Alexandria asphalt cement (AC 40/50). This result suggests that the use of AC 40/50 grade could be a promising alternative for overcoming the reported performance problems that are associated with the use of Alexandria AC 60/70 grade.

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Effect of Diatomite Filler on Performance of Asphalt Pavements

J. H. KIETZMAN and C. E. RODIER

ABSTRACT

Diatomite, a widely used industrial filler, has been evaluated in heavy-duty pavements in Houston, Calgary, and Los Angeles. These pavements typically have high density, extremely low permeability, and a low initial asphalt hardening rate, with or without an increase in asphalt content. After 2 and 3 years in Calgary and Houston, recovered asphalt shows penetration values of 88 and 90 percent of the original 164 and 104 asphalt penetration at 77°F, respectively. Resistance to rutting at low void contents and characteristic abrasion resistance of the mortar is attributed to microaggregate interlock of diatom particles within the mastic films. One percent diatomite appears capable of either stabilizing pavements or permitting a 15 percent increase in standard asphalt content. The primary value of diatomite appears to be that it allows the use of softer asphalt, which alone should greatly increase pavement life. The effect of increasing the cost per ton of mix (10 to 20 percent) on cost per square yard of pavement was eliminated recently in Los Angeles by reducing overlay thickness by 50 percent. Eight different grades, types, and sources of diatomite were also evaluated in small paving sheets under truck traffic at Denison, Texas, and Lompoc, California. Several types gave extremely unsatisfactory resistance to plastic flow. Tests are under way to correlate basic diatomite properties (shape, size, purity, and so forth) with pavement performance. The scope of the program to date has been limited to dense-graded city pavements. The results are reported here to generate interest in more trials needed to justify continuation of the program.

Diatomite products are amorphous silicas produced worldwide from natural sedimentary deposits of diatomaceous earth, which consist of microscopic skeletal remains of diatoms (see Figures 1 and 2). Commercial deposits contain different amounts of impurities, but all require processing for end use to remove clay, silt, silicates, and so forth; all require high temperature drying to remove water and organics; and all require reduction to effective particle-size distribution.

Perhaps the most well-known use of diatomite is for filtration (e.g., for food purification). Uses include hundreds of other products such as the flatting agent in paint (by imparting microtexture to the surface) and an abrasive in automobile polishes. Diatomite has been used for 25 years in hot-poured asphalt joint filling compounds to control flow. In 1928, 5 percent diatomite was used in an overlay for concrete warehouse floors (1).

In comprehensive laboratory evaluations of a variety of fillers, the Asphalt Institute reported that use of too much diatomite (7 percent in a sheet asphalt) caused water susceptibility, which was avoidable by cutting back to 3.5 percent diatomite (2,3).

Preliminary laboratory tests at Manville Research, before the recent field tests, confirmed that in large amounts (3 to 5 percent) diatomite created voids in asphalt concrete rather than filling voids because of the high absorptivity of diatom structures (Figures 1 and 2).

With this background of laboratory testing, a field test program was initiated in January 1981. The objectives were to determine the effectiveness of adding diatomite after premixing the hot aggregate with asphalt (instead of during the dry mix cycle) and to find out how diatomite might improve pavement durability. Laboratory strength tests on laboratory and plant mixes were included only to explain or confirm performance results.

The grade of diatomite used in the field trials described herein is a high grade (pure), high-bulk, natural type produced from marine deposits in Lompoc, California. In the future, this grade will be designated CAP (CELITE for asphalt pavement) to differentiate it from other grades and sources whose effect on pavement performance appears to be unsatisfactory or remains unproven.

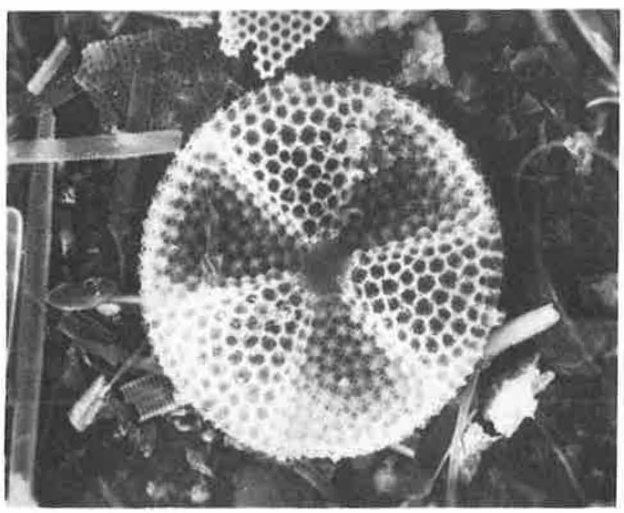

FIGURE 1 Diatomite micrograph (X563 magnification): marine diatom structures.

TEST SECTIONS AND MATERIALS

Field tests have included five sites: the cities of Houston, Calgary, and Los Angeles, and Manville Corporation plants in Denison, Texas, and Lompoc, California.

Materials used in the test pavements represent the best quality crushed stone, stone screenings, and sand available in each area, as described in Figure 3. For preformed paving sheets, stone screenings (dense, nonporous, quartz monzonite) were used with the same type of EXXON AC-10 (104 penetration) asphalt that was used in the Houston pavement trial.

It was discovered after placement that the diatomite-modified pavement in Houston was made with AC-10 asphalt and not the AC-20 asphalt used in the standard pavement. Although this precluded comparison of asphalt hardening, the mistake proved fortunate because performance results gave the first indication that diatomite made it possible to use a softer asphalt for heavy traffic pavements.

The same high bulk, natural grade of marine diatomite from Lompoc was used in the field tests to

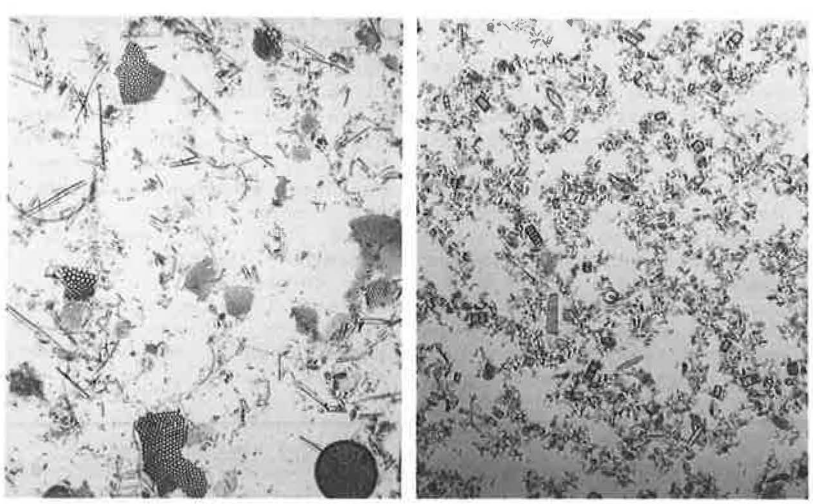

FIGURE 2 Diatomite micrographs (X150 magnification): high-bulk diatomite (left) and Nevada diatomite (right).

