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Numerical and Experimental Study of Effect Woven Geotextile on Clay Soil

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Abstract

Structures erected on soft soil often face challenges related to uncontrollable settlement and critical bearing capacity. The footing of numerous structures is prone to failure and collapse when situated on weak soil. In geotechnical engineering, enhancing the bearing capacity of a shallow footing is imperative. One method for achieving this improvement is the use of woven geotextile (WG) reinforcement, as soil is proficient in compression but lacks tensile strength so by incorporating WG, the tensile potential of the soil is increased, consequently enhancing its load-bearing capacity. This study aims to investigate the effect number of WG layers through a comprehensive series of square model footing load tests. The results showed that increasing the number of WG layers increases the ultimate bearing capacity of soil. Compared to the unreinforced soil, the UBC value of one layer increased by 1.51 times, 1.64 times for two layer, and 1.88 times for three layers. Also, the study simulates the experimental results obtained from model footing tests by using Plaxis-3D software program. The results of these tests provide valuable insights into the effectiveness of the woven geotextile for reinforcement of clay soil.

Keywords— Geotextile, Clay soil, Bearing capacity, Plaxis-3D.

1 Introduction

Soil is usually classified into four major kinds: clay, silt, gravel, and sand and typically characterized by low tensile and influenced by environmental conditions (Hejazi et al., 2012). The existence of clay weak soil, under structural foundations often lead to reduce load-bearing capacity and increased settlements. Also, these conditions can result in a decline in overall performance and structural damage in foundation. Conventional treatment methods typically include, removing the weak soil to a particular depth and replacing it with a layer of soil with suitable strength is a standard engineering procedure for building on weak soil but it is an expensive. However, a more economical and alternative solution lies in utilizing geosynthetics. The strategy involves placing one or more layers of geosynthetic material to form a composite with enhanced performance characteristics. The resultant composite zone, also known as the reinforced soil mass, serves to enhance the load-bearing capacity of the footing and ensures more uniform pressure distribution atop the underlying weak soils. Many studies have investigated the efficacy of geosynthetic in soil reinforcement. (Thamer & Shaia, 2021) investigated the effect of woven geotextiles on silty sand soil in a box measuring 0.6 m x 0.6 m x 0.4 m. The results exhibited an increase in (UBC) from 363 kPa to 575, 611, and 707 kPa when adding one layers, two layers, and three layers of geotextile, respectively. (Ali Fakher & Kadhim Fakhruldin, 2020) investigated the effect of geogrid on sandy

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soil by using strip foundation, with dimensions of 49 cm x 13.5 cm and a thickness of 4 cm. The test results highlighted a 2.5 times improvement in the foundation's bearing capacity with increase number of reinforcing layers. Numerous finite-element (FE) studies have been carried out recently to investigate the behavior of geotextile-reinforced soils. (Hasan et al., 2020) investigated the influence of geogrid on various type of soils to increase bearing capacity and reduce the settlement. A numerical by using the (Plaxis-3D software) and analytical analysis for both reinforced and natural soil was performed. The results show that, in comparison to natural soil, the reinforcement utilizing the geogrid greatly increased UBC while reducing the settlement beneath the foundation. The analytical and numerical findings of the UBC were compared, and the comparison demonstrated good agreement between the two studies. (Seby et al., 2021) conducted a numerical study comparing the influence woven and non-woven geotextiles on clay and sand soil. The study addressed the inherent weakness of soils in tension by incorporating reinforcing elements oriented towards tensile stress. Geotextiles, composed of synthetic polymeric or natural materials, are explored for their ability to increase UBC and reduce settlement by Utilizing numerical modeling in PLAXIS 2D. Key characteristics examined include CBR and Bearing Capacity Ratio values, with results indicating an improvement in soil properties with the introduction of geotextiles. The introduction examines the use of experimental and numeric approach on using geosynthetics, in soil reinforcement. While studies demonstrate the effectiveness of these technical, the research gaps include few studies have investigated the effect of using woven geotextile on the ultimate bearing capacity and settlement characteristics of clay soil by using the model footing load test. On the other hand, a few studies used three-dimensional programs to simulate reinforced soils and study the effect geotextile. This study examines the outcomes of square model test rested on clay soil reinforced with layers of woven geotextile and simulated experimental results using PLAXIS 3D.

