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LOAD CARRYING CAPACITYOF RING FOOTING ON GEOCELL REINFORCED SANDY SOIL

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ABSTRACT
Ring foundations are often adopted for large and tall structures to resist lateral loads and to increase the stability against overturning. This paper is conducted to study the experimental behavior of model ring footing and circular footing resting on reinforced sandy soil subjected to vertical static (monotonic) load. A total of eight models have been tested to study the behavior of shallow footings under monotonic load in case of loose sand (R.D. = 30%), four footing shapes, Df= 0 depth of foundation embedment, (b = 200 mm) width of geocell mat and V= 5 mm/sec. rate of loading were tried. It was concluded that for unreinforced and reinforced soil, the bearing capacity increases with increasing (Din/Dout) ratio of ring footing. Also, the results indicated that an optimum ratio of the inner to outer diameter of the ring footing has been indicated which was (0.4), and after this ratio, the bearing capacity starts decreasing.

INTRODUCTION
Soil reinforcements such as geosynthetics are commonly used for improving the strength of earth structures such as embankments, retaining walls and pavements. The reinforced soil derives its strength from the stress transfer from the soil to the reinforcement that takes place at the soil– reinforcement interface (Sridharan *et al*., 1991) and for proper utilization of the reinforcement strength, strong interfacial bond is required (Jewell, 1990).

Ground improvement using the soil reinforcement technique has grown substantially in the last three decades. The technique has grown from use of metal grids to use of geosynthetic products such as geogrids and geocells to reinforce soft soil. Nowadays, geocells are being widely used in geotechnical engineering to strengthen soft soil. General applications of geocell include pavements, foundations, and embankments. By virtue of its three-dimensional (3D) box-like structure, geocell provides additional confinement to the soil. Geocells offer faster, cheaper, sustainable, and environmentally friendly solutions to many complex geotechnical problems. Geocells have been now used for different structures like embankments, foundations, retaining walls, and also for slope stability.

Wesseloo *et al*. (2009) studied the stress–strain behavior of soil reinforced with single and multiple geocells. It was reported that the geocell reinforcement owing to its three dimensional configuration arrests the lateral spreading of the infill soil and creates a relatively stiffened mat that redistributes the footing pressure over wider area, on the underlying poor soil, thereby giving rise to enhanced load carrying capacity.

In the last few years, the use of ring footings is considered more suitable and economical for axisymmetric structures such as silos, water tower structures, chimneys, and storage tanks. Using a ring footing may fully utilize the soil capacity with less or no tension under the foundation.

Al-Sanad *et al.* (1993) reported the results of a series of plate loading tests on dense sand using circular and ring plate. Found that no significant difference in the settlement of ring and full plates is found, while the ratio of inside to outside diameter of ring, plate is 0.531.

Zhao and Wang (2007) utilized a finite difference code FLAC to study bearing capacity factor $N\gamma$ for ring footings in cohesionless soil. The value of $N\gamma$ was found to decrease significantly with an increase in radius ratio (n), which is the ratio of internal radius to external radius of the ring.

Thebehavior of rigid ring footings resting on cohesionless soils was studied by small scale laboratory or field tests (Boushehrian, 2003 and Sharma, 2017). Based on the experiments, the results showed that the bearing capacity of the ring footing is a function of the ring diameter ratio in such a way that the bearing capacity increases up to a diameter ratio of about 0.3–0.4 and thereafter, it decreases as the diameter ratio increases. It is again reminded that all these works only concerns the behavior of the ring footings under vertical loading condition.

The objectives of the present work is investigating the behavior of ring footings of different radius ratios resting on sand reinforced with geocells under the action of monotonic load.

EXPERIMENTAL WORK

Soil and Materials Used

Air dried sand brought from Karbala city in Iraq was used in the present study. The properties of this sand including specific gravity, grain size distribution, and minimum and maximum dry unit weights were measured. A summary of the test results with standard specifications that are followed in each test is presented in Table1. According to the grain size distribution results, the sand is medium to coarse-grained size. This sand is classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS).

Table 1.Physical properties of the tested sand.

