# Soil-Bituminous Stabilization

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The effect of certain cationic surface active agents, commercially sold as antistripping agents, on the waterproofing properties of bitumen cutback used in soil stabilization was studied. For the sake of comparison paraffin wax and rubber were also included in the study. All these chemicals have been found to have a marked effect in enhancing the waterproofing property of bitumen, consequently effecting saving in consumption of the binder for obtaining the desired results. Paraffin wax was found to be the most effective and economical additive for this purpose.

•SOIL stabilization by incorporation of an admixture such as bitumen is becoming the subject of many research projects, as this type of stabilization has important applications in the construction of both pavements and buildings. Investigations were undertaken to determine whether or not the proportions of bitumen could be reduced and the stabilization process by this method made more economical. Some preliminary investigations on the effect of certain cationic chemicals and different methods of mixing have been carried out. The study was divided into three parts:

1. Influence of cationic additives on the waterproofing quality of bitumen cutback used for soil stabilization;
2. Effect of pretreatment of soil with cationic surface active agents on its strength and stability; and
3. Effect of two different methods of mixing bitumen in soil on the properties of the resultant mixture.

As can be seen from these reports, it is possible to economize considerably on the cost of soil stabilization with bitumen by making use of some chemicals or by adopting the proper method of mixing bitumen in soil.

Antistripping agents, generally cationic chemicals, are now widely used as additives in bitumen for improving its bond with road aggregates during surface dressing operations, and also for bitumen coating of wet stones for road construction during the rainy season (3). These chemicals possess the property of displacing water from the stone surface and insuring the coating of the solid with an uninterrupted uniform layer of binder. They can be used as admixtures in the binder as well as for pretreatment of the stone aggregate to be coated. In both cases results are satisfactory, but their incorporation in the binder is more economical and convenient.

Since bitumen is also used for the stabilization of soil for road construction (1), particularly in water logged (2) or sandy areas, and also for the preparation of improved mud mortar (5) and sundried bricks, laboratory experiments were conducted to study the effect of the addition of such chemicals on the waterproofing property of bitumen when used for soil stabilization.

## Preparation of Bitumen Cutback

In this study, 80-100 penetration bitumen (Mexphalt) was used. Because thinned bitumen is easier to mix with soil and because antistripping agents are more effective

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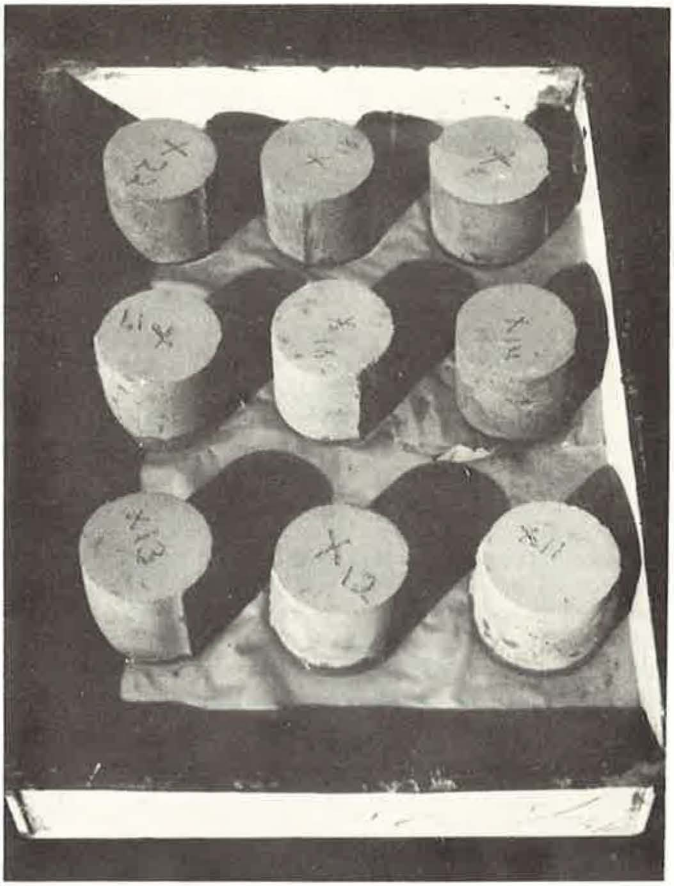


Figure 1. Specimen blocks in wetting tray.

in a less viscous binder, the bitumen was thinned with 20 percent of its weight of kerosine by heating and thorough stirring. In a separate study kerosine was found to be a better and more economical solvent for making such cutbacks than the other common solvents such as diesel oil, petrol and wood preservative oil. Kerosine oil was used as the cutback in all experiments conducted in connection with these investigations.

Soil

The soil used throughout the study was of a graded nature having a plasticity index of about 10 and sand content (fraction passing 40 mesh and retained over 200 mesh) of about 40 percent.

Chemicals

Three proprietary antistripping agents (cationic chemicals), designated as Product A, Product B, and Product C, were studied.

Product A was a long chain diamine, smelling faintly of ammonia and having a chemical formula $C_{18}H35\ NH\text{-}(CH_2)3\text{-}NH_2$. It is marketed under the trade name of Duomeen-T in the form of a pale paste which melts to a liquid at 48 C.

Product B was a plyamine derivative, smelling faintly of ammonia. It is marketed in the form of a dark colored liquid of low viscosity under the trade name of Udol.

Product C was a pale yellow flaky opaque (powder) cationic surface-active agent manufactured in India and marketed under the trade name Hiquat T.

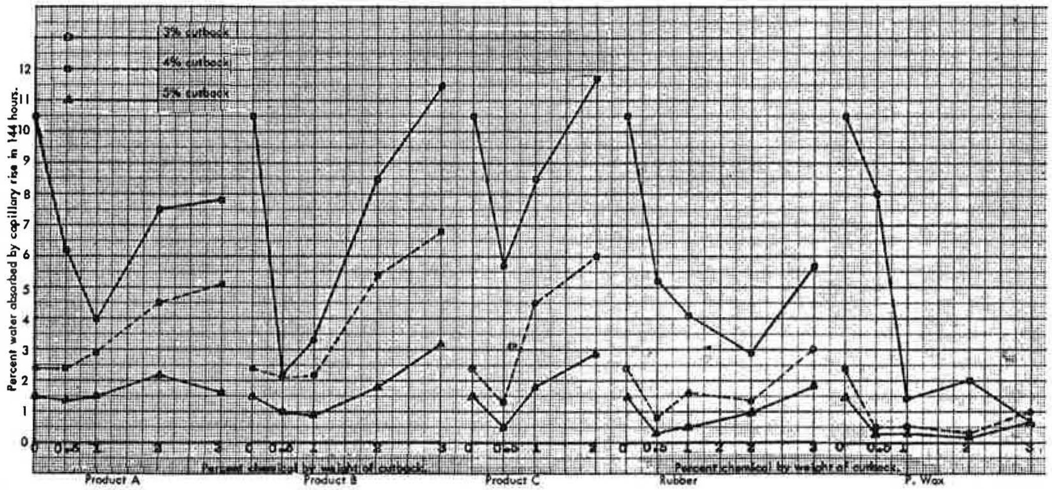



Figure 2. Results of blocks made at workable moisture.