2 Experimental Study

2.1 Materials

2.1.1 Soil

Table 1. Shown the properties of clayey soil utilized for this study was taken from a depth about (3 m) below the surface of the ground from one of the Al-Nasiriya city neighborhoods.

Table 1: Physical properties of clay soil.

Properties of soil	Values
Plastic limit	20
Liquid limit	43
Plastic index	23
Specific gravity	2.65
Classification UCSC	CL
UCS	122 kPa
MDD	1.852 g/cm^3
Cohesion (kPa) from direct shear test	45
Friction angel (ϕ°) from direct shear test	10.2°
Poisson ratio ν	0.3

2.1.2 Woven geotextile (WG)

Woven geotextiles stand out as superior options among geotextile varieties. Fig. 1 illustrated woven geotextile used in this study. Multifilament woven geotextiles provide the highest strength, albeit at a higher cost (Kelechi & Okeke, 2018). Through various weaving patterns, these fibers form a sturdy and uniform fabric, imparting the geotextile with high tensile strength and mechanical stability. These geotextiles primarily serve functions such as separation, filtration, and reinforcement. In numerous applications, (WG) prove to be the most effective and economical choice. Their strengths shine in tasks such as reinforcing foundation layers, providing support under railway ballast, reinforcing roadways, and constructing retaining walls. On the other hand, (WG) offer distinct characteristics, including ease of use, rapid performance, high tensile strength, lightweight design, long-lasting durability, cost-effectiveness, and minimal environmental degradation (Atrechian & Ahmadi, 2019). Table 2 shows the features of (WG) utilized in this research.

Table 2: Properties of WG.

Properties of soil	values
Tensile strength	40 kN/m
Elongation	%15
Thickness	0.8 mm

Figure 1: Woven geotextile used in this study

2.2 Experimental procedure

This investigation made use of a particular test apparatus, that was designed in ref (Altaweel & Shakir, 2021a) with some tools and parts which is illustrated in Fig. 2. Experiment laboratory tests are carried out in a test box with dimensions (0.6*0.6*0.5) m. The weight is applied on foundation with dimensions (10*10*2.5) cm using a hydraulic jack that is electrically operated. Two dial gauges were used in the testing to measure the settlement in the soil beneath the model footing. Both dial gages were maximum range and accurate at 26 mm and 0.01 mm respectively., the ends of each dial gauge are in contact with the model footing surface and are each anchored by magnetic supports. The steps involved for preparing test samples are as follows: First, a (No. 10) sieve was used to remove lumps from the test soil. In a steel test tank with dimensions (600x600x500) mm, the soil was compacted in three layers, each with a thickness of 150 mm. In order to achieve the energy equivalent of the compaction test, a steel hummer with dimensions of (158x158x158) mm and a weight of 10 kg was used to compress the soil layers. In order to reach 17.6 kN/m^3, the energy equivalent of the compaction test, which is 95% of the MDD for all tests, the required number of blows for each layer must be achieved. The soil density within the test tank was checked using the core cutter method to make sure reached the required density. After all layers of soil have been compacted, the surface of top layer's is leveled. In order to reach the desired design thickness, this process was applied to all natural soil layers. The same procedure steps were followed for prepare the soil improved with woven geotextile layers of varying distances. The top layer's surface is leveled, and the model square footing is laid in the center of the test tank. Dial gauges are attached to the tank's edges using magnetic supports, and their needles are in contact with the surface of the model square footing. Two sensitive dial gauges were used to record the load increment for every 50 kg load as shown in Fig. 3. The loading system procedures have been followed according to (Abd-ali, n.d.)