Property	Value	Standard of the test
Specific gravity (G_s)	2.67	ASTM D 854
D_{10} (mm)	0.24	ASTM D 422 and ASTM D 2487
D_{30} (mm)	0.41	
D_{60} (mm)	1.39	
Coefficient of uniformity (C_u)	5.79	
Coefficient of curvature (C_c)	0.50	
Soil classification (USCS)	SP	
Maximum dry unit weight (kN/m³)	19.52	ASTM D 4253
Minimum dry unit weight (kN/m³)	16.63	ASTM D 4254
Maximum void ratio	0.6	------------
Minimum void ratio	0.37	------------
Angle of internal friction (ϕ) at R.D =30% (deg.)	35.2	ASTM D 3080
Angle of internal friction (ϕ) at R.D =55% (deg.)	40.2	
Angle of internal friction(ϕ) at R.D=85% (deg.)	44.7	

Geocell reinforcement

Geocell reinforcement used in this study was fabricated from planar polymeric taps that are sewn to the adjacent taps periodically in order to form a "honeycomb" arrangement; therefore a non-perforated flexible geocell was manufactured locally. The height of geocell walls is 50 mm, the pocket size (d) of geocell is taken as the diameter of an equivalent circular area of the pocket opening (Ag) (i.e. $d^2 = 4/\pi \times Ag$), the pocket size (d) of the geocell used was kept constant (d = 50 mm), and the ratio of the geocell pocket size (d) to the width of model footing (B) equals to 0.5 (i.e. d/B = 0.5) as shown in Figure1.

In addition, the tensile test was performed on the used geocell as per ASTM D6637 to determine its strength and tensile modulus. From the load-strain data obtained from the tensile test, the tensile modulus, M (secant slope of the stress strain curve) is 0.75(MPa) and its yield strength is determined as 39.53 (MPa).

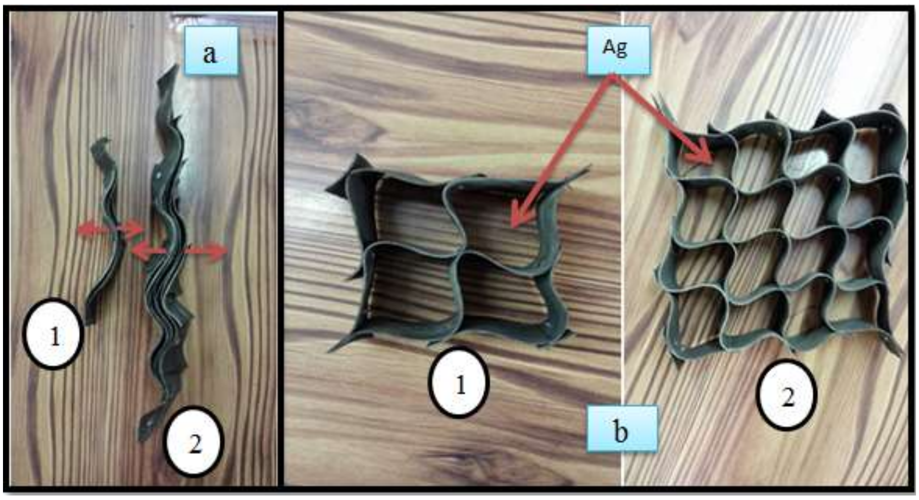


Figure1. Geocell used. (a) geocell before expanding. (b) top view of the geocell mattress after expanding. (1) geocell mat of width b_1=100 mm. (2) geocell mat of width b_2=200 mm.

Loading Machine
The loading machine consists of the following parts:
Steel loading frame, Axial loading system, Model footing, Steel container (testing box), and Shear strength measuring device.

