5. In general, admixtures which minimize the amount of moisture in the stabilized mix seem to provide the most satisfactory bases.
6. In constructing stabilized roads using bituminous admixtures the moisture content should be kept as low as possible to maintain good mixing and compacting conditions.
7. The amount of admixture required depends largely upon the gradation of the material to be stabilized; increasing amounts of fine material require more admixture.
8. In stage construction, stabilized bases should receive a light seal coat as a temporary protective covering. In soil-cement mixtures and mixtures containing bituminous admixtures low in cohesion, this seal coat should be applied as soon as possible.

MIGRATION OF CALCIUM AND SODIUM CHLORIDES IN SOIL

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The study of chemical migration in soil, as far as the Joint Highway Research Project was concerned, resulted from three conditions. First, the Staff had become interested in investigating the permanence in soil of calcium and sodium chlorides, since road treatments with these chemicals are periodically repeated. If such roads must be retreated once or twice a year, what becomes of the salts? Second, the Project had already constructed two test roads, both of which included sections stabilized with calcium and sodium chlorides and from which samples could be readily obtained. Third, the Project's work on frost action in chemically stabilized bases and subgrades had revealed that two or three per cent of either calcium chloride or sodium chloride could practically eliminate frost heaving in certain soils at temperatures as low as -15° F.

Naturally, the Directors and Advisory Board of the Project became interested in investigating the permanence and distribution in soil of such water-soluble, inorganic salts as calcium chloride and sodium chloride. In recent years, the trend in the use of these low-cost compounds has been directed toward their utilization in highway bases as a stabilizing chemical and in highway subgrades as a means of preventing frost damage.

The following discussion will be limited to chemical movement in the Joint Highway Research Project's Test Road No. 1. This test road was constructed in the fall of 1937 to study the effect of weathering, without traffic, on subgrade and stabilized soil. One of its stabilized sections contained 6 per cent of commercial (rock) sodium chloride, and one contained 6 per cent of commercial (flake) calcium chloride, the percentages being based on the dry soil weight. The chemicals were homogeneously mixed with the soil and were included only in the six-inch base course. The soil texture for both the base course and the subgrade was sandy clay. No surface was placed on the base. The idea was to let the weather act directly on the base materials.

Low Ground Water Table

After the unpaved test road had been exposed to weathering for two years, the chemical sections and the adjacent ditch were sampled. The ground water table was low at that time, being about six feet below the centerline elevation of the road.

Calcium Chloride. Fig. 1 shows the results of titrametric chloride analyses of samples from the calcium chloride section. Relatively high concentrations of calcium chloride prevail near the surface; in addition, the percentages in this region fluctu-

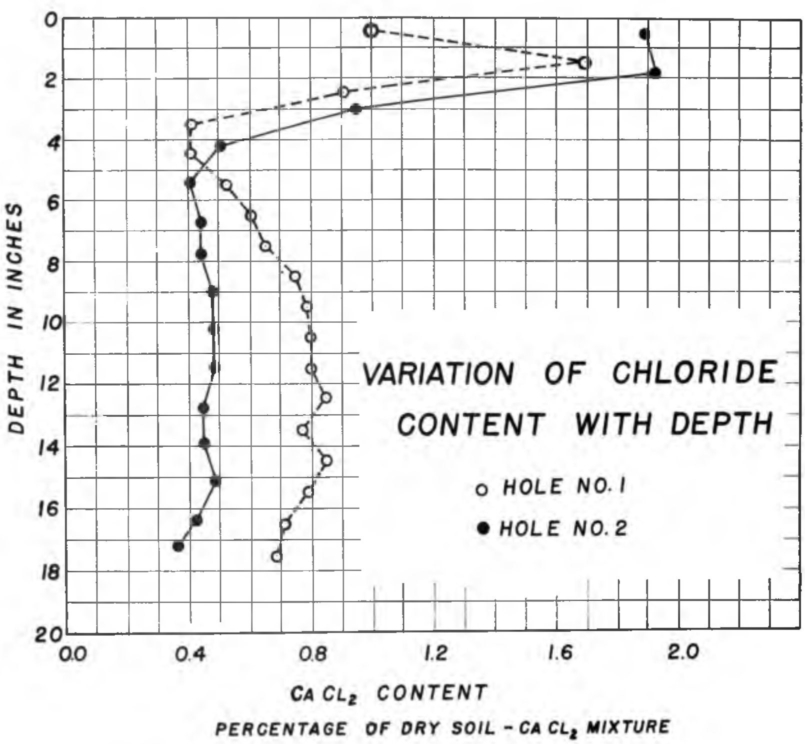

Fig. 1. Data on calcium-chloride penetration secured on J.H.R.P. Test Road No. 1 under low ground-water condition.

ate considerably. At a depth of approximately five inches the curves tend to level off to more or less constant values which are appreciably lower than those near the surface. Finally, at depths of 15 to 17½ inches the percentages are definitely decreasing and presumably would diminish continuously until no chemical was present.

