

## USE OF CALCIUM CHLORIDE IN SUBGRADE SOILS FOR FROST PREVENTION

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### SYNOPSIS

In order to investigate the effects of calcium chloride on the formation of ice lenses in subgrade soils, field and laboratory studies were made on the migration of this salt through soil and laboratory experiments of the effect of calcium chloride on frost heaving were made

Studies of migration were made by introducing salt into the subgrade of a test road through pockets cut through the surface. It was found that calcium chloride will diffuse through the subgrade when applied through pockets, and information was secured on the soil and application factors governing the spacing to the pockets to secure uniform distribution of the salt

The effects of ground water level and the movements of water through soil on calcium chloride migration were further checked by laboratory tests. The rate of migration was found to be faster with higher ground water levels supplying water to the migration zone. It was also noted that movement of water through silt will carry the salt with it

In laboratory tests of heaving of soil specimens due to freezing of capillary water, it was found that 2 per cent of calcium chloride protected the specimens from damaging frost heave

### REVIEW OF FROST HEAVE

The term frost heave designates a condition in which soil has been raised above its normal level by the formation of ice layers somewhere below its surface. Frost heave cannot be accounted for alone by the expansion of water upon freezing, for this causes only about a ten per cent increase of volume of the water and a much smaller expansion of the soil containing the water, while heaves of 40 or 50 per cent of the height of a soil column are not unusual. Taber's early work laid the foundation for our present knowledge of the subject. In the winter of 1914 he conducted a series of field tests (8)<sup>1</sup> and concluded that frost heaving is due to the growth of layers of segregated ice in the soil, and that freezing soils draw water to the zone of ice lense formation from outside sources

The fact that growing crystals can exert tremendous pressure was ably demonstrated by Becker and Day (1) and con-

firmed by Taber (7). The fact that ice crystals are formed in soils is strikingly demonstrated by a series of photographs in one of Taber's articles (11)

The extensive annual damage done by frost heave has forced its recognition as a major highway problem in some sections of the country. *Engineering News-Record* made a survey of frost damage during the winter of 1927-1928 (16); it reported that a tremendous sum of money was spent for repair work only. It was impossible to estimate the indirect costs such as loss of time and depreciation of roads which were not damaged enough to require repairing at the time. Many unsurfaced roads become entirely impassable for a time during the spring break-up because of the melting of ice layers in the soil. The surface drops unevenly and is in contact with water from the melted ice. This water cannot drain downward for a time because of unthawed soil below.

Various solutions to the problem of frost heaving are possible, as pointed out by Beskow (15) and by Winn and Rut-

<sup>1</sup> Numbers in parentheses refer to list of references at the end of the paper

ledge (14): (a) design of pavement strong enough to overcome subgrade defects, (b) replacement of detrimental subgrade with good material, (c) drainage of subgrade and underlying soil, (d) treatment of the existing subgrade soil, and (e) stabilized soil base construction. In order to see how the correction should be applied, the conditions necessary for frost heave must be known. First, water must be available for the formation of ice layers. This means that the soil must be in a state of capillary saturation during the freezing period. In order for the soil to remain saturated as water is being taken from it to form ice, a free supply of water must be available from the ground water or elsewhere. In order for soil to draw capillary water above the ground-water table to supply water effectively for the formation of ice lenses, it must be a fine-grained soil. Second, the temperature drop must be slow. Rapid freezing does not allow sufficient time for growth of large ice layers before the entire mass of soil is frozen solid.

The fundamental factors involved in frost heave are as follows:

1. Frost heave is largely caused by the growth of layers of ice under the surface of the soil
2. Water must be continuously available for the formation of ice layers.
3. The temperature drop must be slow
4. The soil must be fine-grained enough to supply capillary water to the freezing zone.

#### INTRODUCTION

The purpose of this work is to study the characteristics of calcium chloride relating to means of application, permanence, and prevention of frost heave when the material is used in road construction. The use of the chemical for stabilization purposes will not be considered (13).

There are various methods of application of calcium chloride: namely, an admixture and surface application of the flake form; a solution applied as an admixture and on the surface; and the chemical placed in pockets at regular intervals. The choice of method depends upon the conditions of treatment, the type of soil, and the effect desired. In the construction of new roads the flake form is usually mixed dry with the soil, which is left loose until a rain, and is then compacted while wet. It has been recently recognized that application of the chemical on unpaved roads as a dust control measure is of great value in increasing stability and decreasing frost heave, especially on roads that are to be paved in the future.

The problem of permanence is recognized as one of major importance (5). The chemical can possibly be lost by downward movement into the ground water, by upward movement to the surface, then lateral washing to the side ditches by rain on unpaved roads, and lateral underground migration beyond the limits of the road.

Frost heave is responsible for the breakup of many hard-surfaced roads. In winter the pavement is not uncommonly raised one to six or more inches above its normal level. Since adjacent pavement areas heave unevenly, breakups occur. The presence of calcium chloride in the soil lowers the freezing point so that a lower temperature is required to produce the ice lenses that cause frost heave.

The freezing point of pure water is lowered from 32 deg. F. to 23 deg. F. by the addition of 10 per cent of a commercial grade of calcium chloride (commercial calcium chloride usually contains about 80 per cent of the chemical, the remaining portion being water, although one or two per cent may be other inorganic salts). Any fraction or multiple of this amount of calcium chloride will lower the freezing point a corresponding

amount; that is, the freezing point lowering is directly proportional to the amount of salt present. However, a soil containing 10 per cent of calcium chloride will have a freezing point well below 23 deg F. because soil itself begins to freeze at lower temperatures than pure water (3)

It should be noted that just below its freezing point water freezes solid. For example, if pure water is held at 30 deg. F. for some time it will become completely solid. However, a solution of calcium chloride does not freeze solid at or just below its freezing point, only a few crystals of ice are formed. This ice is composed of nearly pure water, which upon being frozen releases its calcium chloride. This extra calcium chloride is added to the remaining solution making it more concentrated and thus lowering its freezing point. Because of this mechanism a 10 per cent solution of calcium chloride does not freeze solid until a temperature of  $-1.5$  deg F. is reached

#### FIELD STUDIES APPLICATION THROUGH POCKETS

##### *Purpose and Scope*

When it is desired to introduce calcium chloride into the subgrade for frost heave control on roads not initially treated with this salt some manner of distributing the chemical under the road is needed. Obviously this should be done with minimum of disruption of the road surface.

One possibility is to supply the chemical from the shoulders of the road without bothering the wearing surface. However, in soils which tend to prevent migration, it is questionable whether or not sufficient calcium chloride will reach the region under the center of the road to be effective. Future investigations will possibly eliminate or substantiate this doubt.

Another possibility—the one with which this thesis deals—is to cut out small sec-

tions of surface, apply the chemical in the openings, and patch the hole (4). Water movement and the forces of diffusion should tend to cause the water soluble calcium chloride to move in all possible directions. The pockets must be placed closely enough together that points midway between them will have accumulated the desired amount of the chemical in a reasonable length of time. This distance will, of course, vary considerably in different types of soil and under different moisture conditions of the soil

##### *The Test Road*

A test road, belonging to the Joint Highway Research Project of Purdue University and located about two miles northwest of West Lafayette, Ind., is being used for field tests (2).

The particular section used for migration tests consists of a silty clay subgrade, a 6-in. base of coarse aggregate, and a bituminous surface. This surface is divided into two parts; the south half is more water resistant than the north half because of an additional treatment with bituminous material and fine stone chips.

##### *Application of Calcium Chloride*

Assuming 100 lb. per cu. ft to be the density of the subgrade soil, it is found that a volume of soil 20 ft wide (the width of the road), 10 ft long, and 2 ft. deep (a depth usually below the frost line in this climate) weighs 40,000 lb. In order to treat this soil so that it will contain one-half of one per cent calcium chloride, 250 lb. of the chemical is required. (This amount, rather than 200 lb. is required because the commercial product is only about 80 per cent pure.) The problem is then how to distribute 250 lb. of calcium chloride in pockets so it will effectively cover a section of road 10 ft. long to a depth of 2 ft.

