

Effect of particle size distribution on shear strength of soil

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Abstract. Soil grain size distribution has a significant impact on the mechanical properties of geotechnical materials. This study presents a laboratory investigation into the effects of fine content and grading factors on shear parameters. A series of shear tests and triaxial tests on sandy soils were performed for this aim. Finally, the outcomes of both strategies were compared and assessed. It was discovered that altering the grain size distribution results in changing the values of shearing parameters. Furthermore, the outcomes of different laboratory tests are not the same.

1 Introduction

Since the weight of all buildings is eventually passed to it, soil, as the most plentiful and readily available building element, plays a unique role in geotechnical matters. Although mixed soil is found more frequently in nature than pure soil, it has less geotechnical information and its qualities are always changing due to variances in the relative amounts of components that make up the mixed soil. We frequently meet soil made of sand–clay or sand–silt mixes while dealing with a site for a building.

To gain a thorough understanding of these places, researchers must conduct field and laboratory experiments to determine their behaviour. For sands, several investigations have shown that the angle of internal friction obtained from plane strain testing differs from that obtained from triaxial compression experiments. Studies comparing the results of angle of internal friction from direct shear tests and triaxial compression testing for granular soils are also available in the literature. While there are a lot of studies on pure sands, there aren't many studies on sand-fine particle mixtures [1-3]. Besides that, in terms of soil qualities, there hasn't been much research into the impact of grain size distribution on shearing behaviour at the soil–structure interface. Indeed, the grain size distribution of the soil has a substantial influence on the mechanical behaviours of geotechnical materials, as stated in the literature [4]. Shear tests should be undertaken to determine the features of stress-strain and volume change in soils subjected to load. By using a shear test, it can be expressed that how soils attain the stage of plastic failure as the stress applied to them increases [5].

To measure the shear strength properties of soils, standard testing procedures include triaxial compression and shear box tests. Because it is straightforward and practicable to

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apply to disturbed and undisturbed soils, the shear box test is widely used. The sample is distorted at a regulated pace until failure occurs in this very simple test, which directly evaluates shear forces. The sample is made to yield via a shear plane at varied shearing rates by the testing apparatus [6]. In this study, a series of shear tests and triaxial tests on six distinct grain size distributions for clayey and silty sand soils were conducted. Each sample's maximum, mean, and lowest grain sizes, as well as its relative density, were held constant. Both methods of tests yielded shear strength metrics such as cohesiveness and internal friction angle, and the results were compared.

2 Literature review

The goal of this research is to determine the impact of particle size on soil shear strength and compare the results of various types of experiments. According to Islam et al. [7], particle size has a significant impact on the strength behavior of granular materials. The fabric is altered by the size of the particles in the granular mass, which is responsible for the variance in strength behavior. In terms of the influence of particle size on shear strength, previous research has produced mixed results. Kirkpatrick [8] used tests on two cohesionless materials to investigate the impact of particle size. The results revealed that when particle size increases, the friction angle decreases, which is consistent with the findings of Marschi et al. [9] and Marsal [10]. Zelasko et al. [11] investigated three sands and discovered that as the mean particle diameter increases, the friction angle decreases somewhat. In the meantime, several research support the opposing viewpoint.

In the case of fine-grained soils, such as the bottom of the circular failure surface under an embankment, it is usually essential to analyze or conduct comparison research. Kulhawy et al. [12] hypothesized that fine-grained soils behave similarly to sands under direct shear and triaxial shear. The same effective stress shear strength characteristics were obtained from experiments conducted on eight specimens of Boulder Clay using the direct shear and triaxial devices, according to Skempton. Casagrande and Poulos provided the findings of CD direct shear and CD triaxial tests performed on compacted specimens of a lean clay, demonstrating that the two tests yielded almost the same shear strength envelope [13]. Abdel-Ghaffar (1990) collated findings from studies that used undisturbed samples of the same soil to perform direct shear and triaxial testing. He came to the conclusion that the effective stress friction angle and cohesion intercept for the direct shear and triaxial devices are comparable [14].