In addition to these three antistripping agents, commercial paraffin wax and a rubber solution were also included in the study as these are supposed to improve appreciably the waterproofing quality of asphalts. The rubber solution containing approximately 20 percent rubber was obtained from M/S Rajsathan Electro-Conductor Manufacturing Corporation Jodhpur and was mixed with hot bitumen in proportions to give the required percentage of rubber; viz., 150 gm rubber solution mixed with 850 gm bitumen to give a mixture containing 3 percent rubber; 100 gm mixed with 900 gm to give a mixture containing 2 percent rubber; 50 gm mixed with 950 gm to give a mixture containing 1 percent rubber and 25 gm mixed with 975 gm to give a mixture with 0. 5 percent rubber.

To study the effect of varying proportions of Products A, B, and C on the properties of the bitumen, 0. 5, 1, 2, and 3 percent of each chemical (by weight of the cutback) was mixed in the requisite quantity of the cutback separately by heating to about 150 C. Twenty cutback samples containing different chemicals in varying proportions were obtained besides the original sample containing no chemical.

## Preparation of Specimen Blocks

Two sets of specimen blocks, one molded at workable moisture and one compacted at optimum moisture, were prepared for testing the effectiveness of the chemicals. The quantity of cutback used varied from 2 to 5 percent by weight of dry soil. For the molded specimens, the requisite quantity of cutback was mixed in the soil after the latter had been well mixed with a sufficient amount of water (about 30 percent by weight of soil) to bring it to molding consistency. The cutback was mixed with a spatula until it was completely dispersed into the mud giving a uniform color and texture. This bitumenized mud was poured into hollow cylindrical split molds (2.5-in. diameter by 2.5-in. high) which were tapped on the sides to remove air pockets and then allowed to set overnight. On the next day the hardened specimen blocks were removed by opening the split molds. The specimens were then allowed to dry.

The compacted specimen blocks were prepared by compaction at optimum moisture (12 percent). For each specimen, 200 gm of dry soil was taken and after mixing with the requisite quantity of water, the designated quantity of cutback was spread over the soil and mixed thoroughly first with a spatula and then by rubbing the mixture between the palms of the hands until a homogeneous mixture was obtained. This mixture was then placed in the modified Abbot compaction apparatus and compacted by 40 blows of the 5-lb hammer dropping from a 12-in. height. The specimen blocks were 2. 5 in. in diameter and about 1. 25 in. high.

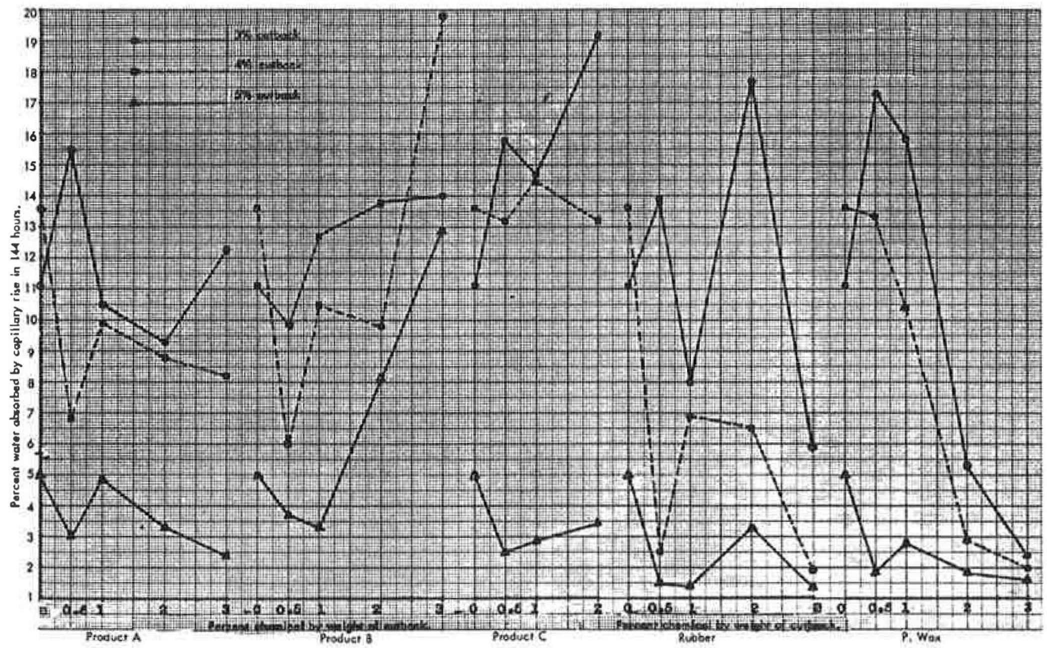



Figure 3. Results of blocks made at optimum moisture.