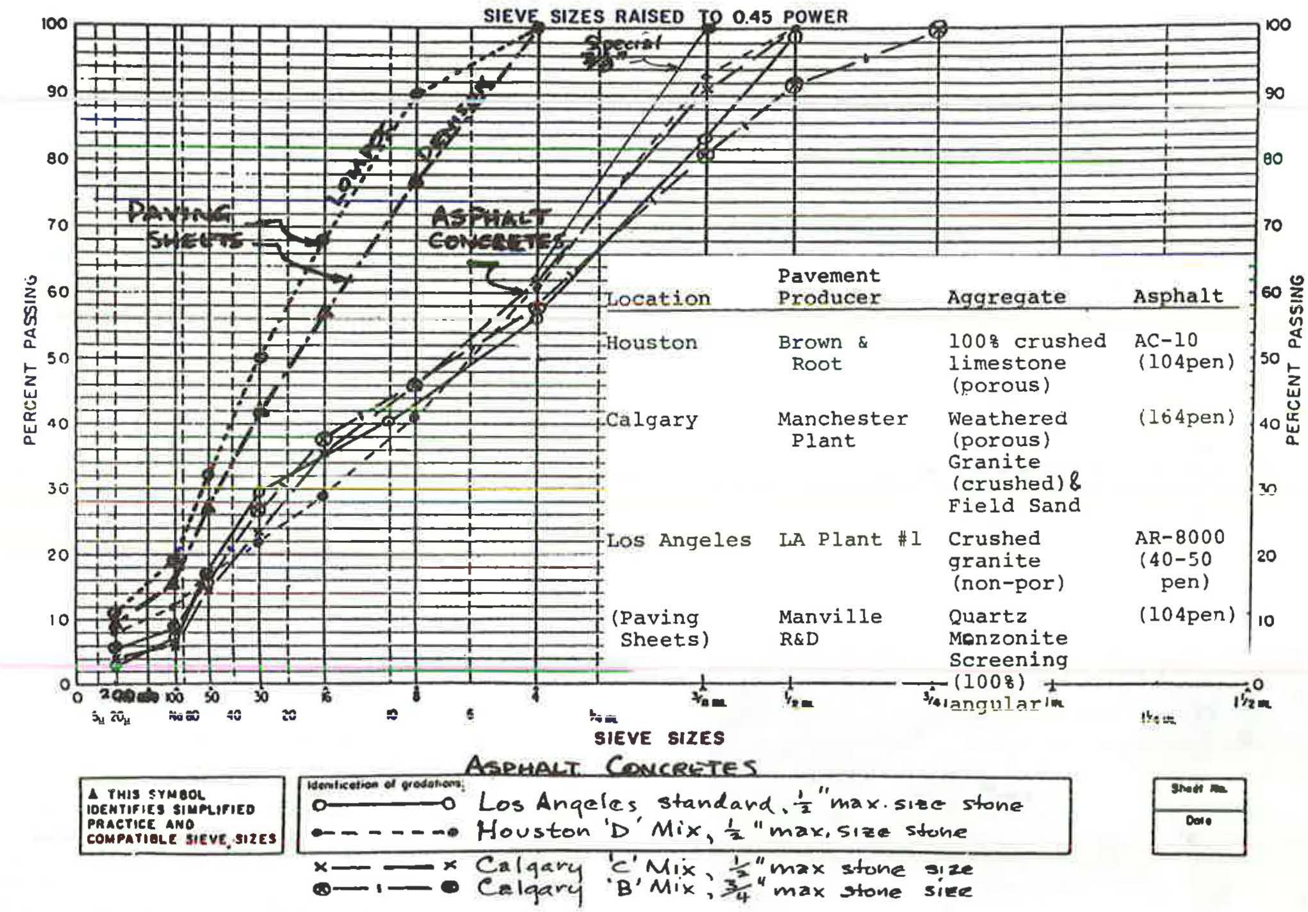

FIGURE 3 Aggregate gradation chart.

date. It has a surface area of approximately 250 000 cm^2/g. Other grades and sources of diatomite tested in the small paving sheets varied widely not only in particle-size distribution, shapes, purity, and so forth, but also in their ability to control plastic flow. Until current laboratory tests demonstrate which diatomite properties determine their effect on pavement performance, it appears advisable not to give identifying properties that could prove to be misleading.

TEST PROCEDURES

The performance evaluation includes visual surface effects such as rutting, cracking, mortar abrasion (exposure of coarse stone), surface friction, and internal effects such as density voids, permeability, and asphalt hardening.

Void contents of pavement cores were measured by the difference between underwater weights before and after vacuum saturation, expressed as a percentage of bulk volume. Vacuum saturation of the cores was done by using vacuum techniques similar to the standard ASTM test for measuring theoretical maximum density of uncompacted pavement mixes. Past correlations indicate that vacuum saturation of cores or compacted pavement samples gives void contents 1 percent total weight less than values obtained by using maximum theoretical density based on the standard Rice test.

Air permeability was measured by Soiltest's pavemeter, modified by reversing the position of tubing to apply negative pressure on pavement surfaces or cores. This allowed use of up to 12 in. of H_2O partial pressure and differentiation of tight pavements (e.g., in Calgary, where all were impermeable to water).

Special Laboratory Tests

The effect of saturation of laboratory cohesive strength of Los Angeles pavement mixes was determined by using a plate flexure test on 6-in.-diameter, 1.25-in.-thick pavement specimens compacted by gyratory shear to initial field density. Each pavement specimen was supported around its top periphery by a ring, with load applied at the bottom center through a rubber ball. Load is applied by using the Marshall tester with load and deflection taken at first visible crack (4).

Vertical shear tests were performed on 4-in.-diameter, 2-in.-thick pavement specimens compacted by 50 and 75 Marshall hammer blows on both sides. The shear equipment was mounted in a Universal testing machine with the specimen mounted horizontally as a fixed cantilevered beam, clamped along the centerline. Vertical load was applied at the overhang (centerline) at a rate of 200 lb/min, and the ultimate load was recorded. Shear strength in pounds per square inch was calculated by dividing the ultimate load by the vertical cross section of the specimen.

