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

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ABSTRACT

Shallow and inclined skirted foundations on 30% sandy soil were examined in the experiment program. The study examined the effects of positive and negative eccentric-inclined loading on foundations. Experimental testing was done in a 600 × 600 mm box with a 50 x 50 mm square footing with a 10 mm thickness. The skirt angles were 10°, 20°, and 30°, and the skirt depth was Ds was 0.5 B. Results showed that using skirts significantly increases load-bearing capacity and decreases tilting. Tilting reduces with a skirt, and skirt inclination (alpha) increases with similar loads. Inclined skirts decrease tilt by (2.3% to 0.66%) at e was 0.15 B, load angle (beta) was 15°, and alpha was 30° in the negative case. Tilting increases with eccentricity. As load inclination grows, unskirted and skirted foundations slide and rotate. For the positive case, the tilting decreases from 10% to 2% with e was 0.15 B, loading angle (beta) was 15°, and alpha was 30° with an inclination skirt. The amount of horizontal displacement of the skirted foundation is more than that of the unskirted foundation when comparing the failure load for the unskirted foundation with the same load for the skirted foundation. Loading a foundation without a skirt causes significant settlement and little horizontal displacement. Increasing the load angle is effective since it greatly affects horizontal displacement. In some situations, such as a negative eccentric-inclined load with Ds was 0.5 B, beta was 15, and e was 0.05 B, the influence of the loading angle may be decreased once failures with eccentricity. When eccentricity increases while the load angle (beta) remains constant, the horizontal displacement of a negative eccentric-inclined load reduces.

Keywords: Inclined skirt, Bearing capacity, Shallow foundation, Tilting, Horizontal displacement.

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تعزيز قدرة القاعدة المربعة على مقاومة التحميل المائل اللامركزي الموجب والسالب باستخدام الحجل المائل

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الخلاصة

تم في التجربة فحص الأساسات الضحلة والمائلة على تربة رملية بنسبة 30%. تناولت الدراسة تأثير التحميل الموجب والسالب المائل اللامركزي على الأساسات. تم إجراء الاختبار التجريبي في صندوق مقاس 600 × 600 مم بقاعدة مربعة 50 × 50 مم وسمك 10 مم. كانت زوايا الحجل 10° و20° و30°، وكان عمق القاعدة Ds = 0.5 B. يؤدي استخدام المحجلات إلى زيادة قدرة تحمل التربة بشكل كبير وتقليل الإمالة. عند استخدام الحجل ، يؤدي استخدام الحجل المائل إلى تقليل الميل من (2.3٪ إلى 0.66٪) عند حمل الفشل (3 كجم) مع e = 0.15B ، زاوية التحميل (بيتا) = 15 درجة ، ألفا = 30 درجة للحالة السلبية. تزداد الإمالة مع الانحراف المركزي، ومع نمو ميل الحمل، تنزلق وتدور الأساسات غير المحجلة والمحجلة. في الحالة الإيجابية ينخفض الميل من 10% إلى 2% مع e=0.15B، وزاوية التحميل (بيتا)=15°، وalpha=30° مع حافة الميل. مقدار الإزاحة الأفقية للأساس المحجل أكبر من الأساس غير المحجل عند مقارنة حمل الفشل للأساس غير المحجل مع نفس الحمل للأساس المحجل. يؤدي تحميل الأساس الغير محجل إلى هبوط كبير وإزاحة أفقية قليلة. تعتبر زيادة زاوية الحمل فعالة لأنها تؤثر بشكل كبير على الإزاحة الأفقية. تعتبر زيادة زاوية الحمل فعالة لأنها تؤثر بشكل كبير على الإزاحة الأفقية. في بعض الحالات، مثل الحمل السلبي المائل اللامركزي مع Ds=0.5B، وbeta=15، وe=0.05B، قد ينخفض تأثير زاوية التحميل بمجرد حدوث فشل مع اللامركزية. عندما تزداد اللامركزية بينما تظل زاوية الحمل (بيتا) ثابتة، تقل الإزاحة الأفقية للحمل السالب المائل اللامركزي.

الكلمات المفتاحية: الحجل المائل, قابلية التحمل, الأساس الضحل, الميلان, الازاحة الافقية.

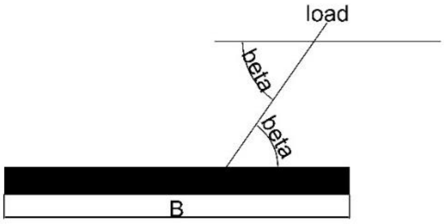
1. INTRODUCTION

Geotechnical engineering focuses primarily on footing settlement and soil-bearing capacity problems **(Al-Saidi, 2009; Al-Mosawe et al., 2010)**. In recent years, numerous techniques for enhancing soil properties have been developed **(Bachay and Al-Saidi, 2022).** However, because of the site's constraints, several technologies are too expensive and cannot be implemented. A skirt is an excellent option for enhancing soil carrying capacity and reducing settling in shallow foundations **(Thakare et al., 2016; Kirtimayee and Samadhiya, 2022)**. depending upon design specifications, The skirted foundation might have a single sidewall or many. Furthermore, those sides may be vertical or inclined under the foundation, The confinement that the Skirt foundation provides for the soil **(Saleh et al., 2008; Sasikumar, 2008; Pusadkar et al., 2013**). steel or concrete walls may be used in the construction of skirted foundations **(Acosta et al., 2008).** To increase the load-carrying capacity and reduce settlement, several technologies and studies have been carried out, such as the use of reinforcing layers (geogrid) **(Al Mosawe et al., 2008; Al-busoda and Salman, 2013)**, stone

