The numerical evaluation of the effect of Geotextile sample size on the behavior of reinforced cohesive soil

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Abstract:

The effect of sample size is a phenomenon that involves the dependence of resistance on the size of the tested sample, where smaller samples exhibit higher resistance compared to larger ones. Due to the importance and sensitivity of determining the resistances of laboratory samples for use in design, codes, and standards, efforts are made to minimize the effects of sample size. This issue holds true for the design of reinforced soil structures. Given the cost and time-consuming nature of laboratory tests and the desire to reduce costs, save time, and facilitate numerical modeling for predicting soil behavior, there is a significant inclination towards numerical modeling.

In this study, after validating the computer model with numerical simulation of triaxial test results, the effect of size was examined by constructing models with different sizes. The PLAXIS 2D software performed this simulation in the axisymmetric pattern and analyzed one-fourth of the total sample. All experiments were conducted on unreinforced cohesive soil with geotextile reinforcement, subjected to confining pressures of 400, 600, 800, and 1000 kPa, with different diameters (38, 100, 200, and 400 millimeters) and modeled with one to four layers of geotextile. The presence of geotextile increases the maximum resistance, and this increase is more pronounced at higher confining pressures and a greater number of reinforcing layers. The results also indicate that decreasing the sample diameter leads to a decrease in confining pressure and the distance between geotextile layers. However, for unreinforced samples and samples with diameters larger than 400 millimeters, the size effect has no significant impact on the results.

Keywords: Reinforced clay, Numerical evaluation, Geotextile, Triaxial test.

1. Introduction

The most significant weakness of soil as the primary material used in earth structures is its low tensile strength. By reinforcing the soil, this weakness can be overcome to a considerable extent. The combination of soil and a reinforcing element result in a composite material known as reinforced soil, which exhibits suitable compressive and tensile strength [1].

Selecting an appropriate soil stabilization method poses a formidable challenge for soil engineers, as it necessitates a comprehensive evaluation of technical, economic, human resources, machinery, personal experience, and test results to identify the most effective approach. Broadly, soil improvement or stabilization methods fall into several categories [2-11].

Reinforcement with geosynthetics is widely used due to their versatile applications in various issues. Considering the cost and expenses of in-situ tests on geosynthetically reinforced soils, numerical modeling can be a suitable option for predicting the behavior of these structures. One reason for using samples of different sizes, besides different shapes, is to determine the material properties. Models are developed for use in standards and codes to determine the ultimate load capacity of the test. Due to the non-conservative nature of predicting sample resistances due to size effects, efforts are made to minimize the size effects in describing them. Understanding the size effect is essential for the accurate interpretation of experimental data, as most laboratory tests are conducted on a small scale and need to be extrapolated for much larger real-world structures. Therefore, there is an attempt to comprehend the effects of this phenomenon [12-13].

The response of soil stress-strain, which is the fundamental behavior of soil, should fundamentally not be related to the sample size. Samples of different sizes lead to different stress-strain behaviors. A larger sample size provides a larger space for particle movement and rearrangement, improving the development of shear bands. The length and thickness of shear bands are the main factors that cause size effects. Smaller samples than usual result in overestimation of shear resistance parameters, leading to conservative analysis and design.

Numerical modeling is one of the engineering problem-solving methods that facilitates modeling in the laboratory, reduces time, and lowers the cost of laboratory tests to investigate and predict the behavior of various parameters [14-17]. Triaxial testing is one of the most common soil mechanics experiments to obtain soil strength parameters. Given the widespread use of triaxial test results, there is a necessity for numerical modeling of these tests to ease the prediction of soil behavior. The 2D PLAXIS software version 8.6 has been used for simulating laboratory test conditions and constructing a numerical model.

Ang EC, Loehr JE [18] investigated the size effects on reinforced clay with 2% (by weight) polypropylene fibers with a length of 12.7 millimeters, compacted at near-optimal moisture content according to the standard Proctor test. They found that the measured resistances for samples with a diameter of 38 millimeters were slightly lower compared to larger samples, and samples larger than 50 millimeters exhibited resistances that were essentially independent of sample size. However, they observed a similar trend for unreinforced samples prepared in a similar pattern, indicating that the observed size effects were more influenced by the sample preparation procedure than the reinforcement.

