Freezing-and-Thawing Tests on Mixtures of Soil and Calcium Chloride

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Three soils, including a silt, silty clay, and clay-like soil, were used in this study. Specimens were molded using varying percentages of calcium chloride as an admixture and freezing-and-thawing tests were made at freezing temperatures of 24 F. and -18 F. The specimens were permitted to absorb water during the thawing cycles in some of the tests, while in other tests they were not. Further, several specimens were permitted to change in volume while others were not. Unconfined compression, and California bearing-ratio tests were made after various cycles of freezing and thawing.

The results of the study indicated that the greatest percentage loss in strength resulted after one cycle of freezing and thawing. It was found that calcium chloride reduced this loss in strength a small amount, due principally to its ability to lower the freezing temperature of the water in the soil. It was further found that restraining the specimens during the freezing cycles and thus keeping them from changing volume increased the effectiveness of the calcium chloride.

● THE problem of loss in soil bearing under highway and airport pavements in the spring has long been recognized. Research has been turned in that direction by pavement performance surveys made during the spring of the year (1, 2). In this connection, frost affects have been found to manifest themselves in two ways: (1) frost heave, an actual heaving of the soil due to growth of ice lenses, and (2) spring breakup, a condition brought about by the softening of the subgrade immediately under the pavement during the spring. Further, many soils become soft and lose considerable strength upon being subjected to alternate cycles of freezing and thawing.

Research dealing with frost action of soils has been varied and covers both laboratory and field investigations of the mechanics of soil freezing. Work has been done in the field, by means of load-bearing tests, on the loss in strength of the subgrade in the spring of the year. This type of work has been carried out extensively in connection with the Highway Research Board committee on Load Carrying Capacity of Roads as Affected by Frost Action (3).

Research has generally been directed towards the rate and amount of heaving resulting from freezing of soils. Work of this type includes that of Taber (4, 5), Winn and Rutledge (6), Haley and Kaplar (7) and others. Slate (8) reported on the prevention of frost heave by the addition of calcium chloride to soils.

A study was made by Johnson and Lovell (9) to determine the needs for future research in frost action of soils. The results of this study indicated a need for increasing present day knowledge of the technology of freezing and thawing processes in soils.

PURPOSE AND SCOPE

The purpose of this project was to determine (1) the effect of calcium chloride on loss in strength resulting from freezing and thawing soil and (2) the effect of calcium chloride on the rate and amount of moisture movement in soil during freezing and thawing. The scope included testing the three types of soils in the laboratory which are listed in Table 1.

Two of the soils were Illinoian drift materials, the silt representing the A horizon and the silty clay the transition to the B horizon. The third soil represents calcareous Wisconsin drift occurring in slight topographic depressions.

The effect of freezing and thawing on the strength of the soils was evaluated by means of unconfined-compression tests as well as California bearing-ratio tests. Calcium chloride was added to the soils in percentages up to two percent by weight.

Freezing and thawing conditions were limited to freezing and thawing of the samples from all directions. Two freezing temperatures were used: 24 F. and -18 F. In addition, several tests were made on samples kept at room temperature during the cycle in which other specimens were frozen. The variables of moisture and density were introduced by molding specimens under the following conditions: (1) 100 percent maximum Proctor density and 100 percent optimum moisture content; (2) 95 percent maximum Proctor density and 100 percent optimum moisture content; and (3) 100 percent maximum Proctor density and 75 percent optimum moisture content.

TABLE 1

SOILS TESTED

Designation and Derivation	L. L %	P L %	Proctor Weight pcf.	C E Frost Class
Vigo silty clay - Illinoian Drift	32	18	114 2	F_3
Brookston Clay - Wisconsin Drift	50	30	105 0	F_3
Vigo Silt - Illinoian Drift	29	25	103.4	F_4

In addition, several tests were made in which the samples were not permitted to absorb water during the thawing portion of the cycle and some in which the specimens were completely or partially restrained curing the cycles.

PROCEDURES

Since it was desirable to determine the rate and amount of moisture movement in soil, as well as the strength characteristics of the mixtures of soil and calcium chloride, procedures were devised whereby both determinations could be made on one soil specimen.

Molding

The procedures adopted for making the compressive-strength specimens were relatively simple and consisted of compacting the soil, in cylinders 2 inches in diameter by 4½ inches in height, to a predetermined density and at a known moisture content. This was done by weighing out a known amount of wet soil, placing the entire amount of soil in the 2-inch-diameter cylinder, and then compacting it until it was exactly 4½ inches in height. Figure 1 shows a view of the disassembled cylinder. The 2-by-4½-inch specimen was used to facilitate the performance of unconfined compression tests. The ratio of h/d for this size specimen is 2¼.

After molding, each specimen was encased in a thin rubber membrane, with both ends of the specimen left exposed to the air. Duplicate specimens were made, in most cases, and the results averaged to insure consistent results.

The California bearing-ratio specimens were molded at the standard Proctor optimum moisture content as determined by previous compaction tests. The height, weight, and number of blows of the compaction hammer were adjusted so that the energy imparted to the soil during compaction was approximately equal to that used in the standard Proctor test (12,400 ft.-lb. per cu. ft.).

Freezing and Thawing

Two types of freezing-and-thawing tests were made. The first was one in which the specimens were frozen radially with the reduced temperature applied to all faces of the specimen. The specimens were allowed to absorb water from the bottom during the thawing period of the cycle.

Twenty-four hours of reduced temperatures and 24 hours of thawing constituted one cycle of freeze and thaw. After both the freezing and thawing portions of the cycle were completed, the specimens were measured and weighed. Following the completion of the desired number of cycles, the specimens were tested for their unconfined compressive strengths and then cut into ½-inch slices for moisture determinations.

The other type of test used was similar to the first, except that the specimens were completely restrained during the cycles (see Figure 2). Water absorption was again permitted during the freezing portion of the cycle.

In addition to the above tests, several specimens in both groups were tested with no free water available for capillary saturation.

To determine the effect of freezing temperatures on strength, tests were made on samples frozen at +24 F., -18 F., and on others which were not frozen at all, but kept at room temperature during the normal freezing cycle.

The C.B.R. specimens were exposed to weathering cycles much the same as were the unconfined-compression samples.

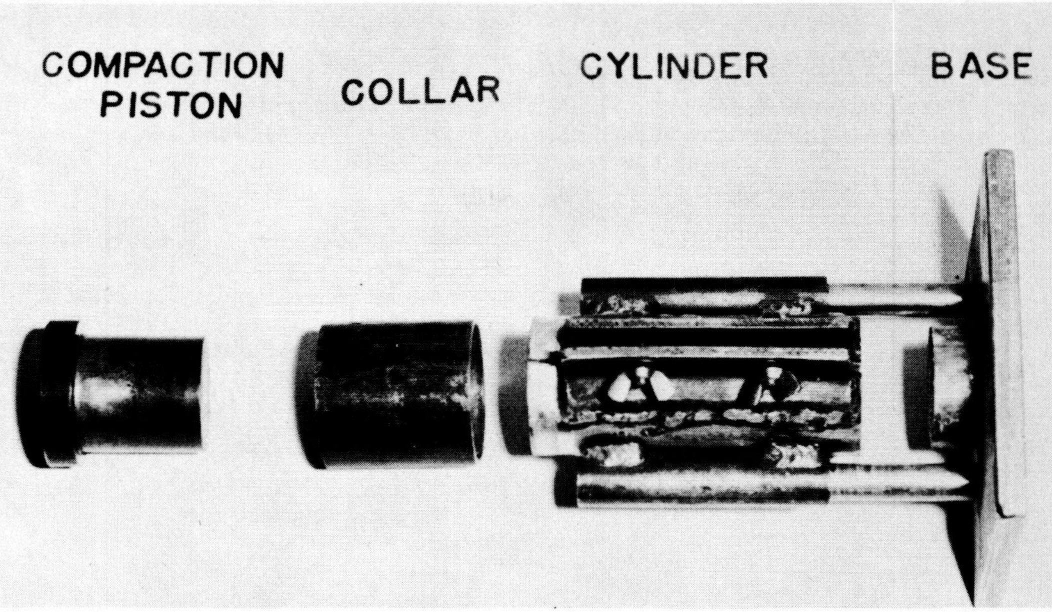

Figure 1. View of compaction mold. The base, cylinder, collar, and piston were machined so that when completely assembled and in contact, the length of the inside of the cylinder was exactly 4½ inches.

