DEPARTMENT OF SOILS

C. A. HOGENTOGLER, *Chairman*

REPORT OF COMMITTEE ON FROST HEAVE AND FROST ACTION IN SOIL

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SYNOPSIS

The present Project Committee on Frost Heave and Frost Action in Soil was constituted in June, 1947. Its scope is intended to cover all phases of frost action in soils. It is an outgrowth of a committee on "Freeze-proofing Treatment of Soils and Calcium Chloride" which was originally organized in the fall of 1943 to study the use of calcium chloride in preventing detrimental frost heave in subgrades. The original committee on freezeproofing treatment of soils with calcium chloride is being continued as a subcommittee under the new project committee.

This report is a summary of the findings of the original committee. The scope of the original committee was twofold, namely; (1) to study the use of calcium chloride as an admixture with soils for minimizing frost heave; and (2) the use of calcium chloride mixed with subgrade soils to minimize frost action and the resulting frost damage to pavements.

There has been much laboratory work performed in this field during the past several years and the available data indicate strongly that calcium chloride mixed with soil will minimize or eliminate frost heave when the calcium chloride is used in sufficient quantities and when the chemicals are not leached from the soil under conditions of adverse water flow.

Field installations of calcium chloride mixed or added to subgrade soils have been made on projects in Minnesota, Indiana, Michigan, and Massachusetts in areas where severe frost heave or frost damage has been noted. The results of these field experiments have been erratic. In several of the installations no apparent benefit resulted from use of the chemical to minimize the frost heave. The data collected by the committee indicate that in some of these cases, adverse water conditions may have been responsible, in part, for the frost heave; likewise, these adverse water conditions may have been largely responsible for leaching the soluble chemical from the treated subgrade.

As a result of these largely negative results, the committee feels that it is not worthwhile to continue the field experiments to eliminate differential frost heave; however, a program is being developed to determine the effectiveness of the use of calcium chloride in subgrades and base courses for the purpose of minimizing the amount of break-up which occurs on some roads during the spring of the year because of saturation of the subgrade during the melting period.

The Sub-Committee on Freezeproofing Treatment of Soil with Calcium Chloride was appointed in the fall of 1943 for the purpose of evaluating the practicability of treating subgrades with calcium chloride to eliminate frost heave, frost action, and frost damage. The committee has had five meetings since it was appointed and a number of field installations have been made in Minnesota, Michigan, Indiana, and Massachusetts. Most of the field installations to date have been made for the purpose of treating subgrades which heave periodically. Most of the highway projects were surfaced with portland cement concrete. The method of treatment, in most cases, consisted of drilling holes through the pavement, removing soil from beneath the holes, and filling the spaces with calcium chloride or with calcium chloride brine. Wherever possible similar sections were left untreated so that a comparison could be made between treated and untreated sections.

MINNESOTA, J. H. Swanberg
T. H. No. 12 - 2.8 Miles East of Willmar

In a shallow cut a series of sharp heaves occurred annually within a length of about 400 feet. The vertical movement amounted to about 0.5 foot in the most severe heave. A section, 160 feet in length, was treated in August, 1944. Holes spaced 3 feet apart were dug from each edge of the slab with 6-inch post hole augers. These holes extended beneath the slab to within one foot of the center of the pavement and were inclined slightly downward toward the center of slab, the bottom of the holes being from one to one and one-half feet below the bottom of slab. Commercial calcium chloride was then placed in each hole at the rate of about 80 lb. per hole, using a pipe and a rammer to force the calcium chloride into the holes. Some water was poured in to dissolve the chloride. A total of 8500 lb. of calcium chloride was used, which was equivalent to slightly less than 27 lb. per sq. yd. of surface. Soils in the subgrade varied, but silt loam pockets in medium to fine sand apparently were the cause of the more severe heaving conditions. Ground water level was more than 6 feet below the bottom of the slab.

A frost proof bench mark was placed and profile levels were taken on center line and 6 feet right and left of center line in August, 1944; January 19, 1945; March 7, 1945; January 16, 1946; March 18, 1946; and on February 12, 1947.

These winter profiles indicate very little, if any, decrease in the amount of heaving within the treated section.

