MOVEMENT OF CALCIUM CHLORIDE AND SODIUM CHLORIDE IN SOIL[1]

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SYNOPSIS

This report treats of the movement of such water-soluble, inorganic compounds as calcium chloride and sodium chloride in soil and the reduction of frost heave by the use of these chemicals as admixtures with the soil. These compounds are used as stabilizing agents in pavement base courses and for the prevention of frost damage in pavement subgrades

One of the main purposes of this investigation is to trace the movement of calcium chloride and sodium chloride in various soils and to evaluate the important variables governing this movement Another objective is to determine the practicability of treating subgrades with these chemicals in order to reduce or eliminate frost heave. This research was pursued by means of both field and laboratory studies.

It was found that calcium chloride and sodium chloride migrated differently under similar conditions of exposure Under the influence of soil capillarity and natural evaporation, sodium chloride tended to form a white crust on the surface of the unpaved road, and, hence, was more susceptible to lateral, surface washing during rain periods than was calcium chloride. On the other hand, calcium chloride did not tend to accumulate on the unpaved road surface to the extent that sodium chloride did, under the influence of soil capillarity and natural evaporation, because of its greater moisture-attracting power and its higher solubility. With exposed fine-grained soils, lateral movement proceeded primarily by surface washing from the top of the road proper to the side ditches, rather than by lateral movement below the surface

Important variables affecting the movement of water-soluble chemicals in soil and hence their permanence included. (1) evaporation, (2) soil texture, (3) percolating water, (4) soil cover, and (5) temperature when high enough or low enough to effect a change of phase of the water. Relative to base-exchange phenomena, the calcium and sodium cations were more persistent in fine-grained soil than the chloride anion

In general, increased effectiveness in reducing heaving in soil resulted from increases in the amount of calcium chloride or sodium chloride added—up to a certain percentage of chemical above which no heaving took place In a coarse-textured soil, heaving was greatly reduced by an admixture of only 0.33 per cent of either chemical One or two per cent of either chemical was effective in reducing heaving in a silt which had heaved badly both in the field and in the laboratory (in the untreated state)

One of the main purposes of this investigation was to study the movement of calcium chloride and sodium chloride in various soils and to evaluate the important variables governing this movement. In brief, since some bases and subgrades are periodically treated with these chemicals, what happens to the chemicals? How often should treatments be applied? How much should be added? What forces induce the compounds to move upward, or downward, or laterally?

A paramount question is, "Is it practical to treat subgrades with these chemicals in order to prevent frost heave?" Frost action leads to the destruction of pavements by heaving of the underlying soil. It has been shown that water-soluble chemicals definitely improve this condition However, there is a lack of data concerning the amount of chemical necessary to prevent frost heave and the permanence of this chemical in the soil.

The construction of two test roads by the

[1] For the complete report of this investigation including an extensive bibliography see Bulletin No 89, Purdue Engineering Experiment Station

Joint Highway Research Project made possible the field studies of the movement of calcium chloride and sodium chloride in soil. By sampling these roads at different seasons, it was possible to compare the movements of the two chemicals under like conditions and to evaluate partially the influence of such important variables as height of ground-water

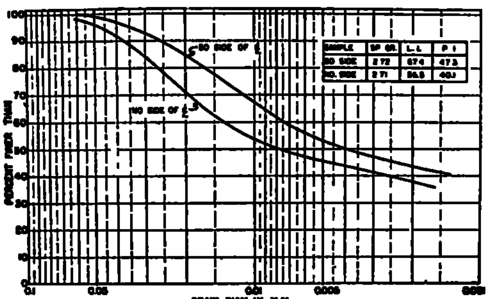

Fig. 1. Analyses of Typical Soil Samples from Test Road No. 1

clay and a comparison of such movement with that of the chloride anion being included in the investigation.