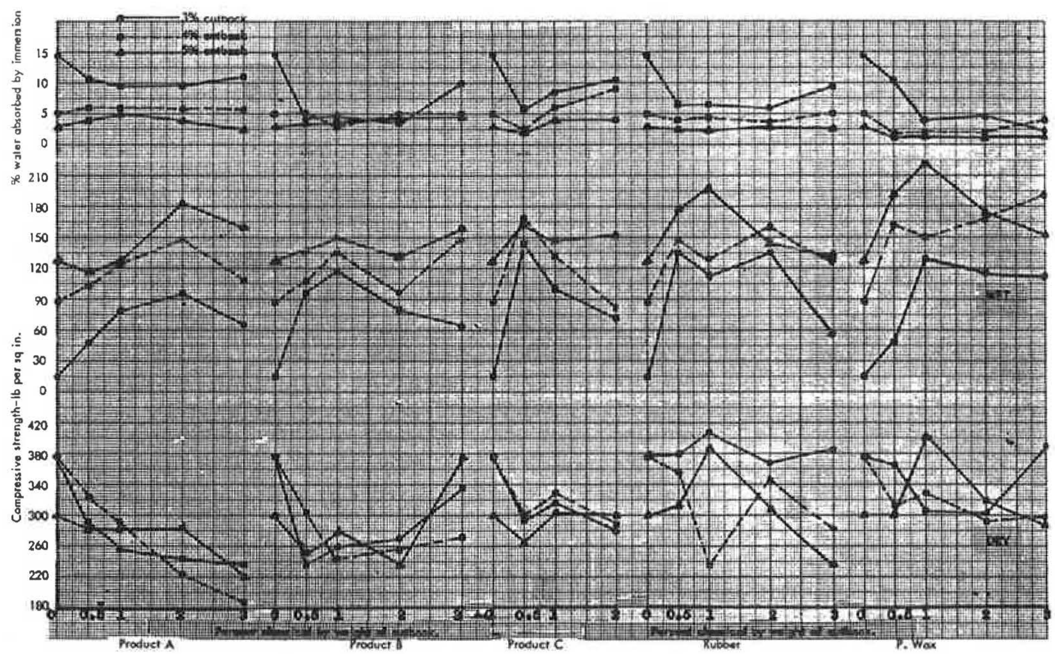



Figure 4. Results of blocks made at workable moisture.

## Tests Performed

The specimen blocks prepared by the two methods were first allowed to dry in the sun and then brought to constant weight in a hot oven maintained at 60 to 70 C. They were then tested for the following properties: (a) moisture absorption by capillary action, (b) resistance to softening effect of water upon complete immersion, and (c) dry and wet compressive strength.

## Testing Procedure and Discussion of Results

Moisture Absorption by Capillary Action. The dry specimen blocks were weighed and placed over sand constantly kept wet in a tray (Fig. 1). Moisture absorbed by each specimen block was determined at 24-hr intervals for as long as 240 hours. Results of specimens at 144 hours containing 3, 4, and 5 percent cutback are shown in Figure 2 for blocks made at workable moisture and Figure 3 for blocks made at optimum moisture. Specimen blocks made without the addition of bitumen cutback became completely wet and soft within 24 hours and could not be handled for further testing. The addition of only 0. 5 percent of all the cationic chemicals considerably reduced the moisture absorption capacity of the cutback and this effect was more marked when 3 percent cutback by weight of soil was used. With the larger quantities of cutback used for soil stabilization the effect of these chemicals was not significant although some improvement was observed with the incorporation of 0. 5 percent chemical. With increasing percentages of these chemicals in the cutback, greater water absorption was noticed particularly in the mixtures containing more than 3 percent cutback. Of the three cationic chemicals, Product C gave best results when 0. 5 percent was used and the percentage of the cutback in the soil was 4 and 5. Other relationships are shown in Figures 2 and 3.

The rubber solution used as an admixture gave results almost identical to those of Product A. In the specimens containing 3 percent cutback, the water absorption steadily decreased with the addition of rubber solution up to 2 percent. In the case of specimens containing a larger quantity of cutback, 0. 5 percent rubber gave best results and further increase tended to have an adverse effect.

The addition of paraffin wax had a marked effect in enhancing the waterproofing property of the bitumen and confirmed the results of previous investigations (7). In the case of specimens containing 3 percent cutback, water absorption appreciably and steadily decreased with an increasing quantity of paraffin wax up to 3 percent, while in the specimens containing 4 and 5 percent cutback the addition of paraffin wax up to 2 percent gave very satisfactory results. Even with the use of 2 percent cutback, which contained 3 percent paraffin wax, the water absorption was fairly low.

In comparing the results of the two sets of experiments, i. e., the specimens prepared at workable and optimum moisture, the results from the blocks made at workable moisture were more consistent.

Generally, the use of paraffin wax gave much better results than other chemicals insofar as the water absorption by capillary action is concerned. It was also observed that there is an optimum quantity of such additives at which they are most effective.

Resistance to Softening Effect of Water by Actual Immersion of Specimen Blocks. In this test, the blocks were immersed in water contained in a tray and their condition and moisture absorption was observed at 24-hr intervals for as long as 120 hours. Results are shown in Figures 4 and 5. Compressive strength of the wet blocks which remained intact after this test was also determined. The compressive strength of the wet specimens generally increased with the increasing quantity of the cationic chemicals up to 2 percent in the case of Product A, up to 1 percent in the case of Product B, and up to 0. 5 percent in the case of Product C. Further increase in the percentage of the chemicals tended to reduce the wet compressive strength. At their optimum percentages, Product C gave better results than Products B and A. In all cases, the beneficial effect of the chemicals was more pronounced when 3 percent cutback by weight of soil was used, as the wet compressive strength increased from about 15 psi in blocks made with cutback containing no additive to over 100 psi in blocks made from cutback containing

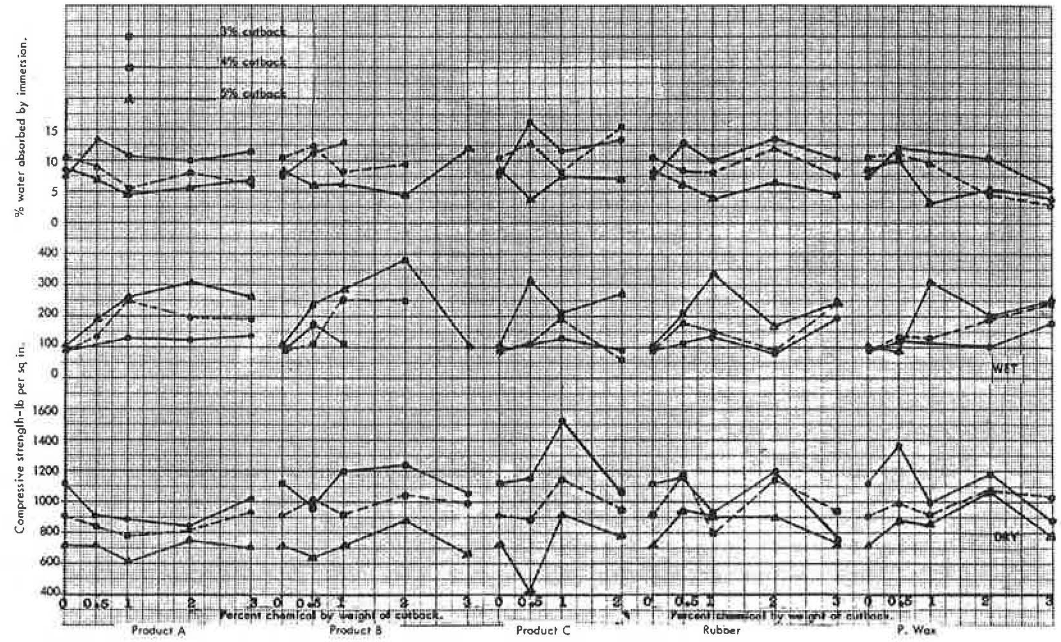



Figure 5. Results of blocks made at optimum moisture.