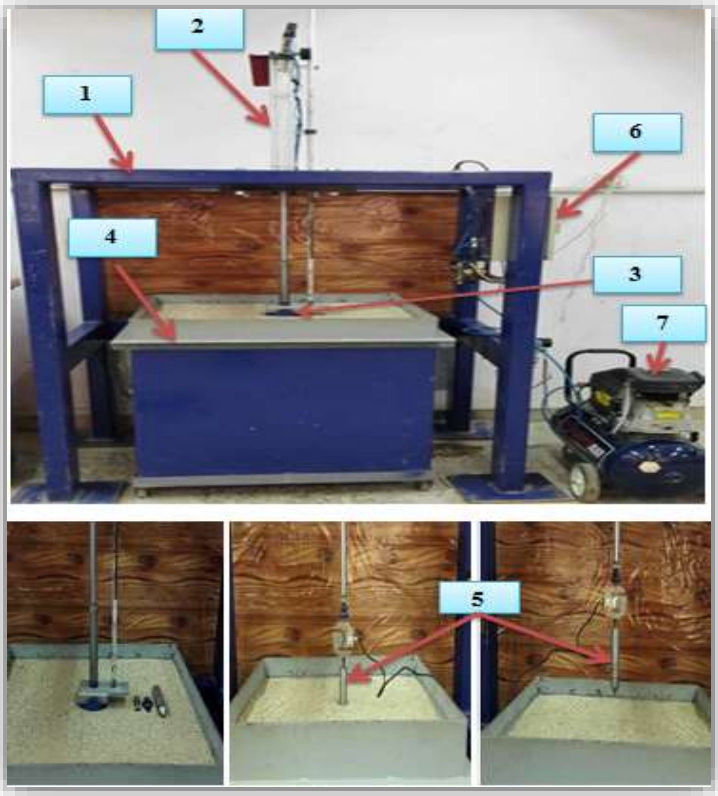


Figure 2. General view of the manufactured apparatus (1-Steel loading frame, 2- Axial loading system, 3- Model footing, 4- Steel container, 5- Strength measuring device, 6- Control system, and 7- Air compressor system).

A 25 mm thick steel plate with dimensions of (800mm×300 mm) was connected to a transverse beam by four bolts (of diameter 20 mm) in the center of the frame in order to carry the pneumatic jack system as shown in Figure 3. The steel frame was fixed to the floor base using four base plates with dimensions of (250 mm×250 mm×10 mm). Each base plate was fixed to the floor using four anchor bolts 12 mm in diameter.

The compressed air system (Project air brand), which consists of a 40 liter metal vessel with a pressure capacity greater than 10 bar, was used. The compressed air system consists of air compressor made of silicon aluminum alloy with air reducing valve and way valve. The compressor is driven by a 2.5 kW electric motor and is a single phase motor with a voltage of 220 V and a frequency of 50 Hz and a rotation speed of 1450 rpm.

A control system was used to control the movement of the device under the effect of applied loads either monotonic or cyclic loading. The system consists of two directional valves one for manual operation and the second for auto operation with electric control, and the movement of the pneumatic cylinder is controlled by these valves and the electrical signal is shown in Figure 4. An electric panel is used to control these valves. This panel allows manual operation by two buttons; one for upward movement and the second for downward movement or automatically by means of timer and relays.

