International Journal of GEOMATE, June 2019, Vol.16, Issue 58, pp.211 -217
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.58.8122
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

THE USE OF WOVEN GEOTEXTILE FOR SETTLEMENT REDUCTION OF SPREAD FOOTING ON GRANULAR SOIL

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*Corresponding Author, Received: 01 Dec. 2018, Revised: 26 Dec. 2018, Accepted: 16 Jan. 2019

ABSTRACT: Utilization of geotextiles has been known to reduce the settlement in any kind of soil such as sand. This study seeks to quantify the magnitude of the settlement reduction of spread footing on sand under concentric loading and reinforced with geotextile. Geotextile was placed at varying depths from the base of footing. The comparison was done between the settlement data obtained from concentrically loaded spread footing with geotextiles and from a spread footing with no geotextile. The model ground was made of an alternating layer of Ottawa sand and black sand to visualize the ground deformation and with a target relative density of 75% prepared using air pluviation technique. From test results, it was concluded that geotextile is most effective in reducing the settlement when placed closest to the base of the footing having a depth of embedment D that is equal to a quarter of the width of the footing. This location displayed the highest magnitude in terms of settlement reduction and consequently having the greatest load-bearing capacity. At this depth, the geotextile was able to reduce soil settlement up to 31% as compared to that footing without geotextile. Punching shear failure developed for footing with geotextile while local shear failure was observed for footing without geotextile.

Keywords: Woven geotextile, Settlement reduction, Spread footing, Embedment, Failure mode

1. INTRODUCTION

Problems in construction are very common in the majority of areas in the Philippines due to the various conditions of the soil. In such predicaments, polymers are commonly used as a major material to remedy the multiple complications caused by the soil or are used to maintain and preserve the desired soil conditions. Polymers, otherwise known as geosynthetics are rapidly emerging family of geo-materials used in wide variety of civil engineering application [1]. Geotextiles are defined as permeable geosynthetics, which is a part of the oldest and largest group of geosynthetics [2]. Geotextiles are composed of two types: woven and nonwoven. Woven geotextiles are made by weaving together fabric on a loom and are relatively high in strength and stiffness but have relatively poor filtration or drainage characteristics. Nonwoven geotextiles, on the other hand, are made by binding the materials through chemical, heat, needle punching or other methods. It has low to medium strength with high elongation at failure but has good filtration or drainage characteristics

Dungca [3] presented that cities near bodies of water in Metro Manila such as Manila, Navotas, and Marikina have low bearing capacities. It is most rational that only shallow foundations may be used when structures are built on a nearby water source such that only low design loads are expected and settlement reduction is maximized. Moreover, soil on nearby shorelines or bodies of water like sand is still not immune to the adverse effects of erosion, infiltration, compaction, and loss of stability due to its granular characteristics. In effect, this limits the capacity of the soil to withstand applied loadings and in most cases, structures constructed near these areas experience greater settlement when subjected to extreme loadings. Thus, reinforcing soil in these areas would be beneficial for construction.

In this study, the woven geotextile is used as a component of ground support for the foundation. The main objective of this study is to investigate the effect of using geotextile for soil reinforcement on the settlement of spread footing founded on granular soil like sand under vertical concentric loading. It specifically aims to determine the magnitude of the settlement produced from spread footing on sand reinforced with geotextile and compare it with the settlement of spread footing without geotextile; to recommend the most appropriate location of geotextile beneath a footing that will result to maximum reduction in settlement; and to determine and analyze the slip failure surface of the supporting ground with and without geotextile.

2. METHODOLOGY

2.1 Woven Geotextile Sample

The woven geotextile used for all testing is of the same material and supplier to ensure equality of properties in all test runs. It is commonly made from the woven strands of polypropylene fabric, which is non-biodegradable and high in UV resistance making it ideal for long-term use [4].