The distance between pockets depends upon the rate of migration in the par-

ticular soil, so to find a suitable interval, a series of three pockets was made. The lateral migration in a given period gives an effective radius of each pocket to govern the placing of pockets in a road to be treated.

The pockets were made as follows. three sections of pavement in the center of the road, 2 ft square and with centers 12 ft apart, were cut out and holes of the same dimensions were dug to a depth of 6 in. Thus, the bottom of the hole just reached to the subgrade soil. In hole No. 1, 66 lb. of commercial, flake calcium chloride was tamped in; in hole No. 3, 33 lb. was treated likewise; and in hole No. 2, 66 lb. was poured into the hole as a saturated solution. Soil was filled in and tamped, and the holes in the black-top pavement were patched with liquid asphalt RC-3 and No 9 (State Highway Commission of Indiana requirements specification) stone. The hole used for the solution could not be patched the same day, three days were required for the solution to soak down. These pockets were made on February 14, 1941.

The different quantities were used in order to determine whether or not twice as much chemical in a pocket would supply twice as much of the chemical at a given distance from the pocket, thus permitting one-half as many holes—each containing twice as much chloride—to do the same work as the larger number of pockets. The solution was used so that any special effect it might have, such as accelerated rate of migration, might be discovered.

### *Sampling*

Samples were taken by boring vertically through the pavement to the desired depths with a 2-in. soil auger. Each inch as numbered represents the soil from a depth  $\frac{1}{2}$  in. above to a depth  $\frac{1}{2}$  in. below the numbered inch. Thus, a 12-in sample represents the soil between  $11\frac{1}{2}$  and  $12\frac{1}{2}$  in.

As each sample was pulled clear of the hole, the outer soil was scraped off with a spatula and discarded; this eliminated a possible error due to sticking on of soil from a shallower sample as the auger was raised. The soil was immediately placed in tightly capped glass jars to prevent changes in the moisture content.

### *Determination of Moisture Content*

The cans holding the samples were wiped clean and weighed, thus giving the weight of can plus soil plus water. Next, the lids were removed, the can and wet sample were heated to 110 deg. C. for 24 hours, the lids were replaced, and the weight of can plus dry soil was obtained after cooling. By using the tare weight of the container, obtained before sampling, it was then possible to obtain the weight of the water and that of the dry soil.

The percentage moisture content was calculated by multiplying the weight of water by 100, then dividing this product by the weight of the dry soil. Hence all moisture contents were based on the dry weight of the soil.

### *Determination of Calcium Chloride Content*

After the last weighing was made in the moisture content determination, the sample was pulverized to a fine powder with a mortar and pestle. Any stones or aggregate included in the sample were powdered and added to the rest so as to obtain a true percentage value of chemical content. The samples were again dried to 110 deg. C. in case any moisture had been picked up during grinding, cooled in a calcium chloride desiccator, and weighed. Samples of 5g were found to be a satisfactory size; they were weighed to the third decimal place.

The weighed sample was placed in a 250-ml beaker, 150 ml. of chloride-free distilled water was added, the beaker was covered with a watch glass, and the mix-

ture was boiled for one hour. The soil was allowed to settle for four or five hours, then it was filtered through a fairly porous filter paper. Five or six thorough washings with hot distilled water removed the remaining chloride from the residue. Further extractions by the same method showed that 98 per cent of the chloride was removed by a single extraction (see Table 1). It was found that a slight cloudiness in the filtrate due to passage through the filter paper of fine clay particles was not harmful, for it did not interfere with the color change of the indicator at the end point.

ance of the red color marks the end point of the titration.

This titration must be carried out in neutral solution, for silver chromate is soluble in acid solution and brown or black silver oxide is often formed in basic solution. However, every one of the soil samples used was sufficiently close to neutrality to permit its use without adjustment of pH.

A 5-ml micro-buret with a mounted reservoir for refilling was used for the titrations. It proved to be very satisfactory, for the weight of sample chosen permitted the 5-ml. range to cover the ma-

TABLE 1  
EFFICIENCY OF A SINGLE EXTRACTION OF CHLORIDE

Sample No	1	2	3	4
Percentage chloride in filtrate				
First extraction	0.311	0.311	0.521	0.189
Second extraction	0.001	0.008	0.008	0.002
Percentage of total chloride in first extraction	99.7	97.5	98.5	99.0

An approximately one-tenth normal solution of silver nitrate was used to titrate the chloride in solution. This standard solution was prepared by dissolving slightly more than the calculated amount of chemically pure silver nitrate in distilled water and standardizing it against a known hydrochloric acid solution which had in turn been standardized against a known sodium carbonate solution. This latter solution was prepared by dissolving a carefully weighed amount of pure sodium carbonate in distilled water.

Potassium chromate was used as an indicator. Since silver chloride is more insoluble in water than silver chromate, the former will be precipitated out as a white salt as long as any free chloride is present in the solution. Upon the first excess of silver ion, a dark red precipitate of silver chromate is formed; the appear-

ance of the red color marks the end point of the titration. The reading error introduced by using only a small volume of titrating agent was negligible because the micro-buret was calibrated so as to read directly to 1/50 ml.

#### Results and Discussion

Several graphs have been drawn to show the data clearly on a comparative basis. The figures used were chosen so as to present a representative sampling of the data.

In Figure 1 are shown the moisture contents obtained from four different borings. The values for percentage of water are almost identical for all four, and are very close to all those obtained throughout the entire test except for one group to be mentioned later. Only one graph was made of these moisture contents, since it is representative of all the samples. It

may be noticed that the amount of water found at depths of 3 and 6 in. was relatively small. This is to be expected, for these depths were occupied by the coarse aggregate base course. A sharp increase in moisture content is found in the silty clay soil at 9 in. depth, followed by a gradual increase as the level of the ground water is approached.

The one exception to the uniformity of the values for water content mentioned above is shown in Figure 2. This

show larger amounts of water than borings away from the pockets, for the former contained larger percentages of calcium chloride than the latter ones. This is true because calcium chloride tends to attract and hold enough water to dissolve itself. The larger percentages of water found in hole No. 1 will be referred to again in connection with migration from the two pockets in question.

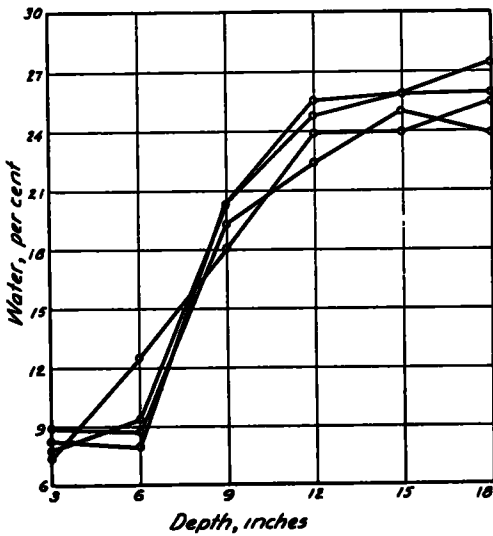


Figure 1. A Typical Example of the Moisture Contents of Field Samples

graph represents borings taken directly into and through the calcium chloride pockets after they had been down for one year. Since no filling material was added with the chemical, migration of the latter left a partially unfilled space below the patch in the wearing surface. This patch sagged and cracked somewhat around the edges; hole No. 1 was affected more than hole No. 2. Because of this it is possible that a little more water seeped through the patch on hole No. 1 than on No. 2. This might account for the higher moistures found in pocket No. 1. However, it is to be expected that these two borings would

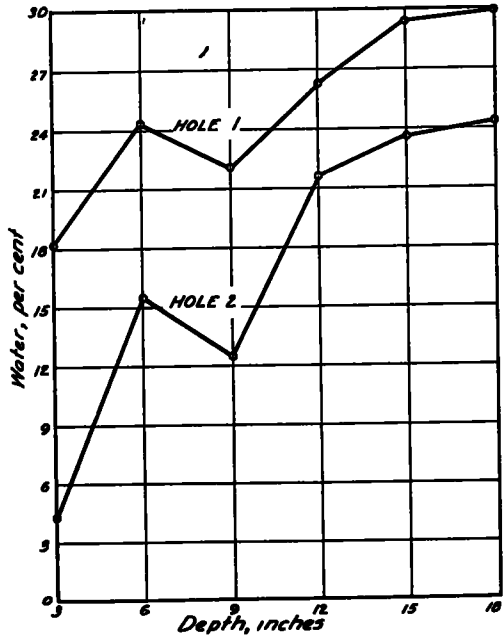


Figure 2. Moisture Contents from Borings Taken Directly through the Pockets of Chemical after they had been Down for One Year.

