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COMPARISON OF BEARING CAPACITY OF FOOTINGS WITH SAME AREA RESTING ON REINFORCED SAND

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ABSTRACT: The Paper presented from an experimental study for circular and square footing with same area that resting on sand bed. The steel model footing with 12 cm diameter (113 cm^2) and square footing with 10.6 cm width in sand with relative density 60% were used. For reinforced conditions geogrid layers were used. The settlement-load responses of the tests were investigated. Results indicated that ultimate bearing capacity increased in square footing in comparison with circular footing, and when reinforcements used with embedment depth (u/D=0.42 or u/B=0.47), the bearing capacity ratio (*BCR*) was increased greatly in circular footing in comparison with square footing. The *BCR* increases with increasing the number of geotextile layers for both of the footings (square and circular) but for reinforced conditions the geogrid layers have a better effect for circular footing in comparison with square footing and the rate of increasing *BCR* for circular footing is higher than square footing.

Keywords: Circular Foundation, Square Foundation, Bearing Capacity, Reinforced Sand

1. INTRODUCTION

In civil engineering near the last four decades, Geosynthetic products application has been known as a common technique to increase the ultimate bearing capacity of soils and decrease the settlement of footing.

Among the range of geosynthetics available on the market, geotextiles are the most preferred type of geosynthetic materials for reinforcing the foundation beds. Das and Shin (1994) [1] investigated the behavior of strip footing on geotextile reinforced sand. They found that full-depth geotextile reinforcement may reduce the permanent settlement of the foundation by about 20%-30%, when compared to the one without reinforcement. When loading has been applied with eccentricity, a few studies were developed experimentally to identify the critical values of reinforcement layers for reinforcing of the soil under the strip and rectangular foundations. Sawwaf (2009) conducted a series of model tests on eccentrically loaded strip footing resting on geogrid reinforced sand, and said that the effect of reinforced soil on the bearing capacity ratio is greater at lower values of eccentricity and greater relative densities. They found out that maximum improvement occurred at a depth ratio of u/B=0.33 and h/B=0.5 [2].

In the field of soil reinforcing with geosynthetic layers (in sand or clay) for circular foundations in centrically loaded, there has not been a lot of researches as compared to other foundations in the literature. Sitharam and Sireesh (2004) conducted a number of laboratory model tests to determine the bearing capacity of an embedded circular footing supported by sand bed reinforced with multiple layers of geotextiles. The test results demonstrated that the ultimate bearing pressure increased with embedding depth ratio of the foundation [6]. Also, Basudhar et al. (2007) carried out experimental and numerical analyses on behavior of circular footings with different size resting on reinforced sand with geotextile and reported that with increase in number of reinforcement layers, the settlement value gradually decreased [8].

Ghosh et al. (2005) [11], Alawaji (2001) [12], Latha and Somwanshi (2009) [3], Vinod et al. (2009) [4], Moghaddas Tafreshi and Dawson (2010) [5] reported when reinforcement were placed in optimum depth from the surface of footing (strip, square, rectangular foundations), the maximum benefit effect of reinforcement in bearing capacity was obtained [1-5]. In the field of soil reinforcing with geosynthetic layers (in sand or clay) for circular foundations in centrically loaded has not received much researchers attention in comparison with other foundations in the literature (Phanikumar et al., 2009.) [7]. Boushehrian and Hataf (2003) found out that for the circular footings on reinforced sand, the maximum bearing capacity occurs at different values of embedment depth ratio depending on the number of reinforcement layers, and for ratio of u/D greater than one reinforcement layers have no significant effect on bearing capacity [9]. They also reported that choosing a rigid reinforcement did not have always better effect on bearing capacity. Lovis et al. (2010) studied behavior of pre-stressed geotextile reinforced sand bed supporting a loaded circular footing and found out that the effect of the pre-stressed geotextile configuration were evident for greater footing depths in comparison with unreinforced and reinforced without pre-stress counterparts [10].