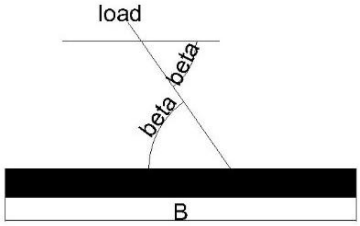
column **(Cheng et al., 2023.)**, piles **(Albusoda and Al-Anbary, 2016; Hadi et al., 2021)** and jet grouting **(AL-Kinani and Ahmed, 2020).** To evaluate the efficacy of a foundation with rectangle-shaped skirts performed when pushed laterally on granular soil. It was found from these analyses the load position is affected, this involves where the location, number, and length of the skirt. The research results indicate a noticeable relationship between the enlargement of skirt length and the addition of multiple skirts, such as two skirts, followed by enhancement of lateral bearing capacity. Furthermore, the skirt's placement significantly impacted the load direction **(Thakare et al., 2016)**. An experiment within a lab setting was undertaken to probe how a foundation shaped like a rectangle with skirts reacts when placed upon sandy soil and exposed to a vertical load. Results showed that making the skirt longer boosts its ability to bear loads; this enhancement in bearing load peaked at 262% more compared to unskirted foundations.
Plus, The enhancement has greater efficacy when applied at lower relative densities. The degree of enhancement exhibited a linear relationship with the width of the foundation, regardless of whether it was skirted or unskirted **(Khatri et al., 2017).** Twelve experimental trials were on foundations of steel circular, varying in diameters and depths of skirts. Moreover, the sandy soil employed for these experiments was consistent in moisture content and compacted process. As a result of their capability for increasing length, it's been demonstrated via tests in a lab setting that skirts fully succeed at boosting ultimate load-bearing capacity; indeed, they enlarge the capacity of bearing roughly by (4.70) times under specific conditions test. Skirts may also assist in lessening settlement **(Satria et al., 2018).** This study aims to evaluate the effect of several variables, including relative density, foundation diameter, surface roughness, and skirt depth, on the load-carrying capacity and settlement of a foundation. Additionally, a comparative analysis will be conducted with a foundation that doesn't have a skirt., A model of a small-scale foundation was created. The results showed that lowering relative density, roughening up the surface of the skirt side, and deepening the skirt would all raise bearing capacity and minimize foundation settlement. In contrast to footing without a skirt, the inclusion of a skirt resulted in a notable enhancement in bearing capacity, with an increase of up to five times. Additionally, the presence of a skirt led to a reduction in settlement by around 8% **(Sajjad et al., 2018).** Investigatory tests got into action to examine impacts, including skirt depth, relative density, and the kind of foundation with the skirt on the sand behavior. Skirts come in several configurations like double and plus box types. The load-carrying capacity and behavior enhanced due to the footing and skirt geometry, as revealed by outcomes. Moreover, improvement ranged from 364% for a double-box footing with (skirt length Ds was 1.5 B, relative density (Dr) was 30%) to 26% for a square footing with (skirt depth Ds was 0.25 B, Dr was 60%) **(Gnanandarao et al., 2020).**
The effects of various configurations of skirt foundation varieties and conditions of loose and dense sand soil were investigated through an experimental study. The findings indicate that there is a positive correlation between the number of skirt components and the final load. The carrying capacity of a strip foundation exhibits a reduction as the load eccentricity increases **(Tu and Kaya, 2021)**. An investigation involving numbers was pursued to evaluate how the skirt's length impacts the lateral capacity of foundations enhanced with skirts set in grainy soil. The enhancement of the lateral load capacity is seen with an increase in the length of the skirt. Additionally, a lengthening of the skirt length leads to a transition in the failure mechanism from sliding to rotating. The happening of sliding failure is seen as the primary form of failure in footings that do not have a skirt **(Bashir et al., 2022).** The performance of a square footing with a skirt was examined in a laboratory to examine the

impact of skirt length in comparison to a square shallow foundation set on gypseous dry soil with a relative density of 33%. Consequently, the implementation of a skirted foundation results in an enhancement of its load-bearing capacity; accompanied by a reduction in settlement. The use of a skirt length of about 1.5 times the diameter of the foundation enhances the load-carrying capacity by a maximum of 190% and decreases settlement by a maximum of 186%. The bearing capacity experienced a significant increase of 120% when subjected to an eccentric load of 8mm and a skirt length of 1.5mm. Similarly, the settlement exhibited a notable rise of up to 105% when the eccentric load was raised to 17mm while maintaining a skirt length of 1.5mm **(Abd-Alhameed and Albusoda, 2022).** The research employed the ABAQUS finite element software to evaluate the influence of various elements, such as skirt length, internal skirt structure, and angle of skirt inclination, on how sandy soil reacts when subjected to vertical pressures. Analysis results show that elongation of skirt length positively impacts load-carrying capacity, while concurrent diminution in settlement is noted. When skirt length equal to 1.5 times the width of footing (B), it's observed the structure's load-bearing capacity increase twice versus a surface footing. Moreover, settlement reduce a by 60%. Load-carrying capacity improves by 1.8% and decrease settlement by 78%, on condition that a skirt angle at an angle measuring 25 degrees contrasted to surface footing. Besides this, appending extra skirts internally has been scrutinized to detrimentally affect both settlement and capacity for carrying loads **(Aljuari et al., 2023)**.

Experiments in series, they utilized a model shaped like the letter T of skirt for studying the effect when depth of skirt in addition relative density of sand within bounds 0.25 to 1.5 and also between 30% up to 60% respectively were done. Research findings show that employing skirts with a shape of T boosts ability bearing loads of soil and decreases settlement. From tests performed results it becomes obvious improvement noticeable happens when relative density is 30%. A comparison was conducted between the h-shape and the t-shape. The research revealed that the T-shape has a greater load-bearing capability in comparison to the H-shape. The experimental results indicate that when the skirt depth was raised from 0.25 to 1.5, the failure of the loads for relative densities of (30%, 40%, 50%, and 60%) exhibited a progressive reduction (**Gnananandarao et al., 2023).** The research review demonstrates that the use of skirts provides enhanced load-carrying capacity and decreased settling throughout many parameters. Furthermore, it has been noted that the use of inclined skirts together with positive and negative eccentric-inclined loading hasn't been used. A modest experimental model was utilized in this research to assess the resistance of a squared foundation sitting on sandy loose soil to negative and positive eccentrically inclined loads as shown in **Figs. 1** and **2** employing an inclined skirt with angle of skirt (10, 20, 30) and Ds was 0.5 B.