Some important variables governing soluble salt movements in soil were suggested by the field studies. It was desirable to evaluate these insofar as possible by controlled laboratory tests. By schematically setting-up tests to simulate field conditions of evaporation, percolation of water, various surface temperatures, and an impervious pavement, it was possible to determine whether or not these variables are of importance in chemical movement in soil. It was possible to study the effect of soil texture by direct comparison of the results obtained from soils of diverse texture, using a given test

The frost-action study included in this investigation is supplementary to that of Winn.[2] For a given soil and a given chemical, under fixed conditions, there apparently should be a "critical chemical content" above which no heaving occurs and below which heaving

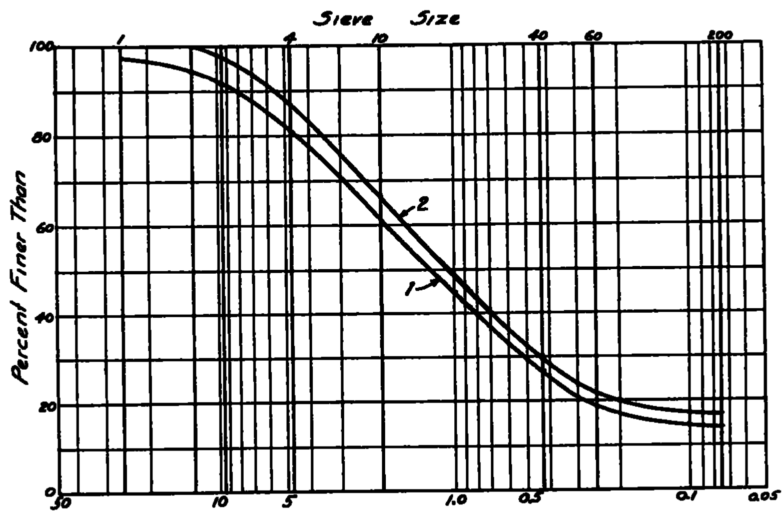

Fig. 2. Sieve Analyses of Base-Course Samples from Chemical Sections of Test Road No. 2

table, soil texture, soil cover, and climatic conditions. Permanence of both chemicals under various field conditions has also been studied, and some attention has been given to the manner of application of the compounds. The problem of base exchange has not been ignored, a limited study of the movement of calcium and sodium cations in sandy

takes place. The determination of the value of the "critical chemical content" was made for silt and for a soil mix consisting of 80 per cent concrete sand and 20 per cent sandy clay using calcium chloride and sodium

[2] Winn, H F—"Frost Action in Stabilized Soil Mixtures," *Proceedings*, Highway Research Board, Vol 18, Part I, p 264 (1938).

chloride. Also, the effectiveness of smaller amounts of the two chemicals in reducing frost heave, and chemical movement in silt under frost-heaving conditions were studied.

PROCEDURE

In general, field samples were taken by increments to a depth of 15 in. or more, the samples being weighed and dried and the percentage of moisture calculated. To determine the chemical content, the samples were leached with distilled water and the extract titrated with standard silver nitrate using potassium chromate indicator, the chloride content thus found being converted to the proper compound. Laboratory migration specimens were generally cut-up into 1-in segments and treated similarly.

In the base-exchange study, ammonium acetate was used to displace the cations from the soil. The sodium content was determined gravimetrically as sodium magnesium uranyl acetate and the calcium content determined titrametrically using standard potassium permanganate.

The frost-action tests consisted of one slow descent of the frost line through the specimen, the temperature being gradually lowered from +30 F. to −15 F. over a period of 22 days. Heave measurements were made daily and recorded to the nearest sixteenth of an inch.

RESULTS

The more important results have been summarized under headings of chemical migration, base exchange, permanence, and frost heave It is intended that they give a qualitative picture of the importance of certain variables in governing chemical movement in soil, of the effectiveness of sodium chloride and calcium chloride in reducing frost damage in soil, and of the permanence of these chemicals in the soil

Chemical Migration

Contrary to what might be anticipated, calcium chloride and sodium chloride may exhibit dissimilar movement under identical conditions For example, in unpaved, sandy clay, sodium chloride was found to deposit on the surface of the treated soil under evaporation conditions. At the same time, no calcium chloride was visible on the soil surface. Under these conditions, there is