Mosallanezhad et al. (2007) dealt with the influence of a new generation of reinforcement (named by them Grid-Anchor) on increasing the square foundation bearing capacity. They found that the critical value of *u*/*B*, h/B and *d*/*B* are equal to 0.25, 0.25 and 4.5, respectively. They also showed that *BCR* for this system is greater than ordinary geotextile. All the above model tests were carried out the optimum condition over which, the highest efficiency of the reinforcing layers is expected. Their studies have focused on the ratio of the first layer of reinforcement from the foundation base, *u*, to the foundation size, *B*, (*u*/*B*); the ratio of the reinforcement width, *d*, to the foundation size (*d*/*B*); and the ratio of the total reinforced depth, *h*, to the foundation size (*h*/*B*), and critical ratios of them. There is no concentration on the effect of footing shapes rested on soil bed [14]. The present research studied the effect of foundation shape (circular and square) on the bearing capacity and settlement and footing in unreinforced and reinforced with geogrid resting sand bed experimentally.

2. MATERIALS

To investigate the effect of eccentric loading on a circular footing resting on reinforced sand with geogrid layers, the necessary details of experimental studies have been presented as follows.

2.1 Sand

In this study oven dried poorly graded medium density sand from Qareh Chay River, Hamedan Province in Iran was used. The particle size distribution curve was determined using the dry sieving method according to the standard of ASTM D 422-02 on two sand specimens weighing 1500 gr .The average of particle size distribution curve is shown in Fig. 1. This sand was classified as *SP* in accordance with Unified Soil Classification System (USCS). Its coefficient of uniformity (C_u) and coefficient of curvature (C_c), were 2.89 and 1.05, respectively. In order to determine the specific gravity of soil particles, maximum and minimum dry densities, maximum and minimum void ratios, three tests were carried out and average values for the sand were found to be 2.65, 1.64 (gr/cm^3), 1.44 (gr/cm^3), 0.89 and 0.65, respectively [13]. The internal friction angle of dry sand at 60% relative density determined by direct shear test (6 cm×6 cm) was 39˚. Sand properties are given in Table 1.

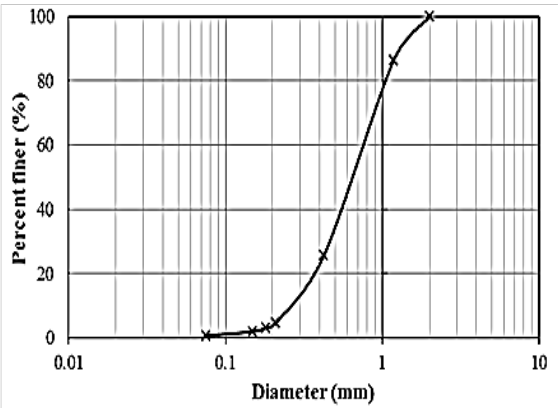

Fig. 1 Grain size distribution curve of sand.

Table 1 Sand properties used in the tests.

Parameter	**Value**
Maximum unit weight (kN/m^3)	16.4
Minimum unit weight (kN/m^3)	14.4
Maximum void ratio	0.890
Minimum void ratio	0.658
Specific gravity	2.72
Coefficient of uniformity	2.36
Coefficient of curvature	1.01
Classification	SP
Cohesion (kN/m^2)	0
Internal friction angle	39˚

2.2 Model Footings

Two circular and square footing models are made of steel plates in 15 mm thickness to provide the rigid footing conditions. The diameter of circular footing is selected 120 mm, and the width of square footing is 106 mm, so that both footings have the same area equal to 113 cm^2. The bases of the both footings were roughened by attaching a layer of geogrid on the bottom of them with epoxy glue to ensure uniform roughness in all tests. On footing surface some holes were created for applying load. Figure 2 shows both circular and square foundations that were used in this research, and in Figures 3 and 4 the rough base was shown, respectively.

