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Strength Assessment of Frozen Soils by Instrumented Dynamic Cone Penetrometer

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ABSTRACT: As an interest in cold region resource development increases, infrastructure constructions on frozen soils have been actively conducted. Thus, the investigation of the frozen soils is fundamental and essential to ensure the stability of frozen ground. The goal of this study is to estimate the strength of the frozen soils by the instrumented dynamic cone penetrometer. The dynamic cone penetrometer is incorporated with strain gauges and accelerometer at the cone tip to figure out transferred energy through rods. During dynamic penetration phase, a rod guide is located on the frozen soils to prevent eccentricity of impact. Specimens are prepared with sand-silt mixture at the silt fraction of 30 % in weight. The relative density and the degree of saturation are of the soils is 60 % and 10 %, respectively. The specimens are located in the freezing chamber at sub-zero temperature to freeze under the specified vertical stresses for simulating frozen ground. The dynamic penetration tests are conducted after freezing phase. Experimental results show that as the vertical stress increases, the dynamic cone penetration index which represents the strength of the frozen soils decreases. The force signal increases and the velocity estimated by accelerometer decreases as the vertical stress during freezing and penetrating phases increases. This study suggests that instrumented dynamic cone penetration test may be suitable for the investigation of the strength of the frozen soils.

1 INTRODUCTION

The characteristics of soils rapidly change when the soils are frozen at sub-zero temperature. Especially, the strength of the frozen soils significantly increases compare to unfrozen soils due to ice bonding between soil particles. A number of studies related to the strength evaluation of the frozen soils have been conducted (Zhu et al. 1988; Fitzsimons et al. 2001; Yasufuku et al. 2003). Furthermore, the characterization of the frozen soils is important factor for the safety design in cold regions. Linell and Lobacz (1980) studied the design and construction of foundations in the frost and permafrost ground. In addition, numerous researchers have been studied pile design in cold region to ensure the stability of infrastructures on the frozen ground (Weaver and Morgenstrern 1981; Landanyi and Theriault 1990).

For the characterization of the strength of the frozen ground, experimental device which could be applied directly to the field has been required. Several devices are developed to perform field tests such as standard penetration test (SPT), cone penetration test (CPT), and dynamic cone penetration test (DCPT). In the cold regions, the accessibility is relatively low because the area is unexplored due to barren surrounding condition. For this reason, dynamic cone penetrometer which is more portable compare to the other devices is applicable. The dynamic cone penetration tests have been frequently carried out to investigate the strength of the ground (Rahim and George 2002; Abu-Farsakh et al. 2004; Chen et al. 2005). Salgado and Yoon (2003) showed result of the dynamic cone penetration test is related to other engineering properties.

In this study, dynamic cone penetration tests are conducted to characterize frozen soils. Specimens are prepared with the relative density of 60 % and the degree of saturation of 10 %. The specimens are located into the ice chamber to freeze at -5 ºC. Vertical stresses of 5, 10, and 25 kPa are applied during freezing and penetrating phases using air pressure. The dynamic cone penetration tests are conducted after the freezing phase. Dynamic cone penetration index (DCPI) and signals through instrumented sensors are measured to characterize the frozen soils with different vertical stress. This paper describes experimental setup including preparing specimens, results of the dynamic cone penetration tests, analyses, and conclusions of this study.

2 EXPERIMENTAL SETUP

2.1 *Preparing specimens*

Specimens are prepared with sand and silt mixture to simulate actual ground state in the field. The silt fraction, which is the ratio of silt weight to sand weight, is fixed at 30%. The prepared specimens are put into mixer with distilled water. The amount of water is determined to be 10 % in degree of saturation during mixing.

The mixture of sand, silt and water is set into calibration chamber whose size is 500 mm in diameter and 400 mm in height. Compaction number with same energy is applied to each 5 layers, respectively. All cases of the specimens are equally compacted to be 60 % in relative density. After the compaction, the top plate of the chamber is bolted to prevent movement or deformation of the plate. Note that, the hole with 50 mm diameter is prepared in the middle of the top plate which will be a path of the dynamic cone penetrometer.