Preformed Pavement Sheets

Field tests on small paving sheets were conceived as an expedient way to compare stability (i.e., resistance to plastic flow) of a large number of paving

formulations under the same concentrated truck loading.

To make small paving sheets, sheet asphalt was mixed in 4000-g batches by using standard mixing equipment and adding the diatomite after premixing of hot aggregate with liquid asphalt. Each hot mix was rolled into sheets 0.375 in. thick, cooled to room temperature, and trimmed to a 12 x 18-in. size.

The paving sheets were tested on pavements at Manville plants in Denison (1982) and in Lompoc (1983). They were placed in rows in the wheel path for exposure to channelized truck traffic of up to 1,500 vehicles per month. A 2:1 water diluted SS-1 emulsion paint coat was used to bond the sheets to the pavements. Increase in width of the sheets (transverse to the direction of traffic) was measured monthly to show plastic flow, which is expressed as a percentage of the original width.

The sheets were exposed to warm weather traffic from June to October (4 months) at Denison and from April to September (5 months) at Lompoc. These tests compared the relative resistance to plastic deformation of different mix formulas. Only the high-quality, high-bulk diatomite was tested at Denison, with 2 to 4.8 percent diatomite and 11 to 15 percent asphalt (diatomite/asphalt ratios of 0.15 to 0.31). In subsequent tests at Lompoc, each type of diatomite was tested in three different formulations (sheets), 1 or 2 percent diatomite with 12.5, 13, and 14 percent asphalt (maximum diatomite/asphalt ratio of 0.15).

The paving sheets were placed in the wheel paths at the exit and entrance gates, where concentrated truck traffic decelerates and accelerates. The sheet asphalt formulations were intended to accentuate the effects of traffic on plastic flow (stability) by leaving out the stone fraction (50 to 60 percent of standard asphalt concrete) to test only the mortar phase and the effect of the diatomite on pavement cohesion (viscosity) and microaggregate interlock within the mastic.

The paving sheets at Lompoc were thoroughly wet with water once a week during the first 2 months.

PAVEMENT PRODUCTION METHOD

Adding diatomite after (or during) the normal wet mixing cycle (aggregate plus hot asphalt) proved to be an effective way to avoid the pulverizing of diatom particles that occurs when diatomite is added during the standard dry mix cycle. This was first demonstrated to be effective in the Houston trials in January 1981 by extracting asphalt from the plant mix in situ on glass slides. Microscopic examination indicated that the only significant effect on particle size during batch mixing was a 25 to 30 percent decrease in the length of spicules. Equally important, diatomite dispersion was good in the pavement mixes.

This simple change in batch plant procedure served a second vital purpose: it prevented loss of the lightweight, easily airborne diatom particles through the dust collector system that occurs when diatomite is added during the dry mix cycle.

In Houston the standard mixing time per batch was increased from 10 to 30 sec in proportion to the time required to pour the diatomite (0.6 to 2.4 percent total weight) into the pug mill by hand.

In Los Angeles diatomite was poured from 50-lb paper bags into the pug mill immediately after the asphalt was added in the standard wet mix cycle. This limited the total increase in batching time to 5 or 10 sec.

Supplying diatomite in heat-degradable plastic bags was first tried in Calgary in 1981 with success. The 25- to 50-lb bags were dropped into the pug mill by an automatic feed system after the normal wet mix cycle, with an additional, final 20 to 30 sec of mixing.

Placeability (paver speed) of the mixes was described by crews as superior in Los Angeles, normal in Calgary, and slower than normal in Houston for the high diatomite content mixes (perhaps because of the combined effect of angularity of the 100 percent limestone aggregate and high diatomite content in two of the Houston mixes).

FIELD TEST RESULTS

Houston

The four paving mixes produced to evaluate the new mixing sequence (four truckloads in all) were included in a city paving project on Franklin Street, a major downtown thoroughfare in Houston. After 1 year the superior resistance to traffic abrasion of the mortar phase was extremely noticeable in the test sections, as shown by the limited exposure of coarse stones compared with extensive surface exposure of stone in the connecting standard mix (Figure 4). After 3 years the coarse stone has become

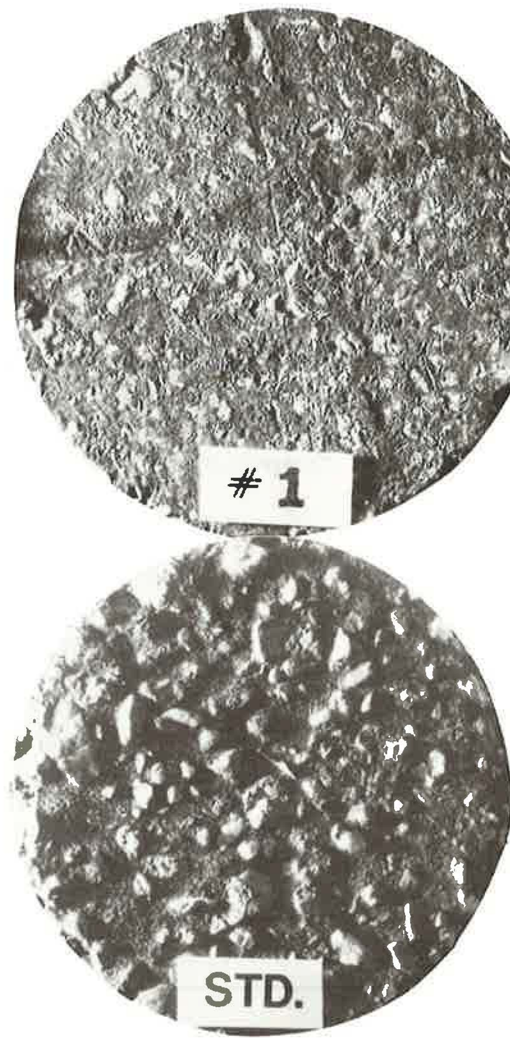

FIGURE 4 Surface abrasion in Houston pavements after 1 year: 0.6 percent diatomite and 6.8 percent asphalt (top) and standard (bottom).