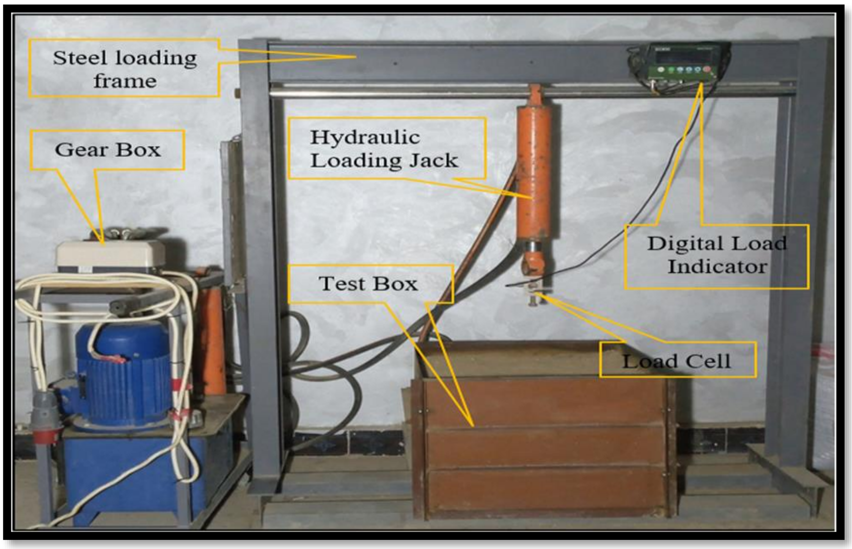


Figure 2: Laboratory test device manufactured by (Altaweel & Shakir, 2021b)

Figure 3: Dial gage and magnetic stands using in work

3 Numerical study

Plaxis-3D is a powerful and widely used computer software program designed for engineers and geotechnical professionals. It helps them analyze and simulate the behavior of soil and rock in three- dimensional (3D) environments. This tool is essential for solving complex geotechnical problems related to foundation design, soil-structure interaction, excavation, tunnelling, and slope stability. With Plaxis-3D, engineers can create detailed virtual models of the subsurface conditions and then apply various loads and boundary conditions to simulate real-world scenarios. By doing so, they can gain valuable insights into how the ground will behave under different conditions, enabling them to make informed decisions and optimize their engineering designs. In essence, Plaxis-3D is a crucial software tool that assists professionals in the field of geotechnical engineering to better understand and predict the behavior of the ground, ultimately ensuring the safety and stability of construction projects. In PLAXIS, different models are available to represent and complicated behavior of soil under various loading situations (Edition & Manual, 2022) .The Mohr– Coulomb model, a perfectly plastic constitutive model, was used to simulate the behavior of clay soil. When using the Mohr-Coulomb constitutive model, five parameters are required as input: young's modulus(E) and Poisson's ratio (v), cohesion (c), and friction angle (ϕ) as shown in Table 1. The only material property required for the geotextile is its elastic normal (axial) stiffness (EA), and can be obtained from material databases. The interaction between the geotextile and the surrounding soil can be simulated through interface elements positioned between the reinforcement and soil surfaces. The case of displacement control is used to analyze all cases, where 25 mm settlement was fixed and the amount of change of the applied load is observed.

4 Results and discussion

4.1 Results of experimental work

In this research, the foundation stress associated with a 10% settlement of the plate width in all plate load tests is designated as the ultimate bearing capacity (Alan & Adams, 1998). Additionally, this study innovatively assesses the bearing capacity ratio (BCR) considering the effect geotextile.

4.1.1 Influence of the top layer spacing of WG

The perfect distance of top spacing of reinforcement by using geotextile can be determined by experiment the footing for range of distance of (0.25B to 0.5B). Fig. 4 explains four curves for clay soil with one reinforcing layer at u/B= (0.25-0.5) for both natural and reinforced soil. When the distance between the geotextile's top layer equals (u=0.25B) and (u=0.35B), the UBC increases after that decreases at (u=0.5B). The UBC increases from 390 KPa on unreinforced clay soil to 500 kPa and 588 kPa on reinforced clay soil, when upper layer spacing (u) between (0.25-0.35B) after that the UBC reduce to 460 kPa when (u) increase from 0.35B to 0.5B. It is clear the maximum bearing capacity value for square footing at (u=0.35B). When u/B decreases, the bearing capacities of square footing on clay soil increases. The increase and decrease in the BCR connected increasing deepness maybe connected to the stress distribution theory. This outcome is similar to those made by (Panigrahi & Pradhan, 2019) showed that the most efficient depth of strengthening using natural geotextile was around 0.25 to 0.75B for square footing. (Shin & Das, 1998) showed that reinforced strip foundation by three geogrid layers, the perfect placement of the upper layer was about 0.4B. (Shrigondekar & Ullagaddi, 2020), Demonstrate that 0.25 is the optimal value for the top layer spacing u/B of square footing. Also, this is consistent with results presented by (Chen, 2007), (Zidan, 2012), (Sakti & Das, 1987). This variation in the perfect value of the first layer of reinforcement may be explained by the difference in soil characteristics and the type of reinforcement used by the researchers.