T. H. No. 61 - 3.2 Miles South of Rush City

A series of six sharp heaves occurred every year in a cut 400 feet in length. The soils in this area consist of a sand mantle of variable depth overlying fine sandy loam and clay loam tills. The grade line cuts through the sand mantle in this cut, and at the crest of each heave, the plastic soils are found directly beneath the pavement. At the low points between the crests of the heaves, medium to fine sand is found for some depth below the pavement slab. A 200 foot section of treatment was placed to include the most severe heaves which had a maximum vertical rise of about 0.4 feet.

Holes were drilled vertically through the slab using pneumatic drills, with a 2-5/8 inch star bit. The holes were drilled on 3-foot centers starting 1-1/2 feet from the edge of the 18-foot slab. Below the slab the holes were en-

larged with soil augers and air jets so that a hole from 6 inches to 8 inches in diameter and from 12 inches to 18 inches below the bottom of slab was formed. A total 9000 pounds of commercial calcium chloride was placed in these holes, an average of about 22.5 lb. per sq. yd. Water was poured in to dissolve the chloride after which the holes were filled with sand. This treatment was completed in September, 1944.

Profile levels were taken over this treatment on October 4, 1944, January 25, 1945 and March 12, 1945. These levels indicated no reduction in heaving in the treated section.

In October, 1945, additional chloride was placed in a 15 foot section of this treatment at the crest of the most severe heave. On the left half of the slab, 400 pounds of chloride was added and on the right half of the slab 1200 pounds of chloride was added. In this treatment the chloride was first dissolved, and the solution poured into the holes over a period of two weeks.

Profile levels were taken over this treatment on January 17, 1946, and on March 14, 1946. These levels showed a reduction in heave over the 15 foot section having the retreatment of from 1 to 1-1/2 inches, but a heave of from 2 to 3 inches still existed.

The cost of the original treatment on this section was $1.35 per square yard.

CONCLUSIONS

From the data obtained, it appeared that these treatments were ineffective. Prints showing the details of these treatments and profiles have been previously submitted to the committee.

INDIANA, R. E. Frost

Route U. S. No. 30, in northern Indiana, has several sections of dual lane pavement which were constructed in 1936 and 1937, in which it was necessary to make some deep cuts. Some severe frost heaves developed in several of these deep cuts on sect ons of this road in Porter County just south of Valparaiso. In the fall of 1944 one of these heaves was treated with calcium chloride to see whether or not the heave could be minimized.

The section of the pavement, which was treated, was in the north lane between Stations 1157 / 98 and 1158 / 38. The heave area in the south lane was left untreated so that the use of calcium chloride in the north lane could be evaluated. A total of 1800 pounds of calcium chloride was applied to the subgrade of this cut section through holes drilled into the concrete pavement and in a trench along the south edge of the pavement. Flake calcium chloride was used to fill each hole which had been drilled through the portland cement concrete pavement and then water was poured into the hole to dissolve the chemical. The procedure was repeated until the desired quantity of calcium chloride had been applied.

Soil samples were taken from several of the holes drilled through the portland cement concrete pavement at 12, 24, and 30-inch depths. In addition, six three-inch galvanized iron downspout pipes were installed for making ground-water observations.

In the early spring of 1945 detailed surveys were made on the treated and untreated sections of this road. It was found that the heave which had been treated was raised a maximum of 0.18 feet as compared with a maximum of 0.68 feet in other adjacent, untreated sections of the north lane. The maximum heave in the south lane in a comparable situation to the frost heave of the north lane was 0.20 feet. From this it was concluded that the salt had not stopped the

heave, but that it may have minimized the total amount somewhat. However, the ground-water records indicate that there is a transverse flow of water through this cut which probably leached the chemical from the soil.

MASSACHUSETTS, J. E. Lawrence

In the spring and fall of 1944 several projects in Massachusetts were treated experimentally with calcium chloride to determine the effectiveness of the chemical in reducing frost heave. One of these roads was on Auto Route 127 in District No. 5, Town of Beverly, The road was a bituminous macadam and the treatment was between Station 1100 and 1100/20. Calcium chloride was applied to 2 1/2-inch diameter holes treated to a depth of two feet. A total of nine pounds per square yard was applied in this fashion. In the fall of 1944 additional chemicals totaling 18.7 pounds per square yard were applied to this experimental section. Observations made in the spring of 1945 indicated that the treatments were somewhat effective in minimizing frost heave. During the winter of 1945-1946 the frost heaving was reduced to a maximum of 2 inches with slight break up in the macadam surface.

