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Enhancing the Ability of The Square Footing to Resist Positive and Negative Eccentric Inclined Loading Using an Inclined Skirt

Ghazwan Salah alhalbusi[1, a*] and A'amal A.H. Al-Saidi[1, b]

[1]Civil Engineering Department, University of Baghdad, Baghdad, Iraq

[a]ghazwan.salah2101m@coeng.uobaghdad.edu.iq and [b]dr.aamal.al-saidi@coeng.uobaghdad.edu.iq

*Corresponding author

Abstract. Laboratory model tests were performed to investigate the behavior of shallow and inclined skirted foundations placed on sandy soil with R.D%=30 and the extent of the impact of the positive and negative eccentric-inclined loading effect on them. To achieve the experimental tests, it was used a box of (600×600) mm cross-sectional and 600mm in height and a square footing of (50*50) mm and 10 mm in thickness attached to the skirt with Ds=0.5B and various an angle of (10°, 20°, 30°). The results showed that using skirts leads to a significant improvement in load-carrying capacity and decreased settlement. In addition, when the skirt angle increased, the ultimate load improved. Load-carrying capacity decreased with increasing eccentricity and load inclination. For load inclination (Beta) 15° when the eccentricity changed from e=0.15B to e=0.05B, the load improvement percentages were (323.2 to 263%) and (214 to 220%). The settlement reduction factor was (83 to 78%) and (62 to 58%) for positive and negative eccentric-inclined loading, respectively. Also, the result showed that the positive effect on reducing soil-bearing capacity is more than the negative. Increasing eccentricity increases the improvement percentage for positive eccentric-inclined load and decreases for the case of negative eccentric-inclined load. Increased skirt angle will increase the Improvement factor (IR). When the skirt angle increased from 10° to 30° for an improved foundation with load angles of 5°, 10°, and 15°, the improvement factor (IR) increased from (2.53, 2.51, 2.4) to (3.45, 3.65, 3.97) and (2.43, 2.58, 2.54) to (4, 4.63, 5.3) for both negative and positive eccentric-inclined load respectively and settlement reduction factor for load angle 15° and skirt angle increase from 10° to 30° were 34% and 27% for positive and negative eccentric-inclined load respectively. The (IR) for the positive eccentric-inclined load is more than the negative eccentric-inclined load for all cases. In addition, the skirt angle of 30° significantly improved the improvement factor (IR).

Keywords: shallow foundation; sand; skirted foundation; eccentric; inclined loading.

1. INTRODUCTION

Geotechnical engineering mostly deals with the problems of foundation settlement and soil carrying capacity [1,2]. Numerous methods for improving soil have been developed in recent years to enhance its characteristics [3]. However, due to the restrictions of the site circumstances, some of these technologies are too costly and cannot be used. It has been discovered that a skirt is an excellent alternative for improving the soil's carrying capacity and decreasing settlement in shallow foundations[4,5]. The skirt foundation may have one sidewall or more depending on design requirements, and these sidewalls can be vertical or inclined under the footing. Skirt foundation creates a confining for soil [6–8]. Skirted foundations can be made from concrete or steel walls [9]. Experimental tests have been done to study the effects of skirt location according to the load position, number, and length of the skirt on the performance of a rectangular skirted foundation under lateral load placed on sandy soil. The results were the lateral bearing capacity increased with increasing skirt length and skirt number, with the optimum being two skirts. Also, the location of the skirt has a significant effect corresponding to load direction [4].

An experimental laboratory test was carried out to study the performance of rectangular skirted footing placed on sandy soil under vertical loads. The result showed that increased skirt length would improve load-carrying capacity. The biggest improvement in bearing capacity was 262% compared with the unskirted foundation, and the improvement is more effective for low relative density. The improvement was linear, with foundation width for both skirted and unskirted foundations [10]. Twelve experimental trials were carried out on steel circular footings of varying diameters and skirt lengths.

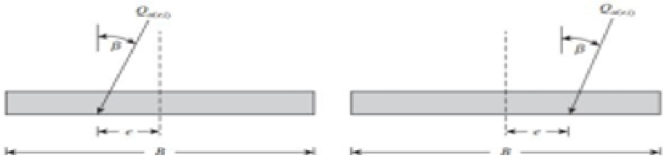
Furthermore, the soil employed in this experiment was sandy soil with a constant moisture content and compaction process. The laboratory experiments showed that skirts successfully increase ultimate carrying capacity because they can extend their length, which increases ultimate carrying capacity approximately (4.70) times in specific experimental conditions. Skirts could also help to decrease settlement [11]. A scale model of the foundation was performed to examine the behaviors of circular-skirted footing placed on sandy soil under vertical loads and study the effect of (relative density, foundation diameter, roughness surface of model, and depth of skirt) on load-carrying capacity and foundation settlement, which will compare with foundation without a skirt. The result showed that increasing the skirt's depth and surface roughness of the skirt side and a decrease in relative density will increase bearing capacity and reduce foundation settlement. The bearing capacity improved up to five times, and the settlement was reduced by 8% from footing without a skirt [12].

The test model was used to study the effect of (skirt depth, relative density, and type of skirted footing) on the sand. The skirt was of varied types, including a plus shape and a double box shape. The outcomes indicated that the bearing capacity and behavior increase due to the geometry of the footing and skirt.