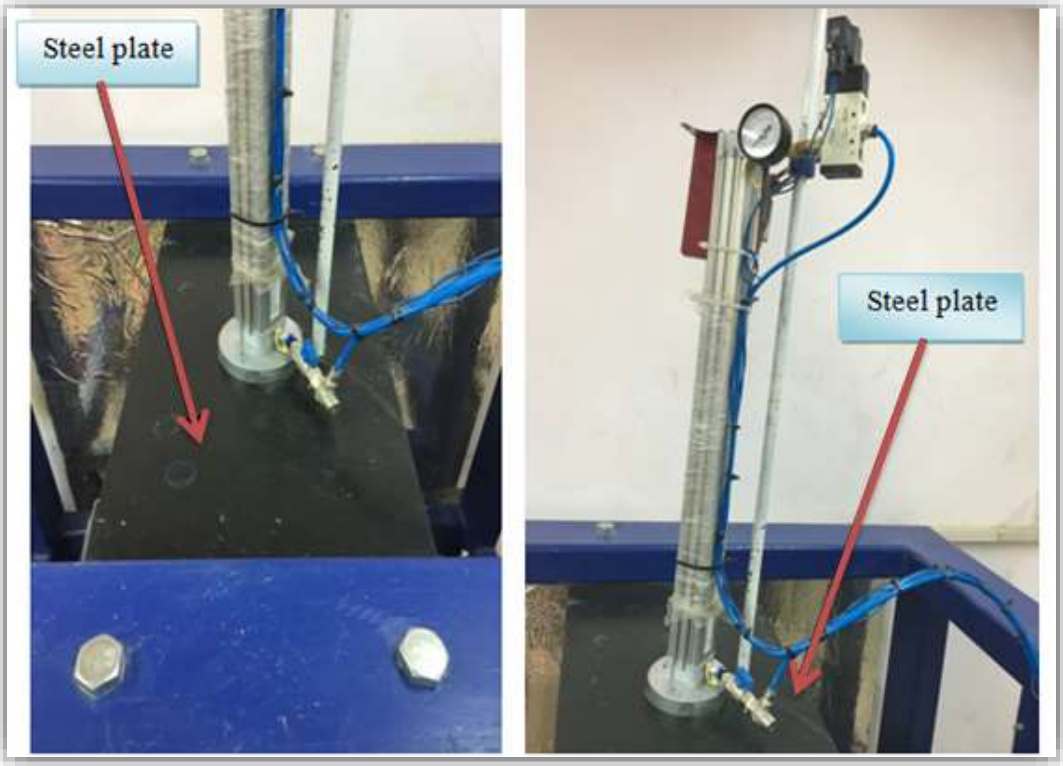


Figure 3. Steel plate to support the jack.

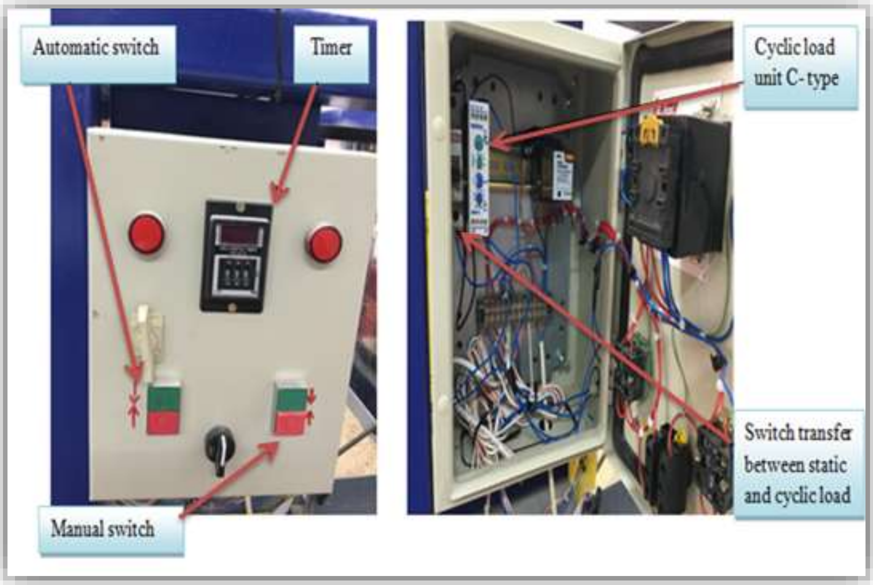


Figure 4. Control system – a general view.

Model Footing and Container

Four steel foundations 20mm in thickness were used with different foundation dimensions for circular footing with diameter (100 mm), $ring_1$ footing with inner diameter of (300 mm) and outer diameter of (100 mm), $ring_2$ footing with inner diameter of (400 mm) and outer diameter of (100 mm) and $ring_3$ footing with inner diameter of (500 mm) and outer diameter of (100 mm).

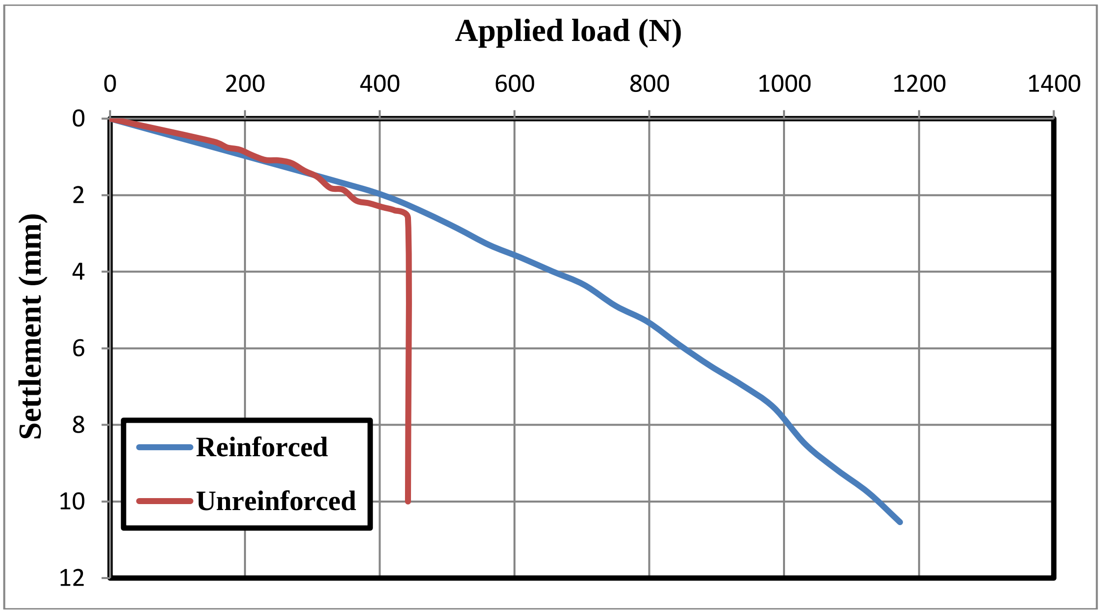
A soil container was used with inner dimensions of (700×700) mm and 800 mm in depth made as one piece, the container is made of (6 mm) thickness steel plate as shown in Figure 2.

