Relation between Effective Particle Size and Angle of Internal Friction of Cohesionless Soil

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Abstract

Slope instability related damage is a major issue in our country. Slope failures often produce extensive property damage and result in loss of life. The shear strength of soils is an important aspect in the stability of the slopes of dams and embankments. The shear strength of soil is influenced by many factors such as particles shape, deformation, presence of water and grain size of soil. This work studies the relation between particle size and the shear strength of cohesionless soil. A total of thirty six direct shear tests have been performed to investigate the shear strength of sand samples at three levels of relative density. Soil samples were collected from different places of Bangladesh namely Gabtoli, Sylhet and Turag river. Reconstituted samples were prepared by adding fine content to these soil samples at varying percentages. The test results showed that an increase in particle size generally reduces the friction angle but the variation is very insignificant.

Keywords: *Effective Size, Friction Angle, Direct Shear Test*

1 Introduction

Cohesionless soils are commonly used as backfill for damns, embankments, trenches and earth retaining structures due to their high strength, high permeability and low compressibility. In order to design civil structures that are supported by soils, the shear strength parameters are very important to produce safe and economic geotechnical structure design. The shear strength of granular material is affected by several factors. According to Yu et al. (2006), 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 maximum friction angle characterizing the beginning of rupture can be correlated with many parameters, among others, size of soil particles. Various studies made on sand samples having constant density show that friction angle increases with the reduction of particle size with an insignificant variation. Some other studies have shown that an increase in the friction angle occurs with the increase of the Uniformity Coefficient (UC) for sands consisting of feldspar and calcite (Viggiani et al. 2001; Whalley 1979). Holtz et al. (1956) conducted triaxial tests on mixtures of gravel and sand in various proportions and indicated that the shear strength increases with gravel content greater than 50–60 % (by weight). Simoni et al. (2006) made 87 large direct shear tests on sand–gravel mixtures and concluded that even with low gravel fractions (10–20 %), the peak strength of the mixtures are higher than those for pure sand at the same density. Holtz et al. (1956) found that shear resistance increases with the increase of gravel content and decrease apparent cohesion; these investigations were based on clay with gravel contents varying from 0 to 65 %. From direct shear tests on boulder and clay mixtures, Patwardhan et al. (1970) indicated a gradual increase in shear strength with boulder content. Miller et al. (1957) stated unconsolidated undrained triaxial tests on mixtures of sand and clay which showed no apparent change in friction angle but a gradual decrease of cohesion with sand content. Prakasha et al. (2005) reported that sand grains in clay mixtures decrease void ratio and increase friction and pore pressure response, which results in a decrease in undrained shear strength.

Islam et al. (2011) 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. Wang et al. (2013) 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. Kirkpatrick (1965) 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. (1972) and Marsal (1973). Zelasko et al. (1975) 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 et al. (1980) 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.

Understanding the effects of particle shape and size distribution on the behavior of soils helps the application and interpretation of laboratory test results (Kakou et al. 2001; Petley 1966). But the impact of different particle size on soil shear behaviour is still the subject of debate. Hence the objective of this study is to assess the influence of particle size on shear strength of granular materials. Investigations into the influence of effective particle size have mainly been focused on binary mixtures of collected sand samples and fines.

2 Methodology

For this study, soil samples were obtained from three different locations- Gabtoli (Gojaria sand), Sylhet (Sylhet sand) and Turag (Turag sand). A detailed laboratory investigation was carried out to determine the physical and index properties of the collected soil samples. The laboratory testing program consisted of carrying out specific gravity, moisture content and particle size analysis. Standard physical (specific gravity of soils ASTM D 854) and classification (Grain size analysis of soil ASTM D 422) tests were performed as per ASTM standard procedure.

Fines was obtained by sieving non-plastic soil (Gojaria sand) through #200 sieve. Then fines was added with these three collected soil samples to obtain varying effective particle size. The fine content was 5%, 10% and 15% respectively of the dry weight of the soil samples. Soil samples were prepared at three different states-loose, medium and dense. Then direct shear tests were conducted in consolidated drained (CD) condition on reconstituted sand samples made by the mixture of collected sands and various percentage of fines content as calculated based on the weight ratios according to ASTM D 3080 standard test procedures. Tests were conducted under one normal stress. As sand samples had no cohesion, shear stress was considered zero at zero normal stress. To ensure the linearity, some tests were done under two normal stresses.

2.1 Test Set-up

To prepare samples for testing, the soil was compacted by a wooden rod inside a probing ring of the size 63.5 mm in diameter and 25.4 mm in height from a falling height of 100 mm. The remolded soil sample was placed carefully in the shear box from the ring. Then the desired normal load was applied. Normal stress was arbitrarily selected as 50 kPa. Vertical displacement dial gauge was attached to record the vertical deformation with respect to time. Enough time was allowed for consolidation before applying the shear force. When two consecutive vertical deformation dial readings were same, the shear force was applied to the soil sample with a constant strain rate of 0.75 to 1.25 mm/min. The lateral deformation was recorded by a lateral constant strain rate of 0.75 to 1.25 mm/min. The lateral deformation was recorded by a lateral displacement dial gauge of 25 mm capacity. The applied shear force was recorded by a load dial gauge of 2.22 kN capacity.