Figures 3 through 10 trace the migration out and down from the pockets with increasing time. All percentages of calcium chloride are calculated as the commercial product, assuming it to be 80 per cent pure. Figures 3 and 6 show that there was substantially less migration to the south of hole No. 1 than to the north. This side of the road was given an extra treatment of stone chips and is less permeable to water than the north side. The faster rate of migration to the north can-

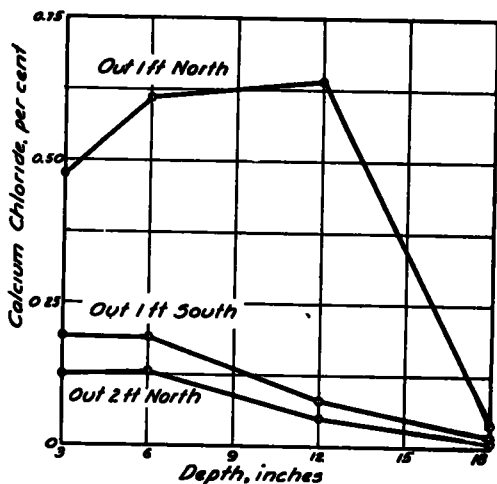


Figure 3. Extent of Migration from Hole No. 1 after Four Months, Showing Effect of Tighter Surface Seal.

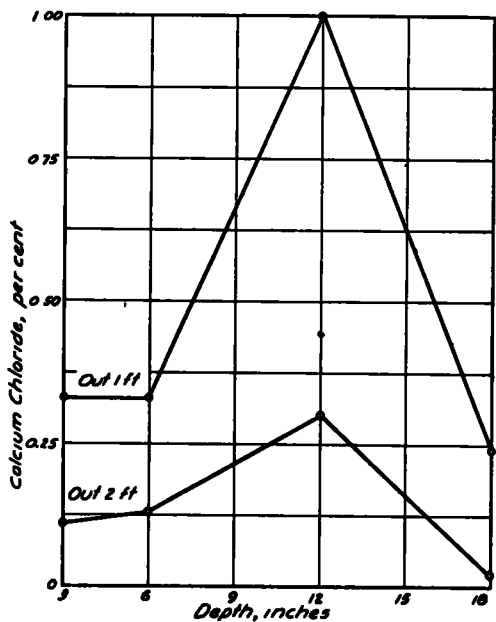


Figure 4. Extent of Migration from Hole No. 2 after 4 Months

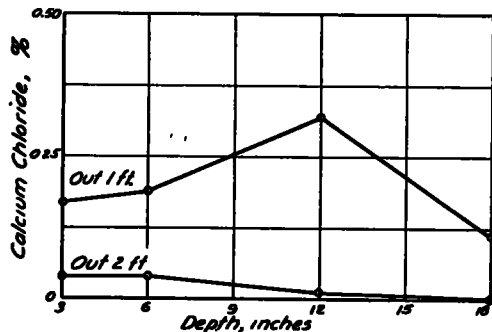


Figure 5. Extent of Migration from Hole No. 3 after 4 Months

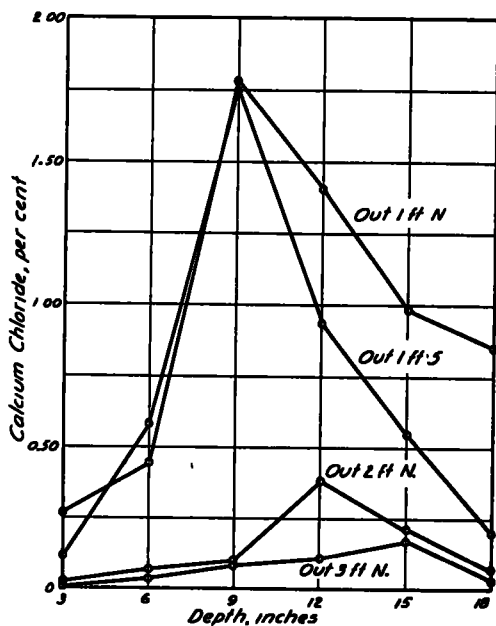


Figure 6. Extent of Migration from Hole No. 1 after 8 Months

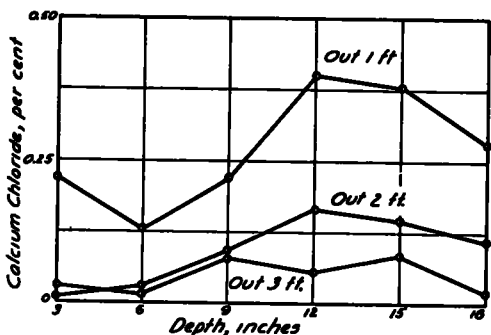


Figure 7. Extent of Migration from Hole No. 2 after 8 Months

not be explained by movement of the ground water, for the general direction of flow toward the road is from the north It will be noticed that in general the chem-

was a slower rate of migration from pocket No. 1 than from pocket No. 2, in which the calcium chloride was applied in solution This would be expected as the latter contained more water to aid migration However, this trend was reversed by the eighth month. A possible explanation is the different character of the patches in the wearing surface. As soon as the effect of its original water wore off, pocket No 2 would be expected to act just as No 1 However, if the patch on No. 1 permitted the passage of more water than that of No 2 (as indicated by Fig. 2), migration would then

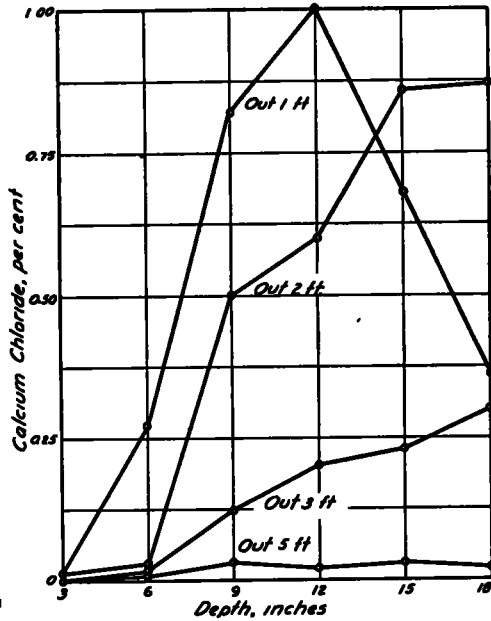


Figure 8. Extent of Migration from Hole No. 1 after 12 Months

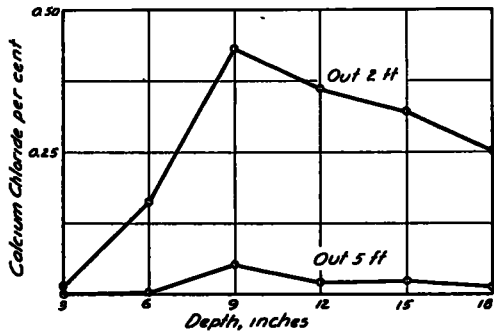


Figure 10. Extent of Migration from Hole No. 3 after 12 Months

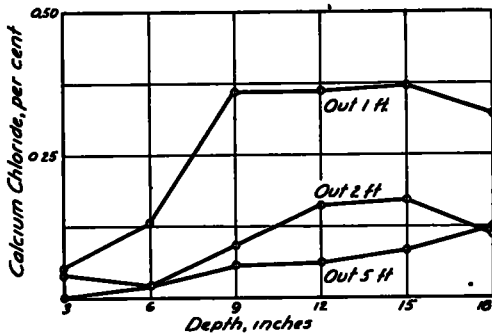


Figure 9. Extent of Migration from Hole No. 2 after 12 Months

ical is concentrated at a depth of nine to twelve inches Naturally very little of it migrates into or remains in the base course layer, for little water is encountered there These graphs indicate that at first there

proceed more rapidly from pocket No. 1 Another possibility is that the migration from pocket No 2 proceeded so rapidly that the chemical content of the soil close to the hole reached its peak early and started to fall off while that of pocket No. 1 was still building up. This latter explanation is contradicted by Figure 11, which shows that at the end of 12 months there is still more calcium chloride left in and under pocket No. 2 than pocket No 1. It should be noted that Figure 6 is drawn to a different scale than the other graphs

