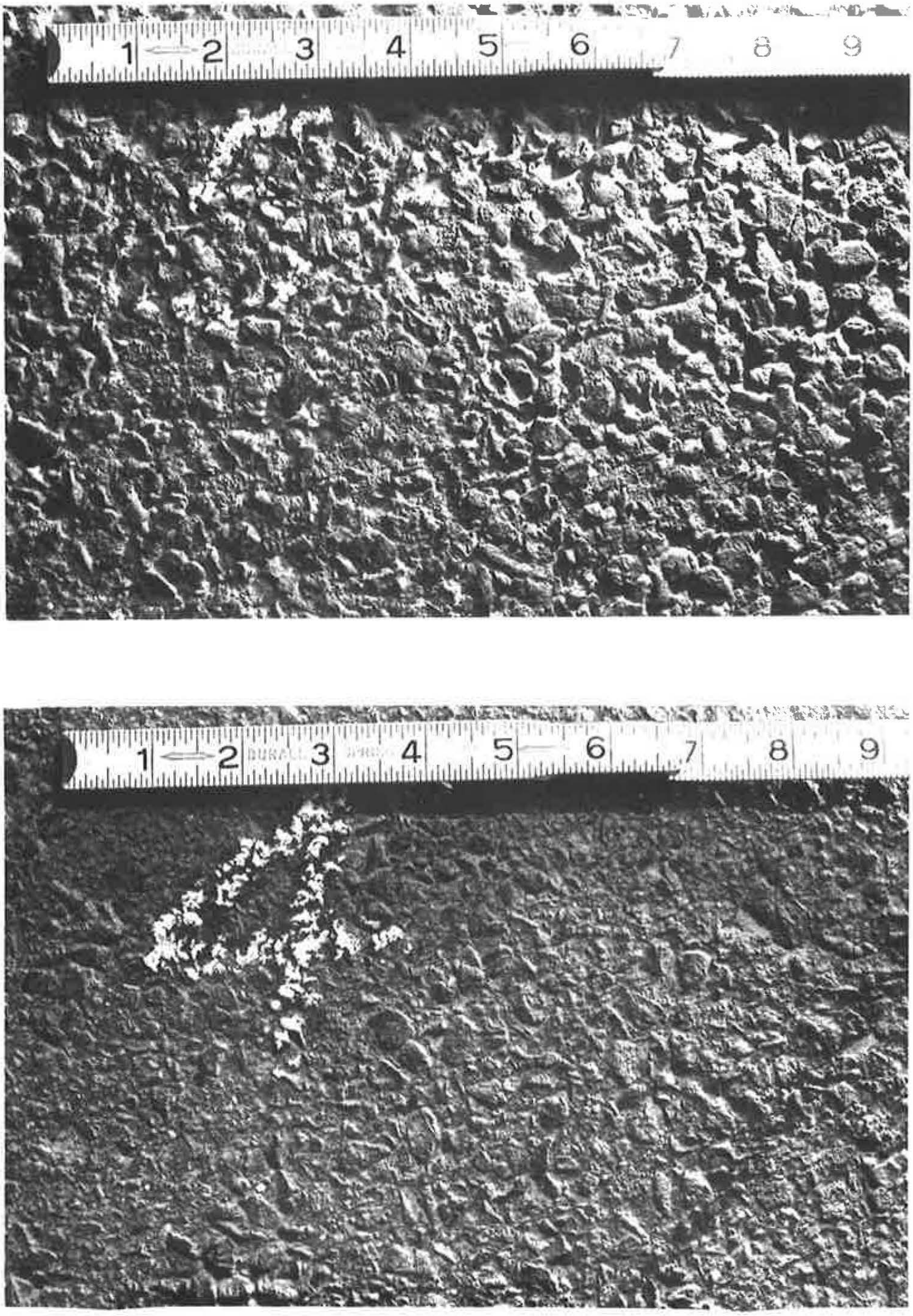


Figure 9. Variations in surface disintegration, North 13th Street, Manville, N. J., August 1962, standard pavement mix.

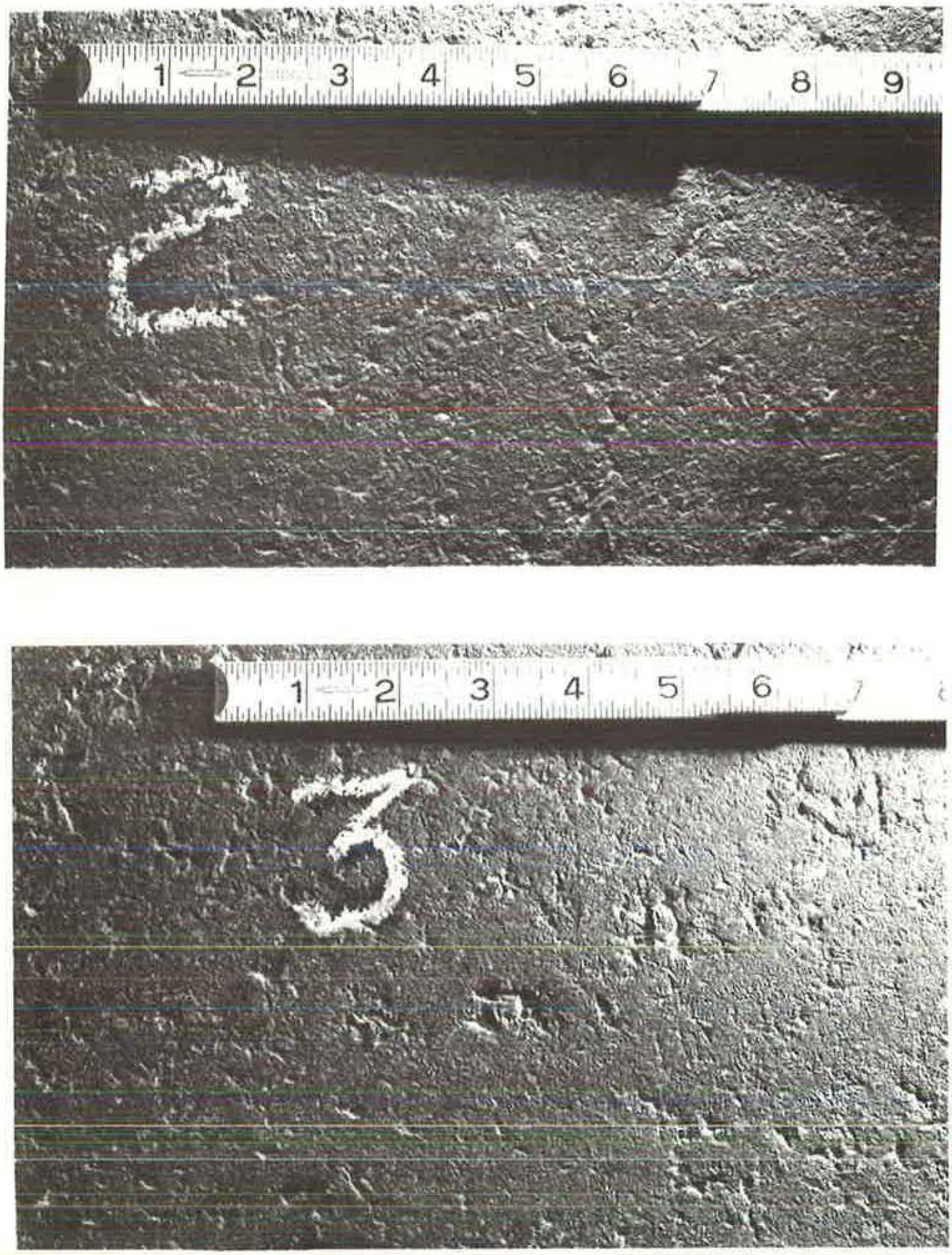


Figure 10. Variations in surface texture, North 13th Street, Manville, N. J., asbestos mix with 8 to 9.5 percent asphalt content.

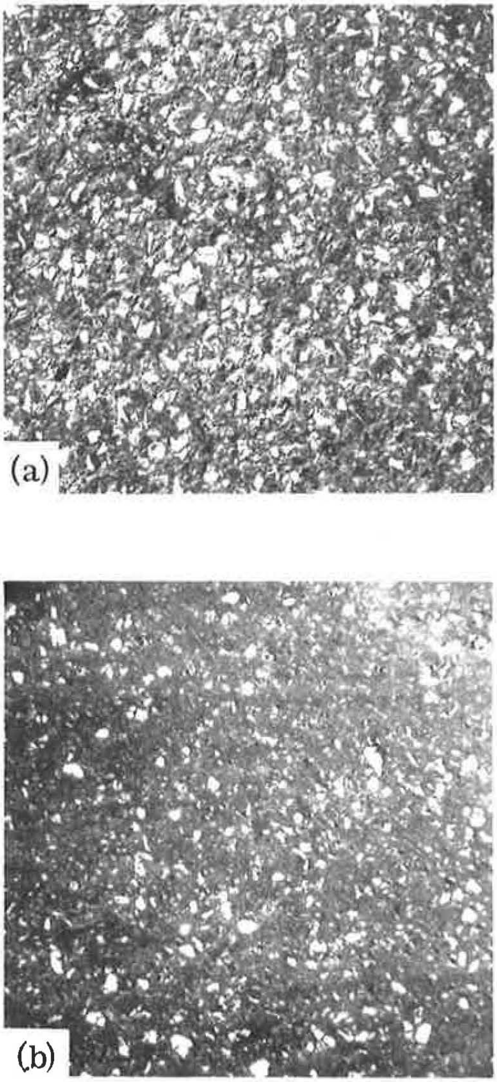


Figure 11. Manchester Avenue (near Tower Grove), St. Louis, Mo., September 1962: (a) standard pavement in traffic lane; (b) asbestos mix in traffic lane approximately 20 ft from (a).

