

BEARING CAPACITY AND SETTLEMENT OF CIRCULAR FOOTING RESTING ON CONFINED SAND (EXPERIMENTAL STUDY)

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Abstract

This paper presents the results of laboratory tests on the effect of lateral confinement on the behavior of a model circular footing resting on sand. The improvement of bearing capacity and settlement of footing supported by confined sand were studied. The effect of confinement dimensions such as confinement height, confinement width and confinement position on the response of footing was presented. The influence of cell, one and two sides confinement on the footing behavior was studied. One and two sides confinement were studied here to simulate the effect of permanent side support on the behavior of shallow foundations. The response of footing performance due to soil confinement compared with that observed for unconfined case was presented. The results indicate that significant increase in bearing capacity was noticed by soil confinement. The position of lateral confinement plays the important role in the improving of footing behavior. The best improvement was observed for the case of cell confinement when it compared with one and two sides confinement. The confinement-sand-footing system acts as one unite for small confinement diameters. Some significant observations on the performance of footing-confinement system with change of the values of parametric study are presented in this paper.

Keywords

Bearing capacity; Confinement; Soil improvement; Granular soil; model test.

1. Introduction

There are several conventional methods used to improve the supporting soil such as, soil reinforcement, consolidation, compaction and grouting. One of the ways to improve the soil bearing capacity is soil confinement. In many cases, underground excavations such as basements, tunnels and pipeline need to be braced during foundation construction to protect the excavation sides, adjacent facilities and structures. There are several conventional techniques that used to support the sides of excavation such as secant piles, sheet piles and diaphragm walls. In most cases, these elements go deeper than the foundation level and are provided as a part of the permanent structure.

The presence of side support system contributes to reduce the lateral movement of the soil underneath foundation. This leads to decrease the vertical settlement then the soil strength increases due to the lateral confinement of the soil .

The effect of horizontal confinement on bearing capacity has been studied by many researchers and they reported significant improvement of bearing capacity and settlement due the soil confinement [1-14]. Rajagopal et al. [15] studied the strength of confined sand by conducting a large number of triaxial compression test to study the effect of geocell confinement on the strength and stiffness behavior of granular soils. Dash et al. [5-6] conducted an experimental study on the bearing capacity of a strip footing on homogeneous dense sand bed reinforced with a geocell mattress. The effect of the reinforcement dimensions and the depth of placement on the improvement of bearing capacity are presented. Elsaywaf and Nazer [8] have conducted laboratory experiments to show the effect of soil confinement on the bearing capacity of circular footing on sandy soil and have found that the bearing capacity is increased 17 times of that without confinement.

Civil engineering professionals have applied the metal cell and geocell as a novel technique in several fields of geotechnical engineering in order to enhance the soil-footing strength.

The aim of this study is to investigate the effect of soil confinement on the bearing capacity and settlement of circular footing based on experimental study. It well known that the footing may be constructed adjacent side support system at one or more side around the footing. In order to simulate several cases of confinement, the influence of cell, two sides and one side confinement on the response of circular footing are presented. The influence of various parameters such as height, width, and the location of confining wall from the footing center on the performance of footing is investigated.

2. Laboratory model

2.1 Test Equipment

The system included a cylinder mold, compaction rammer, measurement devices and loading testing machine. The cylinder model having inside dimensions of $L=27\text{cm}$, $D=23\text{ cm}$ where L and D are length and diameter of mold respectively. The mold is made from steel with thickness of 14 mm. As shown in Fig.1, the load is applied to the footing by solid steel cylinder with diameter of 50 mm placed between the footing and the ring load.

2.2 Sand

Washed and air dried siliceous yellow sand was used in the current experimental study with a specific gravity of 2.66. The basic and index properties of the sand are determined from laboratory experiments according to ASTM standards. The sand was saved through sieve No. 4 (4.75mm) and the particle size distribution characteristics are shown in Fig. 2. From the grain size distribution curve it was concluded that, D10, D30 and D60 were 0.275, 0.45 and 0.68 mm. Uniformity coefficient (C_u) and coefficient of curvature (C_c) were 1.08 and 2.47, respectively. The soil is classified as poorly graded sand with letter symbol SP according to USCS. The maximum and minimum dry densities were found to be 19.84 and 16.21 kN/m^3 and the corresponding values of maximum and minimum void ratio were 0.611 and 0.312 respectively. The friction angle (ϕ) of the compacted sand was obtained from shear box test and it found to be 37° .