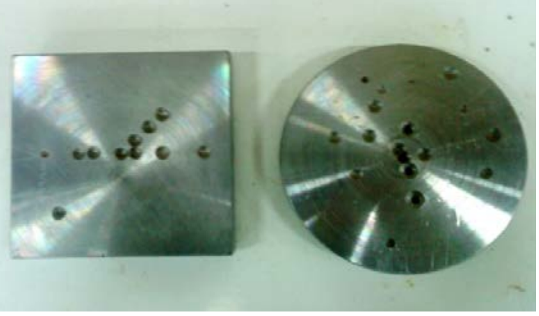

Fig. 2 Circular and square footing.

2.3 Geogrid

In order to provide horizontal reinforcement material for the model test, geogrid CE121 with tensile strength 7.68 kN/m was used. This geogrid has an oval shaped aperture opening (with 6 mm small diameter and 8 mm large diameter) and is made of high density polyethylene (HDPE). The reason for this type of geogrid selection was due to almost same peak tensile strength in every direction. The properties of this geogrid are given in Table 2.

Fig. 3 Rough base of Circular footing.

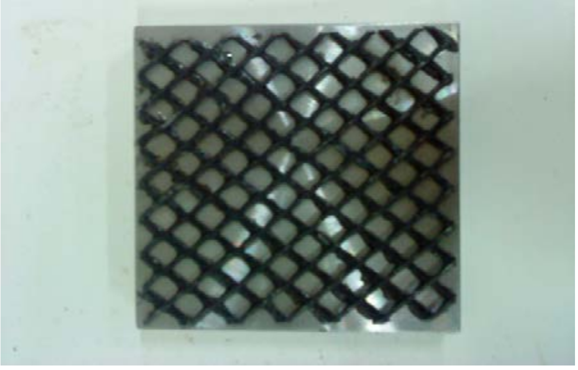

Fig. 4 Rough base of square footing.

Table 2 Geogrid properties.

Physical and Mechanical Property	Value
Aperture shape	Oval apertures
Polymer type	Polyethylene
Mesh thickness (mm)	3.3
Tensile strength (kN/m)	7.68
Extension at $^1/_2$ peak load (%)	3.2
Extension at maximum load (%)	20.2
Tensile strength at 10% extension (kN/m)	6.8
Weight (g/m^2)	730

3. TEST APPARATUS AND ITS PROGRAM

Experimental tests were conducted in an apparatus that was built in Bu-Ali Sina University, Physical Modeling Research Laboratory. It is consisted of cubic tank with inside dimensions of 0.6×0.6×0.6 m. The plan of tank is 5 times the diameter of footing to insure that the footing rupture of failure is inside the test tank. The test tank walls were made of Plexiglas 5 mm in thickness, and were marked at 20 mm intervals to facilitate preparation of the sand in by raining method. The geometry of the reinforced sand and footing is depicted in Figure 5. Chung and Cascante (2006) have shown that a zone between 0.3*B* and 0.5*B* is identified to maximize the benefits of soil reinforcement. They noticed that the accommodation of reinforcements within one footing width (*B*) below the foundation, can result in an increase in *BCR* and the low strain stiffness of the reinforced system. This increase is because of transferring of foundation load to deeper soil layers, as well as reduction of stresses and strains beneath the foundation [15].

In the middle parts and the edge of walls steel strips were used to control deformation of test tank. The tank was fixed and supported by two steel beams (IPE 12), and connected to two steel columns which were placed in the floor of the lab firmly by anchor bolts. An electrically operated hydraulic jack was used for the load application system. The amount of load applied was measured by using a load cell (Esit-STCS 2000 model) with a capacity of 2000 kg. The displacements were measured by LVDT (Linear Variable Differential Transducer), and these data were recorded by means of a data logger that was connected to the computer and were read by ARTIMAN Instrumentation Version 1.3.2 software. The test apparatus is shown in Figure 6. In all tests sand's unit weight and compaction relative density were 15.14 kN/m^2 and 60%, respectively. To achieve the desired relative density, pouring by sand raining technique was used.