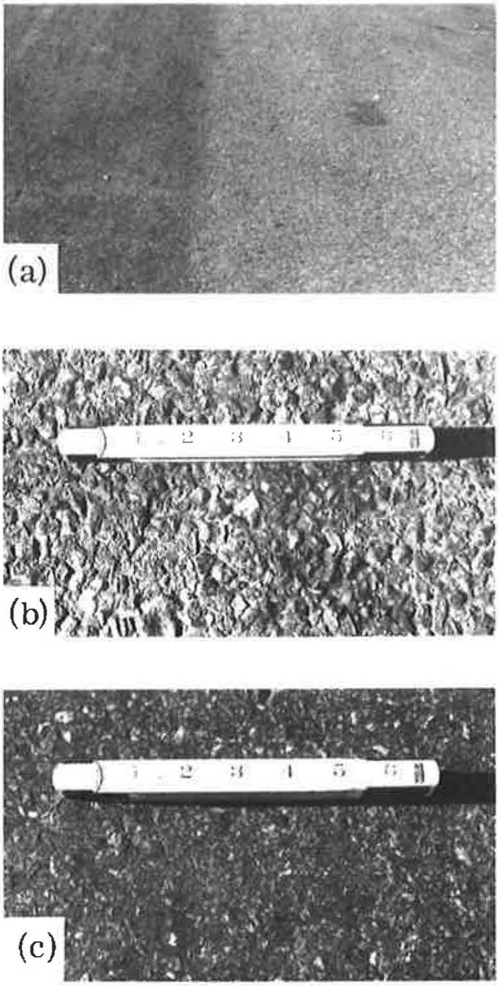


Figure 12. Strodtman Place, St. Louis, Mo., September 1962 (map in Fig. 5): (a) longitudinal boundary, asbestos on left, standard pavement on right; (b) standard pavement in traffic lane, south of asbestos section; (c) asbestos pavement in traffic lane.

reflected joint crack at the end of the new pavement. At both locations, the cracking in the standard pavement stops when it reaches the asbestos sections. Although it is not claimed that the use of asbestos will eliminate cracking, the high asphalt contents, 8 to 9.5 percent in these pavements, and the resulting high extensibility may account for this phenomenon in these cases.

It is apparent from the Dallas pavements (Fig. 15) that reflection cracking has occurred in both the standard pavement and that containing short chrysotile fibers. The cracking is linear and transverse, implying joint crackings reflected from an original portland cement pavement. The same type of reflection cracking has occurred in more recent test pavements at other locations with asphalt-concrete containing approximately 7 percent asphalt overlaid on portland cement pavements. The lower asphalt content

Figure 13. Joint crack in standard pavement stopping at south end of asbestos pavement, North 13th Street, Manville, N. J., July 1962.

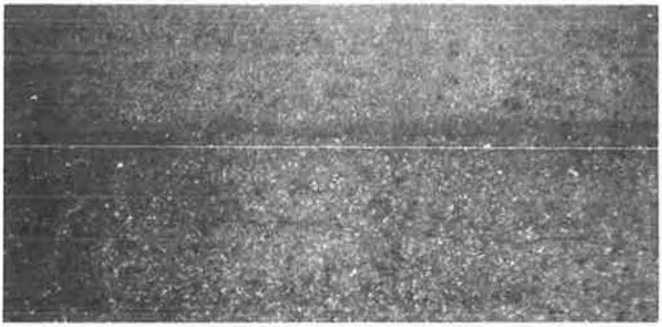


Figure 14. Reflection crack in standard mix, stopping short at longitudinal boundary of asbestos section (dark area left of center), Strodtman Place at Grand Avenue, St. Louis, Mo., September 1962.

itself compared with the Manville and St. Louis pavements may possibly account for the difference.

Stability. — With one exception, the test pavements in the four cities show no instability at present under heavy traffic, despite the fact that the asphalt content was increased 50 percent or more in at least one test pavement in each city (Table 4). The possible reasons for this are discussed in a separate section.

The exception is on Manchester Avenue in St. Louis where rutting up to 1 in. in depth is evident at Tower Grove, directly at the bus stop, and shoving occurred along a 6-ft length of curb at the Kingshighway bus stop. With the low fiber content, present knowledge indicates that the fiber-asphalt ratio of 0.19 is too low for very heavy traffic. Referring to the American Oil Company traffic simulator results (2), a minimum fiber-asphalt ratio of approximately 0.30 should be maintained (for thick overlays) to prevent the possibility of instability under very heavy traffic. It is surprising that plastic displacement is not even more severe and that no flushing or bleeding of asphalt is taking place under present traffic at these locations.

Physical Properties of the Pavements

Core Analyses — Asphalt Properties. — During the first extraction tests three years ago, the Chicago Testing Laboratory discovered that in using the standard centrifuge extraction procedure, the asbestos mixes required as much as 5 or 6 cycles to remove all asphalt, as compared with 3 cycles normally required for standard pavement specimens. Apart from core analyses, a number of test series have been carried out by the Chicago Testing Laboratory on pavement specimens made in the laboratory with specific asphalt contents, from which completeness of asphalt and properties of asphalt could be checked. Results of two of these series, Shattuck oxidation tests and aging tests, which include a wide variety of asphalt sources, are given in Appendixes A and B. Their tests of this type suggest that for the field core analyses performed by the Chicago Testing Laboratory:

1. The recovery of asphalt from the asbestos and standard mixes is equivalent and essentially complete, within the limits of accuracy of the procedure.
2. The effect of very small amounts of retained asphalt (adsorbed on the filler and fiber surfaces or even within the pores of the rock aggregate) on physical properties of recovered asphalt, if any, is the same in both the standard and asbestos mixes.

The authors conclude that the asbestos fibers had no significant differential effect on consistency of asphalt recovered from the test pavements described herein.

Figure 15. Reflection cracking, Ross Avenue, Dallas, Texas, August 1962.

Because the life of all asphalt pavement surface courses is limited by weathering of the binder and progressive loss of cohesive strength, it follows that some indications of ultimate performance may be obtained by core analysis before the extensive deterioration of the surface has occurred. Detailed core analysis data taken from the Chicago Testing Laboratory reports are given in Tables 6 through 9. Table 10 summarizes asphalt contents from core analyses. Comparisons of penetration and ductility of recovered asphalt are shown in Figures 16 and 17.

The average penetration of asphalt recovered from the asbestos pavements is 80 percent higher than that from the standard pavements. In two of the asbestos pavements the recovered asphalt showed more than 90 percent of original penetration, whereas in three of the four standard mixes, asphalt penetration of recovered asphalt was critically low by past performance standards. The ductility of asphalt from three of the four standard mixes was markedly reduced below original values compared to the corresponding asbestos mixes. In only one of the eight asbestos mixes was hardening of the asphalt equivalent to that of the standard pavements. This was the Greenville Avenue pavement in Dallas, which contained the lowest asphalt content (6.5 percent) of the eight asbestos mixes being studied.

There are at least two basic causes for reduction in penetration and ductility of asphalt recovered from asphalt pavements:

1. Hardening during mixing (volatilization and high-temperature oxidation).
2. Hardening due to weathering processes (oxidation-polymerization).

The large increases in asphalt content in the asbestos pavements may have affected both hardening processes favorably through the thicker asphalt coatings on the aggregate particles and by facilitating low initial void contents. The total effect is perhaps best illustrated by the core analyses of the traffic simulator test pavements (2) (Fig. 18) which included the widest range of asphalt for both standard and asbestos mixes (Illinois I-11). From the relatively low penetration of recovered asphalt, it appears that the radiation lamps used to heat the pavements successfully induced accelerated weathering.

The asbestos mixes at 5 and 6.5 percent asphalt content should not be compared with the standard pavements with respect to penetration of recovered asphalt because the former

TABLE 10
ASPHALT CONTENTS

Location	Mix No.	Asbestos Content (% total weight)	Asphalt Contents, % Total Weight of Mix								
			Plant Mix Analysis or Production Record				Recent Core Analyses				
			Asphalt Pen.	Std Mix	Asbestos Mix	Increase Above Standard %	Std. Mix	Asbestos Mix		Increase Above Std.%	
								Set 1	Set 2	Set 1	Set 2
Calgary	1	3.0	100-120	5.5	9.2	67	5.3	8.0	7.2	51	36
	2	3.0	100-120		7.0	27					
								1962	1961	1962	1961
Dallas	1	1.7	85-100	5.0	6.5	30	5.0	6.5	6.9	30	38
	2	2.6	85-100		7.5	50		6.9	7.5	38	50
Manville	1	2.0	85-100	5.9	8.0	36	5.2	8.7		67	
	2	3.0	85-100		9.0-9.5	53-61		9.1		75	
St. Louis	1	1.8	60-70	6.2	9.3	50	5.7	8.5		49	
	2	2.0	60-70		8.4	35	5.9	8.2		39	
	3	3.0	60-70		9.8	58	5.9	9.6		63	

sustained at least one million more wheel passes at temperatures 20° higher than the standard pavements. It appears that for both the standard and asbestos pavements, as asphalt content is increased, the total hardening of the asphalt (during mixing and testing) is sharply reduced. This is, of course, a most desirable effect.

Figure 19 shows a comparable effect in the Calgary pavements (Table 6), both of which contain 3 percent asbestos and equivalent void contents. The Manville pavements, which have equivalent void contents, show the same general effect of increased asphalt content on asphalt hardening (Fig. 16c). At other locations, the effect of the difference in void content on asphalt hardening is apparent.

The relationship between asphalt content and penetration of recovered asphalt is not linear. The core analyses suggest that where asphalt content was increased significantly above 7 percent (total weight of mix), recovered asphalt penetration was high. At 7 percent asphalt content or below, the differences in penetration are usually not evident.

With regard to weathering, the Maryland roads study (7) suggests that the rate of oxidation after placement for a given type of asphalt depends on exposure of the pavement to air in the voids. This effect of void contents on hardening shows up in some of the core analyses; for instance, the St. Louis pavements. The Manchester Avenue pavements, both standard and asbestos, show a higher penetration of recovered asphalt than the corresponding Strodtman Avenue pavements despite the much higher asphalt content in the latter asbestos pavements (Fig. 16). The probable cause is the much higher void contents in the Strodtman Place pavement than in the Manchester Avenue pavements where the traffic was not heavy enough to reduce the void content to a low level.

