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Experimental Study on soil stabilized with Geotextile under a Square Footing

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***Abstract*— By utilising laboratory model footing tests, the performance of foundations on clay soil reinforced with geotextile was examined. The steel plate used to make the square model footing had dimensions of 250 mm by 250 mm. The length of the reinforcement layers, the type of geotextile, and the top layer spacing were among the parameters examined in this study. According to the test findings, adding reinforcement could greatly increase the soil's bearing capacity and lessen footing settlement. The increase in BCR values varied depending on the type of geotextile, its position and how it dealt with the soil. BCR increases as u/B increases until it reaches a certain point where it decreases. The maximum improvement is achieved at u/B=0.67 for both types, this improvement varying depending on the length of the geotextile. The values of L/B that achieve a higher BCR is 8 for woven and nonwoven. The save length ratio that produce positive effect in all position is L/B=6.67. how-ever, in practice, nonwoven can achieve excellent performance with less reinforcement than woven.**

***Index Terms*—square footing, woven geotextile, nonwoven geotextile, bearing capacity, parametric study.**

I. Introduction

Soil reinforcement technology has been known for more than a thousand years, where Various forms of reinforcement have been attempted, including bamboo and steel tapes and this concept was used in ancient civilizations, such as China's Great Wall's construction.

This concept began to be used recently in the sixties in France by Henri Vidal, where he used metal reinforcing tapes in the soil, while the technology of soil reinforcement with geosynthetic began in the eighties and research is still going on to study the best design in terms of performance and cost.

Geosynthetics-reinforced foundation soil is used to sustain a range of structures, such as footings, pavements, embankments, and retaining walls, etc. Among these applications, soil reinforcement under foundations has recently received the most attention. The construction of foundations on geosynthetic reinforced soils provide an economical alternative to traditional deep foundations and other methods that may be expensive or not possible when building on weak soils. Using this approach, one or more geosynthetic layers are placed beneath the foundations within weak soil or granular fill to produce a composite material with better qualities. By redistributing the applied loads from the foundation over a greater area of the subsoil, this reinforced soil increases the soil's bearing capacity and decreases settlements, among other indirect advantages.

This solution performs better than conventional construction methods by eliminating the need for a costly thick granular layer. In addition to being cost-effective, the ease of implementation makes this solution appealing to designers.

Since Binquet and Lee's groundbreaking work that investigated the possibility of increasing the ultimate bearing capacity by using aluminum foil reinforcement [1], numerous model tests have been carried out with the goal of improving soil behavior with reinforcement materials. Some of these studies focus on reinforcement that is comparatively inextensible, like metallic strips [1]; [2];[3] and a large number of studies employ geosynthetics with soil beneath shallow foundations [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12]; [13]; [14]; [15]; [16]. In many ways, geosynthetic-reinforced foundation soils and metallic-strip-reinforced foundation soils behave similarly.

Chakraborty and Kimar, (2014) conducted an experimental study to specify the optimum diameter and critical position of reinforcement layer that yield maximum bearing capacity, The bearing capacity may also be impacted by other factors [17].

Useche-Infante, et al., (2022) investigated whether the following parameters could improve the bearing capacity of a circular foundation on geogrid-reinforced sand: the diameter of the geogrid D, the number of reinforcement layers N, the depth of the foundation Df, the relative density of the sand Dr, the type of geogrid, the impact of the wraparound end of the reinforced layer, and the depth of the first geogrid layer, u. The results were contrasted with analytical and multiple regression models [18].

Kazi, et al., (2015) reported that, using one single layer of geotextile to reinforced sand with wraparound end

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improved The subgrade response modulus and carrying capability more than using reinforcement layer without wraparound end, with increase depth of embedded footing up to depth equal to B [19].

In other study, Kazi, et al., (2016) investigated the optimum embedded depth of strip footing and the number of reinforcement layer that achieved maximum bearing capacity and compared these results with numerical results based on finite element analysis[20].

Shirazi, et al., (2020) was reviewed previous studies to show the benefits on the soil-bearing ability of bio-based geotextile of weak soil foundation, he found that, the most important parameters that improving the carrying capacity are :the length of the layer, the number of reinforcing layers, the vertical distance between layers, and the top layer spacing. The optimum number of layers was recommending to be 3 to 4, and the greatest increase in bearing capacity achieved with length layer ratio up to 3 [21].

Das, et al., (1994) compare the ability of increase the strip foundation's bearing capability on clay and sand reinforced with geogrid, they conduct a model test with variable parameters, the depth and width of reinforcing layers (h,L) and the depth at which the geogrid's initial layer (u) is placed in sand and saturated clay in succession, each of which has an adjustable parameter and others that are fixed. This allows one to identify and compare the ideal parameters that yield the highest possible increasing. They discover that the ultimate load settlement of a foundation on reinforced and unreinforced clay is roughly the same, but in sand, encouragement causes the ultimate load to rise along with the foundation's settlement (the sand-geogrid system's bearing capacity improvement was greater than that of a clay-geogrid system). The geogrid's depth for the maximum ultimate bearing capacity was approximately 2B in sand and 1.75B in clay, whereas the initial layer of geogrid was at a depth of 0.3B to 0.4B with an ideal width of 8B in sand and 5B in clay [22].

A. Pronblem statement

Due to the increased demand for tall and large buildings due to the current population growth, soil improvement is required in the same magnitude as structural materials such as steel and reinforced concrete. Using soil with low bearing capacity (a factor of safety on the failure criterion) results in significant settlement, and it is critical to be aware of the order of the settlements, as the choice of structure that can resist the deformation caused by foundation motion is influenced by these settlements.

Because construction elements such as continuous beams and rigid frames are susceptible to settlement, it is frequently preferable to limit settlement. As a result, using geosynthetic materials to reinforce soil will increase its bearing capacity for economic reasons. Many studies have shown that including layers of high-tensile strength reinforcement in soil for support the foundation level of heavy structures on weak soil can improve the final bearing capacity and the features of settlement, preventing the appearance of cracking in these elements. This study will contribute to the enrichment of scientific research by estimating the loading bearing capacity of soil supported with geotextiles, identifying the factors influencing the design, and explaining the various features provided by this type of reinforcement. It will also highlight the most important design considerations in order to achieve a safe and economical model. Because this type of reinforcement has never been used on Libyan soil, this study provides design guidelines for when this type of textile is used in similar conditions.