TABLE 1 Houston Core Analyses, Franklin Street Pavement

	Texas Modified 'D' Mix				
	Diatomite-Modified				STANDARD
Aggregate	100% Limestone				Limestone + 25% gravel
	I	IV	II	III	Parker Bros.
Diatomite Content %	0.6	0.6	1.8	2.4	
Asphalt Content %	6.8	6.0	7.4	7.3	5.5
Density, gm/cc 1981 (1 yr)	2.31	2.33	2.28	2.35	2.28
1983 (3 yr)	2.384	2.397	2.358	2.398	2.363
Void Content, % 1981 (1 yr)	1.3	1.7	2.0	2.8	4.2
1983 (3 yr)	0.4	1.7	0.4	0.7	2.1
Air Perm. 1981 (1 yr)					
ml/min/in head 1983 (3 yr)	0.10	0.88	0.04	145.5	1.5
Thickness, inch	1.63	1.30	1.47	1.15	1.60
1981-Core Extract (1 yr)					
Asphalt Recovered, %	6.2	5.5	7.7	5.5	4.8
(% of original asphalt)	(91%)	(92%)	(100+%)	(75%)	(87%)
Penetration of Rec. Asph.	89	82	94	73	42
(% of original)	(86%)	(79%)	(90%)	(70%)	(--)
1983-Core Extract (3 yr)					
Asphalt Recovered, %	6.3	5.3	6.6	5.4	4.6
(% of original asphalt)	(93%)	(88%)	(89%)	(74%)	(84%)
Penetration of Rec. Asph.	94	83	85	90	44
(%of original)	(90%)	(80%)	(82%)	(87%)	(--)

NOTE: Test values above are the average of 3 cores in most instances.

exposed in the test sections, but it is less apparent in the standard mix, possibly because of pull-out of coarse stone.

More important are the results of core analyses (Table 1). Despite the range in diatomite content (0.6 to 2.4 percent and asphalt content from 6 to 7.4 percent), all four mixes show high density and low void contents, and after 3 years penetration of recovered asphalt remained as high as 90 percent of the original 104 penetration.

In Figure 5 recovered asphalt penetrations are plotted with data published in 1975 by the Pennsylvania Department of Transportation. The 1975 data

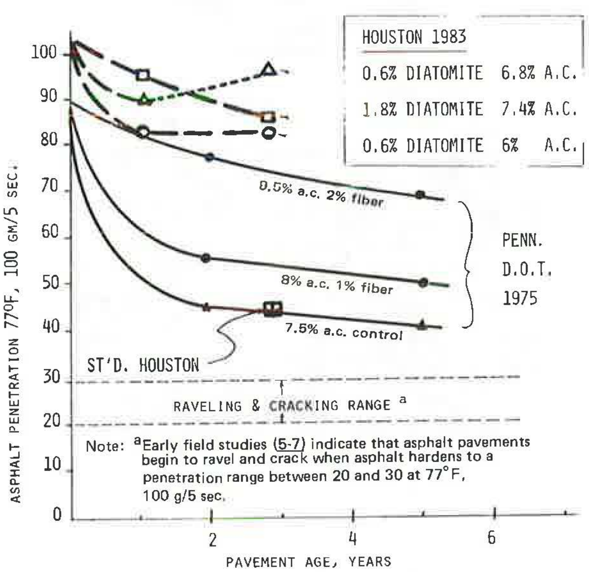

FIGURE 5 Resistance to asphalt hardening in Houston test pavements.

indicate that by increasing asphalt content 25 percent more than standard optimum, initial retained asphalt penetration could be increased from 45 to 87 percent of original penetration. In contrast, all of the Houston diatomite-modified mixes showed 80 to 90 percent of original asphalt penetration after 3 years, with or without an increase in asphalt content.

Rutting remains minimal at the Austin Street stoplight intersection, despite the extremely low diatomite content. Beyond the stoplight rutting is so slight as to be attributable to differential compaction or wear in the wheel path (Table 2).

Laboratory tests on Houston plant mixes indicated that adding 0.5 to 1 percent diatomite prevented the normal decrease in stabilometer values when asphalt content was increased 1 percent total weight more than standard optimum (Figure 6).

Calgary

Success of the simple batch plant mixing procedure at Houston laid the groundwork for further field tests. Starting in June 1981, test pavements were laid in Calgary to make a direct comparison with fiber-reinforced, high asphalt content pavements used for 20 years for all heavy traffic overlays to benefit durability in the cold climate.

The 1981 Calgary trials compared the effect of 1 and 2 percent diatomite with the standard 1 and 2 percent 7M asbestos fiber in pavement mixes made with the same 164 penetration asphalt and aggregate, produced and placed continuously from the city batch plant. The test pavements were located on the main north-south artery, MacLeod Trail, and a major east-west highway, Southland Drive.

In general, results in Calgary have been comparable to those in Houston, with diatomite imparting superior abrasion resistance (Figure 7) and resistance to initial asphalt hardening (Table 3). Most

TABLE 2 Pavement Surface Characteristics

Pavement (Age)	A.C.	Rut Depth, inch		Surface Friction
	%	Inside Wheelpath	Outside Wheelpath	BPN
I. TRANS-CANADA HIGHWAY (1yr.)				(65°F)
0.5% diatomite	7.0	.09	0.19	75
0.75% diatomite	7.5	.06	0	76
1.00% diatomite	7.5	0.13	0	80
Control (2% Fiber)	7.8	.06	.03	74
II. HOUSTON (3 yrs.)		At Stoplight	Beyond Stoplight	(79°F)
0.6% diatomite	6.0	-	0	60
0.6% diatomite	6.8	0.10	.05	61
1.8% diatomite	7.4	-	.03	68
Standard	5.5	0.20	.03	60

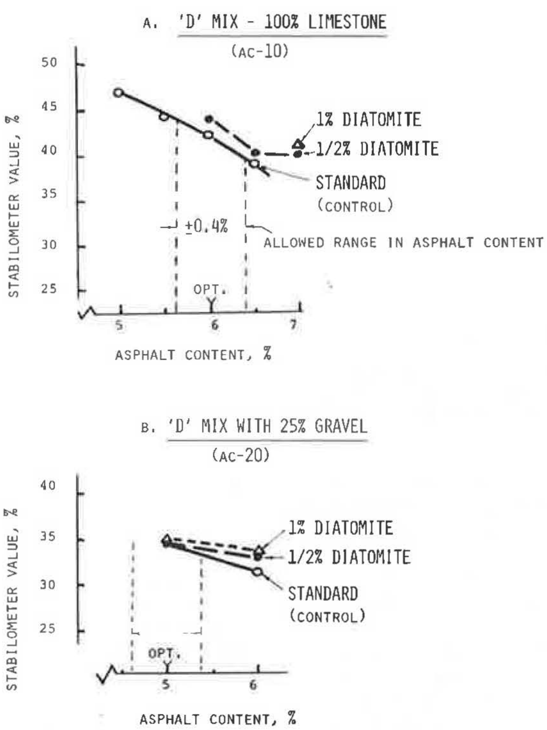

FIGURE 6 Stabilometer tests on Houston plant mixes.

