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Shear Strength Characteristics of Cemented Loose Sand

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Abstract: This paper presents the test results from the experimental investigation on the shear stress-displacement and shear strength characteristics of cemented loose sand, which is proposed as a material used for artificial aquifer. A series of direct shear tests was performed on cemented loose sand samples with different normal stresses and cement contents. The normal stress values used in the experiments, corresponding to light weight structures situated on the artificial aquifer, ranged from 15 to 100 kPa and the cement content values ranged from 0 to 6 percent. The results show an increase in of shear stress level with increasing normal stress. The volume change behavior was contraction for all tests. The results also show stiffening of material response and a decrease in contraction with increasing cement content. With admixing cement, the results show a prominent peak followed by a strain softening of the material response. For each value of cement content, the shear stress-displacement curves converge towards a single line with increasing displacement. For the shear strength characteristic, the values of cohesion are zero for all cement contents and the values of internal angle of friction increases with increasing cement content.

Key words: Cemented Sand; Loose Condition; Direct Shear Tests; Shear Strength.

INTRODUCTION

In Thailand, the irrigation system is very important since a large area of land is used for agriculture. However, the effective managements of water resources are needed in several arid areas to support several activities, including agricultural ones. For areas outside the irrigation zone, the water ponds have typically been used to keep water for utilization. The major problem for pond water is that the pond cannot hold the water all year round, particularly in arid areas with underlain sandy soils. This problem can be solved by improving the pond lining.

Another problem for water storage in the pond is that a massive loss of water due to evaporation is very difficult to prevent since Thailand is located in the tropical zone. The evaporation rate can reach 2,200 millimeter per year in some areas. Thus, underground water storage is one of possible techniques to overcome the evaporation problem.

However, the evaporation problem may be overcome by replacing the water pond with artificial aquifer. The area above the aquifer can be used for other activities. To be capable of storing large amount of water, the artificial aquifer must be made of materials with high porosity and permeability. Sand is considered as a suitable material for this purpose.

In general, the sand layer with loose condition is usually not preferred in constructions and is compacted using deep compaction techniques (Brown, 1977; Leonards and Cutter, 1980; Mayne and Dumas, 1984). However, the sandy soils become dense and low porous with using these techniques. The improvement of sandy soils by adding cement have also been investigated (Wangand and Leung, 2008; Consoli *et al*., 2011) but the initial porosity of soils was still not in loose condition.

Therefore, the main purpose of this research is to investigate the shear stress-displacement and shear strength characteristics of cemented loose sand through results from a comprehensive program of direct shear tests. The test data are carefully presented and discussed.

2. Test Material and Procedure:

2.1. Test Material:

The material used in the experiment was a laboratory-compacted granular soil with various cement content. The granular soil sample is the river sand obtained from the Phimai region of Nakhon Ratchasima Province, Thailand. The grain size distribution of the sample is shown in Figure 1. The index properties of the river sand sample are given in Table 1. The cement mixed in the compacted specimens was Portland cement type 1.

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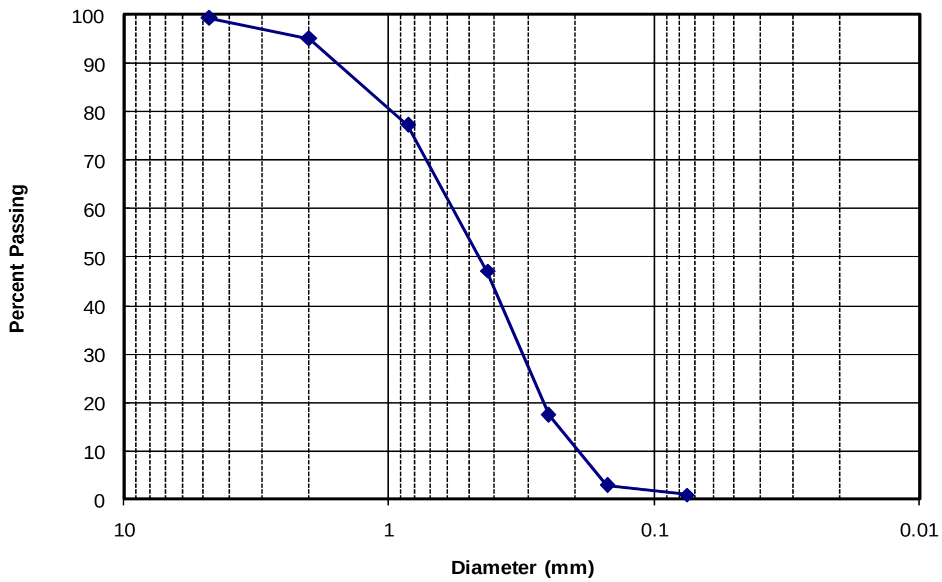

