

# Calcium Chloride in Road Construction

---

Pirjo Kuula-Väisänen, Hanna-Liisa Järvinen, and Pertti Nieminen,  
*Tampere University of Technology, Finland*

The effects of calcium chloride ( $\text{CaCl}_2$ ) on the properties of Finnish road construction materials used in the base course and subbase were examined. The properties studied in laboratory conditions were, first, the basic properties of grain size, specific surface area, water adsorption, and zeta-potential; and second, the compactability, frost heave and migration of these materials. Studies were also performed on full-depth reclamation with  $\text{CaCl}_2$  used in the United States and Canada. The literature review yielded a positive indication for the use of  $\text{CaCl}_2$  in road construction. The materials studied were crushed aggregates and glacial tills. The test results indicate that  $\text{CaCl}_2$  enriches in finer parts of materials, binds the finer particles together, and increases their water adsorption. Changes in the basic properties affect compactability and frost heave. The compaction needed to achieve a maximum dry unit weight decreases with  $\text{CaCl}_2$  use, and the material stays wet for long periods. When  $\text{CaCl}_2$  was used as an additive, the compactability of materials at below-zero temperatures was clearly better and the dry unit weight was nearly the same as at room temperature. Frost heaves decreased remarkably, even by 80 percent in frost-susceptible materials. The migration studies showed that the stability of  $\text{CaCl}_2$  is poor when it is in contact with percolating water. Despite the positive technical facts, the environmental effects should be considered carefully. The environmental effects were not studied, but some estimations were made, mainly based on a literature review.

The Finnish National Road Administration (FinnRa) and Finnish cities have used flake calcium chloride ( $\text{CaCl}_2$ ) for years to aid in dust control. The use of calcium chloride in maintenance is based on its beneficial chemical properties. Calcium chloride is hygroscopic and absorbs moisture from the air. Because of its deliquescence,  $\text{CaCl}_2$  can dissolve in the presence of moisture to form a liquid solution. The vapor pressure of this solution is significantly lower than that of pure water, and surface tension is higher. The properties of  $\text{CaCl}_2$  make it evaporate from solution much more slowly than from pure water. Dissolution of  $\text{CaCl}_2$  in water is an exothermic reaction.

Finland has many low-volume roads, with several problems associated with their maintenance and construction. For example, frost heaves in springtime cause restrictions for traffic and may prevent driving for weeks. The lack of sufficient materials also has led to a need for new materials and methods for base course construction. The chemical nature of  $\text{CaCl}_2$  could make it a beneficial additive to increase the stability of various existing construction materials. Partly due to these problems and lack of knowledge about  $\text{CaCl}_2$ , FinnRA and Kemira Chemicals, Ltd. initiated a project with a literature review and laboratory research on the use of  $\text{CaCl}_2$  in road construction. The study was carried out by the Institute of Engineering Geology at Tampere University of Technology.

The literature review included articles and research reports published in the United States and Canada.

Three main applications were mentioned for  $\text{CaCl}_2$  in road construction: compaction at above and below freezing temperatures, protection from frost heaving, and full-depth reclamation (FDR). All of these could have significance in Finland. The laboratory research to discover how  $\text{CaCl}_2$  affects the basic and technical properties of Finnish road construction materials used in base course and subbase was based on the facts found in the literature.

## LITERATURE REVIEW

Below-freezing temperatures cause problems in obtaining specific densities because of the formation of ice within the pore spaces. Haas et al. (1) found that calcium chloride can significantly improve the compactability of frozen soil. The test was performed at  $-7^\circ\text{C}$  and the silty sand was treated with 2 and 3 percent  $\text{CaCl}_2$ . The effect of  $\text{CaCl}_2$  on compactability was also tested at room temperature. The dry density of soil increased only slightly when compacted with 1 percent of  $\text{CaCl}_2$ .

Slessor (2) and Slate (3) investigated the effect of  $\text{CaCl}_2$  on the formation of ice lenses in subgrade soils. Both studies indicated that a few percent of  $\text{CaCl}_2$  can reduce frost heave noticeably. According to Slessor, 2 to 3 percent of  $\text{CaCl}_2$  can eliminate frost heave from coarser material. Fine-textured material would need 5 to 7 percent of  $\text{CaCl}_2$ . Slate suggested adding 2 percent  $\text{CaCl}_2$  to silt, 1 percent to clay, and 0.5 percent to coarser material.

Reckard (4) examined the effect of  $\text{CaCl}_2$  on frost heave and residual heave. In his experiments a schist material represented common soil types often used locally in road construction. The test results indicated that even small amounts of  $\text{CaCl}_2$  may greatly decrease frost heave as well as residual heave. The results suggest that the freezing point was depressed by  $\text{CaCl}_2$  and material was less frozen with higher salt content. In addition, the results indicated that there might be another mechanism influencing reduction in frost heave. In samples containing more salt, there was a greater delay between the time that freezing temperatures were initiated and the time that heaving began. Reckard also stated that the long-term heave rate (weeks or months) is still unknown.