2.3 Footing and confining model

A circular footing and confining model made of mild steel were used. The model footing was a rigid circular plate of 50 mm in diameter (D) and 12 mm in thickness. In order to achieve a rough base condition, a thin layer of sand is fixed onto the base of footing with epoxy glue. In this study, the confining model takes two shapes with thickness of 1.2 mm and variable dimensions as shown hereafter.

2.4 Experimental procedure

This experimental study was carried out in the foundation and soil laboratory of college of engineering Beni-Suef University, Egypt. The sand is compacted in the cylinder mold according the results of modified proctor test, the maximum dry density and the optimum moisture content are 18.1 kN/m^3 and 11% respectively. The soil is placed in the cylinder model in 5 layers and compact using 25 well distributed blows of the compaction rammer. After each test, the dry density is measured (γ_d) and it found be ranged from 18.1 to 18.15 kN/m^3 .



Fig. 1 Testing loading machine

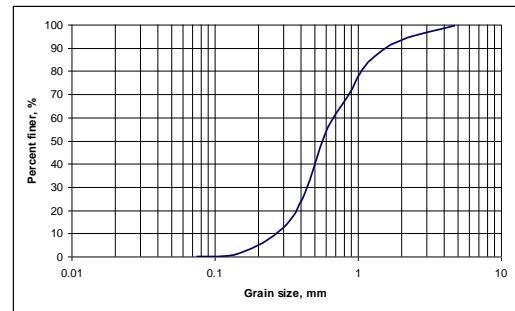


Fig. 2. Grain size distribution of the sand

Upon filling cylinder with sand to the top, the final surface was leveled and the steel footing is centered with the surface. The confining model is driven in the sand with deferent spacing from the circular footing. The influence of cell, two sides and one side confinement on the system response are investigated. After the preparation of sand, footing and confining model into the cylinder container, the cylinder is placed above the base of loading machine and the load was applied to the footing model by the jack through the proving ring. The base of loading machine rises in a small rate (1mm/min) until reaching failure. The corresponding load resistance of sand is measured by the proving ring every 0.25 mm. Each load increment corresponds to 0.25mm, was maintained constant until the footing settlement had stabilized. Before starting of every test, the cylinder model wad emptied and then refilled with sand as described earlier.

3. Parametric study

The test program carried out 37 series tests on rigid circular footing to investigate the effect of soil confinement on the behavior of soil-footing interaction as shown in table1. The definition of problem is sketched in Fig.3. The type of sand and the dimensions of footing model were kept constant throughout the study. Firstly the response of unconfined condition is determined then the effect of variable parameters is studied. The response of footing due to the soil confinement are presented by varying several parameters such as: radius of the confining cell (R), embedded depth of confining (H_c) and (H_p), where the subscribe c indicates to the case of cell confinement and subscribe p indicates to the case of one and two sides confinement using plate sheet, width of plate confinement (B) and the spacing between the steel plate and the center of footing (X). In order to present dimensionless results, all parameters are normalized to the footing diameter (D). To investigate the effect of cell size on the behavior of footing, five values of R/D (0.75, 0.9, 1.0, 1.4, 1.8) were used. Four values of H_c/D (0.6, 1.5, 2, 3) were chosen to study the effect of cell height on the response of footing. For the cases of one and two sides confinement, three values of B/D (0.7,1.5,1.8) are chosen to represent the effect of confinement width and five values of X/D (0.75, 0.9, 1.0, 1.4, 1.8) were used to investigate the effect of plate position from footing center on the footing response.

