An Investigation of Soil Waterproofing And Dustproofing Materials

DEAN R. FREITAG, Chief, Mobility Section, Soils Division; and GEORGE R. KOZAN, Acting Chief, Soils Stabilization Section, Soils Division, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

The capabilities of a number of materials to waterproof and dustproof a lean clay soil are evaluated by means of field and laboratory studies. The field tests were conducted on a test section composed of 16 adjoining panels, 13 of which were surfaced with a 3-in. layer of soil mixed with one of the selected materials; the other three, used as controls, comprised two untreated soil panels and one provided with a bituminous surface. Traffic was applied to the test section at intervals during a 13-month period of exposure to weather; the amount of material abraded by the traffic was measured to determine dustproofing effectiveness of the various treatments. Observations of moisture changes in the compacted soil base under each of the surfaces indicated the degree of waterproofing provided. Several materials were found to be fairly effective both as waterproofers and dustproofers. In general, the materials displaying superior waterproofing ability also were the most effective in controlling dust. Results of laboratory tests to determine waterproofing ability of the various materials were found to correlate well with field data.

● MOST NATURAL fine-grained soils, when compacted to a relatively high density at an appropriate water content, are capable of providing a firm soil surface that is quite satisfactory for construction roads, secondary roads, and military roads and airfields for combat operations. The usefulness of such construction is limited, however, in that a muddy, slippery, and often impassable condition can occur during wet weather, and excessive dust may develop in dry weather. Even relatively small amounts of dust can greatly increase maintenance requirements for engines and other mechanisms and, although the dust condition seldom becomes so severe as to prohibit operations completely, it may reduce visibility to the point that operations become hazardous.

An agent that could be applied readily to the soil to render it immune to the deteriorating effects of water, desiccation, and traffic abrasion would be of material value. The essential requirement for such a material is that it be capable of retaining in a naturally stable or artificially stabilized soil an adequate stability condition; improvement of soil strength characteristics, although advantageous, is not a primary objective It is desirable that a treatment with such a waterproofing and dustproofing material be effective in a relatively thin layer, preferably not exceeding 6 in. Ideally, the additive should be effective when applied in quantities of 5 percent (by weight of dry soil) or less and should retain its effectiveness under the expected traffic for at least one full cycle of seasonal change without additional treatment. The capability of being applied as a penetration treatment, although extremely advantageous, is not considered to be an essential requirement.

In 1956, prior to the initiation of a laboratory and field investigational program, all available reports of soil waterproofing and/or dustproofing studies conducted by the U.S. Army Corps of Engineers and by other agencies were studied and a summary review of this literature was prepared (1). The information from this review and from soil stabilization studies made by the Corps of Engineers provided the basis for selection of the materials evaluated in the study reported herein.

The primary purposes of this investigation were to evaluate, by means of field tests, several materials as waterproofing and dustproofing agents for soil under varied weather conditions and a controlled amount of traffic over a 1-yr period, and to develop correlative laboratory evaluation tests to supplement the field studies.

FIELD TEST PROGRAM

The field test program consisted of traffic tests and related measurements and observations on a test section composed of 16 adjoining panels of soil arranged in two traffic lanes (Fig. 1). A loessial soil typical of those found in the lower Mississippi Valley was used in all phases of construction of subgrade, base, and treated surfaces. It is an inorganic lean clay and is classified as CL according to the Unified Soil Classification System. It has an average liquid limit of 38, an average plasticity index of 16, and a specific gravity of 2.70. The maximum dry density of the soil resulting from the standard Proctor compaction effort is 108 pcf at an optimum water content of 17 percent. Grain-size data indicate approximately 97 percent of the soil to be finer than 0.074 mm (No. 200 sieve) and approximately 25 percent finer than 0.005 mm.

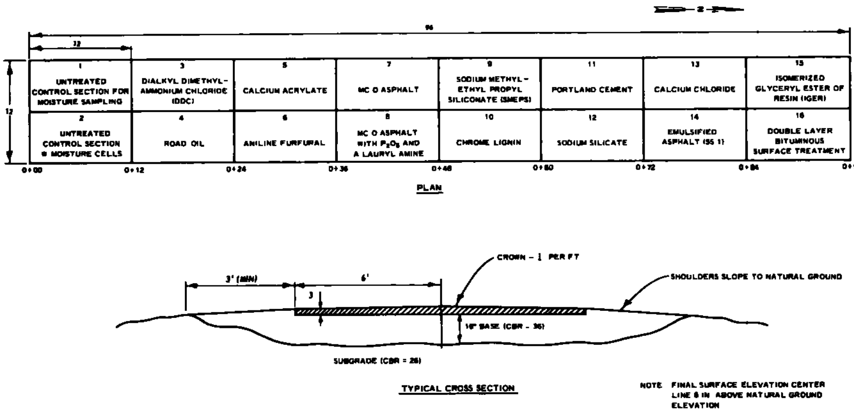

Figure 1. General layout of test section.

Each of 13 panels was treated with a different waterproofing and dustproofing agent. The additives and a description of each are given in Table 1. Two panels were of untreated soil, and the remaining panel consisted of a compacted soil surface on which was applied a conventional double-layer bituminous surface treatment. The latter three panels were used as controls which were anticipated to be representative of minimum and maximum waterproofing and dustproofing effectiveness.

The topsoil in the test area was removed to a depth of 15 in. below natural ground surface. The soil at the bottom of the excavation had a CBR value of 26. The excavation was refilled with soil placed in four lifts, each compacted by means of a rubber-tired roller. This resulted in a 16-in. base having an average CBR of 36 at 10.8 percent water content and 101.9 pcf dry density. The subgrade and base were considered strong enough to assure no failures under the intended traffic unless the surface permitted the ingress of excessive amounts of water.

Nylon electrical-resistance moisture units (2) were installed in the untreated base under each panel to detect trends of moisture change. The units were installed approximately 4 and 12 in. below the top of the final treated surfaces. Temperature recording units also were installed to obtain soil temperature readings by which the measured moisture-unit resistances could be corrected to a common temperature.

The preparation of all the treated surface panels, with the exception of the road oil (panel 4), was similar. The additives were blended with previously processed and stockpiled soil by means of a garden rotary tiller. The mixing was accomplished off-site. The liquids content of the admixtures were controlled to obtain optimum for compaction. The treated soil was placed and compacted on the test section base course in the form of panels 12 ft long by 6 ft wide by 3 in. deep. In the construction of panel 4, a light-grade road oil was applied as a penetration treatment on a 3-in. compacted, untreated-soil panel. The control panels were of compacted, untreated soil, on one of which (panel 16) was constructed a double-layer bituminous surface. A view of the completed test section is shown in Figure 2.