Fig. 1: Grain size distribution of sand sample.

Table 1: Index properties of sample.

Properties	Values
Specific gravity	2.7
Liquid limit	10.0
Plastic Limit	-
PI	NP
Soil Group	SP
Maximum dry unit weight (γ_{max})*	16.67 kN/m^3
Optimum moisture content (OMC)*	7.0%

*Obtained using standard Proctor test.

2.2. Sample Preparation:

The organic and fine materials were first removed from the sand sample. Then the sample was oven-dried for at least 24 hours. The compacted sample preparation technique similar to Uchaipichat (2010) was used in this study. The moist samples of cement admixed sand were statically compacted in the shear box to the dry unit weight of about 12.27 kN/m^3. The values of cement content, defined as a ratio of cement to soil weights, of 0, 2, 4, and 6 percent were used in this study. Since the oven-dried sand can absorb some water within the pores, the high value of water to cement ratio of 0.8 was used to provide enough water for the hydration reaction. The porosity of compacted sand sample at this condition, defined as void volume over total volume, is as high as 0.54. The compacted samples were then cured in the sealed plastic bags for testing at the reference curing time period of 28 days.

2.3. Equipment and Test procedure:

The tests were performed using a conventional direct shear apparatus as shown in Figure 2 to investigate the effect of cementation on stress-displacement and shear strength characteristics of cemented loose sand. Prior to each test, the shear box containing the cured cemented sand sample was removed from the sealed plastic bag and placed in the testing container with the porous disks on the top and the bottom of the sample. The loading cap was placed on the top to uniformly distribute load on the sample. The dial gauges were then set-up to monitor the vertical and horizontal displacements of the sample during shearing stage.

The vertical test load was applied on the loading cap the water was filled in the container to the level above the sample under constant applied load to monitor the compression of the sample. The sample was then sheared under constant load condition. The vertical and horizontal displacements and the shearing force were recorded during shearing stage.

3. Test Results:

A total of 16 direct shear tests were performed to examine the stress-displacement and shear strength characteristics of cemented loose sand samples with different normal stresses and cement content. The normal stress values used in the experiments, corresponding to light weight structures situated above the artificial aquifer, ranged from 15 to 100 kPa and the cement content values ranged from 0 to 6 percent. All tests were performed on the cemented sand samples cured for 28 days. In this study, positive values of vertical displacement indicate the contraction of the sample.

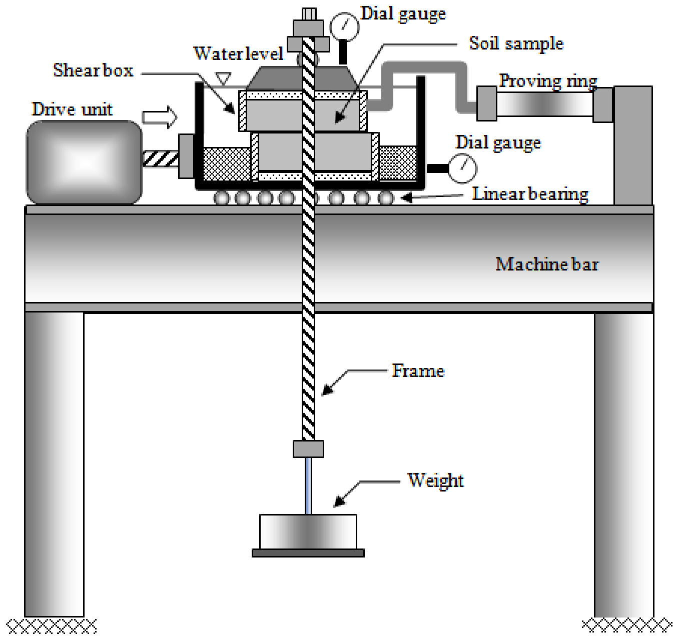

Fig. 2: Direct shear apparatus.