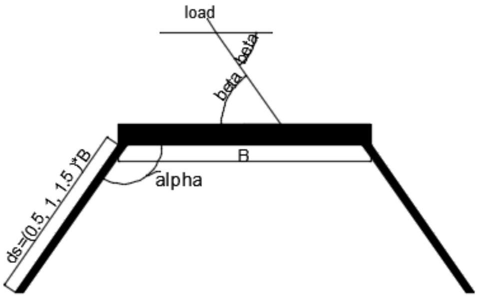


(a)

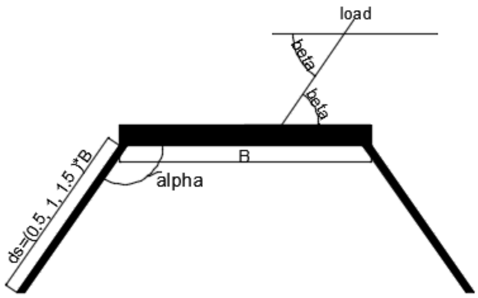


(b)

Figure 1. Foundation exposed to eccentric inclined loadings (a) positive and (b) negative.



(a)



(b)

Figure 2. Foundation exposed to eccentric-inclined loadings with skirt subjected to (a) positive (b) negative inclination.

2. MATERIALS AND TESTING TECHNIQUES

2.1 Instruments for Testing

The testing equipment's three main parts are the footing and skirt model, sandbox, and loading mechanism. Each part has been thoroughly described in the following sections.

2.1.1 The Container of Sand

The sandbox is a steel box with the dimensions of 600* 600* 600 mm in depth, constructed from steel plates with a thickness of 3 mm. Glass 10mm thick was used for the box's side, which is shown in **Fig. 3.** The box was made large enough so that boundary circumstances wouldn't affect the foundation **(Saha Roy and Deb, 2017)** Polyethylene sheets were applied to the inside surfaces of the box for reducing the potential for little friction that might generate between the container and soil.

Figure 3. The sand container.

2.1.2 The Loading Technique

A steel loading frame with an arch for load inclination adjustment applied axial force to the foundation. Additionally, an electrical jack equipped with a transformer for electricity was included to adjust the loading rate. The applied load on the footing was measured using a load cell SC516C-1 tonne plugged into an electrical jack and three linear variable displacements (LVDT). The settlement was measured using two of them located vertically to the left and right of the foundation, while the third was placed horizontally for measuring the lateral movement. The data logger was connected to the load cell and LVDT.

2.1.3 The Footing and Skirt Model

As shown in **Fig. 4**, a square foundation measuring 50mm*50mm and having a thickness of 10mm is equipped with small holes on its surface that prevent the movement of the loading arm. A four-sided skirt, measuring 50mm x 50mm, with a depth of 0.5B (where B represents the width of the footing) and a thickness of 5mm, was used. **Fig. 5** shows skirt angles of 10°, 20°, and 30°. A skirt is attached to the footing by a welded iron strip.

2.1.4 Effects of the Sand Container's Boundaries

The borders of the model box may impact the displacement patterns and stress in the cohesionless soil. Furthermore, the frictional force between the soil particles and the container walls will decrease the vertical stress inside the sand as the depth increases **(Kraft, 1991).** To minimize sand friction against the wall, the container's height-to-diameter ratio should be equal or less than one **(Garnier, 2001 and 2002).** The loading or installation operation will disrupt the soil region around the skirt. The extent of this disruption will depend on factors such as the soil unit weight and the installation method. However, prior research has shown that the extent of disruption spans from 3 to 8 times the diameter of the skirt (foundation) **(Meyerhof, 1959).**

2.1.5 Impact of the Test Soil's Scale

Although a smaller skirt would result in a less noticeable border, there are additional considerations that need the skirt to remain as large as is feasible. For instance, **(Vipulanandan et al. 1989)** suggested that maintaining a ratio of the pile diameter to the effective soil particle-size diameter (D10) at a value of 50 or higher is preferable to reducing internal scale effects between a penetrating object and the test soil. In their investigation, a ratio of 100 was used. **(Bolton et al. 1999)** examined centrifuge cone penetration trials in sand. The cone diameter (B) ratio to grain mean size (D50) was investigated. For a realistic result, the cone diameter (B) should be 20 times the mean grain diameter. The study findings indicate that the value of D50 is 0.425 mm. Consequently, the ratio D/D50 exceeds 100 for the smallest foundation diameter. Hence, the influence of soil particle size (scale effects) on the testing findings is avoided.

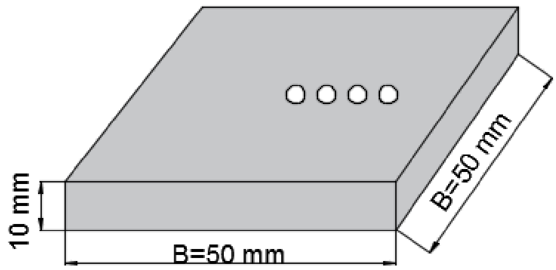


Figure 4. Footing model used.