In District 4, Town of Harvard, Auto Route 111, some experiments were initiated in the spring of 1944 between Station 6900 / 45. The pavement was a sand and gravel tar surface. The calcium chloride was applied in flake form through 2 1/2-inch diameter holes, two feet on center, to a depth of eighteen inches below the surface of the road. The south half of a road only was treated with a total of four pounds per square yard of calcium chloride. In October, 1944, eighteen additional pounds per square yard was applied to this section. In the spring of 1945 observations were made and it was concluded that the calcium chloride had been effective in minimizing the amount of heave. During the winter of 1945-1946, the frost heaving was greatly reduced, but the road surface was so badly damaged and broken up that it was necessary to rebuild the surface.

In District No. 5, Town of North Andover, Auto Route 114, a severe heave was treated at Station 16200 / 30. Chemicals were applied in 1942, 1943, and 1944. It is known that the road heaved at this location to as much as ten inches each year. Following the years of application of chemical, the heave was entirely eliminated. During the winter of 1945-1946 no noticeable heaving was observed and no cracking of the concrete surface resulted. This road is now being reconstructed. A summary of the experiments show that while there was a reduction in the heaving due to the use of calcium chloride there was surface damage resulting from the chloride treatment.

MICHIGAN, A. E. Matthews

In order to determine the effectiveness of treating subgrade soils with calcium chloride for the prevention of detrimental frost action, four locations were selected in Michigan. Following is a brief description of the work at these locations:

Stanwood Location
US-31, Mecosta County, Approximately 500 Feet North of the Village of Stanwood

This heave occurred in concrete pavement. It is 50 feet in length. The maximum amount of heave is 3 inches. The entire heave was treated in September, 1944. Holes (2-5/8" diameter) were drilled through the pavement on 3-foot centers. A combination of air jet

and auger was used to enlarge the holes in the subgrade to 6 inches in diameter and to 12 inches in depth. Thirteen pounds of calcium chloride in solution form was added to each hole. After the solution had soaked away the holes were filled with gravel and covered with cold patch material. Soil profiles were determined by auger borings along the outside edges of the slab (10' R. & L. of C/L). The subgrade soil is variable but the heave was caused mainly by very fine sand and silt with some clay.

A frost proof bench mark was established. Profile levels were taken along the outside edge of the slabs on March 14, 1944, November 1, 1944, January 23, 1945, and February 26, 1945.

The treatment was ineffective in reducing the amount of heaving.

Gladwin Location
M-61, Gladwin County, Approximately 1-1/2 Miles West of the Village of Gladwin

This heave is in a bituminous surface treated gravel road. It is only 10 feet in length. The maximum amount of heave is 1-1/4 inches. The heave was treated in September, 1944. Holes on 3 foot centers were dug through the road surface. These were extended with a 6 inch post hole auger to a depth of 12 inches below the gravel. Thirteen pounds of calcium chloride in solution form was added to each hole. After the solution had soaked away the holes were filled with gravel and capped with cold patch material.

Profiles of the subgrade soil were determined by auger borings 12' R. & 12' L. of C/L. The heave was caused by a small pocket of very fine sand and silt with some clay.

Profile levels (Fig. 1) were taken at center and along each edge of the surface on March 14, 1944, September 1, 1944, January 19, 1945, and March 6, 1945.

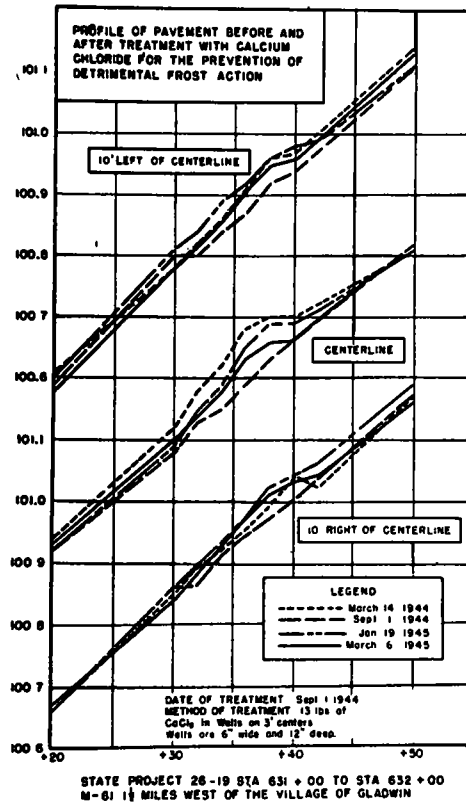

Figure 1. Profile Plot of a Pavement Before and After Treatment with Calcium Chloride.