Figure 12 compares the amount of migration from two pockets which contained different amounts of calcium chloride. At the end of four months it can be seen



that the pocket which contained twice as much chemical as the other supplied about twice as much of the chemical to the surrounding soil as the latter. However,

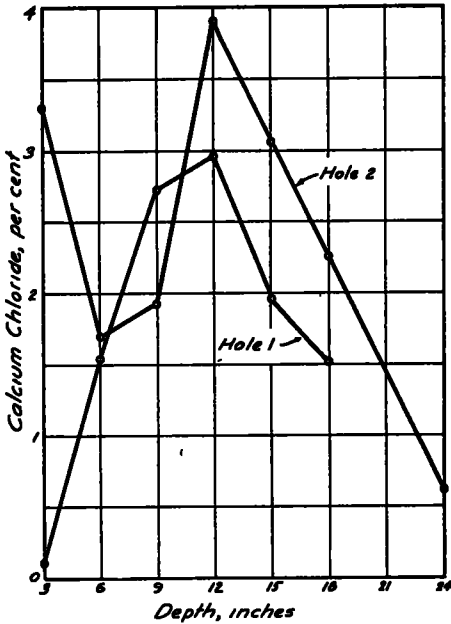


Figure 11. Amounts of Chemical Left in Pockets after 12 Months

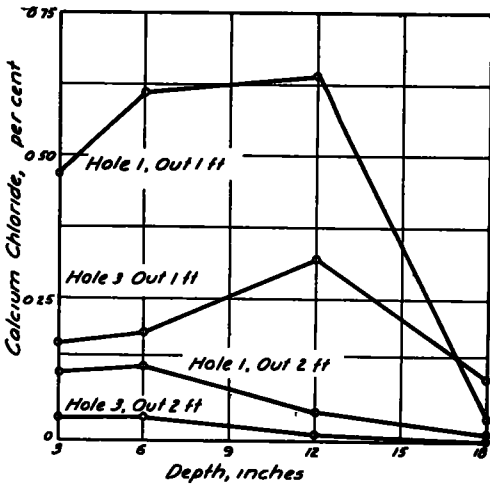


Figure 12. Comparison of Rates of Migration from Pockets (4 Months) Containing Different Amounts of Calcium Chloride.

this difference decreased as time went on as can be seen by comparison of Figures 8 and 10.

Figure 13 traces the extent of migration with increasing time. It seems that a point 12 in. from the pocket held its maximum percentage of calcium chloride at 8 months, after which migration proceeded more rapidly from it to points toward the edge of the road than to it from the pocket. Points 2, 3, and 5 ft

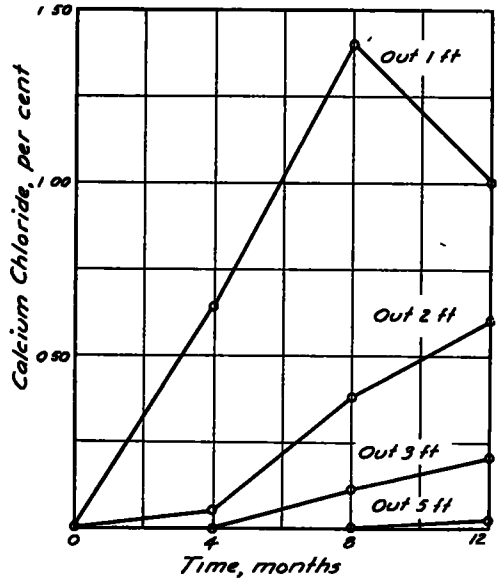


Figure 13. Rate of Migration from Hole No. 1 (12 in. deep)

from the pocket were still building up concentrations of calcium chloride at the end of one year.

LABORATORY STUDIES ON MIGRATION

Purpose and Scope

The laboratory studies were initiated in order to obtain data more quickly than they could be furnished by field tests. An additional advantage lies in the fact that it is relatively simple to control experimental conditions in the laboratory while it is almost impossible to do so in the field.

For example, if it is desired to study the effect of changes in height of ground-water table as an isolated factor, this cannot be done in the field, for rain falls, evaporation takes place, and other uncontrollable changes are occurring continuously. However, in the laboratory rainfall can be measured or eliminated as can evaporation, and even such factors as temperature and relative humidity of the room can be controlled.

The purpose was to observe and measure the effects of such variables as height of ground-water table, amount of rainfall, amount of evaporation, and rate of diffusion through soils.

#### Apparatus

The first series of laboratory models was used to measure effects of changes in height of ground-water table, to measure the effects of different quantities of rainfall, and to trace the vertical and horizontal paths of migration of the chemical. To make these models 5-gal. buckets were cleaned and painted inside to prevent rusting. For each model, the ends were cut from two 1-gal. paint cans—leaving one end on one can—and the cans were joined so as to form a hollow cylinder with the bottom still on the lower can. Waterproof tape was used to hold them together. Holes were punched in the bottom and a cloth was laid in the bottom over the holes to act as a filter to prevent loss of sand. Damp concrete sand was tamped in to the halfway mark, a cloth filter was placed on top of this, then silt containing 20 per cent moisture was packed to a depth of 6 in. and a density of 100 lb per cu. ft. Thus, a cross-sectional representation of a silty soil on a sand base was obtained as is shown in Figure 14.

The second series of laboratory models was used to measure the effects of evaporation and of diffusion. For this series quart cylindrical ice cream cartons made of cardboard were used. The en-

tire container was dipped in paraffin to waterproof it. The bottom was perforated and covered with filter paper to prevent loss of soil. The carton was then stood on the end of a perforated hollow cylinder of glass which in turn stood inside a liter beaker. Water was poured into the beaker to the desired height as in the first series of models. A diagram of a model from the second series is shown in Figure 15.

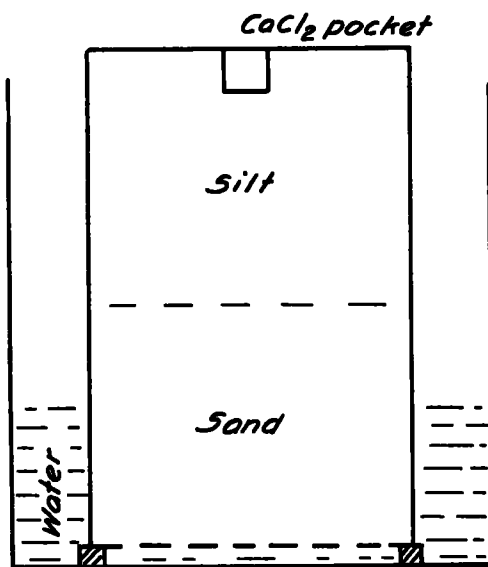


Figure 14. Apparatus Used for Laboratory Studies of Migration of Calcium Chloride in Soil. Series One.