(a) (b) (c)

Figure 5. Skirt models used, a=10°, b=20°, c=30°

2.2 Sandy Soil

The procedure included extracting, washing, and drying sand from the Karbala governorate, which is located in Baghdad's southwest. We used the sand from sieve #4. The grain size is established using the ASTM D422-63 standard. The sand is poorly graded, classified by the grain-size distribution curve in **Fig.6** The additional characteristics of the sand were determined by laboratory testing; the results are shown in **Table 1.**

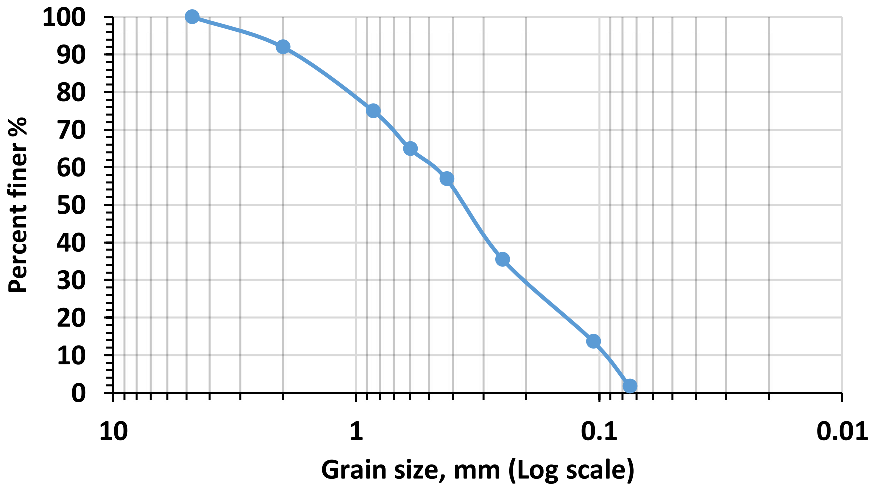


Figure 6. Sand particle size distribution

Table 1. Used sand's physical characteristics.

No.	Property Index	Value	Specifications
1	Specific gravity (Gs)	2.66	**(ASTM D854, 2014)**
2	D10(mm)	0.1	**(ASTM D6913/D6913M, 2017)**
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 D4254, 2006)**
8	Minimum dry unit weight (kN/m^3)	15.6	**(ASTM D 4253, 2016)**
9	Dry unit weight in test (kN/m^3) at R.D=30%	16.32	-------------
10	Maximum void ratio	0.672	**Through phase soil relationships**
11	Minimum void ratio	0.415	**Through phase soil relationships**
12	Relative density (R.D) %	30	**(ASTM D 2049-64.**
13	The angle of interior friction Ø at R.D=30%	32.3°	**(ASTM D3080, 2011)**
14	Soil classification (USCS)	Poorly graded sand (SP)	**Unified soil classification system**

2.3 Test Procedure

The load cell was fastened to the loading arm of a frame used in a laboratory model test, and the measurements of the box were (600 mm * 600 mm) with a height of 600 mm. The box's dimensions were (600 mm * 600 mm) with a height of (600 mm). The load cell was attached to the loading arm of a frame utilized in a laboratory model test, in addition to skirt angles (alpha) of (10°, 20°, and 30°). The sand within the container must have a relative density of R.D% was 30. A raining technique was utilized for preparing the box **(Bieganousky and Marcuson, 1976; Jawad, 2009; Abd-Alhameed and Albusoda, 2022**). The box was filled with washed, dry sand passed through a No. 4 sieve. After many trials, a certain material was selected to get the desired relative density of 30%. It has been shown that sand density increases with increasing drop height. **Fig. 7** shows the variation in dry unit weight and relative density with drop elevation for the used sand. To get a relative density of 30%, Sand was poured into the box at the height of 12 cm. Subsequently, the box was partitioned into six levels, each measuring 10 cm, by marking the glass side of the box. To get the required relative density, an aluminium plate is employed to level the surface of every layer carefully. During the soil preparation process inside the enclosure, the box is filled to the appropriate elevation, which is determined by the type of foundation used, such as a shallow or skirted footing. In the case of shallow surface footing, the procedure involves filling and leveling the box with soil, followed by placing the square footing in the center of the leveled surface, as illustrated in **Fig. 8**. In the case of skirted foundation, the designated box is filled with soil to a chosen height that matches the skirt height. The surface is then leveled, and the skirt is positioned in the center, as shown in **Fig. 9**. After filling the box and skirt with pouring soil, level the surface and set a foundation. The load is applied gradually, and settlement, tilting, and displacement are recorded.

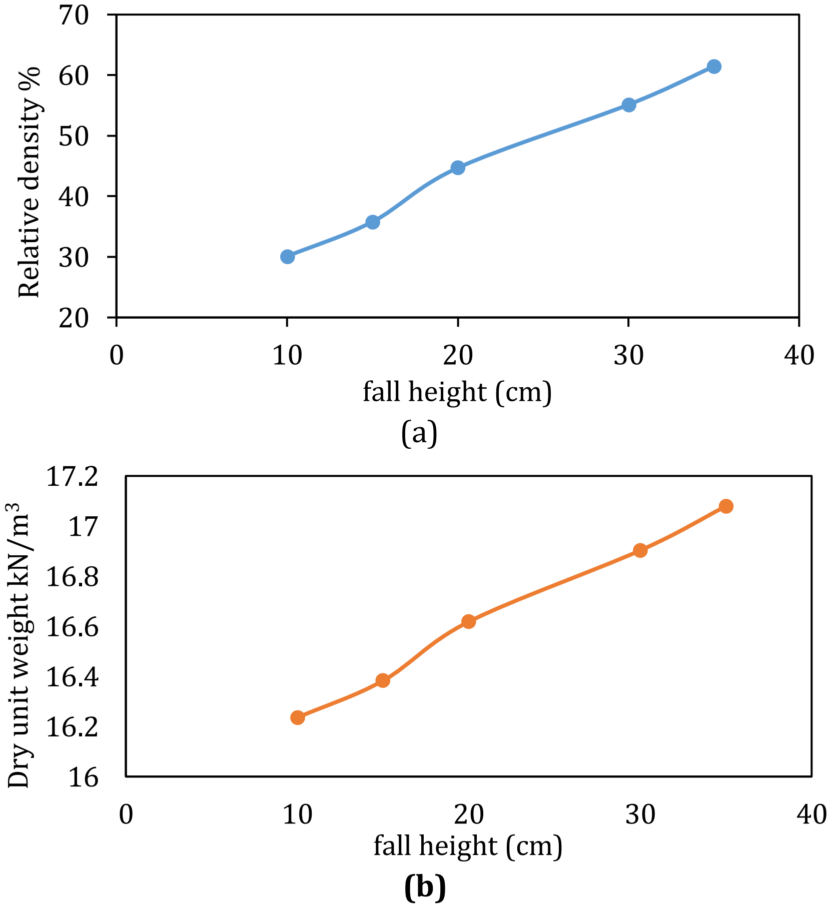


Figure 7. Relationship curve of height with (a) relative density of sand and (b) dry unit weight.