FDR with  $\text{CaCl}_2$  has been applied for low-volume secondary roads requiring rehabilitation in the United States and Canada (5). In this process the existing bituminous surfaces are pulverized and blended with a predetermined amount of granular base material. Liquid  $\text{CaCl}_2$  is added twice; after pulverization and after the material is repulverized, graded, and rolled. The new road surface is allowed to cure for several weeks.

The use of this reclamation technology with  $\text{CaCl}_2$  seems to be based on the good results in field performance rather than on research results.

Slate (3) also investigated the migration of  $\text{CaCl}_2$  under field and laboratory conditions. The research results indicated that lateral migration was slower than vertical migration.  $\text{CaCl}_2$  should not be applied more deeply than necessary because the contact with groundwater will accelerate its migration. According to Slessor's field and laboratory studies (2), sodium chloride ( $\text{NaCl}$ ) was more susceptible to lateral surface washing than  $\text{CaCl}_2$ . A bituminous pavement decreased migration of both salts in fine-grained soils. The pavement prevented the leaching of  $\text{CaCl}_2$  by percolating water as well as surface-washing of  $\text{NaCl}$ . A high groundwater table accelerated the lateral movement of both salts. In sandy clay calcium cations are more permanent than sodium cations, and the two cations are more permanent than chloride anion.

It is not known to what extent  $\text{CaCl}_2$  leaches through the embankment over time, nor how long the lowering effect on frost heave will last. Reckard (6) estimated the migration of  $\text{CaCl}_2$  by applying half-life calculations and assuming that salt dissipates exponentially. Because of difficulties in determining background levels and variations in the test road conditions, the calculated data are inconclusive. However, the field data indicated that very little, if any, salt remains in road embankments several years after application.

Shepard et al. (5,7) investigated residual chloride levels in the test road section that was rehabilitated by FDR with  $\text{CaCl}_2$ . The test results indicate that in FDR,  $\text{CaCl}_2$  is retained effectively in the road structure during the first 10 months. The residual chloride results revealed that after the second and third year,  $\text{CaCl}_2$  had disappeared.

Calcium is essential for plant growth, but high concentrations of calcium will cause excessive salinity and may be specifically toxic. Calcium is added to the soil for pH control and to replace excessive sodium (8). Calcium diminishes plants' ability to absorb sodium, which prevents the negative effects of sodium. The studies indicate that chloride has an especially toxic effect on plants (9). There is currently no definite information on the effects of  $\text{CaCl}_2$  on plants. Many other factors (9), such as changes in weather and plant diseases, can cause the same kinds of damage as salts.

## MATERIALS AND METHODS

Six different types of materials were chosen for the laboratory tests. Three were crushed aggregates that were originally rock, gravel, and glacial till (Figure 1). These kinds of aggregates are usually used in road construc-

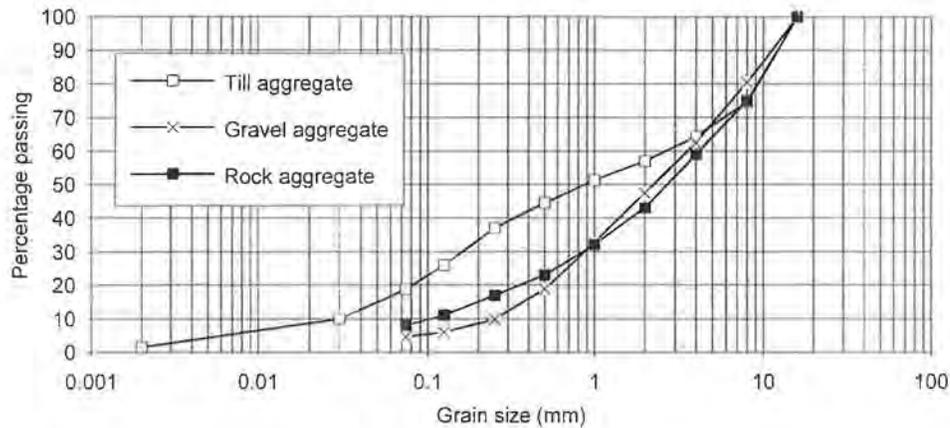


FIGURE 1 Grain size distributions of crushed aggregates.

tion in Finland. According to the Unified Soil Classification System (USCS), the gravel and rock aggregate are well-graded sands (SW) and the till aggregate is silty sand (SM). The mineralogical compositions of the samples were typical to the Finnish aggregates. Samples contained varied amounts of quartz, plagioclase, and feldspar and small amounts of biotite. The rest of the materials were glacial tills chosen for their different frost heave properties (Figure 2). According to the grain size distributions, tills could be classified as SM according to the USCS, although this kind of classification method does not describe the whole nature of glacial tills. Till Number 1 was a highly frost-susceptible, weathered till from northern Finland that contained iron. The two other tills were typical glacial tills with different fines contents (Number 2 had about 30 percent and Number 3, about 10 percent). The mineral composition of these two was typical to Finnish tills, that is, mainly quartz, plagioclase, and feldspar. The bituminous pavement used in FDR was obtained from a

highway and crushed with a laboratory crusher. The amount of bituminous pavement in FDR samples was 25 percent by weight of the aggregate. The  $\text{CaCl}_2$  solution was formed from flakes (77 percent). The solution used in the tests was 32 percent, and the amount used was 1 percent by weight of soil calculated as 77 percent  $\text{CaCl}_2$ .

