Research Article

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Impact of eccentricity and depth-to-breadth ratio on the behavior of skirt foundation rested on dry gypseous soil

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Abstract: Gypseous soils are considered one of the most problematic soils. The skirted foundation is an alternative technology that works to improve the bearing capacity and reduce settlement. This paper investigates the use of square skirted foundations resting on gypseous soil subjected to concentric and eccentric vertical load with eccentricity values of 4, 8, and 17 mm in 16 experimental model tests. To obtain the results by using this type of foundation, a small-scale physical model was designed to obtain the load–settlement behavior of the square skirted foundation; the dimension of the square footing is 100 mm × 100 mm with 1 mm thickness, the skirt depth (D_s) was 0.5, 1, and 1.5B (where B is the footing width). The footing rests on dry gypseous soil with a relative density of 33%. The tests show that the gypsum content of the soil is 59%. The result shows that the highest bearing capacity for the square shape footing with D_s/B = 1.5 subjected to concentric load results in an improvement ratio of 190%. For the eccentric load, with D_s/B = 1.5, the increase in bearing capacity is about 120% at e = 8 mm when compared with using a foundation without a skirt.

Keywords: square skirted foundation, gypseous soil bearing capacity, settlement

1 Introduction

Gypseous soils are one of the most problematic soils to build on. Previous researchers were not thoroughly studied the square skirted foundation on soils and especially on gypseous soils. Therefore, first, it is necessary to study the effect of using a square foundation with different skirt depths on the behavior of gypseous soil in a loose and dry state and how it is possible to improve strength and reduce settlement.

The chemical composition of gypsum in soil consists of hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$) [1–3], or it may be found as anhydrate calcium sulfate ($CaSO_4$) [4]. Collapsible soils can be found in arid and semi-arid regions in hot climate weather when the rain rate is less than the evaporation rate. Gypseous soil can be classified according to the amount of gypsum present. When gypseous soil contains more than 2% of gypsum, it is known as '"gypsiferous soil" as suggested by Van Alphen and Romero [5], whereas Saaed and Khorshid (1989) used the name "gypsiferous soil" when the soil contains gypsum of more than 6% [6].

In Iraq, the amount of gypsum ranges between 3 and 10% and is considered ineffective in soil properties, according to Smith and Robertson [7], while the amount of gypsum ranges between 10 and 25% gypsum crystal tends to break down the continuity of the soil mass. In civil engineering, when the amount of gypsum in the soil causes a change in soil properties, it can consider gypseous soil [8]. Table 1 shows the classification of gypseous soil. In general, gypseous soil covers 1.5% of the world's surface area which is about 186 million ha. The distribution of gypseous soil in spatial aggregation shows a high concentration of gypseous soil in three major geographic regions, where gypseous soil covers about 72 million ha of Middle East surface area, 51 million ha of Eurasia surface area, and 37 million ha of the Mediterranean surface area in addition to small unevenly distributed areas rest of the world.

Gypseous soil found in Russia, Spain, Armenia, and the USA covers more than (20%) of the Iraq area [9].

Figure 1 shows the distribution of gypseous soils globally [2]. One of the most crucial characteristics of gypsum soil is its open structure; gypseous soil has low density, the number of gaps is high, and porosity in

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Table 1: Classification of gypseous soil [3]

Gypsum content (%)	Classification
0–0.3	Non-gypsiferous
0.3–3	Very slightly gypsiferous
3–10	Slightly gypsiferous
10–25	Moderately gypsiferous
25–50	Highly gypsiferous
>50	Sandy gypsiferous soil

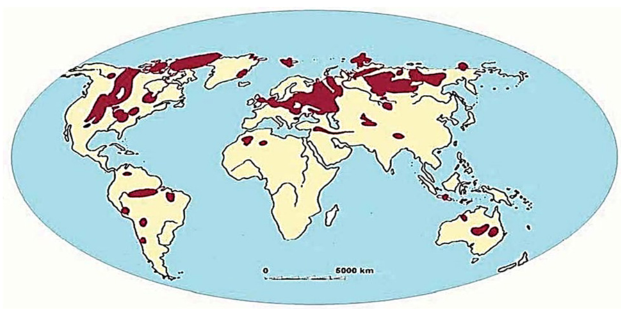

Figure 1: Distribution of gypseous soils globally [2].