Figure 8. Preparation sequence of the test box for surface footing.

Figure 9. Preparation sequence of the test box for a skirted foundation.

3. RESULTS AND DISCUSSIONS

Seventy two experimental experiments were performed to evaluate the behaviours of square shallow and skirted foundations. A skirted foundation and shallow square footing measuring 50 x 50 mm are set on loose sandy soil with (R.D.) of 30%. They are exposed to both positive and negative eccentrically inclined loading. Various factors were examined, including the inclination of load (Beta ß) of 5°, 10°, and 15°, the eccentricity ratio (0.05, 0.1, and 0.15) of the foundation width, and the skirt length (Ds was 0.5 B, where B is the foundation width) and skirt angle (Alpha α) of 30°. A settlement equal to 10% of the footing width was chosen as the failure criterion for each of these test groups, according to **(Terzagh, 1943).**

3.1 Load-Tilting Behavior

To compare the shallow foundation to the skirt foundation under both positive and negative eccentrically inclined loading, 18 experimental tests of the shallow foundation were carried out. Additionally, 54 tests with the same loads were performed on the skirt foundation to compare it to the shallow foundation. For the loading-tilting curve, many curves were constructed to compare how the foundation behaved under the same loading circumstances before and after improving load-tilting behavior. Hence, tilting % = (max. settlement (Dmax)–min. settlement (Dmin) / footing width) * 100% as shown in **Fig.10**. The impact on the two cases of eccentrically inclined loads, both positive and negative, onto improved and unimproved foundations with 30° inclined skirts (Alpha α) together for comparison, as well as different eccentricity conditions represent in **Figs.11 to 16**. Please, illustrate with assistance of sketches how the tilting % was calculated.

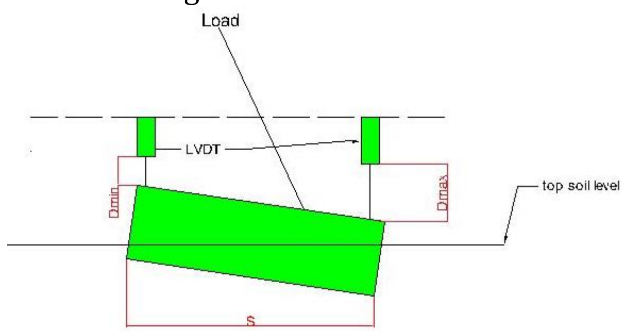


Figure 10. Measuring of tilting.

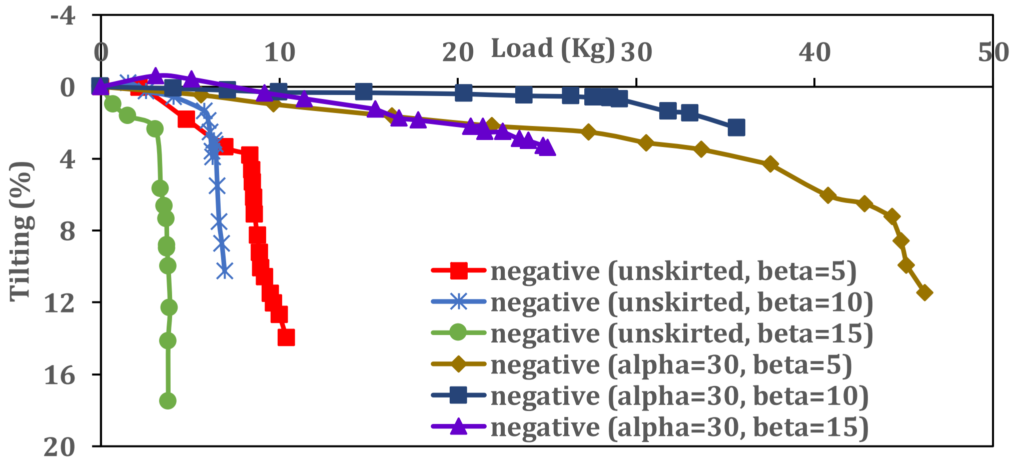


Figure 11. Load-tilting ratio with e/B=0.05 for negative eccentric-inclined loading.

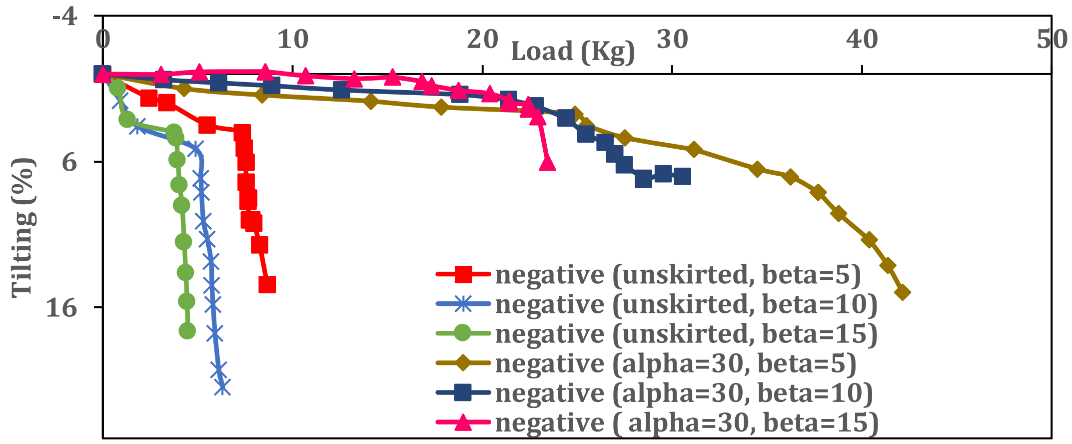


Figure 12. Load-tilting ratio with e/B=0.1 for negative eccentric-inclined loading.