The treatment was ineffective in reducing the amount of heaving.

Saginaw West Location
M-47, Saginaw County, Approximately 1/4 Mile South of Junction with US-10

This slight heave is in a concrete pavement. It extends beyond the limits of our 27-foot treatment. The old pavement was removed in August, 1944, on a patching contract. The right half of the subgrade at this time was treated as follows: Holes 6 inches in diameter and 12 inches in depth were dug in the subgrade on 3-foot centers. Thirteen pounds of calcium chloride

(flake form) was added to each hole.

The soil profile 10' R. of ℄ was determined by auger borings along the edge of the slab. The subgrade soil is variable but the heave was caused mainly by very fine sand and silt.

Profile levels were taken at center and 9' R. & L. of center on November 21, 1944, January 19, 1945, and March 6, 1945.

A comparison was made between the treated section and the adjacent untreated section. The treatment was ineffective in reducing the amount of heaving.

Brighton North Location
US-23, 3.8 miles North of Junction with US-16 Near Brighton, Livingston County

This heave occurs in a concrete pavement. It is approximately 35 feet in length. The maximum amount of heave is 2.5 inches. The east half of this heave was treated in September, 1945. Holes (6" diameter) were drilled through the pavement on 3 foot centers. Holes in the subgrade were enlarged to 8 inches in diameter and 12 to 15 inches in depth. Twenty-five pounds of calcium chloride (solution form) were added to each on September 13, October 3, and November 1, 1945. The holes were then filled with gravel and covered with cold patch material.

Profiles of the subgrade soil were determined by auger borings along each edge of the slab (10' R. & L. of ℄). The soil is variable but the heave is caused mainly by very fine sand and silt.

Profiles levels were taken 5' R. & L. of ℄ at 10' intervals on September 7, 1945, February 25, 1946, and May 22, 1946. By comparing the treated section with the adjacent untreated section, we note that the treatment was ineffective in reducing the amount of heaving. Soil samples were taken during May, 1946, to determine the extent of migration of calcium chloride. From the test data, we note that the desired migration of calcium chloride has not taken place or that a greater part of the material has leached away.

CONCLUSIONS

From the information assembled in this work, we conclude that calcium chloride has not been effective in reducing frost heaving and that the desired migration of calcium chloride has not taken place or that a greater part of the material has leached away.

PURDUE UNIVERSITY, F. O. Slate

Our experiments cover "Permanence of Calcium Chloride in Subgrade and Stabilized Bases and Its Effectiveness on Base Course Densities."

Calcium Chloride is mixed into the base course of a road primarily to obtain and maintain a more or less favorable moisture content and, as a result, obtain a relatively high density. The purpose of this work was to determine the base course densities of several bituminous roads thus treated, after several years of use, and to determine how much of the calcium chloride originally placed there still remains.

Two samplings have been made--the first in the summer of 1942 and the last in the summer of 1946--to determine the changes of density and chloride content with time. Information on the original conditions of density and chloride content of the roads is in some cases so meager and unreliable that conclusions as to changes from the original conditions of the roads cannot be made. However, changes from the time of first sampling to that of the second have been measured and are reported.

Five roads are sampled: Hiwassee Dam Access Road, N. C., built in 1938; Dietrich-Montrose Road, Illinois, 1937; Muscatine County Road C, Iowa, 1939; Lawton-Marcellus Road, Michigan, 1938-39; and Kuttawa-Fredonia Road, Ky., 1941. Base course densities were measured by the sand method. Samples of base-course and subgrade material were analyzed for hygroscopic water content, and for chloride content