B. Scope

The primary objective of this study is to ascertain whether there is a way to improve the behaviour of square footings on clay soil. The experimental study will investigate different parameters that increase soil bearing capacity as well as its ability to withstand higher loads on weak soil (silty clay soil) using two different types of geotextiles. The model tests take into account the top layer depth (u) and layer length (L).

C. Objectives

The following are the study's main objectives:

- Square footings on unreinforced clay soil and square footings on reinforced soil should be compared for behaviour.
- To maximise the bearing capacity of reinforced soil by adjusting various parameters.
- To examine whether a geotextile-reinforced foundation can sustain loads with minimal settlement.

D. Methodology

Examining the various factors that increase square footing's bearing capacity on soft soil is the goal of this study. All laboratory experiments were carried out at Omar Almukhtar University's College of Civil Engineering's Soil Mechanics and Foundations Laboratory. Fig. 1 displays the flow chart for the current investigation.

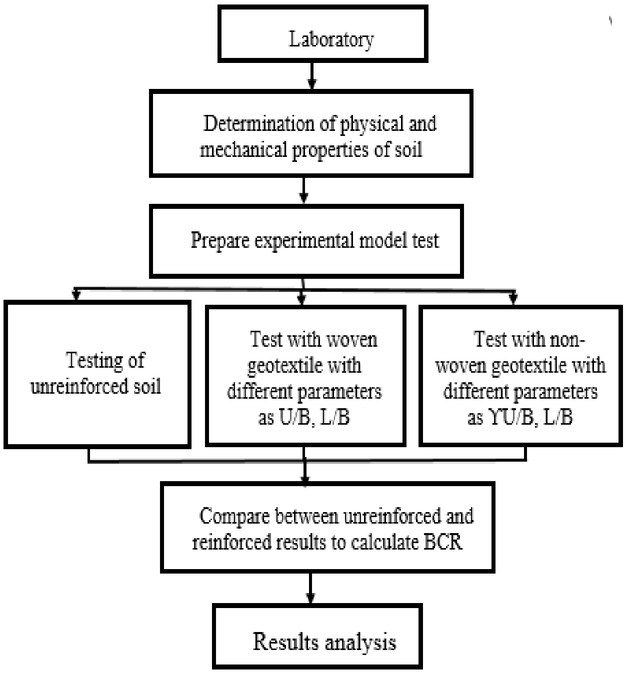

FIGURE 1. FLOW CHART OF METHODOLOGY OF STUDY.

II. MATERIAL PROPERTIES

A. soil

The soil utilised in this investigation was gathered from Shahat-libya, Fig. 2, Table 1 to depth 0.7m, the soil sample was dried under room temperature for month (air dried 25°C ±5), after that, the important physical and mechanical properties that describe and classified the soil were conducted according to American Society of Testing Materials (ASTM) specification. After drying, the soil was aggregated to larger particles, so it had to be washed

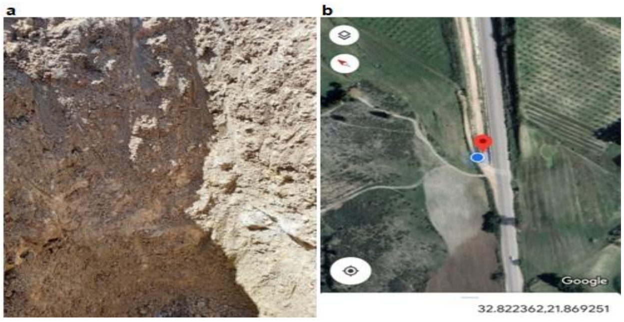

FIGURE 2. SOIL SAMPLE USED FOR LABORATORY TESTING, A): PHYSICAL APPEARANCE, B): SOIL LOCATION FROM GOOGLE EARTH.

TABLE 1 :DETAILS OF SOIL SAMPLE USED FOR TESTING

Sample marking		**Soil sample**
Location		Shahat- Libya
Coordinates	Latitude	32.822362
	Longitude	21.869251
Water content w (%)		15.17
Sample condition		Disturbed
Depth of soil collected		0.7 m
Field density		1.792 g/cm^3

in sieves no.4 and 200 to calculate the retaining percentage of soil. The R4 and R200 were found to be 8.94% and 32.114%, respectively. The ASTM D-2487 uniform classification of fine grained inorganic soil was used to classify soil, with soft soil classified as CL (group symbol)-Sandy lean clay (group name). The chosen soil was a soft dark green clay have a 32.947 % liquid limit and 19.036% plastic limit. The specific gravity was found to be 2.553. the ideal water content and highest possible dry density based on a typical Procter test were 14.831% and 1.825 g/cm^3 respectively. Other properties are given at Table 3.

B. Geotextile

In this study two types of geotextiles will use: woven and nonwoven textile as shown in Fig. 3. A geotextile has a Fabric weight of 250 g/m^2 for woven and 400 g/m^2 for nonwoven and nonwoven geotextile was used with thickness 3.8 mm under 2KN/m^2 and its grab elongation >100%. An axial stiffness, EA, was 2000 KN/m for woven and 2135.2 KN/m for nonwoven geotextile. The physical and mechanical properties of the reinforcement were taken from the producer's data sheet., which are shown in Table 3.

TABLE 2: MOST IMPORTANT MECHANICAL AND PHYSICAL PROPERTIES OF USED SOIL.