The calibration chamber is located in ice chamber. Temperature is set into -5 ºC for 48 hours to freeze specimens. During freezing phase, air pressure is injected to underneath the calibration chamber, and then bottom plate moves up to prepared specimens to apply vertical stress. The applied vertical stresses are 5, 10, and 25 kPa to figure out the influence of the confining stress on the strength of the frozen soils. The target vertical stresses are maintained during whole procedure by using regulator.

2.2 *Instrumented dynamic cone penetrometer*

The instrumented dynamic cone penetrometer is developed to characterize the strength parameter of the frozen soils as shown in Figure 1. Rods are manufactured with 24 mm in a diameter. The angle of the cone tip is 60º. Note that the cone tip is reinforced to minimize wear and tear due to the hardness of the frozen specimens.

Strain gauges and accelerometer are instrumented at the cone tip to measure dynamic responses. The strain gauges are attached symmetrically to compensate an effect of eccentricity, and arranged by the full bridge of wheatstone circuit to minimize a temperature influence. The strain gauges sense physical deformation of the cone penetrometer from changed electrical resistance of the circuit. For the estimation of applied force to cone penetrometer, load calibration tests are conducted as show in Figure 2. The accelerometer is equipped at the same location with the strain gauges to figure out dynamic response. Furthermore, the results of the dynamic response which is get from accelerometer can be used to estimate the strength of the frozen soils.

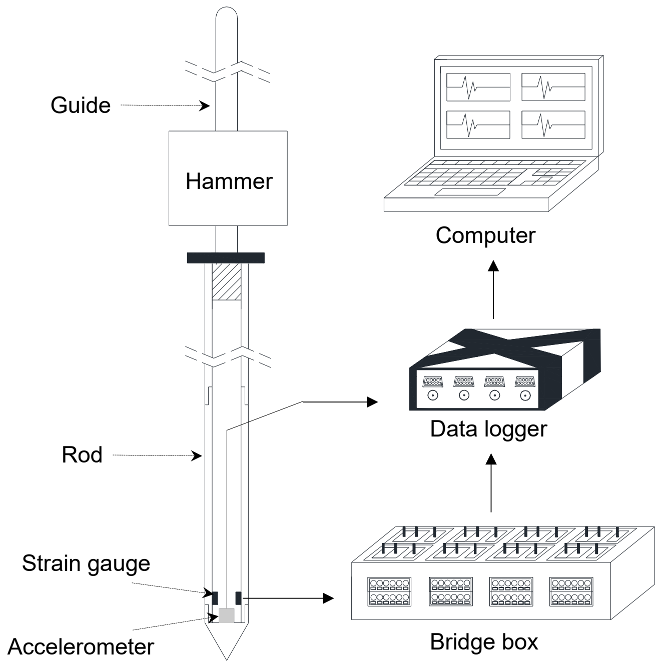

Figure 1. Measurement system of dynamic cone penetration test.

The hammer and hammer guide are manufactured to impact cone penetrometer dynamically. The weight of the cylindrical hammer is 117.6 N. The hammer falls down freely from 383 mm of the height through hammer guide to impact with 46 N·m in potential energy. Furthermore, the guide of the cone penetrometer is manufactured to make sure of straightness when the rods are being penetrated. The level of cone penetrometer guide can be controlled according to process of the cone penetration test.

The signals of each blow are measured through bridge box and data logger. The output voltage from strain gauges is amplified and filtered through the bridge box, and acquired at the data logger. The accelerometer signal is captured at the data logger directly. Both of the signals are monitored through computer, and can be stored automatically.

3 RESULTS AND ANALYSES

3.1 *Dynamic cone penetration index*

The dynamic cone penetration tests are carried out to estimate the strength parameter of the frozen soils. The vertical stresses for setting up different confining conditions are applied during penetration tests. The dynamic cone penetration indices (DCPI) are plotted from 100 mm to 300 mm in depth to minimize boundary effect as shown in Figure 3.