The chloride content of the samples was measured with a chloride-selective electrode from a dispersion containing 70 g of aggregate and 150 mL of distilled water. When the chloride content of finer fractions was measured, the amount of sample was naturally smaller and the amount of water was decreased accordingly. The  $\text{CaCl}_2$  content of the materials was measured before and after the tests.

In order to find out the effects of  $\text{CaCl}_2$  on basic properties of materials, four variables were chosen: grain size, specific surface area, water adsorption index, and zeta potential. Grain size distribution was measured by sieving, and the grain size of fine fractions ( $d < 0.074$

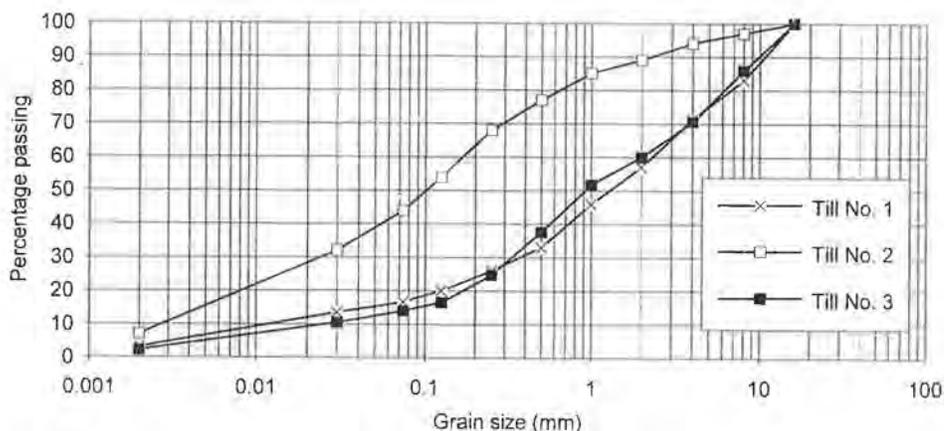


FIGURE 2 Grain size distributions of glacial tills.

mm) was determined with a laser diffraction analyzer. Specific surface area is the cumulative particle area per weight or volume unit ( $\text{m}^2/\text{g}$  or  $\text{m}^2/\text{cm}^3$ ). Grain size distribution, grain shape, and porosity of grains affect the value of a specific surface area. The specific surface area values have proven important, for example, in evaluating the weathering sensitivity of aggregates (10). For normal aggregates the values are between 0.5 and 5  $\text{m}^2/\text{g}$ , although the value varies from case to case. Specific surface areas of fine fractions were measured with the nitrogen adsorption method with Micromeritics Flowsorb. Water adsorption indices were determined using a method developed in the Institute of Engineering Geology at Tampere University of Technology (11). With this method the amount of water adsorbed on an oven-dry sample during a week in a desiccator in 100 percent relative humidity is determined. The water adsorption index is the amount of water adsorbed expressed by percentage of the dry weight of the sample. Normally the water adsorption values are between 0.5 and 2.0 percent. Zeta potential is an experimental value of the charge of a particle in a liquid. The value is expressed in millivolts and the value describes, among other things, the flocculation strength of particles in dispersion. The normal zeta-potential values for aggregates in distilled water are  $-20 \dots -30$  mV. Zeta potentials were measured in distilled water with Zeta Meter System 3.0.

Compaction studies were performed with a gyratory compactor developed in Finland. The compaction effort used can be observed during measurement. The diameter of the compacted specimen is 10 cm and the height of the specimen is 10 to 13 cm. Before the effect of  $\text{CaCl}_2$  was studied, the optimum water content and the maximum dry unit weight of the aggregates were determined. When  $\text{CaCl}_2$  was used, 1 percent liquid  $\text{CaCl}_2$  and an optimum amount of water was mixed with the material, and the compaction was started immediately. When the compactability of frozen materials was studied, materials were mixed with an optimum amount of water and frozen overnight at  $-10^\circ\text{C}$ . Evaporation of water was prevented with a plastic bag. One percent of liquid calcium chloride was added, the sample was mixed, and the compaction was started immediately. The compression strength of specimens compacted with the gyratory compactor was also measured.

