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BEHAVIOR OF SHELL FOUNDATIONS ON SANDY SOIL REINFORCED WITH A CIRCULAR GEOGRID

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Abstract: The purposes of this study are to investigate and evaluate the benefits of using of geogrids as a circular pipe of two different lengths of (20 cm and40 cm) under the footing base in improvement of bearing capacity and settlement in term of the bearing capacity ratio (BCR) and the settlement reduction factor (SRF). A load-frame assembly was designed for the experimental work. Two types of aluminum rigid foundation were used; flat footing and shell footing of dimensions (20× 20 cm) and different angles of (20˚, 30˚, and 45˚) for shell. Sand rainer device technique was used to fill the tank to obtain a homogenous sandy soil. The result show that using a circular geogrid with a length (H=20cm) leads to increase the BCR by (14-41)% higher than that for unreinforced sand, while increasing the geogrid length to 40 cm leads to increase BCR by (6-19)% .The SRF for a certain footing decreases with decreasing the geogrid length from 40 cm to 20 cm by (11-21) % .This may be related to the punching effect caused by the longer geogrid through the loose sand stratum.

Keywords: *Sand, Geogrid Reinforced, Shell Footing.*

تصرف الأسس القشرية على التربة الرملية المسلحة بالمشبك الدائري

الخلاصة :الغرض من هذه الدراسة هو لتحري وتقييم فوائد إدراج المشبكات طوليا كأنبوب دائري على تحسين قابلية تحمل التربة للإنضغاط والهبوط بدلالة نسبة قابلية التحمل وعامل نقصان الهبوط. تم تصميم هيكل تحميل للعمل المختبري . تم أستخدام نوعين من أسس الالمنيوم الجاسئة ،الأساس المستوي والأساس القشري بابعاد (20سم×20سم) وبمختلف الزوايا (20،30،45) للقشري . تم إستخدام طريقة السقوط الحر للرمل لملىء الخزان للحصول على تربة رملية متجانسة .اظهرت النتائج ان استخدام المشبك الدائري بارتفاع (20 سم) يؤدي الى زيادة قابلية تحمل التربة للإنضغاط بنسبة (14-41)٪ عن الرمل غير المسلح، في حين أن زيادة ارتفاع المشبك الى 40 سم يؤدي الى زيادة قابلية تحمل التربة للإنضغاط بنسبة (6 -19)٪. ينخفض عامل نقصان الهبوط لبعض الأسس بانخفاض ارتفاع المشبك من 40 سم إلى 20 سم بنسبة (11-21)٪ .وهذا قد يكون مرتبطا بتأثير الثقب الناتج عن المشبك الأطول خلال طبقة الرمل ذات الكثافة النسبية القليلة.

1. Introduction

Shells, because of their curved topology, have stiffness and strength larger than comparable and corresponding plane surface structural elements. The advantageous use of reinforcement materials like geogrid to increase the bearing capacity of sand has been

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recognized. Several researchers had understood the role of reinforcement materials in improving the bearing capacity of foundation soils.

Phanikumar et al., [1] offered a series of laboratory plate load tests performed on geogrid reinforced sand beds. Fine, medium and coarse sands were used as test sand beds. Circular geogrids of diameter of 120 mm were used as reinforcement layers. The test sand beds were compacted to a relative density of 50%. A surface circular footing plate of diameter 60 mm was used as the shallow foundation. They found that:

1- The geogrid-reinforced sand beds result in improved load-settlement behavior.
2- Increasing the number of geogrids (N) improves the behavior more, and they found that the number of geogrid of (N =3) caused the best load-settlement behavior.

Latha and Somwanshi [2] the results from laboratory model tests and numerical simulations on square footings resting on sand are presented. Bearing capacity of footings on geosynthetic reinforced sand is evaluated and the effect of various reinforcement parameters like the type and tensile strength of geosynthetic material, amount of reinforcement, layout and configuration of geosynthetic layers below the footing on the bearing capacity improvement of the footings are studied through systematic model studies.

A steel tank of size 900 × 900 × 600 mm is used for conducting model tests. Four types of grids, namely strong biaxial geogrid, weak biaxial geogrid, uniaxial geogrid and a geonet, each with different tensile strength, are used in the tests. Geosynthetic reinforcement is provided in the form of planar layers, varying the depth of reinforced zone below the footing, number of geosynthetic layers within the reinforced zone and the width of geosynthetic layers in different tests. Influence of all these parameters on the bearing capacity improvement of square footing and its settlement is studied by comparing with the test on unreinforced sand. Results show that the effective depth of reinforcement is twice the width of the footing and optimum spacing of geosynthetic layers is half the width of the footing. It is observed that the layout and configuration of reinforcement play a vital role in bearing capacity improvement rather than the tensile strength of the geo synthetic material. Experimental observations are supported by the findings from numerical analyses.