Moreover, the lowest improvement was approximately 26% by using square footing with (Ds=0.25B, Dr=60%), unlike the maximum improvement was 364% by using double box footing with(Ds=1.5B, Dr=30% [13]. An experimental test was performed to investigate the effect of (various combination types of skirt footing and loose and dense conditions of sandy soil. The outcomes have demonstrated that more skirt parts improve the ultimate load. A strip foundation's bearing capacity decreases under high load eccentricity [14]. A numerical investigation was carried out using the FEM plaxis3D program (different skirt lengths and skirt angles, eccentric load), and it was discovered that increasing the skirt length improves bearing capacity and decreases settlement due to an increase in the displaced soil volume, which generates an increase in soil pressure, and increasing the eccentricity reduce the load-carrying capacity and increases settlement. On the skirt side, the horizontal soil reaction assists in preventing the foundation from sliding. Because of the horizontal soil reaction generated on the skirt side, the skirt's angle strongly affects the soil's bearing capacity [15].

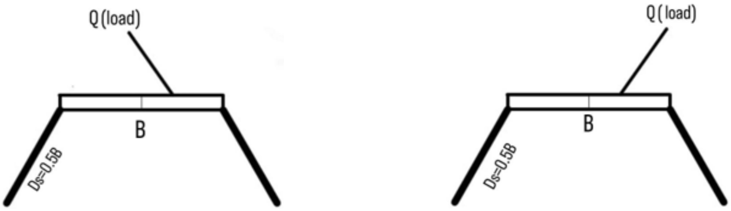
A numerical test was carried out to study the effects of skirt length on the lateral bearing capacity for skirted foundation rest on sandy soil. Lateral bearing capacity increases with the skirt length, and the failure mode changes from sliding mode to rotational when the skirt length increases. The failure mode of footing without a skirt is sliding failure [16]. An experimental test was carried out to determine the behavior of square footing with a skirt compared with a square surface footing placed on dry gypseous soil of (R.D)= 33% and study the effect of skirt length. The result shows that a skirted foundation increases load-carrying capacity and reduces settlement. Using a skirt length of about 1.5B improves the bearing capacity by up to 190% and reduces settlement by up to 186%. Under eccentric load e=8 mm with skirt length =1.5 mm, the bearing capacity increased by 120%, and when e=17mm and skirt length =1.5, the settlement increased up to 105% [17]. Finite element software (ABAQUS) was carried out on the skirted foundation to investigate the effect of (skirt length, internal skirt, and inclination of skirt) under vertical load on sandy soil. The results show that the bearing capacity increases and reduces the settlement when the skirt length increases. Bearing capacity raised to 2 times from surface footing, and settlement decreased by 60% while using skirt length=1.5B (B=foundation width). Furthermore, providing additional internal skirts slightly reduces the value of both settlement and bearing capacity. Bearing capacity was raised by 1.8% compared to surface footing, and settlement decreased by 78% compared to surface footing when the inclination angle of the skirt was 25 degrees [18].

A numerical test using the finite element method was carried out to investigate the behavior of an octagonal mat foundation with and without a skirt under various eccentric load conditions. The results showed that differential settlement reduces when the length of the skirt increases and the reduction value of the settlement in a range of (15-60%). The settlement due to vertical load is not affected by skirt inclusion length up to (3)m. Increasing skirt length leads to a decrease in foundation rotation angle by (50-75%). For 6 m skirt length and 16 m foundation diameter under a maximum eccentricity of 4.01, the reduction of rotation angle was observed at 47% [19]. A numerical test using FEM (GEO STUDIO) was carried out to study the effect of soil infiltration on circular-skirted footing placed on gypseous soil. The result showed that bearing capacity and settlement improved with increasing skirt length, and the settlement under footing was the same and not differential [20]. The above literature shows that using skirts improves load-carrying capacity and reduces settlement under different parameters. In addition, it observed that positive and negative eccentric-inclined loading subjected to inclined skirts had not been used. In this paper, a small experimental model was used to evaluate the performance of a square footing resting on loose sandy soil to resist positive and negative eccentric-inclined loading, as shown in Figures 1 and 2, using an inclined skirt with a skirt angle (10, 20, 30) and Ds=0.5B.



(a) (b)

Figure 1: Footing subjected to (a) positive and (b) negative eccentric inclined loadings.



(a) (b)

Figure 2: Footing with skirt subjected to (a) negative (b) positive eccentric-inclined loadings.

2. TESTING TECHNIQUES AND MATERIALS USED

2.1 Testing Apparatus

The testing apparatus is made up of three major components: the sandbox, the loading mechanism, and the footing and skirt model. The next preceding sections provide a full description of each component. The sand container is a steel box of dimensions (600×600×600 mm depth) made of a steel plate of 3 mm thickness. The side of the box was made from glass with 10 mm thickness, as shown in Figure 3. The box dimensions were chosen to be sufficient to prevent the influence of boundary conditions on the base [21]. The internal faces of the box were covered with polyethylene sheets to reduce the slight friction that might develop between the box surface and the soil.