Traffic was applied to the test section by a military 5-ton truck having a load of 16,000 lb on each of the two rear axles. The dual 11.00-20 by 12-ply tires were inflated to a pressure of 50 psi. The truck was operated at a speed of 5 to 7 mph with the center line of each wheel path coincident with the center line of each row of panels. All passes of the vehicle followed the same track.

Traffic was first applied to the test section two weeks after completion of construction. During the 13-month exposure period, seven traffic tests were conducted. The dates of these were 26 July, 10 August, 20 September, and 27 December 1956, and 17

TABLE 1

AGENTS AND CHEMICALS USED IN FIELD TESTS

Panel No.	Additive	Description	Quantity Used in Percent of Dry Soil Wt
3	Dialkyl dimethyl-ammonium chloride (DDC)	Surface-active organic salt, dispersible in water	0.5
4	Road oil	Blend of a medium volatile distillate and a nonasphaltic, viscous, petroleum base	—[a]
5	Calcium acrylate (precatalyzed)	A water-soluble monomer that polymerizes in the presence of a suitable catalyst system	7.0
6	Aniline-furfural	Organic compounds which when combined interact to form a resin	3.34[b]
7	MC-O asphalt	A blend of a high-penetration asphalt and kerosene	10.0[c]
8	Modified MC-O asphalt (with phosphorus pentoxide and a lauryl amine)	A blend of a high-penetration asphalt and kerosene A highly deliquescent inorganic compound A surface-active, fatty, nitrogenous, water-dispersible compound	10.75[d]
9	Sodium methyl-ethyl propyl siliconate (SMEPS)	An aqueous solution of a sodium salt of a silicone	1.0
10	Chrome-lignin	A combination of a hexavalent chromium compound and a resinous waste product of the sulfite process of the paper industry	5.0
11	Portland cement	Commercial Type I	3.0
12	Sodium silicate	An aqueous solution of 30 percent concentration of sodium silicate	14.5
13	Calcium chloride	A deliquescent, crystalline, inorganic salt	1.0
14	Emulsified asphalt (SS-1)	A colloidal dispersion of a high-penetration asphalt in an emulsifying agent	8.4[e]
15	Isomerized glyceryl ester of resin (IGER)	A hydrophobic, polymer, emulsion-type resin	5.0
16	Bituminous surface	Asphalt cement, 100-150 penetration	—

[a]Applied as penetration treatment at rate of 1 gal/sq yd. [b]2.14 percent aniline to 1.20 percent furfural. [c]50 percent asphalt content. [d]10 percent MC-O asphalt; 0.50 percent phosphorus pentoxide; 0.25 percent lauryl amine. [e]60 percent asphalt content.

January, 17 June, and 7 August 1957. Each traffic test consisted of 40 passes of the vehicle; thus, the panels were subjected to a total of 280 passes during the test period. It should be noted that the time interval between traffic tests was not uniform. The decision to conduct a traffic test was dependent on the weather conditions, the ideal situation consisting of a wet period followed by a sufficiently long dry period for the treated surfaces to have dried to the extent that dust would be created by the traffic. Immediately prior to each traffic test, the test section was swept clean of all loose material. This was done to remove any material that might have been eroed by weathering between traffic tests as well as any material abraded during preceding tests.

TEST RESULTS

The data-collection program included visual observations of the behavior of the surface during traffic, collection of abraded material after each traffic test for dust analysis, periodic moisture-unit readings to determine changes in the subgrade water content, and occasional direct sampling of the surface and compacted soil base for density and water content determinations. In addition, daily rainfall data were obtained with a standard rainfall gage located a short distance from the test site.

Observations of Panel Behavior During Test Period

During the two-week period between the completion of construction and the initial application of traffic, no rain fell on the test section. Some surface cracking due to shrinkage had occurred during this interval but was not severe in any of the panels. Close observation of the test section during the first few passes of the test vehicle in the first traffic test revealed only slight surface deflection under the load for all panels except the modified MC-O asphalt. Here, the deflections were greater, and shoving and rutting of the surface were evident. The early failure of this panel was found to be the result of incomplete curing of the treated surface. The panel was repaired with unmodified asphalt-treated soil and withstood subsequent traffic without distress. The second traffic test followed a two-week period during which a total rainfall of about 1 in. occurred. The only panel showing signs of distress at the end of this test was the one treated with calcium chloride (panel 13). Some deflection and cracking were noted at the outer edges of the tire path.

However, rutting of this panel was not severe and repairs were not necessary. No additional failures or distress were observed on any of the test panels during the five subsequent traffic tests.

From visual observations, it was evident that some panels resisted abrasion better than others. Similarly, progressive deterioration of the surfaces was evident during the course of the test program, apparently as a result of exposure to the weather. Observations of the panels immediately after periods of rainfall and during prolonged dry

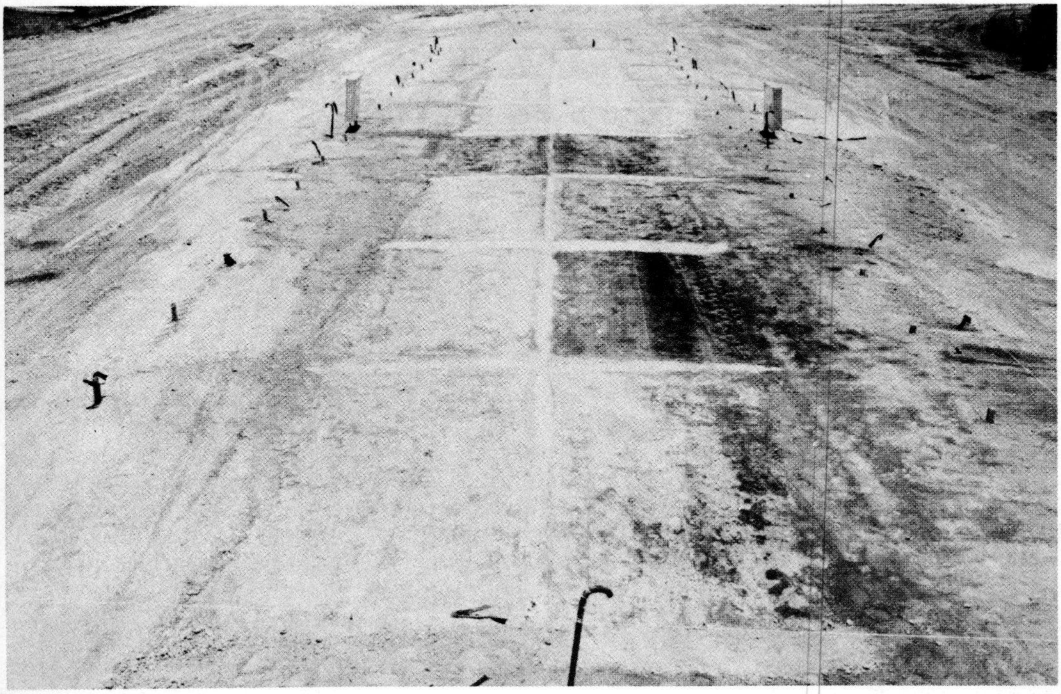

Figure 2. Completed test section, untreated panels in foreground.

periods showed considerable differences in response to alternate wetting and drying. Certain panels retained a dry appearance following a heavy rainfall, with little or no apparent swelling or reduction in strength of the surface. Other panels appeared wet; some of these retained a fairly high surface strength, whereas the remainder had softened considerably.