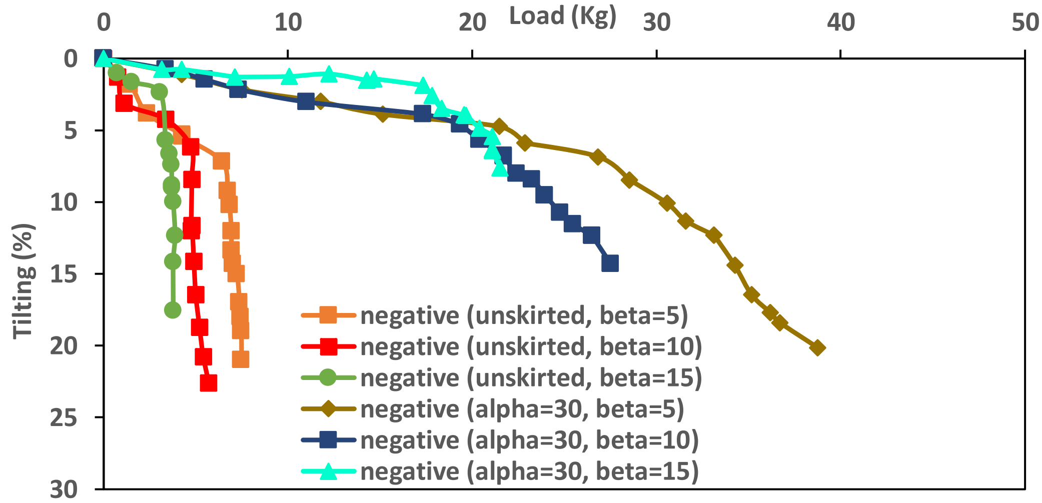


Figure 13. Load-tilting ratio with e/B=0.15 for negative eccentric-inclined loading.

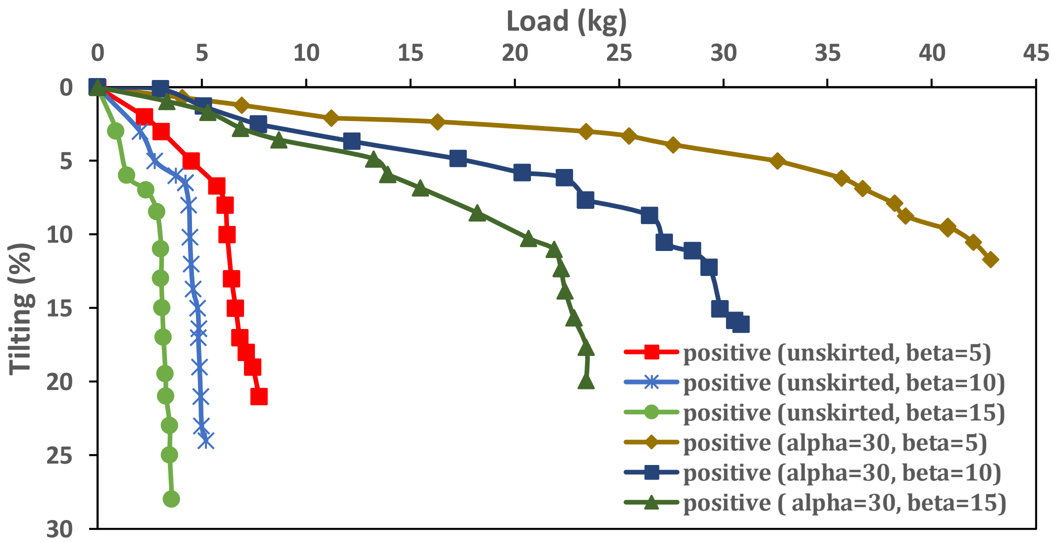


Figure 14. Load-tilting ratio with e/B=0.05 for positive eccentric-inclined loading.

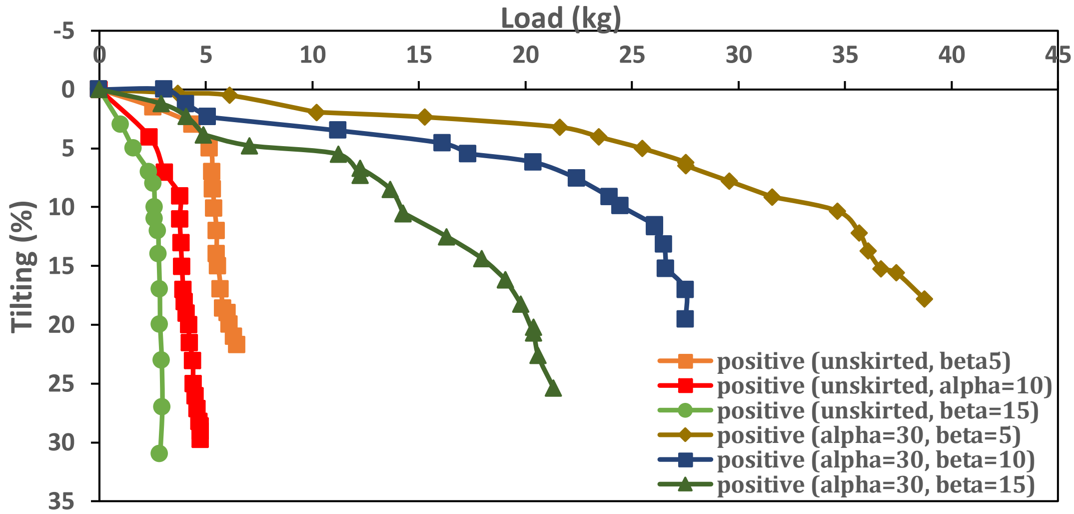


Figure 15. Load-tilting ratio with e/B=0.1 for positive eccentric-inclined loading.

