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Particle Size Effect on Shear Strength of Granular Materials in Direct Shear Test

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Abstract**—**The effect of particle size on shear strength of granular materials are investigated using direct shear tests. Small direct shear test (60 mm by 60 mm by 24 mm deep) were conducted for particles passing the sieves with opening size of 2.36 mm. Meanwhile, particles passing the standard 20 mm sieves were tested using large direct shear test (300 mm by 300 mm by 200 mm deep). The large direct shear tests and the small direct shear tests carried out using the same shearing rate of 0.09 mm/min and similar normal stresses of 100, 200 and 300 kPa. The results show that the peak and residual shear strength increases as particle size increases.

Keywords**—**Particle size, shear strength, granular material, direct shear test.

I. Introduction

GRANULAR materials are widely used as backfill for embankments, trenches, and earth-retaining structures due to their high strength, drain water rapidly, settle relatively little and compaction properties. In geotechnical engineering, the shear strength parameters of granular materials are crucial and useful for design work to produce safe and economic geotechnical structure design. Several factors have been identified could affect the shear strength of granular materials. According to Yu et al. [15], the shear strength of granular materials depends on the relative density, gradation, particle strength, particle size and shape, and degree of saturation of the specimen.

The most common approach to measure shear strength of granular materials used as backfill in commercial geotechnical laboratories in Malaysia is direct shear test. Direct shear testing, as was first used by Coulomb in 1776 [13], has long been used to estimate the strength parameters. The direct shear test is simple and relatively cheap method for determining the granular material shear strength parameters. The construction of apparatus is not complicated, the test is fast to perform, and the output data can be relatively easily processed to obtain the necessary parameters [1]-[3], [11].

The direct shear test is possible to test larger soil samples with relative ease, and so soils with large particle sizes can be tested under conditions that more closely approximate those in the field [12]. However, Bauer and Zhao [4] state that the testing of the coarse soils for shear strength can be a problem since most testing equipment is of small size, relative to the size of particles in the soil. A standard direct shear box (60 mm by 60 mm) is not suitable to test coarse granular materials. Therefore, application of a suitably large scale direct shear test apparatus is one of the most appropriate methods for determination of the shear strength parameters of coarse granular materials.

The objective of this study is to assess the influence of particle size on shear strength of granular materials. Islam et al. [8] reported that the particle size plays an important role on the strength behavior of granular materials. The size of the particles in the granular mass alters the fabric and is responsible for the variation of strength behavior. Previous studies produce different results in terms of the effect of particle size on shear strength. Kirkpatrick [14] studied the effects of particle size from tests on two cohesionless materials. Results showed that an increase in particle size reduces the friction angle, which agreed with the findings reported in Marschi et al. [9] and Marsal [10]. Zelasko et al. [5] tested three sands and found that an increase in mean particle diameter causes a slight decrease in friction angle. Meanwhile, some studies show the opposite views. Charles and Watts [6] showed that the friction angle in material with the maximum grain size of 75 mm is 3 degrees greater than the friction angle in material with maximum diameter of 10 mm. Also, the experiments of Nakao and Fityus [12] revealed that tests on coarser samples record significantly higher shear strengths. The peak and residual effective friction angles for the <4.75 mm sample tests were 32.8° and 31.6°, whereas the peak and residual strengths for the <19 mm sample tests were much higher at 37.1° and 34.2°. Wang et al. [7] investigated the effects of particle size distribution on shear strength of accumulation soil. The test results showed that the angle of shearing resistance is generally increasing with increasing median particle diameter and gravel content.

II. Materials and Methods

For this study, the granular materials were obtained from Nilai quarry. The original sample was dried in the oven for at least 12 hours before the testing program was initiated thus the moisture content was essentially zero. In order to evaluate the influence of granular materials size, two groups of particle size were used. Group 1 with maximum particle size of 2.36 mm is tested in a small direct shear test, while group 2 with maximum particle size of 20 mm is used in a large direct shear tests (Fig. 1). Particle size analysis of sample was performed by sieve analysis. The particle size distribution curve for the

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testing material is shown in Fig. 2. According to the Unified Soil Classification System (USCS), the testing material is classified as (GW) well graded gravel with sand.