The settlement of the footing during the application of cyclic load was measured by using LVDT (Linear Variable Differential Transformer). The system of data acquisition was utilized so that all data could be scanned and recorded automatically by using computer and data logger. A compression/tension load cell was used to measure the applied static load by linking with digital weighing indicator to read and display the load value. A digital weighing indicatorwas used for displaying the load amount.

Model Test Results

Eight model tests, four of them reinforced (with width of geocell b_2= 200 mm) and the rest unreinforced were performed on dry sand at worst case when the foundation is on the surface and relative density (R.D. =30%) which is corresponding to loose sand as a reference under static (monotonic) load. The rate of loading was (V=5 mm/sec). For all model tests, the failure is defined as the load causing a settlement corresponding to 10% of the footing width depending on the failure criterion given by Terzaghi (1943).

Figure 5. demonstrates the relationship between the applied vertical load and the corresponding settlement of the eight model tests. From this figure, it can be seen that the settlement of reinforced soil is less than the unreinforced one for all foundations and this due to increase the bearing capacity of soil. Also, it can be noticed that for both cases of unreinforced and reinforced soil, the bearing capacity increases with increasing (D_{in}/D_{out}) ratio (D_{in} is the internal diameter and $D_{out}$is the external diameter of footing used) compared with the circular footing of the same outer diameter and it reaches a maximum value at (D_{in}/D_{out} =0.4). This ratio could be considered as the optimum ratio, and after this ratio, the bearing capacity starts decreasing. Therefore when the ratio (D_{in}/D_{out}) is extended to (0.5), the bearing capacity will be reduced because of the high interaction between both of the external and internal shear failure surface in small zoneasshown experimentally in Figure 6.



a) Circular Footing.