Sodium Chloride. Fig. 2 shows the results of chloride analyses of samples from the sodium chloride section. The sodium chloride content continually decreases with increasing

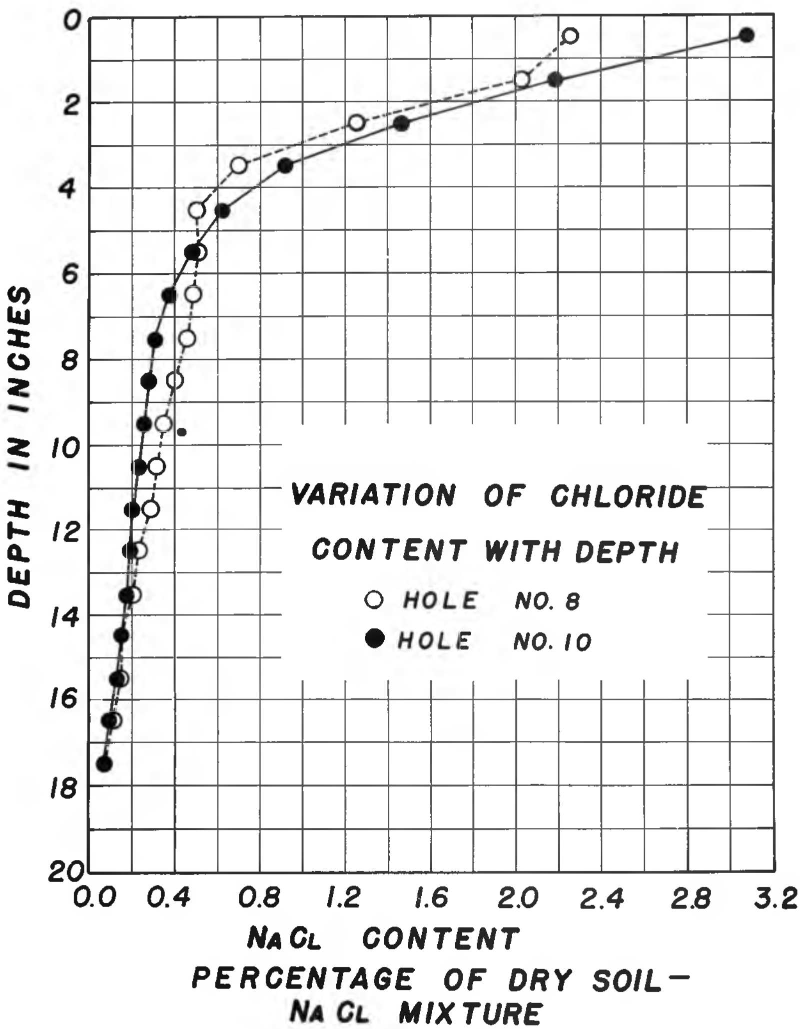

Fig. 2. Data on sodium-chloride penetration secured on J.H.R.P. Test Road No. 1 under low ground-water condition.

depth, the salt content being practically exhausted at 17½ inches. The curves are steep to a depth of 4½ inches but tend to level off thereafter.

Ditch Samples: Calcium Chloride and Sodium Chloride. Fig. 3 shows the results of chemical analyses of samples taken from the ditch alongside the calcium chloride and sodium chloride sections of Test Road No. 1. The solid line represents the movement of NaCl and the dotted line that of $CaCl_2$. In this figure it is apparent that the sodium chloride concentrations are more than nine times as great as the calcium chloride concentrations near the surface of the ditch and that the concentrations of both compounds are about equal at depths greater than eight inches.