The specimens were, however, placed in water during the thawing portion of the sample and permitted to take up water from the top as well as the bottom. A 17-lb. surcharge weight was kept on these specimens at all times during the cycles.

Unconfined Compression Tests

After the desired number of freezing-and-thawing cycles were completed, the specimens were tested for unconfined compression. The specimens were loaded at a rate of 0.05 inches deformation per minute. The ultimate compressive strength was taken either as the peak unit load, or the unit load at 20 percent strain, whichever occurred first, divided by the corrected cross-sectional area.

Since the specimens were permitted to absorb water from the bottom during thawing, some of the specimens were quite soft

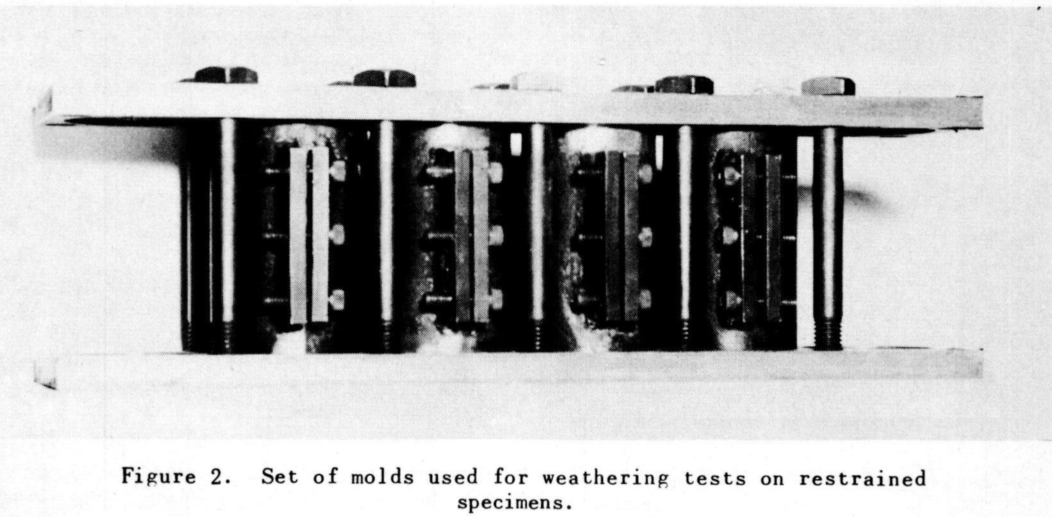

Figure 2. Set of molds used for weathering tests on restrained specimens.

TABLE 2

EFFECT OF SOIL TYPE AND CALCIUM CHLORIDE ON SOIL STRENGTH AFTER ONE CYCLE OF FREEZING AND THAWING

(Freezing temperature = 24 F., all specimens molded at optimum moisture and to 100 percent Proctor density)

Soil Type	$CaCl_2$	Moist	Density	Strength	Loss in Strength from initial	$CaCl_2$ Concentration before freeze	after thaw
	%	%	pcf.	psi.	%	% weight water	
	0	21.2	103.1	6.2	82	0	0
Brookston Clay	1	21.1	104.4	9.0	72	5.45	4.74
	2	19.6	104.6	16.0	50	10.10	10.20
Vigo Silty Clay	0	17.0	111.0	5.0	82	0	0
	1	16.1	112.0	10.5	67	7.10	6.20
	2	13.7	116.5	22.0	21	14.30	14.60
Vigo Silt	0	22.7	100.7	13.8	54	0	0
	2	21.5	101.5	17.0	37	12.3	9.30

in the lower half but relatively firm in the upper half. This was particularly true of those specimens treated with calcium chloride. As a result, failure generally resulted in bulging in the lower half of the specimen.

California Bearing-Ratio Test

The C.B.R. tests were made in the conventional manner using a piston having an end area of 3 sq. in. Loads were applied at a uniform rate of 0.05 inches per minute. The bearing ratio was calculated for each 0.1-inch penetration up to 0.5 inch of penetration; these values were then averaged. A surcharge weighing 17 lb. was used during the test.

Moisture Determinations

After both the unconfined-compression and C.B.R. tests, the specimens were cut in slices ½ inch high. A portion of each of these slices was then weighed and dried to constant weight and reweighed for moisture determinations. An attempt was made to make these slices exactly ½ inch in height so that the variation of dry density with depth, as well as moisture content, could be determined.

RESULTS

Most of the results presented in this section are averaged results. The interrelationship of all the variables was apparent from the start, and even though an attempt has been made to evaluate each variable independently, this interrelationship should be kept in mind.

Effect of Soil Type

The texture of a soil will influence its strength characteristics in a number of different ways: First, soil texture, density, and moisture holding capacity are all interrelated. A fine-grained soil will generally have a lower density (for a given compactive effort) than a coarse-grained soil with a resulting higher moisture content after saturation. Second, the rate at which water will rise in soil by capillary action will also vary with soil type. The amount of water which will freeze in a soil at a given temperature is largely unknown, but this too varies with soil type; or more basically with the amount of adsorbed water, grain shape, etc.

The results of the tests made on the three soils under conditions of 100 percent standard Proctor density and molded at optimum moisture content are shown in Figure 3. These curves reveal that when a freezing temperature of 24 F. was used the calcium chloride was most effective when incorporated in the silty clay.

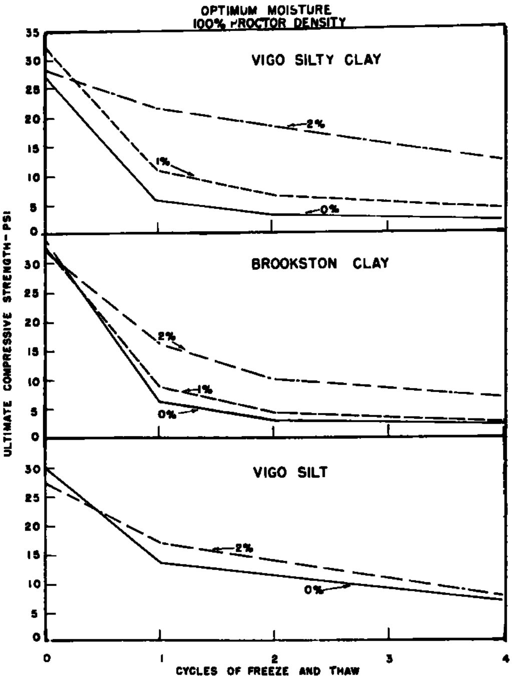

Figure 3. Effect of soil type on unconfined compressive strength.

The effect of calcium chloride at lower temperatures is discussed in the next section. Each of the soils had initial compressive strengths of comparable magnitude, ranging from 27 psi. to 34 psi. However at the end of the first cycle of freezing and thawing, the unconfined compressive strengths of all Brookston clay and Vigo silt samples were below 17 psi. In contrast, the unconfined compressive strength of the specimen of silty clay and 2 percent of calcium chloride was equal to 22 psi.

