Strength of Sand with varying Fine Content in Northeast Thailand

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Abstract. *Silty sand and sandy silt can be found in most areas of Northeast of Thailand. We measured the effective cohesion (c') and internal friction angle (ϕ') of the soil in different proportions between coarse grain and fine grain. Soil samples from Khon Kaen province were separated into two different types: coarse grain and fine grain, and then were mixed in ratios of 0 to 100%. c' and ϕ' values were derived from drain triaxial tests.The finding showed that soil specimens were SM (USCS) or A-2-6 (AASHTO), and and ϕ' of the reconstituted had c' 3-7 t/m^2 and ϕ' 20°-27°. Functional relationships between c' the parameters to the fine content were also derived, which could be used to estimate the value of c' and ϕ'.*

Keywords: Sand, fine content, strength, triaxial, cohesion, internal friction angle

1. Introduction

In the design of footings and pile foundations, the effective cohesion (c') and effective internal friction angle (ϕ') of soil are key strength parameters in the calculation. The triaxial drained test is one of the most effective and reliable tests that can provide both c' and ϕ' (e.g., [1]-[4]). However, the triaxial drained test may not be suitable for medium to small projects or projects in urban areas because the test service may not be available including the test difficulty, the considerable time needed and the relative high cost. Nevertheless, the design of any foundation still requires a reliable estimate of c' and ϕ'.

Simple correlations have been used by many researchers for estimating the value of c' and ϕ' [5, 6]. However, the existing equations were provided for neither clay nor sand. In some areas, *e.g.,* Northeast Thailand, they are not suitable, as the soils are combinations of both coarse and sand and fine sand [7]-[9]. Many recent studies ([10]-

[15]) showed that the strength of silty sand or sandy silt were not the same as pure sand or pure silt.

We aimed to establish simple correlations for estimating c' and ϕ' for sand-silt soil, that can save the cost in foundation design, with a simple and reliable model.

2. Testing Program

In this study, two types of soil were tested by the consolidated drain type (CD) of the triaxial test. The first was the undisturbed soil sample containing both sand and silt as found in nature and the second was a reconstituted sand-silt soils, made in the laboratory. The soils were also classified by sieve and hydrometer analysis, Atterberg's limits and specific gravity. Detail descriptions of the soils follow.

2.1 Soil Samples

Both undisturbed and disturbed soil samples were collected from Amphoe Muang, Khon Kaen province, Thailand (16.4776°N, 102.8285°E) from depths of 1m to 2m from the surface by the pit opening method - see Fig. 1-3.
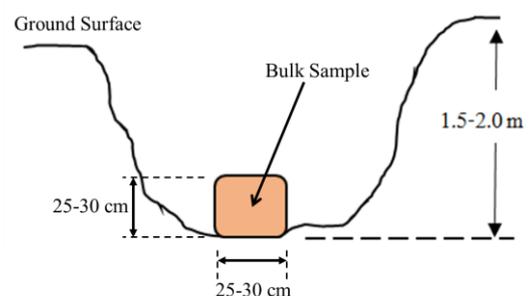

Fig. 1: Schematic diagram for undisturbed soil sampling

Fig. 2: Block soil sampling in pit

Fig. 4: Field density test

Fig. 3: Undisturbed soil samples extracted from the pit

Fig. 5: Measuring depth of soil sample in the pit

In addition to sampling in the field, density by the sand cone method and depth for calculating the original overburden pressure of the soil were estimated as shown in Fig. 4-5.

2.2 Soil Samples

The course and fine components of the disturbed soil samples were separated by #200 sieving (aperture size 0.075 mm) as shown in Fig.6 and then samples were made containing

fine proportions of 0%, 25%, 50%, 75% and 100%, as shown in Fig. 7.

The steps for making the reconstituted soil were 1) add some water in the mixing engine for mixing the course and fine contents, 2) the wet soil was purified in the metal mold to form a cylinder with the confining pressure similar to the overburden pressure in nature as shown in Fig.8 (dial gauge was installed in this stage for measuring settlement of the sample in the mold), 3) after no settlement or small amount of settlement were observed, the soil was then extruded out of the mold and was trimmed for triaxial test as shown in Figs. 9-10.