Data Collection

The material abraded from each panel during each traffic test was collected by means of a common, tank-type, home vacuum cleaner. To afford a uniform area of pickup, a canvas template with a 4- by 2.5-ft rectangular section cut out of it was used. The template was positioned directly on the traffic path, and the abraded material was collected as shown in Figure 3. The material was weighed and its water content and particle-size distribution determined. The quantities of abraded material obtained from the various panels after each traffic test are given in Table 2. The over-all average water content of the abraded material was 1.7 percent, ranging from a low of 0.9 percent to a high of 3.1 percent.

The electrical resistivities of the nylon moisture units installed under each panel were read at frequent intervals during the test period. Also, actual water contents were determined on soil samples taken from the 4- and 12-in. depths in the compacted soil base. The direct-sampling data are given in Table 3. A field calibration curve for each moisture unit was developed from the direct-sampling data. Using these curves, the water contents in the base under each test panel were estimated from the moisture-unit resistance readings. These data and the direct sampling results for the compacted soil base are plotted in Figures 4a through 4c. Direct sampling of the treated surface layers for water content and density determination was accomplished three times during the field investigation. The surface water contents and densities are given in Table 4.

Daily rainfall data are plotted in each of Figures 4a through 4c. The total rainfall for the 13-month period of the test was 54.93 in. The distribution of rainfall by months indicated a slightly below-normal amount for the months of January, February, and March 1957, whereas a record high rainfall was measured in June 1957.

ANALYSIS OF FIELD DATA

The analysis of data and subsequent evaluation of the various treated surfaces tested during this field investigation consist primarily of a comparison of the capabilities of each treatment in (a) resisting

TABLE 2

AMOUNT OF ABRADED MATERIAL COLLECTED FROM TEST PANELS AFTER EACH TRAFFIC TEST

Panel No.	Additive	26 July 1956		10 Aug 1956		20 Sept 1956		27 Dec 1956		17 Jan 1957		17 June 1957			
		Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No. 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No. 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No. 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No. 200 Sieve g	Total Wt Abraded Mtl (Dry) g	Total Wt Abraded Mtl Finer Than No. 200 Sieve g
1	Untreated soil	1,148	630	3,481	1,655	2,783	1,410	3,058	1,710	1,969	1,355	7,824	3,890	3,970	2,235
2	Untreated soil	239	140	3,103	1,440	2,342	1,092	3,000	1,450	1,931	1,473	7,636	3,550	4,631	2,400
3	DDC	166	92	267	138	562	292	644	262	539	284	1,065	572	452	208
4	Road oil	380	148	582	224	631	295	710	202	676	229	1,200	490	1,083	424
5	Calcium acrylate	134	40	299	103	1,731	865	2,298	867	2,016	1,024	6,357	2,555	2,862	1,091
6	Aniline-furfural	350	148	503	236	955	492	674	263	491	234	499	278	241	110
7	MC-O asphalt	185	89	284	115	262	155	368	170	606	307	722	346	516	221
8	Modified MC-O asph.[a]	–	–	–	–	–	–	–	–	973	626	2,350	1,304	654	312
9	SMEPS	202	79	193	112	435	230	310	135	545	386	1,016	509	459	229
10	Chrome-lignin	446	180	1,485	665	1,400	765	1,500	641	807	544	3,002	1,522	2,249	1,030
11	Portland cement	225	109	774	394	869	509	1,025	476	533	396	5,161	3,055	2,136	1,460
12	Sodium silicate	905	452	1,237	600	2,012	1,012	2,730	1,143	2,242	1,262	5,479	2,560	3,164	1,370
13	Calcium chloride[b]	239	126	3,148	1,560	–	–	–	–	2,493	1,590	9,860	4,500	6,006	3,700
14	Emuls. asph. (SS-1)	252	128	532	266	706	372	724	363	1,016	570	7,626	3,490	3,366	1,762
15	IGER	392	184	908	382	1,089	497	1,190	445	1,028	542	3,372	1,406	1,951	651
16	Bit. surf. treat.[c]	5	2	8	6	66	52	63	60	72	53	100	52	62	43

[a]No dust collection made in first four tests because repaired condition following failure of panel in first traffic test was not considered representative of originally designed panel. Dust was collected after last three tests for comparative purposes because panel was behaving similarly to MC-O asphalt (unmodified) panel during this period.

[b]No dust collection following third and fourth traffic tests because it appeared that excessive abrasion was occurring as a result of an approximate failure condition. It was observed that the abrasion was more severe than that on either of the untreated panels during these tests. Collection was resumed for last tests because failure did not progress.

[c]Quantities of abraded material for bituminous-surfaced panel represent material picked up from turnaround area or preceding panel (emulsified asphalt) and deposited by vehicle tires.

the abrading action of traffic and subsequent dust formation; and (b) protecting the base and, to a certain extent, the surface itself from ingress of water. Because there are no criteria by which the adequacy of a given treatment can be defined in specific terms, the use of a comparative-capability approach appears to be the most logical. In this regard, reasonable standards for comparison in a somewhat more quantitative sense are provided by the untreated and the double-layer bituminous-treated control panels.

Dustproofing Effectiveness

In a broad sense, "dust" may be defined as soil and/or other material which has become airborne. In this connotation, no attempt is made to establish a limit of particle size that may be considered dust. In this paper the term "abraded material" is used in place of "dust." Abraded material refers to the total amount of loose material worn away or otherwise eroded from the test panel surface by the action of the test vehicle. For surfaces constructed predominantly of silt- and clay-size particles, such as those in the test section under discussion, virtually all the material that is broken away from the surface can be considered a "dust" potential. Even though the loose material may consist of agglomerations of small particles held together as a result of either treatment or compaction, the action of repetitive traffic will eventually reduce them to a fineness approaching that of the individual soil grains.