The direct shear tests were conducted using an instrumented direct shear machine. The horizontal and vertical displacements were measured using displacement transducer and the shear force was measured using load cell. The direct shear test was carried out according to BS 1377: Part 7: 1990. The small direct shear tests were carried out with a shear box of 60 mm by 60 mm by 24 mm deep. Specimens tested in small direct shear test included only particles passing the sieves with opening size of 2.36 mm.

The large shear box tests were carried out with a shear box of 300 mm by 300 mm by 200 mm deep. Test specimens in large direct shear test included the particles passing the sieves with opening size of 2.36 mm and particles retained on the 2.36 mm sieve to a maximum particle diameter of 20 mm.

(a) Particles passing the sieves with opening size of 2.36 mm

(b) Particles passing the sieves with opening size of 20 mm

Fig. 1 Testing material consist of (a) Group 1 for small direct shear test and, (b) Group 2 for large direct shear test

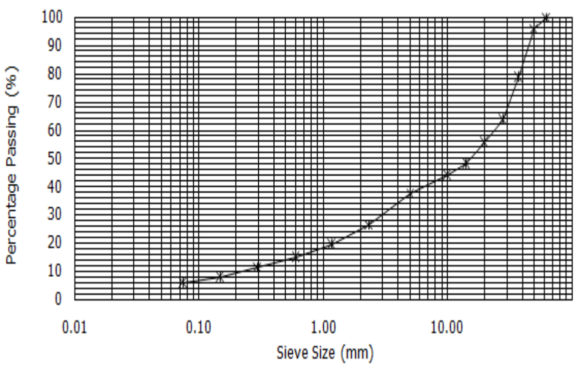


Fig. 2 Particle size distribution curve for the testing material

The specimens for large and small direct shear box were prepared using static compaction at a specified moisture content and density. The large direct shear tests and the small direct shear tests were conducted at the same shearing rate (0.09 mm/min) and using similar normal stresses of 100, 200 and 300 kPa.

III. Results and Discussion

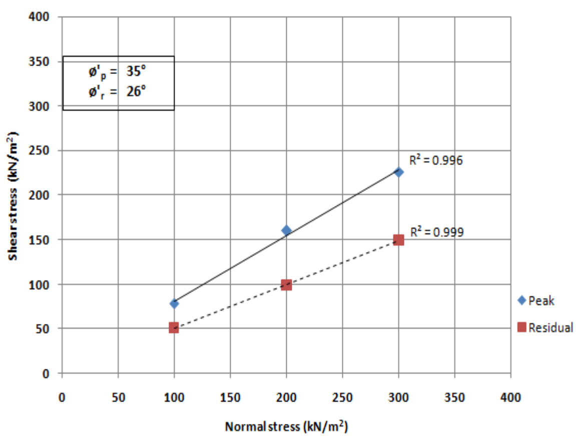
The peak and residual effective internal friction angles for small direct shear test were 35° and 26°, respectively (Table I). Fig. 3 shows shear stress versus normal stress curves, shear stress versus horizontal displacement graph, and vertical deformation versus horizontal displacement for small direct shear test. The vertical deformation for the specimen sheared under normal stress of 300 kN/m^2 is higher than the sample sheared under normal stress of 200 kN/m^2.

The peak and residual effective internal friction angles for large shear box test were 40° and 29°, respectively (Table I). Fig. 4 shows shear stress versus normal stress curves, the relation between shearing stress and horizontal displacement, and vertical deformation versus horizontal displacement for large direct shear test. The vertical deformation dominated for specimens at all normal stress levels was observed.

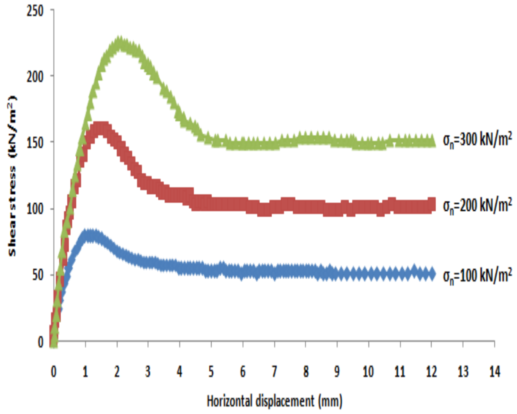
The effective internal friction angles from small direct shear tests and large direct shear tests are compared. The results show that the peak and residual shear strength for both of tests are not identical. The peak and residual effective internal friction angles for large direct shear test is higher than the results obtained from the small direct shear test. The peak and residual shear strength increases as particle size increases. These results agreed with previous studies which, if the particle size increases, the value of friction angle increases [6], [7], [12].