The height of free sand raining was obtained through several trials in an especial aluminum cup with certain volume of 130 ml. Afterward, it was found that the tank should be filled in 50 mm thickness intervals in order to achieve the desired density. The tank was filled up until the depth of the sand reached 50 cm about 4.2 times the diameter of footing. In order to conduct model tests with geogrid reinforcement in sand, it is important to decide the magnitude of *u/D* or *B* and *h/D* or *B* to derive maximum benefit in increasing the ultimate bearing capacity.

By conducting model tests on surface foundations supported by sand with multiple layers of reinforcement, it was shown by several previous investigators that for square and circular foundations *u/D* or *B* and *h/D* or *B* can vary between 0.25 and 0.5. In this paper, in order to find out the effect of number of geogrid layers on bearing capacity ratio (equation 1), the depth ratio of reinforcement layers were considered constant at *u/D=h/D*= 0.42 for circular footing and *u/B=h/B*= 0.47 for square footing (here *u* is the depth of first layer of geogrid and *h* is the vertical spacing between geogrid layers) in the entire test program. The bearing capacity ratio (*BCR*) is expressed as the ratio of the ultimate bearing capacity in reinforced soil to the ultimate bearing capacity in unreinforced soil condition. The number of reinforcement layers was increased from 1 to 3.

$$BCR = \frac{q_u \ (Reinforced)}{q_u \ (Unreinforced)} \tag{1}$$

Figure 5 shows a circular or square foundation (diameter or width *D* or *B*) being supported by sand, which is reinforced with *N* number of geogrid layers. The vertical spacing between consecutive geogrid layers is *h*. The top layer of geogrid is located at a depth *u* measured from the bottom of the foundation. The width of the geogrid reinforcements under the foundation is *L*. The depth of reinforcement, *d*, below the bottom of the foundation can be given as:

$$d = u + (N - 1)h \tag{2}$$

In this research to receive a same reinforced condition, the depth of reinforcement (*d*) for circular and square footing is selected as same as 15.12 cm for three layers of geogrid.

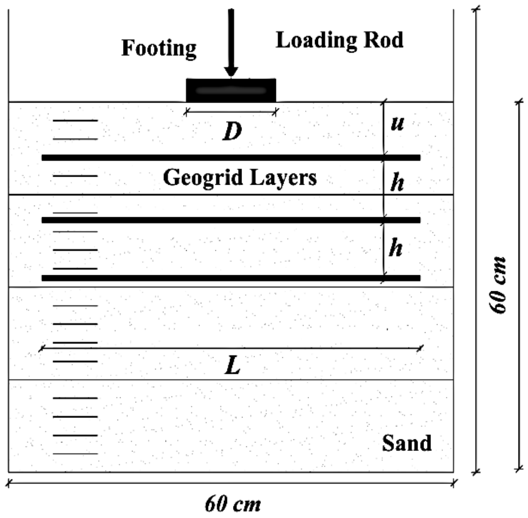

Fig. 5 Geometric parameters of geogid-reinforced sand.

4. RESULT AND DISCUSSIONS

Results of small-scale laboratory model tests conducted to determine the ultimate bearing capacity of circular and square footings with the same area on sand reinforced with multiple layers of geogrid are presented. Load-settlement curves from some of the 8 experimental tests which were carried out on centrically loaded in both reinforced and unreinforced conditions for circular and square footings are shown in Figures **7** and 8 (The all tests were repeated at least twice to verify the repeatability and the consistency of the test data). The ultimate bearing capacity of foundation was obtained from curves of the load-settlement along the load place by the tangent method according to suggestions of Boushehrian and Hataf (2003) because curves didn’t have pronounced peaks [9]. In this method a tangent line is plotted along the start portion of the load- settlement curves, and other tangent line is plotted along the end portion. Then the intersection point of these two lines is considered as ultimate bearing capacity on load axis.

Fig. 6a Schematic view of experimental apparatus.

Fig. 6b Schematic view of experimental apparatus.