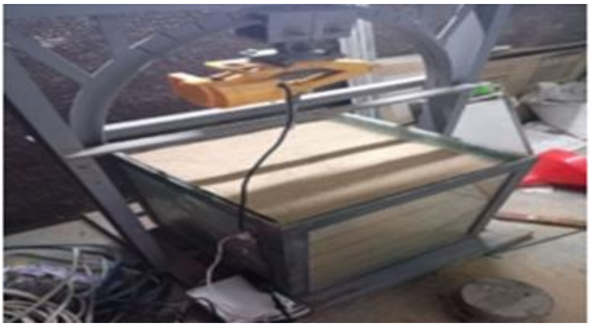
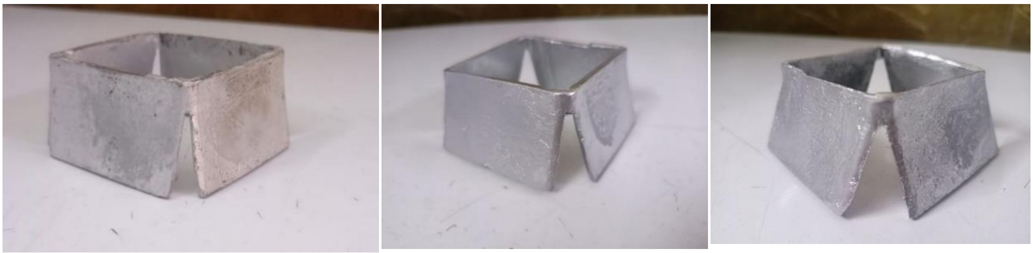


Figure 3: Sand container.

A loading steel frame with an arch to control the load inclination was used to carry out the axial loading on the footing. An electrical jack with an electrical transformer has been added to control the loading speed. A load cell SC516C-1 ton was connected to the electrical jack for measuring the applied load on the footing, and three linear variable displacements (LVDT) were used. Two were placed vertically on the right and left of the footing to measure the settlement, and the third was placed horizontally to measure the horizontal displacement. Loadcell and LVDT were connected to the data logger. A square footing has dimensions of (50×50 mm) and a thickness of 10 mm, shown in Figure 4, and small holes were created on the surface of the footing to ensure that the loading arm does not change its location, as shown in Figure 4. A skirt with four sides was used with a dimension of 50×50 mm, a depth of (0.5B), and a thickness of 5mm. The skirt angles were used (10˚, 20˚, 30˚) as shown in Figure 5. Footing contains a small piece of iron welded over the footing to connect the footing with a skirt.

Figure 4: Footing model used.



(10°) (20°) (30°)

Figure 5: Skirt models used.

2.2 Sandy Soil

Locally sandy soil from the governorate of Karbala, located in the southwest of Baghdad, was collected, washed, and dried. The sand passing from the sieve No.4 was used. The grain size is analyzed according to the ASTM (D422-63). According to the grain-size distribution curve shown in Figure 6, the sand is classified as poorly. Laboratory tests were carried out on the sand to get some other properties, and their values are listed in Table 1.

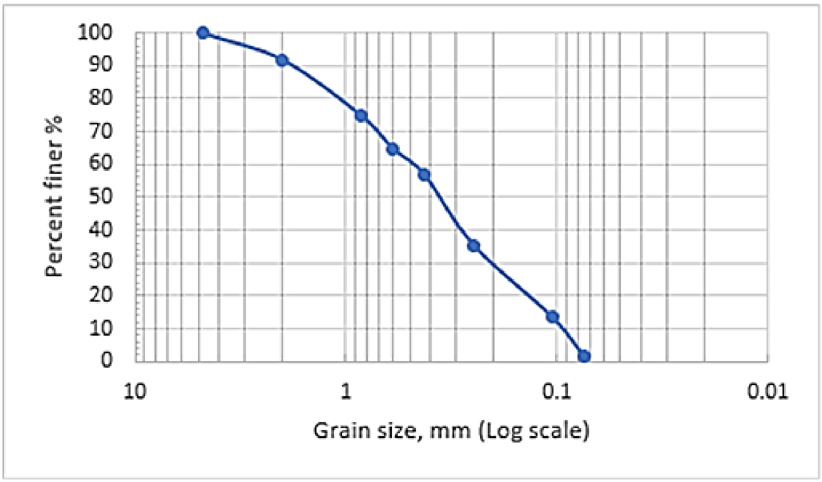


Figure 6: Grain-size distribution of the sandy soil.

Table 1: Physical properties of used sand.

No.	Property Index	Value	Specifications
1	Specific gravity (Gs)	2.664	ASTM D-854-92
2	D10 (mm)	0.1	ASTM D-6913/D6913M-17 [22]
3	D30 (mm)	0.214	
4	D60 (mm)	0.494	
5	Coefficient of uniformity (Cu)	5.117	
6	Coefficient of curvature (Cc)	0.959	
7	Maximum dry unit weight (kN/m^3)	18.3	ASTM D-4253 and D-4254 [22]
8	Minimum dry unit weight (kN/m^3)	15.6	
9	Dry unit weight in test (kN/m^3) at R.D=30%	16.32	
10	Maximum void ratio	0.66	
11	Minimum void ratio	0.415	
12	Relative density (R.D)%	30	ASTM D-2049-64 [22]
13	The angle of interior friction Ø at R.D=30%	32.3°	ASTM D-3080-90 [22]
14	Soil classification (USCS)	Poorly graded sand (SP)	Unified soil classification system