TABLE 1

DENSITIES OF BASE COURSES TREATED WITH CALCIUM CHLORIDE

Road	Year Sampled	Hole	Reported $CaCl_2$ used	Dry Density	Moisture Content	True Sp. Gr.	Maximum [a] Theoretical Dry Density
			lb. per sq. yd.	lb. per sq. yd.	%		lb. per cu. ft.
Hiwassee	1942	1	2.7	151 [a]	2.4	2.75 [c]	161
"	1942	2	2.7	144 [b]	2.6	2.75 [c]	160
"	1942	3	2.7	147 [b]	2.5	2.75 [c]	161
"	1946	1	2.7	150	2.3	2.70	158
"	1946	2	2.7	142	1.9	2.76	163
"	1946	3	2.7	141	2.3	2.80	164
Dietrich	1942	1	1.7	159 [d]	4.0	2.76 [c]	155
"	1942	2	1.7	147	3.3	2.76 [c]	158
"	1942	3	1.7	155	1.8	2.76 [c]	164
"	1946	1	1.7	163 [d]	4.6	2.76	153
"	1946	2	1.7	148	3.4	2.80	159
"	1946	3	1.7	137	2.8	2.72	158
Muscatine	1942	1	1.5	152	2.8	2.68 [c]	156
"	1942	2	1.5	153	2.8	2.68 [c]	156
"	1942	3	1.5	156 [d]	3.0	2.68 [c]	155
"	1946	1	1.5	134	3.5	2.70	154
"	1946	2	1.5	132	2.3	2.65	154
"	1946	3	1.5	145	1.7	2.70	161
Lawton	1942	1	1.1	146	5.0	2.80 [c]	153
"	1942	2	1.1	146	4.3	2.80 [c]	156
"	1942	3	1.1	145	4.5	2.80 [c]	155
"	1946	1	1.1	151	4.5	2.79	155
"	1946	2	1.1	146	2.2	2.77	162
"	1946	3	1.1	143	3.4	2.84	162
Kuttawa	1946	1	2.7	146	5.8	2.70	146
"	1946	2	2.7	137	6 7	2.71	145
"	1946	3	2.7	143	5 7	2.71	147

[a] Formula used: vol. soil (cu.ft) + vol. water (cu. ft) = 1 cu. ft. (assuming complete saturation)

let x = dry wt. (lb.); since vol. given as 1 cu. ft.

x = dry density (lb. per cu. ft.)

$$\frac{x}{(\text{true sp. gr.})\ (62.4)} + \frac{(\%\ \text{M.C.})\ x}{(100)\ \ (62.4)} = 1;$$

$$x = \frac{[\ (6240)\ (\text{true sp. gr.})\ ]}{100 + (\%\ \text{M.C.})\ (\text{true sp. gr.})}$$

[b] Determined by Bernard Thomas.

[c] Average of 1946 values for same road.

[d] Impossible value; experimental error.

by the Mohr titration method. Chloride values from roadside blanks were subtracted from the amounts found under the pavements.

Table 1 lists the densities of the base courses sampled. The values labelled "Maximum Theoretical Dry-Density at M. C. Found" were calculated to determine whether the density values found are possible values (most of the values are so high, approaching those of concrete that doubt might be expresed as to their possibility).

Figure 2 shows the calcium chloride contents of the base courses and subgrades, calculated from the chloride found. Nothing is known of the calcium ion, or the manner in which the chloride is present, except that it is water-soluble. All depths represent distances down from the bottom of the pavement. Values of calcium chloride are expressed as the dihydrate, the commercial form in which the chemical is usually used in road work. All percentages are based on the dry weight of the soil.

The horizontal lines across the graphs represent the total calcium chloride applied (as reported), calculated as though it were mixed evenly throughout the 36 inches below the pavement, including base course and subgrade. In these calculations, an average density of 100 pounds per cubic foot was assumed for the entire 36 inches. In the Muscatine graph it is obvious that more chemical was used than was reported, perhaps for dust control in the years preceding pavement.

In a few years the 1946 values are slightly higher than the 1942 values. This might be caused by changes in ground-water conditions. since the vertical migration of chloride is sensitive to rise and fall of water, but the difference, are too small to be significant in any case.

The density values found are unusually high, but there are no blank values (from untreated sections) for comparison. After a period of five to ten years, one-third to one-half of the chloride originally placed still remained. Almost the entire loss occurred during the first five years.

COMMITTEE SUMMARY

The work of the committee to date has been confined largely to the experimental treatment of existing frost heaves with calcium chloride. Figures 3 to 8, which follow, show typical procedures and records. Results have not been particularly encouraging since, in most instances, there has been no diminishing of the original amount of the heave. In contrast, however, some reports indicate some benefit and, in one instance, a complete cure. Since laboratory experiments have indicated that a moderate concentration of calcium chloride in the soil will practically eliminate frost heave, it is the committee's opinion, which is based in part on experimental data, that adverse water conditions have leached the chemical from the soil thus making the treatments ineffective in some instances.