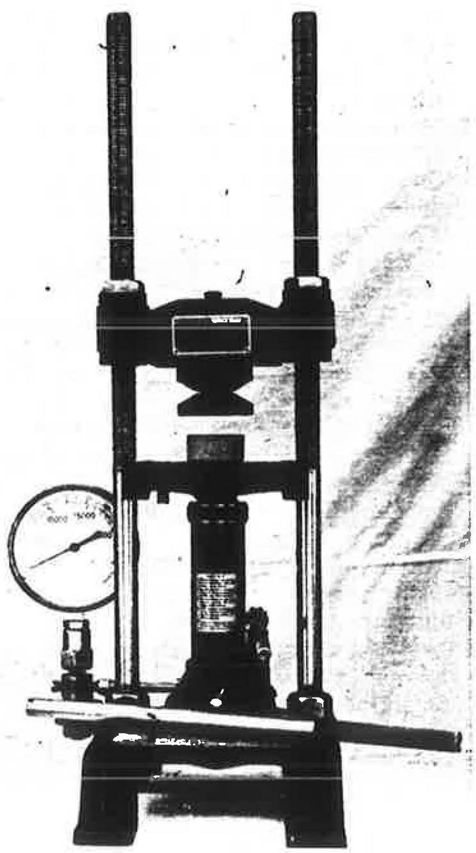


Figure 6. Laboratory Carver press.

optimum quantities of the additives studied Specimens of soil prepared with cutback containing 1 percent paraffin wax and 0. 5 percent rubber compared favorably with those made from cutback containing 0. 5 percent Product C, which was the best fc 3 percent admixture of cutback. When, however, higher percentages of cutback containing these optimum quantities of wa and rubber were used, the results were still better. The optimum quantities of the chemicals which showed highest wet compressive strength showed the minimum water absorption and this effect was again more pronounced in the case of block containing 3 percent cutback.

Dry Compressive Strength. This was determined by the laboratory Carver pre (Fig. 6). Results are shown in Figures and 5. Dry compressive strength of the specimen blocks made at a higher moistur content generally decreased with increasin quantities of all five additives. However, when these admixtures were used for bituminous stabilization of soil by compaction at optimum moisture, they did not show any marked effect on the compressiv strength with increasing quantities. Specimens containing higher proportions of al cutback continued to show less strength than those containing lower (3 percent) proportions.

TABLE 1

| S. No. | Duomeen-T (% by wt. of soil) | Cutback (% by wt. of dry soil) | Dry Comp. Strength (psi) | Moisture (%) Absorbed by Immersion After Time (hr) | | | Wet Comp. Strength After 72-Hr Soaking (psi) |
|---|---|---|---|---|---|---|---|
| | | | | 24 | 48 | 72 | |
| 1. | Nil | Nil | 281.7 | Block disintegrated after 15 minutes | | | – |
| 2.[a] | Nil | 1 | 319.2 | 14.3 | 15.4 | 15.9 | 14.4 |
| 3.[a] | Nil | 2 | 398.5 | 11.6 | 14.0 | 15.3 | 24.0 |
| 4. | Nil | 3 | 300.9 | 6.5 | 9.2 | 11.0 | 49.7 |
| 5. | 0.05 | Nil | 267.8 | Block disintegrated after 8 days | | | – |
| 6. | 0.05 | 1 | 372.6 | 10.6 | 13.9 | 14.5 | 28.8 |
| 7. | 0.05 | 2 | 403.2 | 1.7 | 3.2 | 4.03 | 165.0 |
| 8. | 0.05 | 3 | 298.5 | 0.7 | 1.8 | 1.8 | 237.2 |
| 9. | 0.1 | Nil | 244.5 | Partially disintegrated | | | Block soft |
| 10. | 0.1 | 1 | 260.5 | 9.4 | 11.7 | 12.4 | 40.0 |
| 11. | 0.1 | 2 | 296.6 | 4.5 | 8.2 | 10.0 | 107.4 |
| 12. | 0.1 | 3 | 332.7 | 1.5 | 3.5 | 4.1 | 176.4 |
| 13.[b] | 0.2 | Nil | 145.1 | 8.08 | 10.6 | 10.8 | 25.6 |
| 14. | 0.2 | 1 | 154.7 | 9.5 | 12.8 | 13.09 | 41.7 |
| 15. | 0.2 | 2 | 127.4 | 8.6 | 11.5 | 12.5 | 49.7 |
| 16. | 0.2 | 3 | 169.9 | 4.4 | 6.2 | 7.8 | 72.1 |
| 17.[b] | 0.5 | Nil | 76.1 | 10.3 | 12.9 | 12.9 | 19.2 |
| 18. | 0.5 | 1 | 119.4 | 8.61 | 12.2 | 12.7 | 43.3 |
| 19. | 0.5 | 2 | 109.7 | 2.3 | 4.1 | 5.4 | 67.3 |
| 20. | 0.5 | 3 | 114.6 | 2.0 | 3.06 | 4.3 | 68.9 |

[a]Bottom somewhat soft.
[b]Bottom slightly soft.

## Conclusions and Economics of the Additives

The following conclusions can be drawn from the results previously discussed.

1. The cationic surface active agents, commercially sold as antistripping agents, have a marked effect on the waterproofing property of the bitumen-soil mixture.
2. There is an optimum quantity of each chemical (by weight of bitumen) at which it gives best results.
3. There is an optimum ratio of cutback to soil at which such chemicals are most effective.
4. Soil blocks prepared with 3 percent cutback (by weight of soil) containing 0.5 percent to 1 percent of the chemicals under study compared very favorably in their resistance to water absorption and in their wet compressive strength to those having 4 to 5 percent cutback, containing no chemical. In this way, 1 to 2 percent cutback could be saved by using 0.015 to 0.03 percent chemical by weight of soil (0.5 to 1 percent by weight of cutback) costing less than 40 percent the price of bitumen cutback.
5. Use of paraffin wax is more effective and the most economical of all the additives tried.