It should be kept in mind that each specimen was allowed to absorb water during the thawing cycle, thus the adverse effect of excess moisture was most apparent in those soils which absorbed water most readily. Furthermore, since the effect of the calcium chloride is principally that of lowering the freezing temperature of the soil water, the concentration of the salt in the soil water materially affected the soil strength after freezing.

A summary of the test data after one cycle of freeze and thaw is also shown in Table 2. Observation of this table brings out that a correlation exists between the concentration of the calcium chloride in the water and soil strength. The soils with the highest concentration of calcium chloride in the water (silty clay, 2 percent $CaCl_2$ mix; 14.6 percent calcium chloride in the water) lost the least amount of strength after freezing and thawing. This particular soil also had the highest initial density and lowest initial moisture content of all the soils. Other factors, such as mineralogical content of the soils, no doubt also affected the results, but to an unknown extent.

It was noted throughout the testing program that the greatest loss percentagewise in strength resulted after the first cycle of freeze and thaw. Additional losses in strength resulted after further cycles, but these were small compared to that after the first cycle. The loss in strength after the first cycle was generally 50 percent or more of the original strength.

TABLE 3

EFFECT OF FREEZING TEMPERATURE ON COMPRESSIVE STRENGTH AFTER ONE CYCLE OF FREEZING AND THAWING

Soil Type	$CaCl_2$	Freeze at 24 F		Freeze at -18 F.	
		Strength	Loss in Strength from Initial	Strength	Loss in Strength from Initial
	%	psi	%	psi	%
	0	6.2	82	9.0	74
Brookston Clay	1	9.0	72	9.0	72
	2	16.0	50	9.0	72
Vigo Silty Clay	0	5.0	82	0.5	98
	1	10 5	67	0.5	99
	2	22.0	21	0 5	98
Vigo Silt	0	13 8	54	14.0	53
	2	17 0	37	14.8	46

Effect of Moisture and Density

Figure 4 shows variation of compressive strength, average moisture content, and average dry density during freezing and thawing for the Vigo silty clay.

The data of this figure help explain the reason for the specimens of calcium chloride showing less loss of strength after freezing and thawing than the untreated specimens. Here is shown again in the upper curves, the strength curves for the Vigo silty clay as were shown in Figure 3. The lower and center curves indicate average dry density and average moisture content for the specimens. It will be seen that for this soil the treated specimens had the greatest initial dry densities, and that as the specimens progressed through the freezing-and-thawing cycles, the dry densities of the untreated specimens fell off rapidly with corresponding increases in moisture content. This was felt to be due chiefly to the chemical lowering of the freezing point of the soil water, thus minimizing expansion during freezing.

In this connection, several tests were made to determine the freezing point of the soil water with and without the calcium chloride admixture. These tests consisted of depressing the soil temperature and by taking readings at various intervals, determining the temperature at which the soil-water froze as indicated by the horizontal portion of the curve of temperature versus time. These tests indicated that when 2 percent of calcium chloride was incorporated in the soil, the freezing point of the soil was depressed below 24 F.

Since unconfined-compression testing techniques were used to evaluate the stability of the soils, several pertinent factors should be pointed out that affected the test results. First, at the time of test,

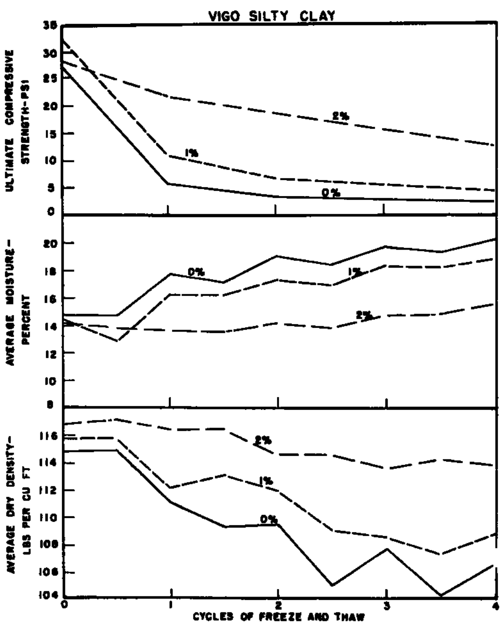

Figure 4. Variation of unconfined compressive strength, average moisture content, and average dry density with cycles of freezing and thawing.

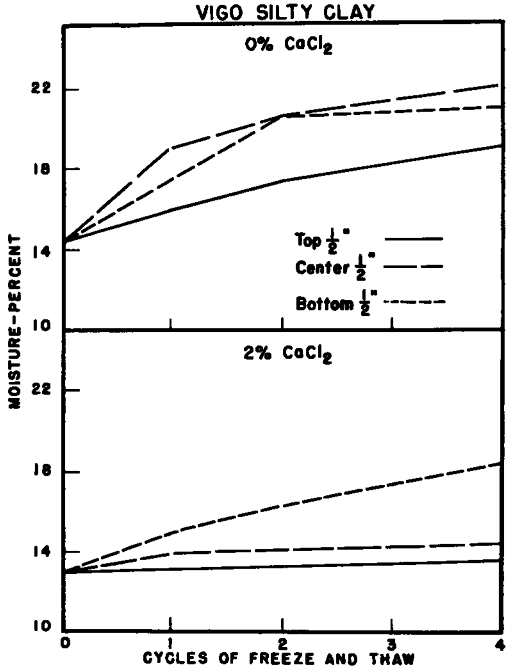

Figure 5. Variation of moisture content with depth of specimen.

after the appropriate cycle of freezing and thawing, the moisture by and large was concentrated in the lower portions of the specimens, as indicated in Figure 5. The density of the specimens likewise varied from bottom to top with lower densities being recorded at the bottom.

The curves of Figure 5 indicate variation of moisture content with depth in the Vigo silty clay samples after one cycle of freezing and thawing. These determinations were made by cutting the unconfined-compression samples into thin slices after the test, measuring and weighing them, and determining their moisture contents. This graph shows moisture content at only three locations: top, center, and bottom ½ inch. It will be noted that the moisture was by and large near the bottom of the specimens. However, it will be seen that the moisture content of the untreated specimen was more nearly the same throughout the height of the specimen than was the one treated with 2 percent of calcium chloride. In other words, not only was the average moisture content of the untreated specimen higher than the treated, but there was less variation from top to bottom in the untreated specimen.

Figure 6 shows the effect of initial moisture content and dry density on the test

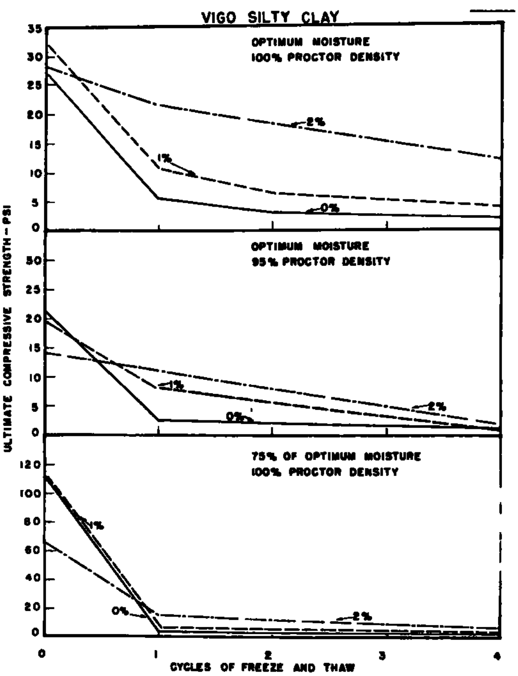

Figure 6. Effect of initial moisture content and dry density on unconfined compressive strength.

results. The upper curves are the same as those previously shown, while the lower and center curves indicate unconfined-compression strength versus cycles of freezing and thawing for specimens compacted at lower initial densities and moisture contents. In the center curve the specimens were compacted at optimum moisture content, but to just 95 percent of maximum Proctor density, while the specimens illustrated by the lower curves were compacted to 100 percent of maximum Proctor density, but at a moisture content of 75 percent of the optimum. It can be seen that lowering either the initial density or moisture content almost obliterated the effect of the chemical. It is further seen that the specimens molded at low moisture contents lost practically all their strength after one cycle of freezing and thawing, even though the initial strengths were very high.

