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Soil classification and correlation between Swedish weight sounding test results and strength parameter

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ABSTRACT: This paper investigates a method for estimating the strength parameter from the results of Swedish weight sounding (SWS) tests. SWS tests are in-situ tests used to obtain the static penetration resistance, such as penetration load W_{sw} and the number of half-turns N_{sw}. The relationship between the angles of internal friction and the SWS test results for two types of silica sand is simply presented. The correlation between particle size and the recorded friction sound during the SWS operation is shown to discriminate the types of soil. The relationship of the angles of internal friction and the SWS test results suggests that the strength parameter can be directly deduced from the SWS test results. Additionally, the correlation between particle size and the recorded friction sound implies the possibility of determining the types of soil.

Keywords: Swedish weight sounding test; strength parameter; friction sound

1. Introduction

Characterizing the properties of soils is of importance due to design and maintenance concerns. These properties are generally evaluated by laboratory and in-situ tests. Swedish weight sounding (SWS) tests [1] in the Japanese Industrial Standards (JIS) are field tests used to obtain the static penetration resistance, such as penetration load W_{sw} and the number of half-turns N_{sw}. From the value of the resistance, the N-value, the unconfined compressive strength, and the bearing capacity can be computed in order to evaluate the soil strength [2-4]. The correlation between the SWS test results and the strength parameters, such as cohesion and the angle of internal friction, is not presented here, even though such parameters are required for conducting a safety evaluation of earth structures.

The strength parameter depends on various factors such as the particle size distribution. The identification of the soil types and an accurate evaluation of the particle sizes of the soil are desirable for the estimation of the strength parameter. It is difficult to quantitatively determine the types of soil from the SWS test results, because the determination is based purely on the experience of the engineers. However, some researchers have attempted to discriminate the particle sizes and the types of soil. Previous papers have suggested that an evaluation of the relationship between the strength parameter and the particle sizes, using the friction sound during the tests, ought to be carried out [5].

This paper showcases the relationship between the SWS test results and the angles of internal friction for two types of silica sand. An evaluation of the particle sizes using the friction sound during the SWS tests is simultaneously carried out.

2. Swedish weight sounding

The Swedish weight sounding (SWS) test in the Japanese Industrial Standards (JIS) is a field test used to measure the static penetration resistance for the purpose of judging the in-situ hardness/softness of compactness of the ground and the soil layer configuration. Figure 1 shows the manually operated test apparatus which consists of a handle, six weights totaling 1,000 N, a loading clamp, a base plate, extension rods, a screw point connecting rod, and a screw point. The field test is comprised of two stages: the static penetration and the rotational penetration. In the static penetration stage, the screw point is attached to the screw point connecting rod, and the screw point is statically penetrated by the weights in stepwise increments. The amount of penetration is obtained and the weight is denoted as W_{sw} kN. If penetration does not occur with 1,000 N, the rod is rotated using the handle in the rotational penetration stage. The number

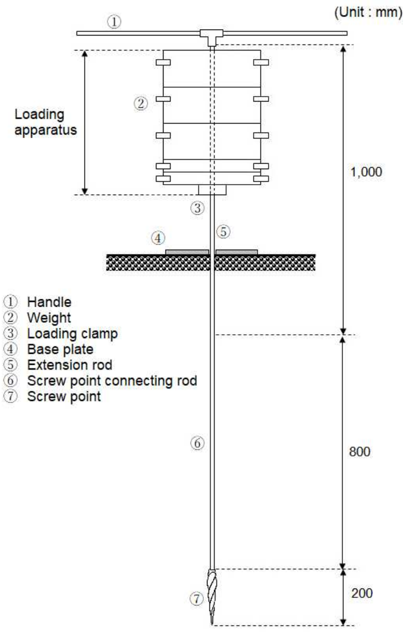

Figure 1. Manually operated test apparatus

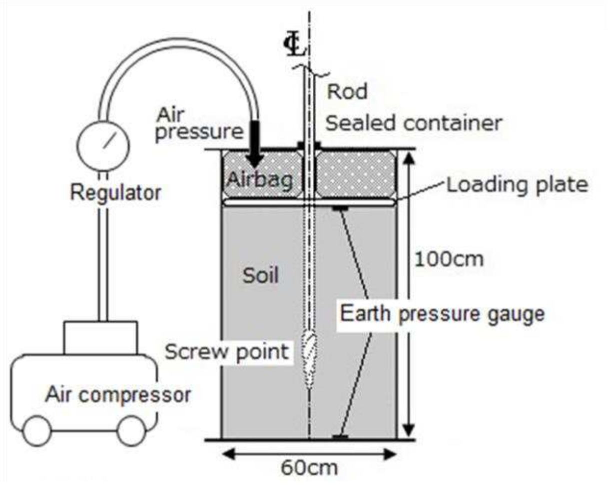

Figure 2. Test apparatus

of half turns necessary to penetrate the rod through 25 cm is denoted as N_a. The value of N_{sw} calculated from N_a is the number of half turns for each 1 m of penetration.