## EFFECT OF PRETREATMENT OF SOIL WITH CATIONIC SURFACE ACTIVE AGENTS ON STRENGTH AND STABILITY

It was found in the previous investigation that the incorporation of certain cationic additives, in certain proportions improves considerably the resistance to softening effect and water absorption of the resultant soil mass and helps in preserving its compressive strength in the wet state. An attempt was then made to study the effect of pretreatment of a soil with certain chemicals on the soil's properties when stabilized with bitumen cutback containing no additive. Accordingly, a graded type of soil having a plasticity index of about 10 and a sand content of about 40 percent, was selected and treated with 0.05, 0.1, 0.2 and 0.5 percent stearyl diamine. The required quantity of the chemical was first dissolved in an amount of water just sufficient to wet the soil when thoroughly mixed. The soil was then dried for use in these investigations.

The specimen blocks were prepared by molding these treated soils in suitable cylindrical molds after mixing with a sufficient amount of water (about 30 percent by

TABLE 2

| Duomeen-T (% by wt. of soil) | Cutback (% by wt. of dry soil) | Percent Moisture Absorbed by Capillary Rise in Hours | | | | | | | | Wet Comp. Strength After 10 Days (psi) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 24 | 48 | 72 | 120 | 144 | 168 | 240 | |
| Nil | Nil | Block became soft after 20 min | | | | | | | | 20.8 |
| Nil | 1 | 2.3 | 9.5 | 13.1[a] | 14.1 | 14.9 | – | 15.6 | 15.6 | 20.8 |
| Nil | 2 | 1.02 | 6.4 | 10.7 | 13.3[a] | 15.1 | – | 16.1 | 16.1 | 24.0 |
| Nil | 3 | 0.25 | 3.1 | 5.6 | 7.4 | 10.8[a] | – | 13.1 | 13.1 | 35.2 |
| 0.05 | Nil | Absorption could not be noticed | | | | | | | –[b] | 13.6 |
| 0.05 | 1 | 1.2 | 3.7 | 6.0 | 7.0 | 9.0 | 10.0[a] | 10.5 | 10.7 | 40.0 |
| 0.05 | 2 | 0.2 | 1.0 | 2.5 | 2.7 | 4.3 | 5.6 | 6.6 | 8.4 | 72.1 |
| 0.05 | 3 | 0.3 | 0.7 | 1.5 | 1.5 | 2.8 | 2.8 | 3.0 | 3.0 | 190.8 |
| 0.10 | Nil | Absorption could not be noticed | | | | | | | –[b] | 20.0 |
| 0.10 | 1 | 1.2 | 4.0 | 6.4 | 7.3 | 9.1 | 9.2 | 9.4 | 9.4 | 39.2 |
| 0.10 | 2 | 0.2 | 1.5 | 3.5 | 4.0 | 6.1 | 7.4 | 7.6 | 8.4 | 71.3 |
| 0.10 | 3 | 0.0 | 0.2 | 1.2 | 1.2 | 2.5 | 2.5 | 3.0 | 3.0 | 160.3 |
| 0.2 | Nil | 1.6 | 4.1 | 4.9 | 5.4 | 6.0 | – | 6.4 | 6.4 | 36.1 |
| 0.2 | 1 | 1.36 | 8.9 | 11.5[a] | 12.0 | 12.7 | – | 13.0 | 13.0 | 36.8 |
| 0.2 | 2 | 0.45 | 4.0 | 7.9 | 10.3[a] | 13.0 | – | 13.3 | 13.3 | 40.1 |
| 0.2 | 3 | 0.25 | 1.29 | 2.6 | 4.2 | 6.5 | – | 9.4 | 11.8 | 60.1 |
| 0.5 | Nil | 3.1 | 6.7 | 7.9 | 8.8 | 9.2 | – | 9.9 | 9.9 | 16.8 |
| 0.5 | 1 | 0.8 | 8.6 | 12.4[a] | 12.8 | 13.5 | – | 13.9 | 14.1 | 40.0 |
| 0.5 | 2 | 0.2 | 1.0 | 1.4 | 2.2 | 3.9 | – | 6.9 | 10.1[a] | 45.6 |
| 0.5 | 3 | 0.1 | 0.7 | 0.7 | 0.9 | 1.3 | – | 1.7 | 1.7 | 75.3 |

[a] Top wet.
[b] Bottom soft.

weight of soil) and 1, 2 and 3 percent bitumen cutback consisting of 80 parts of 80 to 100 penetration bitumen and 20 parts kerosine. The blocks were then allowed to set and dry. The compressive strength of the blocks in both the dry and wet condition, the rate of water absorption by capillarity, and the amount of water absorbed by the blocks on actual immersion in water were determined. The method used was the same as previously described. The results are given in Tables 1 and 2, and shown in Figures 7 and 8.

## Discussion of Results

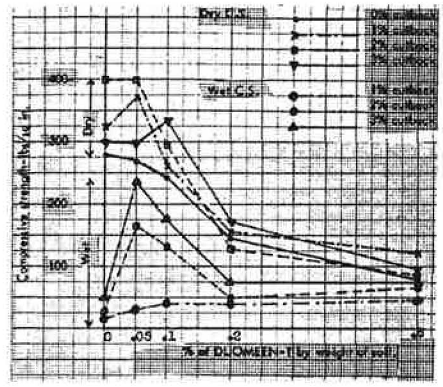
From the results given in Table 1 and plotted in Figure 7, the dry compressive strength of the specimen blocks increased slightly when the soil was treated with 0.05 percent of the cationic chemical but decreased with increasing percentages. On the whole, the treatment of soil with the chemical tended to decrease the dry compressive strength of the blocks. On the other hand, the wet compressive strength generally improved when the soil was treated with the chemical, and it was maximum in the case of soil treated with 0.05 percent. Similarly, moisture absorbed by the specimen blocks on actual immersion in water was much lower in the case of treated soil and was the lowest in the case of specimen blocks of soil treated with 0.05 percent of the chemical and stabilized with 2 to 3 percent cutback.