Fig. 6: Fine and course separation by sieving

Fig. 9: Soil sample from metal mold

Fig. 7: Soil and water Mixing

Fig. 10: Soil sample trimming

2.3 Soil Testing

The test was designed into 2 sets, the experiment set and the control set. The experiment set was the triaxial test of reconstituted soils which were the mixtures of sand and silt with varying fine content. The control set was the triaxial test of undisturbed samples containing both natural sand and silt. Both sets were tested by the Consolidated Drained (CD) approach with a cell pressure of 20, 40 and 60 t/m^2. The schematic triaxial CD test equipment is shown in Fig.11.
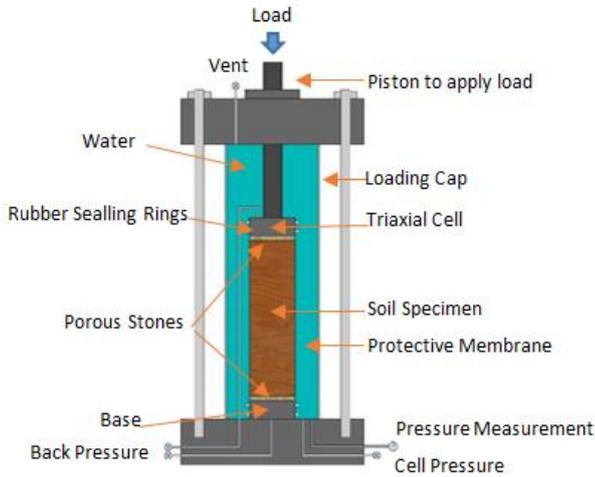

Fig. 8: Soil and water mixing

Fig. 11: Triaxial Test Equipment

3. Results and Discussion

The triaxial test results were presented in the form of Mohr's circles attached to the strength envelope lines as shown in Figs 12-16 and the c', ϕ' pairs for the undisturbed sample are shown in Fig.17.
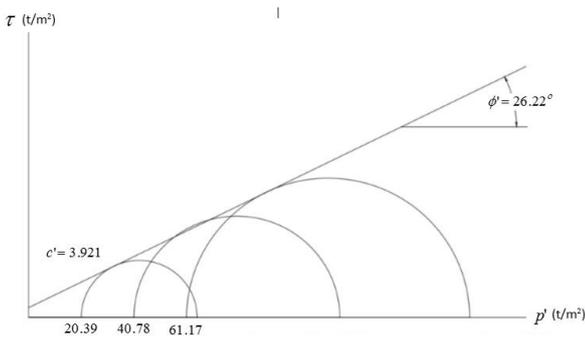

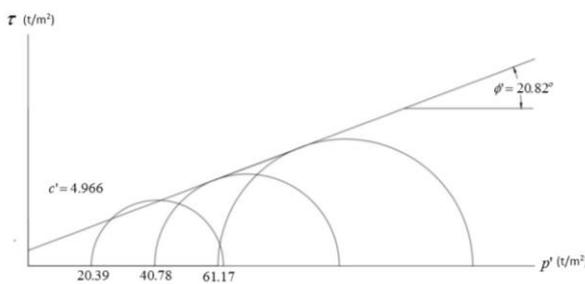**Fig. 12:** Triaxial test results for the coarse reconstituted soil

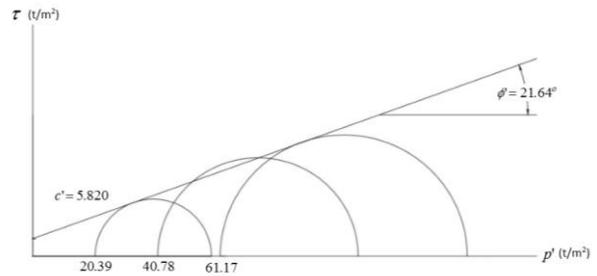**Fig. 13:** Triaxial test results for reconstituted soil)fine:coarse =25:75)

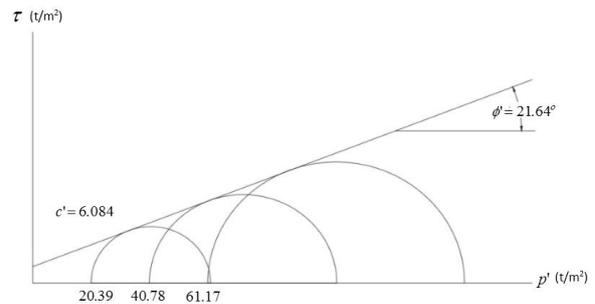**Fig. 14**: Triaxial test results for reconstituted soil)fine:coarse =50:50)

Fig. 15: Triaxial test results for reconstituted soil)fine:coarse =75:25)
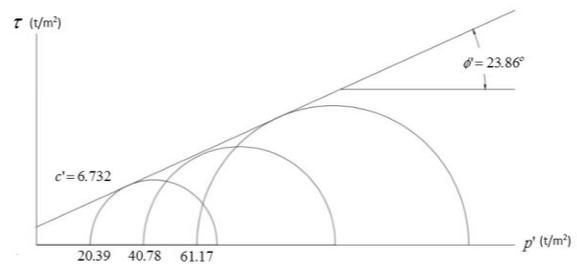

Fig. 16: Triaxial test results for the fine reconstituted soil)fine:coarse =100:0)