3 Results and Discussions

3.1 Index Properties of Soils

Specific gravity of Turag, Gojaria and Sylhet sand are respectively 2.74, 2.69 and 2.68. The fineness modulus of these sands (Turag, Gojaria and sylhet) are 1.0, 0.87 and 2.87 respectively. Figure 1 shows the typical grain size distribution curves of Gojaria sand, Sylhet sand, Turag sand and also fines.

3.2 Strength Properties of soils

Direct shear test results of different soil samples are presented in the table 1. From the table, it is seen that with the increase of fine content in Gojaria sand, effective diameter decreases but the change of angle of internal friction (φ) with effective diameter at three dense states is not regular. For the case of sylhet sand, φ increases with the decrease of effective diameter at 16.5 kN/m^3 density. Again for Turag sand, for 15.8 kN/m^3 density, φ increases with the decrease of effective diameter but for other two densities, at first φ increases to a certain effective diameter and then decreases.

Relationship between grain size of particles and frictional angle is shown in figure 2. From figure 2, it can be noted that at lower density, there is a general trend of decrease in frictional angle with the increase of particle size. But at higher density, frictional angle increases with the increase of effective particle size. But this pattern is not very much regular also.

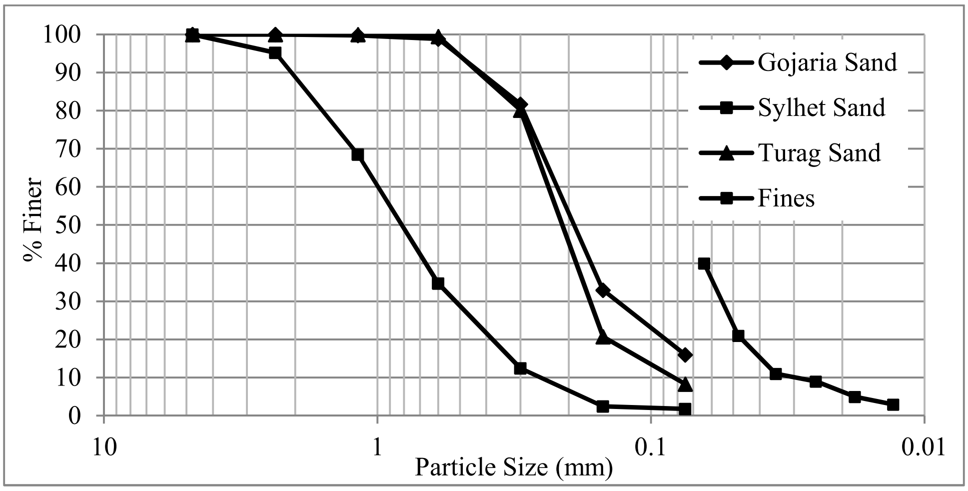
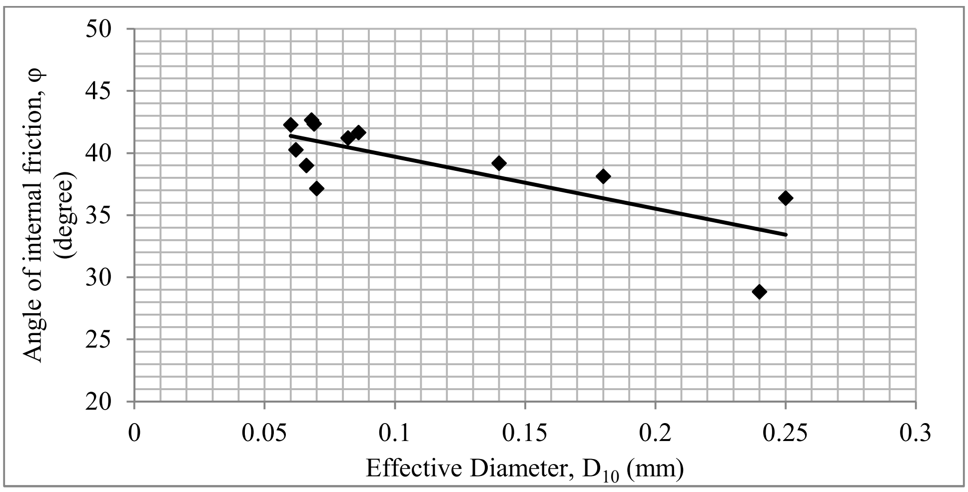