gypseous soil is also a high type of soil that is sensitive to weather factors [4,10,11]. Therefore, many civil engineers have sought to devise an effective and inexpensive method to reduce the risk of building facilities on gypseous soils. Many improvement methods were used to improve the bearing capacity and reduce settlement; some methods are expensive [12,13] and restricted by site conditions, and the others have serious side effects in the future that affect human life and the environment [14]. The skirted foundation is one of the ways that civil engineers have devised to reduce settlement and increase the bearing capacity of footing rest on the soil [15–19], which is one of the latest methods of improving the foundation that is considered an alternative to using the surface, pier, and piles in oil and gas facilities and offshore structures, jacket structures, and wind turbines [20,21].

"Skirt" can be defined as one or more walls made of steel or concrete [22,23]. This wall is either vertical or inclined. The skirt surrounding the foundation is connected to the lower part of the foundation and works as a single unit with the foundation that works to confine soil between the walls and transfers load from the structure to the soil [15,24].

A theoretical solution has been proposed to design a reinforced shallow foundation based on laboratory data from 65 small-scale strip footing bearing capacity tests to develop an analytical procedure for predicting the load–settlement and ultimate bearing capacity of a strip footing on sand that contains horizontal strips of tensile reinforcing. The theory is formulated in terms of the ratio of bearing capacity with and without reinforcing, assuming that existing methods are adequate for predicting bearing capacities on the sand with 0 reinforcing [25].

Other studies used the finite element method to investigate the effect of vertical skirts with strip and circular foundations; the result indicated that the improvement with the use of a skirt with a circular foundation is more than the use of a skirt with a strip foundation [26].

An empirical equation was applied on a skirted strip footing subjected to an inclined load. The behavior of a skirted foundation with an inclined or vertical wall on one (or more) sides under an inclined, eccentric load was investigated. The findings indicate that the skirted foundation with an inclined or vertical wall confines the underlying soil and creates resistance to skirt side sliding Figure 2 [15].

A skirted foundation is considered a shallow foundation; skirts are used with shallow foundations of square circular and rectangular shapes. Skirt sides work to reduce sliding failure. This type of foundation is cost-effective because it consumes fewer materials and is based its ease and short time of installation compared with deep foundations such as piers and piles [3].

In this research, the effect of adding a skirt on a square foundation was studied by conducting 16 small-scale physical models. The adopted square footing has a dimension of 100 mm × 100 mm with 1 mm thickness. Experimental work showed the effect of applying vertical concentric and eccentric load with eccentricity values of 4, 8, and 17 mm on the square skirted foundation resting on dry loose gypseous soil and knowing the extent of adding a skirt on the bearing capacity and settlement at different skirt depths. The skirt depth (D_s) was 0.5*B*, 1*B*, and 1.5*B* (where *B* is the footing width).

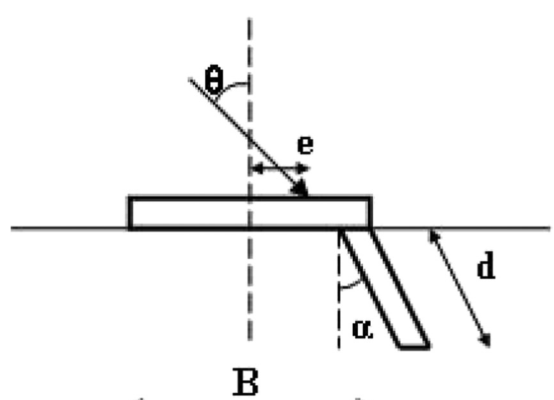

Figure 2: Parameters used in the analysis [15].