2.3 Test Procedure

A laboratory model test was performed in a frame loading with a box of dimension (600×600) mm and height of 600 mm, and the load cell was attached to the loading arm. A square footing of (50×50) mm with 10 mm thickness and skirts of (50×50) mm with 5 mm thickness and d/B=0.5 in addition to skirt angle (alpha) (10°, 20°, and 30°) were used in the test. The raining technique was used to prepare the sand inside the box. For obtaining a relative density R.D%=30, the washed dried sand that passed from the sieve (No.4) was poured into the box from a constant height of 12 cm, which was chosen after many trials to find the required relative density of 30%. The box was divided into six layers of 10 cm by marking the glass side of the box. An aluminum plate is used to level the surface of each layer carefully level to ensure the required relative density. During the preparation of soil inside the box, the box is filled to the required height, depending on the foundation type. For shallow surface footing, the box is filled and leveled on the top surface of the soil, then the square footing is placed on the center of a leveled surface, as shown in Figure 7. For skirted footing, the box is filled with soil to a specific height equal to the height of the skirt, and then the surface and the skirt on the center, as shown in Figure 8, after keeping the poring soil to fill the box and inside of skirt then level the surface and place a footing inside the skirt. The loading is applied gradually, settlement corresponds to the applied load, and displacement is recorded.

Figure7: Preparation of the test box for surface footing.

Figure 8: Preparation of the test box for a skirted foundation.

3. RESULTS AND DISCUSSIONS

A group of 54 experimental tests was conducted to determine the behavior of the square shallow and skirted foundations. Shallow square footing with a dimension of (50*50) mm and skirted foundation placed on the loose sandy soil of (R.D) =30% subjected to positive and negative eccentric-inclined loads. Several parameters have been studied, such as load inclination (Beta) (5°, 10°, 15°), eccentricity ratio (0.05, 0.1, 0.15) of foundation width, in addition, the length of the skirt was Ds=0.5B (B= width of foundation) with various skirt angle (Alpha) (10°, 20°, 30°). For all these test groups, the failure criteria adopted, as Terzaghi mentioned, is a settlement corresponding to 10% of footing width.

3.1 Load Settlement Behavior

Eighteen experimental tests of the shallow foundation were performed as a reference to compare with the skirt foundation subjected to positive and negative eccentric-inclined loads. Also, these same loads were subjected to the skirt foundation, and 36 tests were conducted to compare it with the shallow foundation. Several curves were drawn for the loading-settlement curve to observe the behavior of the foundation before and after the improvement under the same loading conditions. Figures 9 to 14 represent the effect of two cases of negative and positive eccentric-inclined loading on both the unimproved and improved foundations with inclined skirts (Alpha) 20° drawn together for the comparing purpose and various cases of eccentricities.

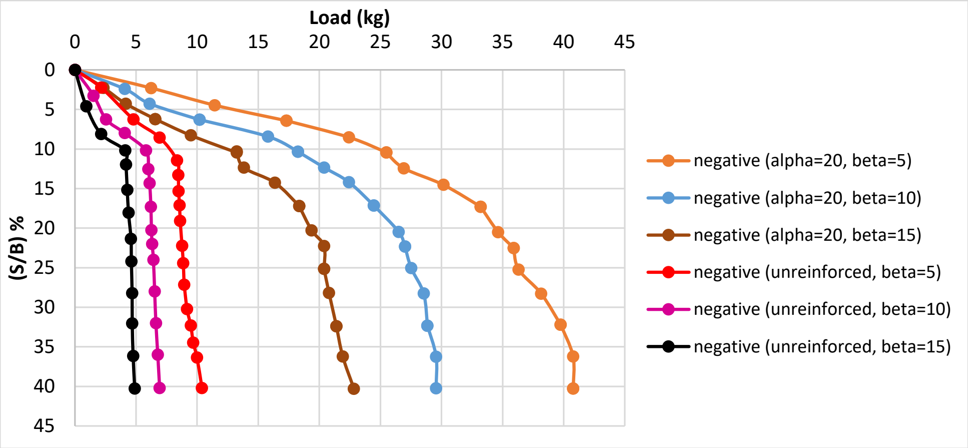


Figure 9: Load-settlement ratio for negative eccentric-inclined load with e/B=0.05 and skirt inclination (Alpha) 20°.

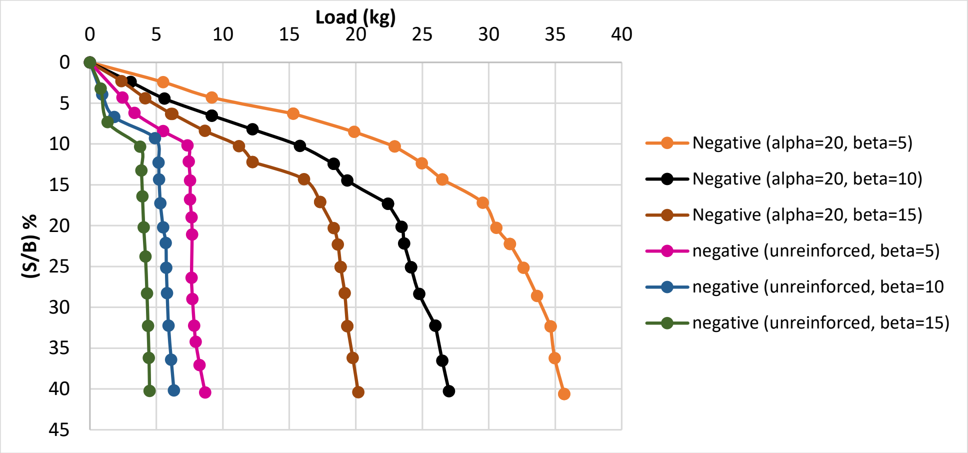


Figure 10: Load-settlement ratio for negative eccentric-inclined load with e/B=0.1 and skirt inclination (Alpha) 20°.