Fakhraldin [3] studied the possible benefits of using the geogrids to improve the bearing capacity and reduce the settlement of shallow foundations. He stately the properties of some geogrids and the straining mechanism occurring in the geogrid layers during loading. Three models of footing were used, strip, circular and square. Twelve types of geogrids were used. The straining mechanism and elongations happening in the ribs of geogrids embedded in sand during bearing capacity tests have been investigated. A finite element program Plaxis-3D foundation has been used to analyze the results of reinforced and unreinforced sandy soil using three types of footings and five types of geogrids. He found that the bearing capacity increases up to about 271, 278 and 336% for strip, circular and square footings respectively, and the settlement decreases about 261, 322 and 380% for strip, circular and square footings respectively.

2. Material Used

2.1 Foundations

Two types of foundations are used in this study; the flat foundation and a pyramidal shell foundation of a width of (B =200 mm) and thickness of (t=10 mm) with different shell angles of 20° , 30°and 45°.

2.2 Geogrid

The goegrid is used as a circular pipe with a diameter of (20 cm) with two different lengths of (20, 40 cm) .Geogrid properties from the manufacturer are shown in Table 1.

Table 1: Properties of geogrid.

Reinforcement	CE121 geogrid
Polymer type	HDPE –high density polyethylene
Grid dimensions aperture (mm)	8×6
Thickness (mm)	2.2
Grid weight (kg/m^2)	0.730
Maximum tensile strength (kN/m)	7.68
Extension at maximum load (%)	20.2
Load at 10% extension (kN/m)	6.8
Extension at 50% max load (%)	3.2
Modulus of elasticity E (GPa)	0.39

2.3 Soil

Al-Ekhaider dry sand was used for testing purposes. The sieve analysis was performed to the grain size distribution of the used sand according to ASTM D6913-04 as shown in Fig.1. The poorly graded sand (SP) is the classification of the sand with a coefficient of uniformity C_u=2.22 and the curvature coefficient C_c=1.08 and the mean particle size D_{50} equals to (0.39mm). A summary of the test results with standard specifications that followed in each test are presented in Table 2.

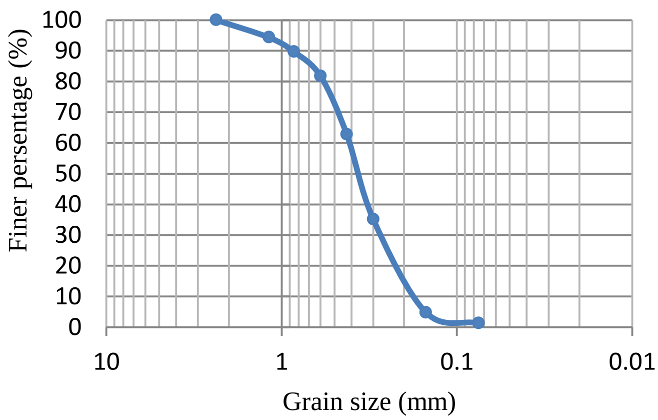


Figure 1: Particles size distribution curve for Al-Ekhaider sand

Table 2: Properties of sand used.

Parameter	Value	Standard
Particle size, D_{10} (mm)	0.18	ASTM D6913
Particle size, D_{30} (mm)	0.28	
Mean particle size, D_{50}(mm)	0.39	
Particle size, D_{60} (mm)	0.42	
Coefficient of Uniformity, C_u	2.33	
Coefficient of curvature C_c	1.04	
Specific gravity, G_s	2.7	ASTM D854-10
Minimum void ratio, e_{min}	1.714	ASTM D4253
Maximum void ratio, e_{max}	1.424	ASTM D4254
Internal friction angle, ϕ (degree)	30	ASTM D3080
Modulus of elasticity E (kPa) At relative density 40%	4952.38	ASTM D2435-04
Soil classification according to unified soil Classification System (USCS)	SP	ASTM D2487

3. Frame of Loading

A lever arm assembly has been manufactured to apply the load on the footing. The loading frame supports the sand box as shown in Fig.2. The loading frame assembly consist of lever arm (beam) with (145 cm) in length and (6mm) in thickness has been connected to the load hanger with a beam ratios as 10:1 where this ratio of doubled the load imposing on the soil .The load cell is connected to a digital load indicator, which measures and shows the applied load.