Table 1: c' and ϕ' pairs vs fine: coarse ratios for sand-silt soil

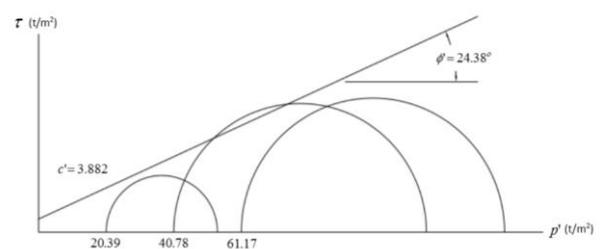| Soil sample index	Fine: Coarse Mixing Ratio	c' (t/m²)	ϕ' (degree)
1	0:100	3.92	26.22
2	25:75	4.97	20.82
3	50:50	5.82	20.02
4	75:25	6.08	21.64
5	100:0	6.73	23.86

Fig. 17: Triaxial test results for an undisturbed sample

The effective cohesion and internal friction angles are presented in Table 1. From Table 1, c' values for reconstituted soils lay in a narrow range of 4-7 t/m^2 and increased with fine content. ϕ' values varied from 20° to 27° with a maximum of 26.22^o at zero fine content. In the following, F $\in$ (0,100), represents the percentage of fine content. The ϕ' vs F curves (shown in Fig 18) were parabolas, with ϕ' decreasing until F=55% and increasing thereafter. At the vertex, F = 55%, $\phi' = 20^o$.

As shown in Fig. 18, the c' vs F was linear (**R^2** = 0.96) and $\phi' vs F$ showed a parabolic (2nd order) relationship (**R^2** = 0.94), as follows :

$$\phi' = 0.002F^2 - 0.2174F + 25.815 \qquad (1)$$

$$c' = 0.027F + 1.1566 \qquad (2)$$

where c' = effective soil cohesion (t/m^2)

ϕ' = effective soil internal friction angle)degrees(
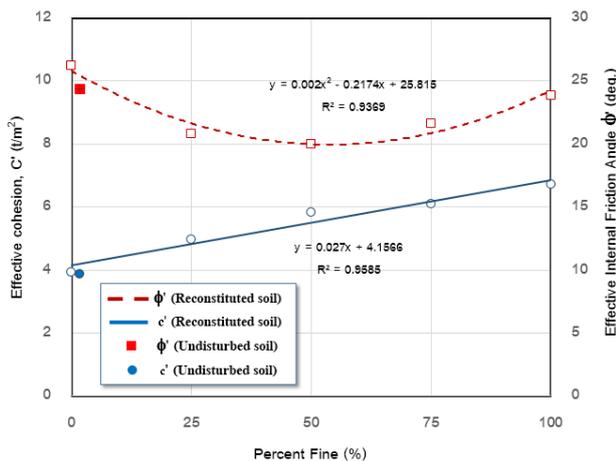
F = percentage of fine content)%(

Fig. 18: c' and ϕ' *vs* fine content, F.

It was seen from Figs. 12–17 that the sample was a c'-ϕ' soil, so that the fine component was composed with both plastic (clay) and non-plastic (silt) material. Therefore, c' tended to increase with F because the more fine content the more clay was in soil structure. It was worth noting that the non-plastic fine was also participated in the soil structure. The slope of the c' vs F relationship in Fig. 18 resulted from a certain proportion between plastic fine and non-plastic fine. The c' vs F slope can have a lower value if the silt role was increased or higher value if the silt role was decreased.

Zhen-Yu Yin (2014) [13] and also the others (e.g. [10], [14]-[15]) reported that the non-plastic fine significantly influences the mechanical properties of sand-silt mixture including the location of the critical state. The

characteristic of the ϕ' vs F curve in Fig. 18 was reasonably consistent with the curves of fine content to the minimum void ratio (F -e_{min}) and fine content to critical void ratio (F -e_{cr0}) [13] which had a minimum between two ends. This is probably depends on degree of active and inactive silt within the soil structure in the load-transfer mechanism.

4.Summary

We used triaxial CD tests to evaluate the effective values of the cohesion, $\boldsymbol{c'}$, and internal friction angle, ϕ', of 2 sets of soils: 1) undisturbed samples and 2) reconstituted sand-silt samples which was composed by different ratios of fine content between 0% and 100%.

The undisturbed samples were classified as SM (USCS) or A-2-6 (AASHTO). The c' and ϕ' for reconstituted soil were approximately 3-7 t/m^2 and 20°-27°, respectively. The relationships between effective cohesion and fine content, c' vs F were linear whereas the relationships between fine content and effective internal friction angle and fine content, $\phi' vs F$, was parabolic. The vertex of parabola located at F $\approx$55% and the corresponding ϕ' was 20°. The c' and ϕ' of the undisturbed sample (F=1.68%) were 3.88 t/m^2 and 24.38^o, respectively and the results: difference between measured and predicted values from equation (1) – (2) was only 4%-7%, confirming that the model can be applied in practical designs.

Acknowledgements

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Biography

Nopanom Kaewhanam was born in Maha Sarakham, Thailand in 1976. He received his M.Sc. from Chulalongkorn University in 2003. His working area is about the ground improvement and his research interests include finite element method, soil modeling, sand-silt mixture behavior. Now he is a lecturer in Civil Engineering, Faculty of Engineering, Mahasarakham University, Thailand.

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