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An experimental examination of some factors affecting frost heave under freezing-thawing cycles

Hakan Alper Kamiloğlu
Res.As., Bayburt University, Bayburt, Turkey, hkamiloglu@bayburt.edu.tr

Fatih Yılmaz
Res.As., Bayburt University, Bayburt, Turkey, fyilmaz@bayburt.edu.tr

Erol Şadoğlu
Assist.Prof., Karadeniz Technical University, Trabzon, Turkey, esadoglu@ktu.edu.tr

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ABSTRACT: In this study the factors that cause frost heave under the freezing-thawing effect were examined experimentally. Within this scope, a total of fifteen soil samples were prepared at different water contents, percentages of fine-grained materials, densities, and mineral matter contents. the soil samples except compacted at different densities, were compacted into standard proctor mould with standard proctor energy. The soil samples were exposed to freezing–thawing cycles and the amount of volume changes were measured (±20 ^{o}C) for a period of seventeen days. Lengths of samples versus time graphs were plotted for all mentioned factors. As a result, minerals that have high swelling property performed high frost heave and frost heave increased with decreasing density.

1 INTRODUCTION

The ground freezing is a common problem in places where effective winter conditions occur and the temperature drops frequently below zero. Freezing-thawing case happens in cold climates seasonally, brings about deformation problem due to freezing and strength loss in virtue of thawing effect. These problems which is observed as ground heave and soil softening are among the important factors that could cause serious damage to structures and financial loss (Altun & Goktepe 2008).

The effect of freezing on ground was initially investigated by Taber (1929, 1930) and Beskow (1947). When some soils were exposed to freezing, they observed that the soils swelled. They also defined that contrary to the popular belief, the swelling on the soil did not arise only from the expansion depending on the freezing of the water. Everett (1960) developed a theory about volume change of the soils that exhibit swelling behaviour depending on the freezing. Miller and Römkens (1973) attached a piece of mineral to the ice block and applied heat treatment. They observed that due to the effect of temperature gradient, the ice particles that were at the hot side of the piece of mineral melted. The water formed by the melting of ice moved towards the cold side and froze again on the cold side of the piece of mineral. Therefore, they determined that the mineral moved from cold side to the warm side of ice block. After this determination, Miller (1978) found the Rigid Ice Model and then O'Neill and Miller (1980, 1985) improved this model which explains frost heave more clearly.

Frost heave is emerged by intermolecular forces which compel ground water to move and lead to formation of ice lenses with the horizontal accumulation of ice particles. Therefore, volume changes are observed at frost susceptible soils at winter condition (Rempel 2007). Ice lenses which occur by the movement of moisture from the unfrozen areas to frozen areas, reduces strength of the soil by supplying excessive water during the thawing phase. For the emergence of the problem with regards to frost heave, freezing temperatures should penetrate deep enough, ground water level should be sufficient depth and soil should be susceptible to the frost (FHWA 2007).

Frost susceptibility of soils depends on permeability and capillarity (suction) (Fig. 1). Low plasticity fine grained soils with high percentage of silt particles (0.005–0.05 mm) that have pore sizes small enough to develop capillary potential and large enough to permit water to move towards frozen zones, are particularly sensitive to frost heave (FHWA 2007).

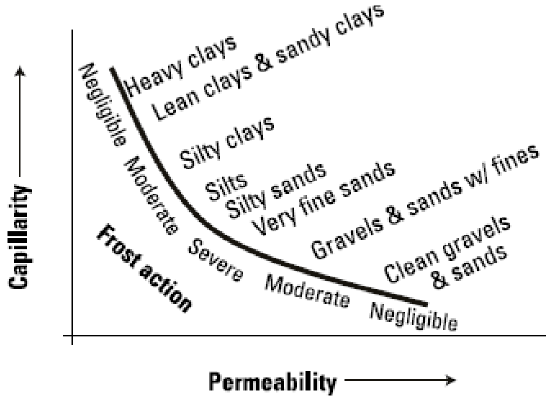

Figure 1. Frost action – soil properties relation (FHWA 2007)

The frost heave behaviour of soil due to freezing-thawing is affected by some factors such as grain size, amount of mineral matter, amount of organic matter, chemical structure of soil grains, water content or degree of saturation, density of soil, ground water level, temperature, chemical structure of ground water, freezing-thawing cycles.