The committee has not expanded its activities to include the treatment of subgrades in general, for the purposes of seeing whether or not the frost line can be lowered in the subgrade and thus decrease the amount of pavement spring break-up.

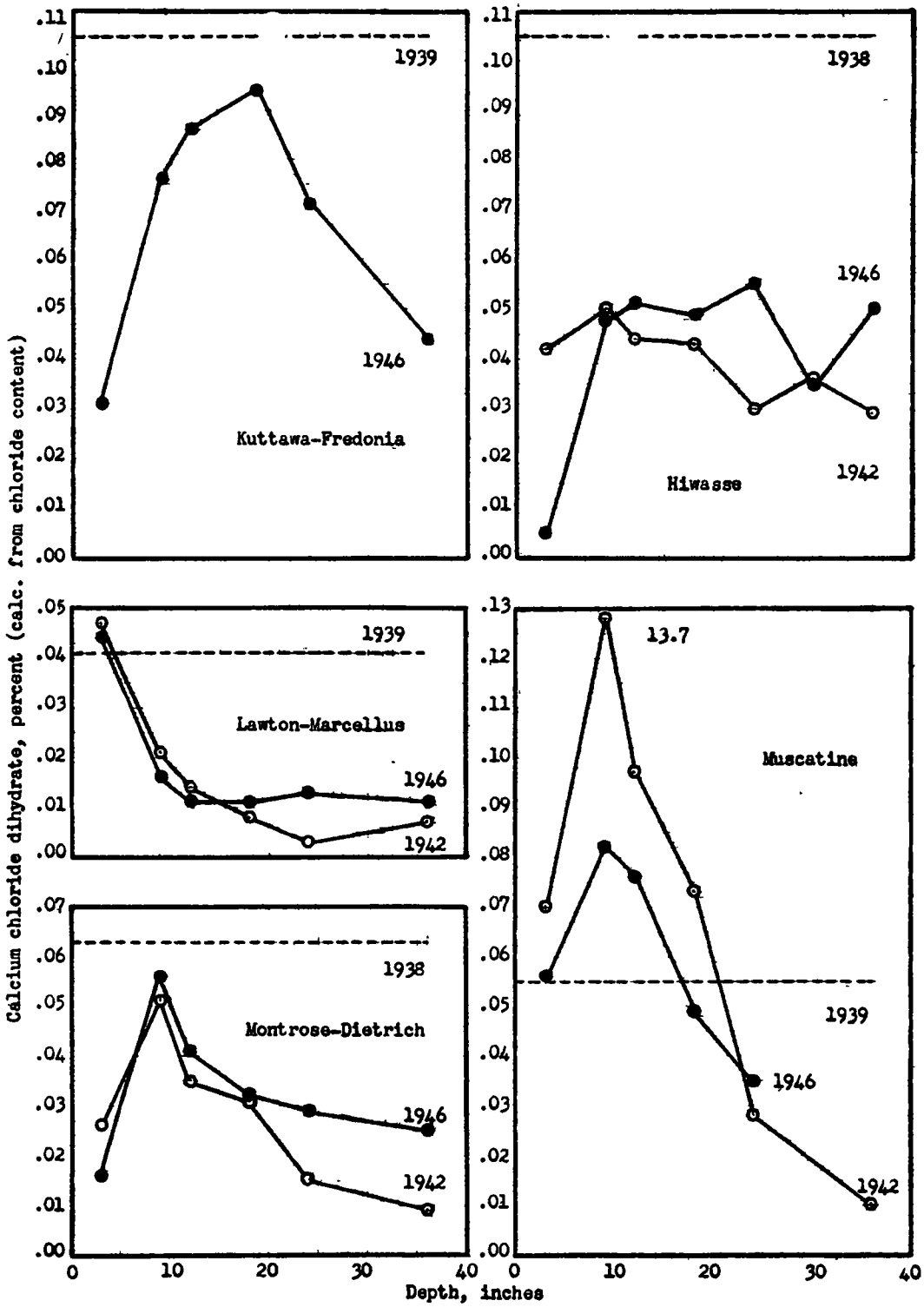

Figure 2. Calcium Chloride Contents of Subgrades and Base Courses of Several Roads. (Hort. dotted lines indicate amount of chemical reported originally used).