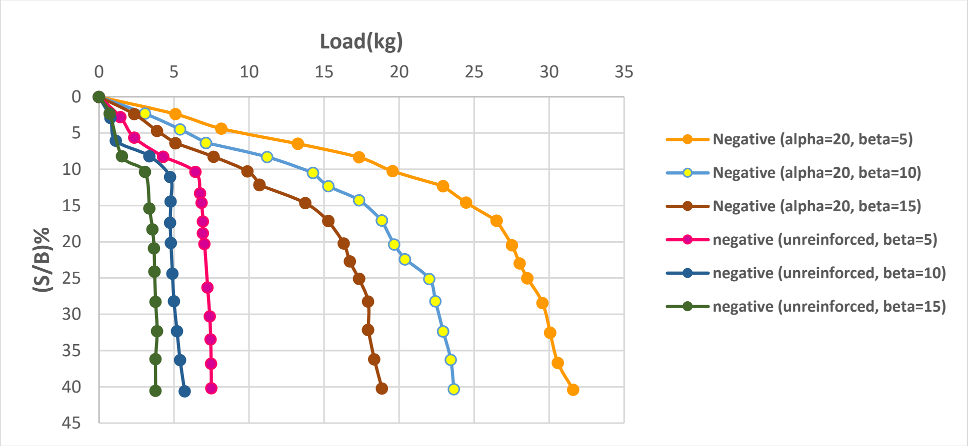


Figure 11: Load-settlement ratio for negative eccentric-inclined load with e/B=0.15 and skirt inclination (Alpha) 20°.

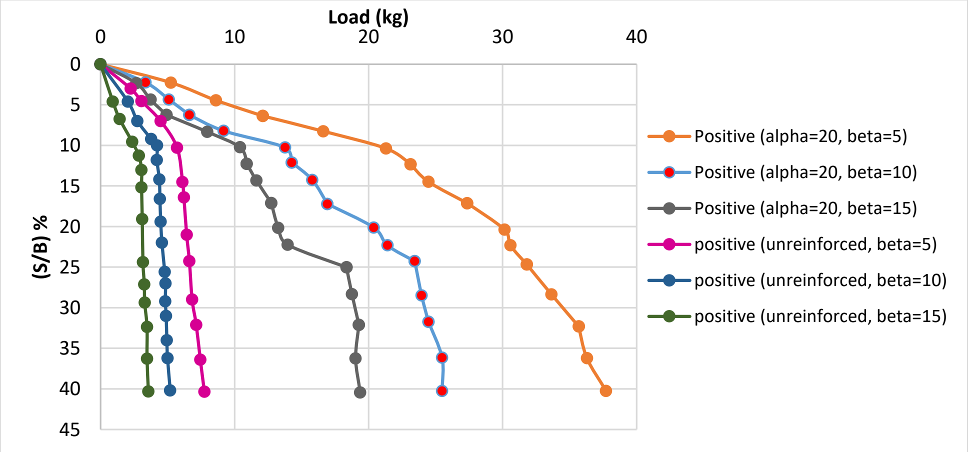


Figure 12: Load-settlement ratio for positive eccentric-inclined load with e/B=0.05 and skirt inclination (Alpha) 20°.

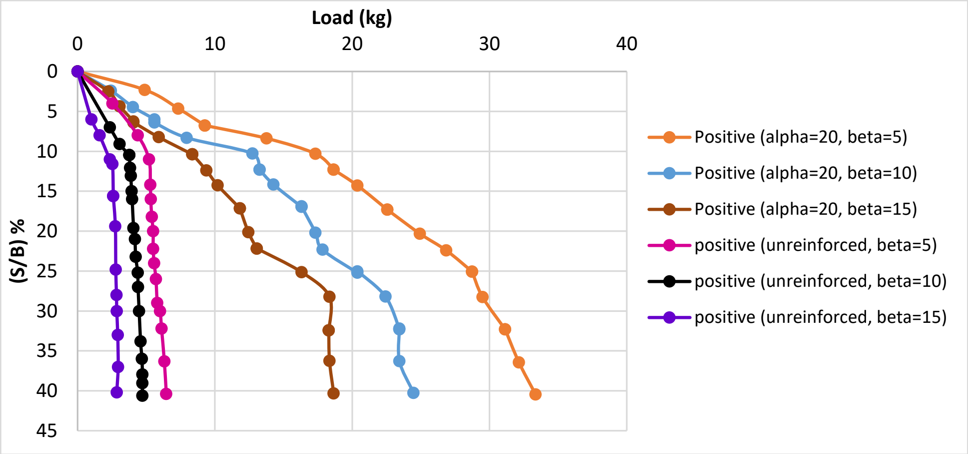


Figure 13: Load-settlement ratio for positive eccentric-inclined load with e/B=0.1 and skirt inclination (Alpha) 20°.

