Effects of fine matters on strength and stiffness

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ABSTRACT

Deposits of fine matters (silt and diatom microfossils) are a common feature in many sites around the world (including Ulleung Basin, Korea, Osaka Bay, Japan, and Mexico City, Mexico), and the existence of such deposits affects soil strength. The objective of this study is to investigate the effects of fine organic matters on the strengths and stiffnesses of soils using a triaxial apparatus incorporated with bender elements. The specimens used are artificial mixtures of sand and organic matters with different fine fraction in weight. Note that in terms of weight, the fines consist of 30% diatom and 70% silt. In addition, the shear waves were measured during shearing. The experiment results illustrated that the shear strengths of soil mixtures increased with increasing fines up to 20%, then decreased with increasing fines thereafter 20%. The elastic wave result shows that shear wave velocity decreases due to changes in the fabrics of soils caused by the increase of fines. The results of this study established a huge impact of fine particles on the strengths and stiffnesses of soils.

Keywords: diatom, fines, shear wave, silt, strength, triaxial

1. INTRODUCTION

Fine organic matters deposits are a common feature in many sites around the world. The existence of these fines significantly affects soil properties (strength and stiffness of soils) (Thevanayagam 1998; Shiwakoti et al. 2002). Previous studies reported that the shear strength of soils decreased as the silt contents increased (Pitman et al., 1994), and varied due to additional matters such as diatom (Shiwakoti et al. 2002). In addition, in order to investigate variations in stiffness, many studies have considered shear wave. For examples, Carraro et al., (2009), showed that both plastic and non-plastic fines significantly reduced the stiffness of soils. The effects of silts on strength and stiffnesses are different from those of diatom, since silt particles are non-plastic while diatom particles are plastic.

The objective of this study was to investigate the effects of fine particles on the strengths and stiffnesses of specimens prepared with sand and fines in different amount such as 0, 10, 20, and 30% using a triaxial apparatus. Triaxial tests are conducted while shear waves are measured during shearing. This paper provides information regarding specimens and set-ups of apparatuses to conduct shearing tests and shear wave measurements immediately after INTRODUCTION. The experimental results, consequently, are provided and discussed in the following sections, and a summary of the results and conclusions come last.

2. EXPERIMENTAL SET-UP

The specimens used in this study were artificial mixtures of sand and fines. The sands had a medium grain size (D50) of 0.14 mm and a specific gravity of 2.65. Fines, in this study, were defined as particles such as diatom and silts in ratios of 7:3 by weight. The silts and fragments of sands, passed through sieve No. 200 (75 μm) and had a specific gravity of 2.65 while diatom were organic particles with a specific gravity of 2.2.

2.1. Specimen preparation

The amounts of sand in the four types of specimens were kept equal while fines were added in at 0, 10, 20, and 30% by weight to form FC00, FC10, FC20, and FC30 respectively. Specimens were of 70 mm in diameter and 140 mm in height, as shown in Table 1.

Table 1. Samples' properties (by weight).

Samples	FC00	FC10	FC20	FC30
Fine content (%)	0	10	20	30
Specific gravity ( )	2.65	2.61	2.57	2.55
Density (g/cm^3)	1.457	1.619	1.821	2.081
Void ratio ( )	0.818	0.612	0.411	0.224

* The specific gravities of sand, silt, and diatom are 2.65, 2.65, and 2.2 respectively.

2.2. Triaxial tests

For consolidated drained (CD) triaxial tests, specimens were consolidated under an effective stress of 66 kPa, then proceeded to a shearing phase under a confining stress of 100 kPa and a shearing rate of 0.08 %/min.

2.3. Elastic wave measurement system

For shear wave (S-wave) measurement, bender elements (BE) were used to generate and detect S-wave. Parallel-type two-layer bender elements were used to prevent electromagnetic coupling (Lee and Santamarina 2005), and were shielded to reduce electrical noise and cross talk (Lee et al. 2008).

The full shear wave measurement system for triaxial tests is shown in Fig. 1. An input was applied to a function generator to emit S-wave into soil specimens via top BE. Therefore, the propagated S-wave arrived in the bottom co-operative sensors and went through a filter-and-amplifier in which signals were filtered with a high pass of 500 Hz and a low pass of at least 10 times higher than the resonant frequency (Lee 2003). Finally, shear wave signals were observed in an oscilloscope at each 0.5% of axial strain until the failure stage.

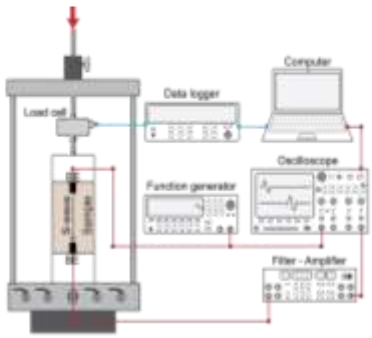

Fig. 1. Triaxial tests' set up.

3. EXPERIMENTAL RESULS

3.1. Strength

The deviatoric stresses versus the vertical strains for the four experiments with specimens of 0%, 10%, 20%, and 30% fines confined under 100 kPa stress were plotted as shown in Fig. 2. The peaks of deviatoric stresses show the lowest value of 353.88 kPa at 0% of fines, and continuously increase to 648.96 kPa as fines increase up to 20%. The specimen with 30% fines, however, shows a drop on deviatoric peak, 400.12 kPa. The triaxial test results are summarized as in Table 2. The critical state angles were calculated using Eq. (1):

$$\varphi = \sin^{-1}\left(\frac{\sigma_1^{'} - \sigma_3^{'}}{\sigma_1^{'} + \sigma_3^{'}}\right) \tag{1}$$

where φ is critical state angles. σ_1' and σ_3' are major and minor effective principle stress, respectively.