2.2 Experimental Procedures

A total of six (6) test runs with spread footing on granular soil subjected to vertical loading was done in the experiment. Ottawa sand and black sand were used to simulate granular soil. One (1) test run was made on granular soil without geotextile while five (5) test runs were made with geotextile buried underneath the soil with a varying depth of embedment. The ground was made of alternating layers of Ottawa sand and black sand to visualize the ground deformation after the application of the vertical concentric load. After loading, the ground was saturated with water in preparation for the slicing at various distances from the center of the footing.

2.3 Air Pluviation Technique

The relative density of 75% was maintained in the conduct of the experimentation for this study. To achieve the required density of the ground, air pluviation technique was performed [5]. To execute this, a tool called the pluviation apparatus was made. The device is constructed with a plastic funnel, a 6-inch long tube with a 2-inch diameter PVC pipe, a ½ inch opening screen and a funnel (Fig. 1).

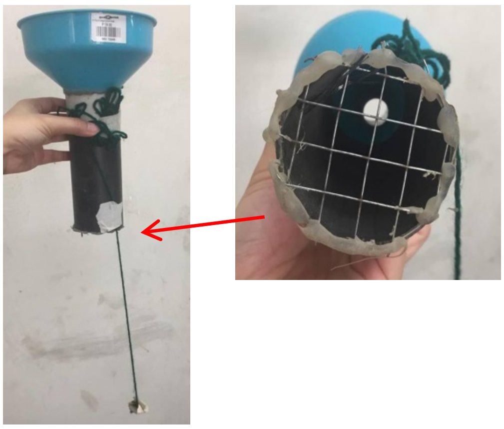

Fig. 1 Air pluviation apparatus

The test is performed by elevating the apparatus above the container at different heights, and then the sand is set free to pass through the tube, beginning from the funnel to the end through the screen. The height of the apparatus above the ground surface, which is termed as the fall height, that produced the desired density was determined.

2.4 Application of Vertical Loading Test

The dimensions of the container used in the experimental set-up were based on the theory of failure surface zone [6]. The friction angle of the sand sample was assumed to be 37 degrees which is the usual friction angle of sand [7]. The width of the footing B is equal to 10 cm, as well as the assumed boundary condition, in which foundation settlement is expected and limited to this value beneath the area of the footing. With these dimensions, it was computed that the length from the center of the footing to the end of the failure surface at one side is 40.17 cm. The total length of the failure zone at the ground surface is equivalent to 80.34 cm as shown in Figure 2. With these computed values, the container used in the experiment was a confined glass box measured with dimensions 100 cm x 100 cm x 50 cm that has an opening on the topside to allow direct contact with the soil to be enclosed. These dimensions are used to allow a 10 cm allowance for each side of the tank horizontally to be able to check if the failure surface will reach beyond its computed value. One of its sides is removable and there were taps used to serve as an outlet to drain water introduced into the tank for visualization of settlement.

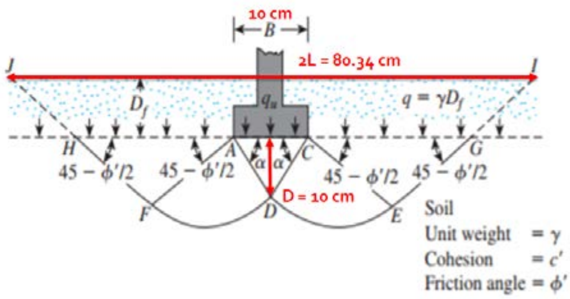

Fig. 2 Dimensions of failure surface zone

The miniature footing made of a steel plate with a base dimension of 10 cm x 10 cm x 0.5 cm, a column dimension of 3 cm x 3 cm x 30 cm and with a top plate for loading purpose. It was embedded within the layers of sand and was subjected to loading from the load cell and hydraulic jack. Throughout the application of force, a data logger was attached to the load cell and transducer to keep track of the displacement and the corresponding applied load. The multi-colored sand is found to have a depth of 22.5 cm and such measurement eliminates the boundary effect of the base of the glass box. Figure 3 shows the schematic diagram of the experimental set-up.