Effect of Freezing Temperatures

Figure 7 shows the results of tests made on the Vigo silty clay using a freezing temperature of -18 F., as well as 26 F. and for samples which were not frozen. Observation of the curves in Figure 7 and the data in Table 3 indicates that the calcium chloride was most effective when the specimens were frozen at relatively high temperatures. However, in the case of the silty soil, no great difference was apparent between strengths of the treated specimens after freezing at -18 F. and after freezing at +24 F. The silty clay soil showed greater loss in strength at -18 F., as did the clay-like soil.

The effect of soil texture on the effectiveness of the chemical was obliterated when a freezing temperature of -18 F. was used. In the previous section, it was brought out that the admixture was most effective when used in the silty clay material (depressed temperature 24 F.). However, when freezing temperatures of -18 F. were used, the unconfined compressive strengths were practically the same, for a particular soil, regardless of the quantity of admixture that was used.

TABLE 4

EFFECT OF LENGTH OF CYCLE (BROOKSTON CLAY)

	$CaCl_2$ (%)	After One Cycle of One Day Freeze at +24 F and One Day Thaw on Porous Stone		After One Cycle of One Week Freeze at +24 F and One Week Thaw on Porous Stone		After One Cycle of One Day Freeze at -18 F. and One Day Thaw on Porous Stone	
		After Freeze	After Thaw	After Freeze	After Thaw	After Freeze	After Thaw
Density	0	104.5	103.1	105.5	105.4	105 8	102.4
($\#ft.^3$)	1	105 0	104 4	106 6	103.0	106.5	103.5
	2	106 5	104.6	105.6	100 2	105.5	102.0
Moisture	0	19 9	21 2	18.3	20 0	18.8	20.7
(%)	1	18.8	21.1	18.1	21 4	18 5	20.0
	2	19.4	19 6	17.7	22.0	19 4	20.5
Strength	0	-	6 2	-	7 0	-	9.0
(psi)	1	-	9.0	-	7.5	-	9 0
	2	-	16.0	-	9.8	-	9.0
Loss in	0	-	82	-	79	-	74
Strength	1	-	72	-	77	-	72
from initial (%)	2	-	50	-	69	-	72

TABLE 5

EFFECT OF WATER ABSORPTION (BROOKSTON CLAY)

Freezing Temp.	$CaCl_2$	Initial Strength	Loss in Unconfined Compressive Strength from Initial: After One Cycle: Water Absorp.	After One Cycle: No Water Absorp	After One Cycle: Diff *	After Four Cycles: Water Absorp.	After Four Cycles: No Water Absorp	After Four Cycles: Diff *
	(%)	psi	psi.	psi.	psi.	psi	psi	psi.
+ 24 F.	0	34.0	27.8	13 0	14 8	31 8	17 0	14 8
	2	32.0	16 0	2 0	14.0	25 0	2 2	22.8
-18 F.	0	34 0	25.0	17 0	8 0	31.0	26 2	4 8
	2	32.0	23.0	3 0	20.0	28 0	20 0	8.0

* Loss in strength that can be attributed to water absorption

Effect of Length of Freezing Time

Several tests were performed in which the freezing and the thawing phases were each increased to one week. The results of these tests are shown in Table 4. The effect of subjecting the soil-calcium chloride mixture to 24 F. for one week was practically the same as freezing it for a shorter period of time at -18 F. The treated specimens lost as much as 10 percent more of their initial strengths when freezing temperatures of 24 F. were used in the 1-week cycle as compared to the daily cycle.

A portion of this loss must be attributed to the longer period of thaw on the porous stones. At the end of one cycle the treated specimens in the 1-week cycle generally soaked up more water during the thawing cycle, and their densities were correspondingly lower after thawing than those whose cycle was 1-day freeze and 1-day thaw.

Effect of Water Absorption

During the thawing portion of the freeze-and-thaw cycles, water was permitted to flow into the majority of the specimens by capillary action. Since it was felt that a large portion of the decrease in soil strength was caused by this water absorption, an attempt was made to isolate this variable by sealing several specimens in paraffin, thereby not permitting them to lose or gain any moisture during the complete cycle. These specimens were first encased in thin rubber membranes, and then the ends were sealed with wax. Thus, expansion was permitted, even though no moisture changes took place.

Results of these tests are shown in Table 5. The data clearly illustrate that considerable loss in strength can be attributed to water absorption. When 24 F. was used with no water absorption, the compressive strength of the 2-percent-calcium-chloride specimen was 2.2 psi. less than the initial. It is seen also that when frozen at -18 F. these specimens showed appreciable losses in strength out to as far as four cycles. This is in contrast to the test results obtained when water absorption was permitted and by far the greatest reduction in strength resulted after the first cycle.

The data in this table also give a clue to the relative effects of soil freezing and

TABLE 6

EFFECT OF RESTRAINT ON COMPRESSIVE STRENGTH (BROOKSTON CLAY)

Freezing Temp	$CaCl_2$	Initial* Strength Restrained	Initial* Strength No Rest.	Loss in Compressive Strength from Initial: After One Cycle: Rest	After One Cycle: No Rest.	After Four Cycles: Rest	After Four Cycles: No Rest.
F	(%)	psi	psi.	(%)	(%)	(%)	(%)
			With Water Absorption During Thawing				
+ 24 F	0	33 0	34 0	9	82	30	93
	2	27 0	32 0	0	50	0	78
-18 F	0	33 0	34.0	28	74	42	91
	2	27 0	32 0	22	72	37	87
			With No Water Absorption During Thawing				
+ 24 F	0	33 0	34 0	15	38	24	50
	2	27 0	32 0	-33*	6	-26**	7
-18 F.	0	33.0	34.0	0	50	0	77
	2	27 0	32 0	-4**	9	-26**	62

* Different size specimens were used accounting for difference in strength

** Minus sign indicates increase in strength moisture changes. The losses in strength given in Columns 5 and 8 of Table 5 can be attributed to change in structure and density brought about by freezing, while those in Columns 6 and 9 are due to moisture absorption. It will be noted that the treated specimens lost little strength during freezing and thawing when no moisture was permitted to enter the specimen.

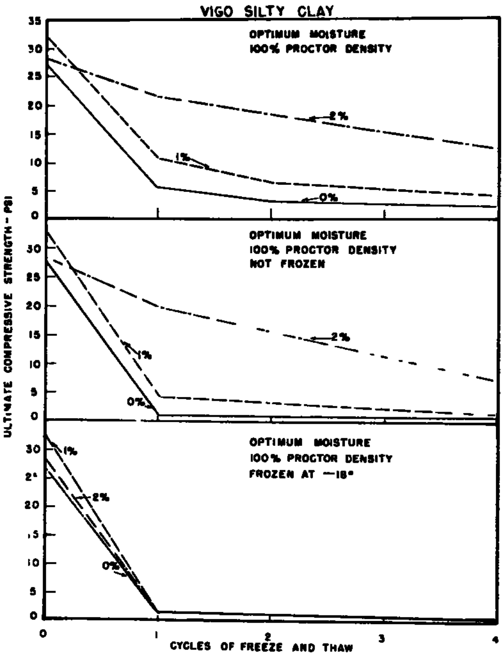

Figure 7. Effect of temperature on unconfined compressive strength.