Table 1. Model tests program

Group	Model description	Constant parameters	Variable parameters
-	Unconfined footing	-	-
A	Cell confining	$H_c/D=0.6$	$R/D=0.75, 0.9, 1.0, 1.4, 1.8$
		$H_c/D=1.5$	$R/D=0.75, 0.9, 1.0, 1.4, 1.8$
		$H_c/D=2$	$R/D=0.75, 0.9, 1.0, 1.4, 1.8$
		$H_c/D=3$	$R/D=0.75, 0.9, 1.0, 1.4, 1.8$
B	Two sides confining	$H_p/D=2$ $B/D=1.8$	$X/D=0.75, 0.9, 1.0, 1.4, 1.8$
C	Two sides confining	$H_p/D=2$ $X/D=0.9$	$B/D=0.7, 1.5, 1.8$
D	One sides confining	$H_p/D=2$ $B/D=1.8$	$X/D=0.75, 0.9, 1.0, 1.4, 1.8$
F	One sides confining	$H_p/D=2$ $X/D=0.9$	$B/D=0.7, 1.5, 1.8$

4. Results and dissections

The load settlement relation for all experimental tests and the ultimate bearing capacity with and without confinement are presented. The improvement of bearing capacity due to soil confinement is represented by non-dimensional factor called Bearing capacity improvement ratio "BCIR". This factor is defined as the ratio of the ultimate footing bearing capacity with soil confinement to that observed in case of without confinement.

The footing settlement (S) is also expressed in non-dimensional form in terms of the footing diameter (D) as the settlement ratio, (S/D). To verify the experimental results, the theoretical ultimate bearing capacity can be calculated from equation (1) then the computed value is compared by experimental result of the unconfined case.

$$q_u = 0.5 \zeta_c \gamma DN_\gamma \quad (1)$$

By De Beer [16], the values of the bearing capacity factor N_γ from Terzaghi [17] and From the characteristic values of the tested sand listed in section (2.2), the theoretical ultimate bearing capacity of circular footing with 50mm diameter is 18.4 kN/m². The measured ultimate bearing capacity for the unconfined case is 19kN/m². This experimental value shows a close agreement between the experimental and theoretical results.

4.1 Effect of cell confinement

Typically pressure settlement relations observed from deferent series test are presented in Fig. 4. It shows the bearing pressure versus settlement ratio (S/D) for test series group A. It can be noted that the applied bearing

pressure versus settlement response for the cases of soil confinement is significantly better than that for the unconfined case.

This improvement can be explained, when the footing is loaded, the confinement around the soil underneath the footing resist the lateral displacement of soil this leads to significant decrease in vertical settlement and hence improving the bearing resistance of footing.

Figure 4 shows the variation of BCIR with normalized cell radius for different cell heights with a constant footing diameter of 50mm. A significant increase in the ultimate bearing capacity of the model footing supported on confined sand with the decrease of R/D is observed. It can be seen that the BCIR can reach to 12 times of that obtained for the unconfined case. At the same of bearing stress level, significant reduction in footing settlement due to the decrease of cell diameter can be noted so; this method is very useful where the structures are sensitive to settlement. It is clear that the best benefit of soil confinement can be achieved with a (R/D) ratio between 0.75 to 1.0 for different heights of confining cells.

It can be observed from Fig. 5 the variation of BCIR with normalized cell height (H_c/D) due to different normalized cell radius (R/D). It shows slightly improvement in bearing capacity with the increase of cell height. It can be noted that the value of BCIR ranges from 9.5 to 12 when the H_c/D ratio ranges from 0.6 to 3. No significant increase in footing resistance can be noted with the variation of cell height when the ratio of R/D greater than 1.

Figure 6 shows the footing model before and after the test. While conducting the model tests, it was observed that the cell and the soil inside it acted as one unit like pile for cases of small cell diameter. When a large cell diameter was used this behavior was no longer noticed especially as the load increased. It can be seen from Fig. 6 that the plastic state starts around footing edges and spreads to the confining cell. The mobilized friction between the cell wall and sand increases as the active earth pressure increases [18]. Steel cells with different height and diameters could easily be manufactured and installed around individual foundations. The installation of cell could be achieved by removing the soil only beneath foundation to the entire depth of cell. The cell is placed around footing and then filled with compacted sand. When the suggested method is compared with the other methods used to improve the bearing capacity such as soil reinforcement by horizontal layers [3,19-22] in which the whole site is excavated and the layers of reinforcement and sand are placed then compacted, the method can be found economic and save effort and time.