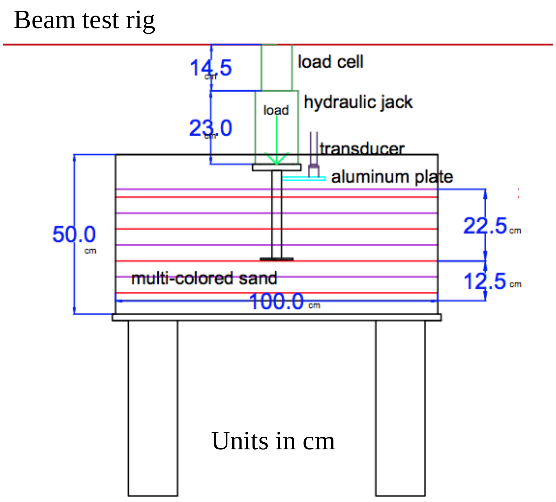

Fig. 3 Schematic diagram of the experimental set-up

2.5 Ground Deformation Visualization

The process used for the visualization of ground deformation was similar to the work of Adajar [8]. For a visual representation of the ground deformation and settlement, water was introduced into the soil after loading while the outlet valves are closed until the sand is moist. The saturation of the soil was done without disturbing the ground deformation. The outlet valves were then opened to drain excess water so that sand would clump together, preserving the settlement that has occurred. The sample was sliced at various distances from the center of the footing to expose the area that has settled. These distances were 30 cm and 15 cm from the center of the footing, at the edge of the footing and at the edge of the column.

3. RESULTS AND DISCUSSION

3.1 Preliminary Data

The specific gravity of the black sand was established to be 2.65 based from ASTM D854. Determination of the maximum and minimum void ratio for both Ottawa and black sand was done based on ASTM D 4254 and ASTM D 4253. The void ratio of black sand and Ottawa sand is calculated to be 0.98 and 0.51, respectively to achieve the target relative density of 75% with a fall height from the air pluviation technique of 12 cm for Ottawa sand and 26 cm for black sand. Table 1 shows the preliminary data.

Table 1 Summary of preliminary data

Property	Black Sand	Ottawa Sand[9]
Specific Gravity. G_s	2.65	2.65
Maximum Void Ratio, e_{max}	1.11	0.62
Minimum Void Ratio, e_{min}	0.93	0.47
Void Ratio, e	0.98	0.51
Dry Unit Weight, γ_d (g/cc)	1.34	1.75
Fall Height (cm)	26	12

4. TEST RESULTS

The expected type of failure for the sample according to a study [10] should either be a local shear failure or punching shear failure for a target relative of 75% and a maximum settlement of 15% of the width of the footing. Table 2 shows the stress-settlement data obtained from experimentation while Fig. 4 summarizes the stress-settlement curve for all test runs.

Table 2 Stress-settlement data

Settlement (mm)	Stress (Pa) at Depth (cm) of Geotextile from Base of Footing					
	None	2.5	5	7.5	10	12.5
0	1	1	1	1	1	1
1	6	6	4	4	3	3
2	8	9	7	6	6	6
3	11	11	9	8	8	8
4	14	14	13	11	9	11
5	16	16	15	13	13	13
6	18	18	15	16	14	16
7	23	23	21	19	18	18
8	24	28	26	23	21	19
9	28	33	29	26	23	21
10	29	35	32	28	24	24
11	33	38	35	31	28	26
12	36	41	39	33	30	29
13	36	43	42	35	33	31
14	36	46	45	38	34	33
15	36	49	47	42	36	34

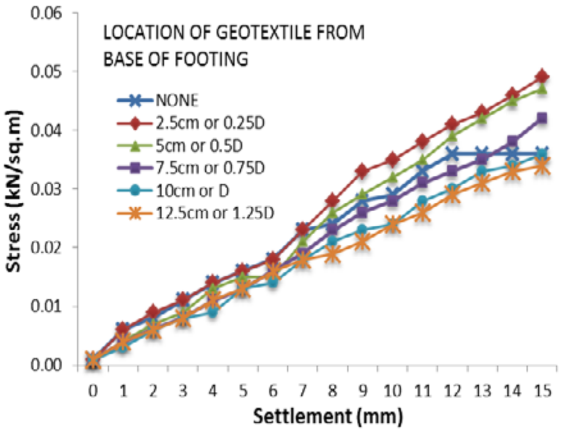

Fig. 4 Data plot of the stress-settlement curve for all samples.