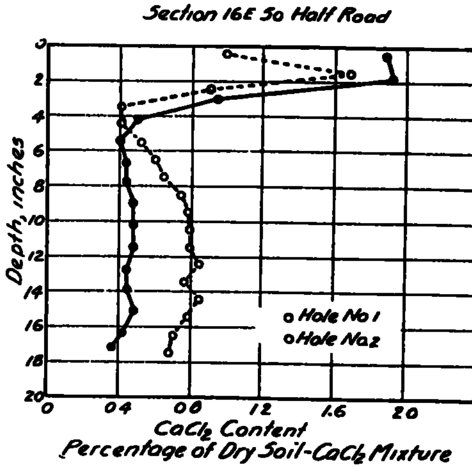

Fig. 3. Variation of Calcium Chloride Content with Depth in Test Road No. 1: Low Ground Water Table, Conditions Favorable for Evaporation. This road section originally contained 4.76 per cent calcium chloride in the 6-in. base course only. Samples taken after two years' exposure without pavement.

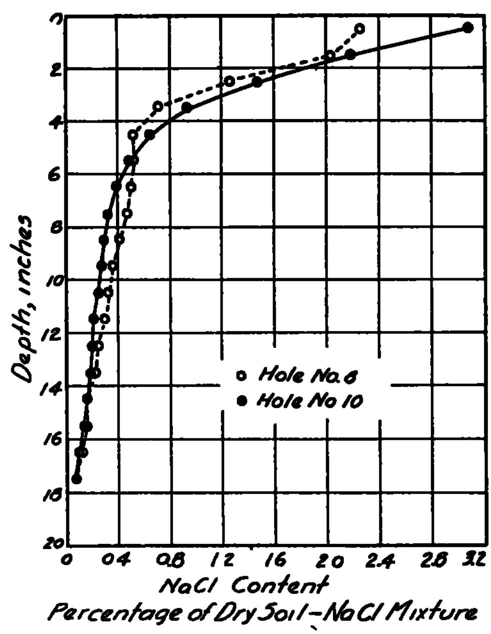

Fig. 4. Variation of Sodium Chloride Content with Depth in Test Road No. 1: Low Ground-Water Table, Conditions Favorable for Evaporation. This road section originally contained 5.52 per cent sodium chloride in the 6-in. base course only. Samples taken after two years' exposure without pavement.

greater loss of sodium chloride by lateral, surface washing than of calcium chloride. Moreover, the calcium chloride migrates downward by leaching to an appreciably greater extent than sodium chloride In the case of either salt, the chemical does not remain as placed

In unpaved, sandy clay the loss of sodium chloride to the ditches and the loss of calcium chloride by leaching become more and more pronounced with time. In fact, in a sodium chloride-treated section, after 55 months' weathering more sodium chloride was found in a given area of the shoulder (2 ft off the

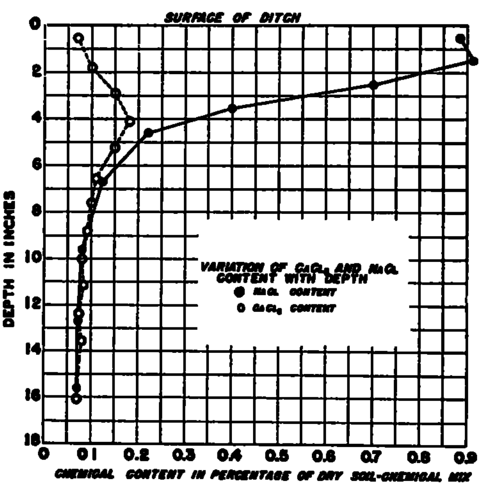

Fig. 5. Variation of Chemical Content of Ditch Samples of Test Road No. 1 with Depth. Note the greater accumulation of sodium chloride at and near the surface of the road. Samples taken at same time as those of Figs. 3 and 4.

edge of the section) than was found in an equal area of the section proper. Warm, wet, windy days favor loss of sodium chloride by lateral washing to the ditches.

An appreciable increase in the persistence of sodium chloride in fine-grained soil results from the use of a protective gravel coating several inches thick placed directly on the treated soil. The gravel does not have the requisite capillarity to cause the chemical to deposit on its surface; hence, protection from lateral washing results. Such a procedure is not applicable to calcium chloride.