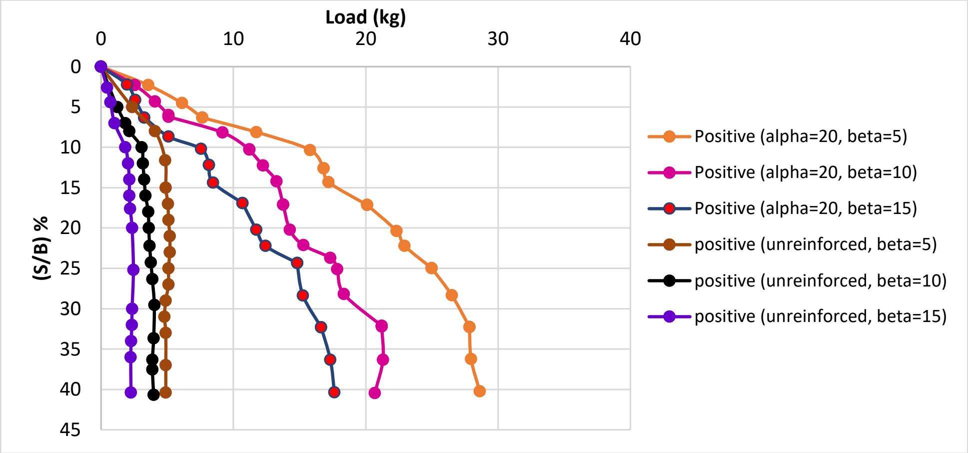


Figure 14: Load-settlement ratio for positive eccentric-inclined load with e/B=0.15 and skirt inclination (Alpha) 20°.

The results generally show that employing skirts improved the load-carrying capacity and decreased settlement for all loading cases because the skirts work to confine the soil below the footing and lead to making the foundation act as a single part to transfer loads to great depths. In addition, the load-carrying capacity of unimproved and improved foundation with skirt is reduced with increasing eccentricity and loading angle for all cases, which agrees with [28–36]. Analysis of experimental results showed that the effect of positive eccentric-inclined loading on the reduction of soil-bearing capacity is greater than negative eccentric-inclined loading for all cases because the applied loading affects away from the foundation's center, which agrees with the result of [29,37].

The load-carrying improvement percentage [(Pr/P-1)×100] (where Pr and P are the maximum loads for improved and unimproved sand, respectively) For load inclination (Beta) 15° when the eccentricity changed from e=0.15B to e=0.05B the load improvement percentages were (323.2 to 263%) and (214 to 220%) and settlement reduction factor were (83 to 78%) and (62 to 58%) for positive and negative eccentric-inclined loading, respectively, and have two results, the first one when eccentricity increased the improvement percentage increase for positive eccentric-inclined load, and decrease for the case of negative eccentric-inclined load. The second result showed that the improvement percentage for positive eccentric-inclined load is more than the negative eccentric-inclined load.

3.2 Effect of Skirt Angle

To analyze the effect of increasing skirt angle (alpha) on the behavior of the foundation placed on sandy soil, skirts with various angles (10°,20°,30°) and Ds=0.5B were used. A bar chart expressed by improvement factor (IR) has been used, as shown in Figures 15 and 16. To assess the effect of skirt angle. It must be noted that IR=1 for unimproved footing.

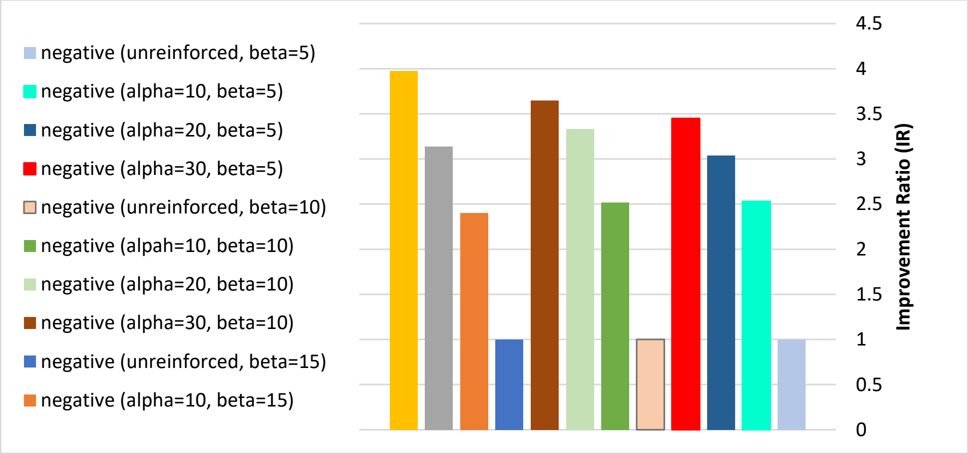


Figure 15: Variation of improvement ratio with skirt angle (alpha) under negative eccentric-inclined load with e/B=0.15.