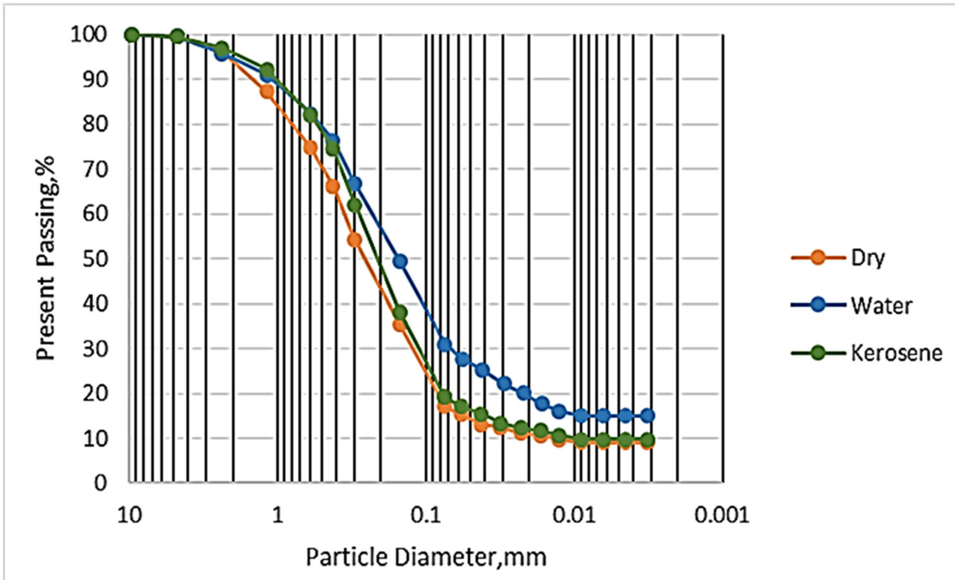

Figure 3: Grain size distribution.

2 Materials and methodology

2.1 Gypseous soil

Experiments were carried out on Gypseous soil. The soil is brought from Tikrit city north of Baghdad with 59% gypsum content. Standard tests found the particle size distribution of the soil used in the research; Figure 3 shows the particle size distribution.

2.2 Model skirted footing

The foundation model has a square shape made of iron with a dimension of 100 mm × 100 mm, skirts are also made of iron welded firmly; the thickness of the foundation and skirt is 1 mm. The depth of skirt (D_s) to the footing width (B), D_s/B values are 0, 0.5,1, and 1.5; the square footing is set above the skirt and works as a single unit. Figure 4 shows the dimension of a used skirt.

2.3 Setup for skirt foundation model tests

A physical model was set up to use in the experimental work to understand the performance of the skirted foundations resting on gypseous soil. The manufacturing setup consists of a glassy container box, the purpose of using the glassy container is to allow better observation of soil homogeneity, and reference markers were used on the sides of the container to help with the formation of the model that has a dimension of 60 cm × 60 cm and 60 cm high, glass thickness 10 mm, as shown in Figure 5.

The second part of the setup is the loading system which consists of a steel arch frame with a mechanical jack of 2 tons attached to the arch frame to apply a concentrated, eccentric load. The jack is connected to a load cell SS300-5T to measure the applied load on the footing. The cell was made from stainless steel with a maximum capacity of 5 tons. Two LVDTs of 75 mm capacity were placed at equal distance on the right and left of the jack sides to measure the settlement when applied load on the footing, and the load cell was connected with the digital indicator to give a reading of the applied load. The two LVDT and the digital indicator are connected to a data logger and “One D.A.Q.” One D.A.Q. can be defined as a new software program developed with python

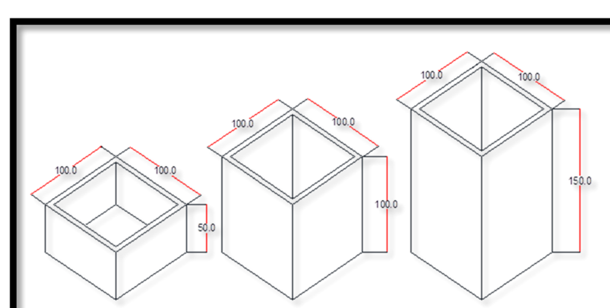

Figure 4: Dimension of a used skirt (mm).