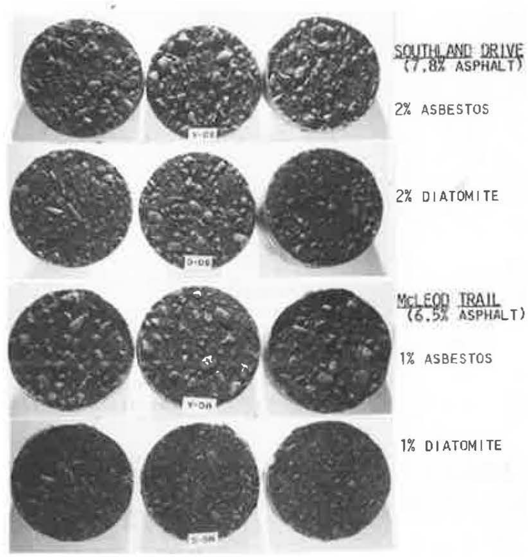

FIGURE 7 Abrasion resistance in Calgary after 1 year.

notable was pavement made with 1 percent diatomite, which after 2 years showed an asphalt penetration of 144, 88 percent of the original 164 penetration, after correction for ash content.

In 1982 more field tests in Calgary on the Trans-Canada Highway indicated that pavement mixes made with less than 0.75 percent diatomite plus an increase in asphalt did not compact to the desired high density and low permeability, and it showed measurable rutting (Table 2).

In another 1982 trial (MacLeod Trial north) a pavement mix was placed by using 1 percent diatomite with asphalt content lower than the connecting control mix with no additive. The surprising results from 1-year core analyses were higher retained asphalt penetration, much lower permeability, and higher density (see Table 4).

The data in Table 5 give the Marshall stability test data on Calgary plant mix samples.

Los Angeles

In the first large-scale field trial of diatomite-modified pavement, 1,000 tons were placed in Los Angeles in 1982 by city crews; 900 tons of the standard (1/2 in. maximum stone) resurfacing mix and 100 tons of a special 3/8 in. maximum stone mix, both with AR-8000 asphalt (about 35 penetration). Primary laboratory mix design objectives included low permeability and increased cohesive strength. The laboratory flex tests on mixes compacted to initial field density (Table 6) and shear tests on pavement mixes compacted to ultimate traffic compaction (Figure 8) both suggested that satisfactory results would be obtained by using 1 percent diatomite with approximately 6.5 percent asphalt. However, 0.5 percent

TABLE 3 Calgary Core Analyses, 1981 Pavements

	Macleod Trail		Southland Drive	
	1% Diatom	Control 1% Fiber	2% Diatom	Control 2% Fiber
Asphalt Content,[a] % wt	6.5	6.5	7.8	7.8
1982 Recovery* % (% initial a.c.)	6.00 (92%)	5.50 (85%)	7.71 (99%)	7.65 (98%)
1983 Recovery* % (% initial a.c.)	6.05 (93%)	5.75 (88%)	7.10 (91%)	7.25 (93%)
Density, gm/cc 1982 (1 yr)	2.327	2.324	2.368	2.354
1983 (2 yr)	2.394	2.379	2.336	2.337
Void Content, % 1982 (1 yr)	4.3	4.4	3.1	2.8
1983 (2 yr)	0.12	1.35	1.14	1.10
Permeability (ml/min/in. head) 1982 (1 yr)	7.0	52.0	0.90	18.0
1983 (2 yr)	0.02	0.17	0.47	0.07
Core Thickness, inch	1.88	1.71	0.84	1.20
Asphalt Penetration at 77°F				
1982 (1 yr)	111	70	100	92
% original	(68%)	(43%)	(61%)	(56%)
1983 (2 yr)	126	83	84	87
% original	(77%)	(51%)	(51%)	(53%)
Ash Content, % of asph. 1983	2.7	1.9	5.2	2.0
Asphalt Penetration Corrected for ASH				
1983	144		104	
% original[b]	(88%)		(63%)	

NOTE: (a) Original asphalt penetration was 164 at 77°F.

(b) A Canadian DPW report of 1973 indicated that increasing asphalt content from 6 to 7.5 percent total weight of mix increased penetration of recovered asphalt after 3 years from 62 to 93 (8).

TABLE 4 Calgary Core Analyses, 1982 Pavements

Additive	Asphalt Content	Density gm/cc	Air Permeability (Max./Min. > Average, ml/min/inch) Wheel Path	Air Permeability Near Curb	Asphalt Hardening: Penetration after 1 Year (% retained)
None (Control)	6.5%	2.345	28 / 15 > 22.0	-	106 (66%)
Standard 2% asbestos	7.8%	2.335	0.21 / 0.13 > 0.17	-	91 (57%)
1% Celite	6.0%	2.371	0.15 / 0.11 > 0.13	2	113 (71%)

diatomite with 6 percent asphalt was also included in the field trials placed on Slauson Avenue between Estrella and Vermont. Placeability was satisfactory. The quick-setting properties of the diatomite mixes permitted traffic on the mat before completion of final rolling, despite the 104°F ambient (air) temperature.

Core analyses 1 year later confirmed the superiority of 1 percent diatomite with 6.5 percent AC, which showed extremely low permeability and averaged 75 percent higher retained penetration than the connecting control (Table 7). Pavements with 0.5 percent diatomite and 6 percent asphalt averaged 30 percent higher penetration of retained asphalt than the control. One beneficial surface effect already shows up, that is, resistance to dripline erosion (see Figure 9). [Note that in Figure 9 the top photograph shows the standard control eastbound at an intersection at Figueroa, and the bottom photograph shows the standard with 1 percent diatomite and 6.5 percent asphalt (one block west of Figueroa).] Although not often seen in Los Angeles' overlays, this kind of localized erosion appears to be a fairly common occurrence in some communities in southern California.

Slight rutting has occurred at only one point on Slauson Avenue, in the truck lane at the stoplight at the Hoover intersection, where the asphalt content exceeded 6.5 percent. Results of Hveem stabilometer tests on plant mixes sampled in 1982 revealed satisfactory values (36 to 38 percent) for the special 3/8 in. stone mixes with 0.5 percent and 1 percent diatomite, 6 and 6.5 percent asphalt content. In the standard 1/2 in. stone mix, 0.5 percent diatomite with 6 percent asphalt showed a 36 percent stabilometer value. But with 1 percent diatomite and 6.5 percent asphalt, the stabilometer value dropped to 16 percent, presumably because laboratory-compacted densities were much higher than the density of the pavement cores.