Soil properties			**25±5°C**	**ASTM test designation**
Consistency limits	LL (%)		32.947	D4318-17
	PL (%)		19.036	
	PI (%)		13.911	
Specific Gravity Gs			2.553	D854-98
Compaction	Max. dry density ϒd (g/cm3)		1.825	D698-91
	O.W.C (%)		14.831	
Hydrometer analysis	Silt (%)		77.3	D422-63
	Clay (%)		29.5	
Unconfined compression test, qu (kg/cm3)	Dry case		17.726	D-2166
	Wet case		2.679	
CBR (%)	Soaked soil	2.5mm	8.694	D-1883
		5mm	7.728	
	Unsoaked soil	2.5mm	14.877	
		5mm	13.782	
Direct shear test	Cohesion (KN/m3)		53.66	D3080-03
	Angle of friction (°)		48	

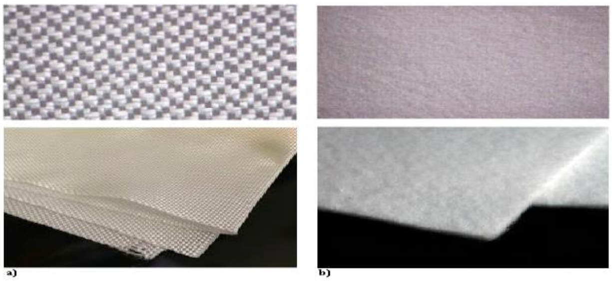

FIGURE 3. GEOTEXTILE USED IN THIS STUDY, A) WOVEN-GEOTEXTILE, B) NONWOVEN-GEOTEXTILE.

TABLE 3. ENGINEERING PROPERTIES OF GEOTEXTILES.

	Nonwoven textile		**Woven textile**
Fabric weight (g/m2)	400		250
Thickness (mm)	3.8		-
Tensile strength (N)	Grab tensile strength (M.D) (N)	1000	1068
	Grab tensile strength (C.D) (N)	1750	
Permeability (cm/s)	0.25		0.04
Transmissivity (L/M/H)	220		-

C. Footing:

The model footing used for the test was a square footing composed of 25*25 cm steel plates with 25 mm thickness, the footing has axial stiffness and bending stiffness of 125000 KN/m and 65.10 KNm^2/m respectively. On a center of footing surface, a hole was created and a rod of diameter similar to the diameter of the bearing rod was installed for applying load as shown in Fig.4

FIGURE 4. MODEL OF THE FOOTING USED IN THIS STUDY.

III. TESTING PROCEDURE

A. Test Setup

The laboratory apparatus consisted primarily of a tank, a rectangular steel footing, and a loading device. Chummar [23] states that the soil failure region is approximately 1.1B deep from the foundation bottom and reaches about 2B on each side from the footing edge, Mandal and Sah [24]، The steel tank's length and depth exceed the simulated footing's width by more than four times. So, to ensure the failure surface develop freely and to minimum the effects of ends, the box was made of steel tank with 1.6×1×m and 0.5m in depth, one of the test tank walls was made of Polycarbonate glass 5mm in thickness, directly anchored by two steel columns and it had markings spaced 10 mm apart to make soil preparation easier. The internal sides of the box were polished to lessen friction with the ends of the foundation, and the tank walls were reinforced by steel supports on the outside to prevent lateral deformation. The glass side allowed for visual inspection of the sample during preparation and observation of soil particle deformation while testing, and In order to sustain plane strain conditions, the tank box was made to be sufficiently tough.

A dial-type gauge with a 200KN ability was used to gauge the applied load, which was applied in increments until the average rate of settlement s/B reached 16%. The load was supplied to the footing using a hydraulic jack that was bonded to a reaction frame. To measure the settlement, two dial gauges were positioned on the footing side. Fig. 5 depicts the model footing setup.

B. Prepartion of Test

A series of laboratory model test were conducted according to Table. 4; the soil was passed on a 9.5mm sieve for soil homogeneity. Then the water was added according to the program of test and mixed by hand.

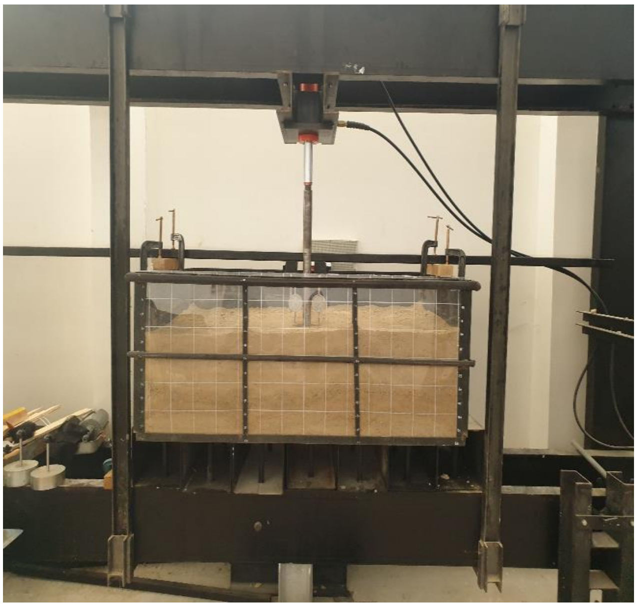

FIGURE 5. MODEL FOOTING LOAD TEST ARRANGEMENT IN THE LABORATORY.

Four layers of soil, each about 100 to 150 mm thick, were placed inside the box. The amount of soil needed for each layer was initially calculated, and then the soil was levelled and compacted using a 15 mm steel plate weighing 8 kg under several blows that produced the desired density (varying from 25 to 50 times depending on the thickness of the layer and the position of a geotextile layer). Each layer undergoes this process until the soil reaches the required depth of 500 mm, after which it is covered for a minimum of 24 hours to ensure even moisture distribution.

After the final layer was completed, the surface was smoothed and the foundation was carefully centered on the loading jack to prevent eccentric loading. A hydraulic jack positioned upon a reaction frame had weighted the footing. A load gauge was used to measure and gradually introduce the weight transmitted to the footing.

In each experiment, after preparing the soil with the desired density, it was checked using small metal cylinders in various places in the box, the dry density was 1.23±0.05 g/cm^3 that achieve 68±3 % from the highest dry density of soil with water content of the soil were calculated as 8.24±1%. The proportion of soil depth to footing width varied from 2-2.2.

In table 4, the experimental cases Wr3-25, Wr6-25, Wr9-25, Wr12-25, Nr3-25, Nr6-25, Nr9-25, Nr12-25, cannot tested experimentally because the length of geotextile exceeds the width of test box, so the other experimental model was repeated utilising Plaxis 2D's finite element analysis to simulate the experimental models with longer width of test box to include the effect of L/B=8. hardening soil HS model can be used to simulate the stress-displacement behaviour in soil modelling. The results of numerical analysis show a greet agreement with the experimental results, so we can rely on the numerical results for cases of L/B=8.