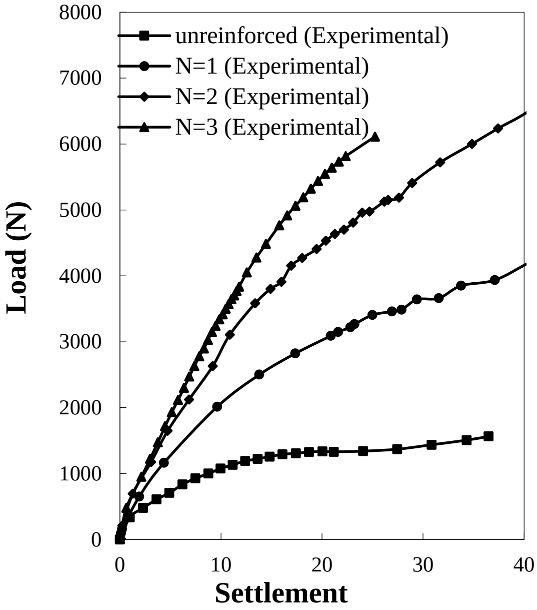

Fig. 7 Load versus settlement for reinforced and unreinforced sand for circular footing.

The load-displacement responses of tests were verified by repeating every test twice, and the difference between the ultimate bearing capacity values was less than 2%. It can be seen that the inclusion of geogrid layers appreciably improves the bearing capacity of both footings as well as the stiffness of the foundation bed. Comparing the curves of unreinforced and reinforced sand for the same bearing pressure in both circular and square footings, can be seen that soil reinforcement much decreases the settlement of foundations. Therefore, in general conditions, it can be concluded that in cases where structures are very sensitive to settlement, soil reinforcement can be used to obtain the same allowable bearing capacity at a much lower settlement with the same sand density. This decrease in vertical settlement is due to inclusion of the geogrid layers can be attributed to the reinforcement mechanism, which limits the spreading and lateral deformations of sand particles.

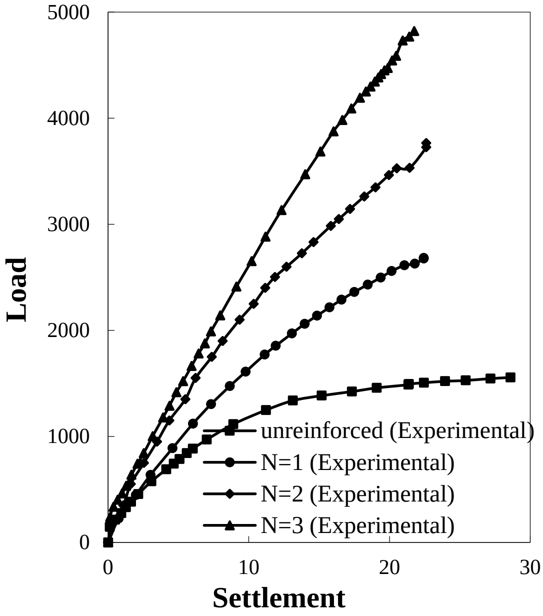

Fig. 8 Load versus settlement for reinforced and unreinforced sand for square footing.

The ultimate bearing capacity for both of circular and square footings in comparison with increasing the number of reinforcement layers were shown in Figure 9. The results show there is not only increase in bearing capacity, but also there is reduction in settlement. The bearing capacity increases at all settlement levels. It is evidenced that the circular and square footings with same area almost have equal ultimate bearing capacity in unreinforced conditions, but in reinforced conditions by increasing the geogrid layers, the circular footings have the bigger ultimate bearing capacity than the square footings. In other word, reinforcement layers have the better effect in circular footing than square footing for increasing the bearing capacity. In Figure 10 the *BCR* versus the *N* (number of reinforcement layers) is plotted, which shows that *BCR* increases with increasing *N*. When geogrid layers are used for reinforcing and enhancing the bearing capacity, it is better to use circular foundation instead of a square one with the same area.