Void Contents and Resistance to Compaction. — At standard asphalt contents or at asphalt contents reduced below standard, it was first shown by the Asphalt Institute (8) that short asbestos fibers produce an outstanding resistance to compaction. This was confirmed by full-scale traffic simulator tests by the American Oil Company (2). No measurable reduction was shown in air void content in the pavement containing 2½ percent asbestos at 5.0 percent asphalt content with either 85-100 penetration or

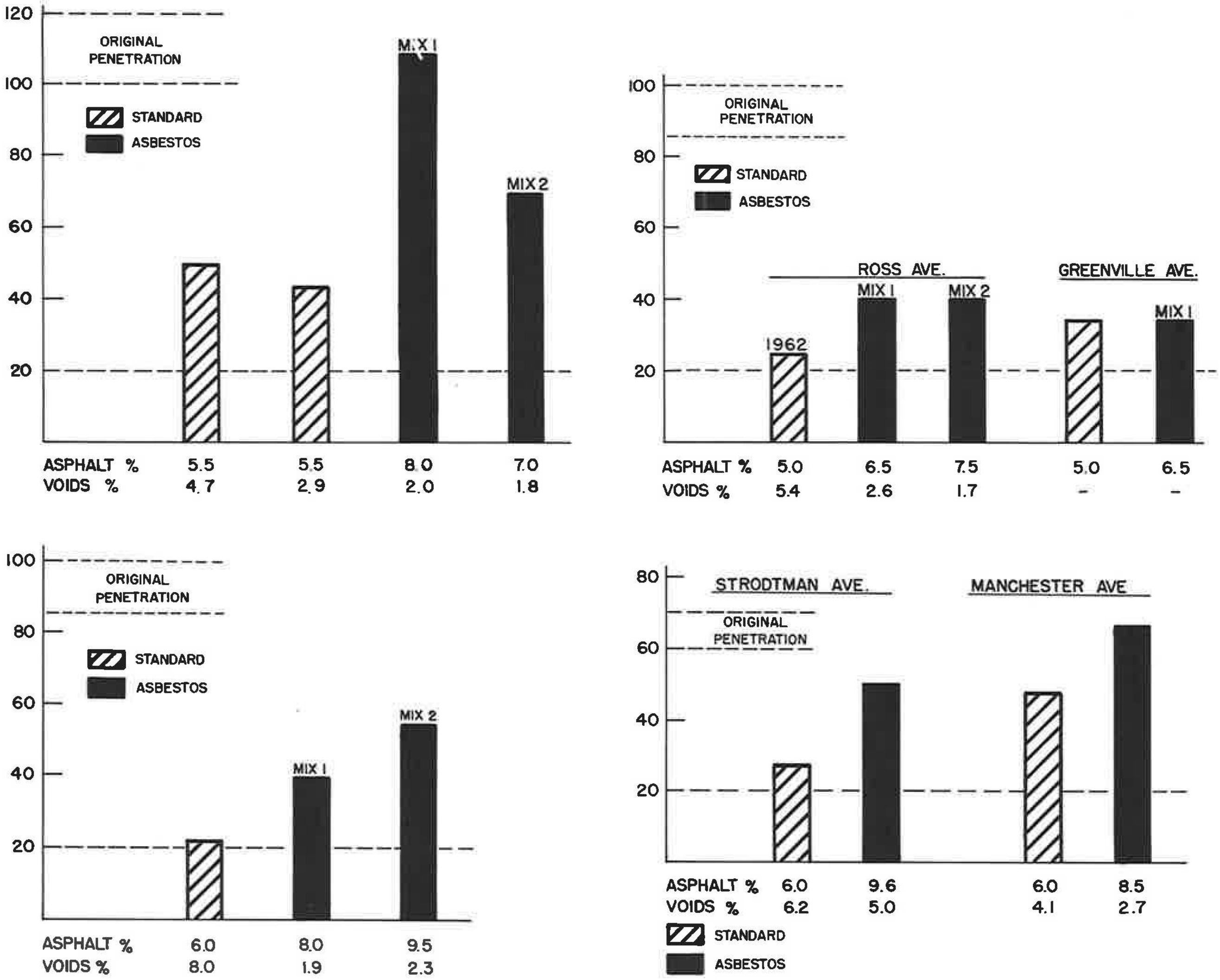


Figure 16. Penetration of recovered asphalt: (a) Calgary, Alberta; (b) Dallas, Texas; (c) Manville, N.J.; (d) St. Louis, Mo.

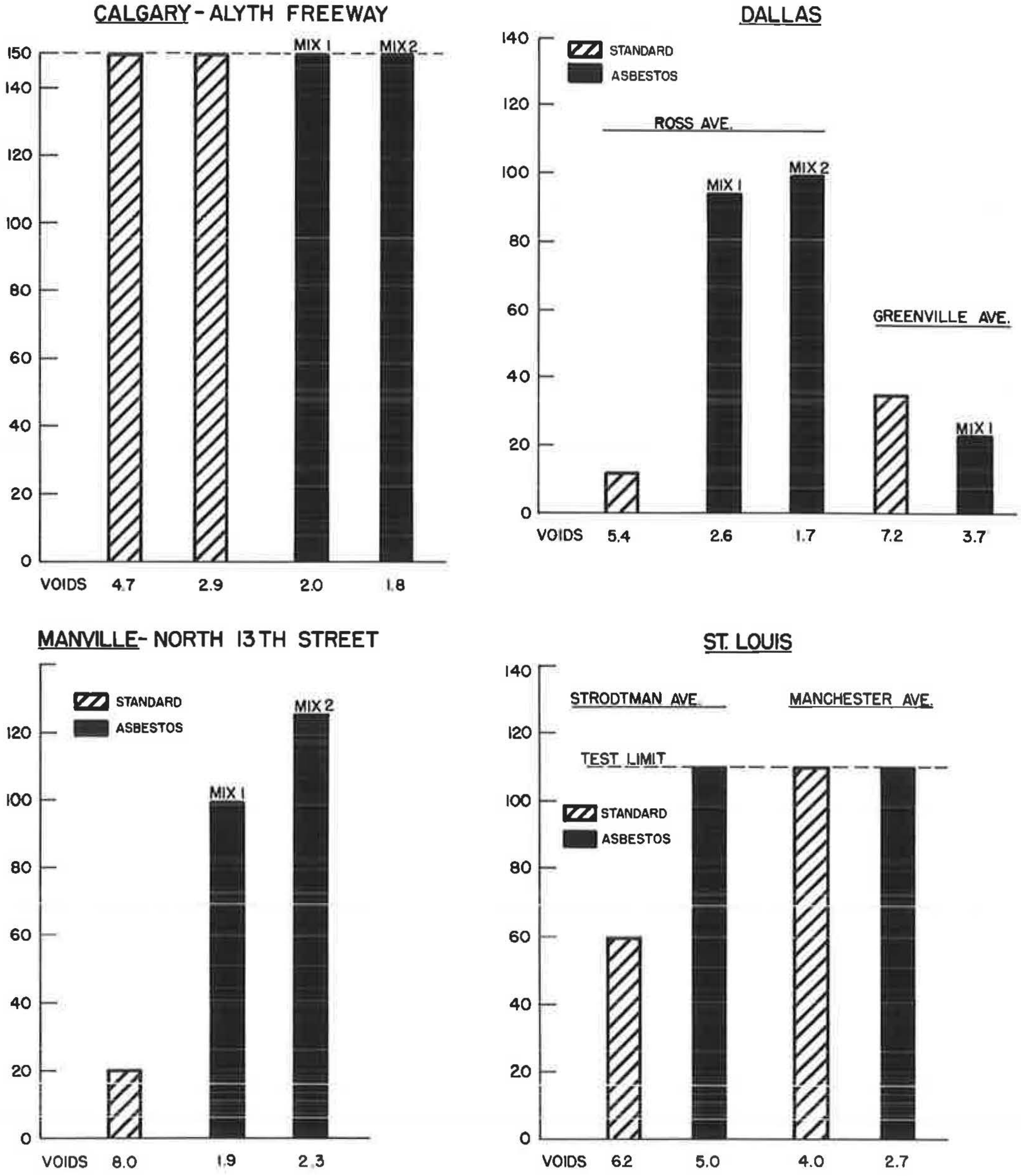


Figure 17. Ductility of recovered asphalt.

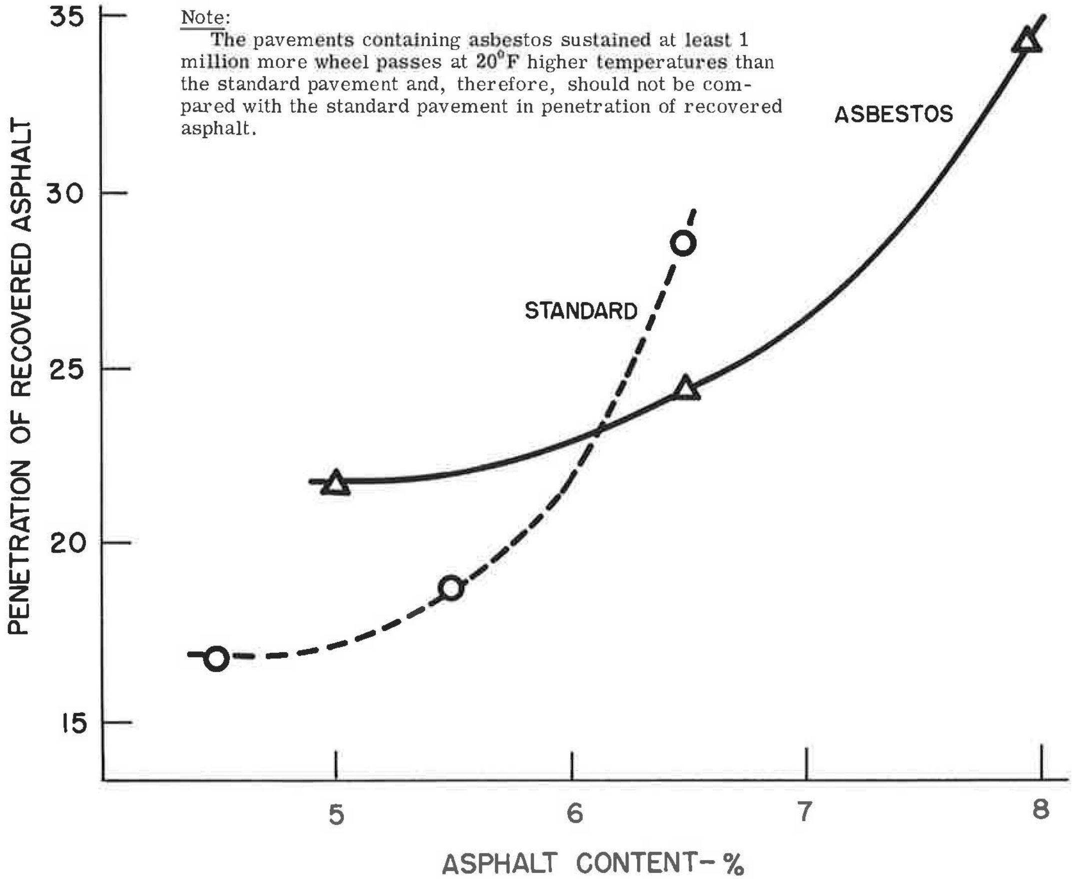


Figure 18. Effect of asphalt content on hardening of asphalt, traffic simulator tests, original penetration 60-70. Pavements containing asbestos sustained at least 1 million more wheel passes at 20 F higher temperatures than standard pavement and therefore are incomparable with it in penetration of recovered asphalt.