4.1 Ground Deformation

4.1.1 Without geotextile

The sample with no geotextile has the least maximum load bearing capacity with a value equal to 36 Pa as shown in Table 2, which is equal to a force of 3.6 kN. The value of the maximum concentric load was retained from 12 mm to 15 mm settlement. Moreover, deformation of the soil sample is not present 50 cm outward from the center of the footing. Slicing of the ground at 30 cm and 15 cm from the center of the footing shows no significant change at 12.5 cm depth. However, at the edge of the support and the column, deformation is now visible beneath the footing and adjacent the column. All layers of Ottawa sand except for the 12.5 cm depth are seen to move downward as it approaches the footing as shown in Fig. 5. Therefore, it conforms to the theory that there will be no settlement beyond the boundary condition [7], which is limited to the width of the footing (B) that is equal to 10 cm. It was found that settlement occurred at roughly 3B or 30 cm horizontally from the center of the footing. The graph for the sample with no geotextile holds true for both types of failure which are the local shear or punching shear failure. Since the deformation is found directly below the footing and there is minimal bulging in the ground surface, the type of failure for the sample with no geotextile is a local shear failure.

4.1.2 With geotextile at depth 2.5 cm beneath the footing

Upon the release of hydraulic jack during the experiment, it was found that the footing followed the rise of the jack to a certain height before it permanently becomes motionless allowing for the assumption that the presence of a geotextile causes the soil to become flexible. The slicing at the edge of the column evidently shows the variability of the second layer with the upward and downward settlement can be roughly measured to be 0.5 cm. The horizontal distance of the deformation reached the length of 2.5B, which is equivalent to 25 cm.

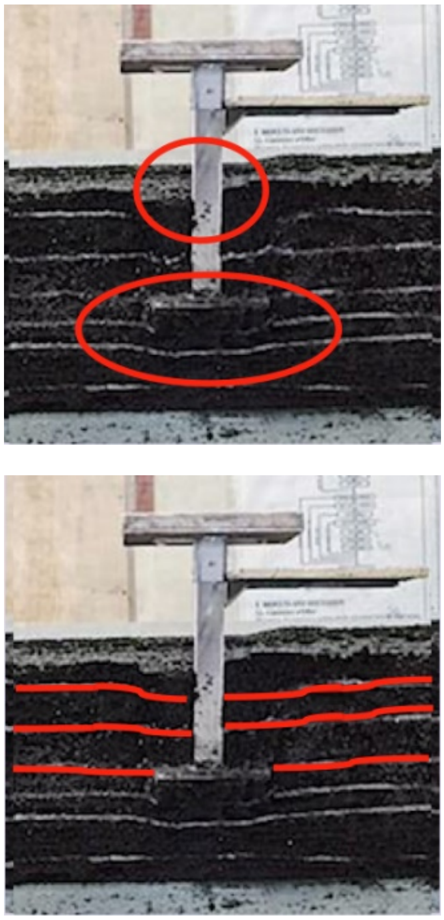

Fig. 5 Ground deformation at the edge of the column of the sample without geotextile

In comparison to the visualization found for the sample with no geotextile, the settlement was still only found when the slicing was done at the edge of the footing and at the edge of the column as shown in Figure 6. Slicing at 30 cm and 15 cm from the center of the footing shows no change in the layers of Ottawa Sand. The effect of the loading did not reach the 12.5 cm depth below the footing as well. Throughout this trial, there is no significant change in the behavior of Ottawa sand below the geotextile which further proves that geotextile alleviates the presence of settlement. Moreover, geotextile at depth 2.5 cm shows the greatest load values among all the depths tested. For this test run, it was found that the settlement exhibits a punching shear failure because there is no gradual movement in the Ottawa sand layers adjacent to the column and no bulging effect on the surface.