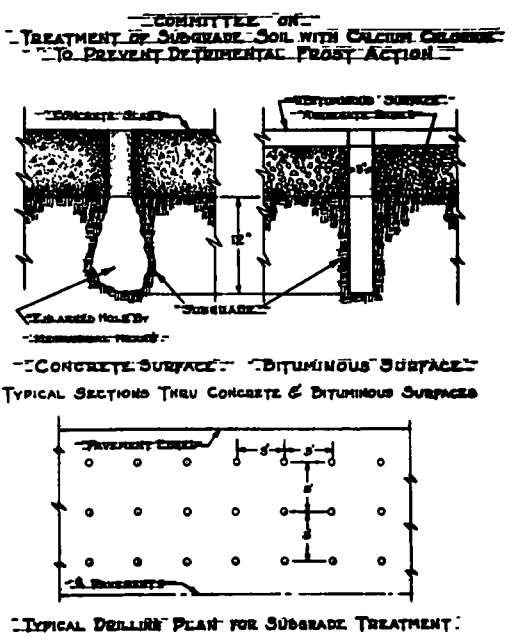

Figure 3. Plan and Cross-Section of Road, Showing Preparation for Application of Calcium Chloride.

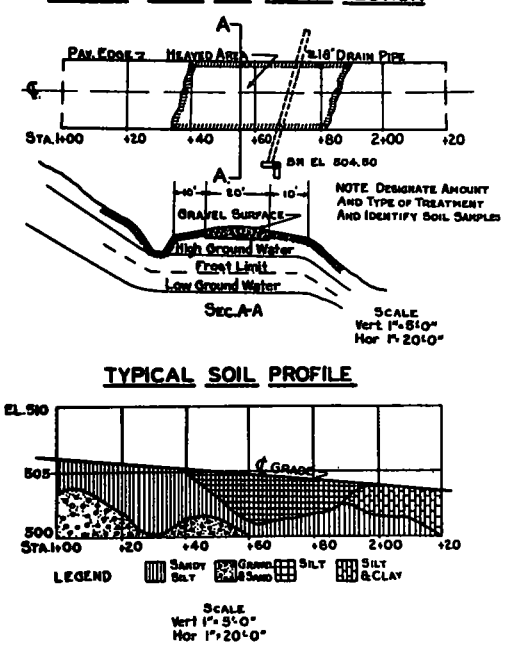

Figure 4. Subgrade Soil Profile and Cross-Section of a Road Treated with Calcium Chloride.