The silt used in both series as well as the frost action tests consisted of 15 per cent sand, 68½ per cent silt, and 16½ per cent clay as defined by grain size. It had a liquid limit of 22.5, a plastic limit of 19.3, and a plastic index of 3.2. The specific gravity was 2.72.

#### Application of the Sample

In the first series a cork borer 1-in. in diameter was pushed into the center of the silt sample to a depth of 3 in., twisted slightly, then pulled out. In this manner a hole in the specimen 1 in. in diameter

and 3 in. deep was formed. Five grams of flake calcium chloride were inserted in this pocket, filling the lower third of the hole. The soil was extruded from the cork borer and two thirds of it was forced into the hole. As the soil was damp enough to form a uniform seal immediately, no abnormal cracks or openings existed where the soil was replaced above the calcium chloride.

In the second series of models the top 2 in. of the soil contained an admixture of

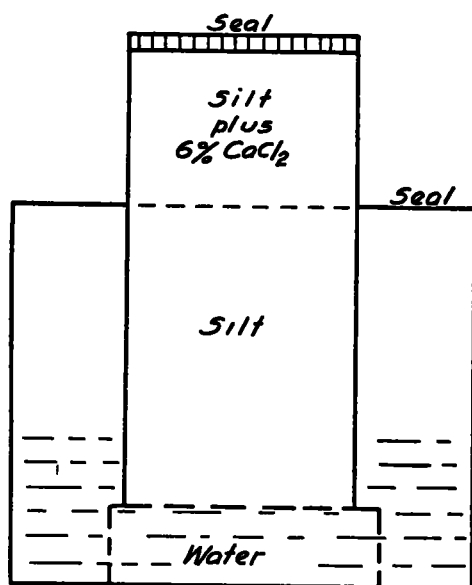


Figure 15. Apparatus Used for Laboratory Studies on Migration of Calcium Chloride in Soil. Series Two.

6 per cent calcium chloride at the time it was tamped into the container.

#### *Fluctuation of Experimental Conditions*

In model No. 1 of the first series water was added to the large outer container until the ground-water table had risen to within 6 in. of the surface of the silt. In model No. 2 of the same series the ground water was adjusted to a level 12 in. below the top of the silt. Rain was simulated by pouring water on top of the

silt and allowing it to drain through. From the diameter of the soil sample it was possible to calculate the volume of water that was equivalent to 1 in. of rainfall. As the water passed through the sample it tended to raise the level of the ground water, therefore, enough water was removed from the outer container to keep the water at a constant level. This water was saved so that the total chloride that leached through the soil could be measured at the end of the experiment.

In the second series two types of experiments were performed. In the first type water was poured into the beaker until it was 6 in. below the top of the soil sample. The container was then sealed at the top and the opening around the top of the beaker was sealed. The samples were allowed to stand for two months to allow sufficient time for appreciable diffusion to take place. In the other part of the second series the top of the beaker was covered with a removable seal and the top of the sample container was removed. Thus evaporation from the top of the soil drew water up through the soil from the supply held in the beaker. The entire apparatus plus water was weighed, then set aside for evaporation to take place. When the water level became low, the entire apparatus was reweighed. The difference in the two weights represented the water that had evaporated. This process was repeated time after time. From the weight of the water and the diameter of the soil sample, it was possible to calculate the amount of evaporation as inches of water. This was done to give a rough comparison with the rainfall tests.

#### *Sampling and Determination of Calcium Chloride and Moisture*

Samples were taken by means of a  $\frac{1}{4}$ -in. cork borer. The instrument was pushed to the desired depth from the top of the soil, removed, and the sample was extruded and cut off as desired. The samples were taken an inch at a time,

rather than as one sampling done by pushing the borer down to its full length then cutting off the samples an inch at a time as they were extruded. This latter method would have caused some compaction, making true depth measurements impossible. As in the field results, any designated inch represents the soil from  $\frac{1}{2}$  in. above to  $\frac{1}{2}$  in. below the numbered inch.

The hole left by removal of the sample was filled with the same type of soil

of migration. In two models of series one, pockets of calcium chloride were placed just under the surface of the soil in the center of the specimen. The ground-water levels were adjusted and the migration allowed to proceed for 72 hours. Samples were then taken at a distance of 1 in. out from the edge of the pocket and at several depths. Percentages of moisture and calcium chloride were determined. It was found that the higher

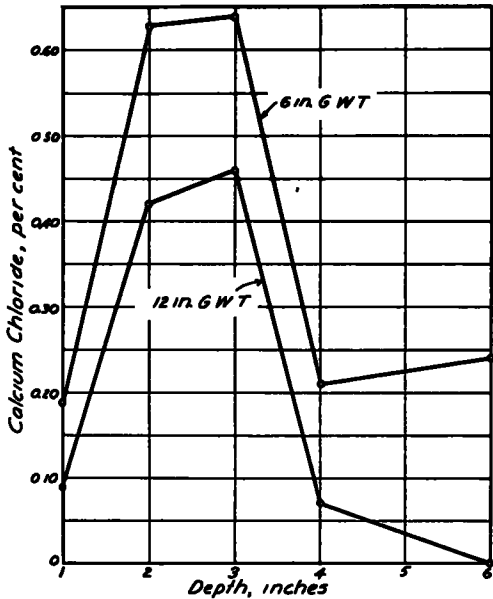


Figure 16. Effect of Height of Ground Water Table upon Rate of Migration

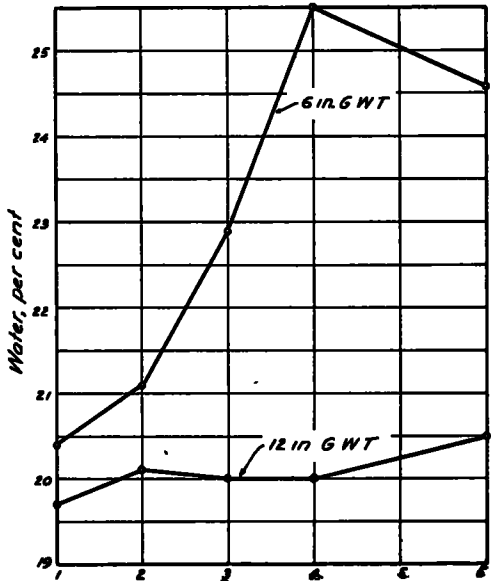


Figure 17. Effect of Height of Ground Water Table on Moisture Content

as that removed. This soil, at its proper moisture content (20 per cent for silt), was tamped into the hole by means of a small probe with a flattened end. This prevented abnormal loss or gain of water through the sample holes.

The calcium chloride and moisture contents were determined as described for field tests. Since the samples were small, the entire amounts were used for the determinations.

*Results and Discussion*

Figures 16 and 17 show the effect of height of ground-water table upon rate

of migration. In two models of series one, pockets of calcium chloride were placed just under the surface of the soil in the center of the specimen. The ground-water levels were adjusted and the migration allowed to proceed for 72 hours. Samples were then taken at a distance of 1 in. out from the edge of the pocket and at several depths. Percentages of moisture and calcium chloride were determined. It was found that the higher

ground-water table supplied more capillary water to the soil above it, and that this greater water content speeded up the migration of the calcium chloride. The effect of diffusion as isolated from other factors is shown in Figure 18. A model in series one was supplied with some calcium chloride on top, followed by 1 in. of rainfall. This carried the chemical downward through the specimen. This treatment was followed by 11 days of evaporation to concentrate the calcium chloride toward the top of the soil. Samples were then taken and analyzed. These values are the original concentrations

shown on the graph. The sample was then sealed on top to prevent loss or gain of water through the soil. The ground-water table was held at 9 in throughout the test. After 30 days, to allow diffusion to take place, the model was re-sampled and the concentrations of calcium chloride after diffusion were found. It can be seen that the concentration of the calcium chloride tended to become more