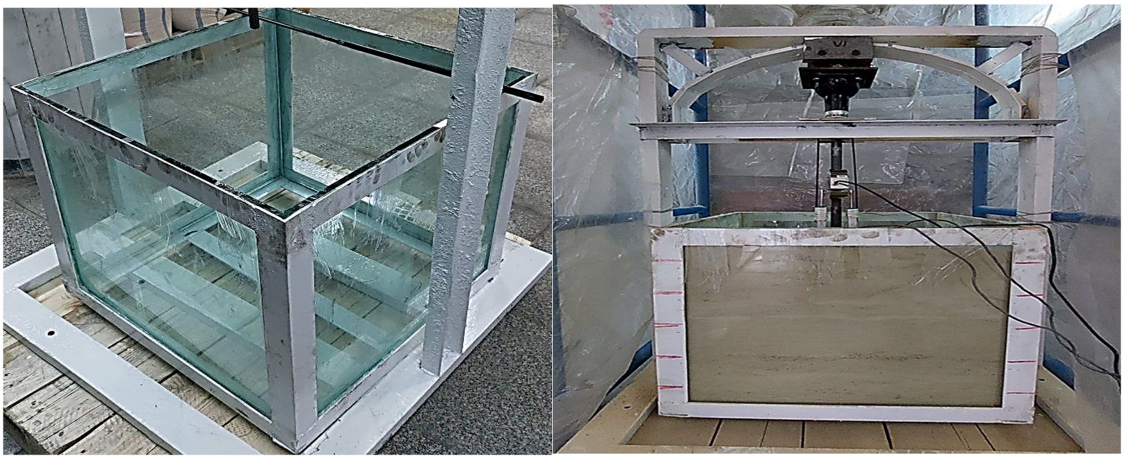

Figure 5: Glassy container and frame model.

programming language specifically for the research. The developed software computes each channel according to predefined instructions based on the sensor type, displays the processed data on the screen in real-time, and stores them into a data file. The program was used to give a reading of the two LVDTs and the applied load. This program gives 13 reads in a second, giving an accurate soil indicator when applied load.

2.4 Skirt foundation model tests: experimental procedure

To study the behavior of a square skirted foundation resting on gypseous soil, laboratory tests were conducted on a square footing with a width (B) equal to 100 mm. To fill the container of a height of 60 cm with gypseous soil, the container was divided into six layers; each layer's thickness was 10 cm. The soil deposit was arranged by using the raining technique. This technique was designed and developed to get the required density and uniform deposit. In this technique, the soil was dropped freely from several heights to achieve the required density for examination. A relationship is established between height and density. The height required to arrange the gypseous soil in a uniform and homogenous with relative density (33%) was calculated to be about 8.5 cm, as shown in Figure 6. After filling the container with gypseous soil, the top surface of the soil was leveled by using a straight steel plate; the soil is leveled gently to maintain the density without any change. Initially, the foundation without a skirt is placed on the gypseous soil's surface at the required level.

For the skirted foundation, the skirt was placed during the raining technique after filling the container; the foundation is placed at the top of the skirt, the two LVDT is placed at an equal distance and then the load is applied. Different skirt lengths of 0.5B, 1B, and 1.5B (where B is the footing width) were adopted in this study. Care was taken to avoid any relative density changes when placing the foundation and skirts. The skirted foundation was subjected to vertical and eccentricity load values of 4, 8, and 17 mm, and the load was applied to the foundations by a hand jack, and the applied load was read by the digital indicator connected to the load cell. A "One D.A.Q." program (Figure 7) was used to record the applied load and the settlement; the program gives 30 reads in a second to present the actual behavior of the soil while applying different loads. Figure 8 shows the test step.