In another research [19], by conducting experiments on sand reinforced with two types of woven and non-woven geotextiles with different diameters (38 and 100 millimeters), demonstrated that soil reinforcement can be a promising solution for reducing the liquefaction potential of sand, and the size effect is negligible. However, in larger diameter samples, higher resistance against liquefaction was observed. Therefore, evaluating the liquefaction potential was suggested based on results obtained from smaller diameter samples.

In another study [20] also performed experiments on samples of different sizes for clay reinforced with 0.1 to 0.3% polypropylene fiber strands with a length of 25 millimeters. They found that the uniaxial compressive strength of unreinforced and fiber-reinforced samples tends to increase as the sample diameter increases from 33 to 70 millimeters. Although they found that the measured strengths for 100-millimeter diameter samples reinforced with fibers were slightly lower than for 70-millimeter diameter samples.

Haeri and colleagues (2000) [21] conducted triaxial compression tests on saturated sand samples reinforced with geotextile. The results for two diameters, 38 and 100 millimeters, showed that the sample size has no significant effect on the behavior of unreinforced samples. However, for reinforced samples, the size effect is evident in the stress-strain curves and consolidation behavior, with 38-millimeter diameter samples exhibiting higher resistance.

2. Method

In order to investigate the effect of various parameters on the behavior of reinforced clay, the following factors are considered in the modeling plan: sample size, confining pressure, and the number of geotextile layers. The specific details are as follows:

Sample Size:

- Different sample sizes with diameters of 38, 100, 200, and 400 millimeters will be considered.

Confining Pressure:

- Various confining pressures, including 400, 600, 800, and 1000 kilopascals, will be applied to the four-sided confined samples.

Arrangement of Geotextile Layers:

- Different arrangements of geotextile layers will be explored in the vertical direction of the sample.

The modeling plan aims to assess the impact of these parameters on the behavior of the reinforced clay samples. The variations in sample size, confining pressure, and geotextile layer arrangements will be systematically studied to understand their individual and combined effects on the stress-strain behavior of the reinforced soil. The numerical modeling will be conducted using the 2D PLAXIS software version 8.6 to simulate the laboratory test conditions and predict the response of the soil under different scenarios.

Due to the presence of a circular cross-section and the application of loading around the sample, the axisymmetric pattern is chosen as a suitable model. Only one-fourth of the soil sample with dimensions *D* and *H* (representing the diameter and height of the sample, respectively) is analyzed. Considering that the left boundary is the location of the symmetry axis and in accordance with the real conditions of deformation in the sample, displacement is zero in the direction perpendicular to it and is free in the boundary direction.

In the horizontal direction and at the bottom, the sample is restrained, while the upper and right surfaces of the sample are free in terms of deformation. The upper and right boundaries are entirely free, and a uniform load is applied to them [16]. These boundary conditions specify how the sample is analyzed under loading and deformation within the studied range.

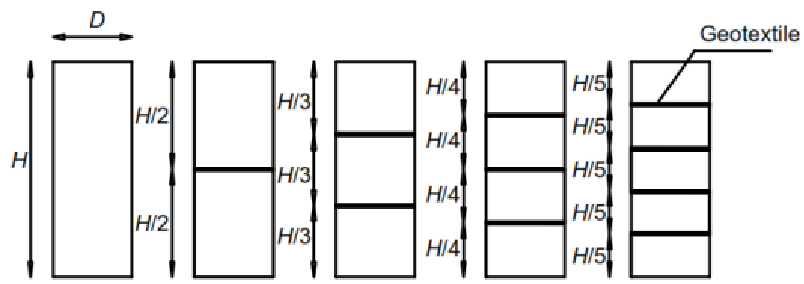

Figure1. the arrangement of geotextile in various samples.

The specifications of the modeled clay are extracted from triaxial tests by Hernandez [22]. The elastoplastic behavior of the clay is modeled using the HS behavioral model, while the geotextile's elastic behavior is predicted.