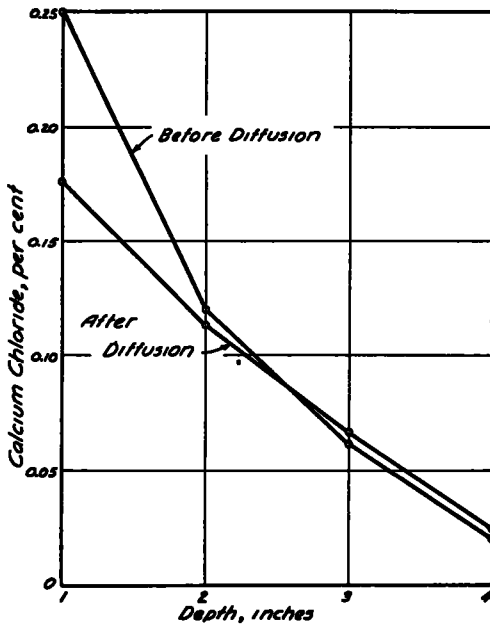


Figure 18. Tendency of Diffusion to Equalize the Distribution of Calcium Chloride in a Soil.

equal throughout the sample, as shown by the fact that the line joining the points representing the final state is more nearly horizontal than that representing the original state. Less total chemical is accounted for in the final analysis than in the original, but this is to be expected since some calcium chloride naturally migrated into the ground water.

Two models of series No. 1 were used to trace the vertical and horizontal migration from a pocket of calcium chloride when rain is passed through the soil. The

ground-water level in each specimen was adjusted to 9 in. To represent rain, measured quantities of distilled water were poured on the soil 1-in. deep at a time and allowed to drain through before the next was added. Figure 19 shows areas of equal concentration of the chemical after 2 in. of rain had passed through the soil (6). These curves were rounded out and are not supposed to represent fixed values of chemical content. However the curves are representative of the per-

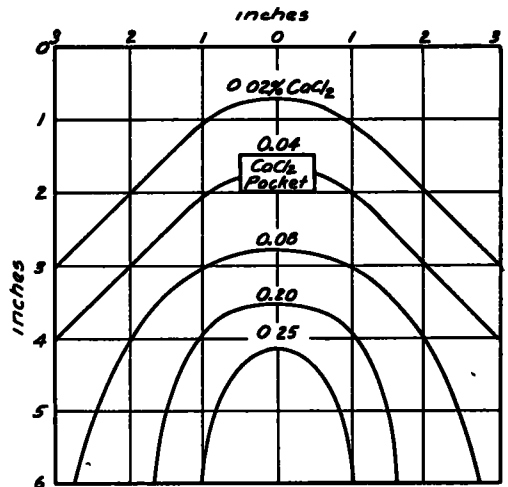


Figure 19. Areas of Equal Concentrations of Calcium Chloride Carried from a Pocket Near the Top of a Soil Specimen by 2 in. of Rainfall.

centages found and all values on the graph are close to the mean value found. Eight inches of rainfall carried 80 per cent of the chemical originally present into the ground water, as shown by analysis of this water. The amount of calcium chloride remaining in the soil at this time was too small to permit interpretation of its paths of migration.

The effect of evaporation was isolated from diffusion in the tests represented by Figure 20. The specimens originally contained 6 per cent calcium chloride in the upper 2 in of soil. None was present below this at the start of the test. The

two lower curves show that the chemical was forced downward by diffusion and a considerable amount was lost into the ground water. This diffusion period was two months. The specimen represented by the upper curve was affected by both diffusion and evaporation. Diffusion tended to force the chemical downward

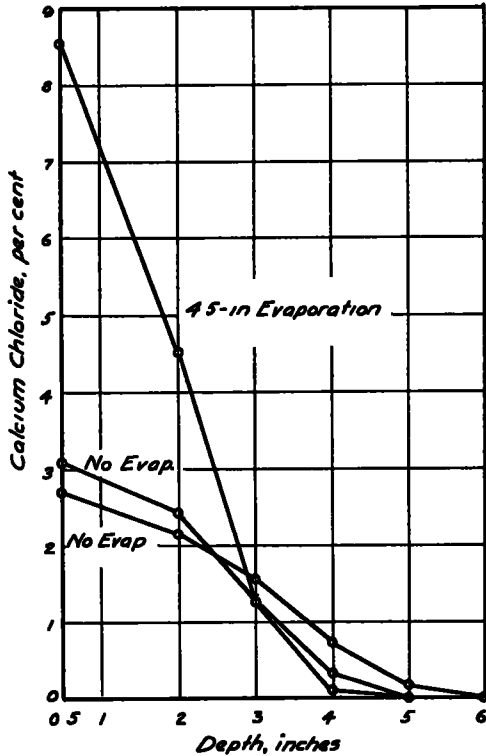


Figure 20. Migration of Calcium Chloride as Affected by Evaporation and Diffusion

and evaporation to force it upward. Only a very small quantity of chemical was lost into the ground water by the evaporation specimen, although its diffusion period was the same length as that of the others.

#### LABORATORY STUDIES ON FROST HEAVE

##### Purpose and Scope

Whenever a soil is to be treated with calcium chloride to prevent frost heave, it is desirable to know the optimum per-

centage of chemical to add. The major factors affecting the quantity of chemical needed are the grain size of the soil, soil density, availability of capillary water to the frost zone, and the temperature encountered (12). Experience has shown that silt is one of the most troublesome frost heaving soils, thus silt was chosen for this investigation as the soil most likely to need treatment.

These tests were designed to give practical data for application to field problems concerning the amount of calcium chloride needed in a certain soil. It must be borne in mind, however, that conditions are never identical at different times, and that there are many considerations which affect the final decision.

Different percentages of calcium chloride were incorporated in several silt specimens, all of which contained the same initial moisture content and were compacted to the same density. The specimens were all exposed to the same temperature fluctuations, and water was supplied to the bottoms of the samples in identical manner. Therefore, the only variable was the amount of calcium chloride. Migration of the chemical and changes in water content were determined at the end of the test.

##### Preparation of Specimen

The specimens were made according to a carefully standardized procedure (14). A quantity of air-dry silt was weighed. To it was added enough water to give a moisture content of 20 per cent. This water contained the chemical admixture as a solution. Following the field procedure, the weight of the calcium chloride was calculated on the basis of dry soil alone, rather than soil plus chemical. These ingredients were thoroughly mixed by hand. Samples were taken at this time, and after molding, to check the moisture and calcium chloride contents. A brass tube 7 in. long and  $3\frac{1}{2}$  in. wide was used

as a mold. This container was oiled, stood on end, fastened down, and filled half full of the soil mix. A 5½-lb hammer was dropped 14 times from a height of 1 ft. and the tube was rotated slightly between blows to equalize compaction. The packed surface was scarified to prevent the formation of compaction planes. This procedure was repeated three times with the same amount of soil added each time and an extension placed on top to hold the soil that was piled up for the last compaction. The specimen was extruded from the mold by means of a hydraulic press, then weighed for a density check. Following this, it was snugly fitted with a rubber sleeve to prevent evaporation.

#### *Frost Cabinet*

The freezing equipment consisted of a room containing a number of drawers insulated on all four sides and the top, but not on the bottom. The freezing coils passed over the drawers and under the top insulation. The bottom of the drawer was a reservoir for water. In the water and extending above its surface were porous carbon discs. The specimens stood on these discs and received their water through them. A wooden panel with holes for the soil specimens was lowered until it rested upon the carbon discs, and then fine dry sand was filled to the top of the specimens to act as an insulator. Thus, the top of the sample could be subjected to a low temperature while the water reservoir remained at the temperature of the room (14). See Figure 21 for a diagram of the arrangement.

#### *Test Procedure*

The exact relative height of each specimen was determined by measuring from its top to any fixed point above. Any decrease in this distance represented an elongation of the soil cylinder and thus a heave. The room temperature was maintained at 40 deg. F. throughout the

test. The temperature of the drawers was dropped as is shown in Table 2. A daily reading was taken to determine the amount of heaving that had occurred. The water in the reservoir below the soil was maintained at a level just below the top of the porous discs.