Examination of results given in Table 2 and shown in Figure 8 will also show that the rate of moisture absorption by capillary action in the case of soil treated with 0.05 percent chemical was almost the lowest. Also the wet compressive strength of blocks tested after 240 hours was highest in the case of soil treated with 0.05 percent chemical. Treated soil stabilized with only 1 percent bitumen cutback in every case showed even a better wet compressive strength than that which was obtained from the untreated soil stabilized with 3 percent bitumen cutback.

## Conclusions

From the preliminary results of this study, it is obvious that some engineering properties of soil stabilized with bitumen can be considerably improved by pretreating the soil with cationic surface-active chemicals, and also considerable savings can be effected in the quantity of bitumen. By using 0.05 percent chemical by weight of soil,

Figure 7. Dry compressive strength when soil was treated with cationic chemical.



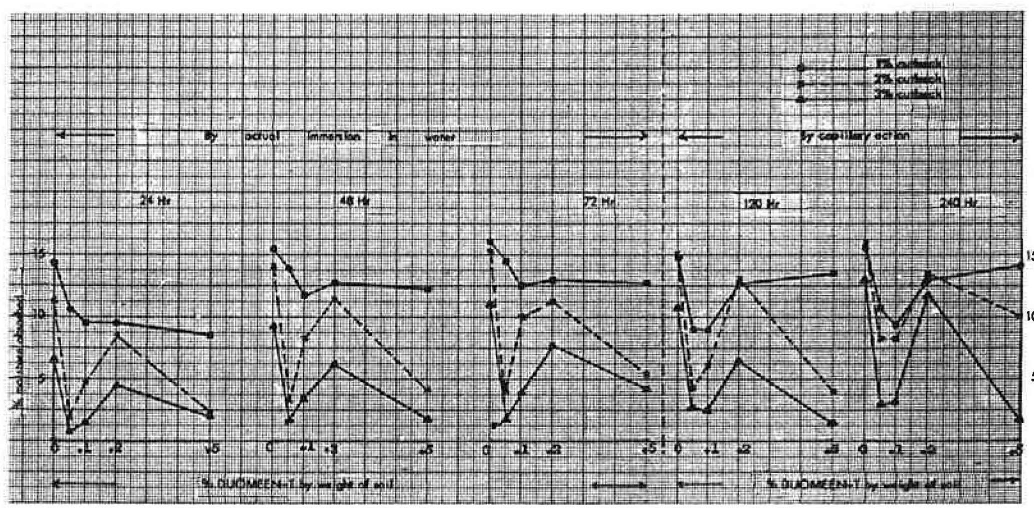




Figure 8. Moisture absorbed when soil was treated with cationic chemical.

TABLE 3

| S. No. | Nature of Soil | Method of Mixing Cutback | Cutback Added (%) | Comp. Strength (psi) Dry | Comp. Strength (psi) Wet (after 72-hr soaking) | Moisture After 72-Hr Soaking (%) |
|---|---|---|---|---|---|---|
| I. | Sandy | I | 0 | 911.4 | – | – |
| | PI = 4.64 | | 3 | 980.7 | 72.03 | 7.0 |
| | SC = 61.9 | | 4 | 725.0 | 88.04 | 10.78 |
| | $SO_4''$ = 0.0 | | 5 | 718.6 | 124.8 | 6.33 |
| | OM = 10% | II | 3 | 592.9 | 32.01 | 14.85 |
| | | | 4 | 420.1 | 92.8 | 8.29 |
| | | | 5 | 438.5 | 201.6 | 5.24 |
| II. | Clayey | I | 0 | 1201.4 | – | – |
| | PI = 18.10 | | 3 | 1015.0 | Block disintegrated after 30 min | |
| | SC = 9.2 | | 4 | 1180.7 | Block disintegrated after 1 hr | |
| | $SO_4''$ = 0.0 | | 5 | 890.0 | Block disintegrated after 4½ hr | |
| | OM = 15% | II | 3 | 1015.0 | Block disintegrated after 6 hr | |
| | | | 4 | 1118.6 | Block disintegrated after 8½ hr | |
| | | | 5 | 870.0 | Block disintegrated after 24 hr | |
| III. | Silty | I | 0 | 141.6 | – | – |
| | PI = 9.43 | | 3 | 144.8 | Block disintegrated after 4 hr | |
| | SC = 10.5 | | 4 | 189.6 | 32.01 | 22.06 |
| | $SO_4''$ = 0.0 | | 5 | 224.9 | 49.9 | 18.62 |
| | OM = 10% | II | 3 | 194.4 | 56.0 | 23.76 |
| | | | 4 | 156.8 | 57.6 | 12.56 |
| | | | 5 | 142.4 | 76.8 | 8.17 |

TABLE 4

| S. No. | Nature of Soil | Method of Mixing Cutback | Cutback Added (%) | Moisture Absorption (%) by Capillary Rise After Time (hr) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 24 | 48 | 72 | 120 | 168 |
| I. | Sandy | I | 3 | 0.0[a] | 6.0[a] | 11.5[a] | 12.0[a] | 12.0[a] | 12.0[a] |
| | | | 4 | 0.49 | 0.99 | 1.48 | 1.48 | 1.48 | 1.48 |
| | | | 5 | 0.5 | 0.58 | 0.97 | 0.97 | 0.97 | 0.97 |
| | | II | 3 | 0.98 | 1.95 | 12.25 | 13.72 | 14.7 | 14.7 |
| | | | 4 | 0.5 | 1.45 | 2.91 | 2.91 | 3.8 | 3.8 |
| | | | 5 | 0.0 | 1.41 | 2.83 | 2.83 | 3.77 | 3.77 |
| II. | Clayey | I | 3[b] | 19.34[c] | 27.3 | 28.77 | 29.24 | 29.27 | 29.27 |
| | | | 4[b] | 6.8 | 26.21 | 27.66 | 29.12 | 29.12 | 29.12 |
| | | | 5[b] | 23.0[c] | 35.0 | 36.5 | 36.5 | 36.5 | 36.5 |
| | | II | 3[b] | 5.31 | 31.40 | 31.40 | 31.40 | —[e] | —[e] |
| | | | 4[d] | 5.94 | 16.33 | 22.77 | 23.76 | 23.76 | 23.76 |
| | | | 5[d] | 0.0 | 17.00 | 22.5 | 22.5 | 22.5 | 22.5 |
| III. | Silty | I | 3[b] | 22.5[c] | —[e] | —[e] | —[e] | —[e] | —[e] |
| | | | 4[b] | 17.07[c] | 20.97 | 21.94 | 21.94 | 21.94 | 21.94 |
| | | | 5 | 2.44 | 12.19 | 13.17 | 13.65 | 13.65 | 13.65 |
| | | II | 3[b] | 0.48 | 10.59 | 20.19 | 22.11 | 25.0 | 25.0 |
| | | | 4 | 0.0 | 0.0 | 0.97 | 0.97 | 0.97 | 0.97 |
| | | | 5 | 0.0 | 0.0 | 0.94 | 0.94 | 0.94 | 0.94 |

[a] Wet but hard.
[b] Block soft.
[c] Top wet.
[d] Block somewhat soft.
[e] Loss of soil.

about 2 percent bitumen by weight of soil can be saved without adversely affecting engineering properties of the soil.