TABLE 4. EXPERIMENTAL TEST PROGRAM FOR REINFORCED SOIL.

No. of test	Reinforcement type	U/B	L/B	No. of test	Reinforcement type	U/B	L/B
Ur1	Without	-	-	-	-	-	-
Wr1-25	Woven geotextile	0.25	3	Nr1-25	Non-woven geotextile	0.25	3
Wr2-25	Woven geotextile	0.25	5.8	Nr2-25	Non-woven geotextile	0.25	5.8
Wr3-25	Woven geotextile	0.25	8	Nr3-25	Non-woven geotextile	0.25	8
Wr4-25	Woven geotextile	0.3	3	Nr4-25	Non-woven geotextile	0.3	3
Wr5-25	Woven geotextile	0.3	5.8	Nr5-25	Non-woven geotextile	0.3	5.8
Wr6-25	Woven geotextile	0.3	8	Nr6-25	Non-woven geotextile	0.3	8
Wr7-25	Woven geotextile	0.67	3	Nr7-25	Non-woven geotextile	0.67	3
Wr8-25	Woven geotextile	0.67	5.8	Nr8-25	Non-woven geotextile	0.67	5.8
Wr9-25	Woven geotextile	0.67	8	Nr9-25	Non-woven geotextile	0.67	8
Wr10-25	Woven geotextile	1	3	Nr10-25	Non-woven geotextile	1	3
Wr11-25	Woven geotextile	1	5.8	Nr11-25	Non-woven geotextile	1	5.8
Wr12-25	Woven geotextile	1	8	Nr12-25	Non-woven geotextile	1	8

IV. RESULT AND DISSCUSSION

In this study, we use two parameters to evaluated the improving of soil by two type of geotextile, woven and non-woven geotextile, the first metric is the bearing capability ratio, or BCR, which is the ratio of the bearing capacities of reinforced and unreinforced soil at the same settlement, and the second parameter is settlement reduced factor SRF that is equal to the rate of settlement of reinforced soil to unreinforced soil at a specific stress value. The test results have been expressed and compared with the help of these non-dimensional factors., they determined at specific settlement/width ratio to canceled the effect of width footing on results.

Table 5 provides a summary of the outcomes of these laboratory model experiments. The BCRs acquired at settlement ratios s/B = 5%, 10%, and 16% are shown in this table. Fig. 6 displays the model footing test results graphically.

We can see from these curves that, for both reinforced and unreinforced soil, the stress rises with increasing settlement. Cerato [25] describes this pressure-settlement behaviour pattern as resembling a typical punching-shear failure. Mandal and Sah [24] found the same thing for a square footing on geogrid-clay soil. The load capacity is calculated at different settlement ratios and utilised to find the BCRs because the point at which they fail is not clearly defined. In the following experimental and numerical sections, we will discuss about the impact of the reinforcement layout for footing with B=250mm.

A. Effect of Top Spacing and length of reinforcement

The optimal location of the reinforcement layer was investigated using two types of geotextile, concurrently with testing of the optimum length of geotextile, to demonstrate how it varies with the other parameters of study.

For the three levels of settlement, the increase in bearing capacity caused by the use of geotextile at different u/B ratios increases with footing settlement.

For woven geotextile, BCRs increase as u/B increases until a certain value is reached, at which point they decrease. Fig.7 shows that as the value of u/B of the woven geotextile that achieves the highest BCR for all length is 0.67 after this value the adding of geotextile have less effect on bearing capacity improvement. the maximum improvement achieved with u/B is 0.65 with L/B=8.

It can be explained that when the depth of the intial layer is small, the initial sliding of the woven geotextile in the soil-geotextile layer occurs at a low bearing pressure. The insufficient friction force between the soil and the geotextile is the cause of this. As a result, for shallow depths, geotextiles have a negligible impact on square footing's bearing capacity at short lengths and increase with length., The need for longer length decreases with deeper depth u/B=1 because the bearing capacity decreases downward. for L/B=8, the maximum improvement is achieved with u/B=0.65 and then decreases; this state has the highest BCR value of up to 2.5. The results of this section can be used to determine the mechanics of the woven geotextile. Because we used one type of reinforcement in this study and its working mechanics differ based on the kind of surrounding soil and the applied loads, this portion of the test was conducted with woven geotextile with a fairly smooth surface. However, because it is woven, it comes into contact with the soil, causing the lateral restrain effect. This effect restricts the movement of soil particles along the reinforcement under the foundation load, activating the friction force at the reinforcement-soil interface.

TABLE 5. SUMMARY OF MODEL TESTS RESULTS.

Test No.	Geotextile Type	*u* mm	*L* mm	s/B=5%		s/B=10%		s/B=16%	
				q KN/m²	BCR	q KN/m²	BCR	q KN/m²	BCR
Ur1-25	-	-	-	310.41	-	478.79	-	626.85	-
Wr1-25	Woven	62.5	750	220.88	0.71	383.79	0.80	535.52	0.85
Wr2-25	Woven	62.5	1666	418.48	1.35	668.68	1.40	907.43	1.45
Wr3-25	Woven	62.5	2000	279.39	0.90	430.92	0.90	553.29	0.88
Wr4-25	Woven	75	750	274.32	0.88	364.67	0.76	483.63	0.77
Wr5-25	Woven	75	1666	361.3	1.16	556.83	1.16	802.49	1.28
Wr6-25	Woven	75	2000	181.54	0.58	286.16	0.60	388.48	0.62
Wr7-25	Woven	167.5	750	380.67	1.23	610.07	1.27	881.28	1.41
Wr8-25	Woven	167.5	1666	481.7	1.55	781.3	1.63	1091.35	1.74
Wr9-25	Woven	167.5	2000	837.64	2.70	1298.57	2.71	1761.64	2.81
Wr10-25	Woven	250	750	348.46	1.12	571.54	1.19	763.16	1.22
Wr11-25	Woven	250	1666	394.74	1.27	642.7	1.34	910.75	1.45
Wr12-25	Woven	250	2000	337.4	1.09	549.94	1.15	773.92	1.23
Nr1-25	Non-woven	62.5	750	221.46	0.71	395.61	0.83	545.33	0.87
Nr2-25	Non-woven	62.5	1666	412.72	1.33	654.98	1.37	894.15	1.43
Nr3-25	Non-woven	62.5	2000	200.23	0.65	324.79	0.68	434.84	0.69
Nr4-25	Non-woven	75	750	222.7	0.72	315.23	0.66	415.45	0.66
Nr5-25	Non-woven	75	1666	489.8	1.58	756.34	1.58	1057.04	1.69
Nr6-25	Non-woven	75	2000	133.09	0.43	201.14	0.42	247.98	0.40
Nr7-25	Non-woven	167.5	750	404.72	1.30	652.75	1.36	919.11	1.47
Nr8-25	Non-woven	167.5	1666	412.23	1.33	651.2	1.36	918.07	1.46
Nr9-25	Non-woven	167.5	2000	921.8	2.97	1418.79	2.96	1878.18	3.00
Nr10-25	Non-woven	250	750	380.07	1.22	612.87	1.28	854.08	1.36
Nr11-25	Non-woven	250	1666	460.07	1.48	741.8	1.55	1007.68	1.61
Nr12-25	Non-woven	250	2000	263.59	0.85	403.24	0.84	538.51	0.86