#### *Analysis of Specimens after Conclusion of Test*

At the end of the test the specimens were removed from the drawers while

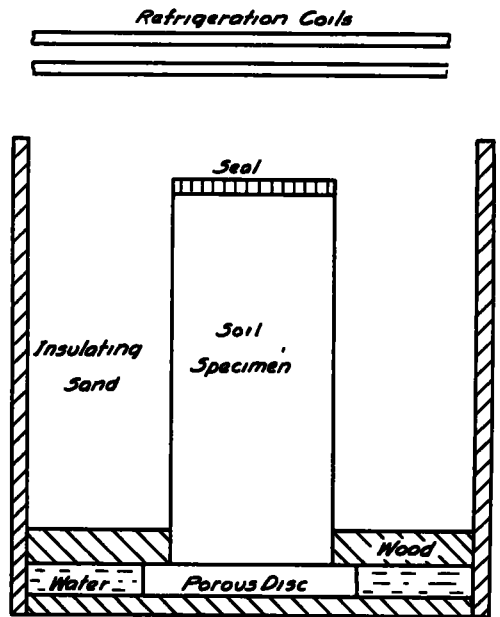


Figure 21. Design of the Frost Cabinet

they were still frozen solid. In this state each was cut into six equal parts and the individual sections were stored in airtight containers for moisture determinations. The specimens were cut while they were still frozen so that a true picture of the distribution of moisture and calcium chloride could be obtained. If the soil had started to thaw, the moisture content would have changed, and the shifting water would have carried chemical with it. The determinations of mois-

ture content and calcium chloride were carried out as described under the field studies

### Results and Discussion

The conditions used in this test were purposely chosen to be extremely severe

have, however, for only a few days are required for a short specimen of this silt to reach capillary saturation when water is available to the bottom.

The silt used is subject to severe frost heave; plenty of water was available for the formation of ice lenses; the final tem-

TABLE 2  
FROST HEAVING OF SILT AS RELATED TO TIME, TEMPERATURE,  
AND PERCENTAGE OF CALCIUM CHLORIDE

CaCl <sub>2</sub> , per cent	Time, days	Temp, deg F	Heave	CaCl <sub>2</sub> , per cent	Time, days	Temp, deg F	Heave
0	0	40	0 0	1 0	13	14	4.5
0	4	25	0 0	1 0	14	12	5 4
0	5	23	0 0	1 0	15	9	7 1
0	6	22	3 6	1 0	16	7	10 7
0	7	21	7 1	1 0	17	6	12 5
0	8	19	12 5	1 0	20	4	12 5
0	9	18	16 0	1 0	21	0	14 3
0	10	17	17 9	1 0	22	-3	16 1
0	12	15	25 0	1 0	24	-8	16 1
0	13	14	26 8	2 0	14	12	0 0
0	14	12	30 4	2 0	15	9	1 8
0	15	9	35 7	2 0	16	7	2 7
0	16	7	39 3	2 0	17	6	2 7
0	24	-8	39 3	2 0	20	4	2 7
0.5	5	23	0 0	2 0	21	0	3 6
0.5	6	22	1 8	2 0	22	-3	5 4
0.5	7	21	3 6	2 0	23	-5	7 2
0.5	8	19	7 1	2 0	24	-8	7 2
0.5	9	18	8 9	3 0	14	12	0 0
0.5	10	17	10 7	3 0	15	9	0 9
0.5	12	15	14 3	3 0	16	7	0 9
0.5	13	14	16 1	3 0	17	6	0 9
0.5	14	12	17 9	3 0	20	4	0 9
0.5	15	9	21 4	3 0	21	0	1 8
0.5	16	7	25 0	3 0	22	-3	1 8
0.5	24	-8	25 0	3 0	23	-5	1 8
1 0	10	17	0 0	3 0	24	-8	1 8
1.0	12	15	3 6	4 0	24	-8	0 0

It is seldom that field conditions become as severe as these. It will be recalled that the specimens were molded with a 20 per cent moisture content. This did not represent capillary saturation in the silt used, which has a value of about 25 per cent. Thus, it is possible that the first specimens to heave did not reach capillary saturation. Most of them must

perature was low; and the temperature drop was slow. A slow temperature drop tends to cause larger ice lenses to be formed than a quick drop. From the above statements it can be seen that normally a smaller percentage of calcium chloride is required to protect the soil from harmful frost heave than the data from the tests indicated, since field condi-



tions are seldom as bad in all respects. However, it must be borne in mind that these percentage values represent actual chemical in the soil at the time of exposure, rather than the amount that was added at the time of construction of the road. The studies on migration show that the chemical is caused to move by the forces of diffusion, evaporation, and rainfall. Thus, it should be assumed that less calcium chloride is present in a subgrade

curves reach a maximum value and then become horizontal. This presumably happens when the soil specimen becomes frozen throughout, leaving no further space for growth of ice lenses. Figure 24 shows that heaving is accompanied by gain in water content due to formation of ice crystals. A maximum value for water content is reached at the top of the specimen where the first and largest ice lenses were formed. There is a gradual decrease

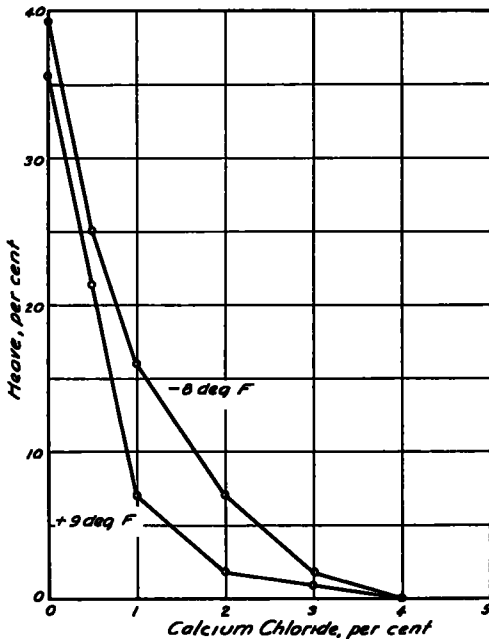


Figure 22. Effect of Calcium Chloride on Frost Heave

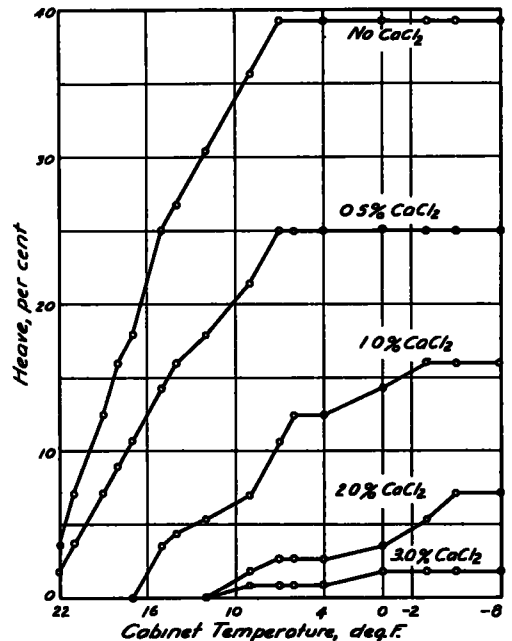


Figure 23. Effect of Calcium Chloride on Frost Heave

at a given time than was originally placed there. How much less depends upon many things, such as permeability of wearing surface to water, height of ground-water table, amount of rainfall, amount of evaporation, soil particle size, soil density, and possibly other factors.

Figure 22 indicates that small percentages of calcium chloride in silt should provide adequate protection, and it can be assumed that even smaller amounts will suffice for other soils. In Figure 23 the

until the depth is reached where the soil was in a state of capillary saturation even before ice lenses started to form. From this point to the bottom of the sample there is an increase in water content.

