Freeze-thaw effect on consolidation properties of fine grained soils from the Mackenzie valley, Canada

Bhuwani Paudel
Trow Associates Inc., Ottawa, Ontario, Canada (formally Natural Resources Canada)

Baolin Wang
Natural Resources Canada, Ottawa, Ontario, Canada

ABSTRACT
This paper presents laboratory test results of freeze-thaw effect on consolidation properties of fine grained soils from the Mackenzie valley, Canada. Soil samples were collected from two landslide sites in the Mackenzie valley. The samples were obtained from the bottom of the active layer at about 1 m depth below ground surface. A total of 32 remoulded samples were prepared with varying water contents to reflect the moisture conditions in the active layer and near the permafrost table. The samples were tested for coefficient of consolidation and hydraulic conductivity after 0, 3, 5 and 10 cycles of freezing and thawing. The coefficient of consolidation increased by an order of magnitude and hydraulic conductivity by one to two orders of magnitude after freezing and thawing. These properties continue to increase with the increase of the number of freeze-thaw cycles, but at a much slower rate.

RÉSUMÉ
Cet article présente une étude en laboratoire de l'effet de gel-dégel sur les propriétés de consolidation de sols à texture fine de la vallée du Mackenzie, au Canada. Des échantillons de sol ont été prélevés dans deux sites de glissements de terrain dans la vallée du Mackenzie. Les échantillons ont été obtenus à partir du bas de la couche active à environ 1 m de profondeur. Un total de 32 échantillons de sol remanié ont été préparés avec différentes teneurs en eau afin de refléter les conditions d'humidité dans la couche active et près du pergélisol. Les échantillons ont été testés pour le coefficient de consolidation et la conductivité hydraulique après 0, 3, 5 et 10 cycles de gel et de dégel. Le coefficient de consolidation a augmenté d'un ordre de grandeur après congélation et décongélation. La conductivité hydraulique a augmenté d'un à deux ordres de grandeur après congélation et décongélation. Les coefficients continuent à augmenter avec l'augmentation du nombre de cycles de gel-dégel, mais à un rythme beaucoup plus lent.

1 INTRODUCTION

Coefficient of consolidation and hydraulic conductivity are important engineering properties of fine grained soils. The properties have critical effects on excess pore water pressure and ground settlement during thawing of frozen soils (Morgenstern and Nixon, 1971). Freezing and thawing process severely affects those properties of fine grained soils (Chamberland and Gow, 1979; Graham and Au, 1985; Viklandar, 1998; Konrad and Samson, 2000; Qi et al., 2006; Hui and Ping, 2009). Chamberland and Gow (1979) reported that hydraulic conductivity of fine grained soils increases with increase of the number of freeze-thaw cycles. Qi et al. (2006) studied the effect of one freeze-thaw cycle with different freezing temperature and dry unit weight of fine grained soils. They proposed a critical dry unit weight. Soil strength parameters either decrease or increase if dry unit weight is higher or lower than the critical dry unit weight before freezing. Viklandar (1998) proposed a critical void ratio after repeated freezing and thawing of fine grained soils. Graham and Au (1985) studied freeze-thaw effect on natural clay and observed that freezing and thawing cause increase in compressibility and pore water pressure and decrease in strength at low stress.

Although some studies have been done on those soil properties as noted above, few research works have been found about the freeze-thaw effect on soil coefficient of consolidation (C_v). Paudel and Wang (2009) summarized some data reported in the literature about C_v values of fine grained soils from permafrost regions. The paper reported test results of C_v values for a number of typical soil samples from the Mackenzie valley, Northwest Territories in Canada. However, the tests were focused on existing conditions of the soils. Given the importance of this parameter to engineering design and analysis for northern projects, a new test program was carried out to further extend the study to investigate the freeze-thaw effect on consolidation properties of such soils. This paper summarizes the test program and the results.

2 SOIL SAMPLING AND TESTING

Soil samples were collected from two sites in the Mackenzie valley, as shown in Figure 1, where I denotes the site in Inuvialuit settlement region and G denotes the site in Gwich'in settlement region. Samples were recovered from the bottom of the active layer at depth of about 1 m from the ground surface. Typical soil gradations for the southern (G) and northern (I) regions are given in Figure 2. The soils from the southern site (G) are finer than that from the northern site (I). Atterberg Limits of these samples are given in Table 1. The samples from the southern G site show higher plasticity than those from the northern I site.