In this a similar savings can be made to that previously discussed.

## EFFECT OF TWO METHODS OF MIXING BITUMEN IN SOIL ON THE PROPERTIES OF THE MIXTURE

Stabilization of soil with bitumen for various engineering works is becoming more popular because of its properties of binding and waterproofing. Besides imparting structural stability to soil, the method of soil stabilization has an important application as a capillary moisture cutoff in water-logged areas.

The conventional method of mixing bitumen with soil is to bring the soil to about optimum moisture content and then add the requisite quantity of bitumen (converted to a form of cutback) either by hand or in mechanical mixers. In this way, the soil

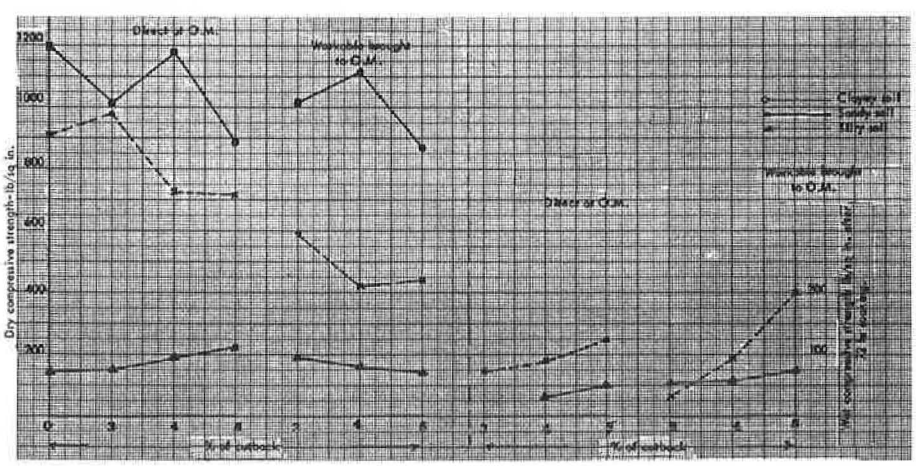



Figure 9. Influence of method of mixing on compressive strength.

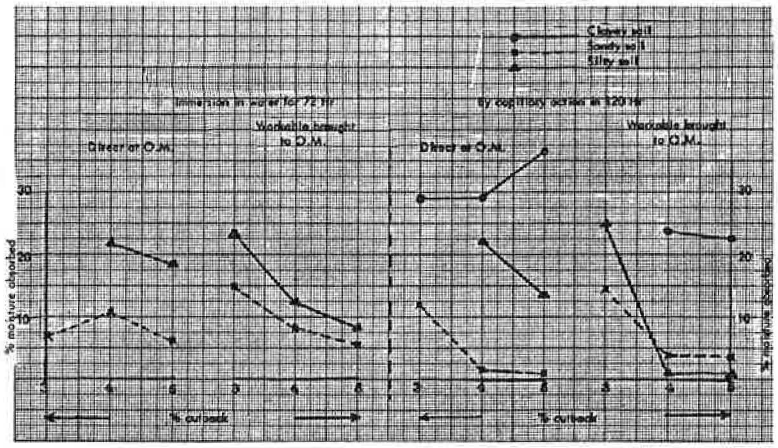



Figure 10. Influence of method of mixing on moisture absorption.

particles are coated with bitumen, and become water resistant. The mixture is then spread and compacted by means of hammers or suitable rollers to the maximum density.

Another way of mixing bitumen in soil is to add a sufficient amount of water and mix to a mortar consistency, then add the requisite quantity of bitumen cutback and again mix manually or in suitable mechanical mixers such as concrete mixers. This method is actually used for the preparation of waterproof mud mortar for masonry or plaster work where a greater amount of water is required for mixing.

For soil stabilization by compaction, this method is not favored because the mixture has to be again brought back to the optimum moisture by evaporating the excess moisture. Some preliminary trials with this method showed that it gives more homogeneous and water resistant soil-bitumen mixtures and also needs less labor than when bitumen is mixed with the soil at optimum moisture. Therefore, in these investigations a comparative study of the effect of two methods of mixing soil-bitumen on the properties of the resultant mixture was made and the results are given in Tables 3 and 4 and shown in Figures 9 and 10. Method I represents the blocks prepared directly at optimum moisture, whereas in Method II, the initial mixing was done at a higher moisture, the mixture was allowed to dry to near optimum moisture and then compacted. Three soils (sandy, clayey, and silty) were used separately. The bitumen was used in the form of cutback consisting of 80 parts of 80 to 100 penetration bitumen and 20 parts of kerosine, which was mixed hot and then cooled. Three proportions (3, 4 and 5 percent) of the cutback by weight of dry soil were used. Methods adopted for preparation of specimen blocks were the same as described previously.

## Discussion of Results

From Table 3, the dry compressive strength, which generally decreased with an increasing quantity of bitumen in both cases, was appreciably lower in the case of specimens made from the mixture prepared at a higher moisture content and then brought to optimum moisture for compaction. But the results of the wet compressive strength test were just the reverse. The wet compressive strength increased with the increasing quantity of bitumen cutback in both cases and was generally higher in the case of blocks made by Method II. The moisture absorbed by these blocks was also generally less than that absorbed by the corresponding blocks made at optimum moisture. In the case of clayey soil, although all the blocks had disintegrated during immersion in water, the blocks prepared by Method II resisted the disintegrating effect of water much longer than those prepared by Method I.

Similarly from Table 4, except in the case of sandy soil, the rate of moisture absorption and the quantity of water absorbed by the Method II blocks was much lower and less than the corresponding Method I blocks. In the case of sandy soil there was not much difference in the moisture absorbed by capillary rise in the blocks prepared by the two methods.