3 Results and discussion

To analyze and determine the behavior of the square skirted foundation, a series of (16) experimental tests were carried out. The skirted foundation rests on loose

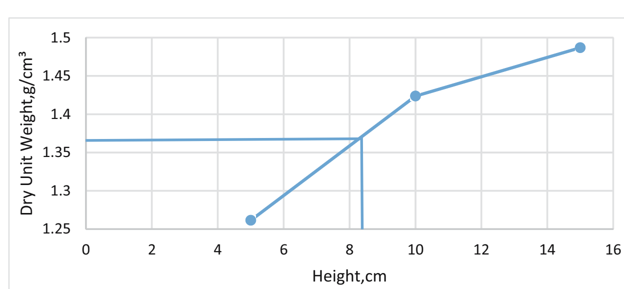

Figure 6: Relationship between dry unit weight and height.

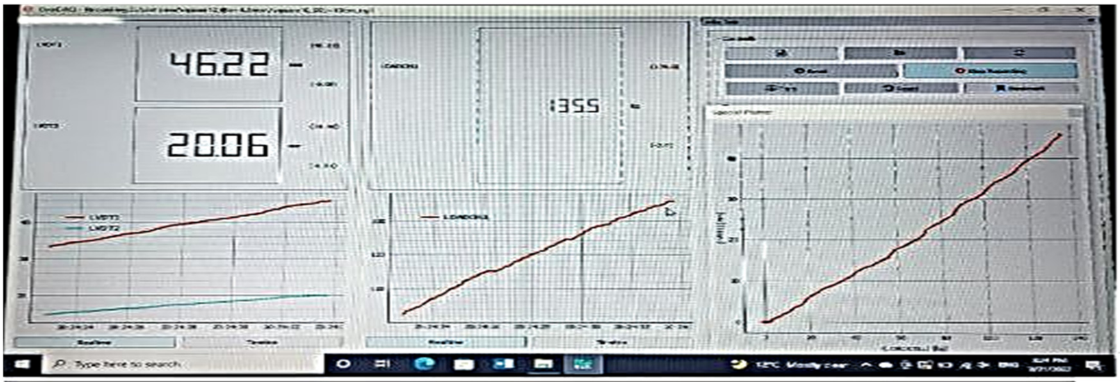

Figure 7: One D.A.Q. Graphical interface. Al-KHAIRO developed it.

Figure 8: Steps of soil preparation and skirt foundation placement.

gypseous soil with 33% relative density. The foundation has a size of 100 mm resting on dry gypseous soil, and the skirts have different lengths 0*B*, 0.5*B*, 1*B*, and 1.5*B*, where *B* is the foundation width. Skirt added to the foundation subjected to vertical and eccentric load with 4, 8, and 17 mm. Figures 9–12 show the results of the model tests. Through the tests, it is possible to raise the effect of eccentric loads on the foundation and know the effect of adding skirts to the foundation and increasing its depth—how it affects improving bearing capacity and reducing settlement.

The result shows the effect of applying eccentricity load on a square foundation with and without a skirt and illustrate the effect of using a skirt increasing its depth. Bearing capacity (at settlement 10%*B*) increases with a skirted foundation for square footing with $D_s = 1.5B$; bearing

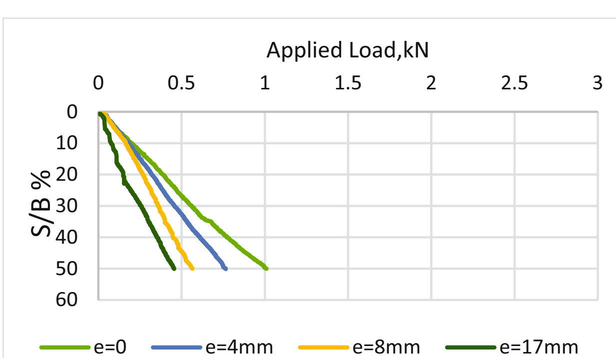

Figure 9: Load–settlement ratio relationship at $D_s = 0B$.