60-70 penetration after three million wheel passes duplicating heavy truck traffic. At high asphalt contents, both types of tests showed greatly reduced resistance to compaction.

Because low void contents are beneficial from the standpoint of pavement durability, perhaps the pertinent point is whether the test pavements have been overcompacted under traffic and become unstable. Core data obtained in 1960 and 1962 from pavements with high asphalt content and sufficient asbestos show that where initial void contents were very low (as in Calgary and Manville) no measurable reduction in voids has occurred under traffic and no instability is evident to date despite an increase in asphalt content of 50 percent above standard optimum.

The Calgary core data are given in Table 6 and Appendix C. The increase in void content since placement, implied by the data, is probably due to differences in sample size, area cored, and methods of laboratory analysis. The cores removed from between the wheel paths (center) showed slightly but consistently lower voids than those taken in the right and left wheel paths. The Manville core data are given in Table 11.

Reference to individual core results illustrates another difference. In addition to consistently lower void contents, the range or variability in void contents for the

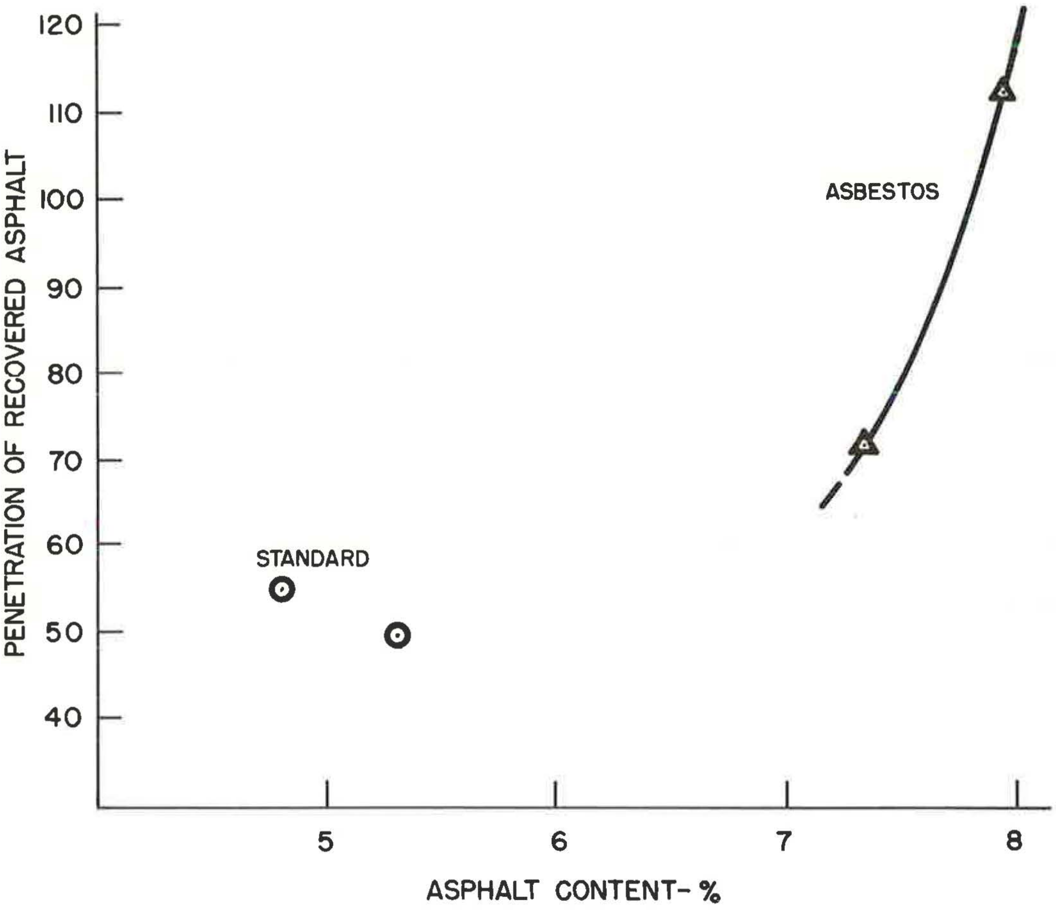


Figure 19. Effect of asphalt content on hardening of asphalt, Calgary, Alberta, original penetration 100-20.

asbestos mixes at each location was consistently one-half (or less) than that of the adjacent standard mix. This uniformity of compaction is, of course, very desirable.

Water Permeability. — Figure 20 shows the general relationship between pavement permeability and air voids as illustrated by data from the Manville pavement. Above a critical air void content (in this case, approximately 6 percent), permeability increased rapidly. Below this void content, permeability was negligible. The two-phase relationship between void content and permeability may be related to interconnection of voids. Further, the test was capable of measuring the slight differences between the pavements with 2 and 3 percent asbestos content.

Average water permeability data from the St. Louis pavements are given in Table 12. Air permeability tests performed at the same locations show a good correlation with water permeability. Both tests indicate that below a critical void content, somewhere between 5 and 7 percent, permeabilities are negligible.

These data suggest that although the asbestos pavements were very tight, small but measurable permeabilities were obtained, with the exception of the Manchester Avenue pavement in St. Louis, which is judged to be too low in fiber content for the existing traffic loads.

The main purpose of these tests is to determine whether a relationship exists between the durability of wearing courses and permeability. This will require periodic retesting for permeability and simultaneous performance evaluations in the future.

Skid Resistance Properties. – The first asbestos test pavement with high asphalt content was placed in Manville on North 13th Street in September 1959. Because considerable flushing occurred under the roller in Mix 2, the skid resistance properties of the pavement were checked to measure the effect, if any, of asphalt contents increased from 5.9 to 9.5 percent total weight.

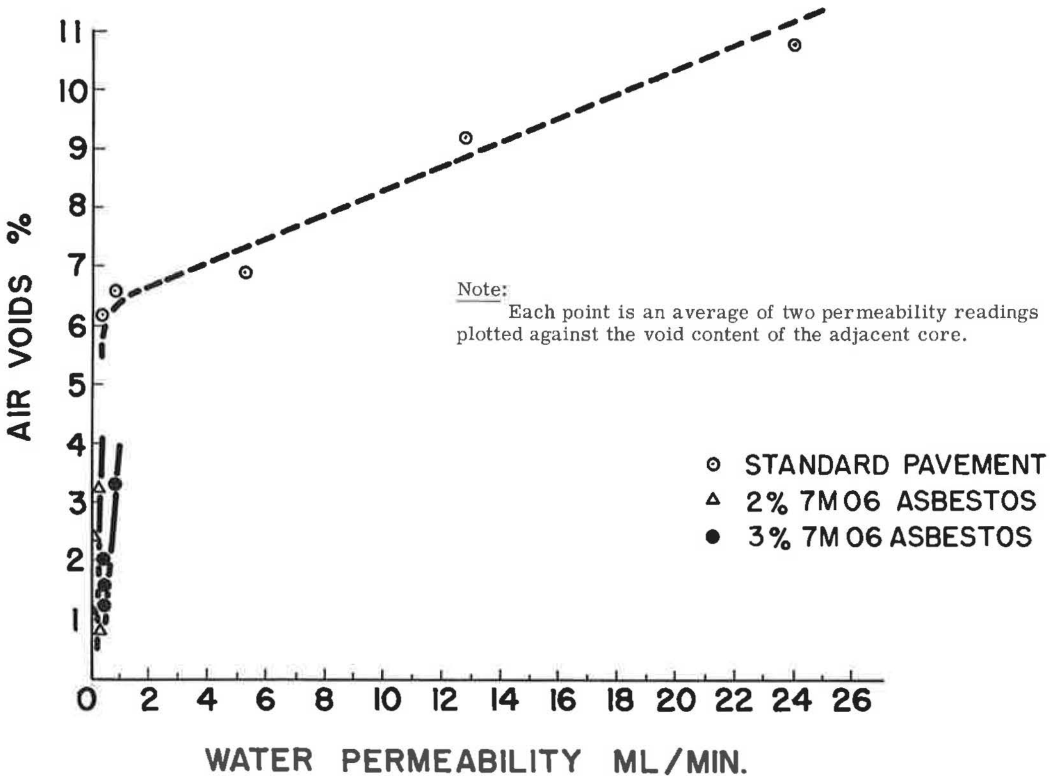
A simple skid resistance test was first used, in which a passenger car was towed at slow speeds over a wet pavement and the force required to pull the car with wheels locked was recorded to determine the coefficient of dynamic friction. These tests showed no significant difference in skid resistance between standard pavement mixes and the two asbestos pavements.

TABLE 11

MANVILLE, NORTH 13TH STREET, CORE DATA

Property	1960 Coring	1962 Coring
Chicago Testing Laboratory report	No. 08411	No. 11297
Number of cores	3	10
Air void content (% by volume):		
Asbestos mix I	1.2	1.9
Asbestos mix II	2.3	2.3

In 1960, one year after placement, a second series of tests was performed at 30 mph using the standard stopping distance tests with a Wagner Stopmeter and fifth wheel



Note:
Each point is an average of two permeability readings plotted against the void content of the adjacent core.