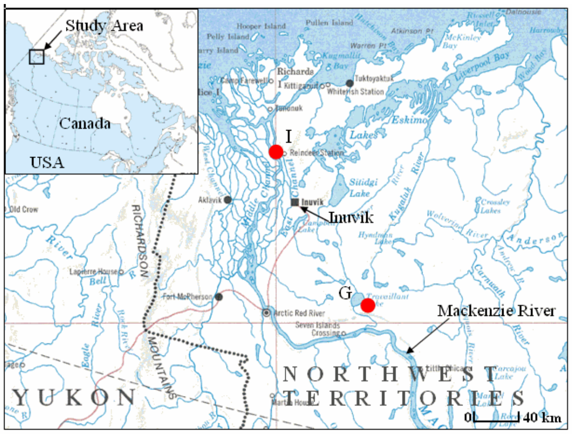

Figure 1. Map showing soil sample locations in (G) Gwich'in settlement region and in (I) Inuvialuit settlement region

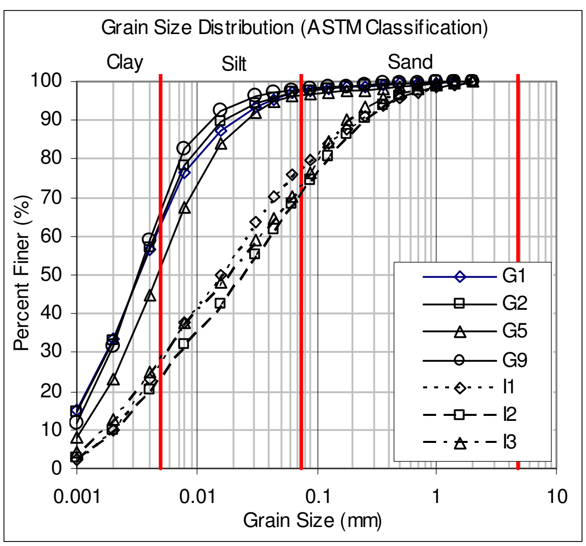

Figure 2. Grain size distribution for samples from I and G regions

Table 1. Index properties of soil samples

Samples	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
I Site	36	13	23
G Site	62	26	36

Soils subject to repeated freezing and thawing usually exhibit various levels of moisture condition depending on the elevation relative to the permafrost table. Normally, the closer to permafrost table, the higher of the moisture content (Wang et al, 2008). In order to investigate freeze-thaw effect on soils of different moisture conditions, specimens were prepared by mixing the samples to have water contents of 30, 35, 40 and 45%, which are representative of the in-situ moisture conditions measured at the sites (Wang et al, 2008).

Conventional sized odometer (consolidometer) of 64 mm diameter and 25 mm in height was used for the test. However, instead of using conventional steel odometer ring, special plastic rings were used for this test. The plastic rings were fabricated from Delrin 100 AF 13% Teflon material. The use of the plastic material was to reduce the lateral heat conduction during freezing and thawing.

The prepared soil specimen was put in the odometer ring sitting on a glass plate. Styrofoam was installed around the odometer ring to limit lateral heat conduction during freezing and thawing. The soil-ring-styrofoam assembly was sealed in a plastic bag to minimize moisture loss (Figure 3).

Figure 3. Sample assembly with insulation for one-dimensional freezing and thawing

The sealed specimen assembly was kept in a cold room at -10ºC to -12ºC for 24 hours for each freeze cycle. It was then taken out of the cold room and exposed to room temperatures for 24 hours to complete a freeze-thaw cycle. The specimens were subject to 0, 3, 5 or 10 freeze-thaw cycles. A total of 32 assemblies were made for the test program (2 sites x 4 moisture contents x 4 freeze-thaw cycles).

Conventional consolidation tests were carried out at room temperatures after the samples have undergone the desired number of freeze-thaw cycles. Figure 4 shows a photo of the test frame. A vertical pressure of 18.5 kPa was applied, which is equivalent to an overburden pressure of the in-situ active layer at the sites. Sample deformation was recorded with a transducer of 0.001 mm precision. A digital readout unit was used to record data every 3 seconds.

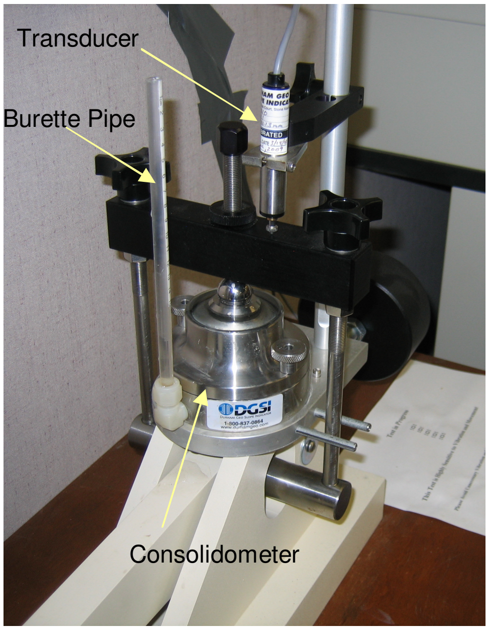

Figure 4. Testing arrangement for coefficient of consolidation and hydraulic conductivity

A burette pipe is attached on the consolidometer to measure hydraulic conductivity of the samples. A falling head method was applied for the measurements.