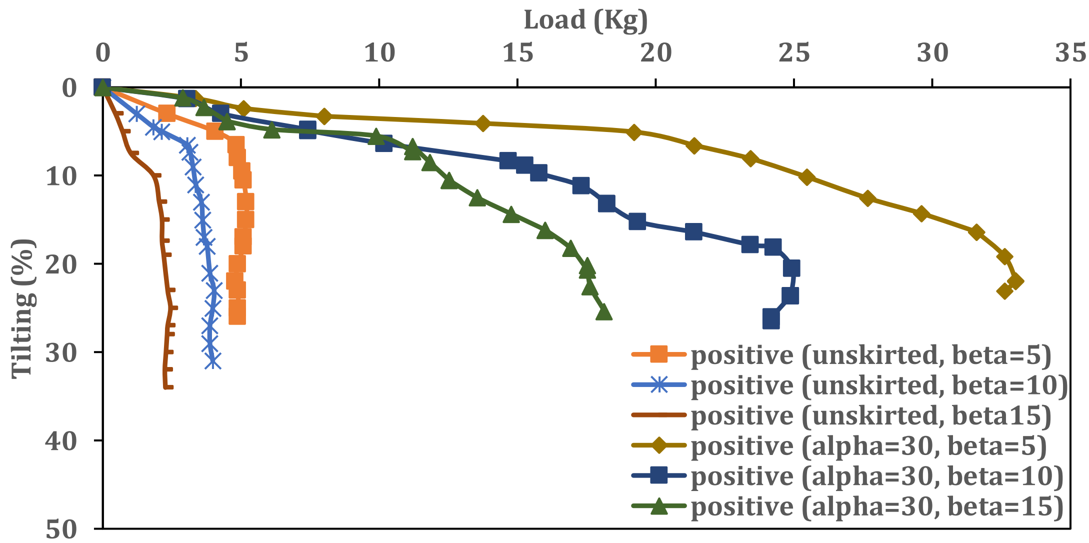


Figure 16. Load-tilting ratio with e/B=0.15 for positive eccentric-inclined loading.

In general, when using a skirt, this leads to a decrease in tilting and when increasing the angle of the skirt angle (alpha) at the same load. For negative eccentric-inclined loading through the experimental test, it was found that when the load angle (beta) is increased, the tilting before and after failure load (The failure load is equivalent to 10% of the settlement of the footing width, as stated by **(Terzagh, 1943)**. decreases for all eccentricity, which is also affected by the angle of the skirt (alpha). Using an inclined skirt leads to a decrease in tilting from (2.3% to 0.66%) with e was 0.15 B, load angle (beta) was 15°, and alpha was 30° For the negative case.
The negative sign for some cases in the load-tilting curve indicates that the base of the skirt foundation turns in the opposite direction to the load. For the positive, the tilting increases with the increase in eccentricity, and it can be explained that the contact area between the soil and the foundation decreases. When the load inclination increases, the skirted and unskirted foundations tend to slide and then turn over simultaneously, which agrees with

(Fazel et al., 2020). For the same load angle (beta), when the eccentricity increases, the foundation slides for a moment before continuing to overturn, and this indicates that with increasing eccentricity, the sliding decreases. Using an inclined skirt leads to a decrease in tilting from (10% to 2%) with e was 0.15 B, load angle (beta) was 15°, and alpha was 30° For the positive case.

The tilting continues after the failure load. This is because the skirt increases the contact area. Therefore, when a load is placed on a certain side, the effect of the load on the other side will be little, so the overturn will be from the side on which the load is placed.

3.2 Load-horizontal displacement

To examine how the skirt impacts the horizontal displacement, Angles of 30° and a ratio of Ds of 0.5 B were used for the footing on sandy soil. **Figs. 17** to **22** show the results of load-horizontal displacement.

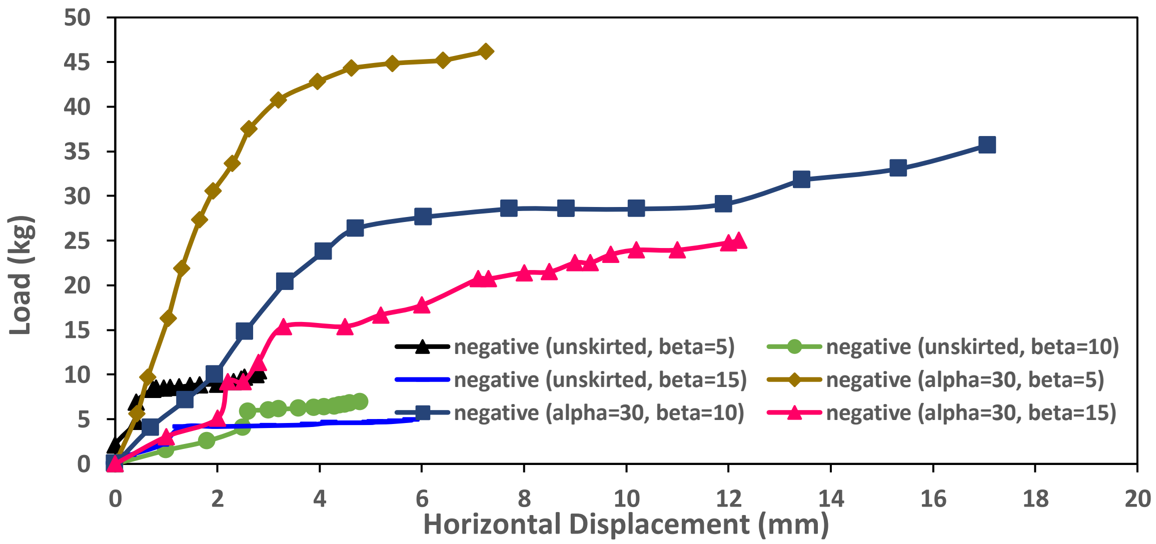


Figure 17. Load-horizontal displacement with e/B=0.05 for negative inclined loading.