3. Estimation of strength parameter

Figure 2 presents the apparatus for the SWS tests. The apparatus consists of a sealed container, an airbag, a wooden loading plate, and an air compressor with a regulator. The inside dimensions of the container are 60 cm in diameter and 100 cm in height. The physical properties and the grain size distribution curves of the two types of silica sand are shown in Table 1 and Fig. 3, respectively. The sand is packed into the container and loaded by the airbag while the air pressure is maintained at constant levels of 100 kPa, 200 kPa, and 300 kPa using a pressure regulator. In order to examine the correlation between the dry density and the strength parameter, the unit weight is set at three different values. Consolidated drained triaxial tests are carried out to study the shear strength of the two types of silica sand at the same density as the SWS tests. The interrelation between unit weight γ_t and the angle of internal friction ϕ, which is given by the triaxial compression tests, is obtained. Furthermore, Fig. 4 depicts the interrelation between γ_t and the number of half turns N_{sw} per 1 m of penetration. Equations (1) and (2), calculated from the equations in Fig. 4, are expressed in terms of silica sands #1 and #2, respectively.

Table 1. Physical properties of silica sands

Sample	Minimum density (g/cm^3)	Maximum density (g/cm^3)	Coefficient of uniformity	Coefficient of cuvature	Maximum grain size (mm)
Silica sand #1	1.343	1.606	1.778	0.840	4.750
Silica sand #2	1.270	1.570	2.143	0.952	0.850

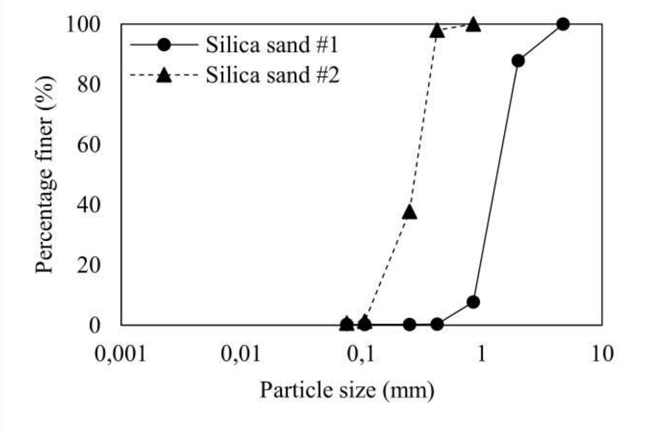

Figure 3. Grain size distribution curves of silica sands

$$N_{sw} = \{(0.299\times10^{-1})\sigma + 0.288\times10^{2}\}\gamma_t - (0.190\sigma + 0.343\times10^{3}) \quad (1)$$

$$N_{sw} = (0.396\sigma - 0.328\times10^{2})\,\gamma_t - (4.720\sigma + 0.407\times10^{3}) \quad (2)$$

where σ is the effective overburden stress. From Eqs. (1) and (2), and the relationship between γ_t and ϕ, Eqs. (3) and (4) are given as

$$\phi = \frac{N_{SW} + 0.268\sigma + 0.417\times10^{3}}{\left(0.125\times10^{-1}\right)\sigma + 12.0} \quad (3)$$

$$\phi = \frac{N_{SW} + 7.00\sigma + 0.596\times10^{3}}{0.210\sigma + 17.4} \quad (4)$$

The angles of internal fricton expressed in Eqs. (3) and (4), and deduced from Eqs. (5) - (8) by the Japanese organizations, are tabulated in Table 2.

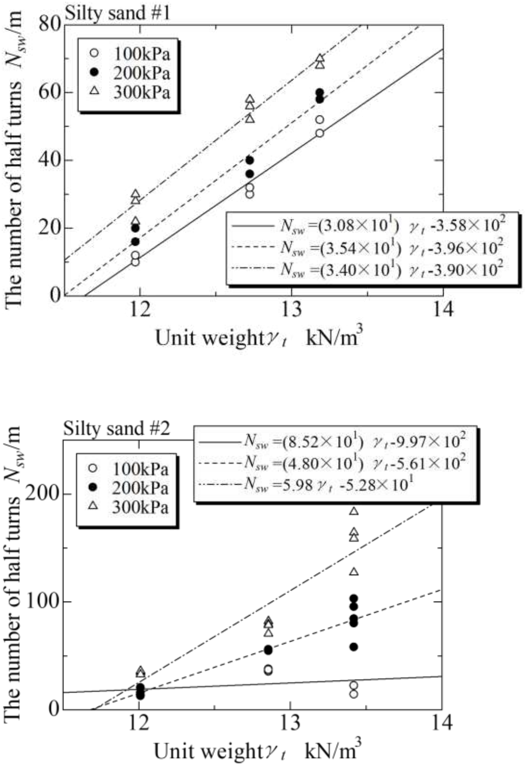

Figure 4. Relationship between γ_t and N_{sw} of silica sands #1 (upper figure) and #2 (lower figure)

1. Japan Road Association [6]

$$\phi = 4.8\log N_1 + 21 \quad (\mathrm{N}>5),\ N_1 = \frac{170N}{\sigma + 70} \tag{5}$$

where N is the N-value.