Figure 20. Pavement permeability vs air voids, North 13th Street, Manville, N. J. Each point is average of two permeability readings plotted against void content of adjacent core.

TABLE 12

WATER PERMEABILITY OF ST. LOUIS PAVEMENTS

Location	Void Content (% by volume)		Permeability[a] (ml/min)	
	Standard	Asbestos	Standard	Asbestos
Strodtman Place	6.2	5.0	0.3 to 4.7	0.1 to 0.2
Manchester Avenue	4.1	2.7	0 to 4.0	0

[a] Two test locations were used for each pavement mix.

TABLE 13

STOPPING DISTANCE TEST RESULTS, 1960
NORTH 13TH STREET, MANVILLE, N. J.

Property	Test No.	Stopping Distance at 30 Mph (ft)	Coefficient of Friction	Average Deceleration (ft/sec)	Condition
Standard mix	1	61	0.49	15.9	Wet
New Jersey standard mix	2	66	0.455	14.6	Rewet
Asbestos modification:					
Mix 1	1	68	0.44	14.2	Wet
	2	67.5	0.445	14.3	Rewet
Mix 2	1	66	0.455	14.6	Wet
	2	68	0.44	14.1	Rewet

attached to a passenger car. The results in Table 13 show again that there was a slight but insignificant difference between the stopping distances of the standard New Jersey SM pavement and the asbestos-modified mixes with high asphalt contents. These tests were performed by Johns-Manville friction materials engineers who concluded from the tests that "friction coefficients showed no significant or consistent relationship to asphalt contents of the test roads." Detailed results, including calculation of coefficient of friction, are given in the table.

The design standard for safe pavements adopted by the American Association of State Highway Officials provides for a maximum stopping distance of 113 ft from 40 mph on a wet pavement, which corresponds to 64 ft at 30 mph. The average stopping distances obtained on the Manville, North 13th Street, pavements are close to this standard.

It has often been shown that polishing of various types of aggregates by traffic or inherent smoothness of gravel is the main cause of progressive deterioration of skid resistance in many standard asphalt pavements. A recent report (11) on pavement slipperiness in Virginia states,

> Although the type of pavement plays an important role in slipperiness during the early life of a pavement, once the cement mortar or bituminous binder has worn from the surface, it is the (aggregate) materials that make up a pavement which determines whether a highway will polish and become slippery.

Because the fine asbestos fibers become an integral part of the binder, the fibers themselves would not be expected to affect skid resistance directly. However, as shown in the foregoing photographs of the pavement surfaces, the increased surface toughness of the asbestos-asphalt pavement with high asphalt contents should help inhibit deterioration of skid resistance by preventing differential abrasion of the fine aggregate and exposure of the susceptible coarse aggregate to tire traffic. Future skid tests will be performed to measure the relative effect of abrasion and aggregate polishing on these test pavements with high asphalt content and adjacent standard pavements.

Pavement Life Predictions

The durability study of Maryland pavement surfaces reported by Goode and Owings (Fig. 1) shows that the initial 4-year hardening rate was proportional to the initial air voids. Their data also suggest that hardening rate decreases as void content decreases, implying that an estimate of relative time required for the pavement to reach a critically low penetration or loss of ductility might be predictable.

In the present report, the average difference in present void content is shown in Figure 21.

These differences in air voids, an average of approximately 50 percent lower voids in the asbestos pavements, undoubtedly account for much of the present differences in penetration and ductility of recovered asphalt shown in Figures 16 and 17.

Taking the core analysis data from the Calgary pavements, which remain well above the critical penetration value of 20, described in past pavement studies, it is possible to estimate the relative life expected in the two types of surface mixes or at least the relative time required for the pavements to reach a critically low penetration

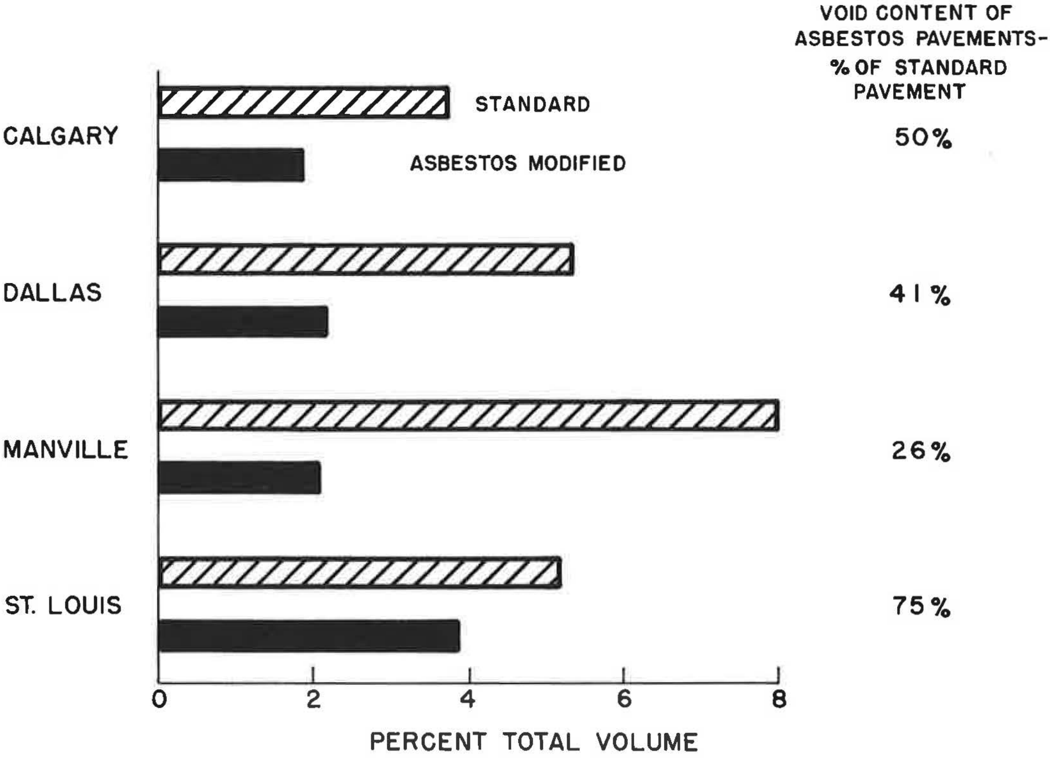


Figure 21. Average void content.

of 20. First, ignoring the present difference in void contents between the standard and asbestos pavements, based on present asphalt penetrations, 30 and 71, respectively (Fig. 16), it should take more than twice as long for the asbestos pavement to reach the critical 20 penetration, assuming the same rate of asphalt penetration loss. However, the standard pavement at present shows twice the void content of asbestos sections and it might therefore be concluded that the rate of penetration loss in the standard pavement would be twice as great as the average rate of loss in the asbestos sections. Allowing for greater future compaction in the standard mix than in the asbestos pavement, it still might reasonably be concluded that the predicted life of the asbestos pavement will be from 100 to 200 percent longer than the standard surface mix. By the same process, it can be shown that the predicted life of the asbestos surface pavement on Manchester Avenue in St. Louis could be twice that of the standard pavement. It should be recalled that at both of the preceding locations visible abrasion has already taken place in the standard pavements, although asphalt penetration and ductility were not critically low.

The service life of most asphalt pavements is determined by (a) structural performance of the pavement section, and (b) the durability of the surface course; that is, the resistance of the surface course to the combined effects of weathering and traffic. Undoubtedly, structural performance, as regards cracking, is to some extent dependent on the durability of the surface course. In some places the structural design is deliberately limited to the expected life of the surface course because resurfacing will upgrade the pavement structurally (12). However, for many asphalt pavements it appears that "structural life" far exceeds the "durability life" of the surface course. In these pavements there is good reason to increase service life of the surface course in the original pavement so that it equals anticipated structural life. Use of asbestos with high asphalt in the surface course of new pavement should help make this performance equality possible.

The increased cost of any modified product must be compared to the improved performance expected. It can be shown that the increase in cost of adding short chrysotile fiber to the top 1 to 1½ in. of surface course is approximately \$0.10 to \$0.15 per square yard, including increased asphalt content.

Mix Design Tests

Standard Design. — In Figure 22 and Table 14, recent mix design test results are

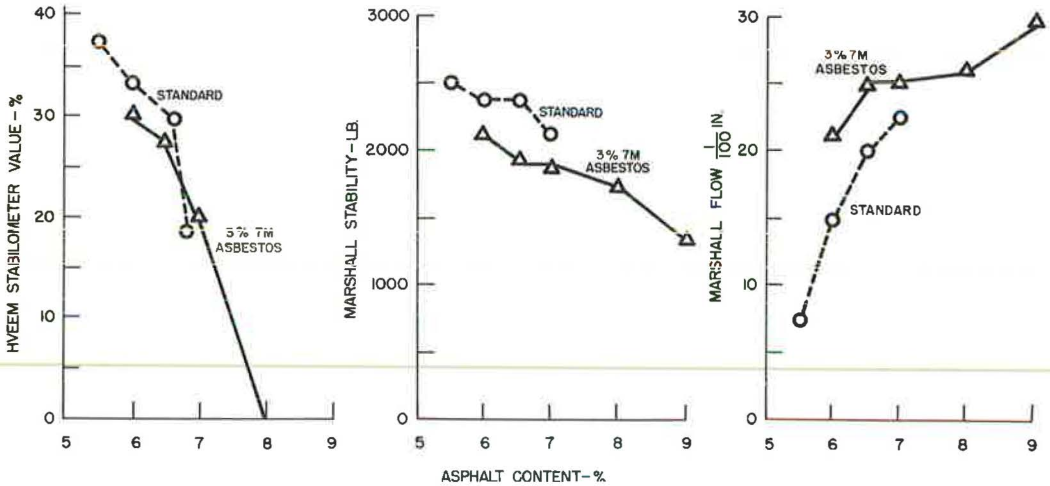


Figure 22. Mix design tests, Calgary, Alberta: (a) Hveem stabilometer; (b) Marshall stability; (c) Marshall flow.