3.1. Shear Stress–Displacement Characteristic:

The test results in terms of shear stress and vertical displacement versus horizontal displacement are presented in Figures 3 and 4. The variation of shear stress-displacement curves with normal stress for samples subjected to direct shear tests at different values of cement content are shown in Figure 3. In general, the results show an increase in of shear stress level with increasing normal stress. The volume change behavior was contraction for all tests.

The variation of shear stress-displacement curves with cement content for samples subjected to tests at different values of normal stress are shown in Figure 4. In general, the results show stiffening of material response with increasing cement content. For the samples without cement (cement content of 0 %), the response was strain-hardening. With admixing cement, the results show a prominent peak followed by a strain softening of the material response. The values of horizontal displacement at the peak shear stress and tendency for contraction decreased with increasing cement content. For each value of cement content, the shear stress-displacement curves converge towards a single line with increasing displacement.

3.2. Strength Characteristic:

The strength envelope of soil is defined based on Coulomb failure criterion, which can be expressed as

$$S = c + \sigma'_n \tan \phi \qquad (1)$$

in which, S is the shear strength, c is the cohesion, σ'_n is the normal effective stress, and ϕ is the internal friction angle.

The shear strength, defined as an ultimate shear stress, for each test can be obtained from the shear stress-displacement curves in Figure 4. Figure 5 shows the shear strength envelopes (the plots between shear strength and normal effective stress) for different values of cement content. Good correlation can be observed in theses plots. As can be seen, the values of cohesion are zero for all cement contents and the values of internal angle of friction increases with increasing cement content. The shear strength parameters of the samples with different cement contents are given in Table 2.