TABLE I
Peak and Residual Shear Strength Values

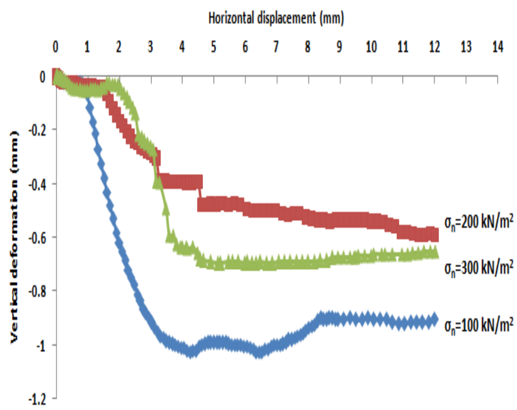
Effective internal friction angle		
Test	Peak	Residual
Small direct shear test	35°	26°
Large direct shear test	40°	29°



(a)



(b)

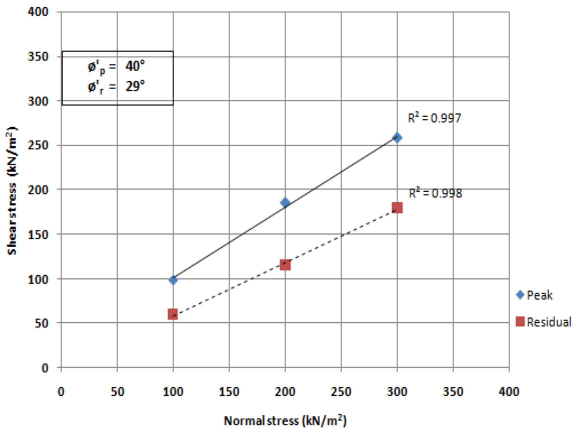


(c)

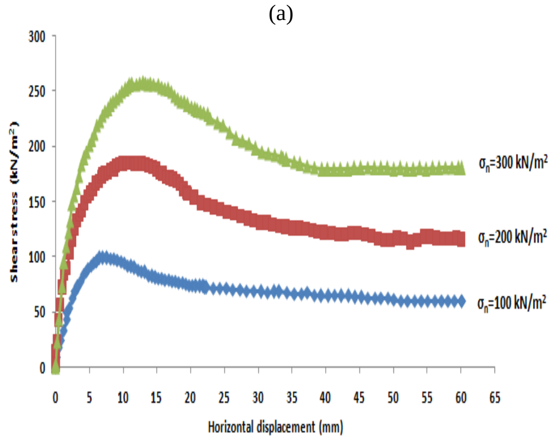
Fig. 3 Relationship between (a) shear stress versus normal stress, (b) shear stress versus horizontal displacement, and (c) vertical deformation versus horizontal displacement for the small direct shear test

IV. Conclusion

The findings of this study are summarized as follows. Results of the direct shear tests show that the effective internal friction angle can be dependent on particle size. Tests with larger size particles produced higher effective internal friction angle and developed high shear strength. The peak and residual effective internal friction angle in small direct shear test and large direct shear test differed about 5° and 3°, respectively. Peak stress behavior exhibited in both of tests. Specimens in both of tests have large vertical deformation at low normal stress.



(a)



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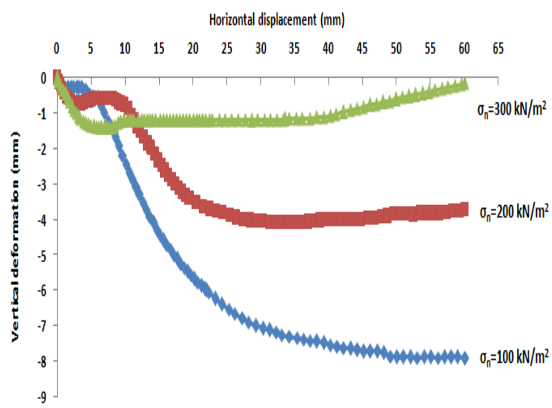

(c)

Fig. 4 Relationship between (a) shear stress versus normal stress, (b) shear stress versus horizontal displacement, and (c) vertical deformation versus horizontal displacement for the large direct shear test

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