The geotextile is of non-woven type with a weight of 180 grams per square meter, tensile strength at break of 5.12 kilonewtons per meter, opening size of 0.125 millimeters, and strain at 30% in ultimate tensile strength. Reinforcing layers are placed horizontally within the soil mass.

Table-1 presents the soil parameters based on the HS model:

E_{50}^{ref} (kPa)	(kPa)$E_{\mathrm{oed}}^{\mathrm{ref}}$	(kPa)$E_{\mathrm{ur}}^{\mathrm{ref}}$	m	C (kPa)	ϕ(°)	R_{f}
12000	27790	36000	0/76	260	2/1	0/9

Other soil parameters include Poisson's ratio of 0.495, and the maximum and dry unit weights of 18.3 and 14.9 kilonewtons per cubic meter, respectively.

Additionally, a non-woven geotextile is used as reinforcement. Fabian and Fourie [24] demonstrated through numerous tests that the shear resistance of clay can increase in both short-term (undrained) and long-term (drained) conditions by selecting an appropriate geotextile. Therefore, non-woven geotextile is chosen for its flowability, high flexibility, and better drainage capability, especially under rapidly applied loads such as earthquakes. All simulated tests are under undrained conditions. The software introduces the geogrid element, characterized solely by its vertical tensile resistance, for geotextile reinforcement. The interaction between soil and reinforcement uses a common surface element. Controlling the performance of geotextile reinforcement involves considerations of load-carrying capacity and interfacial friction. According to research conducted by [25], displacement required for mobilizing critical friction may be crucial for some geotextile applications. Therefore, resistance and displacement must be considered for the intended design, and in PLAXIS software, unlike other software, this value is directly taken as input and simulates the real behavior of geotextile based on the load-displacement curve.

In order to simulate static triaxial tests, modeling was performed using the strain control method. This involved applying loads to a triaxial cell with constant lateral pressure and strain throughout the test until failure. The loading is applied in two stages: in the first stage, isotropic pressures are applied, and in the second stage, with constant lateral pressure, pre-determined displacements, according to the standard [10], which is 20-15% of the sample height, are imposed on the soil. The tests were conducted with a strain rate of 0.01 per minute. However, due to plastic analysis, time is not considered, and displacement is only applied as a percentage of the sample length.

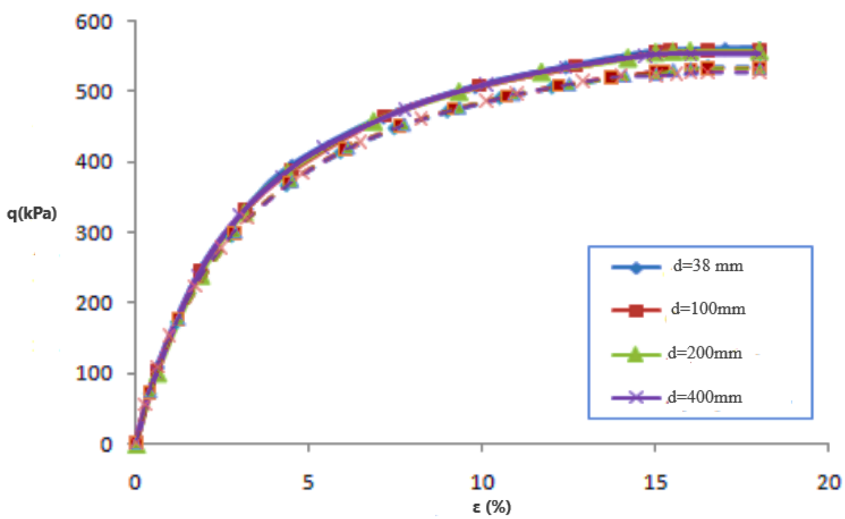

Figure2. The effect of size on unreinforced specimens. Top curve: Lateral pressure of 800 kPa; Bottom curve: Lateral pressure of 400 kPa.