Figure 2: Loading frame and sand box.

4. Preparation and Testing of Procedure

The dimensions of model tank used in this study was (90cm×90cm) and (100cm) length. Steel plate of a 2 mm thickness was used for made the tank and four steel angles were used to prevent buckling of the surrounding middle steel panels. A special raining device was man-made to offer uniform distribution of sand with the desired density according to (Kolbuszewski) [4]. The details of device (cylindrical reservoir) were, the outlet of the conical shape is at the bottom and connected by a pipe of 35 mm diameter to a perforated plate. The perforated steel plate of 100 mm diameter, with opening of 4.3 mm at the pattern of 7 mm spacing was attached to the end of the pipe to switch the rate of flowing sand. The whole rainer was suspended at the top by a cable through the roller to the mechanical lift which it installed by steel frame as shown in Fig.3 , to permit single hose rainer to move upward, the horizontal of movement of the single hose rainer was attain by hand .

a) Single hose. b) Frame of single hose. c) The mechanical lift.

Figure 3: Details of pouring the sand in the model tank (single hose rainer).

The placing of sand in soil core at the desired relative density (the space under the shell) as stated by Hanna and Abdel-Rahman [5] .The sand filling process of shell models were done by placing a thin steel plate at the bottom of the shell models before placing it on its location, then the steel plate was slowly pulled out horizontally underneath the shell from the side while the shell footing was centered in the model tank. After preparation of the loading test instrument, the static compression tests were done according to ASTM (D1194-94). The load is applied incrementally by 5 kg and 10 kg over the steel disk on the load hanger and each load remain for 15 min until reaching the failure load which was defined as the load causing excessive settlement of soil. Four dial gauges with 0.01 mm sensitivity have been used, two dial gauges measured settlements of the footings on rigid plate that it mounted on two opposite sides of the models and the two other observed the displacement (heave or settlement) of the surrounding soil that placed on aplastic ring plate and also installed with side of tank by magnetic stand of its holders. For each increment load, the settlement recorded for two dial gauges and calculates the average of them and recorded the heave or settlement of soil surrounding by other dial gauges .After the reading was completed, the load-settlement curves were plotted. Fig.4 shows the model and the used geogrid.

Figure 4: Rigid model under test.

5. Effect of Circular Geogrid Reinforcement on the Bearing Capacity and Settlement of Foundation.

Figures (5 to 8) show the effect of using circular geogrid reinforcement of a diameter equal to the footing width (i.e D =20 cm) and with two lengths of H=20 cm and 40 cm. It is obvious that increasing the geogrid length leads to reduce the load carrying capacity and increase the settlement of foundation. A longer geogrid column under a footing may cause a punching failure in the loose sand stratum and a less improvement is gained compared to that of a geogrid of length of H =20 cm.

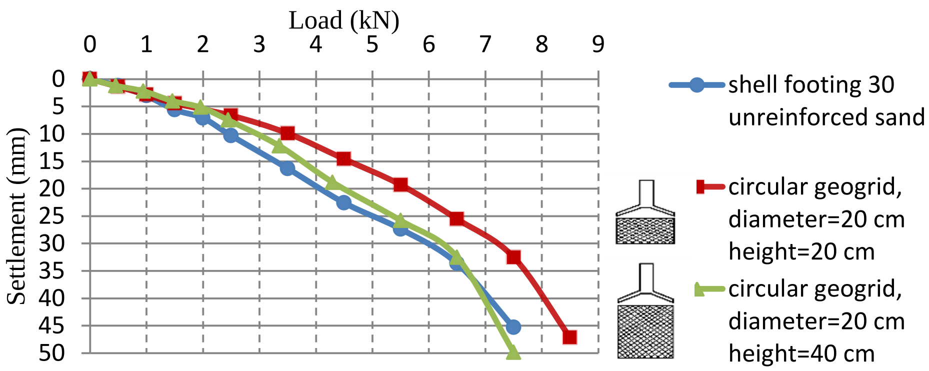


Figure 5: Load- settlement curves for flat foundation on unreinforced and reinforced sand with circular geogrid.