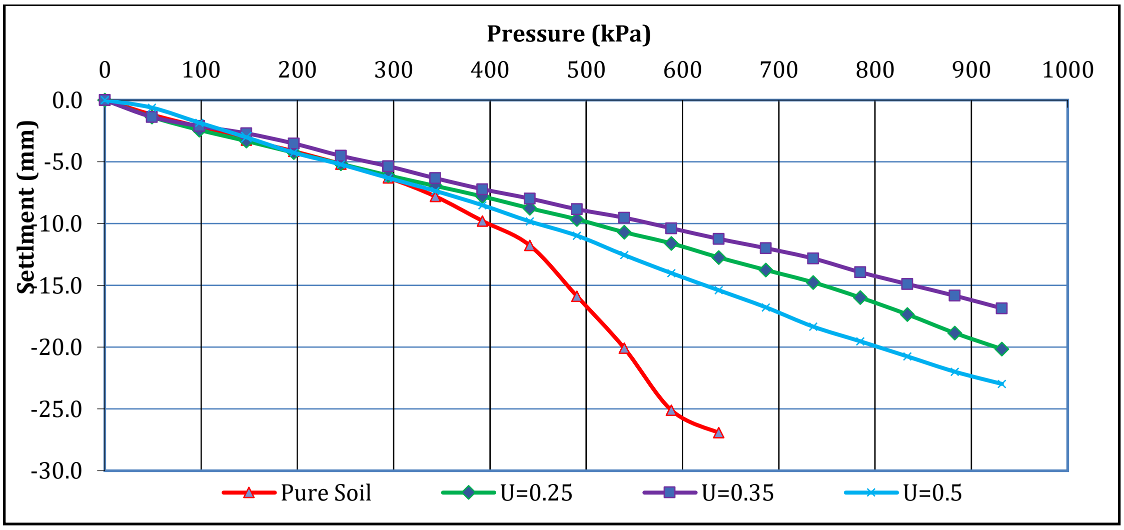


Figure 4: Pressure versus settlement of square footing on clay soil without reinforcement and with a single WG layer with varying u/B values

4.1.2 Influence of the Number of Geotextile Layers

Tests on clay soil were carried out using laboratory models with layers of WG placed at u=35 mm and spacing between layers h=25mm. Fig. 5 illustrated stress versus settlement for reinforced and unreinforced clayey soil by using different numbers of geotextile layers. With the addition of reinforcing layers, the UBC will increase from 390 kpa to 588, 640, 735,and 760 kPa when adding one layers, two layers, three layers, and four layers of geotextile respectively. It is clear from the results that the improvement in UBC after three layers of reinforcement will be insignificant. From this results observed, the increase in BC were 51%, 64% ,88%, and 95% when adding one layers, two layers ,three layers, and four layers of geotextile respectively. Fig. 6 shows the variations in BCR for different numbers of reinforcing layers (N). In Fig. 6 , the BCR increase as the number of reinforcing layers increases and seems constant beyond three layers. This outcome is similar to those made by (Thamer & Shaia, 2021) showed that the improvement in bearing capacity after three layers of geotextile reinforcement will approximately constant. (Jawad & Shakir, 2021) have found increasing in bearing capacity with increase number of geogrids layers, but the rate of bearing capacity increase more than three layers becomes less important. (Hassan & Shakir, 2022) found that increasing in BCR is negligible ,when the reinforcement layers are outside of the foundation influence depth (d/B), which is the overall reinforcement depth below which the BCR increasing rate is constant Also, this is consistent with results presented by (Badakhshan & Noorzad, 2017), (Zamani et al., 2023)