TABLE 14

CALGARY LABORATORY TEST DATA

Sample No.	Asphalt Content (%)	Fiber Content (%)	Density (g/cc)	Void Content (%)	Marshall Stability (lb)	Marshall Flow (0.01 in.)	Hveem Stabilometer Value (%)
10	5.5	0	2.38	2.21	2,550	7	38
11	6.0	0	2.39	0.87	2,420	15	34
12	6.5	0	2.40	-0.41	2,400	20	30
13	7.0	0	2.39	-0.48	2,100	23	19
14	6.0	3	2.30	4.75	2,100	21	30
15	6.5	3	2.32	2.90	1,960	25	28
16	7.0	3	2.34	1.26	1,910	25	20
17	8.0	3	2.33	0.19	1,720	26	0
18	9.0	3	2.30	-0.31	1,380	30	0

shown for aggregates and asphalt received from Calgary. The mix duplicates that used in the test pavement placed in 1960. The specimens were compacted by a gyratory compactor following Asphalt Institute procedure rather than standard Marshall and Hveem methods and, therefore, the actual stability values given are not equivalent to standard test results. Nevertheless, it is apparent that the high asphalt contents permitted in asbestos-asphalt pavements above 7 percent (as demonstrated by this report) could not have been predicted from standard mix design test criteria. The stability tests performed on plant mixes and cores in Calgary and St. Louis by an independent laboratory shown in Appendixes C and D support this conclusion. The curves in Figure 22 are typical of tests on asbestos-asphalt concrete published previously by other laboratories.

It is generally agreed that the stabilometer test measures almost exclusively the aggregate interlock with little effect shown by the cohesion of the binder. Although the Marshall test data are thought to measure a combination of aggregate interlock and cohesion, the main configuration of the curve, if not the stability values, shown in Figure 22b (i.e., optimum asphalt content, etc.) also appears to be controlled by aggregate interlock.

In Figure 22a, above 7.5 percent asphalt contents, the stabilometer values of the Calgary pavement mixes with and without asbestos are negligible. Yet, the Calgary pavement with asphalt contents from 8 to 9 percent containing 3 percent asbestos has remained stable under heavy traffic. The same comparison was observed in the traffic simulator test report (2) and in other high asphalt pavements with asbestos placed for field evaluation. Apparently, performance of the asbestos mixes is not controlled by aggregate interlock as measured by the stabilometer test.

In most pavement mixes, standard mix design compaction procedures give much higher densities and lower void contents than those produced by field compaction of the identical asbestos-asphalt mixes. Correlations between laboratory and field compaction and related mix design criteria established for standard pavements apparently do not apply and should not be used in design of asbestos-asphalt pavements to determine optimum asphalt content or field compaction characteristics.

Mix Design of Asbestos-Asphalt Surface Courses. — The purpose of mix design for standard asphalt surface courses is to determine what is called "optimum asphalt content." The original empirical criteria used to obtain these optimum values imply that the objective is to find the maximum asphalt content that can be used without instability in service. Arbitrary use of asphalt content somewhat below optimum is sometimes used as a safety factor, but little if any increase in asphalt content is permitted.

The asbestos-asphalt pavements placed in each of the four cities, previously listed, include at least one with a 50 to 60 percent increase in asphalt content above standard optimum (Table 10). Apparently, for the typical surface mix gradations represented by these pavements, asphalt content may be chosen independently of standard mix design criteria. These increases would appear to be as much or more than would ever conceivably be needed. This, in effect, adds a new "dimension" to pavement design; i.e., asphalt content. Therefore, other desirable objectives for mix design can be used, most of which relate directly to increased asphalt content, including resistance to asphalt hardening, minimum void content, low temperature impact strength, flexural fatigue strength, etc.

The explanation of how the fine asbestos fibers permit the large increase in asphalt content is beyond the scope of this report. However, there is evidence for at least two basic strength mechanisms: (a) resistance to flow of asphalt by inter-fiber bonding (2) and/or fiber orientation, and (b) resilience of the fiber to asphalt mastic films (10, 13).

Field performance is perhaps the final basis for design. Beginning with asphalt content, the performance data for asbestos-asphalt pavements previously described suggest that a 35 percent increase in standard asphalt content is needed to guarantee a marked increase in pavement life (Figs. 18 and 19, and previous discussion of properties of recovered asphalt). For these typical standard surface courses with 5.5 to 6.0 percent optimum asphalt content, asphalt content should be at least 8 percent total weight of the mix when short asbestos fibers are added. Selection of asbestos content could then be based on minimum fiber-asphalt ratio necessary to maintain adequate stability.

At the 1962 Highway Research Board annual meeting, results of full-scale traffic simulator tests on asbestos-asphalt pavements were reported by the American Oil Company (2). In these tests, heavy wheel loads were applied on pavement slabs for a total of 2½ million wheel coverages at temperatures from 90 to 135 F. The Illinois surface mix with 2½ percent asbestos and 8 percent asphalt content was far superior in performance to the control mix containing 5 percent asphalt (below optimum asphalt), the best standard mix in performance (Figs. 23 through 26). The critical fiber to asphalt ratio for this mix was approximately 0.31.

The field performance of the asbestos-asphalt pavements placed since 1959, including those described in this report, confirms the existence of a critical fiber to asphalt ratio between 0.25 and 0.30 for heavy traffic. Based on present satisfactory performance of pavements under heavy, medium, and light traffic, safe fiber to asphalt ratios for surface courses would be 0.30, 0.25, and 0.20, respectively. For typical surfaces previously described, the corresponding fiber contents with 8 percent asphalt content would be approximately 2.5, 2.0, and 1.6 percent total weight of mix, respectively.

As shown previously, visible surface abrasion was evident in two standard pavements even though the asphalt had not hardened excessively (St. Louis and Calgary pavements). To date, the adjacent asbestos pavements with high asphalt content have resisted this abrasion through increased cohesion which in most cases appears to be proportional to the asbestos content (up to 3 percent). In the preceding mix design recommendations this factor is accounted for inasmuch as the heavy traffic pavements most susceptible to traffic abrasion require higher fiber contents to maintain stability.

The recommended asbestos and asphalt contents should be satisfactory with asphalts up to 100 penetration, with the exception of West Coast States where no asbestos-asphalt pavements with high asphalt contents have been placed from which to judge.

Recent commercial use of asbestos-asphalt pavements include successful use of lower asphalt and fiber contents than those recommended. The main objective is to improve cohesion of those pavements which in performance life are below the average standard asphalt pavement. Among these are thin overlays and pavements made from aggregates lacking in fines, etc. Also, some of these overlay pavements are much finer in aggregate gradation than the pavements described in this report and conclusions given do not necessarily apply to the finer gradations.

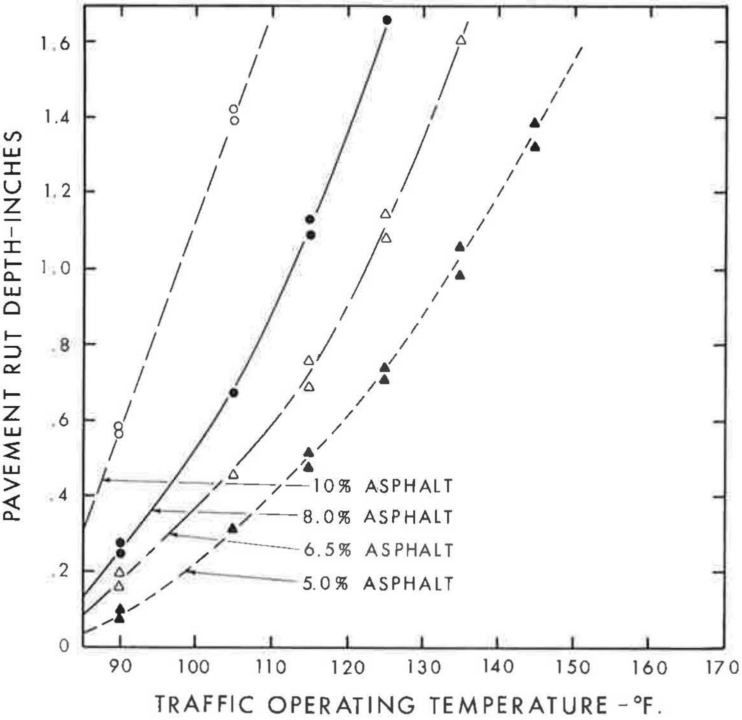


Figure 23. Performance of control pavements with 85 penetration asphalt (from 2).

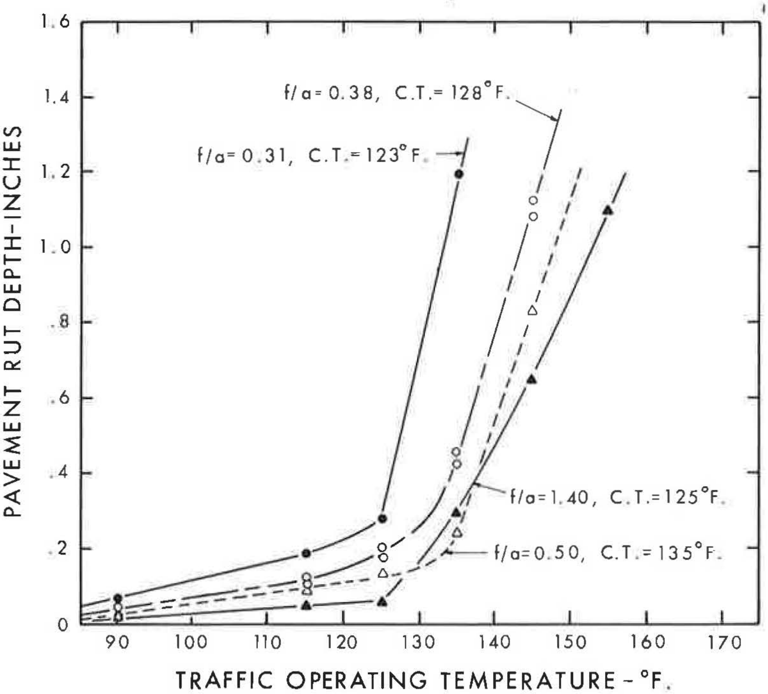


Figure 24. Performance of asbestos pavements with 85 penetration asphalt (from 2).