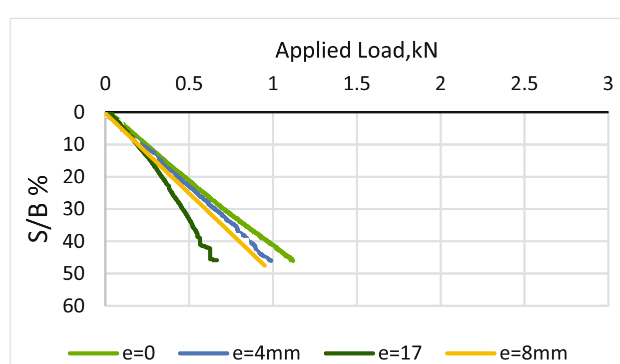

Figure 10: Load–settlement ratio relationship at $D_s = 0.5B$.

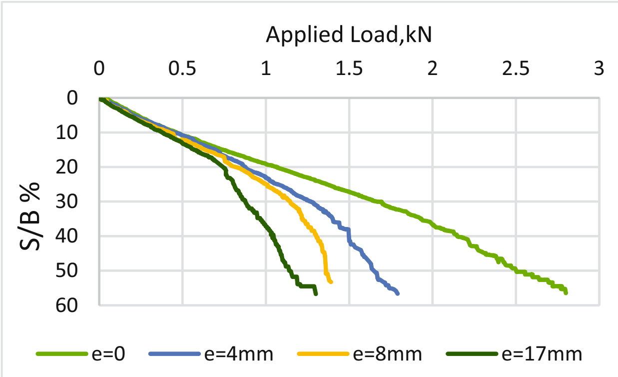

Figure 11: Load–settlement ratio relationship at D_s = 1B.

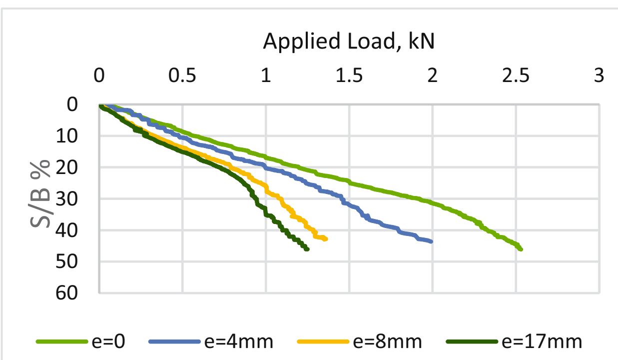

Figure 12: Load–settlement ratio relationship at D_s = 1.5B.

capacity increases about 190%. Also, using a skirt will reduce settlement by roughly 186%. [15–18,24,26–28]. From Figures 13–16, it is observed that the failure load of square skirted foundation increased with increasing skirt depth; for the foundation with a D_s of 1.5B, it is about 0.48 kN. These tests result can be compared with that found by Fattah *et al.* [28], which used a circular skirted foundation with various skirt depths resting on dry gypseous soil with different densities. The general result shows that using skirts with different depths with square or circular foundations increases

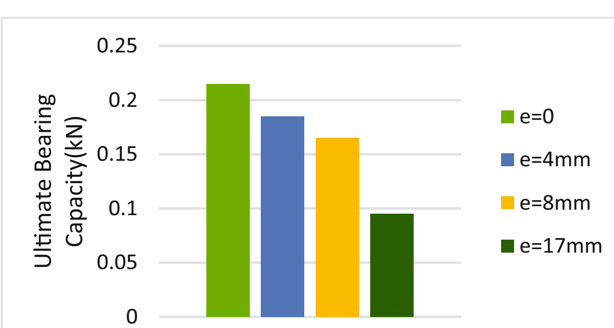

Figure 13: Ultimate bearing load at D_s = 0.