Critical-state friction angles also follow the same trend as deviatoric stress, i.e., increasing from the lowest to the highest, from 39.69° to 45.96° for FC00 and FC20, respectively. At 30% of fines, FC30, the angle falls to 41.78°.

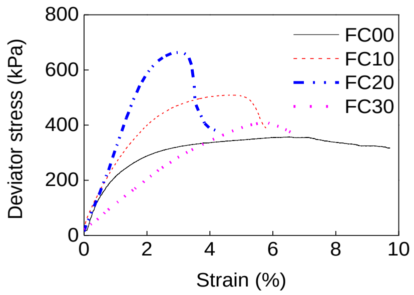

Fig. 2. Stress-strain curves for specimens of 0%, 10%, 20%, and 30% of fines.

Table 2. Triaxial results.

Samples	FC00	FC10	FC20	FC30
Fine content (%)	0	10	20	30
$\sigma_3^{'}$ (kPa)	100.11	99.50	101.16	100.22
$\sigma_1^{'}$ (kPa)	453.99	608.21	750.12	500.34
φ (°)	39.69	45.96	49.67	41.78

3.2. Shear wave

Shear waves were measured during shearing at each 0.5% of axial strain. First arrivals are determined from measured S-wave (Lee and Santamarina 2005). Travel distances were tracked during the shearing phase and used to calculate S-wave velocity. S-wave velocities versus mean effective stresses (σ_1'+σ_3')/2 were plotted as shown in Fig. 3. Fig. 3 shows that the S-wave velocities increase sharply at the initial stage of shearing and are almost constant at the failure stage. The S-wave velocities also decrease as fine contents increase. For example, at 66 kPa, FC00 has the highest velocity while FC30 has the lowest one, at above 153 m/s and below 85 m/s, respectively.

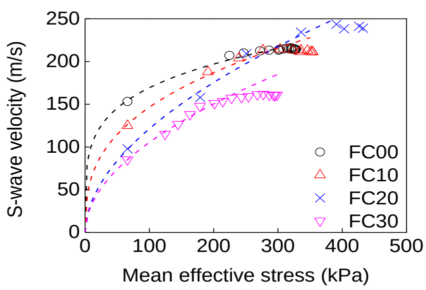

Fig. 3. S-wave velocity.

The S-wave velocities of FC20 at the failure state are approximately 250 m/s and much higher than others due to the stress dependence.

4. ANALYSIS AND DISCUSSION

4.1. Strength

The relationship between friction angle and fine content is illustrated in Fig. 4. The angle increases with increase in fines, up to 20%, then decreases. The addition of silts may contribute to the increase in the shear strength. Shiwakoti et al., (2002) reported that the shear strength of the soils improved significantly when diatom content was continuously increased. Clayed silt and diatom mixtures during the direct shear tests showed that the shear strength increased with increasing diatom content (Wiemer and Kopf 2016).

For FC30, the influence of silt overcame that of diatom, and thus the friction angle decreased. This is consistent with the results of Hsiao et al., (2015) which show that the shear strengths of mixtures of sand and silt decreased sharply as silt contents exceeded 30%.

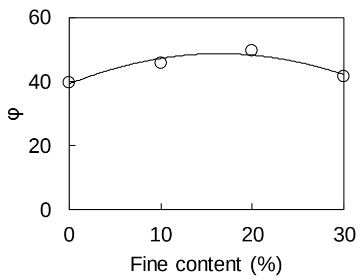

Fig. 4. Critical-state friction angles versus fine contents.

4.2. Stiffness

Fig. 3 shows that S-wave velocity decreased with increase in fine due to the fabric change in mixtures. Fine particles may be ineffectively placed in the sand matrix that they cannot develop effective contacts with the sand particles to optimally transfer S-wave (Salgado et al., 2000). To analyze velocity-stress data, the following empirical power equation (Eq. (2)) is used:

$$V_s = \alpha \left(\frac{\sigma_p' + \sigma_m'}{2kPa} \right)^{\beta} \tag{2}$$

where α is the shear wave velocity at 1kPa indicating particle contact behavior, packing type, and particle properties, β is the exponential factor representing the sensitivity of Vs and indicating contact effects of particles' size, particles' shape, and particles' structure (Santamarina et al., 2001; Lee et al., 2005; Byun et al. 2012), σ_p' and σ_m' are the effective stress in propagating and motion direction of soil particles.

The calculated α and β at each fine content were plotted as shown in Fig. 5. Fig. 5 shows that α continuously decreased while β increases with increasing fine contents. That is, α has a greater value on specimens with lower bulk density while β has a greater value on specimens with higher bulk densities. Soil fabric may change due to the additional fines (Lee et al., 2015).

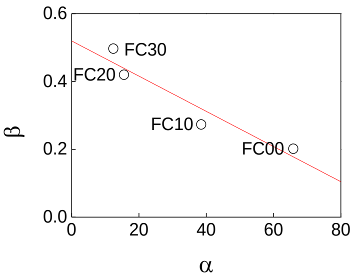

Fig. 5. Factors α versus factor β for shear wave velocity.

5. SUMM ARY AND CONCLUSION

The objective of this study was to investigate the effect of fines on the strengths and stiffnesses of sand. The amount of sand was kept equal while the amount of fine increased to 0, 10, 20, and 30% in weight. Standard CD triaxial tests were conducted, and shear waves were continuously measured at each 0.5% of axial strain in the shearing phase. Based on experimental results, the following observations were made:

(1) The shear strength of sand-fine mixtures continuously increased up to 20% and decreased with increases in fines exceeding 20%.

(2) The stiffness represented by the shear wave velocity decreased with increasing fine contents, which indicates a change on the soil fabric.

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