A bituminous pavement increases the permanence of both sodium chloride and calcium chloride in fine-grained soils, but for different reasons. The bituminous pavement modifies the effects of other important variables, such as evaporation and percolating water By shutting off evaporation, it prevents sodium chloride from being lost at the surface, and by its impervious nature it prevents leaching of calcium chloride by percolating water.

A ground-water table which periodically becomes high enough to engulf the chemically-treated soil horizon and then recedes will rapidly leach either sodium chloride or calcium chloride, irrespective of soil cover. Calcium chloride suffers greater loss under these conditions because of its greater solu-

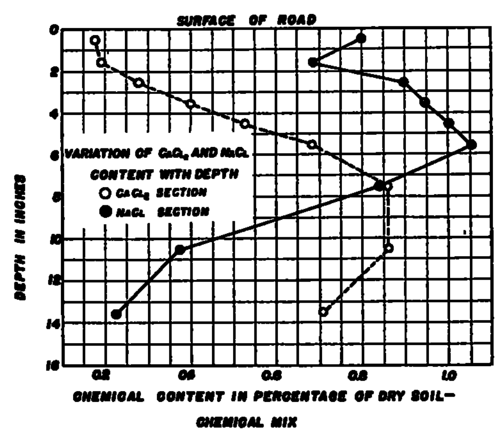

Fig. 6. Variation of Chemical Content with Depth in Test Road No. 1: Receding, High Ground-Water Table, Conditions Unfavorable for Evaporation. Samples taken after 29 months' exposure without pavement.

bility. When such conditions obtain, salt treatment is not advisable

The rapidity with which unpaved fine-grained soils recover chemical in the upper soil layers under evaporation conditions is remarkable After a wet weather period, it takes but one or two hot days to affect a distribution of chemical in which the highest percentages are at or very near the soil surface.

Because of the great susceptibility of water soluble chemicals to lateral migration when placed directly on the soil surface, it is not advisable, in stage construction procedures, to apply sodium chloride or calcium chloride directly on the road surface for stabilization

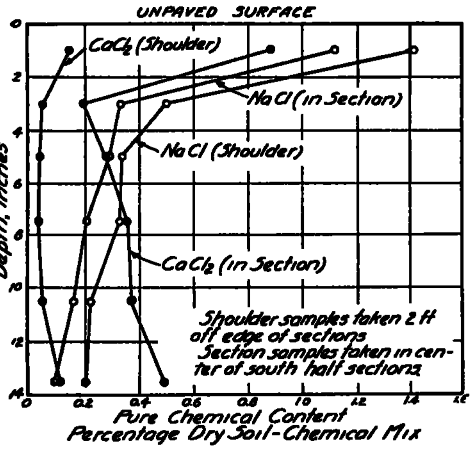

Fig. 7. Comparison of Permanence of Salts in Test Road No. 1 After 55 Months' Exposure Without Pavement. Note that there is more sodium chloride in shoulder than in section.

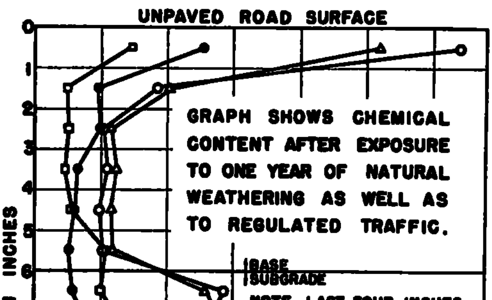

Fig. 8. Variation of Chemical Content with Depth in Test Road No. 2: Low Ground-Water Table, Conditions Favorable for Evaporation. The sodium chloride section originally contained 0.5 per cent chemical (97.6 per cent pure) throughout the 6-in. base course. The calcium chloride section originally contained 0.5 per cent chemical (84.1 per cent pure) in the top 2-in. of the base course; later the surface of this section was treated with a quantity of calcium chloride equal to the initial application. Base-course is coarse-textured soil: subgrade is fine-textured soil.