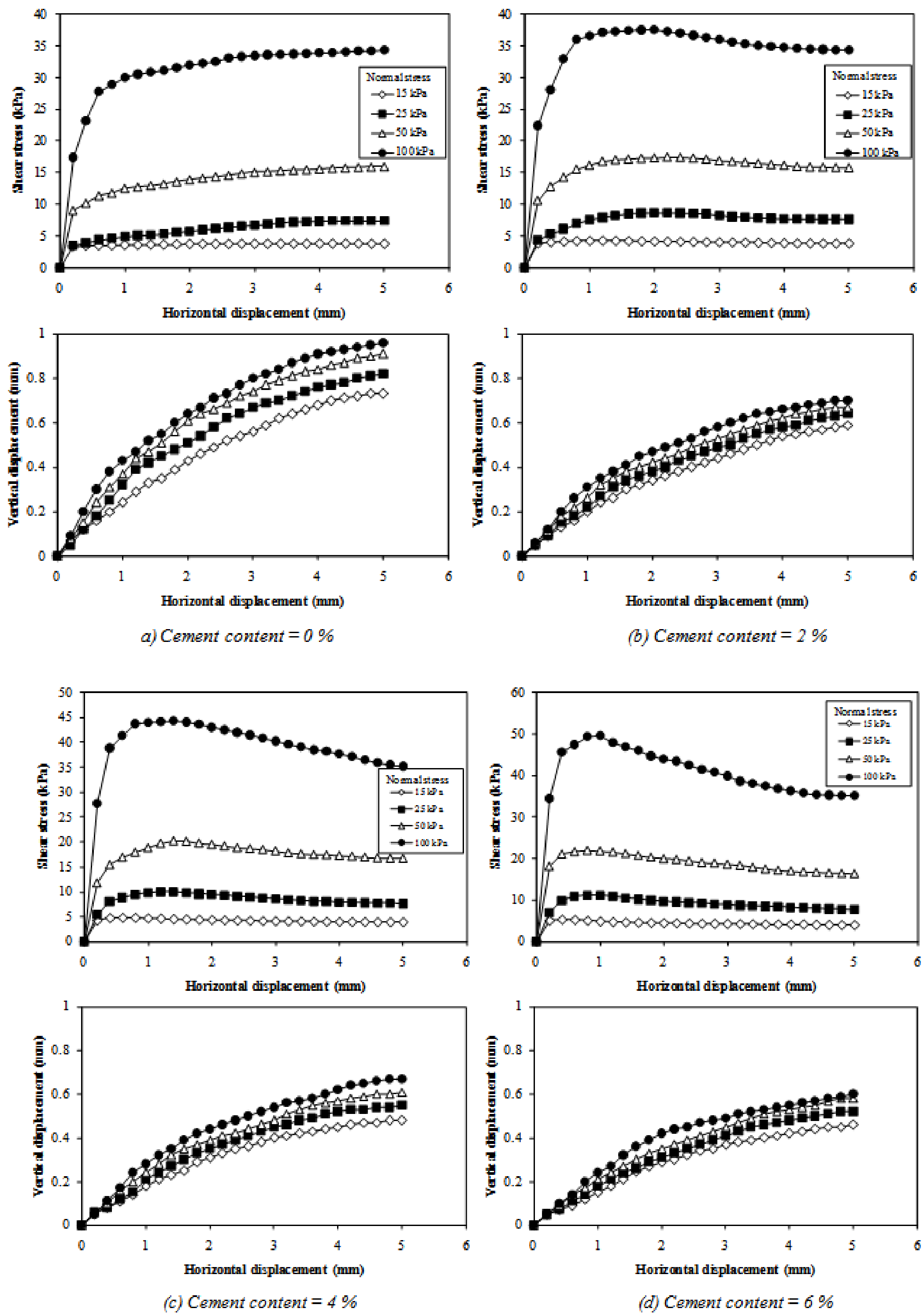

Fig. 3: Test results at different values of normal stresses.

Table 2: Shear strength parameter of the samples with different cement contents.

Cement content (%)	Cohesion (kPa)	Angle of friction (°)
0	0	18.6
2	0	20.2
4	0	23.3
6	0	25.7