As evident from Figure 2, the size of the specimen has a negligible effect on the strength of the unreinforced specimen. This effect can be disregarded for both lateral pressures. The soil stiffness increases with the increase in the applied stress level, and larger specimens will experience higher stresses under larger lateral pressures. In Figure 2, it is clear that the size of the specimen has minimal impact on the strength of the unreinforced specimen. This effect can be considered negligible for both applied lateral pressures. The stiffness of the soil increases as the level of applied stress rises, and larger specimens will undergo higher levels of stress when subjected to larger lateral pressures.

Table-2: The Effect of the Number of Reinforcement Layers on the Size Impact on the Stress-Strain Curves of Reinforced Clay under 600 kPA of Confining Pressure.

Number of Geotextile	d (mm)	Maximum deviator stress	Size effects
1	38 400	545 540	0.9
2	38 400	552 543	1.7
3	38 400	592 544	8.8
4	38 400	631 550	14.7

The provided table illustrates that the maximum deviator stress experiences an increase as the number of geotextile layers rises. The influence of size effects becomes more apparent with an increasing number of reinforcing layers. Notably, in larger-diameter samples, the impact of the number of reinforcing layers on size effects is minimal. This observed increase is consistent across all reinforced samples, and the presence of geotextile in larger-diameter samples has a less pronounced effect.

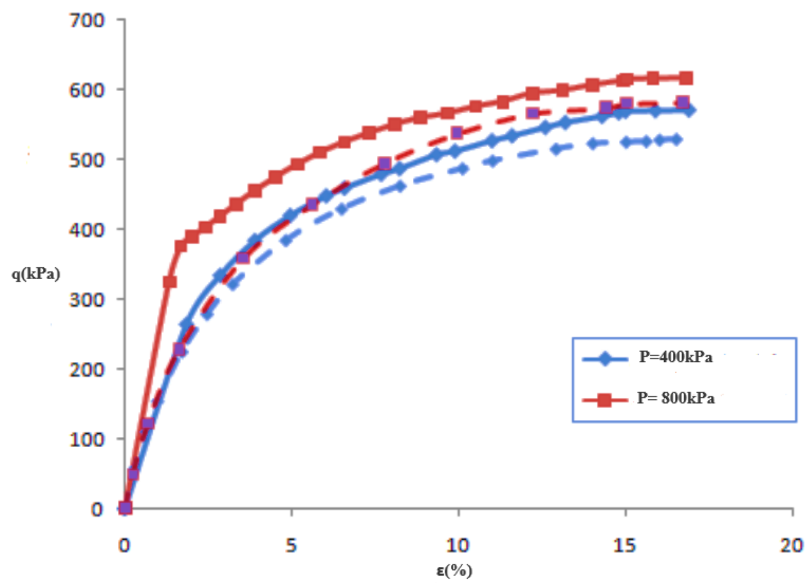

Figure-3 depicts the effect of confining pressure on the size effect on the stress-strain curves of the reinforced clay with three layers of geotextile.

The solid line represents the sample with a diameter of 38 millimeters, while the dashed line represents the sample with a diameter of 400 millimeters.

At lower confining pressures, the size effect is more noticeable. For instance, at a confining pressure of 400 kilopascals, its magnitude is 10%, and at a confining pressure of 800 kilopascals, it is 6.2%. As observed, the size effect diminishes at higher confining pressures.

Figure 4 illustrates this reality, showing that the maximum resistance of reinforced clay decreases with an increase in sample diameter. In other words, larger-diameter samples exhibit lower maximum resistance compared to smaller-diameter samples. The size effect can be disregarded for diameters of 400 millimeters and larger.

The influence of sample diameter indicates that the increase in confining pressure resulting from the presence of geotextile, which contributes to increased resistance in geotextile-reinforced samples, is more pronounced in smaller-diameter samples compared to larger-diameter ones. The size effect becomes more prominent with an increase in the number of geotextile layers and a decrease in confining pressure.

