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Estimation of undrained shear strength for peat using CPT

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ABSTRACT: Fibrous and high organic peat is distributed widely in Hokkaido, the northernmost island of Japan. Peat ground is extremely soft and has strange engineering properties. Since behavior of peat ground differs greatly from that of ordinary soft ground, it is classified as a problematic soil. Peat ground is a significant hindrance to infrastructure construction. Electric cone penetration tests (CPT) for peat deposit were conducted at several sites on peat ground in Hokkaido, Japan and K_0 consolidated-undrained triaxial compression test on undisturbed peat collected from the same sites, to clarify the undrained shear strength (S_u) of such ground. This paper presents that results of the tests, and proposes a method for determining S_u for peat using CPT.

1 INTRODUCTION

When embankment such as road and river levee is constructed over soft ground, the stability of the ground is commonly evaluated by the safety factor obtained from circular slip analysis. In this analysis, it is very important to determine the undrained shear strength (S_u) of the ground. As peat, which is a widely distributed soft and problematic soil in Hokkaido, Japan, is accumulated heterogeneously (Noto, 1991), unconfined compression tests, vane shear tests and other tests performed for only a few samples lack validity. The electric cone penetration test (CPT) is more reasonable and valid than these, in that CPT can estimate average S_u from in-situ tests, which continuously provide information. Therefore, the aim of this study is to establish a method for estimating the S_u of peat ground by performing CPT.

A series of K_0 consolidated-undrained triaxial compression tests (K_0CUC tests) on undisturbed peat soil collected at several sites in Hokkaido was conducted. Also the CPT was performed at the same sites. This report describes the relationship between S_u obtained from the K_0CUC tests and CPT cone resistance (q_t), and a method for estimating S_u in peat soil from q_t.

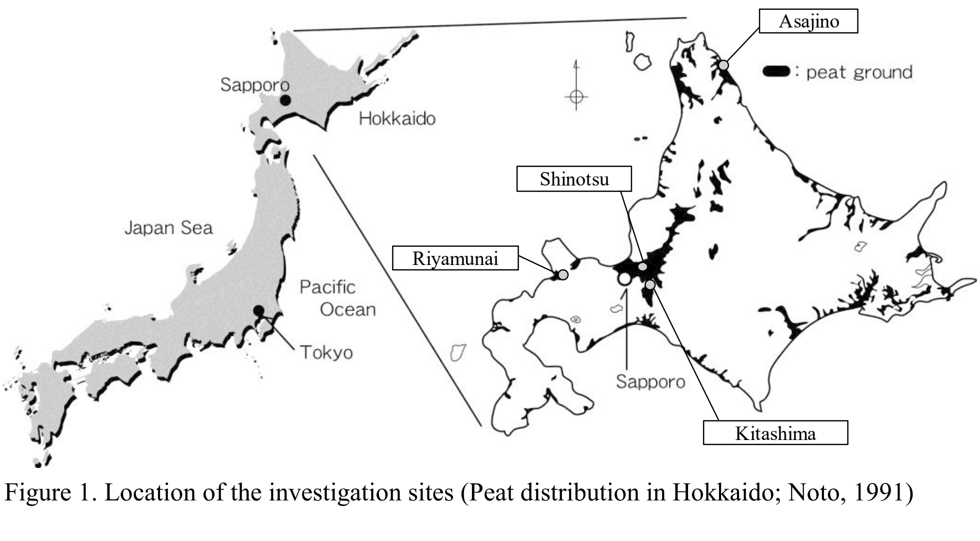

Figure 1. Location of the investigation sites (Peat distribution in Hokkaido; Noto, 1991)

Table 1. Engineering properties of the soil samples

Site	Soil type	Number of samples for K0-consolidated triaxial compression test	Natural water content W_n (%)	Ignition loss Li (%)	Degree of decomposition von Post	In-situ void ratio e_0	Conmpression index C_c
Shinotsu	Peat	3	323～459	37～66	H5	7.9	5.1
Asajino	Fibrous peat	1	860	92	H2	14.8	9.3
Riyamunai	Fibrous peat	3	724～945	82～94	H3	13.5	10.0
Kitashima	Peat	1	387	55	—	—	—

2 INVESTIGATION METHOD

2.1 *Investigation site*

A series of CPT and collection of undisturbed samples for the laboratory tests were conducted at the four sites (Shinotsu, Ebetsu city; Asajino, Sarufutsu village; Riyamunai, Kyowa town and Kitashima, Eniwa city) in peat ground in Hokkaido, Japan (Fig. 1). The undisturbed samples were collected using a thin-wall sampler with a fixed piston (JGS 1221; JGS, 2015). Table 1 shows the soil types and the engineering properties of the sampling soils at the investigation sites. The sampling soils at the Asajino site and the Riyamunai site were classified as fibrous peat.