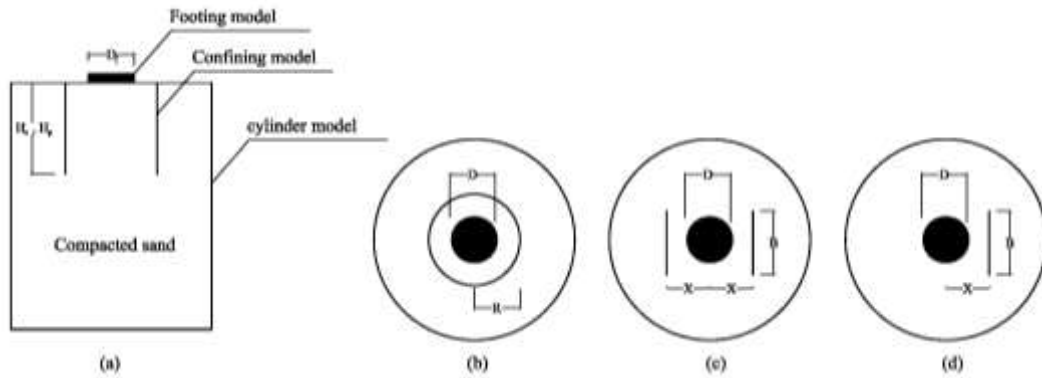


Fig. 3 definition of problem; (a) elevation ; (b) cell confinement; (c) two sides confining; (d) one side confining

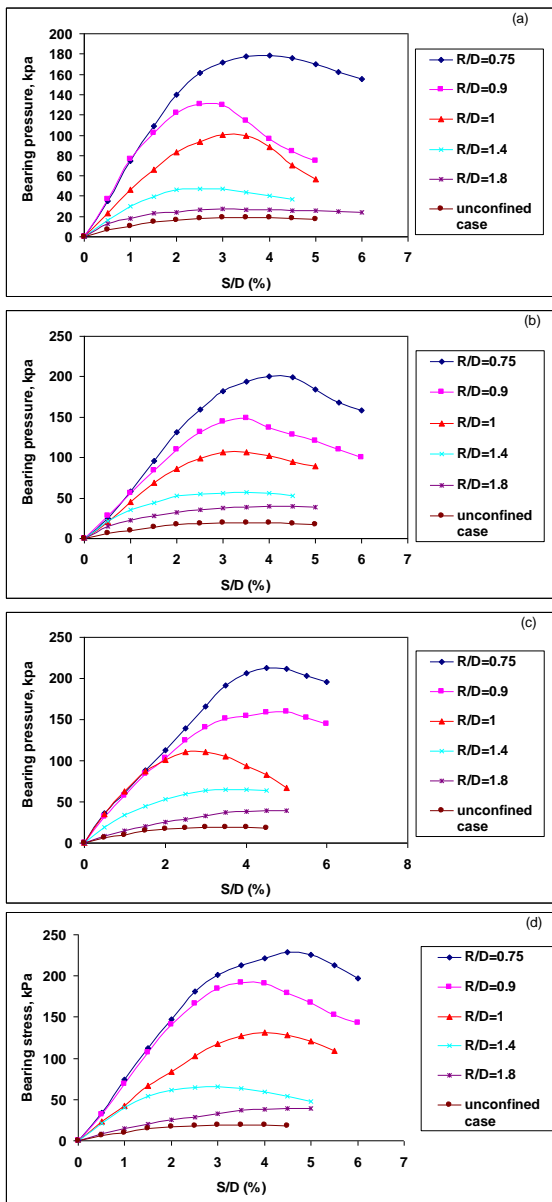


Fig. 4. Bearing pressure versus settlement ratio (S/D) for different cell radii (R/D), (a) $H_c/D= 0.6$; (b) $H_c/D= 1.5$, (c) $H_c/D= 2$, (d) $H_c/D= 3$.