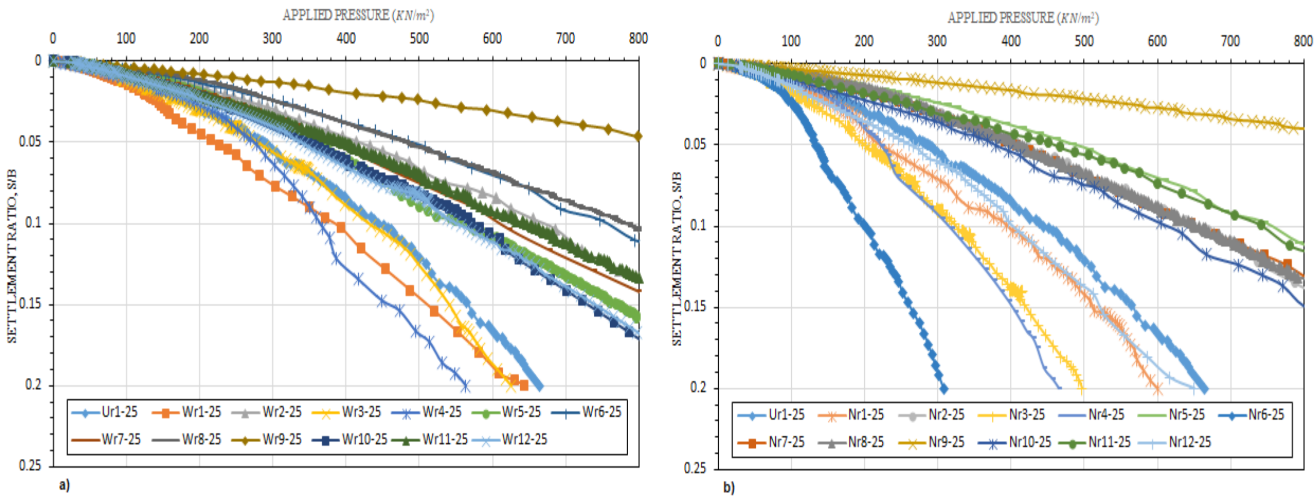

FIGURE 6. PRESSURE–SETTLEMENT CURVES FOR 250mm MODEL FOOTING TESTS, A) WOVEN GEOTEXTILE REINFORCED SOIL, B) NON-WOVEN GEOTEXTILE REINFORCED SOIL.

This effect reduces horizontal movement, enhancing the soil's compressive strength and lateral confining pressure beneath the footing. As a result, the ultimate bearing capacity of the foundation improves. The mesh may play an important role in the soil-reinforcement interaction for woven geotextiles, but pull-out failure may occur with short lengths of woven geotextile, which explains the results of the experiment.

For Nonwoven geotextile, as shown in Fig.8, the similar results were found. The behavioral different may occur in L/B=6.67 of the non-woven geotextile used in the current study. We can see from Fig 8 For L/B=6.67, the maximum improvement of BCR occur at u/B=3 then decreases as u/B increases. With a smaller depth ratio u/B, the maximum BCR occurs at a short length, and a greater length is required as U/B increases. For non-woven geotextile, the maximum improvement is achieved at u/B=0.65 and L/B=8.

For u/B=1, the bearing capacity of soil decreases. This may occur because when the depth of geotextile is

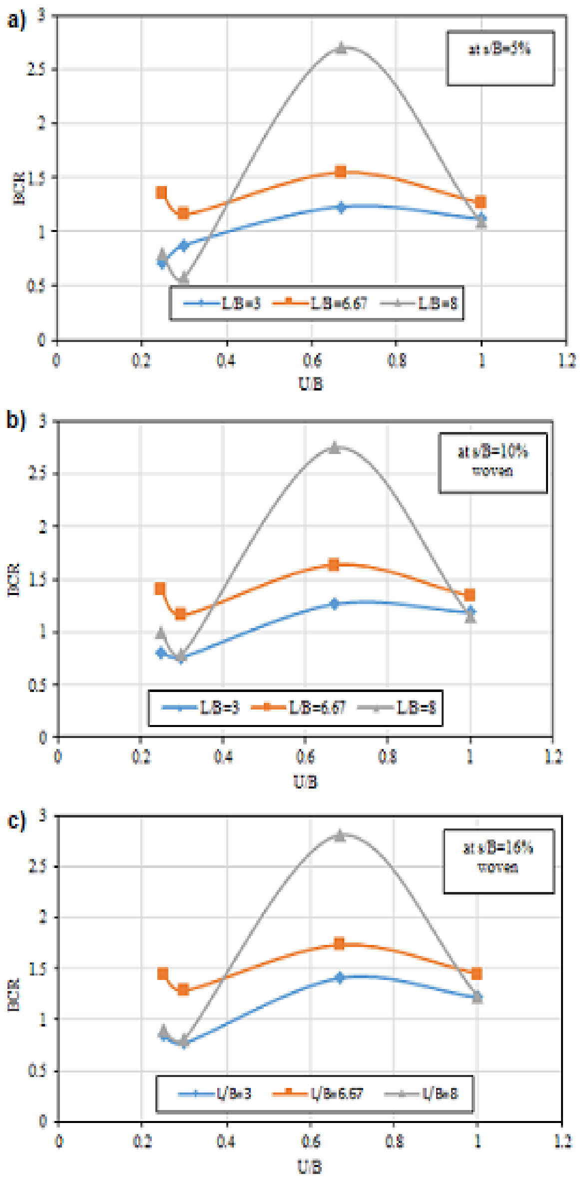

FIGURE 7. BCR VERSUS U/B AT DIFFERENT LENGTH RATIO L/B FOR WOVEN GEOTEXTILE. FOR SETTLEMENT RATIO A) S/B=5%, B) S/B=10%, C) S/B=16%.