2. Railway Technical Research Institute [7]

$$\phi = 1.85\left\{\frac{N}{(\sigma/100)+0.7}\right\}^{0.6} + 26 \tag{6}$$

3. Japan Port and Harbor Association [8]

$$\phi = 25 + 3.2\sqrt{\frac{100N}{70+\sigma}} \tag{7}$$

4. Architectural Institute of Japan [9]

$$\phi = \sqrt{20N_1} + 20 \quad (3.5 \le N_1 \le 20)$$

$$N_1 = N\sqrt{98/\sigma} \tag{8}$$

In Table 2, it is seen that Eqs. (3) and (4) tend to overestimate the angles of internal friction in all cases treated. This overestimation implies that the well-known equations, (5) – (8), are derived from the soil samples, which have properties that are different from those of silica sands #1 and #2.

Table 2. Angles of internal friction in Japanese organizations

	N-value	Earth pressure		
		100kN/m^2	200kN/m^2	300kN/m^2
Silica sand #1	5	39.1	37.6	36.3
Silica sand #2	5	34.9	34.9	34.5
Japan Road Association	5	24.4	23.4	22.7
Railway Technical Research Institute	5	29.5	28.7	28.2
Japan Port and Harbor Association	5	30.5	29.4	28.7
Architectural Institute of Japan	5	30.1	28.0	27.8

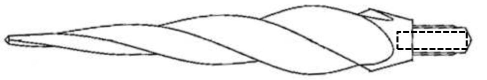

Figure 5. Screw point

Figure 6. Installed microphone

4. Soil discrimination using friction sound

The friction sound is measured continuously during the SWS operation by an installed microphone and can be transferred to a computer. The microphone is placed in the screw point. Figure 5 shows the screw point; the broken line represents the placement of the microphone shown in Fig. 6. The recorded data are transformed to the frequency-domain via the fast Fourier transform. Figure 7 shows the correlation between the sound pressure level and the frequency of the fricative sound. The results of clay are also simultaneously displayed in order to make a comparison with the results of the silica sands and to investigate the particle size effect. The physical properties and the grain size distribution curve of the clay are shown in Table 3 and Fig. 8, respectively. In Fig. 7, it is seen that large particle sizes generate high sound pressure levels and that the two types of silica sand have a peak around a frequency of 2,000-3,000 Hz. In contrast, the clay generates low sound pressure levels. The sound pressure levels and the peak suggest the possibility of determining the particle sizes and the soil types.

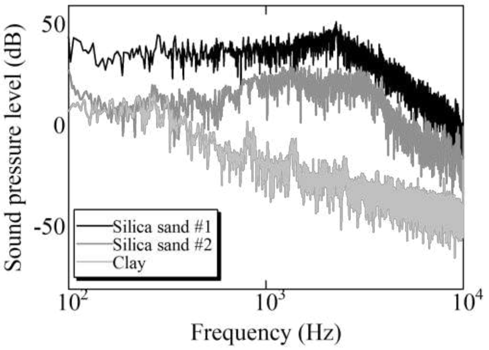

Figure 7. Data recorded during SWS operation

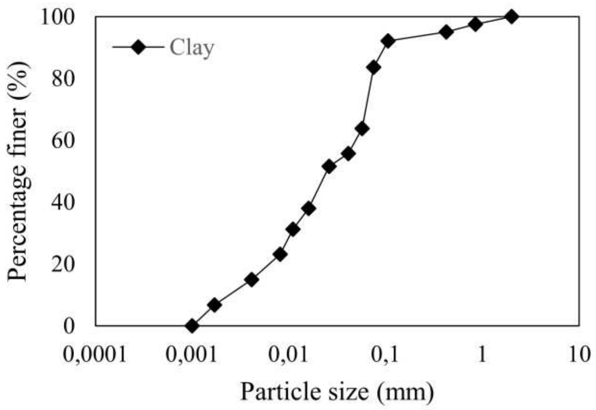

Fig.8. Grain size distribution curve of clay

5. Conclusions

Swedish weight sounding tests were conducted to obtain the interrelation between the angles of internal friction and the SWS results. The experimental interrelation was expressed as fitting equations, and the equations were found to overestimate the angles of internal friction. The friction sound during the SWS operation was recorded to evaluate the particle sizes of the soil. The particle sizes corresponded to the sound pressure levels, and the two types of silica sand were seen to have a peak. The results imply that an evaluation of the strength parameter and the determination of the soil types ought to be simultaneously carried out.

Table 3. Physical properties of clay

Density (g/cm3)	Liquid limit (%)	Plastic limit (%)	Plasitisity index	Water content (%)
2.495	46.7	27.8	18.9	6.95

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