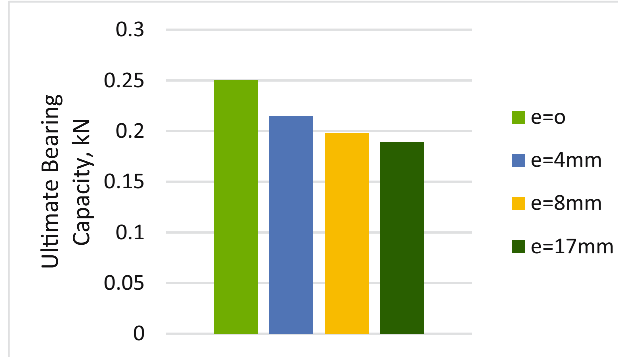

Figure 14: Ultimate bearing load at D_s = 0.5B.

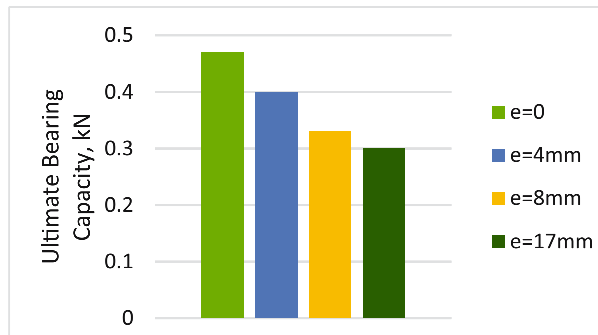

Figure 15: Ultimate bearing load at D_s = 1B.

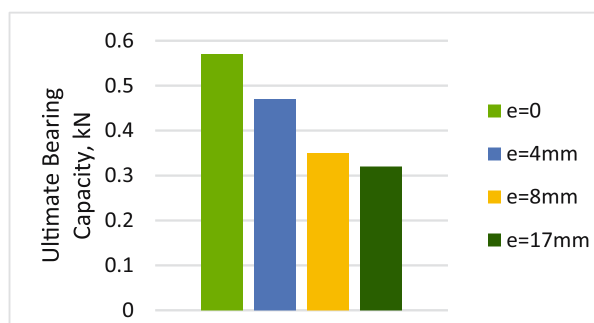

Figure 16: Ultimate bearing load at D_s = 1.5B.

bearing capacity and reduces settlement. The amount of improvement increases with increasing the diameter or width to the depth ratio of the skirted foundation.

4 Conclusion

The tests aim to study the load–settlement behavior of square foundation with and without skirt resting on dry gypseous soil with a relative density of 33% and also to know the effect of increasing skirt depth on bearing capacity and settlement. From test data and results, we can summarize the conclusions as follows:

1) Using skirts with foundation increases the bearing capacity and reduces the settlement of foundation resting on dry gypseous soil with a concentrated load. Bearing capacity improves about 190% when using a skirt with a depth equal to 1.5*B* (where *B* is the footing width). From the result, it is observed that the ultimate bearing capacity of square skirted foundation increases with increasing skirt length.
2) The settlement of the square foundation decreases with using the skirt. For the experimental work results, the settlement decreased by about 186% when using a skirt with a depth equal to 1.5*B* (where *B* is the footing width) and applying vertical load (concentrated load).
3) The behavior of the footing and the displacement of the square skirted foundation depends on the skirt's length, the type of the applied load, and the relative density of soil. Skirts work as a single unit with a foundation that works to confine the soil between the walls and transfer load from the structure to the soil.
4) Using a square skirted foundation improved the bearing capacity of loose gypseous soil when the centric load was applied. For a square skirted foundation with $D_s/B = 1.5$, the bearing capacity increases about 120% at $e = 8$ mm compared with a foundation without a skirt.
5) The settlement decrease when using a skirted foundation and applying eccentric load. For a square skirted foundation with $D_s/B = 1.5$ at $e = 17$ mm, the settlement improved by about 105% compared with a square foundation without a skirt.

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