In this study, the effect of shear rates has also been investigated. so it is better to consider the previous works regarding that. To investigate the effects of shear rate on internal friction angle and cohesiveness, Thermann et al. [15] employed a direct shear apparatus and applied varied shear rates to silty sand soils. At four different shear rates, Saito et al. [16] performed direct shear experiments on silica sands containing illite and bentonite. The effective residual internal friction angle of the silica sands remained practically constant at 34° for all shear speeds, according to these researchers. Shear box studies on coarse grained granular backfill soils were conducted by Nakao et al. [17], who discovered that peak and residual internal friction angles varied in response to different shear rates.

3 Methodology

The investigated soil of our study was taken from the Hejopapi region located in northern Hungary. The soil was sieved and remixed into different soils compound with different course contents. Figure 1 shows the grain size distribution of samples. The soil specimen

was prepared in agreement with the testing standard. The initial density, water content, compaction process, and other sample state parameters were given special attention because the outcomes are influenced by all of these factors. A series of direct shear box tests were performed to characterize the shear strength of the soil. The properties of different tested soils are listed in Table 1.

Table 1. Properties of samples.

Sample No.	Water content <i>w</i> (%)	Average diameter <i>D</i> ₅₀ (mm)	Fines content%
			Clay+silt
#1	15	0.002	50
#2	15	0.2	45
#3	15	0.26	40
#4	15	0.3	35
#5	15	0.33	30
#6	15	0.36	25

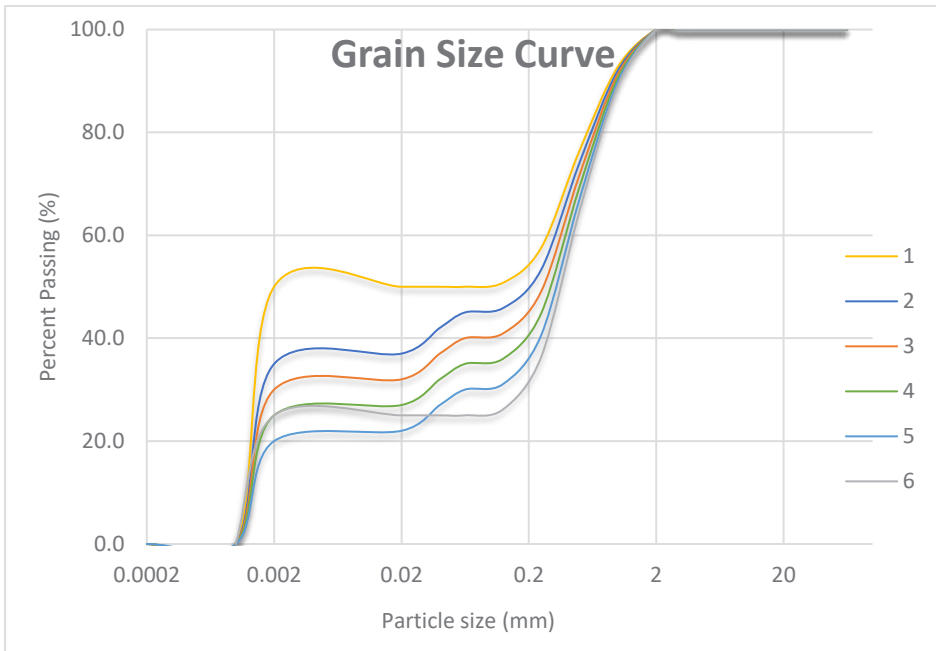


Fig 1. Grain size distribution of samples.