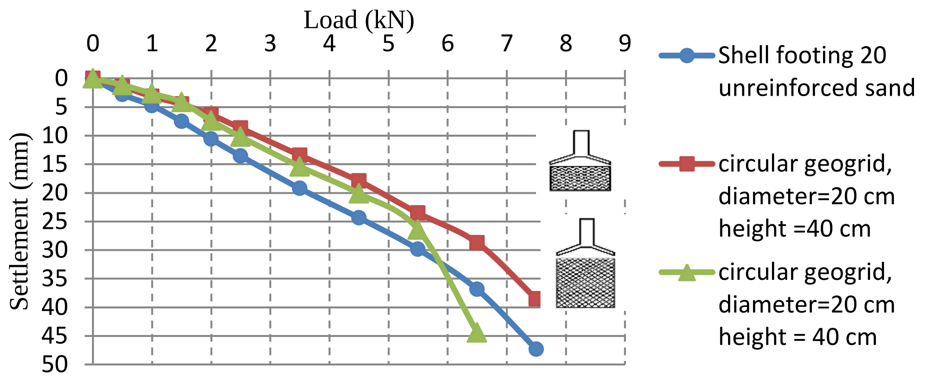


Figure 6: Load- settlement curves for pyramids shell foundation 20˚ on unreinforced and reinforced sand with circular geogrid.

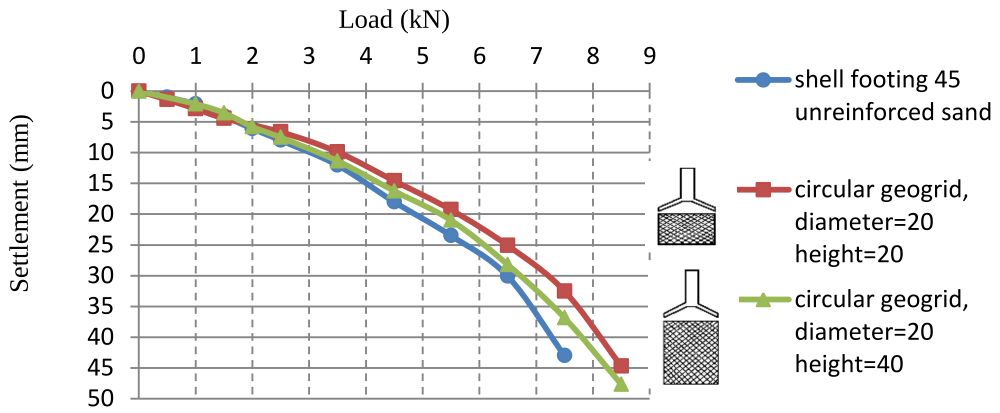


Figure 7: Load-settlement curves for pyramids shell foundation 30° on unreinforced and reinforced with sand circular geogrid.

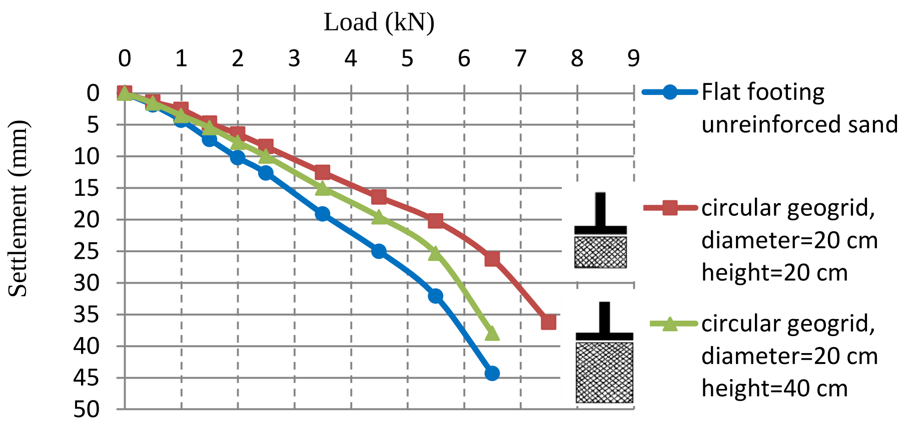


Figure 8: Load- settlement curves for pyramids shell foundation 45° on unreinforced and reinforced Sand with circular geogrid.