In these figures, the effect of increasing *N* on *BCR* is evident. However, for *N* greater than 2, this effect is negligible. This is because the depth of influence under the footing in both cases (i.e. circular and square footing) affected by loading (i.e. extent of stress bulb) is finite beyond which replacing reinforcement has not any effect on bearing capacity improvement. Soil reinforcement significantly improves the *BCR* of an eccentrically loaded strip footing leading to significant decrease in the footing area. There is up to 3 to 4 times increase in ultimate bearing capacity of circular footing resting on sand reinforced with three layers of geogrid, in comparison of 2 to 3 times increase for square footing with the same area.

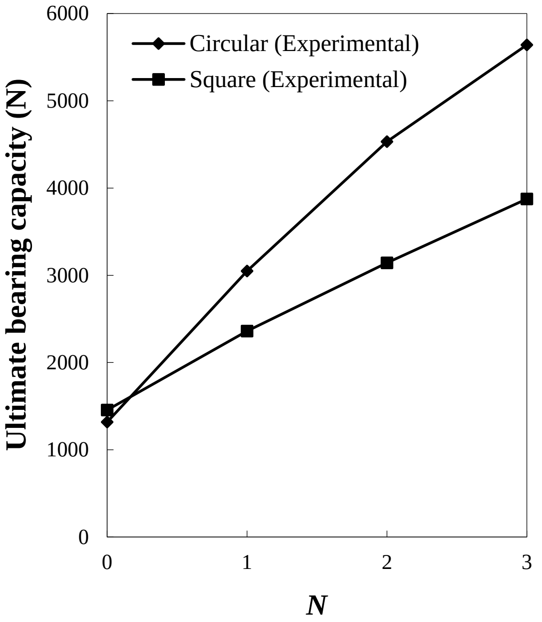

Fig. 9 Load versus *N* for reinforced and unreinforced sand for circular and square footings.

The results clearly show that the effect of the ordinary geogrid in improving the soil bearing capacity of square footing was less than that of the circular footing. With increasing the reinforcement depth (*d*) the *BCR* increased for circular footing about 1.42 to 1.60 times of square footing. In the other words, in three layers of reinforcement (*d*=15.12 cm) the *BCR* is 4.28 and 2.66 for circular and square footing, respectively. With increasing the number of geogrid layers, the contact area and the interlocking between geogrid layers and soil increase. Consequently, larger soil displacements and horizontal shear stresses built up in the soil under the footing were resisted and transferred by geogrid layers to larger mass of soil.

5. MODULUS OF SUBGRADE REACTION

The modulus of subgrade reaction is a conceptual relationship between contact pressure and footing deflection that is widely used in structural analysis of foundation members. This modulus evaluates the stiffness of subgrade soils in either the unreinforced and reinforced conditions.

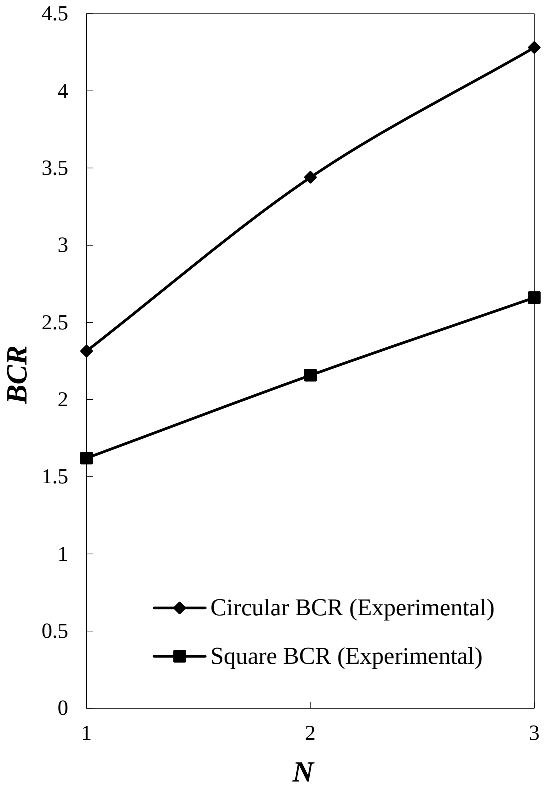

Fig. 10 *BCR* versus *N* (number of geogrid layers) for circular and square footings.