Effect of Restraint During Freezing and Thawing

To further isolate the variable of moisture and density on strength, weathering tests were made on samples of the Brookston clay when in a completely confined condition. The specimens were encased in metal cylinders and held firmly by means of bolts. It was assumed that the plates on either end of the specimens were sufficiently rigid to make expansion negligible. The specimens were removed from these cylinders and tested in unconfined compression at the end of the weathering cycles.

The results of these tests are shown in Table 6. The results were slightly erratic, inasmuch as the treated specimens (which were in a restrained condition and not permitted to absorb water during the weathering cycles) showed increases in strength with cycles of freeze and thaw.

In general, when the specimens were permitted to absorb water they picked up just sufficient water to completely saturate the specimens. None of the specimens lost a great amount of strength during the cycles, the average being about 25 percent of the initial.

It will be noted in Table 6 that the effectiveness of the calcium chloride was materially increased by restraining the specimens. It is felt, however, that more tests need be made before any definite conclusions can be reached.

Effect of Calcium Chloride and Freezing and Thawing on C. B. R.

Only a limited number of C. B. R. tests were made, the results of which are shown in Figure 8. These tests were made using standard procedures utilizing a 17-lb. surcharge weight. The end point was to determine the effect of partial restraint during freezing and thawing. When the specimens were tested in a soaked condition, the calcium chloride increased the soil-penetration resistance after freezing and thawing, but not to any great extent.

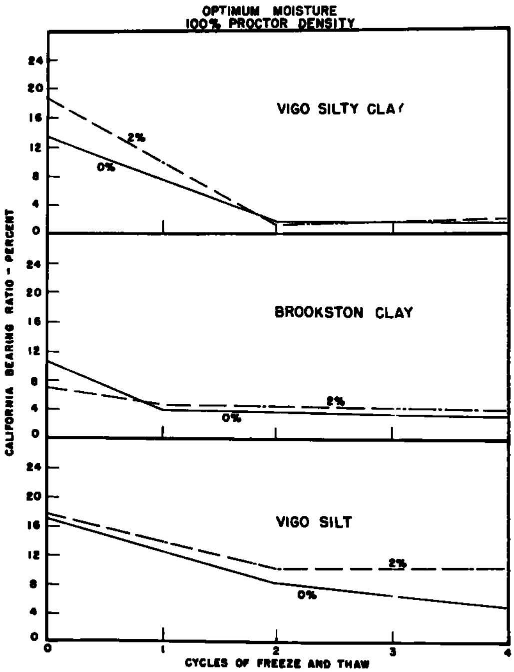

Figure 8. Effect of soil type on California Bearing Ratio.

The results indicated that the calcium chloride was effective in decreasing loss in C. B. R. in some cases, but that partial restraint of the surcharge did not have the effect of full restraint.

SUMMARY

The effects of freezing and thawing on soil strength are variable, depending on soil texture, density and changes in density, moisture content and changes in moisture content, duration of freezing, freezing temperature, and degree of confinement. The degree to which calcium chloride affected the strength of the soils differed for all of the above-mentioned variables and by restricting or controlling any one of the variables the effectiveness of the calcium chloride was increased.

The effectiveness of the calcium chloride was found to be principally due to its property of lowering the freezing point of the soil moisture. When the specimens were frozen at very low temperatures the salt was ineffective. Likewise, increasing the freezing time decreased the effectiveness of the calcium chloride.

The results and conclusions of the study are summarized below. They apply only to the conditions of test imposed in this study. The variable of permanence of the chloride, formation of ice lenses, and prevention of frost heaving, were not included in the study.

1. Soil texture influenced the effectiveness of the calcium chloride in preventing loss in strength after freezing and thawing. Moisture content and density played a very important role in this as did the actual concentration of the chloride in the soil water. For the three soils tested the calcium chloride was most effective in the silty clay soil.

2. When the specimens were molded at optimum moisture content and 100 percent of Proctor standard density, the calcium chloride reduced the loss in unconfined compressive strength resulting from the weathering cycles. This reduction was as much as 60 percent of the soil's initial strength.

3. Calcium chloride was found to be most effective at relatively high freezing temperatures. The principal effect of the chloride was that brought about by lowering the freezing point of the soil water.

When the specimens of soil and calcium chloride were frozen at relatively high temperatures for long periods of time, the effect was similar to that of freezing them at low temperatures for a short period of time.

5. Water absorption effected the test results appreciably. A larger portion of the reduction in strength of the specimens was attributed to water absorption rather than to the freezing temperature. However, in the case of the raw soil, the actual freezing of the soil had about the same effect as the water absorption.

6. Restraining the soil specimens, and thus preventing expansion, increased the effectiveness of the calcium chloride materially.

7. The calcium chloride was effective in decreasing loss in C. B. R. after freezing and thawing. The effect of partial restraint was not nearly as pronounced as that of total restraint on soil strength.

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9. Johnson, A. W. and Lovell, C. W., "Frost Action Research Needs", Soil Temperature and General Freezing, Highway Research Board, Bull., No. 71, 1953.
10. Yoder, E. J. and Korman, Oktay, "Second Progress Report on Freezing of Soil-Calcium Chloride Mixture", Progress report submitted to Calcium Chloride Institute, January 1953.

Discussion

ROBERT E. PYNE, Assistant Maintenance Engineer, Massachusetts Department of Public Works—In the fall of 1947 as a part of a reconstruction project on Route 116 in the town of South Hadley, an experimental section using calcium chloride as a deterrent to frost heaves was incorporated in the design. This research project was under the supervision of J. E. Lawrence, former maintenance engineer of the Massachusetts Department of Public Works and member of the Committee on Frost Heave and Frost Action in Soil of the Highway Research Board.

A plan and cross-section of the test section is attached. The northerly side of the road was the location of the former roadway which was completely removed to subgrade and a foot of permeable gravel was placed on the subgrade. The pavement consisted of 3½ inches of crushed stone bound with sand under a wearing course consisting of 2½ inches of crushed stone penetrated with bitumen, bound with keystone and sealed with bitumen and peastone. On the southerly side of the road new fill was placed to permit widening.

On top of the compacted fill calcium chloride was placed between: Station 3+0 and 4+0, 2¼ lb. $CaCl_2$ per sq. yd.; Station 4+0 and 5+0, 9 lb. $CaCl_2$ per sq. yd.; Station 5+0 and 6+0, 36 lb. $CaCl_2$ per sq. yd.; Station 6+0 and 7+0, 18 lb. $CaCl_2$ per sq. yd.; and Station 7+0 and 8+0, 4½ lb. $CaCl_2$ per sq. yd.