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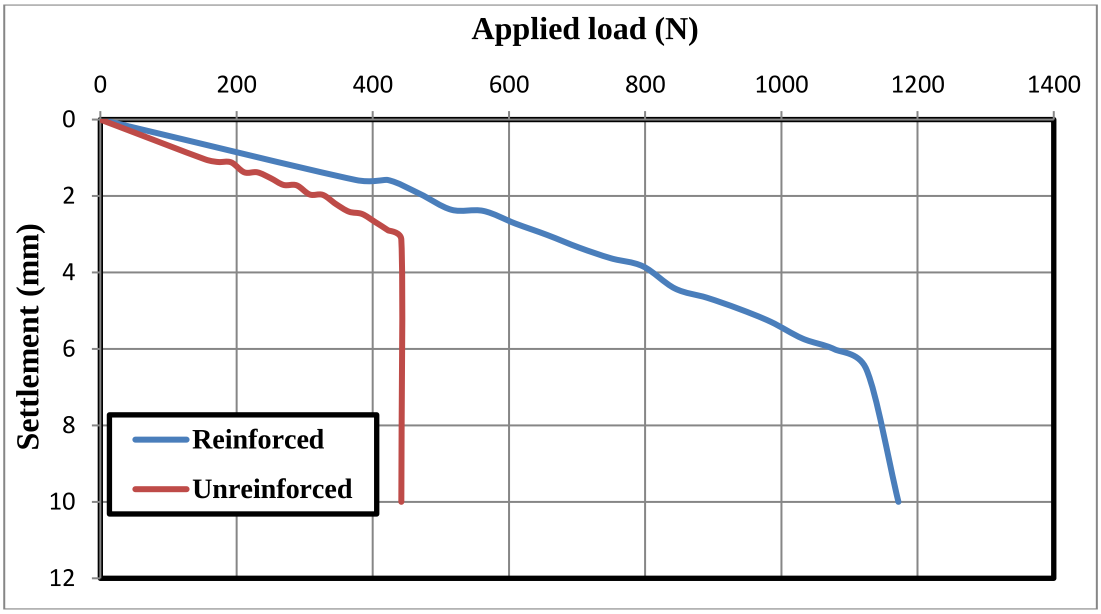
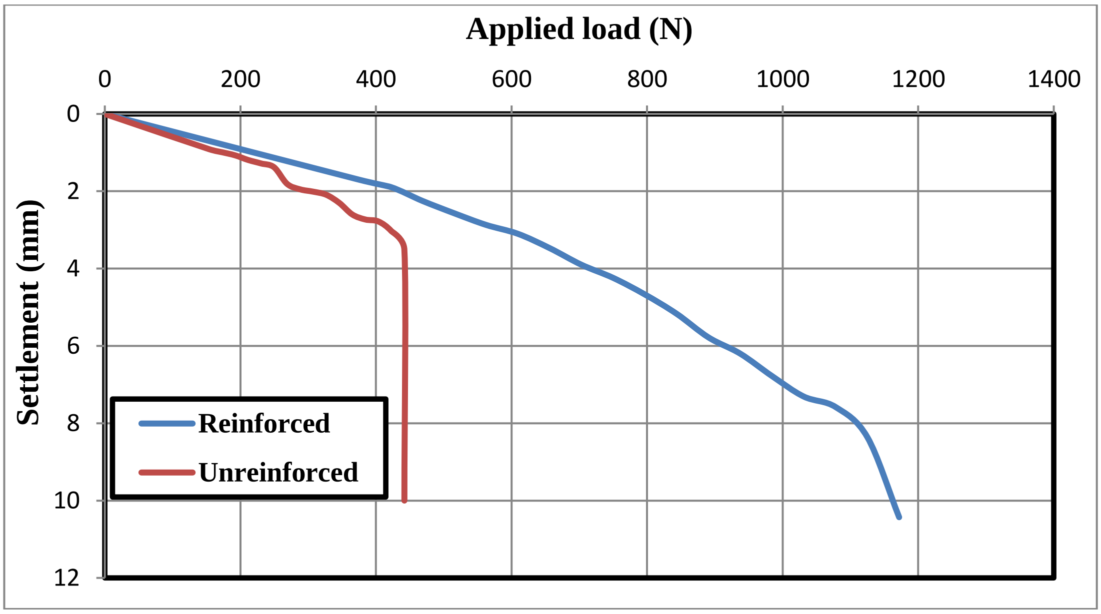
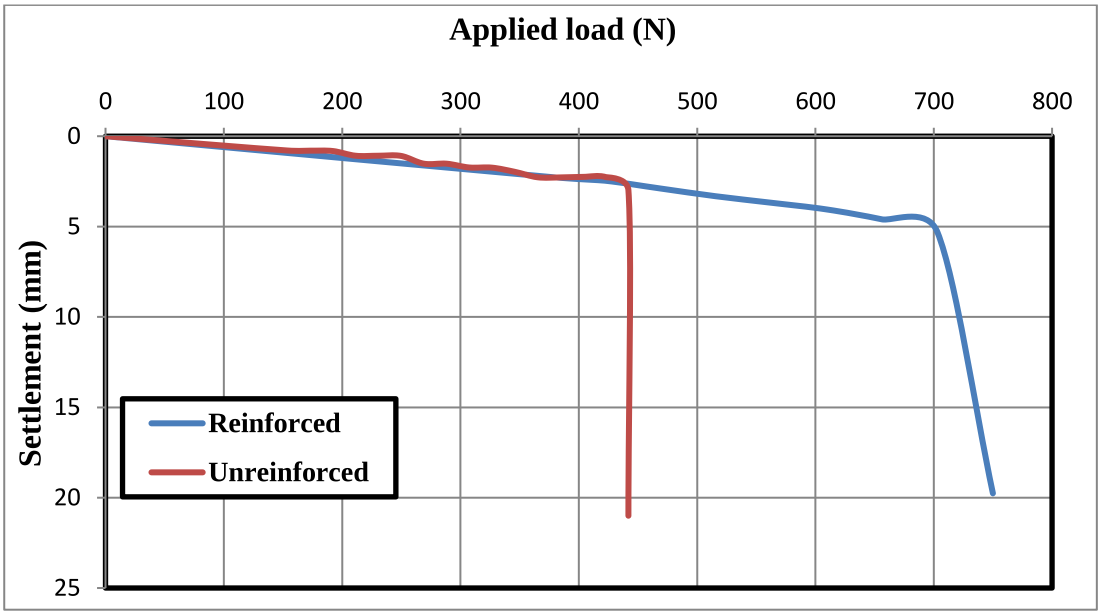