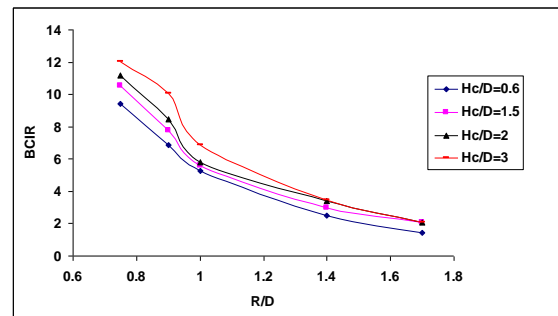


Fig. 5 Variation of improvement factor (BCIR) with normalized cell height (H_c/D) and normalized cell radius (R/D).



Fig. 6 soil footing system before and after load application

4.2 Effect of one and two sides confinement

One and two sides confinement is examined in this study to represent the cases where the piles or sheet piles are used at one side or more around the side before the excavation to protect the neighboring structures. If these elements are permanent, it act as lateral confinement around shallow foundations and contribute in the improvement of bearing capacity. Fig. 7 shows typically pressure settlement response observed from different series tests "group B and D" for different values of (X/D). It can be seen significant decrease in settlement with the decrease (X/D) and hence improvement in bearing capacity. Fig. 8 shows comparison between the main cases in this study (cell, one and two sides confinement). It can be noticed that the maximum improvement of bearing capacity can be achieved when the soil is surrounded from all sides (cell

confinement).it can be noted that the value of BCIR for case of two sides confinement is about 1.85 of that observed for the case of one side confinement. For example, for case of $(X/D) = 0.8$ (note that $X/D=R/D$) the value of BCIR equal to 12, 4.3, 2.36 for cases of cell, two sides and one side confinement respectively. It can be observed that no significant variation in results between cases of cell confinement and two sides confinement when the confinement wall is spaced from the footing center 1.5 times footing diameter.

In order to investigate the effect of confinement width (B) on the footing behavior, the results series tests groups (C, F) is presented in Fig. 9 for cases of one and two sides confinement. It shows that the strength of soil footing system increases with the increase of confining width. The effect of confinement width on the BCIR for cases of one and two sides confinement is presented in Fig.10. It can be observed that the value of BCIR for the case of two sides confinement equals about 1.7 times of that observed for one side confinement.

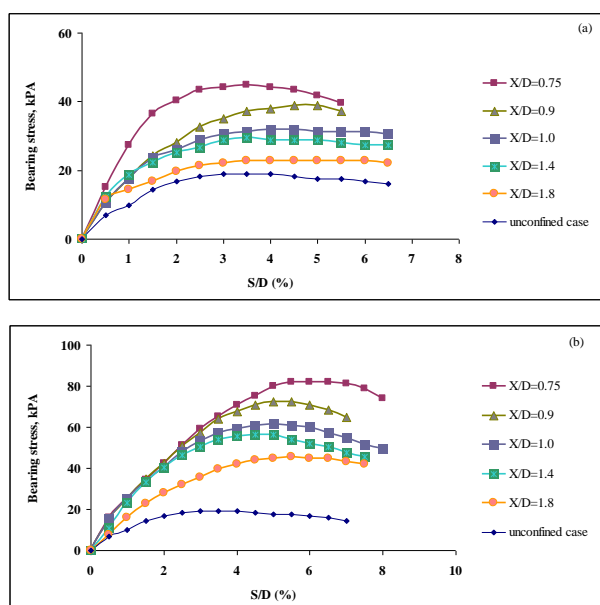


Fig. 7. Bearing pressure versus settlement ratio (S/D) for different plate position (X/D), (a) one side confinement; (b) two sides confinement