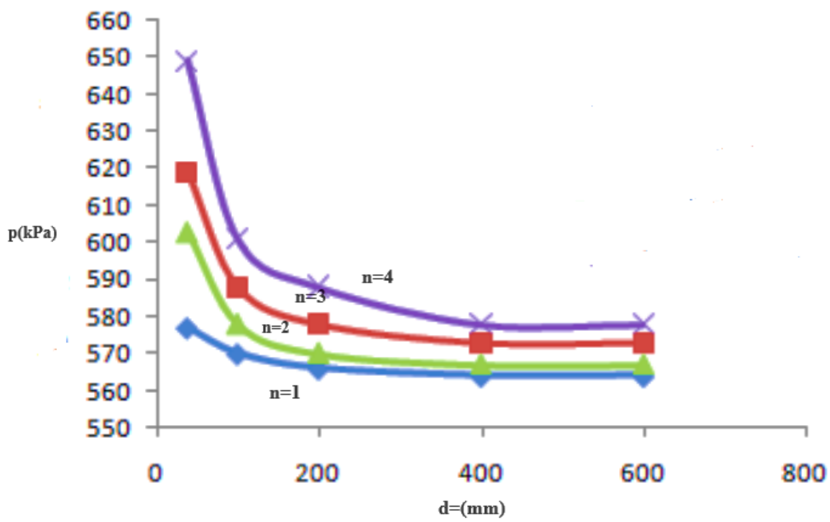

Figure 4 illustrates the effect of size on various diameters of samples under a confining pressure of 800 kPa.

Discussion and Conclusion

In the course of this research, an in-depth analysis of cohesive soil reinforced under unreinforced drainage conditions was conducted using the PLAXIS 2D software. The utilization of the HS behavior model in simulating triaxial conditions revealed notable findings, highlighting the influential role of geotextile reinforcement on the soil's mechanical properties.

The results clearly demonstrate that the presence of geotextile leads to a considerable increase in maximum resistance. Moreover, this augmentation is more pronounced under higher confining pressures and with an increased number of geotextile layers.

In contrast to unreinforced clay, the size of the sample significantly impacts the behavior of reinforced clay. Smaller-diameter samples exhibited a substantial rise in resistance compared to their larger counterparts under identical geotextile layering and confining pressure conditions.

The influence of size on the behavior of geotextile-reinforced clay becomes more apparent with an escalating number of geotextile layers and a reduction in confining pressure. This can be attributed to the heightened interaction between the reinforcing material and the soil under lower confining pressures, coupled with the increased confining pressure resulting from additional geotextile layers. The impact of size is particularly conspicuous in smaller samples.

Furthermore, the behavior of the soil is minimally affected by the size of samples with diameters larger than 400 millimeters. In these larger diameter samples, the shear band has more space and flexibility for expansion, resulting in a more pronounced reduction in soil resistance.

In summary, this research underscores the intricate interplay between geotextile reinforcement, sample size, and confining pressure in shaping the mechanical response of cohesive soils. The insights gained from this study contribute valuable knowledge to the understanding of geotechnical engineering applications involving soil reinforcement.

In this study, the behavior of cohesive soil reinforced under unreinforced drainage conditions has been evaluated using PLAXIS 2D software. By simulating triaxial conditions and utilizing the HS behavior model, the results showed that the presence of geotextile increases the maximum resistance. This increase is more pronounced with higher confining pressure and more layers of geotextile.

Contrary to unreinforced clay, the size has a considerable effect on the behavior of reinforced clay. Smaller-diameter reinforced clay samples under the same conditions of geotextile layers and confining pressure showed a significant increase in resistance compared to larger-diameter samples.

The effect of size on the behavior of geotextile-reinforced clay increases with the higher number of geotextile layers and reduced confining pressure. This is due to increased interaction between the reinforcing material and the soil under lower confining pressure and the higher confining pressure resulting from the presence of more geotextile layers, leading to such behavior. The magnitude of this increase is more visible in smaller samples. Moreover, the behavior of the soil is not significantly affected by the size of the sample with a diameter larger than 400 millimeters. In larger diameter samples, the shear band has more space and possibilities for expansion, leading to a greater reduction in soil resistance.

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