purposes. They are preferably mixed in with the soil to be stabilized. If one is merely attempting to lay the dust, then surface application of calcium chloride is satisfactory

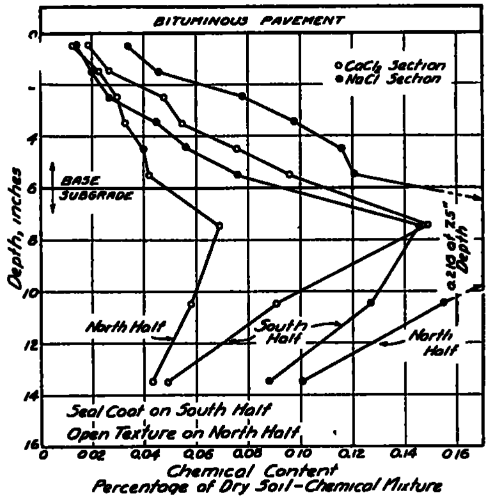

Fig. 9. Effect of a Bituminous Pavement on the Vertical Movement of Chemicals in Test Road No. 2. Pavement down 7 months, after 14 months' exposure without pavement.

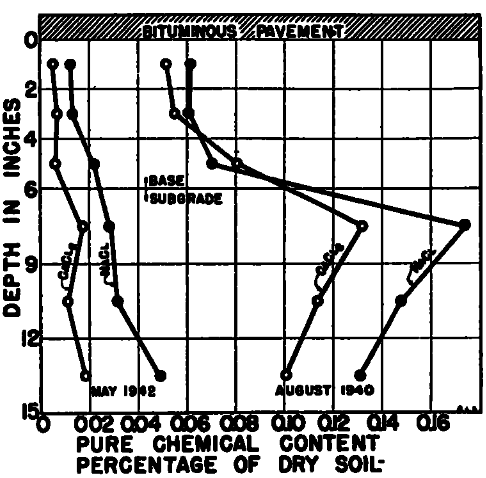

Fig. 10. Loss of Chemicals Under a Bituminous Pavement, Test Road No. 2. There is an appreciable loss of both chemicals in the time interval from August, 1940, to May, 1942.

Base courses consisting essentially of granular materials (sand and gravel) do not retain chemicals sufficiently well to justify salt treatment. The chemical is readily leached from such soils, and they do not possess the necessary capillarity to regain the chemical by capillary action. Even if a bituminous pavement exists, loss to an underlying fine-grained subgrade is excessive.

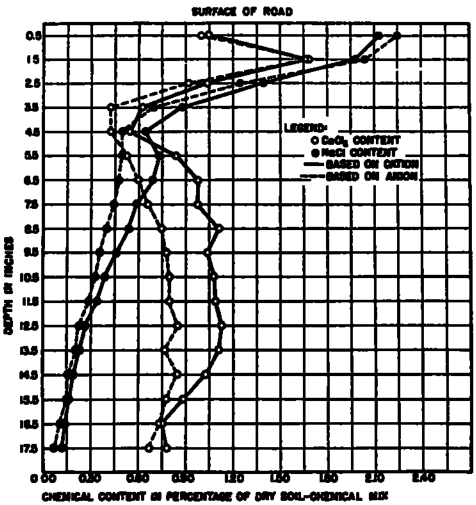

Fig. 11. Comparison of Chemical Contents on an Anion and on a Cation Basis, Test Road No. 1.

the bituminous pavement and of the fact that coarse-grained soil overlies fine-grained soil. Either condition by itself does not lead to the distribution described.

It was found that, by using laboratory specimens, it was possible to obtain results on chemical movement in soil comparable to those obtained in the field under similar conditions By schematically arranging these specimens, it was possible to demonstrate that evaporation, soil texture, percolating water, and soil cover are important variables governing chemical movement in soil and that temperature is not a particularly important variable unless it is high enough or low enough to affect a change of phase of the water.