Calcium chloride was carried up with the water rising to form the ice lenses, as shown by Figure 25. In all specimens that heaved, the upper portion of the soil contained more chemical at the end of the test than it originally received; the lower portion always contained less. In all cases,

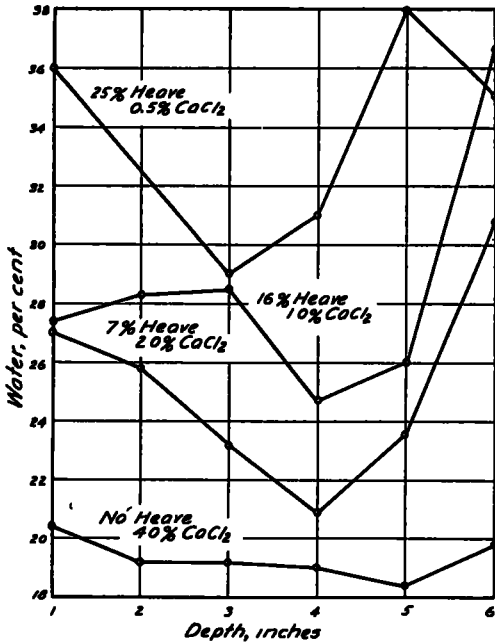


Figure 24. Shift of Water in Soil Due to Frost Heave

notably the one in which no heaving occurred, calcium chloride was lost into the ground water by diffusion

CONCLUSIONS

The following conclusions were drawn from the experimental work

Field Migration Studies

1. Calcium chloride will migrate laterally when it is applied in pockets under paved surfaces; therefore, it can be used in this manner to treat paved roads which were laid without use of the chemical.
2. Calcium chloride need not and should not be placed deeper than necessary below the top of the subgrade when it is applied in pockets, for vertical migration is more rapid than horizontal. Sufficient chemical will migrate downward in any case, and a greater quantity will be lost into the ground water if the pocket is placed at more than the minimum depth.
3. Lateral migration is very slow in silty clay soils under pavements. Corrective results cannot be expected for some time after the chemical is applied in this case. The time necessary will vary with the soil conditions.
4. Pockets of calcium chloride must be placed at close intervals in order to insure that sufficient chemical will reach the regions midway between the pockets. No general recommendation can be made; the interval will vary with different soil conditions
5. Calcium chloride applied as a solution in a pocket under a paved surface will migrate more rapidly for a short time than that applied as a solid.

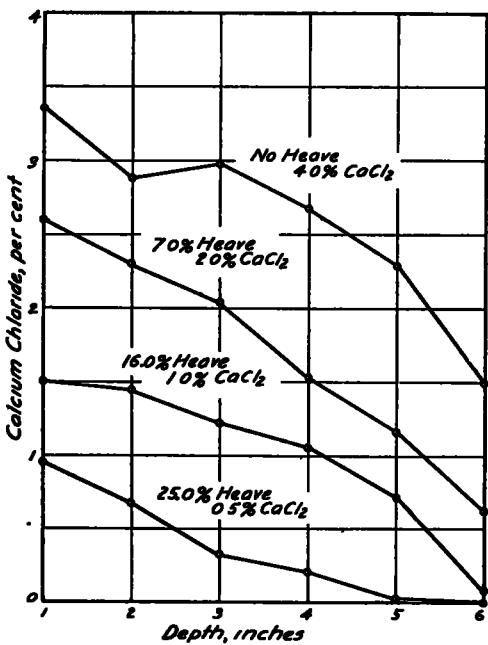


Figure 25. Migration of Calcium Chloride as Affected by Frost Heave

- 6 A pocket containing twice as much calcium chloride as another pocket will supply about twice as much chemical to the surrounding soil as the latter for a certain length of time only. After this, the amounts tend to become more nearly equal, although more chemical is still supplied by the larger pocket. The larger pocket will not supply chemical to a much greater distance than the smaller one.
7. The more permeable a pavement is to water, the faster migration from a pocket of calcium chloride under that pavement will proceed.

#### *Laboratory Model Studies*

1. The higher of two ground-water levels, when both supply water to the migration zone, will cause a faster rate of migration than the lower level.
2. Silt has little ability to hold calcium chloride when water is being passed through the soil in any direction.
3. Diffusion causes calcium chloride to migrate to the region of least concentration in soils.
- 4 The passage of water downward through a soil carries calcium chloride with it.
5. Evaporation of water from a soil carries calcium chloride upward through the soil, especially if there is a continuous supply of capillary water available at the surface for evaporation.
6. When calcium chloride is carried either up or down through a soil by rainfall or evaporation, there is very little lateral movement of the salt compared to vertical

#### *Effect of Calcium Chloride on Frost Heaving in Soils*

1. The presence of a small percentage of calcium chloride in silt will

- usually protect that soil from damaging frost heave.
2. Small quantities, as low as one-half of one per cent, of calcium chloride in silt will reduce the frost heave of that soil appreciably.
- 3 A soil that has heaved because of frost contains a moisture content greater than normal. This water makes up the ice lenses causing the heave, and it is drawn up from the ground water.
4. The water rising to form the ice lenses carries calcium chloride upward with it.
5. As a general average, it can be said that protection from frost heave in silt is afforded by 2 per cent  $\text{CaCl}_2$ , in clay by 1 per cent  $\text{CaCl}_2$ , and in graded mixes by  $\frac{1}{2}$  per cent  $\text{CaCl}_2$

#### ACKNOWLEDGMENTS

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#### REFERENCES

- 1 Becker, G F, and Day, A L, "The Linear Forces of Growing Crystals," *Proceedings*, Washington Academy of Sciences, 7, 283-8 (1905).
2. Belcher, D J, "A Field Investigation of Low-Cost Stabilized Roads," Purdue University Engineering Experiment Station Bulletin No 81 (1941)
- 3 Bouyoucus, G J, "Further Studies on the Freezing Point Lowering of Soils," Michigan Agricultural College Experiment Station Technical Bulletin No. 31 (1916).
4. Miller, H H, and Smith, D N, "Methods for Prevention of Road Failures Due to Frost," *Roads and Streets*, June, 1934
- 5 Slesser, Charles, "Field Studies of Migration of Calcium Chloride and Sodium Chloride in Soil," Thesis, Purdue University, 1940
- 6 Slichter, C. A., "Field Measurements of the Rate of Movement of Underground

- Waters," *U S Geological Survey, Water Supply and Irrigation Paper No 140*, 29-49 (1905)
- 7 Taber, Stephen, "The Growth of Crystals under External Pressure," *American Journal of Science*, 41, 544-5, 552 (1916)
  - 8 Taber, Stephen, "Surface Heaving Caused by Segregation of Water Forming Ice Crystals," Letter, *Engineering News-Record*, 81, 683-4 (1918)
  9. Taber, Stephen, "Frost Heaving," *Journal of Geology*, 37, 428-61 (1929)
  - 10 Taber, Stephen, "The Mechanics of Frost Heaving," *Journal of Geology*, 38, 303-317 (1930).
  - 11 Taber, Stephen, "Freezing and Thawing of Soils as Factors in the Destruction of Road Pavements," *Public Roads*, 11, 113-132 (1930).
  - 12 Taber, Stephen, "Discussion on Frost Heaving," *Proceedings, Highway Research Board*, Vol 11, 173-7 (1931)
  - 13 Wilford, H D, Downey, B. R, Hogen-togler, C. A , Jr, Knight, J. A , Elleman, John, and Burggraf, Fred, "Use of Calcium Chloride in Road Stabilization," *Proceedings, Highway Research Board*, Vol 18 Part II, 209-256 (1938)
  14. Winn, H. F, and Rutledge, P C, "Frost Action in Highway Bases and Subgrades," *Purdue University Engineering Experiment Station Bulletin No 73* (1940).
  15. Beskow, Gunnar, "Prevention of Detrimental Frost Heave in Sweden," *Proceedings, Highway Research Board*, Vol. 18, Part II, 366-370 (1938)
  - 16 "Heavy Frost Damage to Roads Follows Open Winter," *Engineering News-Record*, 100, n 17 (1928)