2 EXPERIMENTAL STUDY

In this study the factors that cause frost heave under the freezing-thawing effect examined experimentally. Sieve analysis, liquid limit, plastic limit tests and x-ray diffractometry analysis were done to classify and identify the soil samples. Additionally, standard compaction tests were performed to determine optimum moisture contents.

The soil samples except compacted at different densities were compacted into standard proctor mould with standard proctor energy. Soil samples were wrapped by stretch film to maintain constant water content during experimental procedure and the samples were also putted into plactic (polythene) bags for secondary prevention to provide constant water content. The water contents of samples are kept constant during the freezing–thawing cycles in close system. As a result of this procedure, a total of fifteen soil samples were prepared at different water contents, percentages of fine-grained materials, densities and amounts of mineral matters (Fig. 2).

Figure 2. Soil Samples.

A dial gauge was fixed to a steel frame to determine volume change after each freezing cycle and each thawing cycle by measuring length change in one dimension. Measurement points were marked on the upper and lower sides of the samples by acetate pen. The prepared soil samples were exposed to freezing–thawing effect (±20 ^{o}C) and the amounts of volume changes were observed for a period of seventeen days. Additionally, reference volume of the samples were determined in the same manner before the freezing-thawing cycles.

2.1 Grain Size

In order to observe the effect of grain size to the frost heave under freezing-thawing effect, four different soil samples were prepared. The soil samples were classified according to the UCSC via soil classification tests (sieve analysis, liquid limit, plastic limit tests). Optimum moisture contents of soil samples were determined with standard compaction test (Table 1). Soil samples were compacted into moulds of 94.2 mm diameter and 129.0 mm height with standard compaction energy. The prepared samples were subjected to freezing–thawing (close system) cycles for seventeen days. Volume changes were measured on the 4^{th}, 6^{th}, 7^{th}, 8^{th}, 10^{th}, 12^{th}, 16^{th} and 17^{th} day of the seventeen-day freezing-thawing cycles.

Table 1. Soil properties

Sample Number	**Soil Type (UCSC)**	**Passing No. 200 Sieve (%)**	**Optimum Water Content (%)**
1	CL	68	28
2	CL	64	26
3	CL	64	26
4	CL	58	22

2.2 Density

Low plasticity clayey soil samples were compacted into moulds of 900 cm^3 volume with different compaction energies at constant water content to examine the effect of different densities on frost heave after freezing-thawing cycles. Modified and standard proctor hammers were used with different hammer blows to compact soil samples with different compaction energies. The magnitudes of compaction energy were shown in Table 2. After the compaction soil samples were subjected to the seventeen-day freezing-thawing effect and values of frost heave of samples were measured.

Table 2. Compaction energy parameters

Sample Number	**Soil Type (UCSC)**	**Compaction Energy (kN-m/ m^3)**	**Blows Per Layer**	**Number of Layers**	**Type of Hammer**
8	CL	619,76	25	3	Standard
7	CL	867,66	35	3	Standard
6	CL	2373,76	35	3	Modified
5	CL	2712,32	40	3	Modified

2.3 Water Content

Four different soil samples were prepared at different water contents in order to determine water content and frost heave relation under freezing-thawing effect (Table 3). Soil samples compacted into moulds of 900 cm^3 volume with standard proctor energy. The water contents of the compacted samples were 33.42 %, 27.3 %, 25 % and, 19.97 %. After the compaction, soil samples were exposed to freezing–thawing cycles for seventeen days and frost heave values were measured at the 4th, 6 th, 7 th, 8 th, 10 th, 12 th, 16 th and 17 th day of freezing-thawing process.