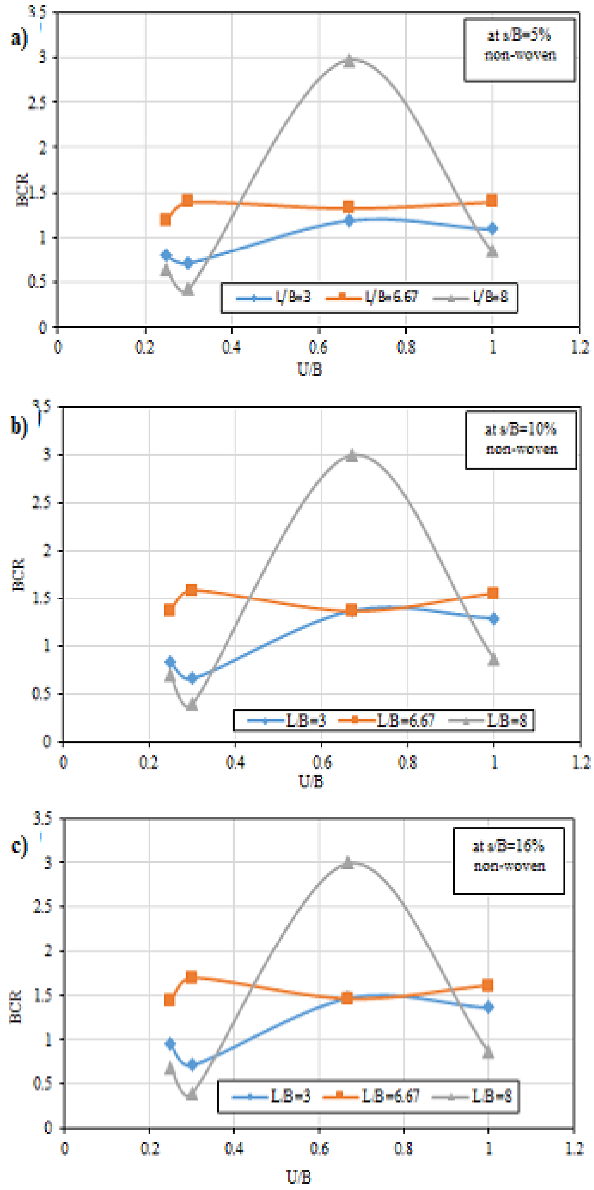

FIGURE 8. BCR VERSUS U/B AT DIFFERENT LENGTH RATIO L/B FOR NON-WOVEN GEOTEXTILE. FOR SETTLEMENT RATIO A) S/B=5%, B) S/B=10%, C) S/B=16%.

too great, failure could happen in-between the geotextile layer and the foundation base, resulting in the tensile force of geotextile not being developed. at u/B=0.3 for both geotextile, we noted decrease in bearing capacity, that's may occur because, in this region, the stress concentration is at its highest, so failure occur according to the type of geotextile.

Nonwoven geotextiles, unlike woven geotextiles, have a high elongation and an almost rough surface; laboratory observation show that they interact heavily with the soil. As a result, samples in which the length of the nonwoven geotextile crossed the stress influence zone had higher bearing capacity improvements. As depth increases, the load spreads out in the soil at a steeper angle, requiring more length to cross this zone. So, when u/B is higher, and because nonwoven has a - high resistance to pull out failure, the tensioned member effect develops, so that as the geotextile moves downward caused by footing settlement in the reinforced zone due to load, which is higher beneath footing and decreases deeper, who by creating an upward force that opposes the applied load, the bent geotextile increases bearing capacity. This explains why the bearing capacity increased up to 3.

This finding similar to Khing et al. [26] who studied the role of geogrid in improving sand soil under strip footing and observed that the optimal depth and length of geogrid to achieve maximum BCR were 0.67 and 6, respectively. Similar findings were reached by other literature-based studies, some of which are displayed in the Table.6 alongside our study's findings.

TABLE 6. SUMMARY OF THE SMALL MODEL TESTS ON PLANAR GEOSYNTHETIC-REINFORCED SOIL SIMILAR TO OUR RESULTS.

Reference	Footing	Reinforcement	Soil	u/B	L/B
Akinmusuru and Akinbolade [26]	Square	Rope fiber	Sand	0. 5	10
Kim and Cho [27]	Strip	Geotextile	Sand	0.5-1	11
Huang and Tatsuoka [3]	Strip	Metal strip	Sand	0.5	6
Khing et al. [28]	Strip	Geogrid	Sand	0.67	6
Sawwaf [33]	Strip	Geogrid	Sand	0.6	5
Shin et al. [34]	Strip	Geogrid	Clay	0.4	5
Omer et al, [8]	Strip	Geogrid	Sand	0.4	8
Our study	Geotextile	Square	Clay	0.67	8

B. different in behivour betweem woven and nonwoven geotextile

Fig.9 and Fig.10 depict the differences in reinforcement behaviour between woven and non-woven geotextile at two stages of settlement s/B= 5% and 16%.

Because of the initial applied loading increment in the situation of s/B=5%, the geotextile's tensile strength is not activated, and in the majority of test cases, the interaction forces are not mobilised. So for low elongation, we can see for both geotextile at L/B=3 with small depth ratio, the BCR was small and increases as U/B increase, as the overlaying load increase that may mobilized the interaction forces. The same thing happened for L/B=8. At this higher width of geotextile with smaller depth ratio, the geotextile separated the soil into two parts and act like a soil bed with small depth and loss its interaction forces, which in turn weakens the soil. For deeper ratio od depth, the upward loade spreaded on geotextile, induceed the interaction forces, so increases the BCR.