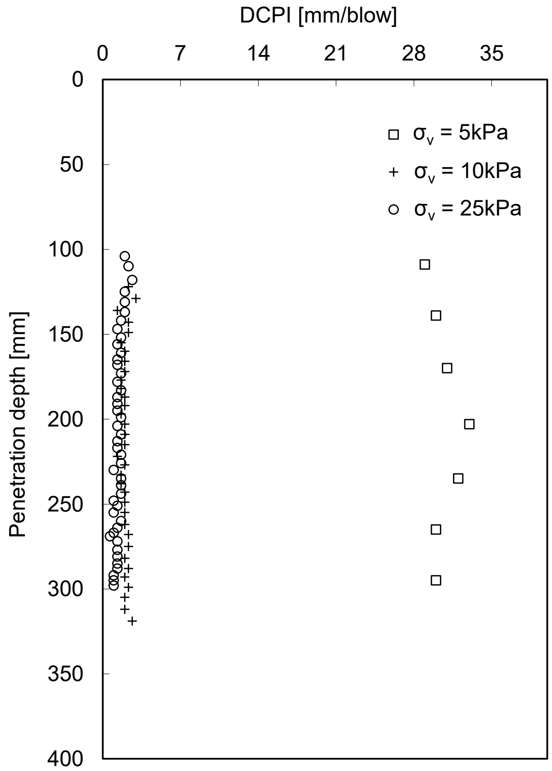

Figure 2. Results of dynamic cone penetration index.

The measured dynamic cone penetration indices are averaged at the penetration depth of 100 ~ 300 mm to find out representative set value for each condition of the frozen soils. The averaged DCPI of 30.5, 2.0, and 1.4 mm/blow are calculated for the vertical stresses of 5, 10, and 25 kPa, respectivly. The dynamic cone penetration index decrease significantly as the vertical stress increases from 5 kPa to 10 kPa. However, the index slightly decreases from 10 kPa to 25 kPa. The result shows that the effect of the vertical stress on the strength of the frozen soils decreases with an increase in the confining stress.

3.2 *Dynamic responses*

Force and velocity signals are measured during penetration phase. The signals of force and velocity multiplied by impedence (Z) are captured at the penetration depth of 200 mm under different confining stresses are plotted in Figure 4. Figure 4(a) shows the response with the vertical stress of 5 kPa, and Figure 4(b) expresses with the vertical stress of 25 kPa. In the case of the vertical stress of 5 kPa, the duration of the signals is longer than the vertical stress of 25 kPa. As the strength of the frozen soils increases, the force signal from strain gauges increases due to the greater deformation of the rods. However, the velocity integrated from the measured acceleration shows higher value for the specimen prepared under the higher vertical stress. The dynamic responses show that the strength of the frozen soils can be evaluated from the force and velocity signals. Furthermore, transferred energy at the cone tip can be obtained by integrating force and velocity values. The transferred energy can improve the accuracy of estimating the strength of the soils by dividing DCPI.