To show the improvement of bearing capacity and settlement of the foundation, the bearing capacity ratio is defined as the ratio of bearing capacity at specific and ultimate settlement according to behavior types of load- settlement for a foundation resting on reinforced (q_R) to that resting on the unreinforced soil (q) as follows:

$$\mathrm{BCR} = \frac{q_R}{q} \qquad (1)$$

The settlement reduction factor is defined as the ratio of settlement at specific and ultimate load according to behavior types of load- settlement for a foundation resting on reinforced soil (s_R) to that resting on unreinforced soil (s) as follows:

$$\mathrm{SRF} = \frac{s_R}{s} \qquad (2)$$

Where the ultimate load and settlement of the foundations were obtained by the tangent method.

To examine the settlement characteristic of shell foundations as compared to their flat counterparts, a non-dimensional settlement factor (F_s) is introduced in Equation (3) (Hanna and Abdel Rahman (1998)) [6].

$$F_s = \frac{s_u \, A_h \, \gamma}{q_u} \qquad (3)$$

Where, s_u is the settlement at the ultimate load, γ is the soil unit weight, A_h is the area of the footing in horizontal projection and q_u is the ultimate load.

To show the increase in the ultimate load of a shell foundation compared to that of a flat one in the study as shown in Table 3 ,the shell efficiency factor (η) is used which represents the ratio of the difference in ultimate loads of shell foundations to the ultimate load of flat foundation.

$$\eta = \frac{q_{us} - q_{uf}}{q_{uf}} \qquad (4)$$

Where, η shell efficiency; q_{us} ultimate load of shell foundation; and q_{uf} ultimate load of flat foundation.

The results of BCR and SRF are also summarized in Table 3. The results of this Table show the following:

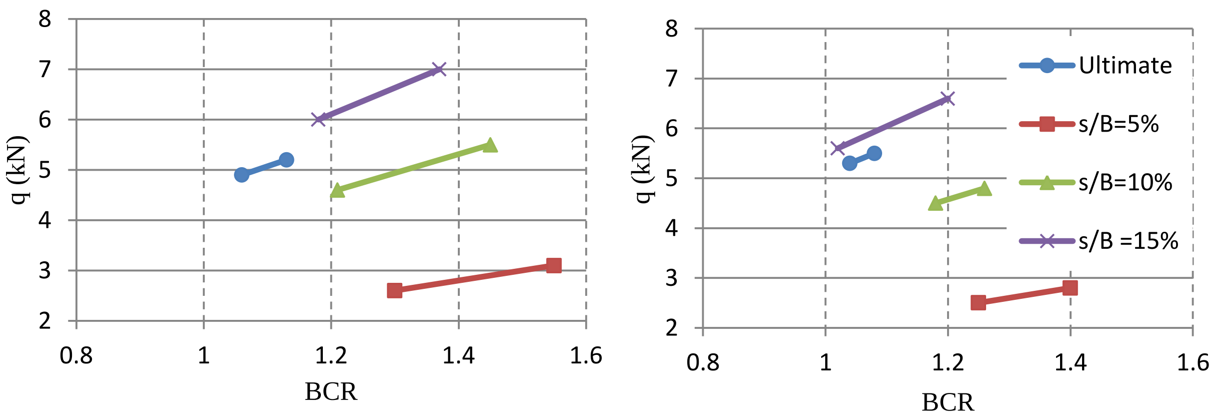
1. Using a circular geogrid with a length (H=20cm) leads to increase the BCR by (14-41)% higher than that for unreinforced sand, while increasing the geogrid length to 40 cm leads to increase BCR by (6-19)% as shown in Figure (9).
2. The SRF for a certain footing decreases with decreasing the geogrid length from 40 cm to 20 cm by (11-21) % .This may be related to the punching effect caused by the longer geogrid through the loose sand stratum as shown in Figure (10).
3. Non-dimensional settlement factor Fs is decreased for reinforced sand as compared with that of unreinforced sand for shell and flat foundations. This is due to the existence of reinforcement which reduces the settlement by 54% for flat foundation and by 40.7% for shell foundation when reinforced with circular geogrid of a length 20 cm.
4. The shell efficiency increases when the shell's angle increases. It increases by 25% when reinforced with circular geogrid with length 20 cm and increased by 18.37 %

when reinforced with circular geogrid with length 40 cm as compared with that of unreinforced sand flat foundation and reinforced with 20, 40 cm.

Table 3: Summary of results of flat and shell footings on sand unreinforced and reinforced with circular geogrid reinforcement (D=20cm).