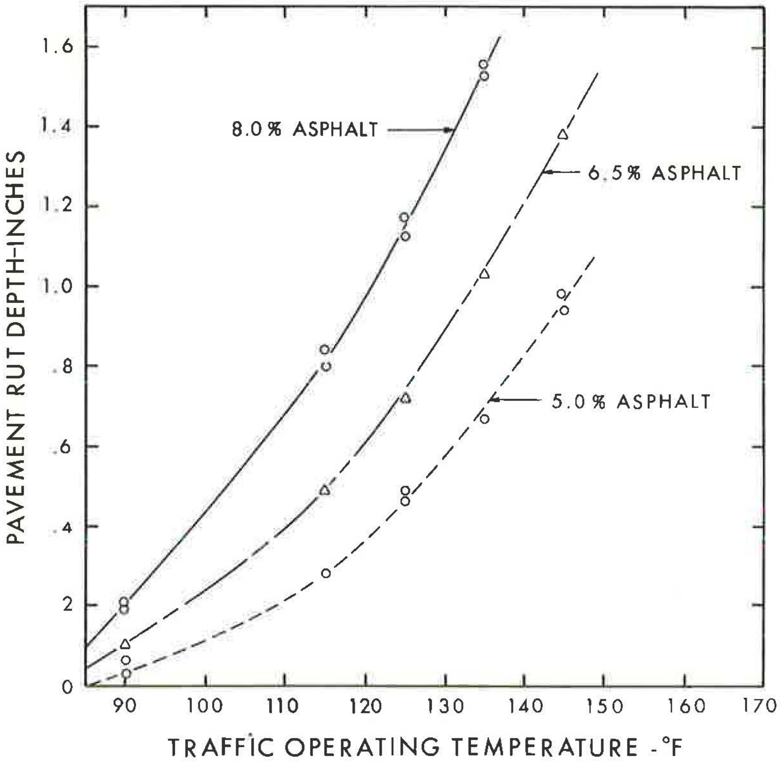


Figure 25. Performance of control pavements with 60 penetration asphalt (from 2).

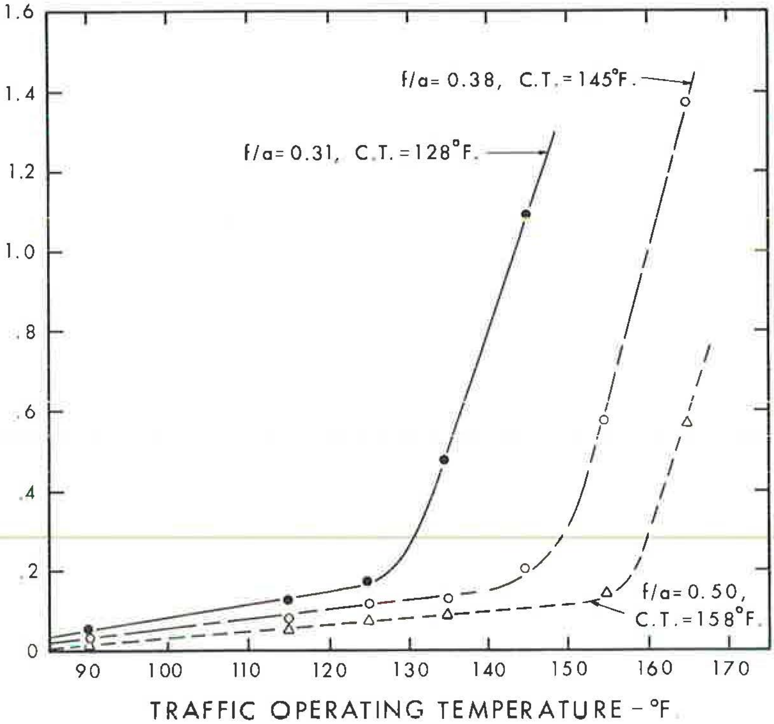


Figure 26. Performance of asbestos pavements with 60 penetration asphalt (from 2).

SUMMARY AND CONCLUSIONS

The following tentative conclusions are based on 2½- to 3-year performance of eight asphalt pavements containing Johns-Manville 7M06 asbestos placed in four cities. All these pavements were modifications of standard dense-graded surface mixes 1¼ to 1½ in. in thickness containing approximately 50 to 60 percent stone retained on the No. 8 mesh sieve.

1. With correct fiber to asphalt ratios, asphalt contents can be increased 50 percent or more above standard optimum without instability under heavy traffic.
2. Core analysis indicates that, where initial void contents were low, no significant reduction in air voids under traffic occurred.
3. Where standard asphalt content was increased 35 percent or more in the asbestos mixes, hardening rate of the asphalt was markedly reduced.
4. In two cities, more than 90 percent of the original asphalt penetration value still remains in the asbestos-asphalt pavements.
5. Incipient raveling of varying degree, already evident in most of the standard mixes, has not occurred in adjacent asbestos-modified pavements.
6. Hardening of the asphalt appears to be responsible for incipient raveling or surface abrasion in the standard pavements at two locations.
7. In at least two cities, surface abrasion of the standard pavements has occurred even though the asphalt penetration is not critically low. The toughness of the adjacent asbestos-asphalt surface mixes has prevented this type of surface deterioration.
8. The permitted 50 percent increase in asphalt content demonstrated by these asbestos-asphalt pavements could not have been predicted by standard mix design tests. Optimum asphalt content of asbestos-asphalt pavements is not limited by standard mix design criteria.
9. Concerning stability in service, the controlling factor in mix design appears to be fiber to asphalt ratio and not asphalt content as in standard pavement mixes.
10. Fifth wheel stopping distance tests on the Manville pavements showed no reduction in skid resistance when asphalt content was increased from 5.9 percent in the standard mix to 9.0 percent in the asbestos pavements.

Based on these performance data, general mix design recommendations, including fiber and asphalt contents, are given for the typical aggregate gradation represented by these surface courses.

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The various paving projects and related performance information included in this report were made possible by the cooperation of officials and engineers of all the cities involved. Through direct cooperation with Johns-Manville, the authors are especially indebted to Adason Miller of the Trumbull Asphalt Company; R. A. Goddard of Harrisons and Crosfield (Canada), Limited; Charles L. Pratt of the Bridges Paving Company in St. Louis; A. M. Johnson and John Wendling of the City of St. Louis Street Department; Michael S. Kachorsky of the Boro of Manville; the Wright Asphalt Products Company of Dallas; and H. H. Stirman of the Dallas Public Works Department. The interest and willingness of the various sponsoring agencies to experiment with asbestos-asphalt pavement mixes at high asphalt contents is greatly appreciated.

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Appendix A

SHATTUCK OXIDATION TESTS—EFFECT OF ASBESTOS ON THE HARDENING OF ASPHALT DURING MIXING

Laboratory. — Chicago Testing Laboratory, Report 03886, February 2, 1961.
Test Method. — Shattuck Oxidation Tests Described in AAPT Proceedings, 11: 193-194 (1940).
Materials. — Johns-Manville's 7M06 asbestos
Ottawa silica sand
Asphalt from six sources (Table 15)

TABLE 15

RESULTS OF SHATTUCK OXIDATION AND RECOVERY TESTS

Asphalt Crude Source	Original Asphalt Cement		Recovery After Regular Shattuck				Recovery After Shattuck with 2.5% Asbestos			
	Pen. at 77 F	Duct. at 77 F	Pen. at 77 F	% of Orig.	Duct. at 77 F	Ash (%)	Pen. at 77 F	% of Orig.	Duct. at 77 F	Ash (%)
Boscan	91	150+	36	39.6	63	0.01	38	41.8	55	1.7
Wyoming	93	150+	47	50.5	110+	0.02	46	49.5	110+	1.9
Mid. Cont.	88	150+	47	53.3	22	0.01	49	55.7	24	2.0
Smackover	82	150+	48	52.8	110+	0.01	47	51.7	110+	1.5
E. Texas	91	150+	39	42.8	68	0.03	38	41.8	55	1.6
Oklahoma-solvent ppt.	95	150+	57	60.0	92	0.03	59	62.2	145	1.3

Appendix B

EFFECT OF AGING ON THE PROPERTIES OF ASPHALTIC-CONCRETE MIXTURES CONTAINING ASBESTOS

Laboratory. — Chicago Testing Laboratory, Report 08362, March 23, 1962.
Materials. -- Illinois Type I-11 asphalt concrete.

1. Limestone - Material Service Company, Chicago, Ill.
2. Torpedo sand - Material Service Company, Chicago, Ill.
3. Lake sand - Material Service Company, Chicago, Ill.
4. Limestone dust - Waukesha Lime and Stone Co., Waukesha, Wis.
5. Asbestos grade 7M06 - Johns-Manville Products Corporation, Manville, N. J.
6. Asphalt A. C. 85/100 - Trumbull Asphalt Company, Detroit, Mich.

The asbestos mixture was identical to the regular mix with the exception that 2.5 percent of the limestone dust was replaced with an equal amount of 7M06 asbestos fiber; and the asphalt content was increased from 5.8 to 6.8 percent.

Test Method

Immediately after preparation of the mixtures, they were loosely placed in quart friction top cans with the cover removed. After the mixtures had cooled to room temperature, the lids were placed to air-seal the cans which were stored in the laboratory at room temperature.

One set of mixtures was tested for asphalt properties immediately after cooling. The others were tested after 3, 6, 9, and 12 months of aging.

Asphalt extraction using a Houghton centrifugal extractor with trichloroethylene and recovered by the Abson method (ASTM D 1856-61T). Tests included penetration, ductility, and ash content. Results are given in Table 16.

TABLE 16

RESULTS OF AGING TESTS ON BITUMINOUS MIXTURES[1] WITH AND WITHOUT ASBESTOS[2]

Aging Period (mo)	Asphalt (%)		Penetration at 77 F		Ductility at 77 F		Ash (%)	
	No A. C.	2.5% A. C.	No A. C.	2.5% A. C.	No A. C.	2.5% A. C.	No A. C.	2.5% A. C.
Initial	5.7	6.7	75	74	150+	150+	1.5	1.9
3	5.7	6.7	57	60	150+	150+	0.5	1.1
6	5.8	6.8	48	48	150+	150+	1.6	0.8
9	5.8	6.8	46	48	150+	150+	1.4	1.8
12	5.9	6.9	46	48	150+	150+	1.5	0.5

[1] Original asphalt: penetration @ 77 F, 100/5 = 94; ductility @ 77 F, 5/60 = 150+ cm.

