Effects of particle size and distribution on strength estimated by dynamic cone penetrometer in arctic region

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ABSTRACT: Site investigation for the active layer during thawing period is necessary to ensure the ground stability in cold region. For the thawed active layer, the strength of the ground is dependent on the characteristics of soil particles rather than ice amount. The objective of this study is to evaluate the effect of particle size and particle distribution on the strength of soils. The dynamic cone penetrometer instrumented with strain gauges and accelerometer is developed to investigate the active layer in the field. The dynamic cone penetration index (DCPI) is measured for the strength characterization. Furthermore, the dynamic cone resistance is estimated using the transferred energy at the cone tip. The soil samples at 4 different depths are gathered after the dynamic cone penetration test. The particle size at 60% finer (D60) and coefficient of uniformity (Cu) of soil samples are estimated for the comparison with the dynamic penetration index and dynamic cone resistance. Experimental results show that the dynamic cone penetration index increases, and dynamic cone resistance decreases as both particle size and coefficient of uniformity increase. In addition, the dynamic cone resistance is more reliable than dynamic cone penetration index because the transferred energy is considered. This study suggests that the particle characteristics affect the strength of the soils in active layer, and the dynamic cone resistance can be used as an effective tool for the ground investigation.

Keywords: dynamic cone penetration index; dynamic cone resistance; particle distribution; particle size; strength.

1 INTRODUCTION

In arctic regions, seasonal climate change may occur the freezing-thawing cycles of the ground. The active layer, which is the soil layer between permafrost and atmosphere, is determined as the upper ground layer undergoing the freezing-thawing cycles (Anisimov et al., 1997). Furthermore, global warming may increase the thickness of the active layer (Nelson et al., 2001). The active layer is significantly weakened during seasonal thawing period because the ice between soil particles changes the phase into water. In addition, the number of freezing-thawing cycles affects the characteristics of the soils because volume expansion during freezing disperses the soil particles, and cannot be recovered to the initial state after thawing (Kang and Lee, 2015). Thus, the strength and stiffness of the soils may decrease after freezing-thawing cycles due to the weakened inter-particle contacts (Qi et al., 2008).

For the strength characterization of the active layer at in-situ state, the field test is necessary. Since the accessibility and temperature of arctic region is hostile, portable and rapid strength assessment device is required. The dynamic cone penetrometer (DCP) has been generally used for the subgrade characterization due to the lightness and quick test procedure. However, the dynamic cone penetration index (DCPI), which represents the strength of the soils determined as the penetration depth per blow, may change due to the energy loss. For this reason, the strain gauges and accelerometer are instrumented to estimate the transferred energy (Byun and Lee, 2013). In addition, the instrumented dynamic cone penetrometer is applied to the active layer for the strength characterization (Byun et al., 2014). Byun et al. (2014) demonstrated that the energy corrected resistance detected the weak layer. Note that the weak layer is significantly affected by the soil particle characteristics rather than water content. Thus, in this study, specimens are sampled for the estimation of the particle size and distribution, and the particle characteristics are used for the comparison with strength assessment results.

The objective of the study is to characterize the soil strength in active layer, and compare the strength with particle size and distribution characteristics. This paper introduces particle size at 60% finer (D60) and coefficient of uniformity (Cu) of soil samples, and describes the dynamic cone penetrometer at first. Then, the dynamic cone penetration index (DCPI) and dynamic cone resistance results in the field are estimated. Finally, the evaluated strength indices are compared with the soil particle characteristics, and discussed.

2 EXPERIMENTAL SETUP

2.1 *Specimens*

Field for the strength assessment test in arctic region is located in Ny-Alesund, Svalbard (78^{o}N 11^{o}E). Four specimens are sampled at different depths in active layer, and sieve analysis is carried out in the laboratory. Sieves from #4 to #200 are prepared, and the percent of passing particles in weight is measured to determine particle size at 60% finer (D60) and coefficient of uniformity (Cu). The values of particle size at 60% finer and coefficient of uniformity are summarized in Table 1. The particle sizes at 60% finer are 7.7, 2.3, 3.3, and 5.1 mm, and the coefficient of uniformities are 17.2, 5.0, 5.8, and 11.1, respectively. The coefficient of uniformity increases with an increase in the particle size at 60% finer in the specimens used in this study.

Table 1. Particle characteristics of samples.

Properties	Sampling depth			
	S-1	S-2	S-3	S-4
D60 [mm]	7.7	2.3	3.3	5.1
Cu [ ]	17.2	5.0	5.8	11.1

* D60 and Cu denote the particle size at 60% finer and coefficient of uniformity, respectively.