The specimens were compacted in three equal layers in the shear box using a rubber hammer for the direct shear test, with a water content of 15%. After applying vertical pressure to the specimen in the shear box of 100 kPa, 200 kPa, and 300 kPa, horizontal thrust was applied to the top box until soil collapse. The horizontal loading rate in the experiments was set at 0.05 and 0.5 mm/min as a slow and rapid rate for comparative

purposes. The rate of displacement was determined using ASTM D3080-90 (ASTM, 1990) and Bishop and Henkel's findings (1957) [18]. A linear fit through the origin in the plot of peak or maximum shear stress against normal stress defines the peak angle of shearing resistance. In addition, the tests revealed the cohesiveness of each sample. Furthermore, the materials were put to drained triaxial compression testing. The experiments were conducted with effective confining forces in place. During the consolidation and shearing phases, filter paper side drains were used to shorten the test duration. Before testing, the samples were soaked by applying back pressure. To derive the cohesion and internal friction angle from triaxial test, the p-q diagram has been used. The p-q diagram is a method of simplifying the analysis of triaxial and other stress data which are commonly used in soil mechanics. It can be used in a variety of applications and solve a range of problems. Using this method, you won't have to solve two equations with two unknowns. Thus, the results obtained by triaxial test and direct shear test for sand with different fine content were compared and analyzed. In addition, the effect of shear rate has been investigated.

4 Result and discussion

The effects of the Median particle diameter and fines content on the shear strength parameters of the soil by using different methods were discussed in present section. Using a linear fit across the origin in the plot of shear stress versus normal stress, the internal friction angle and cohesion were computed for the direct shear tests. It should be taken into consideration that the shear rate applied for these tests was 0.05 mm/min. Figure 2 to 7 shows the result of direct shear tests for sample number 1 to 6 respectively.

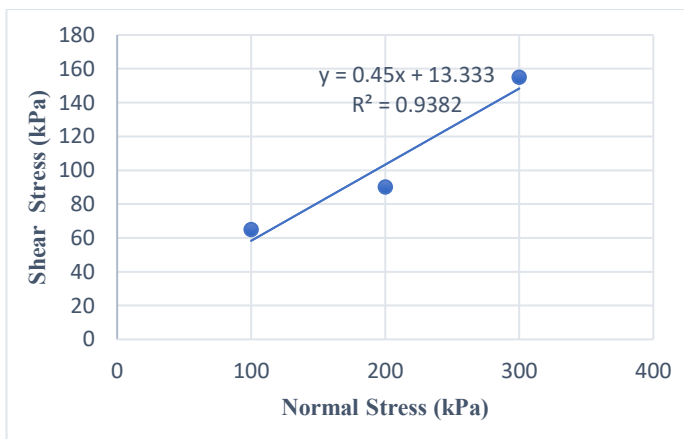


Fig 2. Shear stress versus normal stress for sample #1.

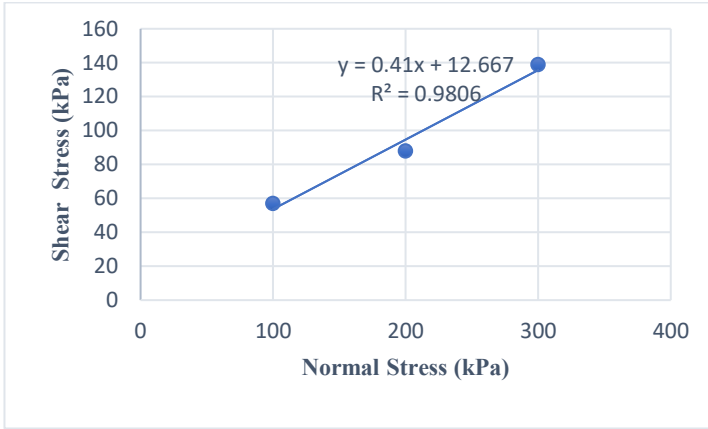


Fig 3. Shear stress versus normal stress for sample #2.