A second large-scale test pavement was placed on

TABLE 5 Marshall Stability Tests of Calgary Plant Mixes (trials placed 9/82)

	Marshall 50-blow Compaction				
Additive	Asphalt Content (165 pen) %	Density gm/cc	Air Voids % (Vac sat)	Stability (140F) Lbs	Flow .01 in
1% CELITE	6.0	2.351	2.1	3820	14.7
3/4% CELITE	7.5	2.348	1.8	2100	18.3
1% CELITE	7.5	2.344	1.6	2180	20.0
2% CELITE	7.8	2.335	1.2	2060	22.7
2% 7M Fiber	7.8	2.348	1.6	1715	19.7
None	6.5	2.365	3.0	2740	11.0

TABLE 6 Effect of Saturation on Cohesive Strength of Los Angeles Pavement Mixes

Standard L.A. Resurfacing Mix

				PLATE FLEXURE TESTS(a)			
						After Vacuum Saturation & 24 Hr. Immersion 140°F	
CELITE Content % Total Wt.	Asphalt Content	Density gm/cc	Water Permeability ml/min. (12" head)	Load at Crack 140°F lb.	Deflection at Crack inch	Load at Crack 140°F lb.	Deflection at Crack inch
0	5.2	2.20	670	25	.027	20	.033
1/2	5.2	2.16	154	45	.039	20	.033
1/2	5.7	2.20	120	35	.038	40	.038
1	6.2	--	20	--	--	40	.035
1	6.7	2.30	2.2	45	.028	50	.033
2.2	7.5	2.285	1.3	25	.027	55	.039

(a) Gyratory Compacted Samples (6" diam., 1 1/4" Thick)

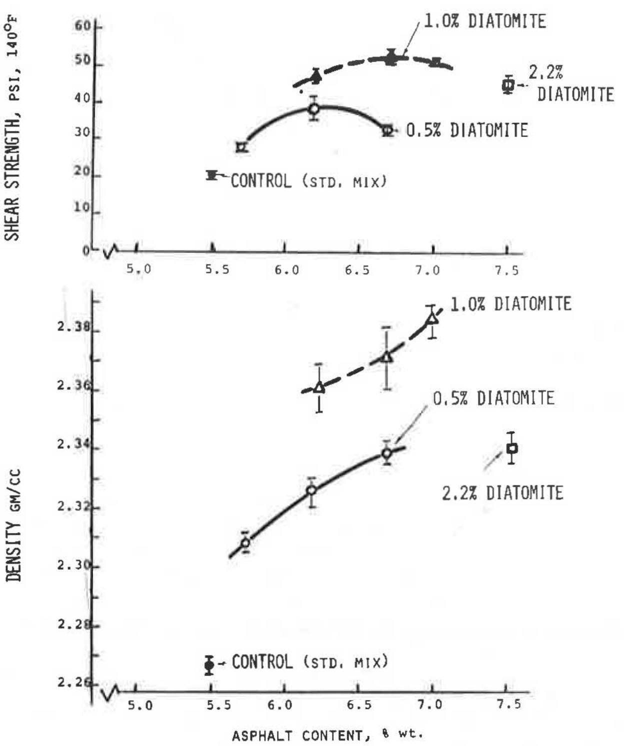

FIGURE 8 Los Angeles mix design.

FIGURE 9 Resistance to drip-line erosion, Slauson Avenue.

TABLE 7 Slauson Avenue Core Analyses After 1 Year

	Control (Std Mix) 5.2% a.c.	Diatomite-Modified ½% Diatom 6.0% a.c.	1% Diatom 6.5% a.c.
I. Std. Resurfacing:1/2"Max Stone			
Asphalt Recovery, % (a)	4.6	6.0	6.5
(Ash Content, % of asphalt)	0.12	1.38	1.93
Density gm/cc	2.255	2.270	2.346
Void Content, %	8.2	6.2	1.2
Permeability ml/min/in. head	106.1	45.4	1.40
Thickness, in.	1.49	1.46	1.46
Penetration of Recovery Asphalt at 77°F	10	15	21
II. Special Mix:3/8" Max Stone			
Asphalt Content, % (a)	5.2	6.0	6.5
Asphalt Recovery (1983) % wt	5.25	6.2	6.6
Ash Content, % of asphalt	(0.56)	(1.19)	(0.87)
Density, gm/cc	2.235	2.286	2.338
Void content, %	6.9	6.1	1.8
Air permeability ml/min/in. head	166	10.9	0.63
Thickness	1.21	1.22	1.11
Penetration of Recovered Asphalt at 77°F	15	16	21

(a)AR-8000 (30-40 pen)

Chatsworth Avenue in Los Angeles in August 1983. The purpose was to evaluate the special 3/8 in. stone mix made with 1 percent diatomite and 6.5 percent AR-2000 asphalt (70 penetration). This softer asphalt reportedly cannot normally be used for heavy traffic pavements because of slow setting properties. However, when placed in August, adding diatomite made the mix set up quickly like the standard pavement mix made with AR-8000 (hard) asphalt. Initial core analyses demonstrated the higher retained penetration (60 percent) in the diatomite-modified mixes, but all mixes showed considerable asphalt hardening.

Tests on these plant mixes also gave Hveem stabilometer values of 34 to 35 percent.

The diatomite-modified overlay on Chatsworth westbound lanes was placed and compacted to a 1-in. nominal thickness without problems. The standard 1/2 in. stone mix placed on the adjacent eastbound lanes was 1.5 in. nominal thickness.

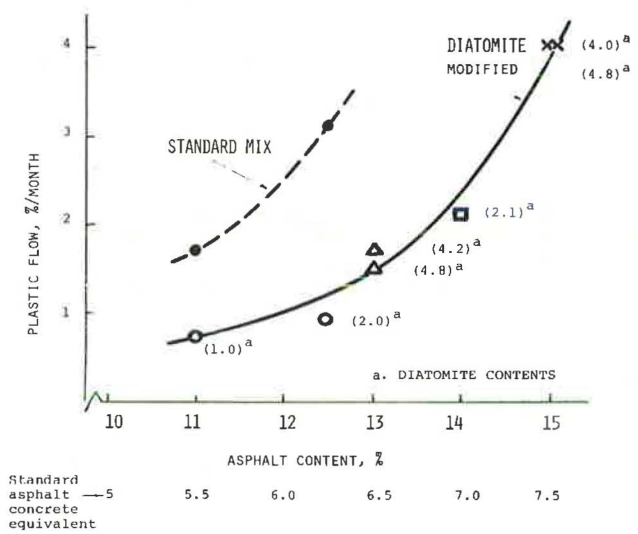

FIGURE 10 Resistance to plastic flow (Denison paving sheets).

