Effects of Freezing and Thawing on Undisturbed and Compacted Soil Samples

freeze-thaw testing  compaction  grain size distribution  Shell Services International  Ian Rogers  Chiyoda Corporation  Toyokazu Fujioka

1. Introduction

The development of a project located in a region which is subjected to significant periods of sub-zero temperatures raised concerns over the performance of soil in a proposed earth embankment as various case studies reported shallow slide failures. This technical note investigates the affects of frost heave testing on the shear strength of clay for both disturbed and undisturbed specimens and makes observations on the results of the frost heave test.

2. Samples and physical properties

A sample was taken from 1.3 m depth using rotary coring techniques. The sample was 150 mm diameter and 250 mm in length. Two specimens were prepared from the sample, one being tested from an undisturbed state, the other being disturbed. Frost heave testing was performed on the undisturbed specimen after which CU strength testing and classification testing were carried out. The disturbed sample was initially compacted in a standard proctor testing mould. Frost heave testing was then carried out after which strength testing was conducted. Finally, the sample was remolded and a second strength test was performed along with the various classification tests. The purpose of this program of testing was to assess the possible affects of low temperatures on the behavior of the soil. The specimens were logged in detail on completion of frost heave testing to identify any fabric that may dominate the material behavior.

Description of undisturbed specimen: Firm very closely layered CLAY. Layers brownish gray and gray with occasional orange brown staining. Occasional small (1 to 5 mm) of light brown siltstone, grey mudstone and plant fragments. Evidence of fabric and possible sample disturbance.

Description of disturbed specimen: Firm light brown, mottled light grey CLAY with a little (<10%) debris comprising fine to medium (2 to 10 mm dia.) reddish brown subangular gravel and occasional inclusions of grey mudstone and yellow to orange siltstone generally up to 5 mm dia. Rare fragments of organic debris (>3mm dia.). No fabric evident.

The physical properties of the materials are presented in Fig. 1 and on Table 1 which indicate the clay to be of high plasticity and the disturbed specimen to have a slightly higher clay content.

3. Freeze-thaw tests

Freeze-thaw tests were run in accordance with JGS standard\(^1\). The results are shown in Fig. 2. Freezing was initiated from the lower end of the specimens with a constant temperature drop rate of \(-0.1^\circ\)C/hr beyond the point at which water stopped being absorbed by the specimen, indicated by the arrow (\(\blacktriangle\)). After an unspecified duration indicated by the arrow (\(\blacktriangledown\)), the temperature of Effects of freezing and thawing on undisturbed and compacted soil samples, Ian ROGERS (Shell Services International) and Toyokazu FUJIOKA (Chiyoda Corporation)
the base of the sample was reduced to $-10\, ^\circ C$ and maintained until no further movement was observed. Photo. 1 shows the network of open fissures resulting from freezing in both the undisturbed and disturbed specimens during the second frost heave cycle. It was noted that fissures were more open during the first frost cycle than the second frost cycle, however, the network of fissures resulting from the second frost cycle was far more extensive. Further, the fissures which occurred in the undisturbed specimen were generally horizontally aligned, whilst those in the disturbed specimen were randomly orientated.

In both tests, the frost heave rate of the first cycle was greater than the second. The frost rate in the undisturbed specimen reduced from 0.083 mm/hr (2.0 mm/day) in the first cycle, to 0.058 mm/hr (1.4 mm/day) in the second. For the compacted specimen the frost heave rate reduced from 0.072 mm/hr (1.7 mm/day) in the first cycle to 0.046 mm/hr (1.1 mm/day) in the second cycle. It is noted that the frost susceptibility of the compacted specimen is lower than that of the undisturbed specimen. The water intake and discharge profiles have a similar pattern for the two specimens with the discharge portion of the curves being almost parallel. However, the intake volume for the undisturbed specimen is significantly greater than for the disturbed specimen. The duration of freezing between the point at which water intake ceases ($\theta$) and the lowering of the temperature to $-10\, ^\circ C$ ($\phi$) is different for the two specimens. Whilst in the disturbed specimen the rate of discharge of water is low before the temperature is reduced to $-10\, ^\circ C$, in the undisturbed specimen the rate of water discharge remains relatively high. For comparison, the frost heave curve has been extrapolated from ($\phi$) to 100 hours which would result in the base of the specimen being at a temperature of $-10\, ^\circ C$. The extrapolated values are 3.3 and 1.7 mm for the undisturbed and disturbed specimens respectively, these being 26 and 7% larger than the respective measured values after freezing at $-10\, ^\circ C$. The frost susceptibility of both specimens are classified as very low by ASTM frost susceptibility classification system in which the specimen is exposed to two freezing cycles, each comprising $-3\, ^\circ C$ for 8 hours followed by $-12\, ^\circ C$ for 16 hours.

4. Shear strength

CU triaxial tests were run to estimate effect of freezing and thawing. The results are shown in Fig. 3 which represents the failure envelope in $t - s'$ stress paths. Based on this limited data, it is noted that there is no significant effect from the freezing and thawing on the effective stress parameters.

5. Conclusions and Comments

Frost heave action on this soil is not considered to have a significant affect on strength and any long term affects are likely to arise from mechanical action such as solifluction. The reason for the relatively larger rate of frost heave and water intake exhibited by the undisturbed specimen is not known, but has been reported by Loch. This may be due to pre-existing fissures in the undisturbed specimen providing planes of weakness which open readily in a generally horizontal alignment at an early stage of freezing enabling water to be more readily absorbed. Therefore, it is concluded that soil structure has an influence on this material. In assessing the frost susceptibility of materials, it is recognized that a high rate of freezing will result in a higher frost heave rate. In addition, it appears from the extrapolation of the frost heave data that by rapidly cooling the specimen, the frost heave ratio will be underestimated. Further investigation is needed to assess the implications of this observation and consider whether a standard procedure should be specified to ensure reliable and reproducible results can be attained. In addition, it is felt that the physical process occurring in the sample to change from a water intake to a water discharge phases is not clearly understood and could be a useful additional indicator in classifying the frost susceptibility of materials.

References

2) ASTM D5918: Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils, 2002
3) Loch, J. P. G.: Influence of the heat extraction rate on the ice segregation rate of soils, Frost i jord, pp.19-30, 20, 1979