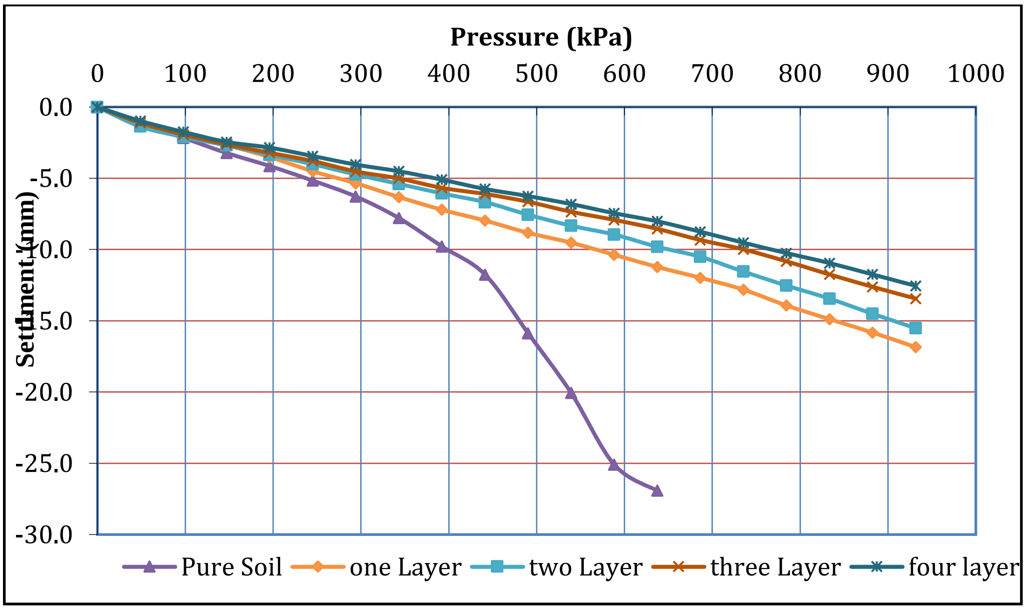


Figure 5: Pressure versus settlement curves for square model with different numbers of WG layers

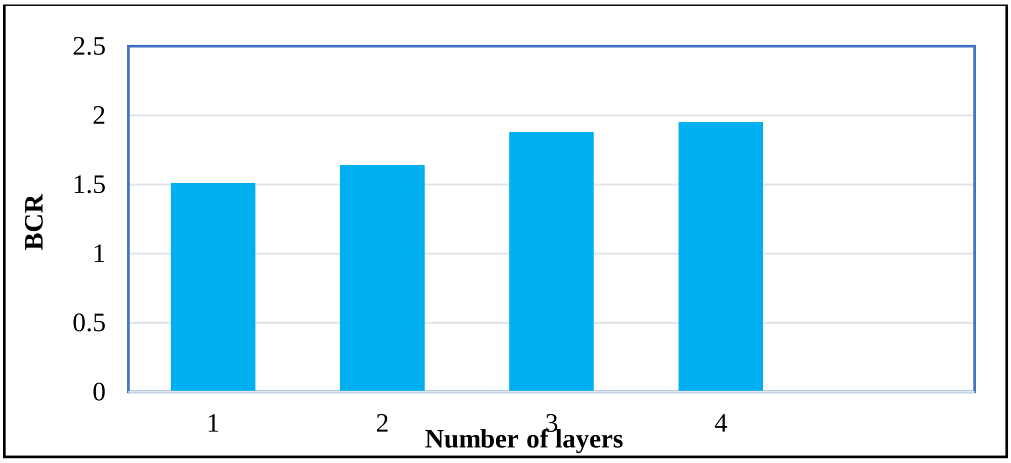


Figure 6: BCR vs. N for square footing rested on clay soil

4.2 Result of numerical work

4.2.1 Analysis Bearing Capacity of Unreinforced Soil

Fig. 7 presents the load-settlement relationship for a square model foundation rested on unreinforced soil using (0.1B) method based on experimental and numerical (Plaxis-3D method). In Fig. 7, the UBC of unreinforced soil was approximately 390, 421 kPa at experimental and numerical method, respectively. Based on results, it is evident that PLAXIS has demonstrated robust modeling capabilities in simulating the load-settlement behavior of foundation rested on unreinforced soil. Fig. 8 shown the displacement of unreinforced soil.