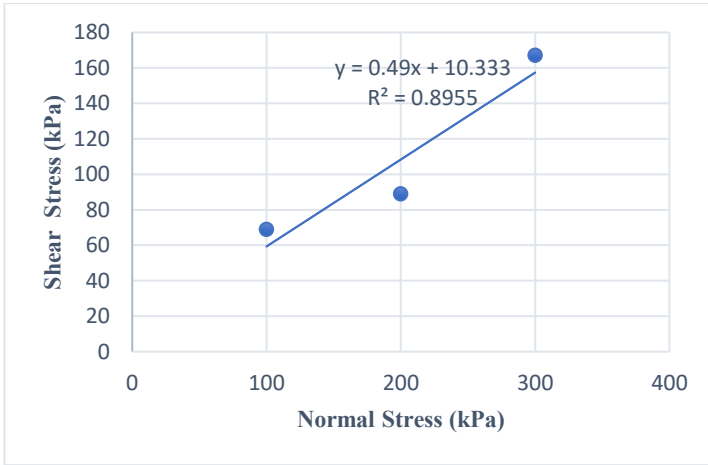


Fig 4. Shear stress versus normal stress for sample #3.

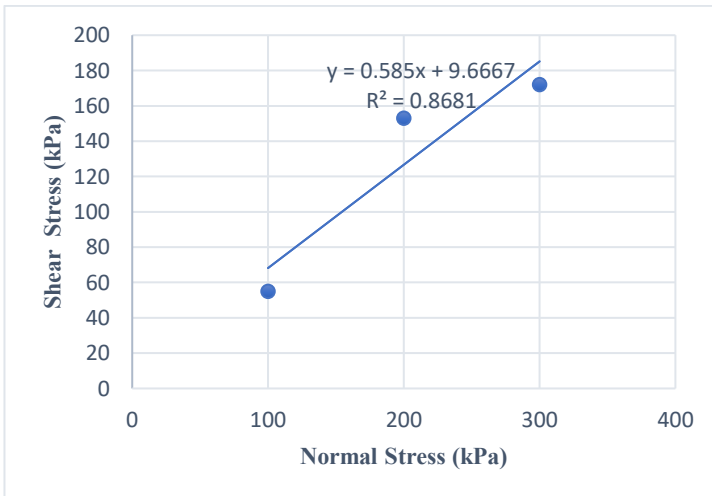


Fig 5. Shear stress versus normal stress for sample #4.

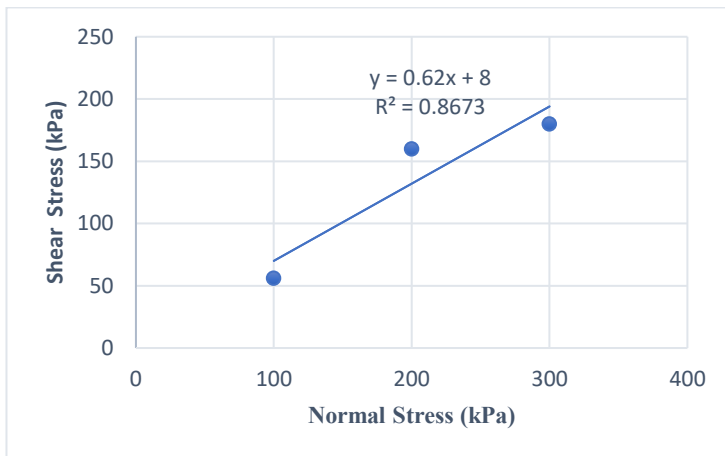


Fig 6. Shear stress versus normal stress for sample #5.

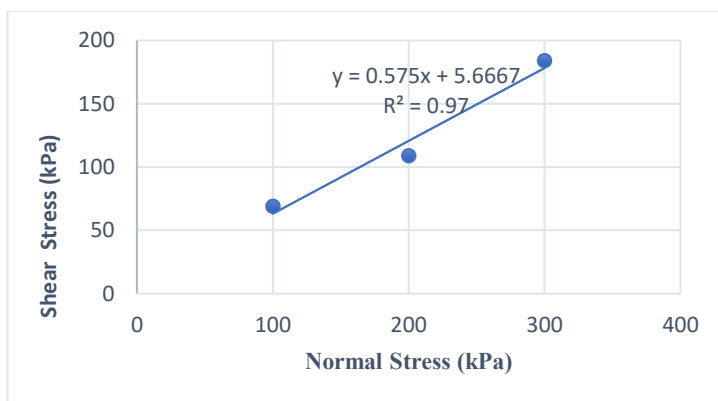


Fig 7. Shear stress versus normal stress for sample #6.