Fig. 6 Ground deformation at the edge of the column of the sample with geotextile at a depth of 2.5 cm

4.1.3 With geotextile at depth 10 cm beneath the footing

The behavior of the soil at 10 cm depth is different compared to the sample with no geotextile. There is still no alteration in the behavior of Ottawa layers in slicing at 30 cm and 15 cm distance from the center of the footing. No change was also found at the 12.5 cm depth beneath the footing. Slicing at the edge of the footing and at the edge of the column, however, shows a different behavior from the sample with geotextile at depth 2.5 cm; the 10 cm geotextile depth displays a gradual downward behavior. This then would set apart the two samples, further supporting that the 2.5 cm depth geotextile experiences punching shear failure, while the 10 cm depth geotextile experiences local shear failure. The failure surface zone of the 10 cm depth geotextile is present at the radial and Rankine surface zones similar to the sample with no geotextile. Additionally, there was a slight bulging on the surface of the sample adjacent to the column as shown in Fig. 7. Observing the values at Table 2, the values were relatively close leading to the conclusion that geotextile at a depth of 10 cm no longer bears effect of having a geotextile upon loading compared to other geotextile values in between 2.5 cm to 10 cm. At this sample, the maximum load applied was also found to be 3.6 kN, identical to the maximum load of the sample with no geotextile. Supporting the statement that at a depth equal to B, which is 10 cm in this study, the presence of geotextile has little or has no effect on the settlement reduction.

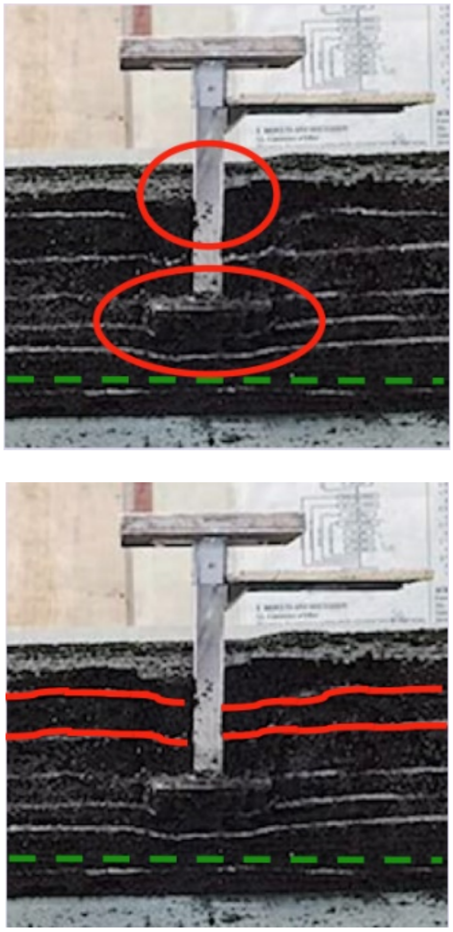

Fig. 7 Ground deformation at the edge of the column of the sample with geotextile at a depth of 10 cm

Another observation shows that when the geotextile is relatively close to the footing, the mode of failure is punching shear failure whereas the distant depth of geotextile reveals the local shear type of failure. Hence, the distance of the geotextile beneath the footing reveals significance not only to the values of the load but also to the behavior of the settlement and the mode of failure.

4.1.4 With geotextile at depth 12.5 cm beyond boundary condition

The magnitude of the load applied in this trial was lower than that of without the presence of the woven geotextile as shown in Table 2. Therefore, placing the geotextile beyond the boundary condition will not produce a reduction in settlement of granular soil. A factor to consider in such conditions is the distance of the woven geotextile to the bottom of the tank at 1.0 cm. This may prevent the geotextile from performing its use because of the little amount of sand under it or the little gap of the geotextile from a rigid body.