The data given in Table 2 indicate significant differences in the amount of material abraded from the various surfaces by the imposed traffic. The quantities shown represent only the material abraded by traffic and do not include material eroded by weathering between traffic tests, inasmuch as the test section was swept clean of loose material immediately prior to each test. The quantities of abraded material collected from each panel generally fall between the amounts collected from the untreated and the double-layer bituminous-treated control panels. A small quantity of material was recovered from the double-layer bituminous surface panel. This was not material abraded

Figure 3. Collection of abraded material from traffic lane.

from the panel, but material that had been picked up and carried from the adjacent panel and the north turnaround area by the vehicle's tires. Inasmuch as this amount of material was small, and because the tendency for carry-over in all panels was similar, no correction for this occurrence was made.

The conditions under which the traffic tests were performed were constant with respect to the number of passes per traffic test, and relatively similar with regard to surface water contents at the time of the tests. Therefore, it is considered that differences in abrasion among the various panels for a given traffic test are primarily a function of the differences in the quality of the surfaces provided by the several treatments. Similarly, the differences indicated for any given surface from one traffic test to another must be a result of some change in a property of the treated surface layer that has occurred between traffic tests. Assuming that curing of a surface had been essentially completed by the time the traffic tests were begun, any change taking place is probably a result of weathering. Because no freezing occurred during the test period weathering effects are primarily those resulting from wetting and drying cycles.

To examine the possible influence of weather on abrasion, total rainfall from the time of completion of test-section construction to the time of each traffic test has been plotted against total abraded material collected from the beginning of the tests for each panel (Fig. 5). It is seen that the relation of total rainfall to abraded material is nearly rectilinear for each panel beginning with the third traffic test, with the general slope probably dependent on the effectiveness of the surface treatment. The deviations from a constant slope observed in these plots are believed to be due to a nonuniformity of rainfall patterns for the intervals between successive traffic tests.

To provide a uniform basis for comparing the relative abrasion-resistant characteristics of the various surfaces, a statistically averaged general slope was determined for each panel, using the data shown in Figure 5 and beginning with the third traffic test. From a comparison of these slopes, it was considered that the most effective dustproofing material tested was aniline-furfural (panel 6), followed in close order by MC-O asphalt (panel 7), SMEPS (panel 9), DDC (panel 3), and road oil (panel 4). Quantitatively, the accumulative amounts of abraded material from all traffic tests on these

TABLE 3

COMPACTED SOIL BASE WATER CONTENTS (4- and 12-in. Depths)

Panel No.	Additive	Water Content (% on Dry Weight Basis) 28 Feb 1957 4 in.	28 Feb 1957 12 in.	5 Apr 1957 4 in.	5 Apr 1957 12 in.	8 May 1957 4 in.	8 May 1957 12 in.	12 Aug 1957 4 in.	12 Aug 1957 12 in.
1	Untreated soil[a]	20.4	19.7	18.3	19.5	14.6	14.8	—	—
2	Untreated soil	18.7	19.2	18.9	19.0	14.8	16.8	10.3	13.9
3	DDC	7.5	9.3	10.3	8.7	12.1	11.7	9.4	13.1
4	Road oil	14.2	14.2	7.6	9.7	7.9	10.0	8.3	9.8
5	Calcium acrylate	14.4	15.1	15.7	14.3	14.8	15.0	14.5	14.7
6	Aniline-furfural	9.5	11.3	8.9	11.0	8.2	10.6	6.8	9.8
7	MC-O asphalt	8.6	9.8	9.5	10.1	8.1	9.0	11.0	13.7
8	Modi. MC-O asphalt	9.0	10.5	9.1	9.9	8.3	9.4	8.8	11.3
9	SMEPS	9.0	9.4	7.5	10.8	9.1	12.9	8.1	11.6
10	Chrome-lignin	10.1	9.6	11.7	11.6	13.5	15.2	10.4	11.1
11	Portland cement	18.4	18.2	18.7	18.9	16.3	17.0	14.3	16.6
12	Sodium silicate	14.7	15.8	19.0	16.8	18.3	15.9	13.0	13.2
13	Calcium chloride	13.0	18.9	21.1	19.4	16.0	17.7	16.1	16.3
14	Emuls. asphalt (SS-1)	15.0	16.7	19.2	18.5	15.9	16.5	15.2	15.9
15	IGER	13.7	11.8	15.6	15.0	15.5	15.6	12.7	13.7
16	Bit. sur. treat.	9.4	10.3	13.1	12.0	14.4	12.9	12.4	15.3

[a]During first seven months sampling was accomplished only in panel 1 (untreated surface without moisture units); Water Content as follows: 27 July 1956, 4 in. = 8.0 percent, 12 in. = 10.8 percent; 29 Nov 1956, 4 in. = 13.8 percent, 12 in. = 11.2 percent; 26 Dec 1956, 4 in. = 18.2 percent, 12 in. = 17.4 percent.

five surfaces range from 12 to 22 percent of the total amount collected from the untreated control surfaces. The aniline-furfural panel was rated the most effective on the basis of the slope analysis, even though the total amount of abraded material (all traffic tests) collected from this panel slightly exceeded that from three other panels. The remaining materials, in the order of decreasing dustproofing effectiveness, were chrome-lignin (panel 10), IGER (panel 15), portland cement (panel 11), sodium silicate (panel 12), emulsified asphalt (panel 14), calcium acrylate (panel 5), and calcium chloride (panel 13). The modified MC-O asphalt data (panel 8) are omitted from Figure 5 because of the failure of this panel during the first traffic test. On the basis of the data collected during the final traffic tests this panel, had it cured properly, probably would