The frost-heave tests were performed with equipment developed at the Institute of Engineering Geology at Tampere University of Technology (12). The set-up for tests was the so-called "open system" in which water flows through the unfrozen portion of the sample into the freezing front, and the sample is frozen from the bottom. Materials were mixed with water containing liquid  $\text{CaCl}_2$  one night before the test was begun. Samples were compressed under a strength of 38.5 MPa

overnight, and plain water or water with  $\text{CaCl}_2$  was conducted into the sample during compression. The test contained two freezing steps: the temperature of the freezing liquid was initially  $-10^\circ\text{C}$ , decreased to  $20^\circ\text{C}$  after a day. The frost heave and the temperatures inside samples were measured with sensitive elements. The data were collected with a data acquisition/control unit and transmitted to a computer. After the tests the height and the water content of the freeze-and-thaw zone were measured. At least two parallel samples were studied.

The migration of  $\text{CaCl}_2$  was studied by conducting water through specimens compacted with a gyratory compactor. The samples were set up in a tube with a specimen containing  $\text{CaCl}_2$  on top and a specimen with water only on the bottom. Water was conducted from the top to the bottom of the sample. The amount of  $\text{CaCl}_2$  was measured from the percolating water and the samples after the test. The test was complete when the amount of chloride in the percolating water reached the chloride content of tap water.

## RESULTS

The influence of  $\text{CaCl}_2$  on basic properties of soils is due to its chemical properties, mentioned earlier.  $\text{CaCl}_2$  has an effect on the finer particles of the aggregate, and the largest chloride contents are observed in the finer fractions (Figure 3).  $\text{CaCl}_2$  also binds finer particles together. This phenomenon was observed in grain size distributions, in which the amount of finer particles decreased remarkably depending on the total amount of fine fractions (Figure 4). When materials with  $\text{CaCl}_2$  were compacted, the amount of fine fractions showed only a slight decrease. This result indicates that the binding effect is permanent and cannot be broken mechanically. The binding effect can also be observed in the change of specific surface area: the values decrease remarkably (Table 1). The amount of water adsorbed on the surface increases when  $\text{CaCl}_2$  is added. The results were nearly 10 times larger than the normal values.  $\text{CaCl}_2$  changes the electrophoretic properties of fine fractions, as can be observed from results of zeta potential measurements in Table 1. The result indicates that the particles flocculate more easily. All these surface chemical properties correlate fairly well with  $\text{CaCl}_2$  content of the sample (Figure 5).

The compaction studies at room temperature did not show results as remarkable as those mentioned in the literature. The maximum increase in the dry unit weight was  $0.7 \text{ kN/m}^3$  (Figure 6). When the amount of the compaction effort was studied, the results were more encouraging. The compaction effort to achieve the same dry unit weight was an average 20 percent smaller when 1 percent  $\text{CaCl}_2$  was added (Figure 7). The effect of

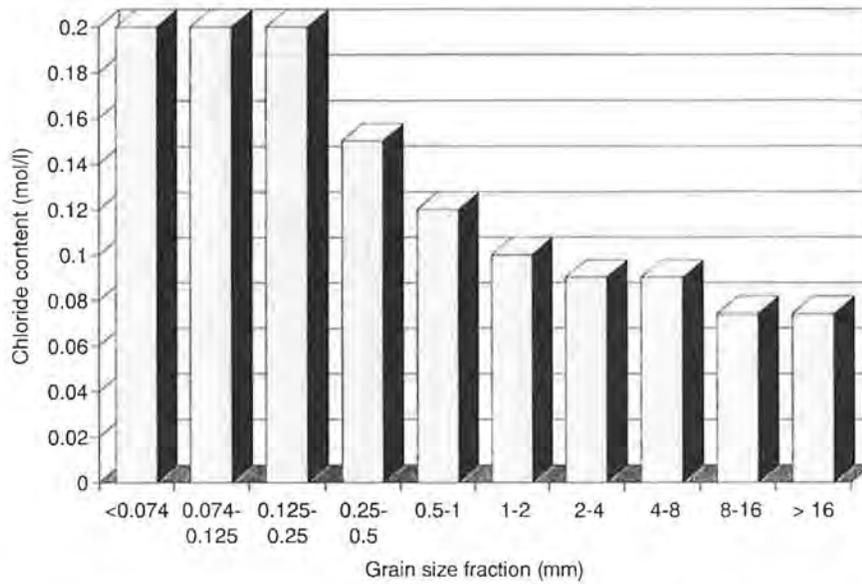


FIGURE 3 Chloride content of different grain size fractions of crushed rock aggregate.