The data developed in the static load test is used in the calculation of the modulus of subgrade reaction, which is a modification of ASTM D 1196 [16]. The modulus of subgrade reaction for different settlement ratios from s/D=5% until s/D=20% are shown in Figure 11 for unreinforced and three layers of reinforced conditions. This plot shows that by increasing settlement, the modulus of subgrade reaction has reduced, and the rate of decreasing k_s by increasing settlement has reduced. This ratio was defined as follows:

$$k_s = \frac{q}{s} \tag{3}$$

where, q is the bearing capacity pressure and s is the settlement of footing.

From this fingers it can be shown that subgrade reaction k_s of cohesionless soil under circular footing is higher, about 1.25 and 1.10 times than that under square footing (at same equivalent area) in unreinforced and three layers of reinforcement, respectively. It can be concluded that soil reinforcement much decreases the settlement of square footing.

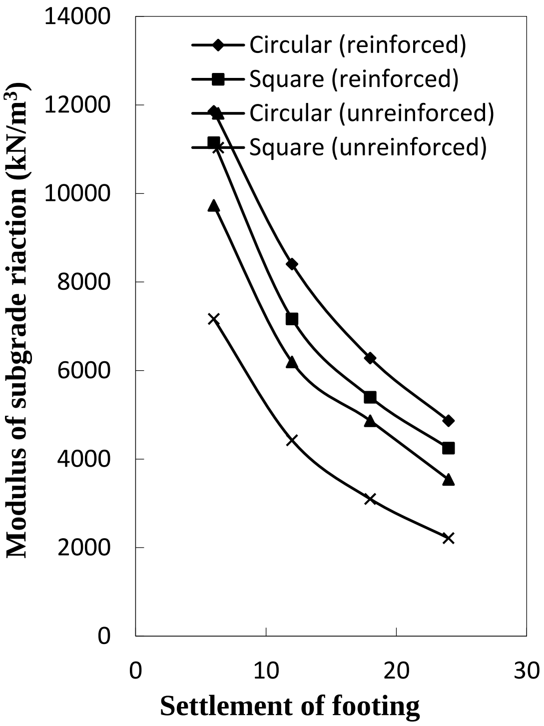

Fig. 11 Effect of footing settlement on modulus of subgrade reaction for circular and square footings in unreinforced and three layers of reinforced conditions.

6. CONCLUSION

The behavior of centrically loaded circular and square footings with the same area supported on unreinforced and reinforced sand with geogrid layers was studied based on a series of experimental tests. In order to understand the beneficial effects of geogrid reinforcement layers on the bearing capacity, tests with different number of geogrid layers (*N*= 1, 2 and 3) were performed. The following conclusions can be drawn from this study.

1. In unreinforced condition, the ultimate bearing capacity for both of the footings almost have equal ultimate bearing capacity (although for square footing have slightly more than circular footing), but with reinforcing and increasing the number geogrid layers, the ultimate bearing capacity for circular footing increased with a higher rate in regard to square footing.
2. The *BCR* increases with increasing the number of geogrid layers for both footings (square and circular); but for reinforced conditions the geogrid layers have the better effect for circular footing in comparison with square footing, and the rate of increasing *BCR* for circular footing is higher than square footing.
3. Calculating the modulus of subgrade reaction (k_s) shows that by settlement increasing, this modulus decreases. Also, the modulus of subgrade reaction decreases; however, the rate of decrease becomes lower by increasing the settlement.
4. The modulus of subgrade reaction (k_s) for circular footing is bigger than square footing.

It is worth to note that the model footing adopted in laboratory study was reduced to a certain scale while the used sand, and geogrids were the same in the model. It should be noted that the results presented in this paper are related to model footings (circular and square footing with same area as 113 cm^2) on sand surface and are limited to these conditions, and the effect of some other parameters such as scale effect, density of soil, etc. have not been investigated.

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