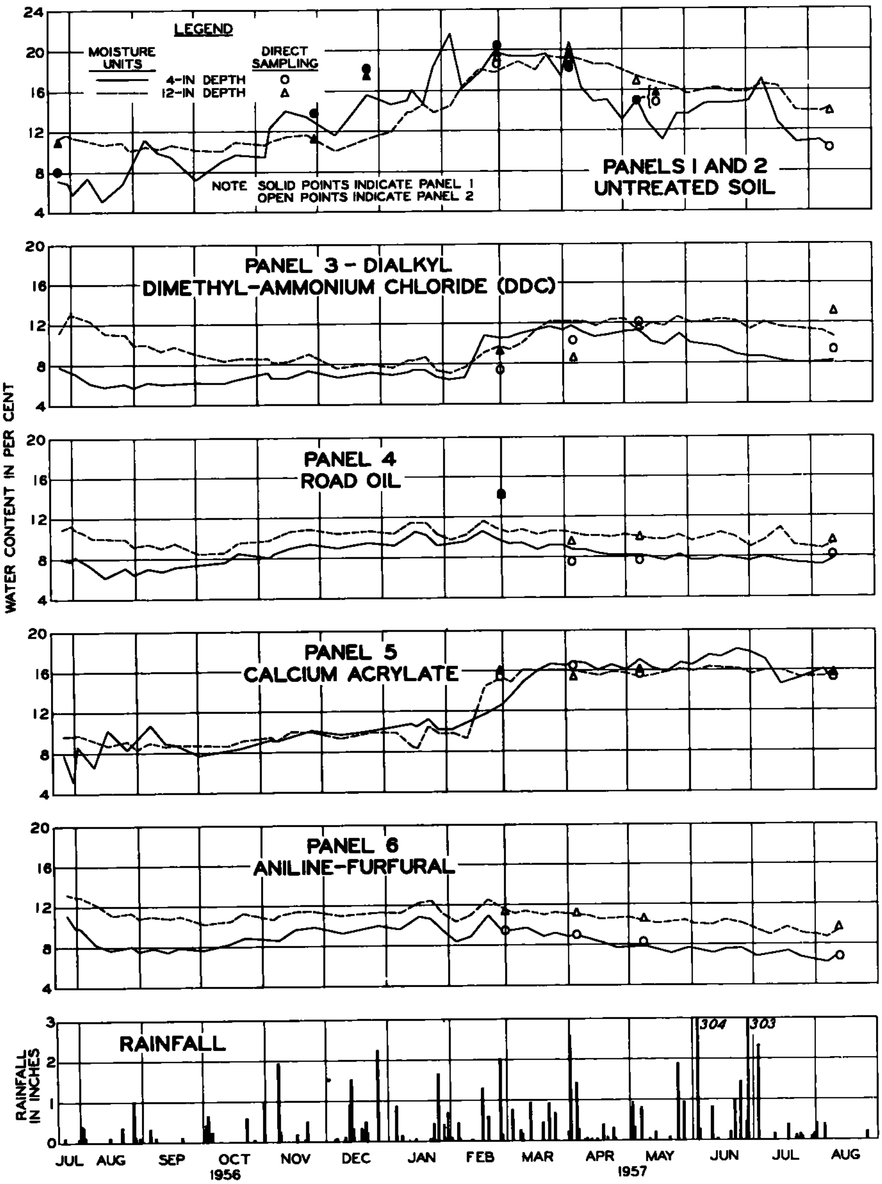

Figure 4a. Moisture trends in compacted soil base.

have performed about the same as the unmodified MC-O asphalt panel.

In evaluating these results, it should be noted that the calcium chloride treatment consisted of a single initial application with no subsequent re-treatment or sprinkling during dry periods, although this is the usual practice. The data showed that calcium chloride was more effective than several other treatments during the first traffic test. However, it appeared to be more adversely affected by weathering than the other materials. Similarly, it should be noted that the portland cement panel contained only 3 per cent cement. The low percentage was selected because it was desired to examine a cement-modified soil rather than a soil-cement.

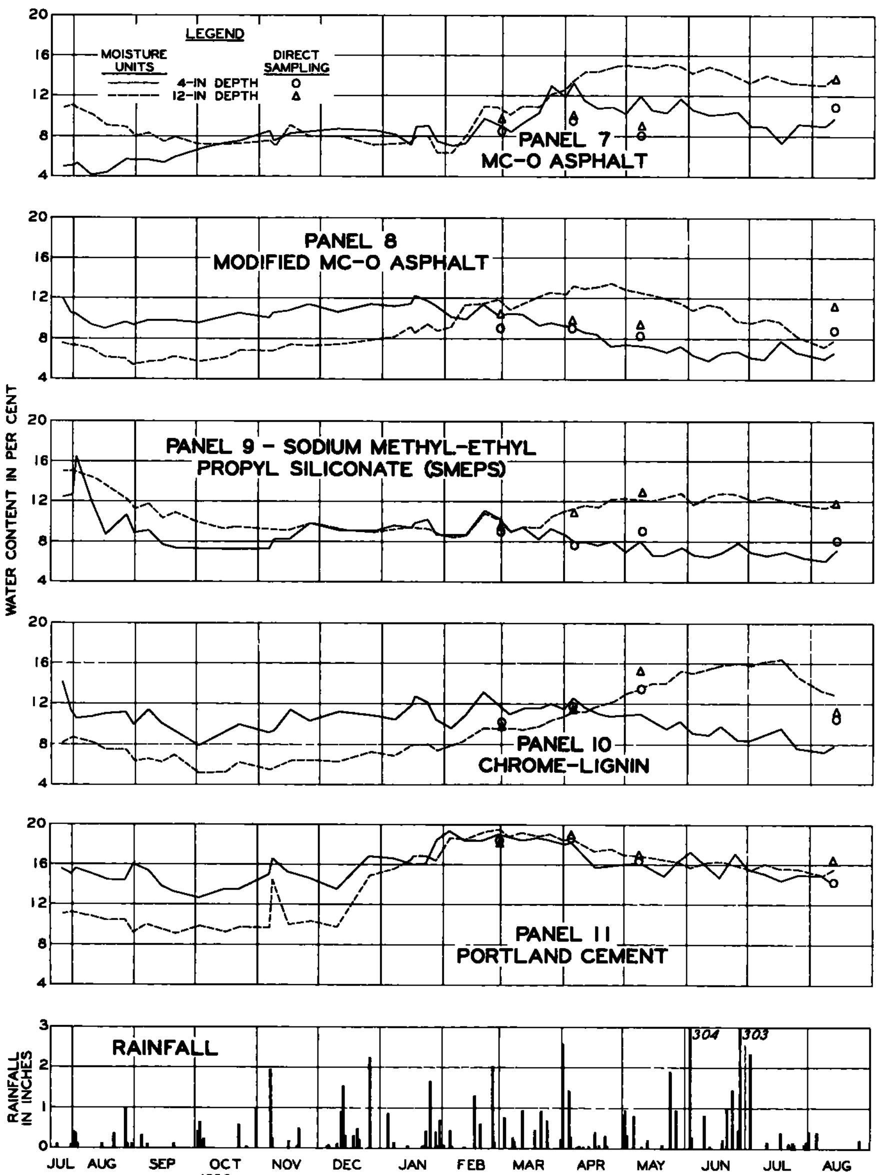

Figure 4b. Moisture trends in compacted soil base.