High Ground Water Table

The chemical sections of Test Road No. 1 were resampled on March 21, 1940. The ground water table had reached its

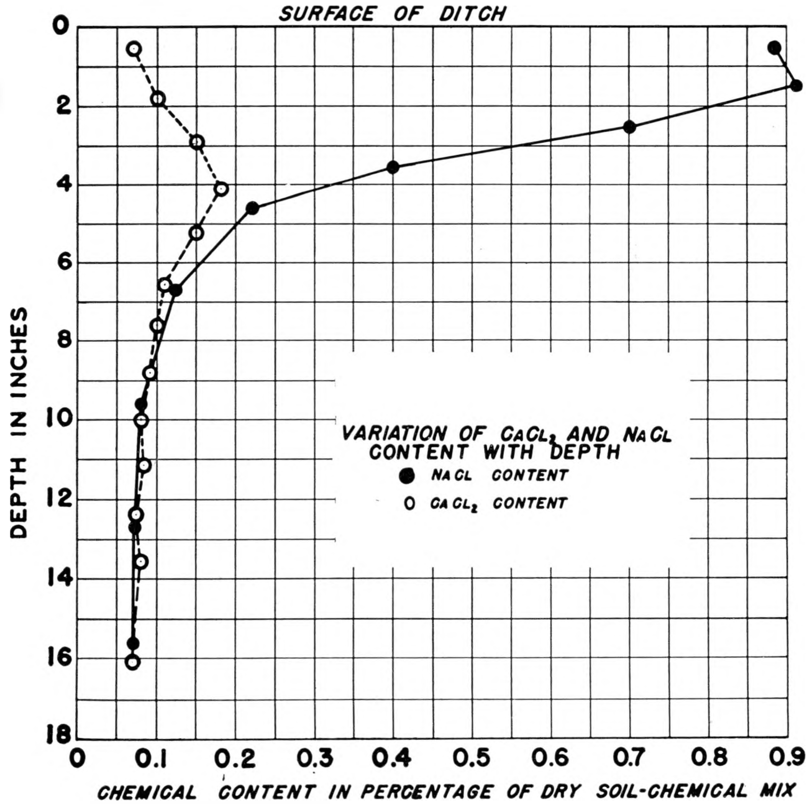

Fig. 3. Penetration of chlorides as determined from ditch samples adjacent to J.H.R.P. Test Road No. 1 under condition of low ground-water table.

peak on March 5 at a height of 15 inches below the centerline elevation of the road. At the time of sampling it had receded to a level which was 3.75 feet below the centerline elevation.

Fig. 4 reveals that the migratory characteristics of both calcium chloride (dotted line) and sodium chloride (solid line) under the influence of a high water table are distinctly different from those observed when the water table is low.

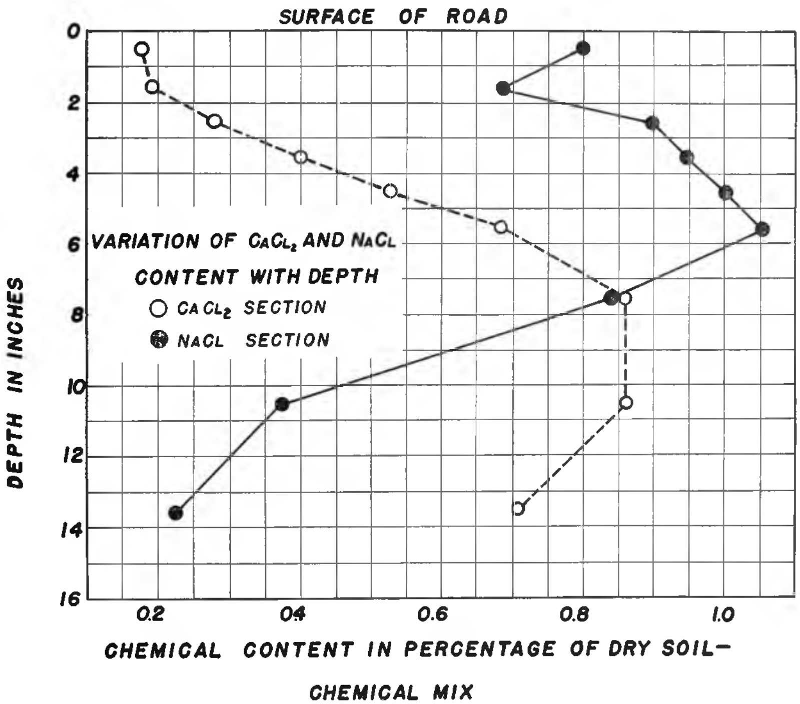

Fig. 4. Penetration of chlorides on J.H.R.P. Test Road No. 1 under condition of high ground-water table.