2.2 *CPT*

Figure 2 shows the dimension of the CPT cone used. The penetration velocity was set at 2 cm/s, and q_t, skin friction (f_s) and pore water pressure (u) were continuously measured at each 1 cm of penetration. The cone resistance (q_t) obtained from the CPT is a value that takes into account the influence of water pressure at the filter, as determined by Equation (1), where q_{ce} is the measured cone resistance (kN/m^2), A_e is the effective cross-sectional area of the cone (m^2), A_p is the area of the base of the cone (m^2) and u is the pore water pressure (kN/m^2).

$$q_t = q_{ce} + (1 - A_e/A_p)\, u \qquad (1)$$

2.3 *K_0 Consolidated-Undrained Triaxial Compression Test*

To calculate the undrained shear strength of peat, the K_0CUC test (JGS0525: JGS, 2011) was performed for undisturbed soil samples (Fig. 3). Each sample was 75 mm in diameter and 150 mm in height. The samples were carefully trimmed and set on the test device to avoid unnecessary disturbance. As the S_u of the soil is significantly affected by the confining pressure, K_0 consolidation was conducted with a

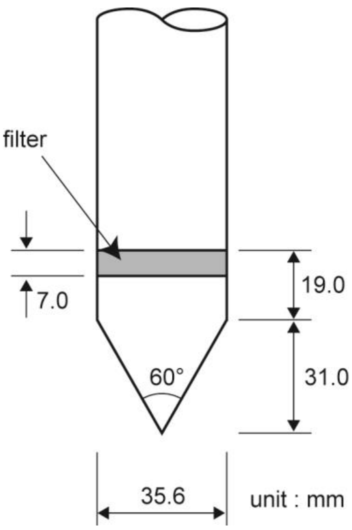

Figure 2. Dimension of the CPTU cone used in this study

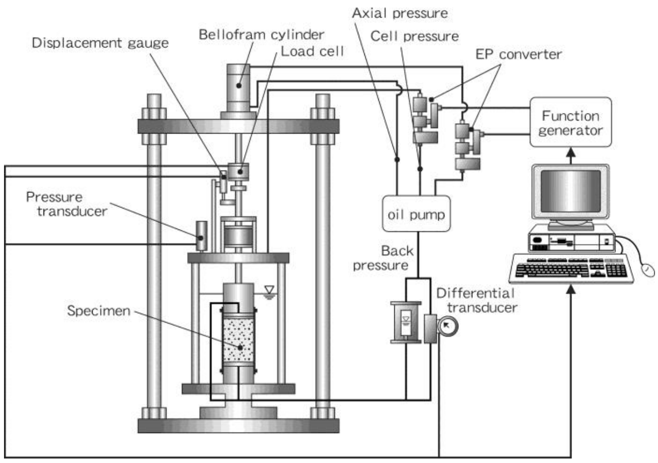

Figure 3. Set up of the K_0 consolidated-undrained triaxial compression test used in this study

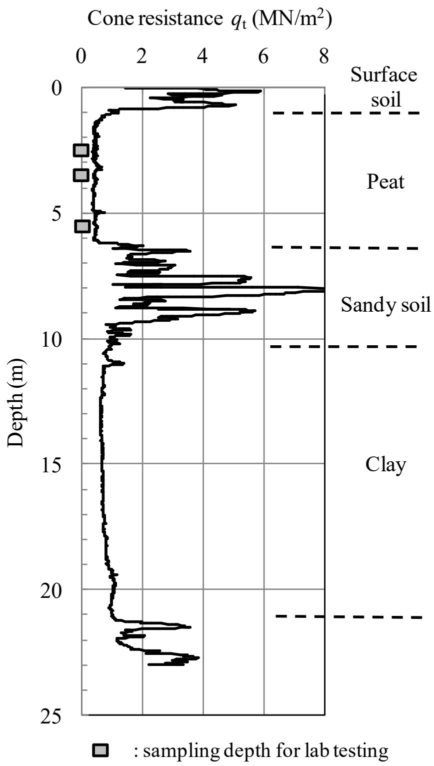

Figure 4. Depth distribution results of the CPT at the Shinotsu site

pressure equivalent to the in-situ stress. This means that the in-situ anisotropic consolidation was reproduced in the laboratory. After the K_0 consolidation, compression (0.1%/min of strain rate) under an undrained condition was done. Additionally, an oedometer test and physical index tests were conducted.

3 RESULTS AND DISCUSSION

3.1 *CPT Profile*

Figure 4 shows the depth distribution results of the CPT at the Shinotsu site. This is the typical CPT profile (q_t, f_s and u) of this study. The geologic columnar section obtained from drilling at the Shinotsu site was added to the figure. The q_t in the peat layer (q_t = 0.33-0.71 MN/m^2) was lower than that in the other soil types, which indicates that the peat layer is very soft. Great excess pore water pressure, which was caused by the cone penetration, was generated in the peat layer and the clay layer.