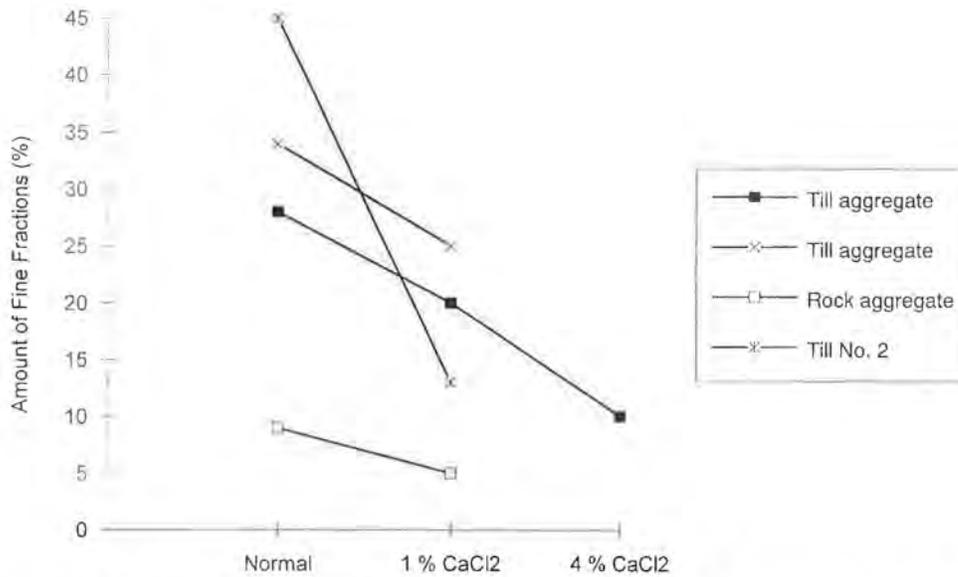


FIGURE 4 Change in amount of fine fractions in rock aggregate, till aggregate, and till after addition of 1 or 4 percent of liquid CaCl<sub>2</sub>.

TABLE 1 Effect of CaCl<sub>2</sub> on Properties of Fine Fractions of Different Materials

Material	Water ads. index (%)	Sp. Surface Area (m <sup>2</sup> /g)	Zeta-potential (mV)
Till Aggregate	1.4	5.15	-22
-"- + 1 % CaCl <sub>2</sub>	12.7	0.89	-7
Rock Aggregate	2.1	2.5	-24.4
-"- + 1 % CaCl <sub>2</sub>	22.2	0.89	-6.6

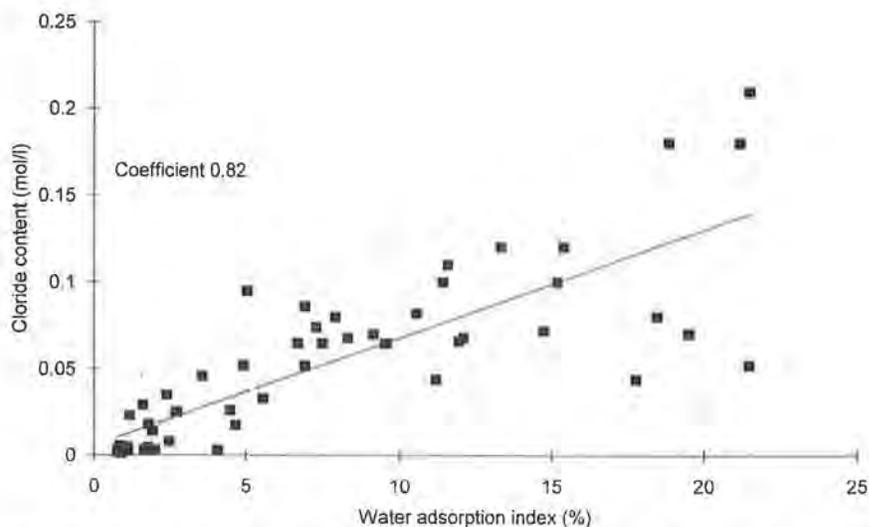


FIGURE 5 Correlation between chloride content and water adsorption index.

$\text{CaCl}_2$  on the compaction effort was strongest with materials containing larger amounts of fine fractions, such as glacial tills and crushed till aggregate. When the compacted specimens were stored in 60 percent relative humidity for a week, the water content of the specimen with  $\text{CaCl}_2$  was 10 times larger than that of normal specimens.

Compaction of soil below  $0^\circ\text{C}$  temperatures always demands extra effort to achieve a firmly compacted layer and usually the dry unit weight is much lower than that obtained at room temperature. When the compacted material thaws, a structural collapse is often observed. By adding  $\text{CaCl}_2$  the compaction becomes easier and the dry unit weight is nearly the same as it

is at room temperature (Figure 8). The temperatures of the samples after compaction were still below  $0^\circ\text{C}$ .