In the length ratio L/B=6.67, for small depths, the width is large enough to resist the pull out strength, and small enough to separated the soil body. So the BCR value is more than 1 in all cases.

There are a different in behivour between woven and nonwoven geotextile at this point, when the depth of the first layer is small, the overlying load is highest. the initial sliding of the woven geotextile in the soil-geotextile layer occurs at a low bearing pressure. This is due to the low friction force between the geotextile and the soil since woven geotextile has a fairly smooth surface. The mesh may play an important role in the soil-reinforcement interaction for woven geotextiles, but pull-out failure may occur with short lengths of wo-ven geotextile, which explains the results of the experiment so larger depth with higher length is needed.

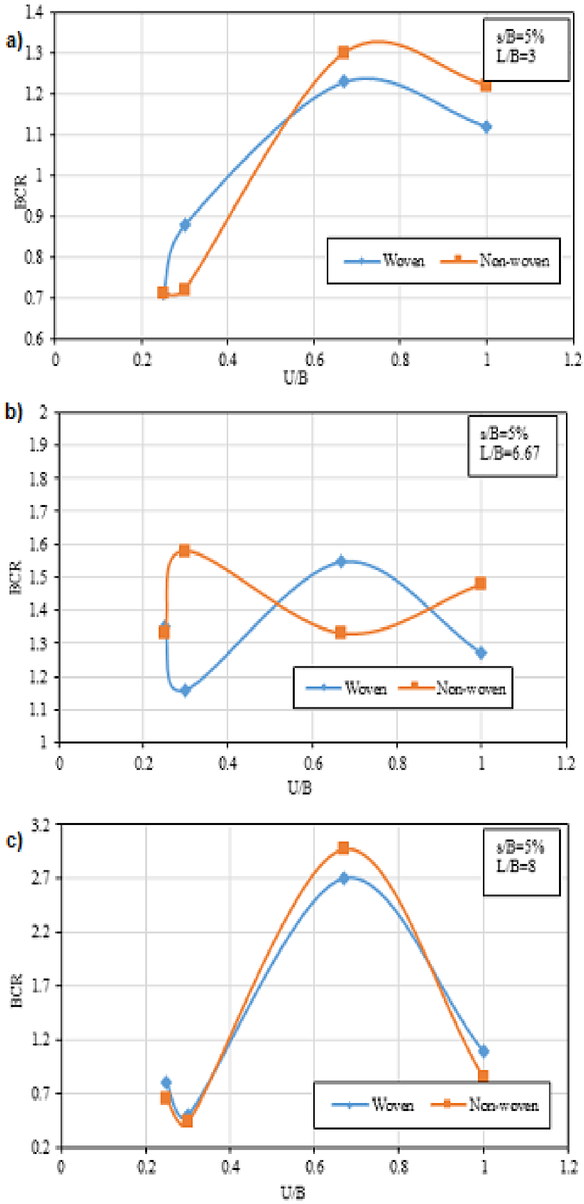

FIGURE 9. DIFFERENT BETWEEN WOVEN AND NONWOVEN AT S/B= 5%. A) L/B=3, B) L/B=6.67, C) L/B= 8.

on contrast of woven, non-woven geotextile has a higher elongation and an almost rough surface; laboratory observation show that they interact heavily with the soil, so it improves the BCR at small depths since it has a high resistant to pull out forces. With its own membrane effect, it gives the overlying a vertical support while lowering the outward shear forces transferred from the soil above. this improving decreases as u/B increases due to increase in overlying loading. That's performance of nonwoven explain tha maximum improvement value achieved by used it.

In long length L/B=8, woven geotextile and non-woven geotextile has almost identical results. as for large L/B ratio, the pull out resistant improve, and with its higher tensile strength the maximum BCR achieves.

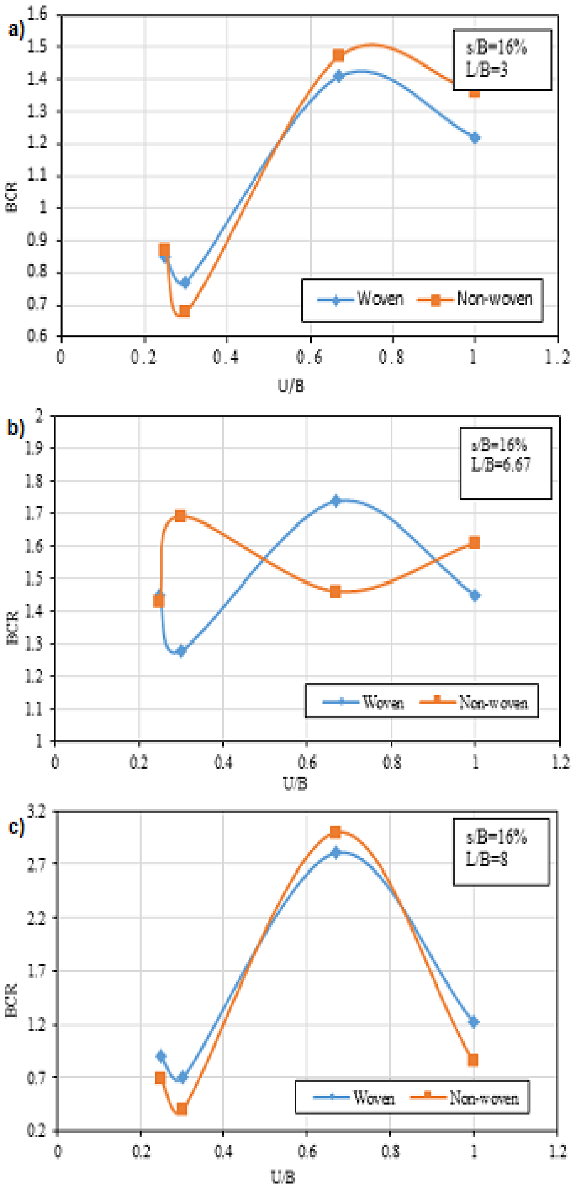

FIGURE 10. DIFFERENT BETWEEN WOVEN AND NONWOVEN AT S/B= 16%. A) L/B=3, B) L/B=6.67, C) L/B= 8.