Base Exchange

The phenomenon of base exchange is important in tracing chemical movement in soils with high clay content. The colloidal fraction of the clay consists of negatively charged particles which have the faculty of exchanging ions (particularly cations) on their surfaces. This fact results in a differential in the movement of the cations as against the movement of the anions of water-

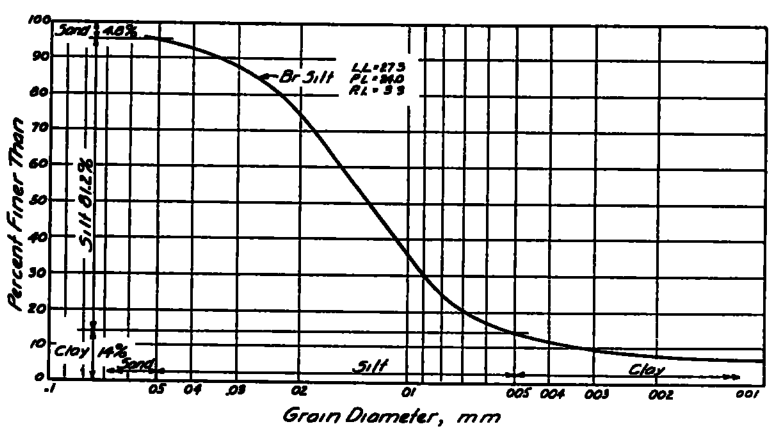

Fig. 12. Grain Diameter Distribution Curve for Laporte Silt. This silt was the one used for the laboratory migration and frost-heave studies

If a bituminous pavement covers a coarse-textured base course overlying a fine-grained subgrade, the chemical distribution to be expected is one in which the chemical content increases continuously from the top of the base course down to the upper layers of the subgrade and then decreases. Such a distribution is a consequence of the presence of soluble chemicals and should not be ignored in considerations of chemical movement in fine-grained soils.

Calcium and sodium cations were found to be more persistent in sandy clay than the chloride anion. Also, the divalent calcium cation was more persistent than the monovalent sodium cation. Ca-clay is known to be more permeable than Na-clay, a fact which helps account for the greater leaching of chemical in the calcium chloride sections as opposed to that in the sodium chloride sections.

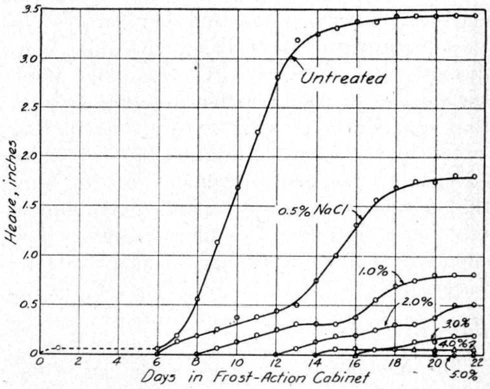

Fig. 13. Rate of Heaving Curves for Untreated Silt and for Silt Treated with Sodium Chloride

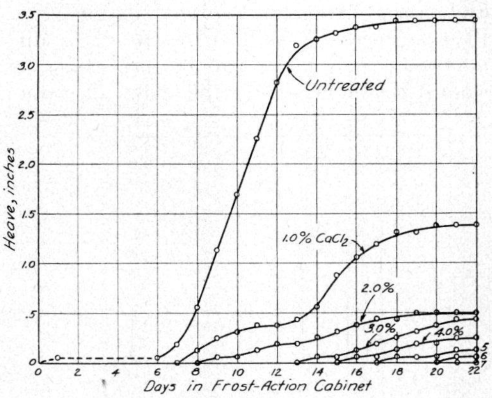

Fig. 14. Rate of Heaving Curves for Untreated Silt and for Silt Treated with Calcium Chloride

Permanence

Since the conditions of weather and ground-water obtaining during the period immediately preceding sampling play a part in determining permanence values, this summary of the permanence of calcium chloride and sodium chloride in the Project's test roads is intended merely to give one a rough idea of the persistence of the chemicals after a lengthy weathering period.

In unpaved sandy clay (Test Road No. 1), after 55 months' weathering, the cumulative chemical contents[3] to a depth of 15 in. were 15.3 per cent sodium chloride and 23.0 per cent calcium chloride in the section and 20.6 per cent sodium chloride and 4.1 per cent calcium chloride in the shoulder, 2 ft. off the edge of the section.