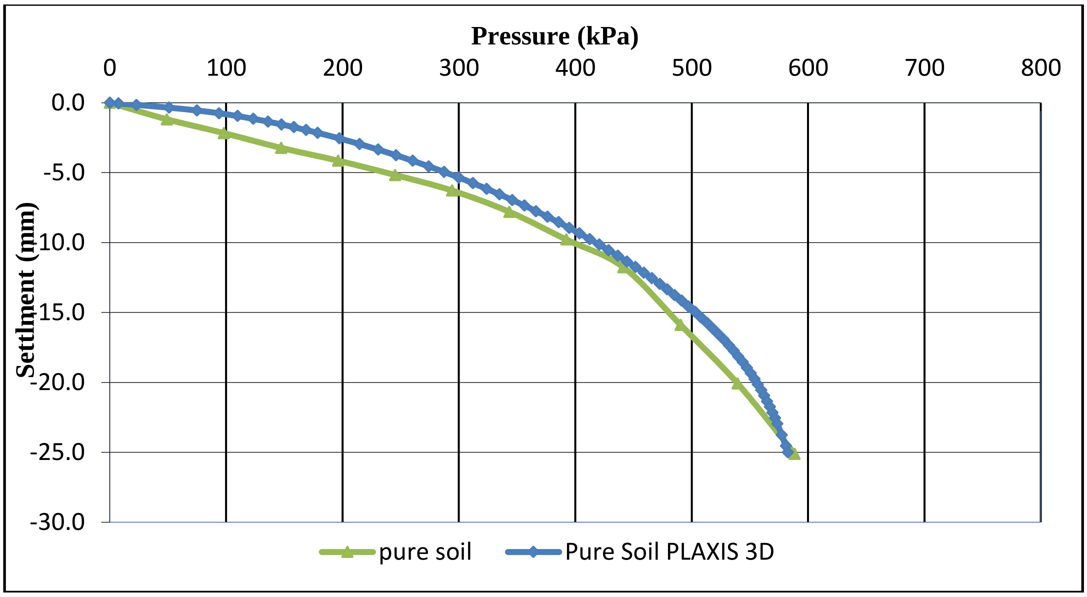


Figure 7: Experimental and numerical load-settlement of unreinforced soil

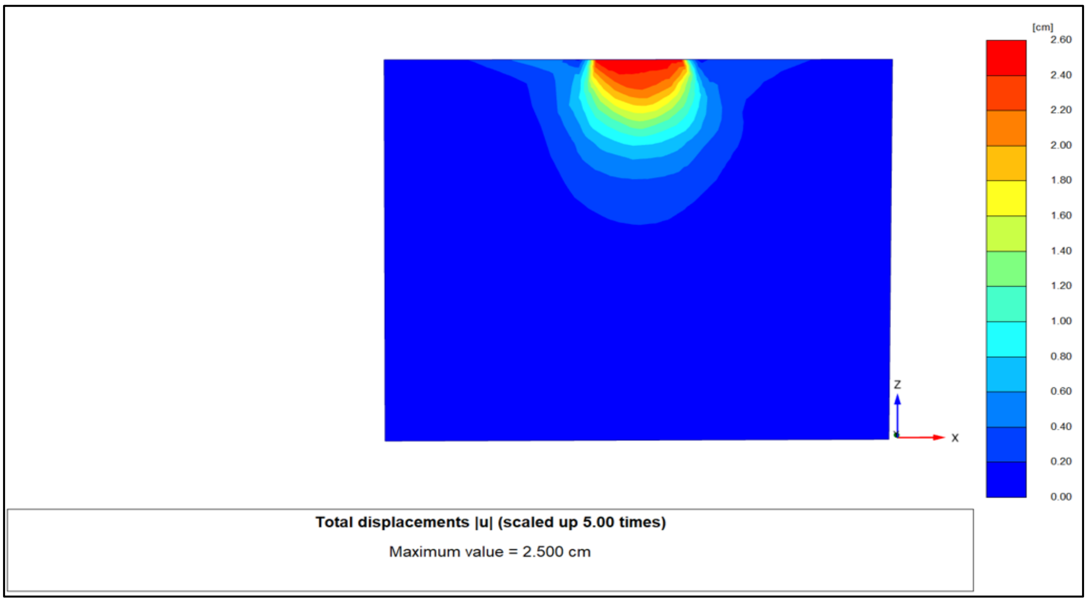


Figure 8: Displacement of unreinforced soil

4.2.2 Analysis Bearing Capacity of Reinforced Soil

Fig. 9 presents the load-settlement relationship for a square model foundation rested on reinforced soil with one and three layers of WG using (0.1B) method based on experimental and numerical (Plaxis-3D method). In Fig. 9, the UBC increases as the layers of geotextile increases. The (qu) of clay soil increase from 588, 590 to 735 ,701 kPa at experimental and numerical method by using one and three layers of woven geotextile, respectively. It is clear that the finite element analyses have a reasonable agreement with model test results, although there are some discrepancies between them. Fig. 10 present the displacement of reinforced soil with WG for square footing rested on clay soil by using Plaxis-3D program. In Fig. 10, the displacement decreases as the layers of geotextile increases. When addition the single layer of reinforcement, the displacement was approximately 17mm, but with the addition of three layers of geotextile, the displacement drops to 14 mm. The displacement values obtained from the PLAXIS analysis closely matched the experimental results, demonstrating the effectiveness of the modeling approach. These correlations enhance the confidence in the accuracy of the numerical simulation by using PLAXIS programs.