A graph of deformation vs. square root of time was plotted to determine the coefficient of consolidation.

Equation 1 (Taylor, 1948), given below, is used for calculation of coefficient of consolidation (C_v).

$$c_v = \frac{T_{90} H^2}{t_{90}} \quad [1]$$

Where, T_{90} is a dimensionless time factor for 90% consolidation and equal to 0.848. The notation t_{90} is the required time for 90% consolidation and H is the drainage length, half of the specimen height (12.5 mm).

3 RESULTS

After freezing and thawing, some cracks were observed on the surface of some samples. Although, zip lock plastic bags were used to enclose samples during freezing and thawing a slight change in moisture content was observed. Some spilled water was observed on the glass plate for samples with 45% moisture content after freezing and thawing.

Coefficient of consolidation and hydraulic conductivity of the samples from the northern I site are shown in Figures 5 and 6. The results for the samples from the southern G site are given in Figures 7 and 8. As noted from these charts, both the coefficient of consolidation and hydraulic conductivity increased sharply after the samples were subject to initial freeze-thaw effect. The increase was by an order of magnitude for the coefficient of consolidation and by one to two orders of magnitude for the hydraulic conductivity. The properties continue to increase with the increase of the number of freeze-thaw cycles. However, the increase was at a much lower rate.

Figures 9 and 10 show comparisons of results between the northern and southern sites. The coefficients of consolidation are identical for both groups of samples (Figure 9). These results are consistent with those reported by Paudel and Wang (2009) for the similar pressure range applied with another study.

The hydraulic conductivities are lower for the southern G site samples than for the northern I site samples (Figure 10). This is agreeable with the fact that the G site samples are finer than that from the I site (Figure 2). Hydraulic conductivities of southern G samples were consistently lower than that of the northern I samples up to five freeze-thaw cycles for all tested moisture contents. While two southern G samples continued to exhibit lower hydraulic conductivity after 10 cycles of freezing and thawing, the other two showed similar data as that of the northern samples for the 10 cycle case. The results could be due to increased number of freeze-thaw cycles causing soil structure change, or more likely caused by some unknown errors.

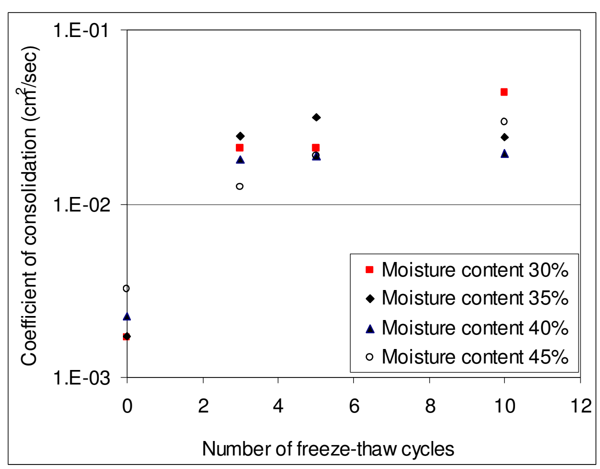

Figure 5. Coefficient of consolidation with number of freeze-thaw cycles for samples from I site

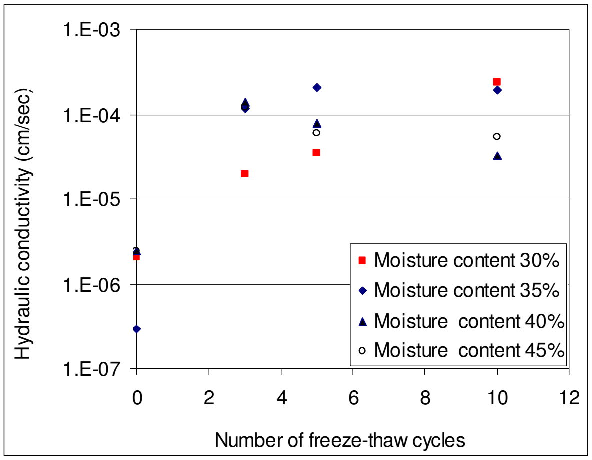

Figure 6. Hydraulic conductivity and number of freeze-thaw cycles for samples from I site