2.2 *Dynamic cone penetrometer*

For the strength assessment of the active layer in arctic regions, the instrumented dynamic cone penetrometer is developed. The dynamic cone penetrometer consists of a guide, hammer, rod, and cone tip. The apex angle of cone tip is 60 degrees, and the diameter and thickness of the rod are 20 mm and 5 mm, respectively. For the dynamic cone penetration test, hammer with a weight of 117.7 N freely falls from the height of 575 mm. Thus, the potential energy at each blow is 67.7 N·m. Strain gauges and an accelerometer are incorporated at the cone tip for the estimation of transferred energy. The strain gauges are connected with a full bridge circuit to amplify the electrical signals and minimize bending and temperature effects. The accelerometer is installed at identical location with strain gauges, and measures the dynamic response at the cone tip. By using the force and velocity signals obtained from the strain gauges and accelerometer, the transferred energy can be calculated using Eq. (1) as follows

$$E = \int F \times V \, dt \qquad (1)$$

where E, F, and V are transferred energy, measured force from strain gauges, and calculated velocity from accelerometer.

The value of the calculated transferred energy is lower than the potential energy because the energy loss occurs during dynamic penetration. The energy loss includes impulse and sound energy at the anvil, attenuation at the rod connections, and skin friction between the soil and rod. The calculated transferred energy is considered for the estimation of the dynamic cone resistance.

3 RESULTS AND ANALYSES

3.1 *Dynamic cone penetration index (DCPI)*

The DCPIs versus D60 and Cu are plotted in Fig. 1. The DCPI increases with an increase in D60 as shown in Fig. 1(a), because the strength generally decreases as the particle size increases (Li and Wu, 2005; Fu et al., 2008). In addition, the DCPI increases with an increase in Cu as shown in Fig. 1(b). The strength decreases as the coefficient of uniformity increases because the small particles may disperse the main skeleton composed of large particles (Wang et al., 2013).

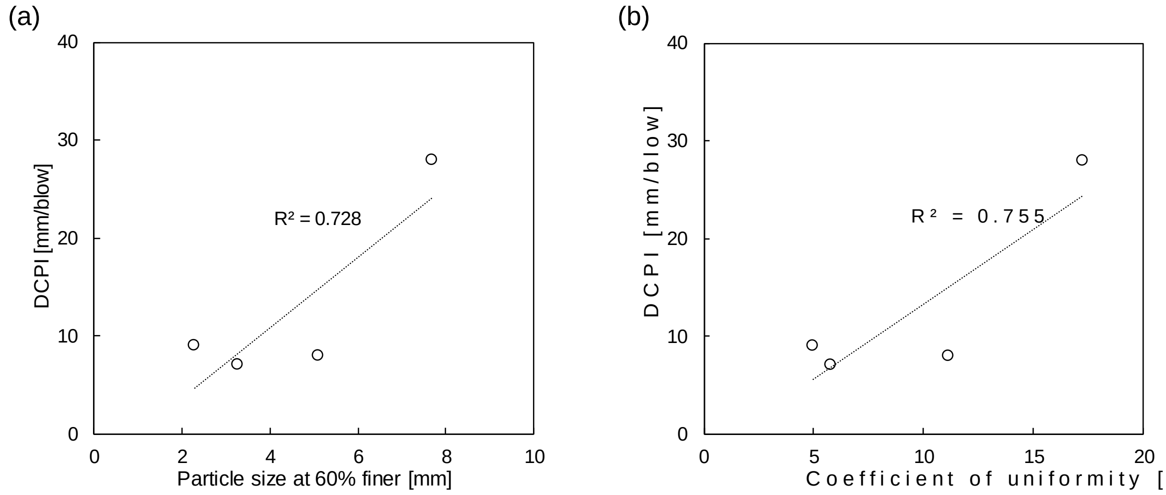

Figure 1. Relationship between DCPI and particle characteristics: (a) D60; (b) Cu.

3.2 *Dynamic cone resistance*

The dynamic cone resistance versus D60 and Cu are plotted in Fig. 2. The dynamic cone resistance decreases with an increase in D60 and Cu because the strength generally decreases as the D60 and Cu increase as shown in Fig. 1.