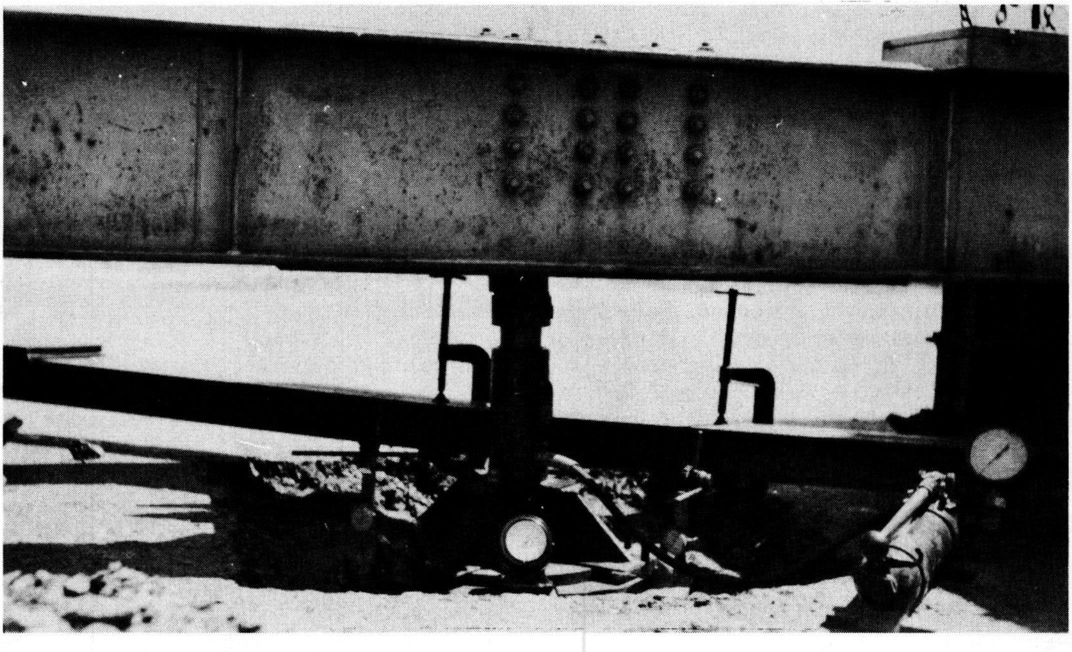


Figure A. Closeup of laboratory bearing-power equipment on South Hadley test.

The location of the project was selected because of its proximity to the Connecticut River and the resultant large volume of silt deposits which would tend to cause a maximum frost action. Generally, the subgrade soils consisted of sandy silts in the A-3 class.

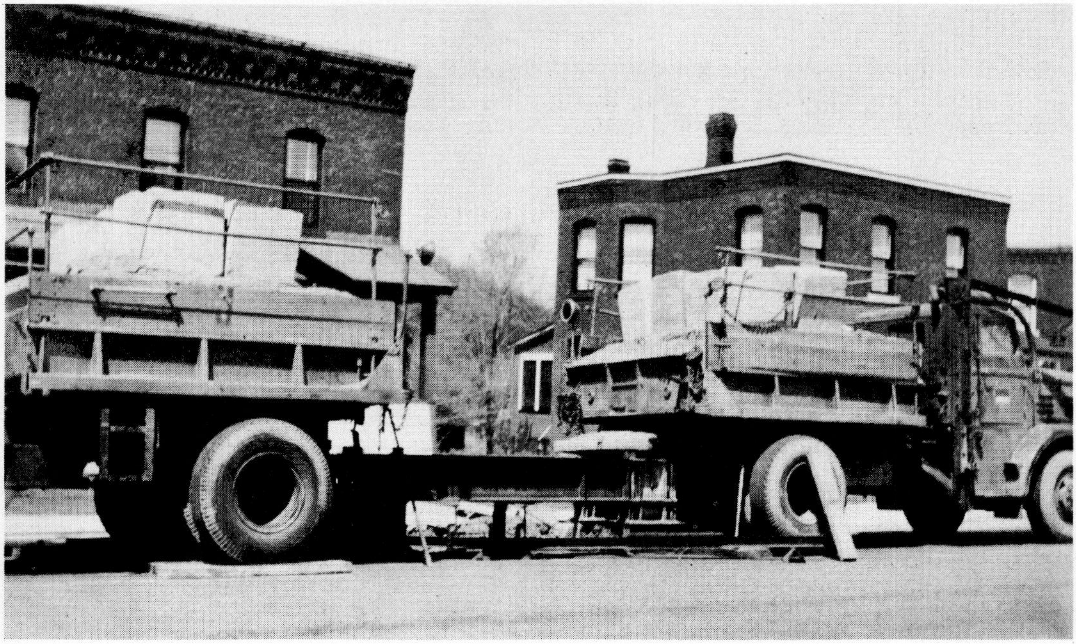


Figure B. Laboratory bearing-power equipment, showing position of loaded trucks.

On top of this treated subgrade the same construction was used as on the northerly side; that is, 1 foot of gravel, 3½ inches of sand-bound stone and 2½ inches of penetrated stone.

The project was completed very late in the fall and the top course was penetrated during a cold spell which caused considerable ravelling in the winter months, necessitating a surface treatment in January of 1948.

During the first winter following construction, two sets of levels were taken during a protracted cold spell from January 8 to February 3, there being but two cycles during this period. The third set of levels was taken on March 24 in more-moderate weather with a total of 22 cycles during the 7-week period. As indicated in the attached chart of frost movements, there was considerable variation between Station 1+50 and Station 3+0 on the southerly side which was untreated as compared with the treated section from Station 3+0 to Station 8+0.

It was noted on February 25, 1948, that a longitudinal crack appeared between Stations 3+0 and 8+0, approximately 1.5 feet to the left of the treated area. Between Station 3+0 and 7+0 on the treated

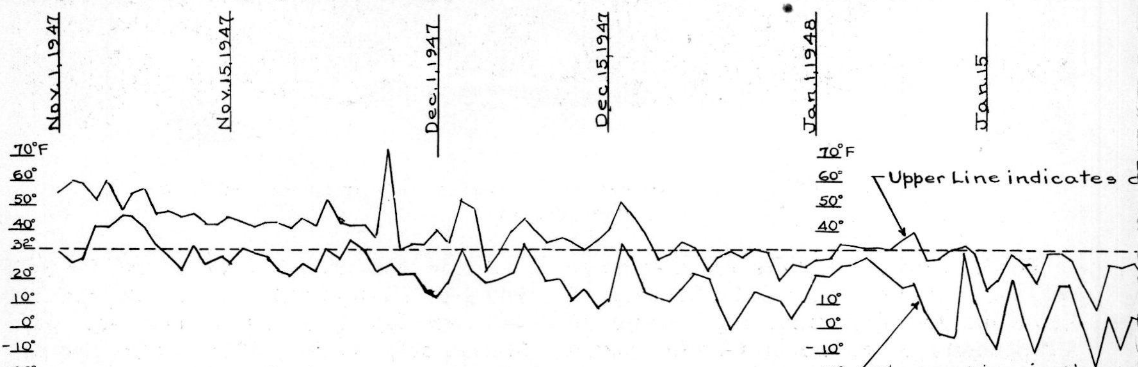


Figure C. Daily temperature chart for Newton Str

TABLE A

GRADATION AND LIMITS FOR SOILS FROM NEWTON STREET, SO. HADLEY, MASS.