When s/B= 16%, the bearing ability was higher and the tensile geotextile forces and interaction forces were mobilized, so the different in behaviour decreases.

C. settlement reduction factors

Fig.11 and Table.7 show the settlement reduction factors (SRF) at various geotextile-soil models for a 250mm footing width. The ratio of a footing's settlement on reinforced soil to that on unreinforced soil at a given applied pressure is known as the SRF. The SRF was calculated using the applied pressure of 600 KN/m2. It is clear that the use of geotextiles could significantly reduce settlement. We can see that, geotextiles with smaller depths and longer lengths, and geotextiles with smaller depths and shorter lengths show increasing in settlement ratios (up to 1). This observation deal with the results of this study. Even this results, other cases of tests show the geotextile reduce settlement by more than 70%. This reduction decreases and increases according to the layout of geotextile in soil body. The maximum decreasing in settlement achieve at L/B=8 with u/B=0.67 up to 80%.

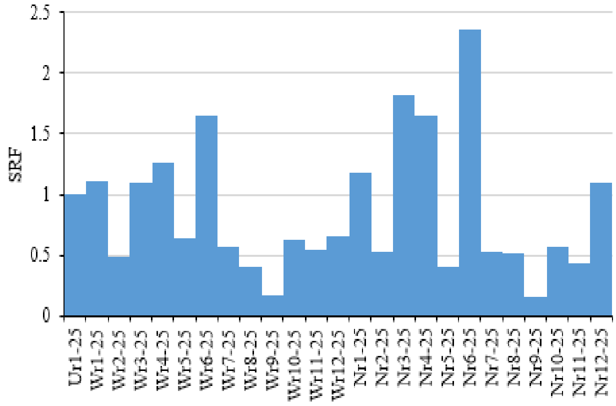

FIGURE 11. SRF VALUES FOR THE GEOTEXTILE-SOIL TEST MODELS.

TABLE 7. EFFECT OF GEOTEXTILE INCLUSION ON SETTLEMENT REDUCTION.

Woven Geotextile	Settlement mm	SRF	Non-woven Geotextile	Settlement mm	SRF
Ur1-25	42.5	1.00	-	-	-
Wr1-25	47	1.11	Nr1-15	50	1.18
Wr2-25	20.75	0.49	Nr2-15	22.5	0.53
Wr3-25	46.75	1.10	Nr3-15	77	1.81
Wr4-25	53.75	1.26	Nr4-15	70.25	1.65
Wr5-25	27.25	0.64	Nr5-15	17.5	0.41
Wr6-15	70.25	1.65	Nr6-15	100	2.35
Wr7-15	24.25	0.57	Nr7-15	22.5	0.53
Wr8-15	17	0.40	Nr8-15	22	0.52
Wr9-15	7.5	0.18	Nr9-15	6.75	0.16
Wr10-15	26.75	0.63	Nr10-15	24.25	0.57
Wr11-15	23.25	0.55	Nr11-15	18.5	0.44
Wr12-15	28	0.66	Nr12-15	46.5	1.09

V. CONCULSION

To determine the bearing capacity behaviour of square footing installed on clay soil reinforced with geotextile, several tests were conducted in the current study, with varying values of the layer's length and depth, and how the behaviour varies with type. It is possible to draw the following conclusion:

1. The application of geotextile at various u/B and L/B ratios enhanced the soil's carrying capability.
2. BCRs increase as u/B increases up to a certain value, after which they decrease. This point was established by the length and position of the geotextile layer in the soil.
3. The optimal u/B value for woven and nonwoven geotextiles was 5.8-6.67 resulting in up to 280% increase in bearing capacity.
4. The most effective L/B values for higher BCR values is 8 for woven and nonwoven geotextile.

5. The effect of length is contingent upon several factors, such as the soil's stress distribution, the sort of reinforcement is used, the depth of the geotextile, and its ability to resist pull-out forces.
6. Because woven geotextile has a lower elongation ratio than nonwoven ones, the resistance to pullout test will be much higher for the latter. That is result in safe length L/B=6.67 the behaviour of nonwoven outperforms on the woven geotextile. In fact, woven materials even had higher BCR values. A viable solution could be to use nonwoven fabric with less reinforcement.

Laboratory observations reveal that nonwoven geotextiles interact significantly with the soil due to their high elongation and nearly rough surface compared to woven geotextiles.

The SRF shown the same observation, the cases of tests with smaller depth ratios (u/B=0.25-0.3) weak the soil instead improved it in the case with very short length L/B=3 and very high length L/B=8. The length ratio L/B=6.67 always give a positive result. The maximum decreasing in settlement achieve at L/B=8 with u/B=0.67 up to 80%.

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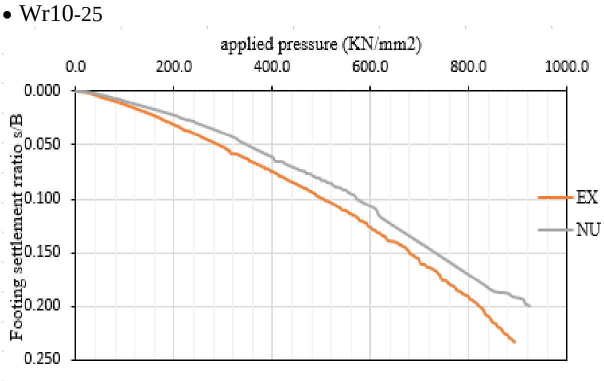
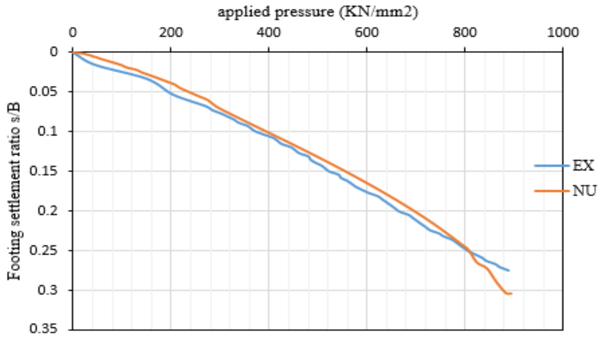
VII. APPENDIX

Some of results of numerical analysis comparing to experimental.

- Wr10-25



- Nr11-25:



- Wr2-25