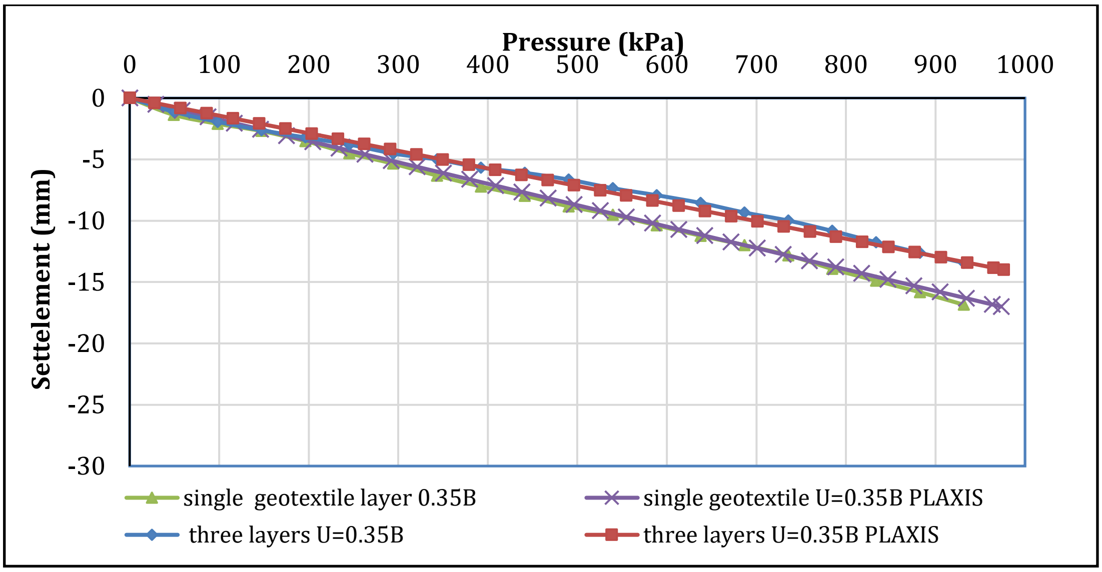
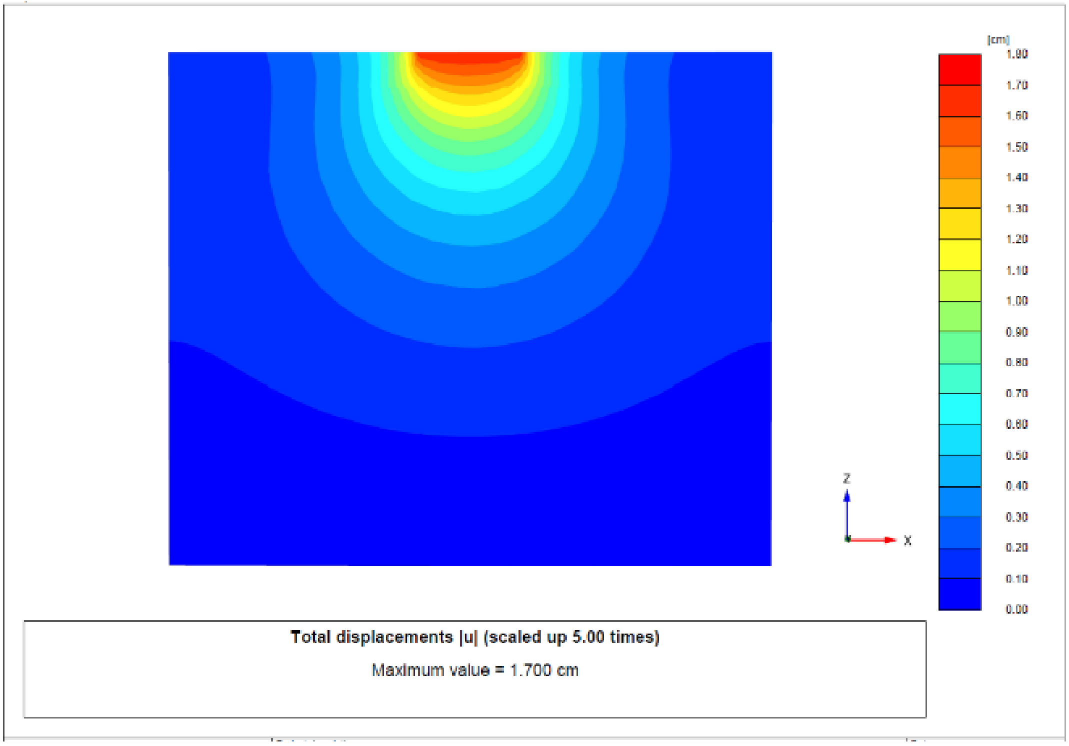
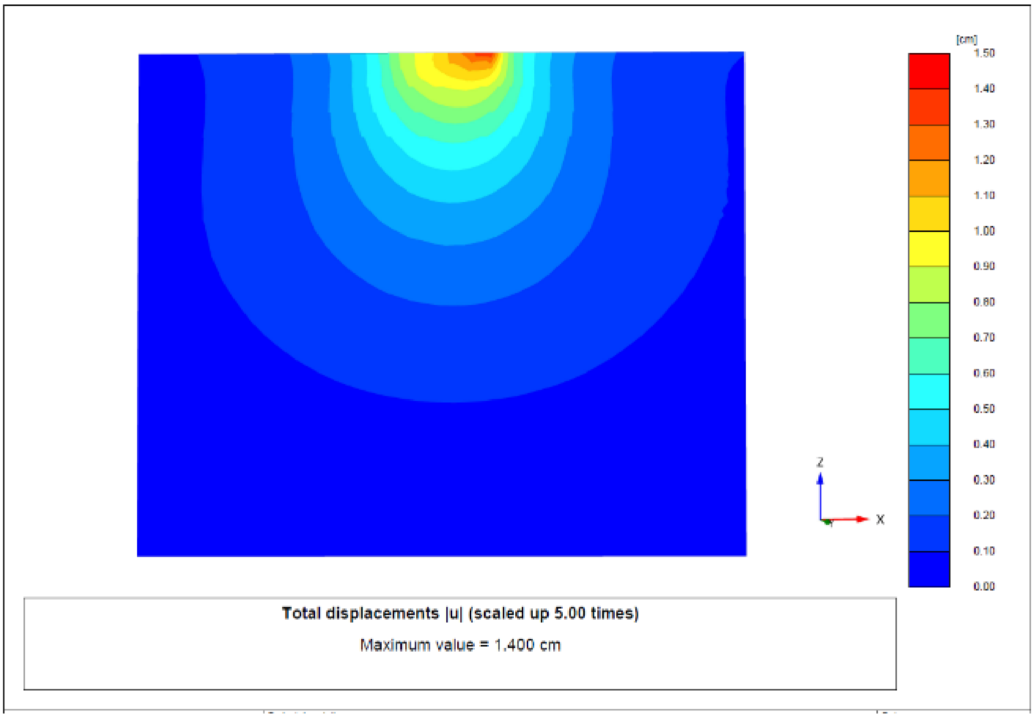


Figure 9: Pressure versus settlement curve of square foundation reinforcement with one and three layers of WG.



(a)



(b)

Figure 10: Displacements of reinforced soil with WG, (a) using one layer, (b) using three layers.

5 Conclusion

This study showed a series of numerical and experimental studies performed on a square footing resting on reinforced clayey soil with WG. The conclusions of study could be summarized as follows:

1. The optimum depth to the first layer WG reinforcement (u) was founded about 0.35B under the footing which give the best BCR for soil.
2. Increasing the number of WG layers increases the UBC of soil, compared to the unreinforced soil, the UBC value of one layer increased by 1.51 times, 1.64 times for two layer, and 1.88 times for three layers.
3. The optimum number of reinforcing layers for clay soil was three layers. The importance of an additional reinforcing layer, on the other hand, diminishes as the number of layers increases. Below the influence depth, the reinforcing effect becomes negligible.
4. The FEM analysis using Plaxis-3D application showed that the UBC and settlement values obtained from using Plaxis-3D program was relatively close from the results obtained from experimental tests. The good correlation between numerical and experimental results validates the modeling approach and suggests the reliability of PLAXIS in capturing the complexities of soil-structure interactions.

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