Paving Sheets

The first tests on paving sheets exposed to concentrated truck traffic at Denison, Texas, in 1982 contained only the high-bulk, high-grade Lompoc diatomite and diatomite/asphalt ratios of 0.15 to 0.32 (2 to 4.8 percent diatomite, 11 to 15 percent asphalt). In Figure 10 the relation between plastic flow (increase in width) and asphalt content is apparent. Results imply that the minimum diatomite/asphalt ratio of 0.15 percent had optimum effect on stability and would permit approximately 2 percent total weight increase in asphalt content (1 percent in comparable asphalt concrete) without increasing the standard plastic flow.

A second and more extensive series of tests on paving sheets at Lompoc in 1983 included diatomite/asphalt ratios of 0.15 or lower. The data in Table 8 demonstrate the effect of the high-bulk Lompoc diatomite content on the control of plastic flow.

Other paving sheets at Lompoc compared the effect of other grades of diatomite and other types or sources on resistance to plastic flow. Results plotted in Figure 11 show that a finely pulverized diatomite failed to prevent excessive plastic flow. This confirms the necessity of adding diatomite to the pug mill after premixing the asphalt and hot aggregate to minimize crushing of diatom particles. Paving sheets that contain diatomite made from a low-

TABLE 8 Effect of Diatomite Content on Plastic Flow in Lompoc Paving Sheets

Asphalt Content % Total Wt. (equivalent to asphalt concrete)		PLASTIC FLOW (6 Wks.), % Diatomite Content,[a] % 0	1[a]	2[b]
11	(5.5%)	4.4	2.6	-
12.5	(6.25%)	8.2	4.7	-
13	(6.5%)	(12.0)est.	(6.8)	5.0

(a) Equivalent to 1/2 % in asphalt concrete.

(b) Equivalent to 1% in asphalt concrete.

grade California crude also showed excessive plastic flow.

A diatomite from France was slightly less effective in controlling plastic flow than the high-bulk commercial grade from California (Figure 12). Diatomites from Spain and Mexico were one-third to one-half as effective. Results with paving sheets containing a Nevada diatomite stand out in Figure 12 because with 13 percent asphalt content, excessive plastic flow continued through July and August.

Other data from Lompoc (not reported here) indicate that (a) reducing aggregate fines from 14 to 7 percent in the sheet asphalt mix had little effect on plastic flow, and (b) with 164 penetration asphalt, a diatomite/asphalt ratio higher than 0.15 would be needed to control plastic flow in southern California.

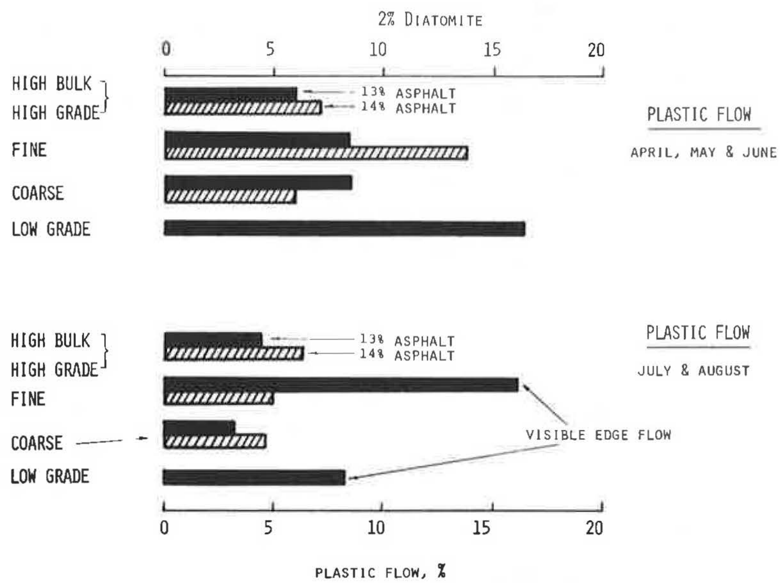

FIGURE 11 Effect of grade of diatomite (Lompoc) on plastic flow.

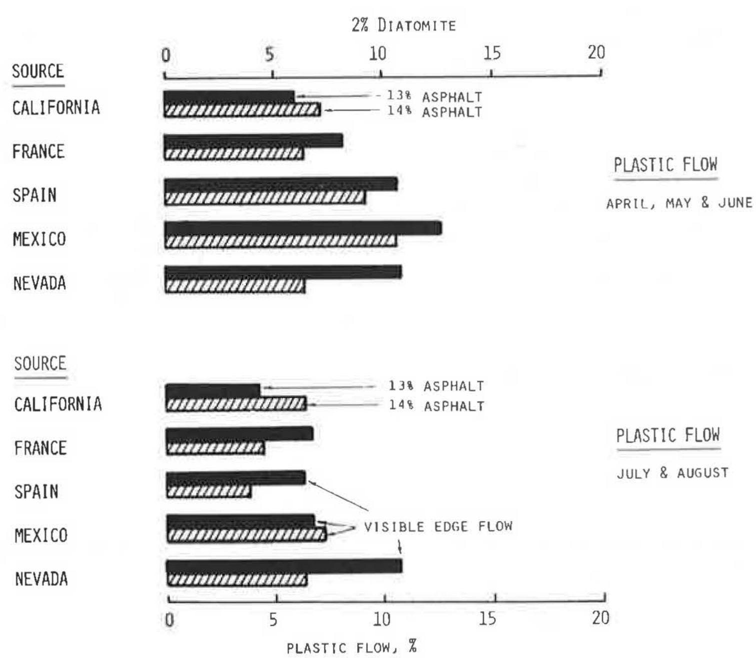

FIGURE 12 Effect of source of diatomite on plastic flow.

INTERPRETATION OF RESULTS

Compaction and Asphalt Hardening

Field tests have indicated that the high-grade Lompoc diatomite used in the field tests tends to promote pavement compaction. In Calgary, even with asphalt content below normal, adding 1 percent diatomite gave higher initial density and much lower permeability than the control mix. The test pavements in all three cities also demonstrate a marked resistance to initial asphalt hardening with or without a nominal increase in standard asphalt content. In both respects, the diatomite-modified pavements during mixing and placement act like high asphalt content pavements, as illustrated in Figure 5.