Table 2 shows all the values of cohesion and internal friction angle obtained from the diagrams. It can be seen that the angles of shearing resistance of the samples vary from 22 to 32 degree. The range of cohesion is also claimed to be between 5 and 14 kPa. The results also shows that generally by increase in median diameter of particles, the values of cohesion decrease and the amount of internal friction angle increase.

Table 2. Results of direct shear tests.

Sample No.	Cohesion (kPa)	Internal friction angle (degree)
#1	13.1	24.23
#2	12.7	22.29
#3	10.2	26.10
#4	9.5	30.32
#5	8	31.79
#6	5.1	29.88

All samples were subjected to a triaxial test to improve accuracy and compare shear strength data acquired using different techniques. The data were retrieved in a p-q diagram for simplicity, and the quantity of cohesion and internal friction angle were then derived from them. As an example, for specimen number one, Figure 8 illustrates a p-q diagram. The same procedure was followed for all samples, with the findings listed in Table 3.

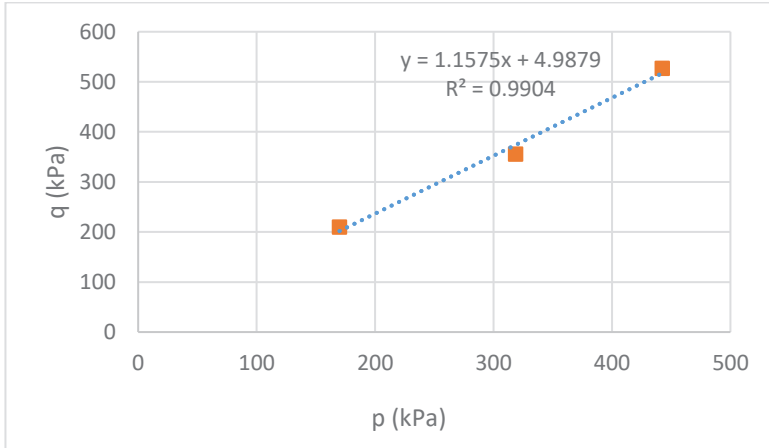


Fig 8. p-q diagram of a triaxial test for sample number 1.

Table 3. Results of direct shear tests.

Sample No.	Cohesion(kP)	Internal friction angle (Degree)
#1	15.4	29.2
#2	13.8	25.7
#3	10	27.9
#4	9.8	32.4
#5	7.3	33.1
#6	4.1	33.8

Figures 9 and 10 illustrate a better comparison to notice the differences in the results. In terms of increasing the average dispersion rate of grains, this graph compares the cohesion and internal friction angles acquired from two tests. According to the results of a series of direct shear and triaxial tests on different sands, the angle of internal friction values obtained from triaxial tests are about 1–5° higher than that obtained from direct shear tests. In general, it appears that the difference is greater in soils with a higher median particle diameter. It can be referred to amount of fine which each sample contain. Regarding cohesion parameter, while there is a significant difference, there are no discernible tendencies. As it was mentioned before, to have a consideration about the effect of shear rate parameter on the results, the specimen was tested with a faster rate in direct shear test. The applied rate for rapid test was 0.5 mm/min. Table 4 shows the effect

of shear rate on shearing characteristics under both testing circumstances for sample numbers 1 to 6.