b) Ring$_1$ Footing, D_{in}/D_{out} =0.3.



c) Ring$_2$Footing, D_{in}/D_{out} =0.4.



d) Ring$_3$Footing, D_{in}/D_{out} =0.5.

Figure 5. Monotonic test results of models resting on loose sand of different foundations.

a. Unreinforced soil model.

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b. Reinforced soil model.

Figure 6. Failure of ring foundation on loose sand with D_{in}/D_{out} =0.5 subjected to static (monotonic) load.

These results are compatible with the findings of Hataf and Boushehrian (2003) who performed a series of laboratory tests on model ring footings and found thatfor radius ratio (n), which is the ratio of internal radius (r_i) to external radius (r_o) equals to0.4, the bearing capacity reaches its maximum for sand. Also, Hataf and Razavi (2003) stated that the radius ratio value for maximum bearing capacity of sand is not a unique value but is in the range of 0.2 to 0.4.

However, it is clearly shown that the failure mode varies from punching shear failure to local shear failure and general shear failure depending on the state of relative density of the sand and shape of footing, punching shear failure occurred in loose sand test (i.e., R.D = 30 %). This result agrees well with Terzaghi equation (Terzaghi, 1943 and Bowles, 1996).

Table 2 shows a comparison between the values of q_{ult} measured experimentally with theoretical ones. The results reveal that the theoretical theories are conservative. Also, the bearing capacity of the footing was greatly improved with the inclusion of geocell.

In footings resting on reinforced soil, the shear strength (angle of friction) may be increased due to the presence of geocell.

When the geocell reinforcement is filled with soil, it appears to behave as a stiff bed that redistributes stress over a wider area, instead of a narrow stressed area at the point of applied load when no reinforcement is used.

Moreover, interpretation can be made according to the findings of Tafreshi and Dawson (2010), who suggested the following reasons: The geocell reinforcement keeps the encapsulated soil from being displaced from directly beneath the applied load by confining the material via hoop action in the cell walls, thereby increasing the shear strength of the composite system. The load redistribution that occurs within the confined zone involves a three-dimensional interaction between the infill sand and the cellular structure.

Table 2: Summary of the static bearing capacity values of footings on loose sand.

□	**Type of Footing**	**q_{ult} Theoretical (kPa)**	**q_{ult} Experimental (kPa)**	**The percentage increase of q_{ult} (%)**
35.2 °	Unreinforced soil, D_f= 0			
	Circular	17.88	84.42	372.15
	$Ring_1$	17.88	92.76	418.80
	$Ring_2$	17.88	100.50	462.08
	$Ring_3$	17.88	112.55	529.47
	Reinforced soil, D_f= 0			
	Circular	17.88	223.82	1151.79
	$Ring_1$	17.88	246	1275.84
	$Ring_2$	17.88	266.45	1390.21
	$Ring_3$	17.88	191	968.23

CONCLUSIONS

1. The settlement of reinforced soil is less than that of the unreinforced one for all foundations due to increase the bearing capacity of soil.
2. In unreinforced and reinforced soil, the bearing capacity increases with increasing (D_{in}/D_{out}) ratio (D_{in} is the internal diameter and D_{out} is the external diameter of footing used) compared with the circular footing of the same outer diameter and it reaches a maximum value at (D_{in}/D_{out} =0.4).
3. D_{in}/D_{out} =0.4 can be considered as the optimum ratio, and after this ratio, the bearing capacity starts decreasing. Therefore when the ratio (D_{in}/D_{out}) is extended to (0.5) in $ring_3$, the bearing capacity will be reduced because of the high interaction between both of the external and internal shear failure surface in small zone.

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