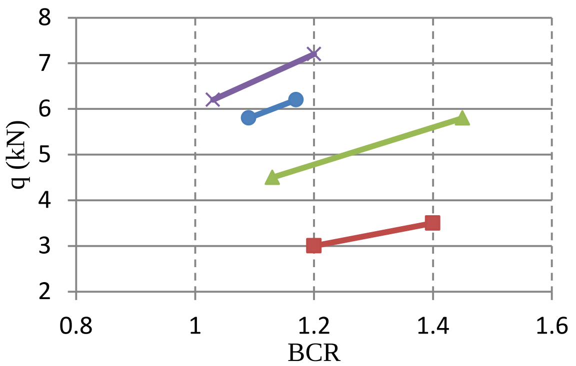
	Soil reinforcement configuration	H. cm	F_s *10^{-3}	(η)	Ultimate			*s/B = 5%			s/B=10%			s/B=15%		
					q_u (kN)	BCR_u	SRF_u	q_s kN	BCR_s	SRFs	q_s (kN)	BCR_S	SRF_s	q_s kN	BCR_s	SRF_s
Flat footing	Unreinforced sand	-	3.59	-	4.6	-	-	2	-	-	3.8	-	-	5.1	-	-
	Reinforced circular geogrid	20	1.65	-	5.2	1.13	0.52	3.1	1.55	0.6	5.5	1.45	0.55	7	1.37	0.67
	Reinforced circular geogrid	40	1.87	-	4.9	1.06	0.56	2.6	1.3	0.7	4.6	1.21	0.8	6	1.18	0.73
Shell footing 20°	Unreinforced sand	-	3	10.87	5.1	-	-	2	-	-	3.8	-	-	5.5	-	-
	Reinforced circular geogrid	20	1.78	5.7	5.5	1.08	0.64	2.8	1.4	0.6	4.8	1.26	0.7	6.6	1.2	0.83
	Reinforced circular geogrid	40	2.42	8.4	5.3	1.04	0.68	2.5	1.25	0.8	4.5	1.18	0.8	5.6	1.02	0.97
Shell footing 30°	Unreinforced sand	-	2.65	15.22	5.3	-	-	2.5	-	-	4	-	-	6	-	-
	Reinforced circular geogrid	20	1.58	19.23	6.2	1.17	0.69	3.5	1.4	0.6	5.8	1.45	0.65	7.2	1.2	0.77
	Reinforced circular geogrid	40	1.79	18.37	5.8	1.09	0.74	3	1.2	0.7	4.5	1.13	0.85	6.2	1.03	0.93
Shell footing 45°	Unreinforced sand	-	2	19.56	5.5	-	-	3	-	-	4.9	-	-	6.5	-	-
	Reinforced circular geogrid	20	1.32	25	6.5	1.18	0.78	3.5	1.17	0.8	5.7	1.16	0.75	7.2	1.11	0.87
	Reinforced circular geogrid	40	1.75	14.28	5.6	1.02	0.89	3.1	1.03	0.9	5.3	1.08	0.9	6.7	1.03	0.93

*(s/B) is defined as the ratio of footing settlement (s) to footing width (B)

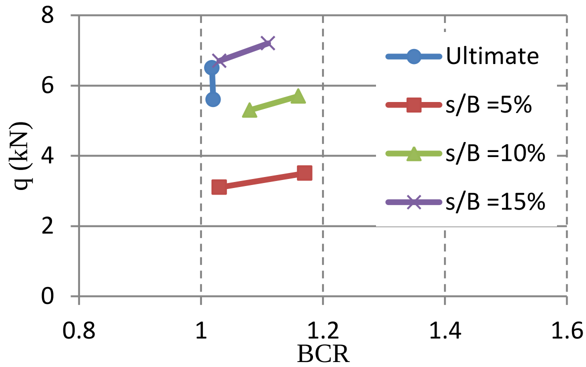


a) For flat footing b) For pyramidal shell 20˚

Figure 9: The variation of the ultimate and specific load with BCR for a circular geogrid.