Calcium Chloride Movement. With a low water table the percentages of chemical were highest near the road surface; in addition, percentages in this region showed the greatest fluctuations. With a high water table the calcium chloride percentages were smallest at the surface (considering only the top 15 inches) and steadily increased to a depth of 10.5 inches before the values started to drop.

Sodium Chloride Movement. With a low water table the percentages of sodium chloride were highest at the surface and steadily decreased with increasing depth. With a high water table the sodium chloride percentages no longer decrease with increasing depth. They tend to increase to a depth of 5.5 inches and then drop off rather rapidly.

Conclusions from Figs. 1, 2, and 3. Some of the conclusions reached as a result of the study of chemical movement in the sandy clay of unpaved Test Road No. 1 under the influence of a low ground water table were as follows:

1. When the two compounds, calcium chloride and sodium chloride, are applied to the road in the same amount and manner and exposed to the weather, sodium chloride travels to the surface more than calcium chloride and leaches down into the subgrade less than does calcium chloride.
2. Sodium chloride tends to crystallize and form a white coating on the surface of the road and hence is more susceptible than calcium chloride to being washed by rain to the shoulders and ditches.
3. Because of its moisture-attraction power and its high solubility, calcium chloride does not tend to accumulate on the road surface to the extent that sodium chloride does.
4. With fine-grained materials, lateral migration proceeds primarily by surface washing from the top of the road proper to the side ditches, rather than by lateral movement at horizons below the surface.
5. In stabilization operations, both chemicals should be incorporated in the mix rather than applied on the surface.

Conclusions from Fig. 4. Conclusions reached as a result of the study of chemical movement under the influence of a high water table include the following:

1. A high ground water table accelerates the downward movement of both chemicals; calcium chloride is more affected than sodium chloride.
2. A receding high ground water table tends to counteract the powerful, natural forces of evaporation which build up high chloride concentrations on the road surface.

Permanence of the Chemicals

Expressed as a percentage of the amount of chemical originally placed in the test road, the cumulative calcium chloride content to a depth of 15 inches was about 40 per cent in the case of a low water table and about 33 per cent in the case of a high water table.* The corresponding values for sodium chloride were 32 and 29 per cent, respectively.*

Other Studies

Other studies, directly related to this one and either completed or in progress, include the following:

* These values are not to be compared directly because the samples were exposed to weathering for different periods of time.

1. Investigation of the permanence and movement of calcium and sodium chlorides in the Joint Highway Research Project's Test Road No. 2. (In this case the base course consisted of a graded mix containing 88.5 per cent pit-run gravel and 11.5 per cent sandy clay in the six-inch base course, and the study included a comparison of chemical movement in the unpaved road with that under a bituminous surface.)

2. Investigation of the permanence and movement of these chemicals in sections of Indiana State Roads 62 and 161.

3. A study of cation movements in highway bases and sub-grades.

4. A laboratory study of chemical migration.

5. A study of the effect of small additions of either calcium or sodium chlorides on frost action in fine-grained soils. (The amounts of chemical added vary from 0.33 per cent to 2.00 per cent in the present study.)

DRAINAGE OF HIGHWAY SUBGRADES

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Land drainage, like many other branches of engineering, can be traced to remote antiquity. The use of simple ditches as a part of agricultural development is reported as far back as 400 B. C., when the Egyptians employed such methods along the Nile Valley. Later reports show that the Romans used a type of closed conduit three feet deep and filled to half its depth with pebbles, stones, and brush. The remainder of the drain was back-filled with the excavated soil.

During the seventeenth century the population of Europe had increased to the point where additional arable land and more intense cultivation of existing farms became an economic necessity. As a result of this necessity, land drainage was begun on a large scale. The practices developed during this period contributed greatly to the present knowledge concerning this subject.

The first tile drain in the United States was laid on the farm of John Johnston of Geneva, New York, in 1835. Since this time, agricultural development has employed the use of drains extensively to increase the productivity of the soil and to reclaim swamp lands. The United States Census Bureau (1929-1930) reports that 44,523,685 acres of farm land have been provided with drainage facilities.

The necessity for adequate drainage systems in the construction of highways has been recognized by engineers since the earliest days of road building. The familiar saying, "The