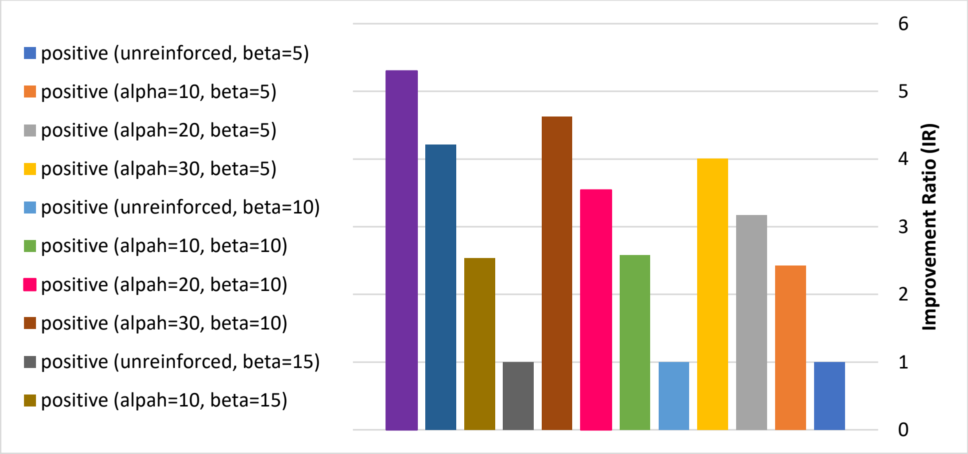


Figure 16: Variation of improvement ratio with skirt angle (alpha) under positive eccentric-inclined load with e/B=0.15.

From the result above, the increasing skirt angle leads to an increased improvement factor (IR). When the skirt angle increased, the ultimate load improved due to a contact area being created between the inclined skirt angle and soil, which agrees with the result of references [8,15,18]. The improvement factor (IR) for positive eccentric-inclined loading was more than negative. When the skirt angle increased from 10° to 30° for an improved foundation with load angles of 5°, 10°, and 15°, the improvement factor (IR) increased from (2.53, 2.51, 2.4) to (3.45, 3.65, 3.97) and (2.43, 2.58, 2.54) to (4, 4.63, 5.3) for both negative and positive eccentric-inclined load respectively and settlement reduction factor for load angle 15° and skirt angle increase from 10° to 30° were 34% and 27% for positive and negative eccentric-inclined load respectively. From the results above, when the loading inclination increased, the improvement factor increased for both negative and positive eccentric-inclined loading. The skirt angle of 30° significantly improved the improvement factor (IR).

4. CONCLUSIONS

- Loads-carrying capacity decreased, and settlement increased with increased both eccentricity and loading angle for all cases. For load inclination (Beta) 15° when the eccentricity changed from e=0.15B to e=0.05B, the load improvement percentages were (323.2 to 263%) and (214 to 220%) and the settlement reduction factor was (83 to 78%) and (62 to 58%) for positive and negative eccentric-inclined loading, respectively.
- The effect of positive eccentric-inclined load on reducing soil-bearing capacity and increasing settlement is more than negative eccentric-inclined loading for all cases.
- The improvement percentage for the positive eccentric-inclined load is more than the negative eccentric-

inclined load.

- Increasing eccentricity increases the improvement percentage for positive eccentric-inclined load and decreases for the case of negative eccentric-inclined load.
- Increased skirt angle will increase the Improvement factor (IR), and the (IR) for positive eccentric-inclined load is more than the negative eccentric-inclined load for all cases. When the skirt angle increased from 10° to 30° for an improved foundation with load angles of 5°, 10°, and 15°, the improvement factor (IR) increased from (2.53, 2.51, 2.4) to (3.45, 3.65, 3.97) and (2.43, 2.58, 2.54) to (4, 4.63, 5.3) for both negative and positive eccentric-inclined load respectively and settlement reduction factor for load angle 15° and skirt angle increase from 10° to 30° were 34 and 27% for positive and negative eccentric-inclined load respectively.
- The skirt angle of 30° significantly improved the improvement factor (IR).