Table 3. Water contents of the samples

Sample Number	Soil Type (UCSC)	Water Content (%)
9	CL	33
10	CL	27
11	CL	25
12	CL	20

2.4 Mineral Type

In this part of the study, different types of minerals were added to the same type of soil samples with same water content. The types of the minerals were defined with x-ray diffractometry analysis and the results are given in Table 4. The soil samples, compacted into moulds of 900 cm^3 volume at standard compaction energy, were exposed to freezing-thawing effect for seventeen days. After freezing-thawing cycles the frost heave values were measured.

Table 4. Mineral percentage, water contend and mineral type of samples

Sample Number	Water Content (%)	Added Mineral Percentage (%)	Added Minerals
13	13	10	Calcite, Quartz, Norsetite
14	13	10	Quartz, Volkonskoite, Sodium Gallium Oxide
15	13	10	Quartz, Montmorillonite, Taranakite

X-ray diffraction is a technique that provides detailed information about the atomic structure of crystalline substances. It is a powerful tool in the identification of minerals in rocks and soils. The bulk of the clay fraction of many soils is crystalline. Therefore, XRD has long been a mainstay in the identification of clay-sized minerals in soils (Harris and White 2008). Fig. 3 shows the X-ray diffraction plots of the minerals added to Sample 13, 14 and 15 used in this study.