Cumulative chemical contents to a depth of 15 in. in Test Road No. 2, consisting of a coarse-textured base and a fine-textured sub-

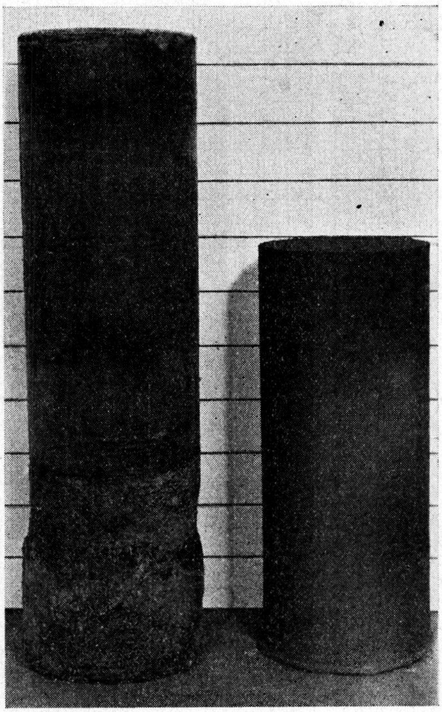

Fig. 15. Comparison of Untreated and Chemically-Treated Silt at the End of the Freezing Test. Note the thickness and spacing of the ice layers in the untreated specimen.

grade, were 13.2 per cent sodium chloride and 9.6 per cent calcium chloride after 46 months' weathering. (A bituminous pavement was constructed after 14 months' exposure without pavement. Also, the two chemicals were not applied in the same man-

[3] Cumulative chemical contents are expressed as a percentage of the amount of chemical originally placed in the section proper. No chemical was placed in the shoulders or the ditches.

ner) Relatively little lateral movement took place on this test road Lateral movement was investigated after 25 months' weathering and the cumulative chemical contents to a depth of 14 in. found to be 4.1 per cent sodium chloride and 6 2 per cent calcium chloride in the shoulder, 1 ft. off the edge of the section.

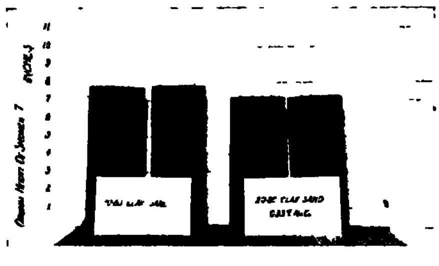

Fig. 16. Effectiveness of 0.33 Per cent of Sodium Chloride in Reducing Front Heave in a Sand-Clay (80–20) Soil Mix. Note the duplication of results by the use of check samples.

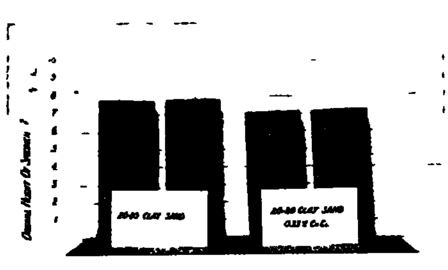

Fig. 17. Effectiveness of 0.33 Per cent of Calcum Chloride in Reducing Frost Heave in a Sand-Clay (80–20) Soil Mix. Note the duplication of results by the use of check samples.

Frost Heave

The results indicate that frost heave can be completely eliminated in any soil if sufficient water-soluble chemical is used as an admixture The amount of sodium chloride or calcium chloride necessary to accomplish this in the case of coarse-textured soils, under conditions optimum for the promotion of heaving, is only 2 or 3 per cent In the case of fine-textured soils which display excessive heaving in the untreated state, 5 to 7 per cent of chemical is necessary. It is frequently enough to greatly reduce heaving, rather than eliminate it entirely, and for this purpose only 2 or 3 per cent of either chemical is necessary, even when the untreated soil heaves seriously

CONCLUSIONS

The more important conclusions have been listed under the headings of chemical migration, permanence, frost heave, and general. These conclusions apply only to the soils, chemicals, and conditions of test used.