WATERPROOFING EFFECTIVENESS

Determination of the comparative capabilities of the various treated surfaces in preventing surface water from entering the soil base was based on the maximum moisture contents measured at the 4- and 12-in. depths. Although it is believed that the moisture-unit resistance data are indicative of the over-all trends in the compacted-base water content, their validity in terms of absolute water content is questionable. The direct-sampling data (Table 3) were therefore used as the principal criterion in determining the relative waterproofing capabilities of the various surfaces. To provide a uniform basis for comparing the different surfaces, a representative maximum water content under each surface was determined by averaging all the values at the 4- and 12-in. depths

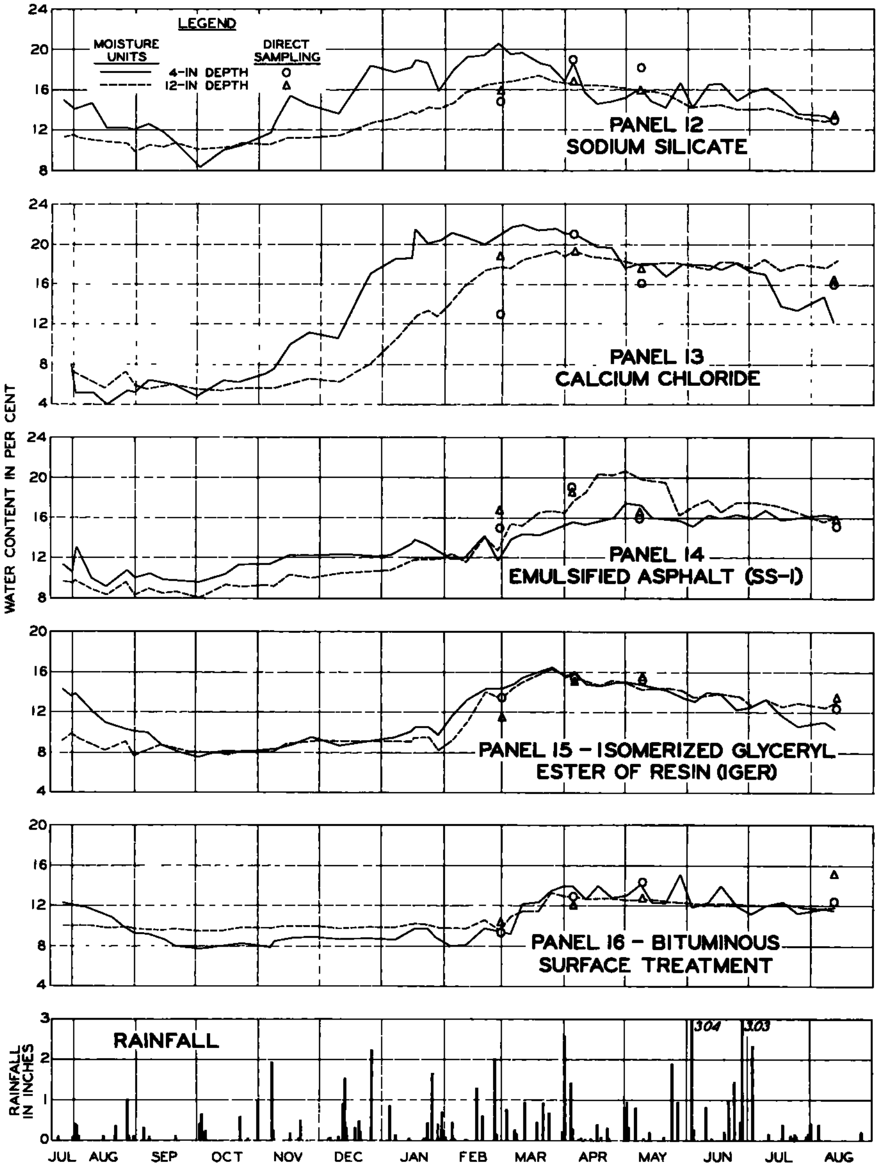

Figure 4c. Moisture trends in compacted soil base.

TABLE 4

SURFACE WATER CONTENT AND DENSITY (0- to 3-in. DEPTH)

Panel No.	Additive	28 Feb 1957 Water Content (%)	28 Feb 1957 Dry Density[a] (pcf)	5 Apr 1957 Water Content (%)	5 Apr 1957 Dry Density[a] (pcf)	8 May 1957 Water Content (%)	8 May 1957 Dry Density[a] (pcf)
1	Untreated soil	18.4	104.7	19.3	103.5	14.4	104.6
2	Untreated soil	17.1	110.9	18.5	107.7	14.8	105.3
3	DDC	7.3	109.6	7.6	108.0	6.7	106.0
4	Road oil	6.0	113.7	6.2	110.0	4.3	103.5[c]
5	Calcium acrylate	16.5	106.7	19.1	102.8	17.5	104.3
6	Aniline-furfural	6.4	105.0	5.2	108.8	5.8	104.4[c]
7	MC-O asphalt	5.9	109.4	6.9	111.4	6.8	110.6
8	Mod. MC-O asphalt	5.1	110.0	7.2	113.0	5.4	104.0[c]
9	SMEPS	6.9	112.8	11.3	107.5	6.4	114.1
10	Chrome-lignin	12.7	100.2	13.1	100.5	10.9	101.6
11	Portland cement	17.9	106.5	18.6	105.9	15.5	100.4[c]
12	Sodium silicate	18.2	102.9	19.8	97.1	16.9	93.0
13	Calcium chloride	16.6	107.1	19.1	105.9	13.8	103.4
14	Emuls. asphalt (SS-1)	10.9	114.1	15.3	107.8	12.0	112.1
15	IGER	13.3	105.0	15.4	103.6	13.0	104.0
16	Bit. surf. treat.[d]	9.6	110.1	10.4	108.8	11.2	110.6

[a] Percent by dry solids weight.
[b] During first seven months sampling was accompiched only in panel 1 (untreated surface without moisture units); on 27 July 1956 water content[a] was 5.7 percent, dry density 107.7 pcf; on 29 Nov. 1956 water content was 10.3 percent; on 26 Dec. 1956 water content was 14.7 percent.
[c] Samples very poor for density determination.
[d] Represents 3-in. soil depth immediately beneath 3/4-in. double-layer bituminous surface.