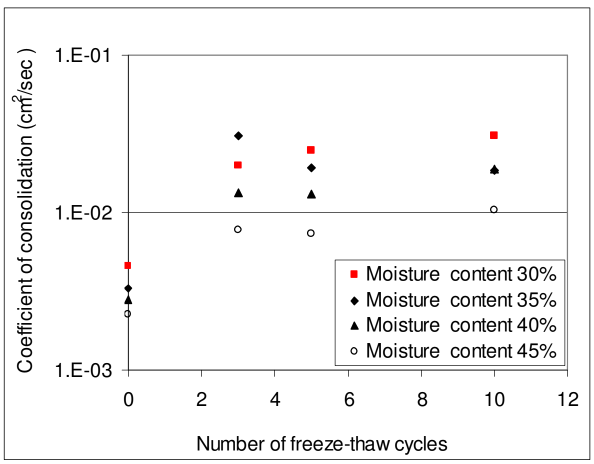

Figure 7. Coefficient of consolidation and number of freeze-thaw cycles for samples from G site

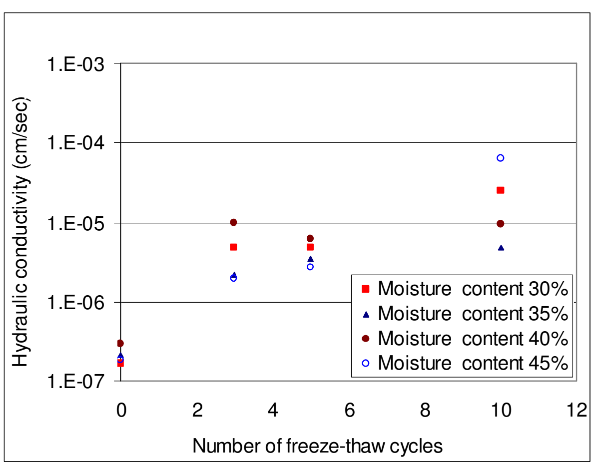

Figure 8. Hydraulic conductivity and number of freeze-thaw cycles for samples from G site

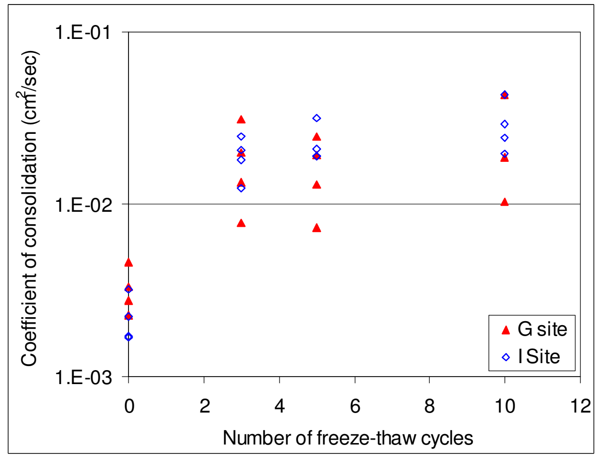

Figure 9. Coefficient of consolidation for samples from I and G sites

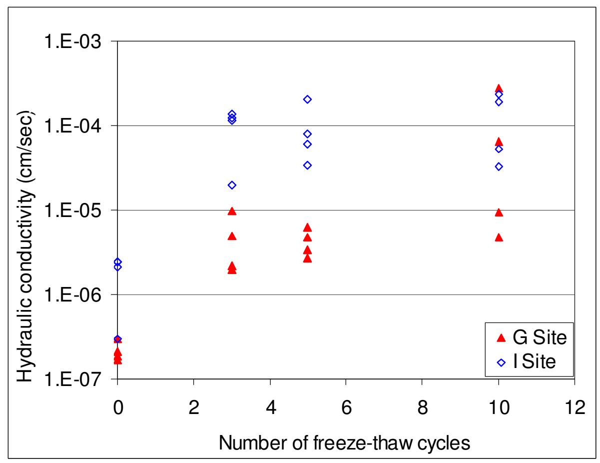

Figure 10. Hydraulic conductivity of samples from I and G sites

4 CONCLUSIONS

Freezing and thawing effect on consolidation properties of remoulded fine grained soils was studied. The results show that coefficient of consolidation increases sharply by an order of magnitude after the soils were subject to freezing and thawing. A more pronounced change was observed on the effect freeze-thaw cycles have on the hydraulic conductivity (by one to two orders of magnitude). The coefficients continued to increase with the number of freeze-thaw cycles, although the rate of change was slower with a higher number of cycles. The data provide insight into understanding the effect of repeated freezing and thawing on soil consolidation properties, which, hopefully, can be used as a reference for estimation of the properties of similar materials.

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