(Samples taken from 2.0 to 4.0 feet down at each station)

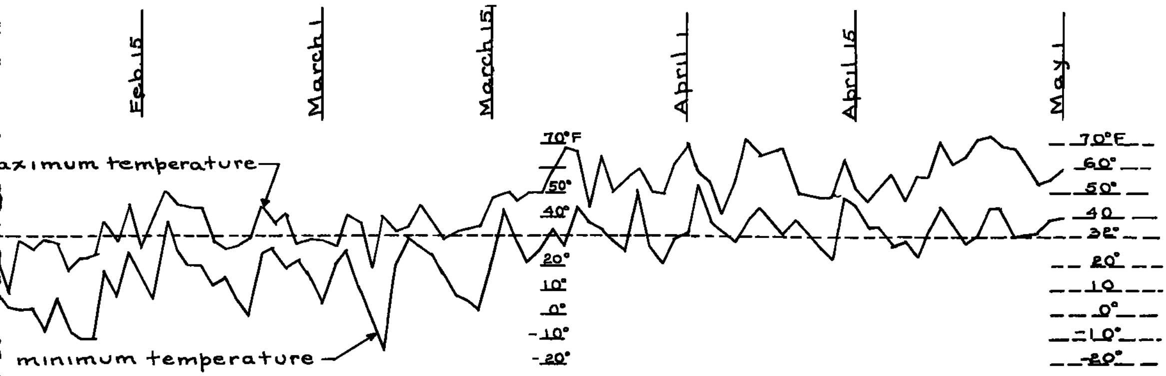
			Station				
			7+50	6+50	3+50	4+50	5+50
Gradation							
		Ret. 1½-in.	-	25.4	-	0.0	0.0
Pass.	1½-in.	1-in.	-	0.0	19.7	13.5	0.0
	1-in.	¾-in.	-	5.3	4.0	0.0	0.0
	¾-in.	½-in.	-	0.8	1.1	0.0	0.0
	½-in.	⅜-in.	-	-	3.5	-	-
	½-in.	No. 4	0.0	3.6	-	0.0	1.1
	⅜-in.	No. 4	-	-	0.9	-	-
	No. 4	No. 10	0.4	2.3	6.8	0.0	0.4
	No. 10	No. 20	1.2	8.5	6.1	0.6	0.4
	No. 20	No. 40	0.6	11.8	10.9	1.0	0.3
	No. 40	No. 80	3.4	15.1	9.5	3.1	0.6
	No. 80	No. 200	3.4	18.1	1.0	5.7	1.1
	No. 200	Pan	91.0	9.1	36.5	76.1	96.1
Limits							
Plastic Limit			26.9	None	11.7	18.3	21.2
Plastic Index			9.5	N.P.	4.3	5.3	7.1
Liquid Limit			17.4	15.6	16.0	23.6	28.3

side, the frost action was approximately 25 percent of that on the untreated area. The results between Station 7+0 and 8+0 were somewhat spotty but generally showed less frost action on the treated side.

This first winter proved to be an abnormally cold one with more than average snow fall. The frost depths as noted by public utility companies varied from 3.5 to 5.0 feet in depth under the roadway, whereas in the areas adjacent to the highway (covered with snow the entire winter) there was an average of 1 foot of frost. Attached to this report is a chart of Meteorological observations for the period from December 1947 through March 1948.

Field Bearing Tests

These tests were run with a 30-inch-diameter plate on the surface of the 12-inch gravel layer. The attached tabulation indicates bearing power at 0.20-inch Deflection in pounds per square inch. The average bearing power of all stations for an individual series of tests, or of any station for all series of tests, indicate that the treated area has higher bearing power than the untreated areas.



h Hadley, from November 1, 1947, to May 1, 1948.

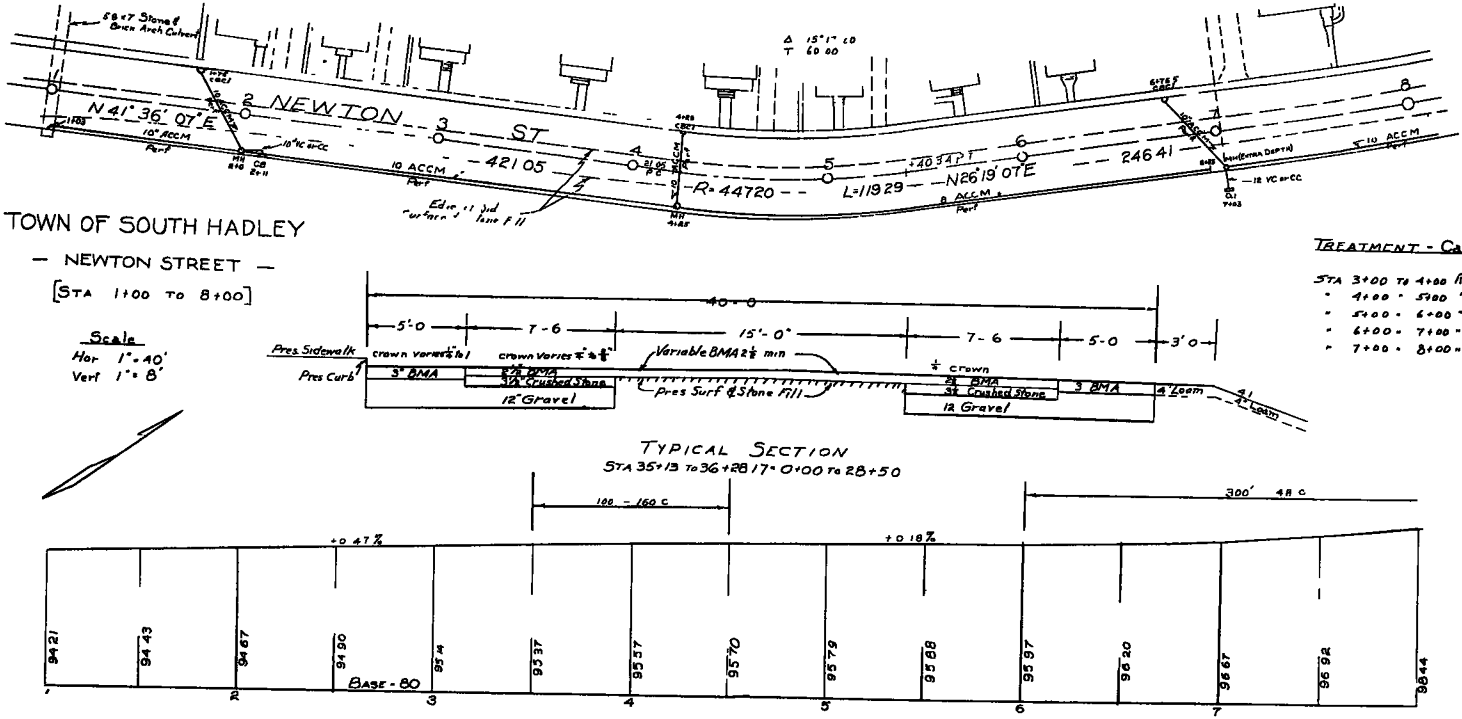

TOWN OF SOUTH HADLEY
— NEWTON STREET —
[STA 1+00 TO 8+00]
Scale
Hor 1" = 40'
Vert 1" = 8'
NEWTON ST
N 41° 36' 07" E
421 05
R = 44720
L = 119 29
N26° 19' 07" E
246 41
Δ 15° 1' 00
T 60 00
10" ACCM Perf
10 ACCM Perf
8 ACCM Perf
10 ACCM Perf
TREATMENT - CaCl2
STA 3+00 TO 4+00 Pr - 2½ #/sy
" 4+00 " 5+00 " - 9 #/sy
" 5+00 " 6+00 " - 36 #/sy
" 6+00 " 7+00 " - 18 #/sy
" 7+00 " 8+00 " - 4½ #/sy
40 - 0
5'-0
7 - 6
15' - 0"
7 - 6
5 - 0
3' 0
Pres Sidewalk
Pres Curb
3" BMA
12" Gravel
Variable BMA 2½ min
Pres Surf & Stone Fill
crown
3 BMA
12 Gravel
4" Loam
TYPICAL SECTION
STA 35+13 To 36+28 17 - 0+00 To 28+50
100 - 160 C
300' 4A C
+0 47 %
+0 18 %
94 21
94 43
94 67
94 90
95 14
95 37
95 57
95 70
95 79
95 88
95 97
96 20
96 67
96 92
98 44
BASE - 80
1
2
3
4
5
6
7

Figure D.