REFERENCES

[1] Al-Mosawe MJ, Al-Saidi A.A., Jawad FW. Improvement of Soil Using Geogrids to Resist Eccentric Loads. Journal of Engineering. 2008 Dec; 14(4): 3198-3208.
[2] Al Mosawe MJ, Al Saidi A.A., Jawad FW. Bearing Capacity of Square Footing on Geogrid Reinforced Loose Sand to Resist Eccentric Load. Journal of Engineering. 2010 Jun;16(2).
[3] Bachay H.A. and Al-Saidi A.A. The optimum reinforcement layer number for soil under the ring footing subjected to inclined load. Journal of Engineering. 2022 Dec; 28(12).
[4] Thakare PSW, Shukla AN. Performance of Rectangular Skirted Footing Resting on Sand Bed Subjected to Lateral load. 2016; 3(2013):11075–1183.
[5] Kirtimayee B, Samadhiya NK. Behavior of Loose Geogrid Skirted Square Footing Resting on Reinforced Sand Subjected to Eccentric and Inclined Loading. Indian Geotech J. 2022; 52(4): 895–906.
[6] Sasikumar A. Behaviour of Circular Skirted Footing Resting on Sea Sand. Int Res J Eng Technol [Internet]. 2008. Available from: www.irjet.net
[7] Pusadkar SS, Tejas Bhatkar M. Behaviour of Raft Foundation with Vertical Skirt Using Plaxis 2d. Int J Eng Res [Internet]. 2013; 7(6):20. Available from: www.ijerd.com
[8] Saleh NM, Alsaied AE, Elleboudy AM. Performance of Skirted strip footing subjected to eccentric inclined load. Electron J Geotech Eng. 2008.
[9] Acosta-Martinez HE, Gourvenec SM, Randolph MF. An experimental investigation of a shallow skirted foundation under compression and tension. Soils Found. 2008; 48(2): 247–254.
[10] Khatri VN, Debbarma SP, Dutta RK, Mohanty B. Pressure-settlement behavior of square and rectangular skirted footings resting on sand. Geomech Eng. 2017;12(4): 689–705.
[11] RENANINGSIH, Renaningsih, et al. Method to increase ultimate bearing capacity of skirted circular footing. In: AIP Conference Proceedings. AIP Publishing. 2017.
[12] Sajjad G, Masoud M. Study of the behaviour of skirted shallow foundations resting on sand. Int J Phys Model Geotech. 2018; 18(3): 117–130.
[13] Gnananandarao T, Dutta RK, Khatri VN. Model studies of plus and double box shaped skirted footings resting on sand. Int J Geo-Engineering [Internet]. 2020;11(1). Available from: https://doi.org/10.1186/s40703-020-00109-0
[14] ÖRNEK, Murat, et al. Investigation of skirt effect on eccentrically loaded model strip footing using laboratory tests. Soil Mechanics and Foundation Engineering. 2021, 58(3): 215-222.
[15] SINGH, Chamjeet, et al. Performance of Inclined Skirt Footing: Numerical Analysis. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing. 2021.
[16] Bashir K, Shukla R, Jakka RS. Lateral Capacity of Skirted Footing Resting on Level Ground. In: Lecture Notes in Civil Engineering. 2022.
[17] Albusoda BS. Impact of eccentricity and depth - to - breadth ratio on the behavior of skirt foundation rested on dry gypseous soil. 2022.
[18] Lepcha ON, Deb P, Pal SK. Parametric Studies on Skirted Foundation Resting on Sandy Soil. Lect Notes Civ Eng. 2023; 296(1):297–309.
[19] KATARIYA, Piyush; VANZA, Mayur G. Behaviour of Skirted Foundation Under Different Loading Conditions Using FEM Approach. In: Indian Geotechnical Conference. Singapore: Springer Nature Singapore. 2021.
[20] Aljuari KA, Fattah MY, Alzaidy MNJ. Behavior of circular skirted footing on gypseous soil subjected to water infiltration. 2023.
[21] Saha Roy S, Deb K. Bearing Capacity of Rectangular Footings on Multilayer Geosynthetic-Reinforced Granular Fill over Soft Soil. Int J Geomech. 2017; 17(9):1–17.
[22] ASTM (D4253-14). Standard Test Method for Maximim Index Density And Unit Weight Of Soils Using A Vibratory Table. 2015.
[23] ASTM D3080 / D3080M-11. Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM International, West Conshohocken, PA. 2011. www.astm.org.

[24] ASTM D 2049-64. Standard Test Methods for Calculation of Relative Density. Annual Book of ASTM standards. American society for testing and materials, Philadelphia, United States. www.astm.org.
[25] ASTM D 4254. “Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.” Annual Book of ASTM Standards. American society for testing and materials, Philadelphia, United States, www.astm.org.
[26] ASTM D854-14. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. ASTM International, West Conshohocken, PA. 2014. www.astm.org.
[27] ASTM D 4253. Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table. Annual Book of ASTM Standards. American Society for Testing and Materials, Philadelphia, United States, www.astm.org.
[28] ORNEK, Murat. Estimation of ultimate loads of eccentric-inclined loaded strip footings rested on sandy soils. Neural Computing and Applications. 2014; 25(1): 39-54.
[29] KRABBENHOFT, Sven; DAMKILDE, Lars; KRABBENHOFT, Kristian. Bearing capacity of strip footings in cohesionless soil subject to eccentric and inclined loads. International Journal of Geomechanics. 2014; 14(3): 04014003.
[30] PUSADKAR, S. S.; NAVKAR, Y. S. Performance of Square Footing Subjected to Eccentric-Inclined Load. International Journal of Engineering Research. 2016; 5(1): 44-46.
[31] HALDER, Koushik; CHAKRABORTY, Debarghya. Effect of inclined and eccentric loading on the bearing capacity of strip footing placed on the reinforced slope. Soils and Foundations. 2020; 60(4): 791-799.
[32] Karkush MO, Aljorany AN. Analytical and numerical analysis of piled-raft foundation of storage tank. InConstruction in Geotechnical Engineering: Proceedings of IGC 2018 2020 (pp. 373-384). Springer Singapore.
[33] Karkush M. Behavior of pile groups subjected to axial static and lateral cyclic loads in contaminated soils. InGeo-China 2016 2016 (pp. 166-174).
[34] Karkush MO, Ala NA. Numerical evaluation of foundation of digester tank of sewage treatment plant. Civil Engineering Journal. 2019 May 22;5(5):996-1006.
[35] Karkush MO, Kareem MA. Behavior of pile foundation subjected to lateral cyclic loading in contaminated soils. Journal of Civil Engineering Research. 2015;5(6):144-50.
[36] Karkush MO. Impacts of soil contamination on the response of piles foundation under a combination of loading. Engineering, Technology & Applied Science Research. 2016 Feb 5;6(1):917-22.
[37] Sharma V, Kumar A. Journal of Rock Mechanics and Geotechnical Engineering Behavior of ring footing resting on reinforced sand subjected to eccentric-inclined loading. J Rock Mech Geotech Eng [Internet]. 2018; 10(2):347–357. Available from: https://doi.org/10.1016/j.jrmge.2017.11.005.