The results of the frost heave tests indicated that  $\text{CaCl}_2$  prevents frost heave. An 80 percent decrease in frost heave was even observed with frost-susceptible materials (Figures 9 and 10). Also the frost heaves of frost-resistant materials were smaller (on average 20 percent). Samples with  $\text{CaCl}_2$  froze more slowly than those without it. When the temperature of normal sample was  $-4^\circ\text{C}$  at a certain point after 24 h of freezing, in the sample with  $\text{CaCl}_2$  the temperature was  $0^\circ\text{C}$ . After the test had proceeded for 48 h the temperatures were, respectively,  $-8^\circ\text{C}$  and  $-4^\circ\text{C}$ . The measurements of chloride content in the different parts of the sample

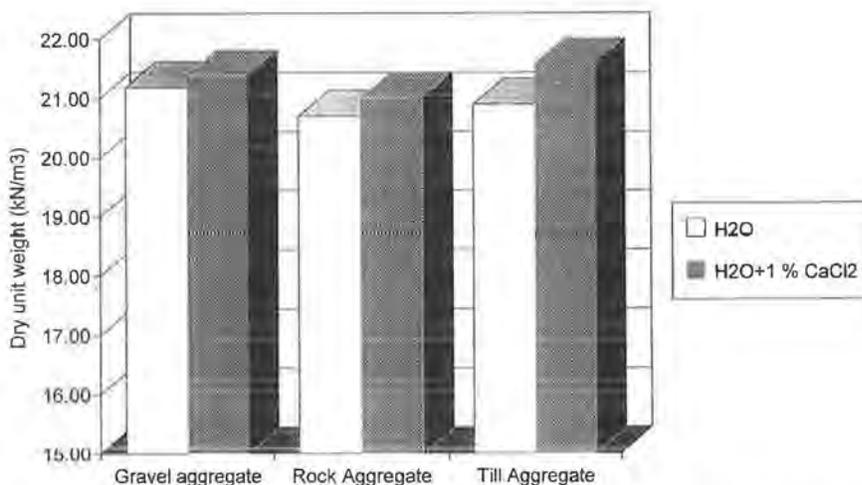


FIGURE 6 Effect of  $\text{CaCl}_2$  on dry unit weight of different materials at room temperature.

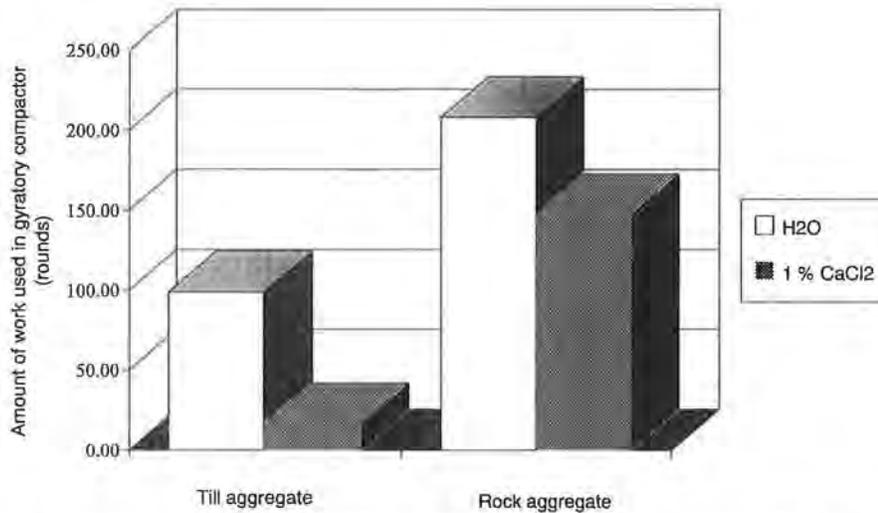


FIGURE 7 Effect of CaCl<sub>2</sub> on compaction effort needed to achieve equal dry unit weight.

showed that the content in the frozen part was nearly the same as before the test. In the thawed parts of the sample the chloride content showed a decrease because of the percolating water.

In the migration tests the results were not encouraging, although the test conditions were severe compared with field conditions. CaCl<sub>2</sub> disappeared from the specimens after 1 week. This was due to the solubility of CaCl<sub>2</sub>. The best results were achieved with materials containing larger amounts of fine fractions. The amount of CaCl<sub>2</sub> in percolating water remained high for 2 days with till and till aggregate. When the gravel aggregate was

tested, the amount of chloride decreased during the first day to a low level. This was partly due to the different velocities of water within different types of samples.

All the tests mentioned above were performed also for FDR materials. The results were not encouraging: CaCl<sub>2</sub> did not improve the compactability of the samples, and the permanence of salt in specimens was as poor as mentioned before. CaCl<sub>2</sub> did not increase the compression strength of FDR specimens; the compression strength, on the contrary, showed a small decrease. This was due to higher water content in samples with CaCl<sub>2</sub> than in those without it.