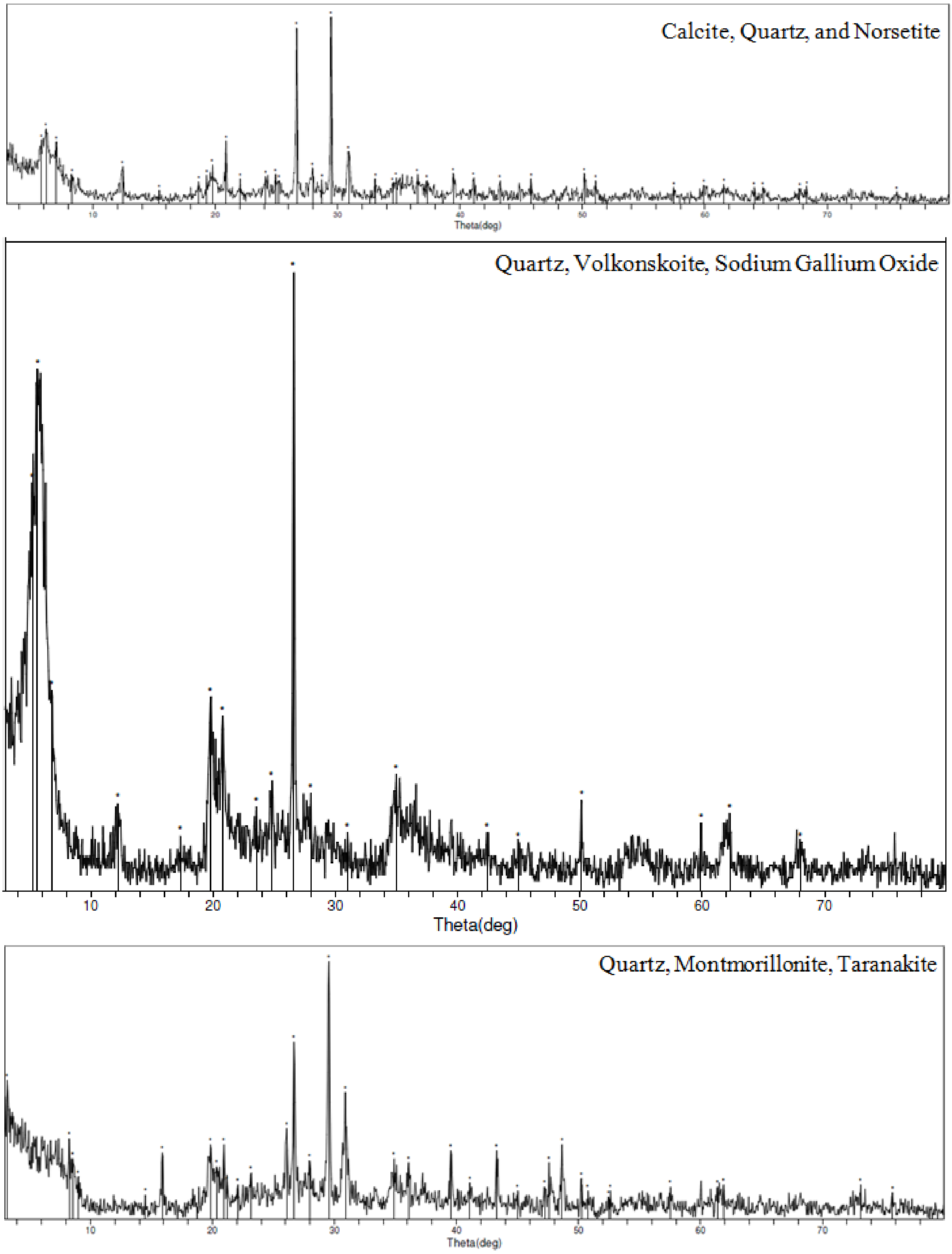

Figure 3. X-ray diffraction plots of three kinds of added minerals used in this study

3 PRESENTATION AND DISCUSSION OF RESULTS

A series of tests were done to examine the influence of density, water content, mineral type and grain size on frost heave behaviour of soil under freezing-thawing circles. Therefore, volumetric changes were measured during 17-day test procedure and the results are presented graphically.

The samples, containing different percentage of fine grained particles given in Table 1, were subjected to freezing-thawing cycles. It was realized that volume changes of the samples increased with increasing percentage of fine grained particles (Fig. 4).

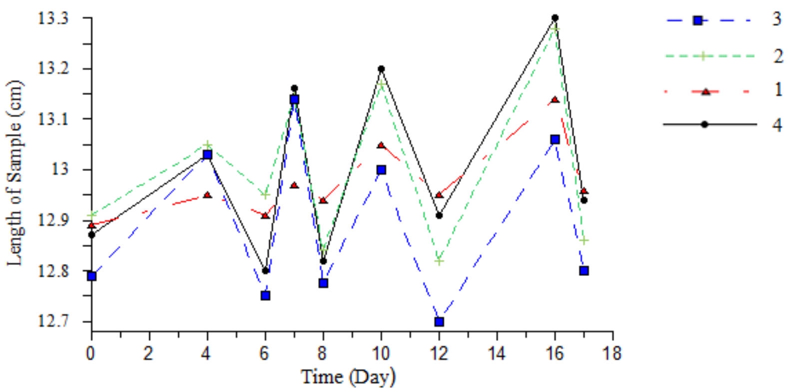

Figure 4. Frost heave – grain size relation

Different compaction energy were subjected to the samples given in Table 2 to observe the effect of different-density values on frost heave during freezing – thawing cycles. After the cycles frost heave– time graphs were plotted (Fig. 5) and it was seen from the graph that the largest volume change was seen at the minimum density samples and it was determined that frost heave decreased with increasing density.

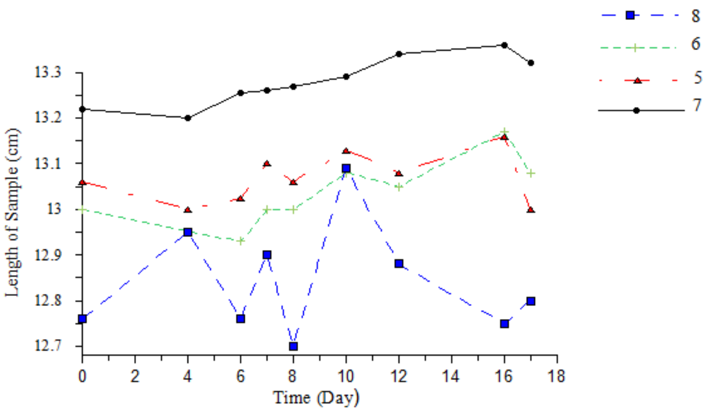

Figure 5. Frost heave – density relation

The samples made of same soil were compacted with different water contents to determine the effect of the water content on frost heave (Table 3). After the freezing-thawing cycles length of samples-time graphs were obtained. it was seen from Fig. 6 that the largest volume change occurred at the sample of biggest water content and frost heave increased with amount of water content (Fig. 6).