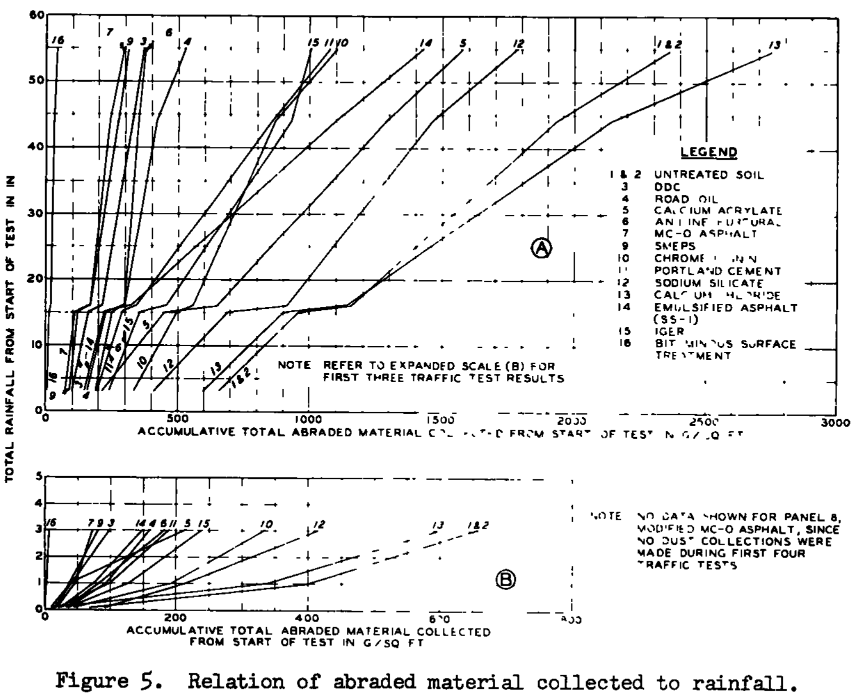

Figure 5. Relation of abraded material collected to rainfall.

TABLE 5

RESULTS OF LABORATORY CAPILLARY RISE TESTS

			As Molded		After 4-Day Air-Drying		After 4-Day Rewetting		
Panel No.	Additive	% Additive by Dry Soil Wt	% WC by Total Wt Dry Solids	Dry Density in lb Total Solids per cu ft	% WC by Total Wt Dry Solids	Dry Density in lb Total Solids per cu ft	% WC by Total Wt Dry Solids	Dry Density in lb Total Solids per cu ft	Remarks
1&2	Untreated soil	–	16.9	110.5	2.7	115.3	25.3	96.1	Uniformly wet, very soft
3	DDC	0.5	18.0	108.8	3.0	115.1	6.0	113.4	Bottom 0.5 in. wet, top dry
4	Road oil (dipped)	5.5	16.0	109.5	2.8	115.7	4.5	114.9	No apparent absorption
5	Calcium acrylate	7.0	16.0	110.9	4.2	116.3	10.9	116.3	Uniformly wet, firm
6	Aniline-furfural[a]	3.3	16.5	106.8	2.0	110.1	3.9	109.2	Bottom 1.0 in. wet, top dry
7	MC-O asphalt[b]	10.0	13.9	108.8	4.1	110.2	5.2	109.2	No apparent absorption
8	Mod. MC-O asphalt[c]	10.0	13.7	107.7	4.2	110.0	4.8	109.7	No apparent absorption
9	SMEPS	1.0	17.5	109.5	2.8	116.0	9.4	111.0	Bottom 1.0 in. wet, top dry
10	Chrome-lignin	5.0	16.8	110.4	3.3	118.4	12.7	112.5	Bottom 2.0 in. wet, top dry
11	Portland cement	3.0	15.8	109.9	2.2	111.6	19.2	107.8	Uniformly wet, soft
12	Sodium silicate[d]	14.5	16.7	103.0	3.8	105.7	25.0	95.8	Uniformly wet, very soft
13	Calcium chloride	1.0	16.5	111.9	3.6	117.4	28.5	95.1	Uniformly wet, very soft
14	Emuls. asphalt (SS-1)[e]	8.4	19.9	103.9	2.5	112.4	20.0	100.7	Uniformly wet, soft
15	IGER	5.0	15.2	105.6	2.8	109.0	23.3	96.4	Uniformly wet, soft

[a] 2.1 percent aniline and 1.2 percent furfural.
[b] 50 percent asphalt content.
[c] Modified with 0.5 percent phosphorus pentoxide and 0.25 percent of a lauryl amine.
[d] 30 percent solution.
[e] 60 percent asphalt content.

for the three sampling dates of 28 February, 5 April, and 8 May 1957. This average water content value was considered indicative of the waterproofing afforded and was employed to obtain a relative comparison of treatments. On this basis, the panels were rated in the order of decreasing waterproofing effectiveness as follows: MC-O asphalt (panel 7), SMEPS (panel 9), aniline-furfural (panel 6), DDC (panel 3), road oil (panel 4), double-layer bituminous surface (panel 16), chrome-lignin (panel 10), IGER (panel 15), calcium acrylate (panel 5), sodium silicate (panel 12), emulsified asphalt (panel 14), calcium chloride (panel 13), portland cement (panel 11), and the untreated surfaces (panels 1 and 2). It is to be noted that the modified MC-O asphalt (panel 8) was not rated although the data for this treatment are included in the tables and figures. For purposes of analysis, this panel was not evaluated because it had been repaired early in the tests with unmodified MC-O asphalt and its performance was not significantly different from the unmodified asphalt panel.

The impervious double-layer bituminous-treated surface (panel 16), which originally was expected to produce a surface of maximum effectiveness, showed a higher water content in the soil base than did several other surfaces. This moisture buildup is believed to have been a result of the surface acting as a highly effective vapor barrier that prevented evaporation of subgrade water even during dry periods. There did not appear to be a great deal of difference in the respective capabilities of the five materials rated more effective than the double-layer bituminous surface. However, it is significant that, with the exception of a single high value recorded for road oil on 28 February 1957 (Fig. 4a), the water contents beneath the better surfaces were either lower than or about equal to the initial water content (10.8 percent) of the soil when the base was originally compacted. In contrast, maximum water contents ranging from 14 to more than 20 percent were observed under the remaining panels.

Examination of the surface water content data (Table 4) indicates that the bet-

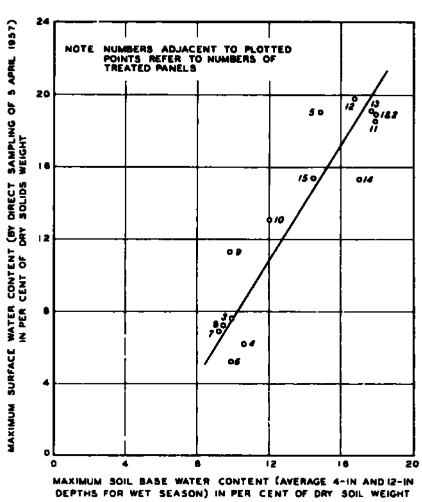

Figure 6. Comparison of maximum water content of soil base and maximum surface moisture.