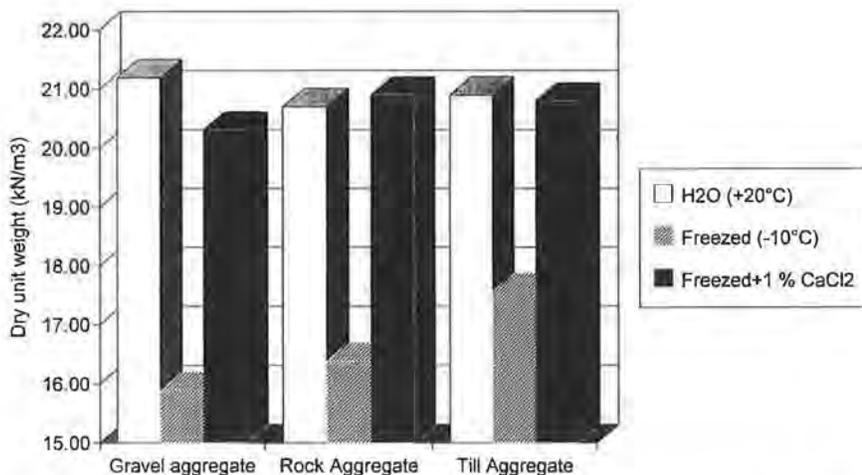


FIGURE 8 Effect of CaCl<sub>2</sub> on dry unit weight of different materials below 0°C.

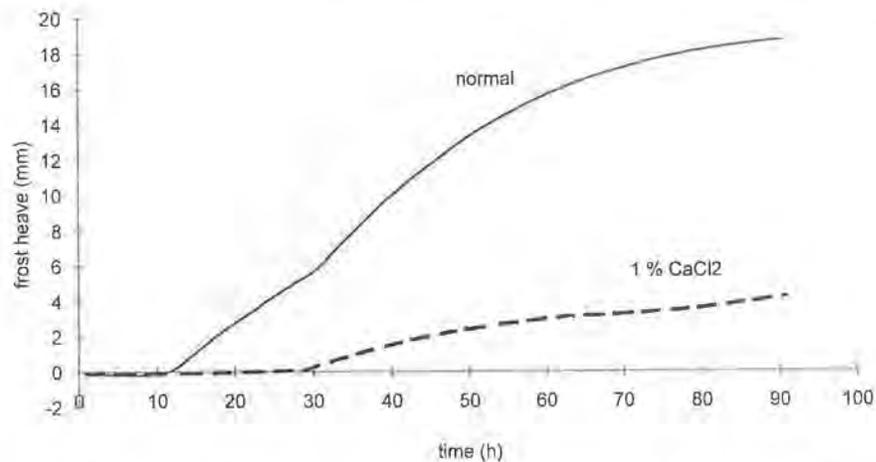


FIGURE 9 Effect of  $\text{CaCl}_2$  on frost heave of frost-susceptible tills: weathered till No. 1.

## CONCLUSIONS AND DISCUSSION

$\text{CaCl}_2$  binds the finer particles together, changing the basic properties of the fine fraction. The properties of whole aggregate material are changed by adding even only 1 percent of  $\text{CaCl}_2$ . This is due to the chemical properties of  $\text{CaCl}_2$ . Probably  $\text{Ca}^{2+}$  ions are adsorbing on the negatively charged small particles. A suitable method for evaluating the chloride content is to measure the changes in water adsorption index of fine fractions.

Calcium chloride does not increase the maximum dry unit weight in room temperature significantly but the compaction effort needed to achieve maximum dry unit weight decreases. The advantage of using  $\text{CaCl}_2$  in com-

paction is its hygroscopicity. The material keeps its moisture for long periods; for example, in the summer the material need not be wetted often, and dust problems are avoided. During winter, frozen compaction becomes much easier if  $\text{CaCl}_2$  is used and the collapses of structures in the spring are avoided. For example, when an excavation must be done in winter, the refilling and compaction with  $\text{CaCl}_2$  could yield as compacted a layer as in summertime.

$\text{CaCl}_2$  has proven useful in preventing frost heave although there is no evidence that salt stays in the structure for long periods. The chemical nature of  $\text{CaCl}_2$  makes the stability uncertain.

The migration of  $\text{CaCl}_2$  is evident in contact with percolating water. However, in normal situations, there should be no running water in road construction. Ac-

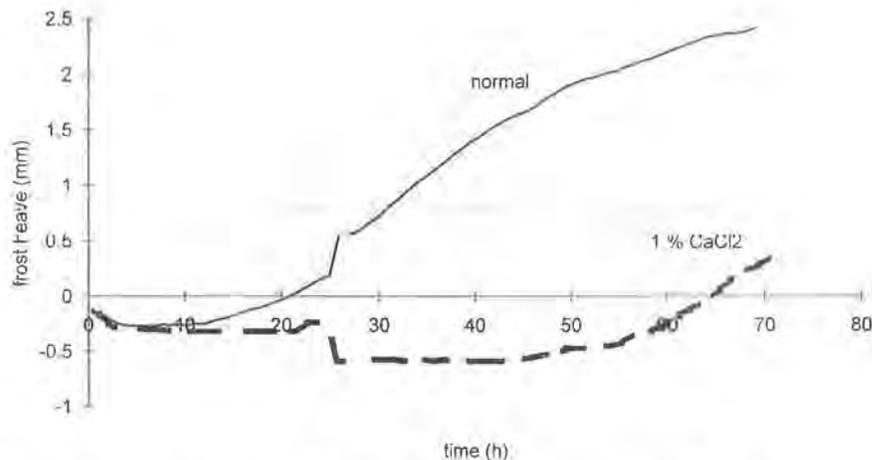


FIGURE 10 Effect of  $\text{CaCl}_2$  on frost heave of frost-susceptible tills: glacial till No. 3.

ording to the present study no conclusions can be made on the stability of  $\text{CaCl}_2$  in road construction.