4.2 Settlement Data

The data presented in Table 3 shows the value of settlement achieved at a load of 3.6 kN. The settlement is 15mm for this applied load in the sample without geotextile. For samples with geotextile at a varying depth of embedment, the settlements were found to vary for every test trial.

Table 3 Settlement reduction of all trials

Depth of Geotextile (cm)	Settlement (mm) at P = 3.6 kN		Settlement Reduction (%)
	Without Geotextile	With Geotextile	
2.5	15	10.33	31
5		11.25	25
7.5		13.33	11
10		15	N/A
12.5		16.33	N/A

The least settlement among all trials is 10.33 mm at 3.6 kN load and is found to be at a depth of 0.25B equivalent to 2.5 cm from the base of the footing. At this depth, the geotextile was able to reduce soil settlement by 31% compared to that of without geotextile. On the other hand, the maximum settlement reached within the boundary condition is 13.33 mm, where the soil settlement is reduced by 11%. However, at a depth equal to 10 cm and 12.5cm, the geotextile is no longer effective in reducing the settlement of footing. It can be deduced from test results that the geotextile is effective in reducing the settlement when placed within the depth below the base of footing equal to the width of the footing. Figure 8 shows the relationship between the settlement and placement of geotextile with respect to the base of the footing. Soil settlement is seen to have a linear relationship with the depth of geotextile from the base of footing. When the geotextile is placed further from the base of the footing, the settlement is also seen to increase. Thus, the most suitable location of geotextile to reinforce the soil is at the depth equal to one-fourth the width of the footing (0.25B) because this is where the soil can withstand greater loads and consequently results to a greater settlement reduction.

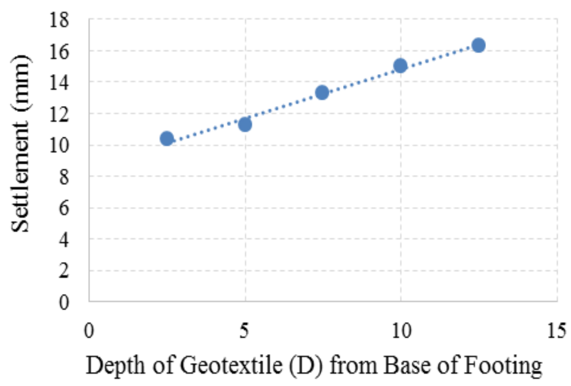

Fig. 8 Settlement vs. depth of geotextile

4. CONCLUSIONS

In this study, the effect of woven geotextile as reinforcement for the settlement reduction of spread footing founded on granular soil under vertical concentric loading was investigated. Through this study, the following results were obtained:

The granular soil was simulated by using an alternating layer of Ottawa sand and black sand with a relative density of 75%. The target relative density was achieved using air pluviation technique with a fall height of 12 cm for Ottawa sand and 26 cm for black sand.

Test trials were done on spread footing without woven geotextile and with woven geotextile placed at varying depths from the base footing. Test results showed that settlement has a linear relationship with the depth of embedment of geotextile. Geotextile is found to be most effective in reducing the settlement when placed closest to the base of the footing having a depth of embedment that is equal to the quarter of the width of the footing (0.25B). This location displayed the highest magnitude in terms of settlement reduction and consequently having the greatest load-bearing capacity. At this depth, the geotextile was able to reduce soil settlement up to 31% as compared to that footing without geotextile. On the other hand, when geotextile is placed at a depth beyond the width of the footing, geotextile is longer effective in reducing the settlement.

The failure mode was found to vary depending on the presence of the geotextile. Footing without geotextile exhibited a local shear failure. When geotextile was used as reinforcement beneath the footing, the mode of failure shifted to punching shear. This holds true for footing with geotextile placed at a depth equal to the width of the footing. But as the depth of embedment of the geotextile increases to the value beyond the footing width, the mode of failure leans toward a local shear failure similar to footing without geotextile.

The study was able to prove that woven geotextile may be used as a soil reinforcement material of spread footing on granular soil for settlement reduction. It is recommended for future study that experiment will be done on a test set-up that considers scaling laws like the use of centrifuge technology.

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