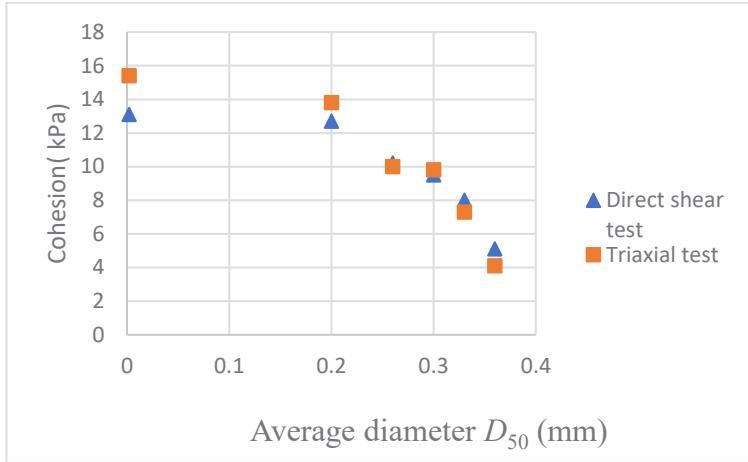


Fig 9. Comparison of cohesion obtained by both methods.

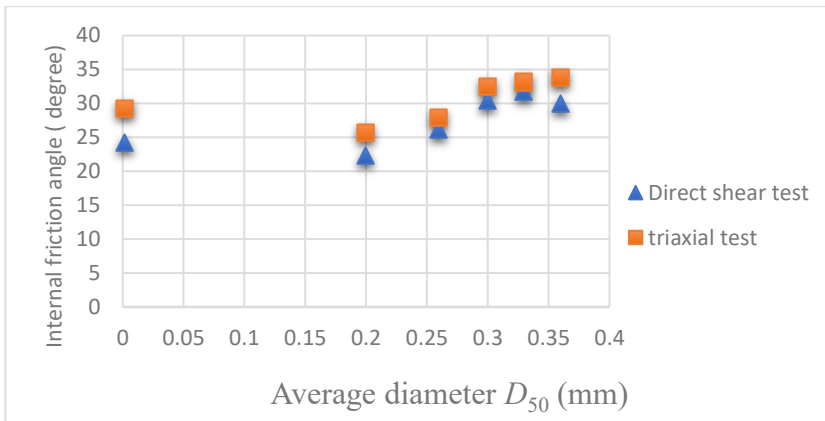


Fig 10. Comparison of internal friction angle obtained by both methods.

Table 4. Results obtained by direct shear tests with different shear rates.

Sample No.	Cohesion(kPa)		Internal friction angle (degree)	
	Shear rate = 0.05mm/min	Shear rate = 0.5mm/min	Shear rate= 0.05mm/min	Shear rate= 0.5mm/min
#1	13.1	14.2	24.23	28.33
#2	12.7	13.9	22.29	26.24
#3	10.2	11.1	26.10	28.07
#4	9.5	9.1	30.32	31.42
#5	8	8.2	31.79	33.78
#6	5.1	5.3	29.88	34.2

Internal friction angle and cohesion parameters are both affected by shear rate. When shear rate was increased, the internal friction angle increased further. There is also a rise in cohesion values, which may be neglected. Furthermore, the results show that the values of the internal friction angle obtained by the high-speed rate direct shear test are almost similar to the values acquired from the triaxial tests.

5 Conclusion

A series of shear tests and triaxial tests on sandy soils were conducted in this study. The soils have different fine contents. The results obtained by both types of tests were compared and the effect of median particle diameter was investigated. The results of direct shear test shows that generally by increase in median diameter of particles, the values of cohesion decrease and the amount of internal friction angle increase. According to the results of triaxial tests, the angle of internal friction values obtained from triaxial tests are about 1–5° higher than that obtained from direct shear tests. In general, it appears that the difference is greater in soils with a higher median particle diameter. It can be referred to amount of fine which each sample contain. In addition, it was found out that internal friction angle and cohesion parameters are both affected by shear rate which is the same as that research done in the past. By increasing in shear rates, higher values of internal friction angle were observed. those values are almost similar to the values acquired from the triaxial tests.

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