3.2 *Relationship between Cone Resistance and Undrained Shear Strength*

To calculate the S_u of the ground from CPT, Equation (2) is commonly applied. Where, the S_u and q_t are both expressed in units of kN/m^2, σ_{v0} is the total

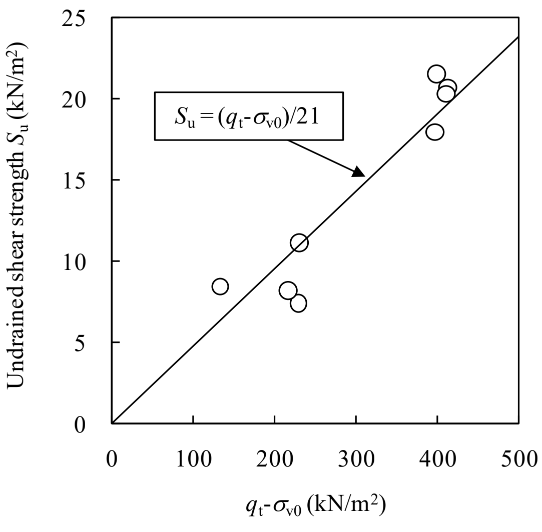

Figure 5. Relationship between (q_t-σ_{v0}) and undrained shear strength for peat

overburden pressure (kN/m^2), and N_k is a correction coefficient called the cone coefficient.

$$S_u = (q_t - \sigma_{v0}) / N_k \quad (2)$$

Konrad & Lan (1987) reported that N_k in Equation (2) greatly varies by soil property. Figure 5 shows the relation between (q_t - σ_{v0}) and S_u obtained from the K_0CUC test, to reveal the N_k of peat. As shear strength does not peak in the K_0CUC test on peat, S_u was assessed by assuming 15% of the shear-

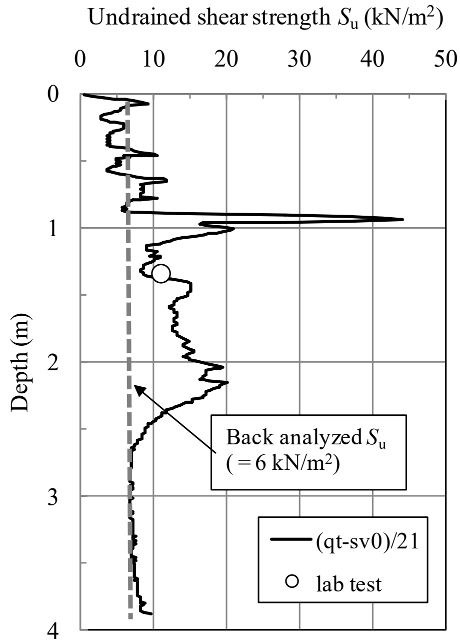

Figure 6. Undrained shear strength calculated using N_k = 21 and Eq. (2), and obtained from the K_0 consolidated-undrained triaxial compression test at the Asajino site

ing strain as failure. Overall, the S_u in peat was only between 5 - 20 kN/m^2, and S_u increased linearly with increase in (q_t - σ_{v0}). This relation proves that N_k value in Equation (2) of peat is 21.

Noto (1991) reported that the N_k of peat is 20, based on the cone resistance obtained from a mechanical cone penetration test. Konrad & Lan (1987) reported that the N_k of clay is between 10 and 20. In this study, the N_k of peat was found to be similar to that reported by Noto (1991), and was found to be greater than that of clay.

Figure 6 shows the depth distribution of S_u, calculated by the q_t measured at the Asajino site and N_k = 21 for Equation (2). At Asajino, sliding failure happened during embankment construction. Back circular slip analysis was performed based on this fact of the sliding failure, which led S_u of the peat layer to be 6kN/m^2. This roughly corresponds with the S_u calculated by N_k = 21 for Equation (2). This indicates that it is possible for Equation (2) and N_k = 21 to estimate S_u in peat ground.

4 CONCLUSIONS

To clarify the estimation method of undrained shear strength (S_u) for peat ground, a series of electric cone penetration tests (CPT) and laboratory tests were conducted for peat ground in Japan. The main results can be summarized as follows:

(1) The S_u value for peat ground increases linearly with the increase in cone resistance (q_t) of CPT.

(2) The relationship between q_t and S_u in peat ground can be approximated by "$S_u = (q_t - \sigma_{v0})/21$", where σ_{v0} is whole overburden pressure. It is possible to estimate of S_u value for peat ground using this relationship.

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