Chemical Migration

1. Under the influence of soil capillarity and natural evaporation, sodium chloride tends to crystallize and form a white coating on the surface of the unpaved road, and, hence, is more susceptible to lateral, surface washing than calcium chloride. Calcium chloride does not tend to accumulate on the unpaved road surface to the extent that sodium chloride does, under the influence of soil capillarity and natural evaporation, because of its greater moisture-attracting power and its higher solubility.

2. With exposed fine-grained soils, lateral movement proceeds primarily by surface washing from the top of the road proper to the side ditches, rather than by lateral movement below the surface.

3 A receding, high ground-water table accelerates the downward movement of both chemicals, calcium chloride being more affected than sodium chloride

4 Important variables affecting the movement of water-soluble chemicals in soil include evaporation, soil texture, percolating water, soil cover, and temperature, when high enough or low enough to effect a change of phase of the water.

Permanence

5 Both a bituminous surface treatment and a protective gravel coating on the road surface tend to conserve sodium chloride in the road by inhibiting lateral, surface washing

6 Calcium chloride is somewhat more permanent than sodium chloride in exposed, sandy clay soil.

7. In fine-grained soils, cations tend to be more permanent than anions because soil colloids have a greater attraction for cations. Soil colloids are negatively charged.

8 In sandy clay, the calcium cation is more permanent than the sodium cation which, in turn, is more permanent than the chloride

anion when the permanence of the ions is measured under comparable conditions.

Frost Heave

9. Chemical treatment to reduce or eliminate frost heave is preferably applied to fine-grained subgrade soils (silts and silty clays) rather than to comparatively coarse soils (fine gravels and sands), since rapid loss of chemical by leaching results in the latter case.

10. In general, increased effectiveness in reducing heaving in soil results from increases in the amount of chemical added—up to a certain percentage of chemical above which no heaving takes place.

11. Amounts of admixtures as small as one or two per cent of either sodium chloride or calcium chloride (technical products) are effective in reducing heaving in silt when subjected to temperatures as low as −15 F. On a pure-chemical basis, 5 per cent of either sodium chloride or calcium chloride will eliminate heaving under these conditions.

12. Small percentages (0.33 per cent of the technical products) of either sodium chloride or calcium chloride are effective in reducing frost heave in a soil mix consisting of 80 per cent concrete sand and 20 per cent sandy clay, at temperatures as low as −14 F. Not more than 2 per cent of either chemical is required to eliminate heaving under these conditions, the chemicals being about equally effective (gram for gram) in reducing frost heave in this soil.

General

13. From the standpoint of reducing the loss of chemical by surface washing, water-soluble chemicals, such as sodium chloride, calcium chloride, and calcium magnesium chloride, should preferably be mixed with the soil rather than be applied on the surface of the road, particularly in stabilization operations where stage construction methods are employed.

14. Under identical conditions, the fine-textured soils are more capable of holding and replacing their chemical content by capillarity than the coarse-textured soils.

15 The conditions of weather and ground-water table obtaining during the period immediately preceding sampling have considerable influence on the existing distribution and concentration of water-soluble chemicals.

The author gratefully expresses thanks to all members of the Joint Highway Research Project for their co-operation and particularly to Professor K B Woods, Assistant Director of the Joint Highway Research Project, for his activity in promoting this study and for his enthusiastic interest in it

DISCUSSION ON MOVEMENT OF CALCIUM AND SODIUM CHLORIDES IN SOIL

Mr. H. G. Nevitt, *Socony-Vacuum Oil Co.:* Is the loss in chemical progressive with time in more or less direct proportion, or is it progressive with the amount of chemical?

Dr. Slesser. With respect to the progressive loss of chemical with time, we have found that the particular distribution at any given time depends somewhat on the weather and ground water conditions existing during the period immediately preceding sampling. In other words, we have found that after a lapse of three months we might find a greater amount of chemical in the top 15 in. than we had in the previous sample, because the ground water and the weather conditions were more suitable for retaining the chemical. In the long run, however, the chemicals are lost progressively with time.

Mr Nevitt In direct proportion to time?

Dr. Slesser I do not think we have enough data to evaluate it that far