The environmental effects of salt (mainly  $\text{NaCl}$  used in ice control) are widely discussed in Finland, and the chloride contents of groundwater are measured. Although the increase in the chloride contents of groundwater is only partly due to the  $\text{NaCl}$  used in ice control, there is evidence of its immediate effects. The effects of using  $\text{CaCl}_2$  on road construction could also be harmful for groundwater. On the other hand, surface water flows into the groundwater aquifers through ditches and embankments. When salt is added in the base course the flow of water is prevented.

There are no unambiguous estimates on the effect of  $\text{CaCl}_2$  on plants. The results of the literature review were contradictory. Also interesting is that  $\text{CaCl}_2$  is used in greenhouse farming for moisture control. Road construction itself may be a greater environmental risk than the use of salt in either dust and ice control or in road construction. If  $\text{CaCl}_2$  is added to the base or subbase layers during road construction, it might be more likely to stay in these layers than on the surface. The only way to prove this theory is to build a test road.

$\text{CaCl}_2$  is an effective additive during road construction to prevent dust, keep the material compactable, and decrease the needed compaction effort.  $\text{CaCl}_2$  is also useful in wintertime construction. In all these applications the long-term stability is unimportant. In preventing frost heave,  $\text{CaCl}_2$  is an efficient additive but its long-term stability is uncertain. The migration of salt is an environmental risk that should always be taken into account. During this research, the benefits of FDR with  $\text{CaCl}_2$  could not be proven with laboratory research.

#### ACKNOWLEDGMENTS

The financial support of Kemira Chemicals Ltd. and the Finnish National Road Administration is gratefully acknowledged.

#### REFERENCES

1. Haas, W., D. Bernard, and T. Kaderabek. Using Additives to Improve Cold Weather Compaction. In *Transportation Research Record 560*. TRB, National Research Council, Washington, D.C., 1976, pp. 57-68.
2. Slessor, C. Movement of Calcium Chloride and Sodium Chloride in Soil. *HRB Proc.*, Vol. 23, 1943, pp. 460-468.
3. Slate, F. Use of Calcium Chloride in Subgrade Soils for Frost Prevention. *HRB Proc.*, Vol. 22, 1942, pp. 422-440.
4. Reckard, M. *Economic Aspects of High Speed Gravel Roads*. Final Report AKRD-83-20. FHWA; Alaska Department of Transportation, Juneau, 1982.
5. Shepard, J., J. Pickett, and M. Kienzle. Full-Depth Reclamation with Calcium Chloride. In *Transportation Research Record 1295*, TRB, National Research Council, Washington, D.C., 1991, pp. 87-94.
6. Reckard, M., and T. Kinney. *Effects of Salts on Road Embankment Stability Under Freezing and Thawing Conditions*. Final Report AKRD-87-09. FHWA; Alaska Department of Transportation and Public Facilities, Juneau, 1986.
7. *Presentation of 1992 FWD and Residual Chloride Testing Results, Chinguacousy Road, Caledon, Ontario*. Project G-02008-E/P. Trow Consulting Engineers Ltd., 1992.
8. Prior, G., and P. Berthouex. A Study of Salt Pollution of Soil by Highway Salting. In *Highway Research Record 79*, HRB, National Research Council, Washington, D.C., 1967, pp. 8-21.
9. Rich, A. Effects of Salt on Eastern Highway Trees. *American Nurseryman*, Vol. 11, No. 135, June 1972, pp. 36-42.
10. Nieminen, P., R. Salomaa, and R. Uusinoka. The Use of Specific Surface Area, Pore Volume, and Pore Area in Evaluating the Degree of Weathering of Fine Particles: An Example from Lauhavuori, Western Finland. *Fennia*, Vol. 163, 1985, pp. 373-377.
11. Kellomäki, A., and P. Nieminen. Adsorption of Water on the Fine Fractions of Finnish Tills. *Bulletin of Geological Society of Finland*, Vol. 58, Part 2, 1986, pp. 13-19.
12. Nieminen, P. Porosity and Related Properties of Frost Susceptible Tills. In *Proc., International Symposium of Frost in Geotechnical Engineering* (H. Rathmayer, ed.). Technical Research Centre of Finland, Espoo, 1989, pp. 557-564.