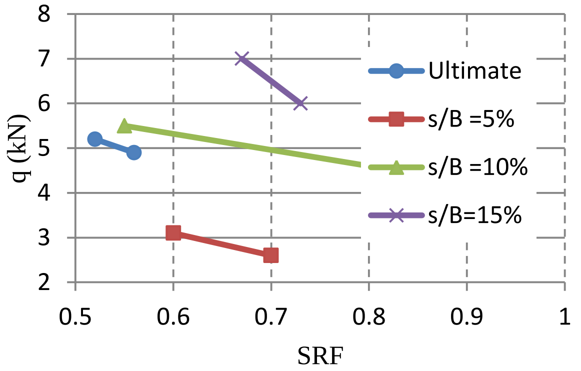


c) For pyramidal shell 30°

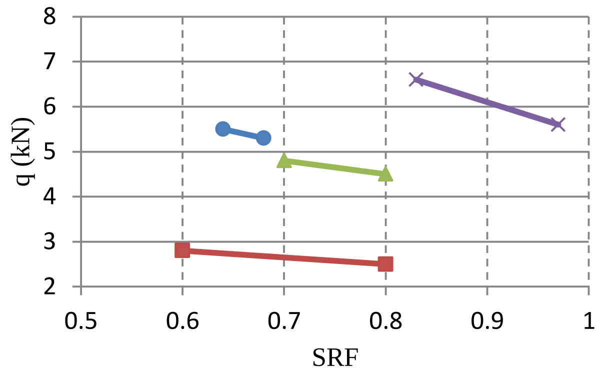


d) For pyramidal shell 45°.

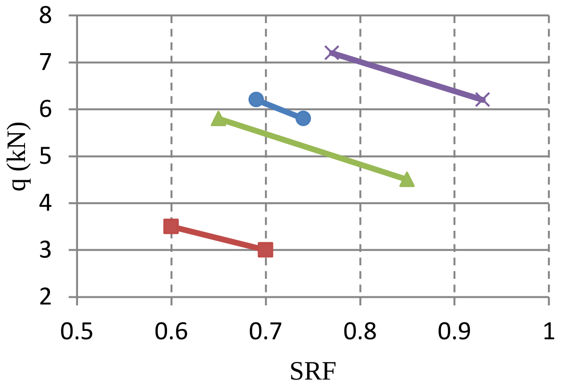
Figure 9: Continued



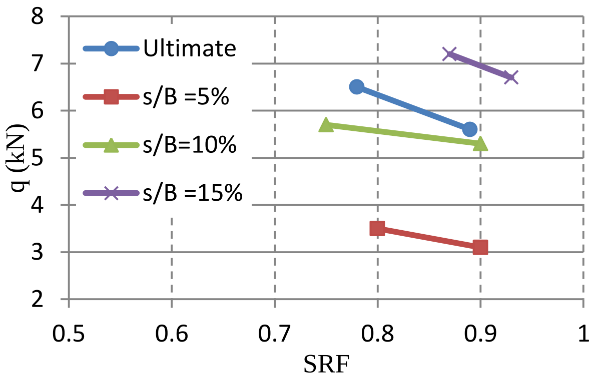
a) For flat footing.



b) For pyramidal shell 20°.



c) For pyramidal shell 30°.

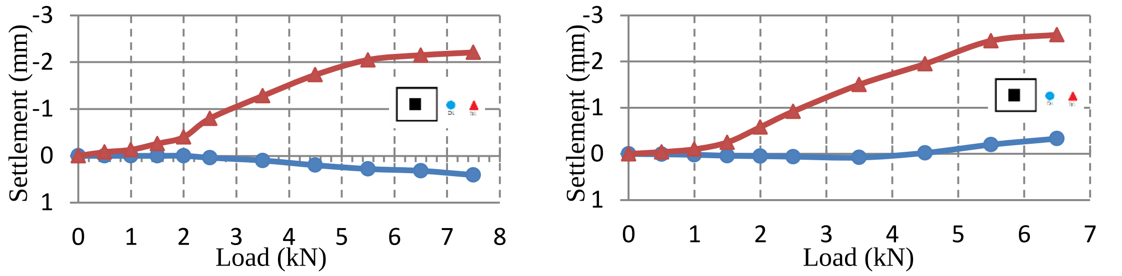


d) For pyramidal shell 45°.

Figure 10: The variation of the ultimate and specific load with SRF for a circular geogrid .