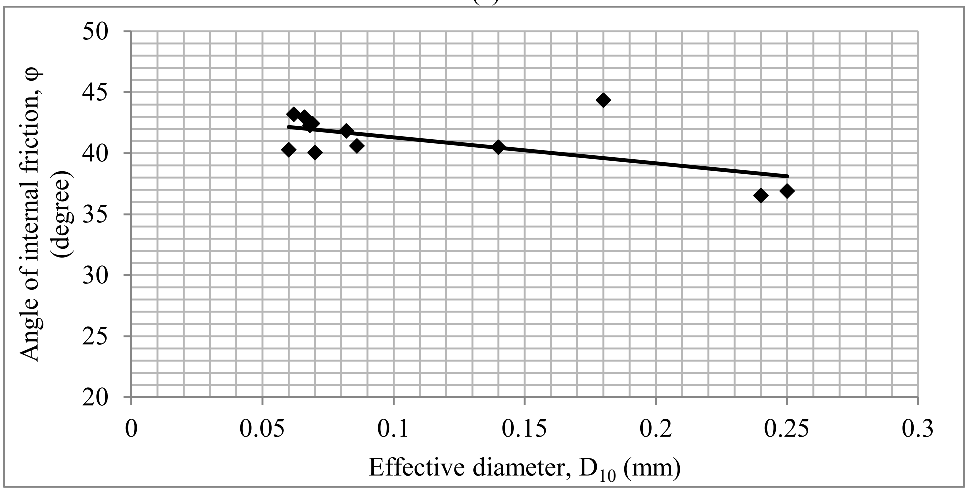
Figure 1. Grain size distribution curves of collected soil samples and fines

Table 1. Comparison of angle of internal friction of reconstituted soil samples at different densities

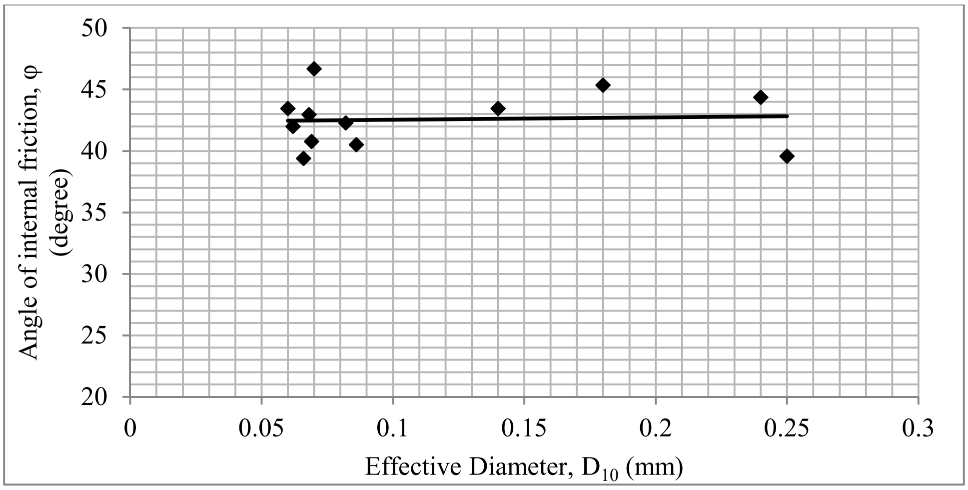
Sample	Effective diameter, D_{10} (mm)	Angle of internal friction, φ (deg)		
		Density= 15.2 kN/m^3	Density= 15.8 kN/m^3	Density= 16.5 kN/m^3
100% Gojaria Sand	0.068	42.66	42.27	42.96
95% Gojaria Sand+ 5% fine	0.066	39	42.96	49.38
90% Gojaria Sand+ 10% fine	0.062	40.27	43.21	44
85% Gojaria Sand +15% fine	0.06	42.27	40.3	43.46
100% Sylhet Sand	0.25	36.39	36.9	39.57
95% Sylhet Sand+ 5% fine	0.24	28.85	36.54	44.36
90% Sylhet Sand+ 10% fine	0.18	38.14	44.36	45.35
85% Sylhet Sand+ 15% fine	0.07	37.15	40.04	46.67
100% Turag Sand	0.082	41.22	41.84	42.27
95% Turag Sand+ 5% fine	0.14	39.19	40.5	43.46
90% Turag Sand+ 10% fine	0.086	41.66	40.59	48.5
85% Turag Sand+ 15% fine	0.069	42.36	42.45	42.77



(a)



(b)



(c)

Figure 2. Variation of frictional angle with effective size at density (a) 15.2 kN/m^3(b) 15.8 kN/m^3(c) 16.5 kN/m^3

4 Conclusions

Particle size has an influence on the shear behavior of soils but the effect is not clear. So an attempt has been made in this study to characterize the correlation between the friction angle and the effective particle size. The main findings of the study are as follows:

1. The angle of internal friction decreases with the increase of effective size at lower densities.
2. At higher density of soil, the angle of internal friction increases with the increase of effective particle size.
3. But the variation of angle of internal friction with effective particle diameter is insignificant.

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