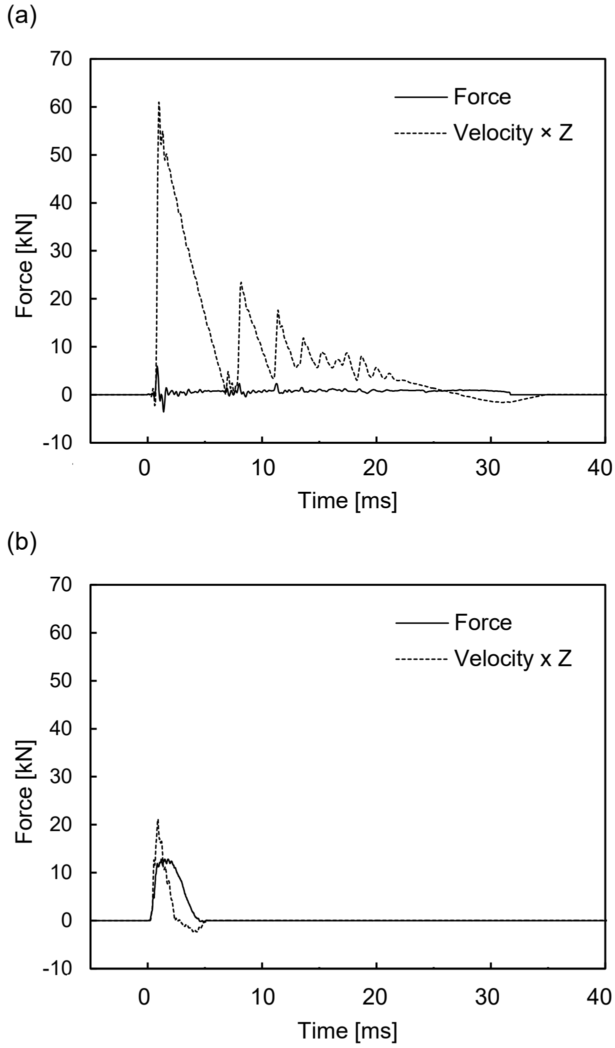

Figure 3. Signals of dynamic responses: (a) 5kPa of vertical stress; (b) 25kPa of vertical stress.

4 SUMMARY AND CONCLUSIONS

The goal of this study is to characterize the strength of the frozen soils by using instrumented dynamic cone penetrometer. The specimens with the degree of saturation of 10 % and the relative density of 60 % are prepared in the freezing chamber. The applied vertical stresses during freezing and penetrating phases are 5, 10, and 25 kPa. The dynamic cone penetration tests are conducted after freezing phase to measure dynamic cone penetration indices. Furthermore, the force and velocity signals are acquired using instrumented strain gauges and accelerometer at the cone tip. The observations of the study are as follows at 200 mm in depth:

(a) The dynamic cone penetration index decreases as the strength of the frozen soils increases. The difference of the strength which can be evaluated by dynamic cone penetration indices decreases with an increase in the vertical stress.

(b) As the vertical stress increases during freezing and penetrating phases, the force measured by strain gauges increases and the velocity estimated by the accelerometer decreases because the strength of frozen soils increases.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Abu-Farsakh, M.Y., Alshibli, K., Nazzal, M. & Seyman, E. 2004. Assessment of in-situ test technology for construction control of base courses and embankment. *Louisiana Transportation Research Center.*

Chen, D.H., Lin, D.F., Liau, P.H. & Bilyeu, J. 2005. A correlation between dynamic cone penetrometer values and pavement layer moduli. *Geotechnical Testing Journal* ASTM 28(1): 42-49.

Fitzsimons, S.J., McManus, K.J., Sirota, P. & Lorrain, R.D. 2001. Direct shear tests of materials from a cold glacier: implications for landform development. *Quaternary international* 86(1): 129-137.

Ladanyi, B. & Theriault, A. 1990. A study of some factors affecting the adfreeze bond of piles in permafrost. *In Proc. of Geotechnical Engineering Congress GSP* 27: 213-224.

Linell, K.A. & Lobacz, E.F. 1980. Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost. *Report of Cold Regions Research Engineering Laboratory* U.S. Army: 80-134.

Rahim, A. & George, K. 2002. Automated dynamic cone penetrometer for subgrade resilient modulus characterization. *Journal of the Transportation Research Board* 1896: 70-77.

Salgado, R. & Yoon, S. 2003. Dynamic cone penetration test (DCPT) for subgrade assessment. *Joint Transportation Research Program*. West Lafayette.

Weaver, J.S. & Morgenstern, N.R. 1981. Pile design in permafrost. *Canadian geotechnical journal* 18(3): 357-370.

Yasufuku, N., Springman, S.M., Arenson, L.U. & Ramholt, T. 2003. Stress-dilatancy behaviour of frozen sand in direct shear. *In 8th International Conference on Permafrost*. Rotterdam: 1253-1258.

Zhu, Y.L., Zhang, J.Y. & Shen, Z.Y. 1988. Uniaxial compressive strength of frozen medium sand under constant deformation rates. *In 5th International Symposium on Ground Freezing*. Rotterdam: 225-232.