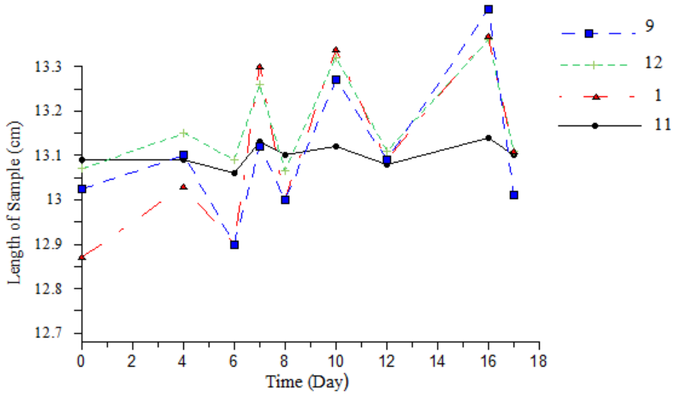

Figure 6. Frost heave – water content

Mineralogical effects on frost heave can be evaluated from Fig.7. The biggest volume change happened at the sample containing montmorillonite mineral (Table 4). Clay minerals that had high swelling property performed high frost heave too.

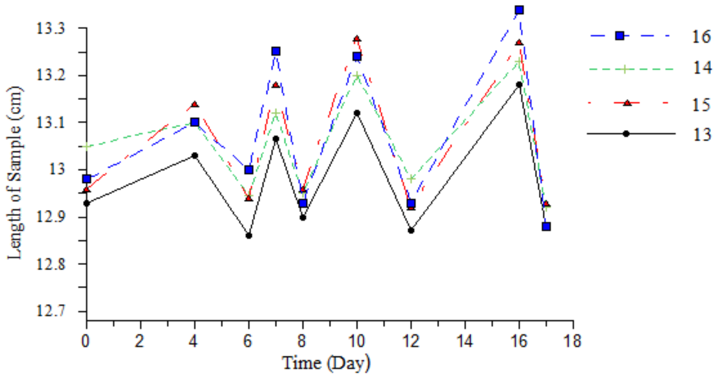

Figure 7. Frost heave – Clay mineral relation

4 CONCLUSIONS

The factors that cause frost heave under the freezing-thawing cycles were examined experimentally. Within this scope, a total of fifteen soil samples were prepared at different water contents, percentage of fine-grained material, densities and mineral matter contents. The samples were subjected to freezing-thawing cycles during the experimental process. Total of four freezing-thawing cycles were performed in seventeen days and at the end of the 17-day cycles water content value did not change. The samples were cooled at a temperature of – 20 ^{o}C and heated to a temperature of + 20 ^{o}C during this cycles. The observed results are given as follows:

- During the freezing the lengths of the samples extended, and during the thawing the lengths shortened in general. As a result frost heave were observed in all samples.
- In the thawing phase of the cycles the length of the samples decreased. It was also determined that the lengths of the samples were bigger than previous cycle.
- The amount of volume change of the samples grew up with the increasing fine grained particle content.
- Frost heave increased with decreasing density and the largest frost heave was seen at the minimum density sample.
- The largest volume change was observed at the samples of biggest water content and frost heave increased with the magnitude of water content.
- Minerals that have high swelling property performed high frost heave.

Lime and calcium chloride have been used to improve clay soils. Frost heave behaviour of lime and calcium chloride stabilized soils can be investigated in further studies.

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