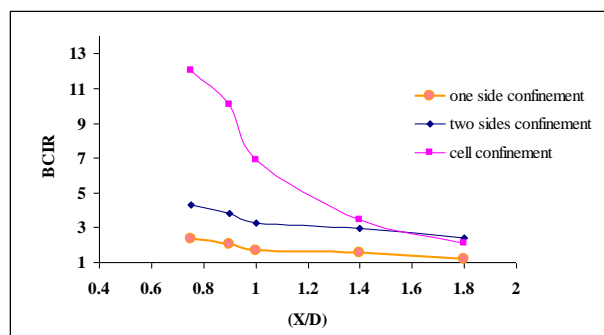


Fig. 8. Variation of bearing capacity improvement ratio with normalized confinement position (X/D) for cases of one side, two side and cell confinement.

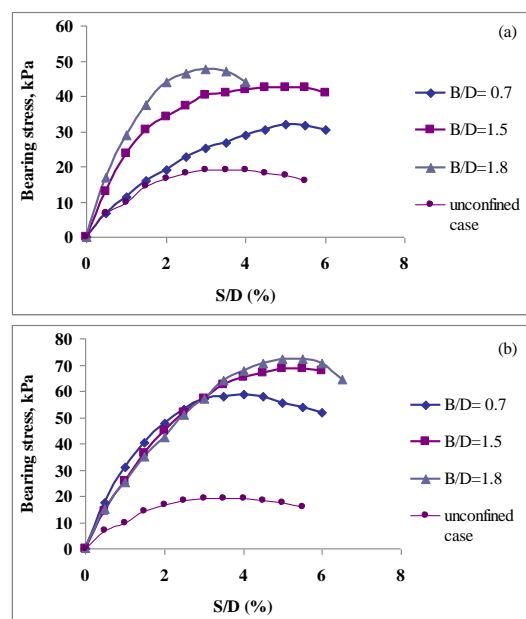


Fig. 9. Bearing pressure versus settlement ratio (S/D) for different cell width (B/D), (a) one side confinement; (b) two sides confinement

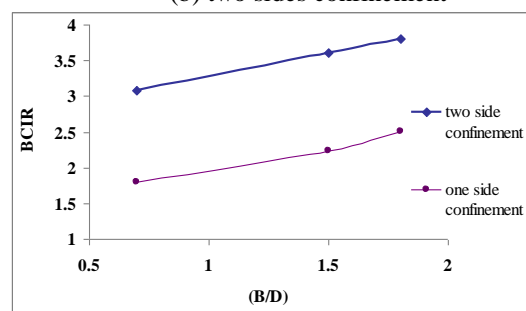


Fig. 10. Variation of bearing capacity improvement ratio with normalized confinement width (B/D) for cases of one side and two sides confinement.

5. Conclusion

This paper investigates the influence of lateral confinement on the bearing capacity of circular footing on sandy soil. The effect of three cases of lateral confinement with some of variable parameters on the BCIR are studied these cases are cell, one and two sides confinement. Based on the obtained experimental study the following conclusions are drawn:

- 1- Soil confinement has a significant effect on the improvement of bearing capacity. It was found to increase by a factor of 12 times of that observed for unconfined case for case of cell confinement. For the cases of one two sides confinement the value of BCIR can reach to 4 and 2.5 respectively.
- 2- The footing settlement decreases significantly due to lateral confinement so; this method is very useful where the structures are sensitive to settlement.
- 3- The improvement of bearing capacity is highly dependent on cell diameter. The improvement increases significantly with the decrease of cell diameter. The results show that the value of

BCIR slightly increases with the increase of cell height.

- 4- The results showed that the optimum improvement is achieved when the cell diameter equals to 1.5 times of footing diameter.
- 5- For cases of one and two sides confinement, the value of BCIR increases with decrease of spacing between confinement and footing center as well as the confinement width. These types of confinement simulate the using of piles or sheet piles to support deep excavation. These systems have a significant effect on the improving of bearing capacity beneath shallow foundations.
- 6- Based on the experimental results, The improvement in bearing capacity of circular footing subjected to two sides confinement equal to about 1.85 of that observed for one side confinement.

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