[2] Chicago Testing Laboratory, Inc., Report 08362, March 23, 1962.

Appendix C

PLANT MIX AND CORE ANALYSIS AFTER PLACEMENT, CALGARY, ALBERTA-ALYTH FREEWAY

Laboratory:	MacDonald and MacDonald, Ltd. - Rep. 5, 30 June, 1960
Order No:	Tender 0-119 Part #2-B
Mix Classification:	III

Plant Mix Sample Analysis:

Property	Standard Mix			Mix 1[a]			Mix 2[a]		
Specimen No.	23a	23b	23c	25a	25b	25c	26a	26b	26c
Marshall stability (lb)	3,118	2,407	2,407	2,115	2,545	3,120	3,540	2,830	3,400
Marshall flow (1/100 in.)	10	10	9	19	18	12	8	11	9
Asphalt content by extraction (%)		5.52			9.17			6.90	
Sp. gr. cake		2.34			2.35			2.32	
Sp. gr. agg.		2.62			2.62			2.61	
VMA (%)		15.7			17.50			17.20	
Voids filled (%)		82.1			100+			93.40	
Voids air (%)		2.8			None			1.20	
Unit wt (pcf)		146.2			146.6			144.7	

[a] Containing 3 percent 7M06 asbestos.

Core Analysis[1]:

Property	Asbestos Modified (3% 7M06)		
Specimen No.	25a	25b	25c
Marshall stability (lb)	970	1,150	950
Marshall flow (1/100 in.)	21	15	16
Asphalt content by extraction (%)		7.65	
Sp. gr. mix		2.38	
Sp. gr. agg.		2.61	
VMA (%)		15.90	
Voids filled (%)		100+	
Voids air (%)		None	
Unit wt (pcf)		148.5	

[1] Cores taken from pavement laid from loads sampled for preceding plant mix analysis; only average values reported for constituent analysis.

Appendix D

PLANT MIX ANALYSIS, ST. LOUIS PAVEMENTS*

Laboratory: Municipal Testing Laboratory, City of St. Louis.

Samples from Strodtman Avenue, October 6, 1959

Property	Lab. No. 593641		Lab. No. 593642	
Sample No.	1		2	
% asbestos (7M06)	2		3	
Bitumen content	8.4		9.8	
Density (pcf)	150.4		147.9	
Marshall stability (lb)	1,070	1,130	1,083	1,050
Marshall flow (1/100 in.)	29	27	31-41	34-49

*"Note the unusually high flow values obtained with relatively high stability, considering the asphalt content. We noticed that the load on the stability test dropped in the usual manner (yield point) and then picked up again and held the same (optimum) stability for an additional .010-in. to .015-in. of flow. In a regular asphaltic concrete sample the load does not pick up again once it fails. The initial flow value is normally the point of failure."

Report of October 9, 1959, by John M. Wendling, Chief Engineer.

Samples from Manchester Avenue at Tower Grove Avenue, November 5, 1959

Property	Lab. No. 594078	Lab. No. 594079
% asbestos:	1.2	1.2
7M06	0.6	0.6
4T28		
% bitumen	9.1	9.4
Density (pcf)	151.2	151.4
Marshall stability (lb)	1,428	1,188
Marshall flow (1/100 in.)	32-39	30[a]

[a] Load did not pick up again.

Sample from Manchester Avenue Near Kings Highway Intersection, November 9, 1959

Property	Value
% asbestos	1
% bitumen	8.1
Density (pcf)	152.2
Marshall stability (lb)	1,308
Marshall flow (1/100 in.)	32-39

Appendix E

SKID RESISTANCE TESTS ON MANVILLE PAVEMENTS SEPTEMBER 1960

Test Equipment

Car — 1958 Chevrolet, six-cylinder, four-door sedan, 4,200-lb weight including driver, observer, and instruments.
Tires — Goodyear Custom Nylon, 750 x 14. Good tread, 28-psi tire pressure.
Instruments — Wagner stopmeter with fifth wheel assembly (Fig. 27).

Location

Manville, N. J., North 13th Street.

Test Conditions

Pavement — flushed with fire hoses continuously.
Speed — 30-mph vehicular speed.

Figure 27. Wagner stopmeter with fifth wheel assembly.

Appendix F

WATER PERMEABILITY TEST PROCEDURE

The apparatus in Figure 28 consists of a graduated cylinder with an opening at the bottom attached through a valve connection to a shallow cup which rests in an inverted position on the pavement. The cylinder, valve, and cup are fixed rigidly together by means of a frame which includes lateral projections for support of weights added to counteract the upward force of water pressure on the apparatus.

The solution used is 95 ml of 75 percent aerosol solution in 5 gal of water (as in the California test method). Dye is added to the solution to facilitate reading the height of the water column during testing.

Initial procedure is as follows:

1. Clean pavement surface with wire brush.
2. Mark a 6-in. diameter circle on pavement with crayon using a template.
3. Apply sealer to circle. Johns-Manville "Albaseal" caulking strips or equivalent.
4. Put the permeability apparatus on the pavement with the periphery of the cup resting on the sealer.
5. Apply pressure to the lateral extensions on the frame and rotate slightly at the same time. Apply finger pressure against sealer on the outside of the cup to insure a tight seal.
6. Put the necessary weights on the frame extensions.
7. Fill the cylinder with solution keeping the valve closed.

To start the test, open the valve and start the stop watch. Normally, 30 sec are required for solution to fill the cup and for air to escape to the surface, during which time solution is added to keep the cylinder filled.

At 30 sec, the initial surface level of the liquid at the top of the cylinder is read using a millimeter scale attached to the cylinder. The decreasing level of the surface is observed and recorded at 15-sec intervals for a total of 4 min. By calibration of the cylinder, the amount of solution penetrating into the pavement is obtained and plotted against time. The slope of the curve from 30 to 90 sec is arbitrarily used as a measure of surface permeability. Readings taken from 90 sec to 4 min are used primarily for very tight pavements to insure that the flow is continuous and to increase precision of flow rates obtained.

For pavements with a very low permeability, the sensitivity of flow rates is increased by extending the initial height of the water column, using a small diameter graduated tube on top of the plastic cylinder (Fig. 28). This method was used to obtain all of the permeability data described in this report.

The relatively small decrease in head during each test period was found to have a negligible effect on flow rates. The effect can be measured for any pavement by duplicating tests at a lower head.

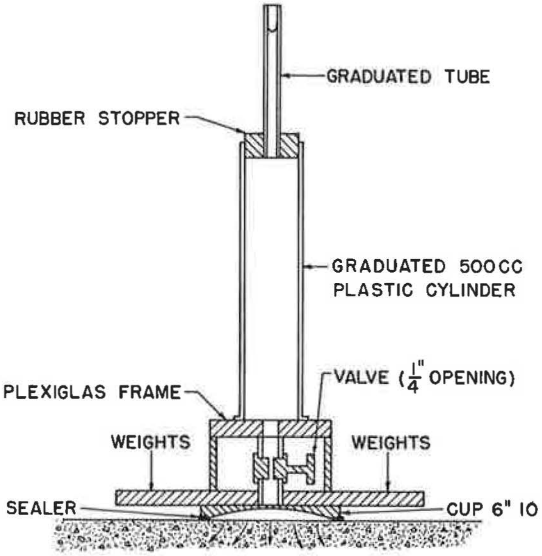

Figure 28. Cross-section of water permeability apparatus.

Appendix G

RECENT ASBESTOS-ASPHALT CONCRETE SURFACE COURSES WITH SUBSTANTIALLY INCREASED ASPHALT CONTENT

City, State, Street Name or Rt. No.	Supervisory Authority	Date of Installation	Type of Installation	Type or Classification Mix	% Asbestos	Type of Asphalt Pen.	Optimum % A.C. for Standard Mix	% A.C. in Asbestos Modified Mix	% Increase in A.C. Content	Remarks
*Ottawa, Ill.	Ill. Hwy. Dept.	9/62	1½-in. wearing course	A-1 IV-A Ill. I-11	2.0	85/100	5.5	6.7	22	Rehabilitated AASHO Test Road
*Hampden/Newburg, Me.	Me. Hwy. Dept.	6/62	1½-in. wearing course resurfacing over existing bit. concrete pavement	A-1 IV-A	1.5	85/100 60/70 120/150	6.4 6.4 6.4	7.8 7.8 7.8	22 22 22	3 pen. grades of asphalt being evaluated in combination with fillers
*Raleigh, N. C., Rt. 64	N. C. Hwy. Dept.	5/23/62	1½-in. wearing course on 3½-in. resurfacing project		2.5 1.67		6.7 6.7	8.5 8.0	27 20	
St. Louis, Mo., Jefferson Ave.	City of St. Louis	8/6/62	3/4-in. thin surfacing over spalled p.c. concrete	A-1 V-A	1.5	60/70	5.8	8.5	46	Thin overlay
Madawaska, Me., US 1 Supr. to Canada	Me. Hwy. Dept.	7/11/61	1-in. surface course over asbestos-asphalt concrete binder and base course	A-1 V-A Modified	2.0	85/100	7.0 (est.)	8.5 to 9.1	22 to 30	New construction
*Asbestos/Danville, Quebec, Canada Rt. 12	Que. Dept. Hwys	6/28/62	1-in. wearing course	A-1 IV-A	2.0	85/100	6.0	8.0	33	New construction
*Lafayette, Ind., US 52 Bypass, Ind. 25	Ind. Hwy. Dept.	7/25/52	7/8-in. surface course	Ind. Type-B	2.0	60/70	6.5	8.2	26	
		7/25/62	7/8-in. surface course	A-1 Skip A	2.0	60/70	6.5	8.2	26	
*Last Chance, Colo., H.S. 36	Colo. Hwy. Dept.	4/4/62	1-in. wearing surface on 1½-in. binder on 4-in. soil cement base (new construction)	Pit run Plant mix	2.0	85/100	5.8	7.3	26	New construction
Banff, Alberta Trans-Canada Highway	Canadian Dept. of Public Work	6/5/52	-	-	-	-	5.3	7.5	42	New construction

*Experimental project.