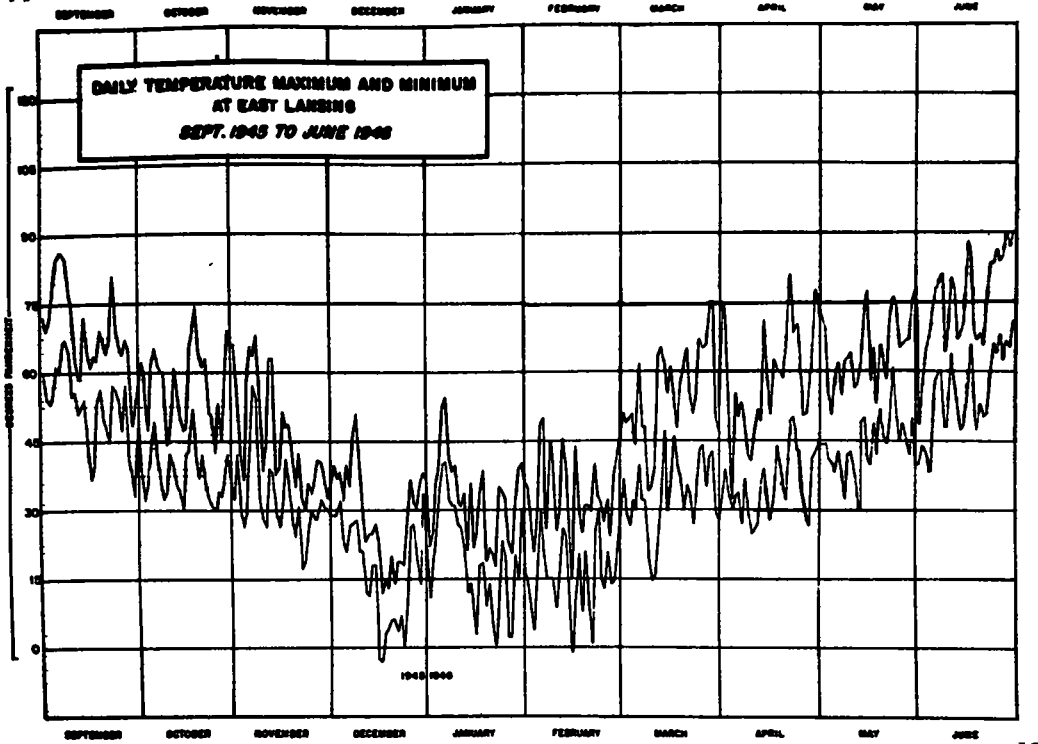

Figure 5. Typical Temperature Record Used for Frost Action Studies.

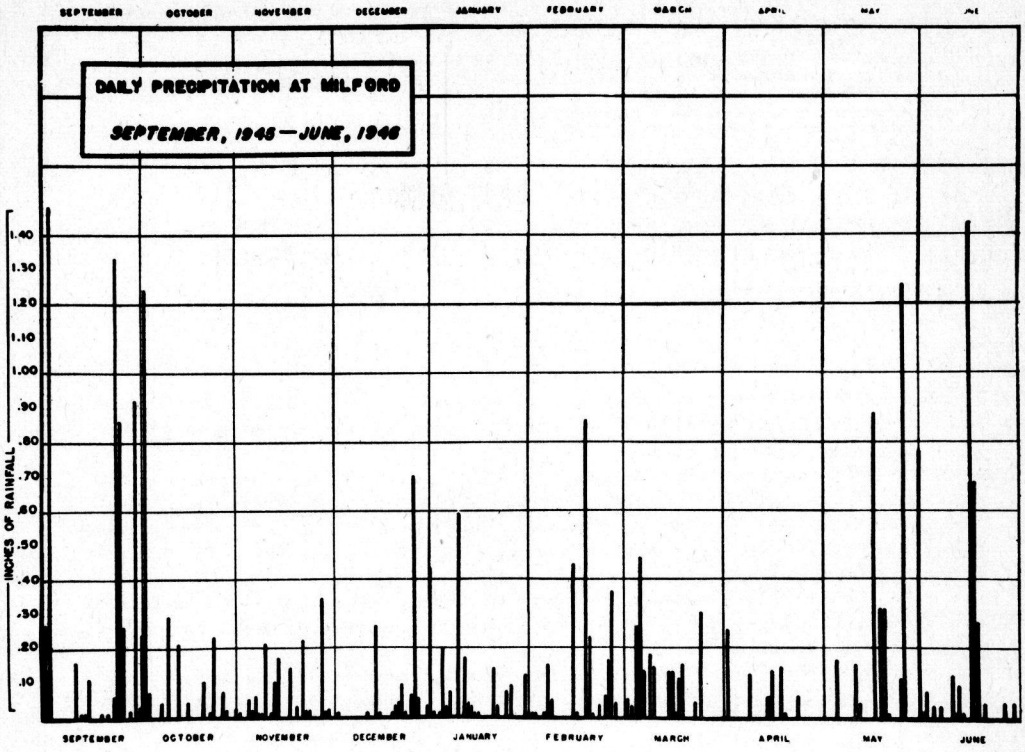

Figure 6. Typical Precipitation Record Used for Frost Action Studies.

Figure 7. Addition of Calcium Chloride and Water to the Subgrade of a Highway.

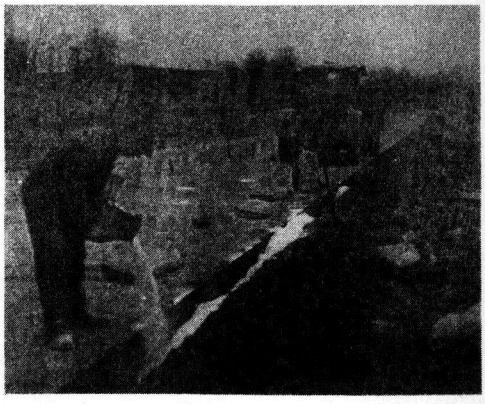

Figure 8. Calcium Chloride Being Poured Into a Trench Alongside a Pavement.