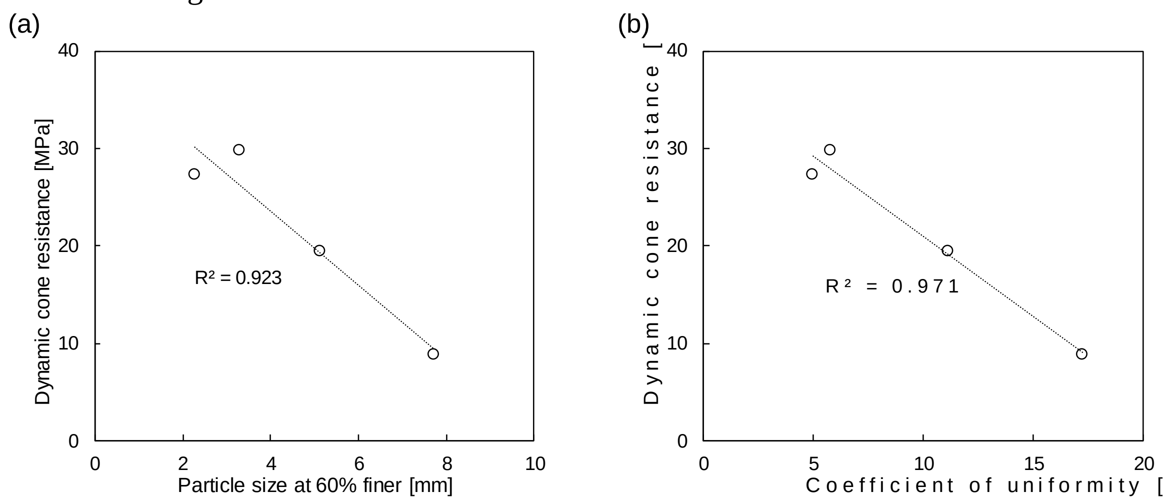

Figure 2. Relationship between dynamic cone resistance and particle characteristics: (a) D60; (b) Cu.

The coefficients of determination in dynamic cone resistance versus D60 and Cu are 0.923 and 0.971, respectively. The coefficients of determination in dynamic cone resistance are higher than those in DCPI, which are 0.728 and 0.755, respectively. Thus, the dynamic cone resistance considering the transferred energy is more reliable than DCPI.

4 SUMMARY AND CONCLUSIONS

The goal of this study is to evaluate the particle size and distribution influence on the soil strength in active layer. The dynamic cone penetrometer incorporated with the strain gauges and accelerometer is used for the strength assessment test in the field. The transferred energy is calculated by force and velocity signals from sensors. Furthermore, the particle size at 60% finer (D60) and coefficient of uniformity (Cu) are estimated in the laboratory. The particle characteristics from lab test are compared to the evaluated strength from field test. In addition, the dynamic cone resistance considering the transferred energy is compared to the dynamic cone penetration index (DCPI). The main observations of this study are as follows:
(a) The dynamic cone penetration index increases, and dynamic cone resistance decreases as the particle size at 60% finer and coefficient of uniformity increase. The strength generally decreases with an increase in the particle size and coefficient of uniformity due to the small particle role in main skeleton.
(b) The coefficient of determination in dynamic cone resistance is higher than that in dynamic cone penetration index. The strength assessment using dynamic cone resistance is reliable due to the consideration of the transferred energy.

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REFERENCES

Anisimov, O.A., Shiklomanov, N.I., & Nelson, F.E. 1997. Global warming and active-layer thickness: results from transient general circulation models. Global and Planetary Change, Vol. 15(3-4), pp. 61-77.
Byun, Y.H. & Lee, J.S. 2013. Instrumented dynamic cone penetrometer corrected with transferred energy into a cone tip: a laboratory study. Geotechnical Testing Journal, ASTM, Vol. 36(4), pp. 533-542.
Byun, Y.H., Yoon, H.K, Kim, Y.S., Hong, S.S., & Lee, J. S. 2014. Active layer characterization by instrumented dynamic cone penetrometer in Ny-Alesund, Svalbard. Cold Regions Science and Technology, Vol. 104-105, pp. 45-53.
Fu, S.Y., Feng, X.Q., Lauke, B., & Mai, Y.W. 2008. Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate–polymer composites. Composites Part B: Engineering, Vol. 39(6), pp. 933-961.
Kang, M. & Lee, J.S. 2015. Evaluation of the freezing-thawing effect in sand-silt mixtures using elastic waves and electrical resistivity. Cold Regions Science and Technology, Vol.113, pp. 1-11.
Li, G. & Wu, X. 2005. Influence of fly ash and its mean particle size on certain engineering properties of cement composite mortars. Cement and Concrete Research, Vol. 35(6), pp. 1128-1134.
Nelson, F.E., Shiklomanov, N.I., & Mueller, G.R. 2001. Subsidence risk from thawing permafrost. Nature, Vol. 410(6831), pp. 889–890.
Qi, J.L., Ma, W., & Song, C. 2008. Influence of freeze–thaw on engineering properties of a silty soil. Cold Regions Science and Technology, Vol. 53(3), pp. 397–404.
Wang, J.J., Zhang, H.P., Tang, S.C., & Liang, Y. 2013. Effects of particle size distribution on shear strength of accumulation soil. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 139(11), pp. 1994-1997.