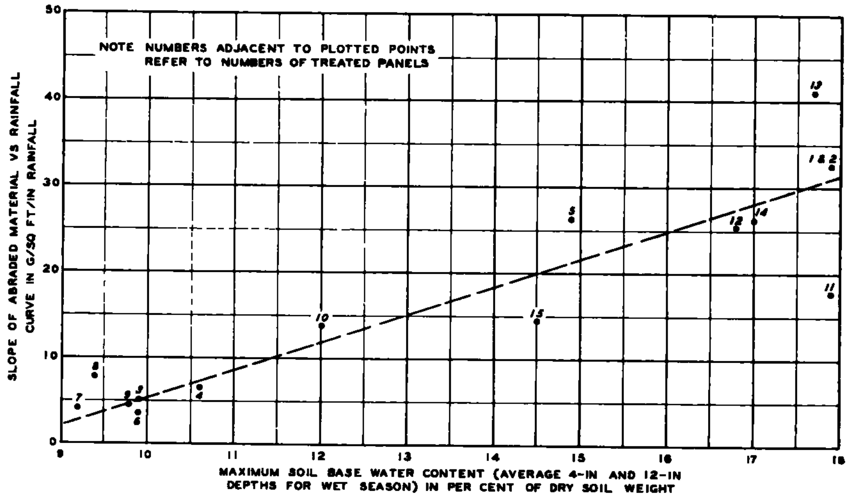

Figure 7. Relation of maximum water content of soil base and slope of abraded material vs rainfall curve.

ter base-protective surfaces are those which appear themselves to absorb the least water. A comparison of the moisture content of the base with that of the surface for all the panels during the wettest period is shown in Figure 6. From this plot, it is seen that there is a general relation between the moisture that may be absorbed by the surface and the water present in the base. An interesting observation in this respect is that the water contents in the base under the more effective surfaces are somewhat greater than those in the surfaces themselves, whereas the reverse appears to be true for the less effective surfaces. The existence of the surface-base moisture relation suggests the possibility of determining the waterproofing capability of a specific treatment by convenient laboratory techniques, which are discussed later.

Combined Dustproofing and Waterproofing Effectiveness

Because the purpose of the treatments was to provide both waterproofing and dustproofing capabilities, the effectiveness of the various treatments in accomplishing the combined purpose was examined. It has been stated previously that the ability of a surface to resist abrasion is apparently a function of its ability to resist changes as a result of weathering. Thus, it might be expected that a surface achieving high water contents during a wet period would show both poor abrasion-resistant qualities and little waterproofing protection for the soil base or subgrade. Also, it would appear that the better waterproofing materials are the better dustproofers.

In Figure 7, the maximum water content measured at the 4- and 12-in. depths in the soil base during the wet season (average direct-sampling data of 28 February, 5 April, and 8 May 1957) was plotted against the general slopes of the "ab-

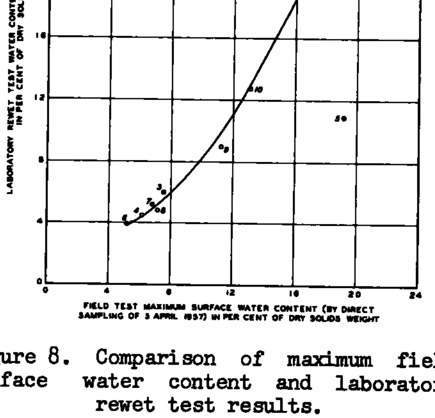

Figure 8. Comparison of maximum field surface water content and laboratory rewet test results.

raded material versus rainfall" curve for each panel (Fig. 5). It is apparent from Figure 7 that a general relation does exist between the waterproofing and abrasion-resistant characteristics of a given surface. Although the points plotted are not without scatter, the trend is sufficiently consistent to be considered significant.

Quantitatively, five materials of those tested were considered sufficiently effective as combination soil dustproofers and waterproofers to warrant additional investigation. These materials are: aniline-furfural (panel 6), MC-O asphalt (panel 7), SMEPS (panel 9), DDC (panel 3) and road oil (panel 4). Of particular interest are DDC and SMEPS, because they were found to be effective in such small quantities; that is, 0.5 and 1.0 percent, respectively, by dry soil weight. The MC-O cutback asphalt is of interest because it is so commonly available, although the quantity required (10.0 percent by weight of soil) is considered rather high. The road oil has an advantage in that is was effective when applied as a penetration treatment, thus reducing construction requirements. Aniline-furfural, although highly effective, has the disadvantage of being a two-chemical system, one highly toxic, thus requiring special handling and storage precautions as well as complicating the construction operation.

CORRELATION OF LABORATORY AND FIELD RESULTS

Concurrently with the field test program, comprehensive tests were made in the laboratory to assist in evaluating the materials used in the field investigation. Furthermore, it was intended that these laboratory tests assist in developing suitable laboratory methods and procedures for determining the effectiveness of other proposed materials without extensive field investigation. The same type of loess soil and the same additives and quantities were used in all phases of the laboratory investigation as had been used in the field tests. Test specimens were prepared using the Harvard miniature compaction apparatus and cured under ambient laboratory conditions for at least four days before any tests were performed. A variety of tests were made, including rewet tests, strength tests, and abrasion tests. Of these, the most satisfactory correlation with field results was obtained with a capillary-rise rewet test. Laboratory abrasion test results were not satisfactory because none of the test procedures devised truly duplicated the kneading-abrading action of a rolling, pneumatic-tired wheel on a weathered soil surface.

In the capillary-rise rewet test, air-dried specimens were inserted in a membrane that was open at both ends, and placed in an upright position on a ⅜-in. porous stone in an evaporating dish. Water was placed in the dish and maintained approximately ⅛ in. below the bottom of the specimens for a period of four days. Following this, the specimens were removed from the membrane and the densities and water contents determined. The results of these tests are given in Table 5.

In the discussion of field results, it was shown that the maximum water content of the base, as well as observed abrasion, was related to the maximum field surface water content. In Figure 8, maximum field surface water content is plotted against capillary-rise rewet test data for each treatment. With the exception of calcium acrylate (panel 5), a good correlation is observed. It may be noted that the materials indicated to be better by the capillary test show a smaller water pickup than was evident in the field surfaces, whereas for the poorer materials, the water pickup exceeded that observed in the field panels.

SUMMARY

Field tests of a number of soil waterproofing and dustproofing materials have been described. Analysis of the results of these tests showed that all the test surfaces were adversely affected by weathering. The better treatments reduced surface abrasion to about ⅕ that of the untreated soil and did not allow the water content of the soil base to exceed the as-constructed value. Those materials that displayed superior waterproofing ability also were found to be the most effective in controlling abrasion of the treated surfaces. Five of the 13 materials evaluated were markedly superior as waterproofers and dustproofers for the lean clay soil tested. These were: aniline-furfural, MC-O asphalt, sodium methyl-ethyl propyl siliconate, a quaternary ammonium chloride, and a road oil. Laboratory tests conducted concurrently with the field tests showed that the waterproofing ability of the materials tested could be related to the results of a laboratory rewet test.

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