It can be concluded that mixing the soil with water first at mortar consistency, and then incorporating the required quantity of bitumen and bringing back to optimum moisture (Method II) yields better mixing and uniform coating of the soil particles, thereby increasing resistance to water absorption. As the loss in the soil strength with an increasing quantity of bitumen is generally due to its lubricating effect, the lower dry strength of blocks made by Method II confirms the better mixing of bitumen in soil by this method.

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## *Discussion*

HANS F. WINTERKORN, Department of Civil and Geological Engineering, Princeton University—The purpose of this discussion is to place the interesting results obtained by Dr. Uppal within the larger content of factual and theoretical knowledge on bituminous soil stabilization developed within the past forty years, and to point out certain facts that are of particular interest.

### The Beneficial Effect of High Water Contents

The better ultimate wet strength and water resistance of soil-bitumen, achieved whe mixing and molding were conducted on the wet rather than the dry side, had been recog nized in the earliest field and laboratory studies and reported in the pertinent literatur (10, 11). This was before the concept of the optimum moisture content and maximum density in compaction had become widely known through the work and publications of Proctor (9). In early field work on clay soil stabilization with bitumen, the water content used exceeded even that needed for plastic mixtures since the available pug mill mixers could not handle the soil in the truly plastic state. Although such mixes required a considerable time to reduce their moisture content sufficiently for compaction with sheepsfoot rollers, the final soil-bitumen systems were of excellent quality.

Actually, many experienced soil engineers hesitate to use the term "optimum" wate content for compaction methods that involve more energy than that employed in the original and in the ASTM and AASHO standardized procedures which is about 12, 375 ft-lb/cu ft. Significantly, the optimum moisture for this energy of compaction usually fal within a few points of the plastic limit. At this limit, the water affinity of a clay soil is considered to be sufficiently satisfied to allow the water molecules most distant from the mineral surfaces to approach the state of free water.

There are a number of good reasons for having a sufficiently high water content, at the time of incorporation of the bitumen, to do more than just satisfy the water affinity of the clay minerals. First, below this condition, the water is likely to be nonuniformly distributed and even if its total amount is theoretically sufficient, there are likely to be mineral surfaces or portions of such that are not satisfied and provide energy potentials for later water adsorption. Second, hydrophilic materials are also oxophilic. This means that in a dry condition they have films of strongly adsorbed oxygen-molecules which are not easily wetted or displaced by bitumen. After these oxygen films are replaced by water films, wetting by bitumen can take place. Diffusion and evaporation of the less strongly held water molecules in the outer layers permits the bitumen and its more active constituents to come ever closer to the mineral surfaces until they interact with the latter and the very strongly held water molecules by physical and/or chemical interchange. Third, in the presence of water-bitumen interfaces, molecules of sizes up to the colloidal that possess affinity for both water and hydrocarbons on different parts of their structure tend to collect at the water-bitumen interface where they can satisfy both affinities. The extent and rate of this phenomenon depends among other factors on the total amount of water-bitumen interface and on the distance the molecules have to travel to reach this interface. Both depend on the amount of water present in the system. The same phenomenon also takes place with adhesion promoting agents that have been admixed either to the aqueous or the bituminous phase, such as fatty and resinous acids, soaps, amines, and their salts, and even more "inert" materials such as long chain paraffines and asphaltenes.

## Dangerous Overemphasis on Maximum Dry Density

Unwarrented and actually unscientific emphasis has been placed by too many engineers within recent years on obtaining as high a dry density of soil-bitumen and other stabilized soils as possible with available equipment at the price of an insufficient water content. While the inherent danger of this was first recognized for soil-cement where water is required as a reactant as well as for initial lubrication of the system, it was more easily overlooked in the case of soil-bitumen where water was supposed to be the enemy. The results of many investigations, especially those on the effectiveness of various anionic and cationic additives, were falsified by the use of too low a water content combined with too high a compactive effort. This is well illustrated by the test results obtained by Dr. Uppal on the dry-mixed specimens. The water content employed was a so-called "optimum" of 12 percent; however, this "optimum" went with a compacting effort of more than 4½ times that of the standard Proctor method. For the latter and the type of soil employed, the optimum moisture content should have been between 20 and 25 percent. The fact that the dry mixed specimens behaved as well as they did is due to the high temperature range 60 to 70 C or 140 to 158 F at which they were cured to constant weight. This high temperature reduced the viscosity of the bitumen and allowed it to spread more uniformly over the mineral surfaces. This spreading and homogenizing was facilitated by the fact that the higher temperatures had cleansed surfaces, left uncoated by the bitumen, of adsorbed oxygen-molecules and of the more loosely held water molecules some of which had migrated to previously unsatisfied locations of high water affinity. The lowered viscosity of the bitumen also enhanced the diffusion of active molecules contained in it to the bitumen-mineral interfaces. In view of the determinant role of a sufficient water content in allowing important physicochemical reactions to proceed in a soil-bitumen system, it was very fortunate that the monumental work on "Physico-Chemical Factors of Importance in Bituminous Soil Stabilization" sponsored by the Missouri State Highway Department and the U. S. Bureau of Public Roads during the 1930's, was planned and started before Proctor's publications, and had provided for mixing water contents in the normal plastic range. This insures the continued validity of the results obtained and of the conclusions drawn from them (14).

## Results Obtained With Additives

In the absence of specific data on the surface-chemical characteristics of the soil employed, the results obtained with the particular additives used (cationic, rubber and paraffine) do not lend themselves to physicochemical analysis. The existence of optimum percentages for particular additives in particular bitumen-soil-water combination has been found previously and recorded in the literature (11). Of particular interest is the good showing of paraffine which was previously reported by Endersby (8) for certain soil-bitumen combinations.

It would be a worthwhile job to study the range of soil types for which paraffine is of equal or greater effectiveness than cationic and anionic additives. The reason for this importance transcends the possible economies derived from the lower cost of the paraffines. Many cationic agents have irritative effects on skins and mucous membranes of living beings. This poses special problems in warm climates and particularly under conditions where plastic soil-bitumen mixes are densified by the action of bare feet. Use of paraffine as additive would avoid this health hazard as would, where applicable, the use of such anionic agents as resinous and fatty acids and soaps. Use of irritative cationic agents can be justified only if they are unmatched in performance and if the entire mixing and compaction process is so mechanized that no health hazard exists.

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