TABLE B

EXPERIMENTAL SECTION

SOUTH HADLEY, MASS. - AUTO ROUTE 116

Determination of Cl computed to $CaCl_2$

Sta. #3 - 3+50 R 2.25 lbs. $CaCl_2$ per sq. yd.				Sta. #2 - 4+50 R 9 lbs. $CaCl_2$ per sq. yd.				Sta. #1 - 5+50 R 36 lbs. $CaCl_2$ per sq. yd.			
7/2/48		1/23/50		7/2/48		1/23/50		7/2/48		1/23/50	
Depth	% $CaCl_2$	Depth	% $CaCl_2$	Depth	% $CaCl_2$	Depth	% $CaCl_2$	Depth	% $CaCl_2$	Depth	% $CaCl_2$
2.33'	0.00196	3.0'	0.023	2.33	0.00246	2.5'	0.018	2.33	0.00222	1.5'	0.009
		4.0'	0.016			3.5'	0.018			2.75'	0.023
		5.0'	0.022			4.5'	0.020			3.5'	0.040
		6.0'	0.011			5.5'	0.022			4.5'	0.031
		7.0'	0.011			6.5'	0.024			5.5'	0.201
						7.5'	0.002			6.5'	0.944
						8.5'	0.002			7.5'	0.363
						9.5'	0.003			8.5'	0.142
						10.5'	0.002			9.5'	0.027
						11.5'	0.004			10.5'	0.020
						12.5'	0.003			11.5'	0.011
						13.5'	0.002			12.5'	0.004
										13.5'	0.006
										14.5'	0.011

Calcium-Chloride Content

Tests of the amount of calcium chloride in the soil samples gave variable results. Initial soil samples tested for chloride content were taken in July 1948 at the edge of the pavement and at a depth of 28 inches. The results showed that considerable leaching action had taken place at the southerly edge of the pavement.

Samples taken in July 1949; January 1950; July 1951; and January 1954 were from the test pits for bearing power tests located in the center of the treated pavement. Test results are attached.

All test data was taken and compiled under the supervision of A. V. Bratt, testing engineer.

Conclusions

Based upon a study of data accumulated over the past six years during which this project has been under observation, the following general conclusions are made:

Calcium chloride, when used to reduce frost heave of pavements by treatment of the subgrade soil, does have beneficial results as long as the chemical is not dissipated.

The effective life of a calcium chloride treatment as used on this project depends upon permeability of the subgrade soil, drainage conditions, and tightness of the

TABLE C

SUMMARY OF FIELD BEARING LISTS

TEST DATE	STATION 3+50		STATION 4+50		STATION 5+50	
	Left 11.25' Untreated Subgrade	Right 11.25' 2¼# $CaCl_2$ per sq. yd.	Left 11.25' Untreated Subgrade	Right 11.25' 9# $CaCl_2$ per sq. yd.	Left 11.25' Untreated Subgrade	Right 11.25' 36# $CaCl_2$ per sq. yd.
November 1948	51.0# sq. in.	68.5# sq. in.	48.0# sq. in.	64.0# sq. in.	48.5# sq. in.	65.5# sq. in.
April 1949	51.8# sq. in.	59.5# sq. in.	28.0# sq. in.	53.3# sq. in.	47.0# sq. in.	71.5# sq. in.
June 1950	66.5# sq. in.	111.0# sq. in.	59.0# sq. in.	100.5# sq. in.	54.5# sq. in.	89.5# sq. in.

TABLE D

CHART OF MOVEMENTS IN NEWTON STREET, SOUTH HADLEY, SURFACE IN RELATION TO ELEVATIONS TAKEN MAY 26th 1948

	January 8					February 3					March 24				
Station	20	10	0	10	20	20	10	0	10	20	20	10	0	10	20
1+50	+ 03	-.01	-.01	+.06	+ 15	+.07	+ 05	+ 05	+.12	+.14	-.01	+.04	00	+ 10	+.06
2+00	00	+ 03	+ 03	+ 07	+.08	+ 10	+.07	+ 05	+ 07	+ 04	+ 04	+ 08	+.02	+.06	+ 07
2+50	00	00	+.01	+.05	+ 12	+ 01	+ 09	+ 06	+ 06	+ 18	+ 03	+ 10	+ 02	+ 08	+ 21
3+00	+ 01	- 02	+ 01	+ 07	+ 01	+ 07	+ 07	+ 08	+.09	- 01	+.01	+ 07	+ 02	+ 09	+ 09
				2¼ lb											
3+50	- 03	+.34	+ 01	+ 01	-.01	- 02	+ 11	+ 09	+ 05	+ 04	.00	+.05	+ 01	+ 01	- 03
				Sq Yd.											
4+00	+ 06	+ 02	+ 04	+.03	00	+ 03	+ 08	+.08	+ 09	+.11	+.04	+.04	+ 02	+ 03	+ 13
				9 lb											
4+50	+ 06	- 07	+.01	+ 05	+ 03	+ 04	+.02	+ 12	+ 05	+ 02	+ 06	- 04	+.11	+ 02	+.08
			Treated Area	Sq Yd.					Treated Area					Treated Area	
5+00	-.01	- 03	+ 10	+ 03	- 02	+ 03	+.09	+.18	+ 04	00	+ 04	+ 03	+ 16	+.01	+.02
				36 lb											
5+50	+.05	+ 05	+ 01	+.02	+ 02	+ 04	+ 26	+ 08	+ 08	+.06	+.05	+ 08	+ 05	+ 01	+ 06
				Sq Yd											
6+00	+ 04	+.04	+ 06	+.04	00	+ 01	+ 27	+ 13	+.01	00	+.06	+.06	+ 08	+ 04	+.08
				18 lb.											
6+50	+ 06	+.16	+ 02	+ 01	+ 01	- 01	+ 18	+ 06	00	+.03	+ 10	+ 06	+ 08	+ 03	+ 02
				Sq Yd.											
7+00	+ 07	+.05	+ 02	+.07	+ 01	+.12	+.22	+ 08	+ 04	+ 02	+ 05	+ 06	+ 08	+ 05	+ 02
				4½ lb											
7+50	-.02	+.01	- 02	+.02	+ 02	+ 01	+ 05	+ 05	+ 06	+.02	+.03	+.05	+ 04	+.04	+ 02
				Sq. Yd											
8+00	.00	+ 03	- 01	00	+ 05	- 01	.00	+ 04	+ 07	-.02	+ 02	-.02	+ 04	+ 07	+ 08
8+50	+ 01	+.04	-.01	+.03	+ 02	- 01	+.01	+ 03	+.05	.00	+.02	+.01	+.02	+ 09	+.02
9+00	+.02	+.03	+.04	+ 08	-.01	-.01	+.09	+.08	+.03	- 06	+ 03	+.02	+.06	+ 09	-.01
9+50	+.04	+.03	+.05	+.06	+.06	-.02	+.04	+.01	+.04	-.01	+.06	+.04	+.04	+.05	+.05

pavement against percolation of surface water. On this project, not only was the penetration pavement sufficiently pervious to permit surface water to percolate through into the subgrade, but there was also a horizontal flow of water which caused additional leaching of the calcium chloride from the subgrade, thereby destroying its effectiveness. The effective life on this project was about 3 years. No calcium chloride remained in the subgrade after 6 years.

The proper application of calcium chloride for most-effective results varies with the individual project conditions. On this project 9 lb. of calcium chloride per square yard of subgrade surface seemed most effective.