The best explanation for these effects to date is that the diatomite extends the volume of hot asphalt mastic. By out-gassing of adsorbed water (6 percent of diatomite weight), adsorption of asphalt is apparently delayed until the mix cools below about 200°F. The high-bulk diatomite has an absorption capacity equal to 3 times its weight of asphalt. One percent diatomite could theoretically extend the volume of 6 percent asphalt by 50 percent. Actually, the volumetric extension and delayed absorption is much less than theoretical maximum and depends on asphalt viscosity, aggregate fines, and so forth. This explanation could explain the observed effects of diatomite on pavement properties. Note that poor performance of some types or sources of diatomite (Figure 12) could be related to asphalt absorption.

Stability

Considering the twofold function of fillers (3), interparticle contact, and increase in asphalt consistency, the first term appears to describe the main effect of low diatomite contents. By using the term microaggregate for fine fillers, a term coined by Tons and Henault (9), a primary function of diatomite appears to be increasing microaggregate interlock. Because diatom structures are 85 to 90 percent voids after complete absorption, 1 percent diatomite with 6.5 percent asphalt may occupy up to 55 percent of the asphalt mastic (excluding rock dust). With rock dust included, the total point-to-point interparticle contact and internal friction within the mastic films must be greatly multiplied. Differences in physical properties of diatomites (e.g., effective absorption, particle size) help to explain the results shown in Figures 11 and 12.

The fact that diatomite increases asphalt mastic viscosity and cohesive strength of pavements is its second function. However, pavement performance to date shows little correlation between high diatomite contents (and resulting high cohesive strength) and pavement stability for mixes with diatomite/asphalt ratios greater than 0.15 and with AC-10 asphalt.

Use of too much diatomite content where absorptive capacity equals or exceeds the volume of asphalt present could possibly cause water susceptibility problems.

Crack Resistance

The standard pavement adjacent to the test sections in Houston shows very fine but extensive cracking, both longitudinal cracking in the wheel paths and short transverse cracks extending out from joints in the gutter. No fine cracking is visible in the diatomite-modified sections (made with softer asphalt). However, several coarse, random reflection cracks are visible in the test section with high diatomite content mix at the south end (intersection) and in the adjacent standard overlay.

There is no evidence from other test sections that adding diatomite to asphalt concrete will alone greatly affect reflection cracking. However, by permitting use of softer asphalt (e.g., AC-10), diatomite should give significant resistance to some types of reflection cracking, as it did, for instance, in Houston.

MIX FORMULATION

The criticality of the 0.15 minimum diatomite/asphalt ratio, based on the paving sheet results, was not recognized until after the 1982 test pavements had been placed. A typical asphalt concrete (e.g., one of those placed in Los Angeles) that would meet the stability criteria for heavy city traffic would include 1 percent diatomite (the high-bulk, high-quality Lompoc type) and 6.5 percent asphalt (AC-10). The aggregate recommended for thin surface overlays is 3/8 in. maximum size stone (e.g., the special 3/8 in. stone mix first placed in Los Angeles in 1982 and 1983). Note that both of these plant mix samples contained 6.5 percent asphalt and both met the California stabilometer criteria for stability. Use of diatomite with less than 5.7 percent asphalt is not recommended for general use, based on the data given in Table 6.

CONCLUSIONS

1. Adding diatomite during or after the normal wet mix cycle in batch plant production proved to be an effective way to avoid both pulverizing of diatomite when added in the dry mix cycle and loss of airborne diatomite particles by dust collection.
2. Core analyses consistently showed much less asphalt hardening in the diatomite-modified pavements than the standard or control pavements.
3. With the high-grade, high-bulk Lompoc diatomite, a minimum diatomite/asphalt ratio of 0.15 maintains stability of asphalt concrete with AC-10 (85 to 100 penetration) asphalt. Where stability of asphalt concrete is adequate, 1 percent diatomite should allow an increase in standard optimum asphalt content of 1 percent total weight of mix.
4. Adding diatomite consistently facilitated compaction of dense-graded pavement mixes, even without increasing asphalt content; after 2 or 3 years of heavy city traffic the pavements appear capable of maintaining stability despite low void contents.
5. Several other types and sources of diatomite did not control pavement stability under heavy traffic. Although none of the test pavements with high-bulk, high-grade Lompoc diatomite shows any evidence of water susceptibility, other types of diatomite (impure, low absorption, and so forth) may cause such problems.
6. The combined effects of the Lompoc high-bulk diatomite, such as compaction, abrasion resistance, and increased cohesive strength of asphalt hot mixes, suggests special benefit to thin pavement overlays.

Many dense-graded pavements, such as those used in these field tests, may require one of the surface treatment methods that create the macrotexture required for high traffic speeds, that is, open-graded friction courses (OFC), aggregate sprinkle treatments, or grooving. The impermeability typical of diatomite-modified dense-graded pavements could prove valuable, however, in binder courses used to support OFC surface overlays.

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Texas stabilometer tests were performed on Houston plant mixes by Southwestern Laboratories, Inc. LaBelle Consultants measured stability of the recent Los Angeles pavements by using standard California procedures. The Chicago Testing Laboratory ran Marshall stability tests on Calgary plant mixes and performed extraction-recovery tests on all pavement cores reported herein.

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Combo Viscoelastic-Plastic Modeling and Rutting of Asphaltic Mixtures

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ABSTRACT

Constitutive equations used in solving the boundary value problem of flexible pavements employ linear elastic or viscoelastic theory. Accordingly, permanent deformations are calculated based on elastic or viscoelastic deformation laws. Advances in the field of constitutive modeling of materials indicated the need to develop a constitutive relationship that better replicates asphaltic mixture responses under various loading and environmental conditions. In this paper a one-dimensional combo viscoelastic-plastic constitutive model composed of Burger-type mechanical elements connected in series with a friction slider is used. The friction slider is the mechanical representation of plasticity with a Drucker-Prager yield criterion. This model is solved under creep phase loading conditions, and the solution is used to develop a rutting model that incorporates a densification phase represented by a relaxing spring. Within the verification of the constitutive model a true yield line has been identified and used instead of the Mohr-Coloumb failure line. The two developed models are supplemented by appropriate experimentation phases to identify and numerically evaluate the relevant parameters. Experimentation is based on actual existing routine methods, with proper adjustments, modifications, or extensions to comply with proper evaluation of the model parameters, and kept as simple as possible to encourage wider user acceptance. An example using actual data is worked out and compared with results obtained from the VESYS III structural subsystem program.