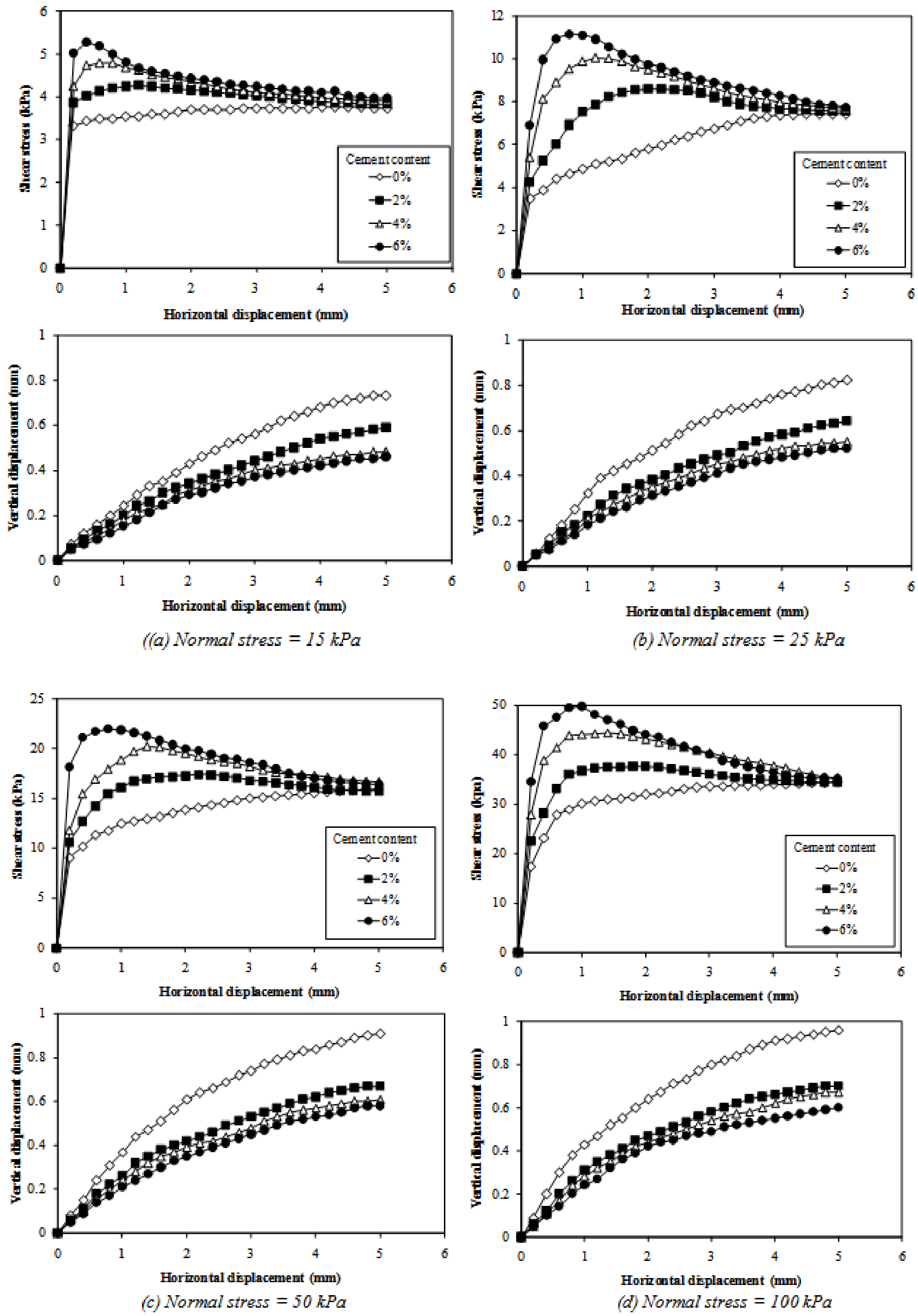

Fig. 4: Test results at different values of cement content.

4. Discussions:

The direct shear test results show the cementation-hardening behavior in all cases. However, the shear stress-displacement curves for cemented samples converge to those for uncemented samples. This implies that the shear resistance increases due to cementation bond. After reaching the value of peak shear stress, the cementation was destroyed and the similar shear behavior of uncemented samples was observed.

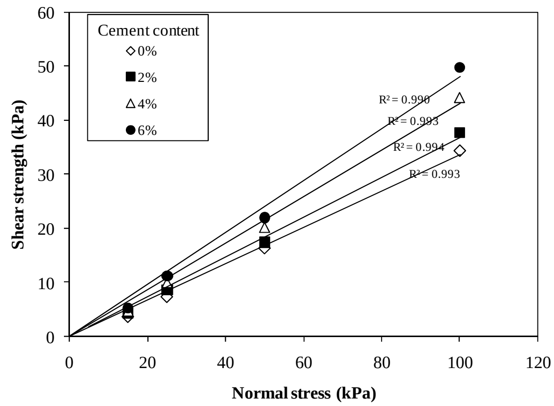

Fig. 5: Shear strength envelopes of samples with different values of cement content.

Furthermore, the results show that contraction of sample was observed in all tests, indicating that both cemented and uncemented samples were in loose state. It was also observed that increasing cement content caused a less contractive response during shearing. This indicates that the resistant force against the movement between the soil particles increased with increasing cement content.

The results also show that the cementation bond affects shear strength characteristic. Moreover, the cemented loose sand exhibited cohesionless behavior while the internal friction angle increased with increasing cement content due to an increase in resistant force.

5. Conclusions:

The shear stress-displacement and shear strength characteristics of cemented loose sand were investigated by performing a series of direct shear tests. The results show an increase in shear stress level with increasing normal stress. The volume change behavior was contraction for all tests. The results also show stiffening of material response and a decrease in contraction with increasing cement content. With admixing cement, the results show a prominent peak followed by a strain softening of the material response. For each value of cement content, the shear stress-displacement curves converge towards a single line with increasing displacement. For the shear strength characteristic, the values of cohesion are zero for all cement contents and the values of internal angle of friction increases with increasing cement content.

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