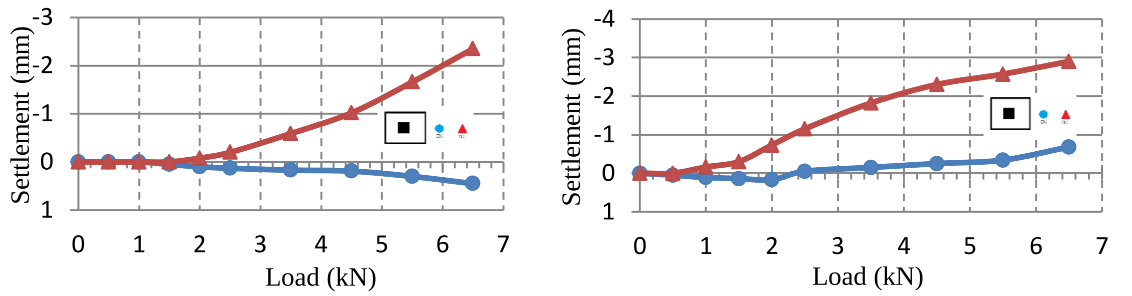
6. Vertical Displacement of Sand Surrounding the Foundation's Model

Figures (11 and 12) show the effect of circular geogrid reinforcement on the surrounding soil at a distance equal to 5 and 25 cm from footing. A clear effect is restricted on the heave of soil that is appeared at a distance equal to the footing width.

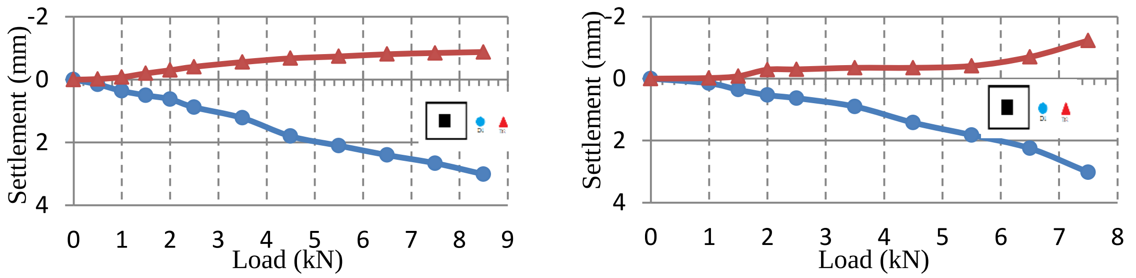


a) Length of circular geogrid =20 cm. b) Length of circular geogrid =40 cm.

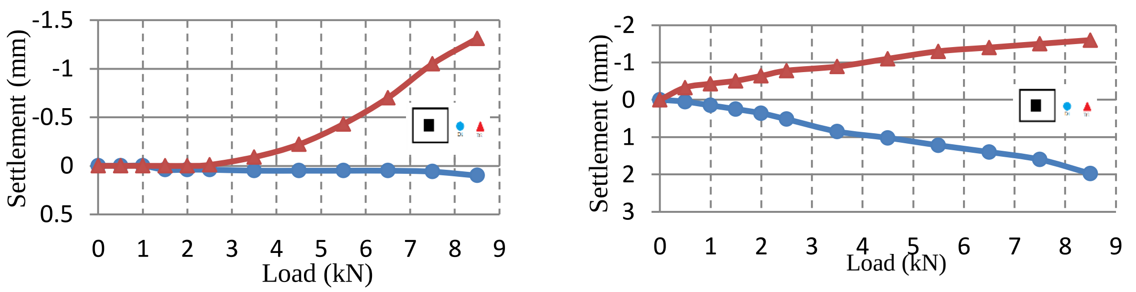
Figure 11: Vertical displacement of soil surrounding flat foundation reinforced with circular geogrid.



a) Length of circular geogrid =20 cm. b) Length of circular geogrid =40 cm.



c) Length of circular geogrid =20 cm. d) Length of circular geogrid =40 cm.



e) Length of circular geogrid= 20 cm. f) Length of circular geogrid= 40 cm.

Figure 12: Vertical displacement of soil surrounding shell foundation of angles of 20°, 30°and 45° reinforced with circular geogrid .

7. Conclusions

1. Using a circular geogrid with a length (H=20cm) leads to increase the BCR by (14-41)% over that for unreinforced sand, while increasing the geogrid length to 40 cm leads to increase BCR by (6-19)% .
2. The SRF for a certain footing decreases with decreasing the geogrid length from 40 cm to 20 cm by (11-21) % .This may be related to the punching effect caused by the longer geogrid through the loose sand stratum.
3. The non-dimensional settlement factor (F_s) of flat foundation is reduced by 54% for flat foundation and by 40.7% for shell foundation.
4. The shell efficiency increases remarkably for the tests with increasing shell angle, where increased by 18.37% and by 25% as compared to their counterpart unreinforced and reinforced with circular geogrid flat foundation respectively.

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