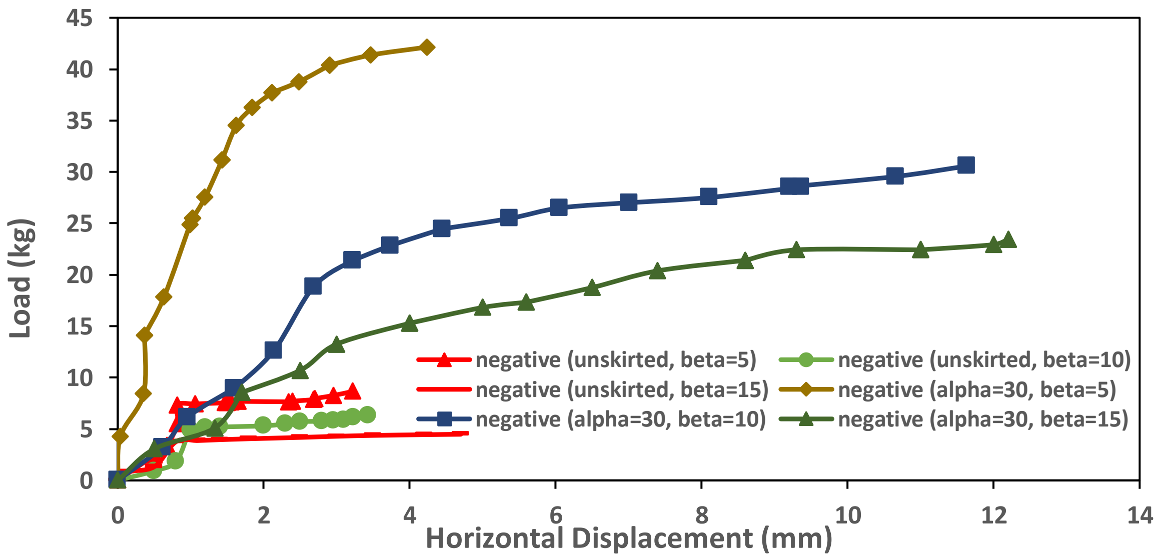


Figure 18. Load-horizontal displacement with e/B=0.1 for negative inclined loading.

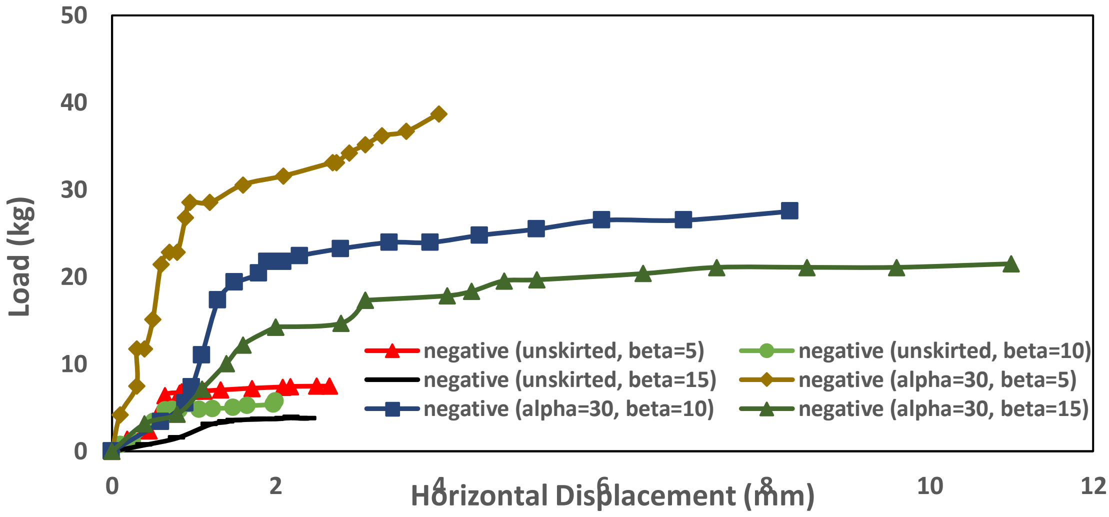


Figure 19. Load-horizontal displacement with e/B=0.15 for negative inclined loading.

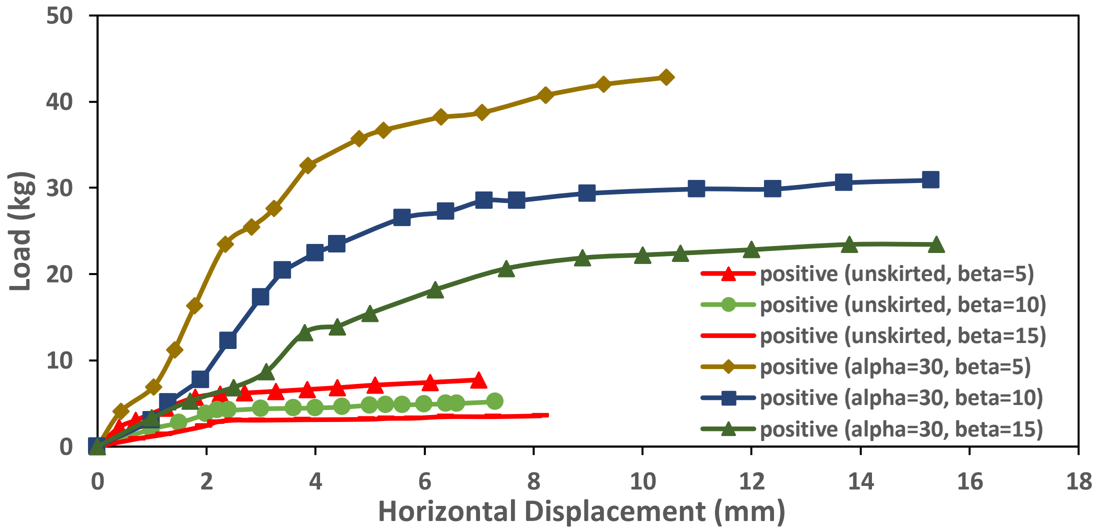


Figure 20. Load-horizontal displacement with e/B=0.05 for positively inclined loading.

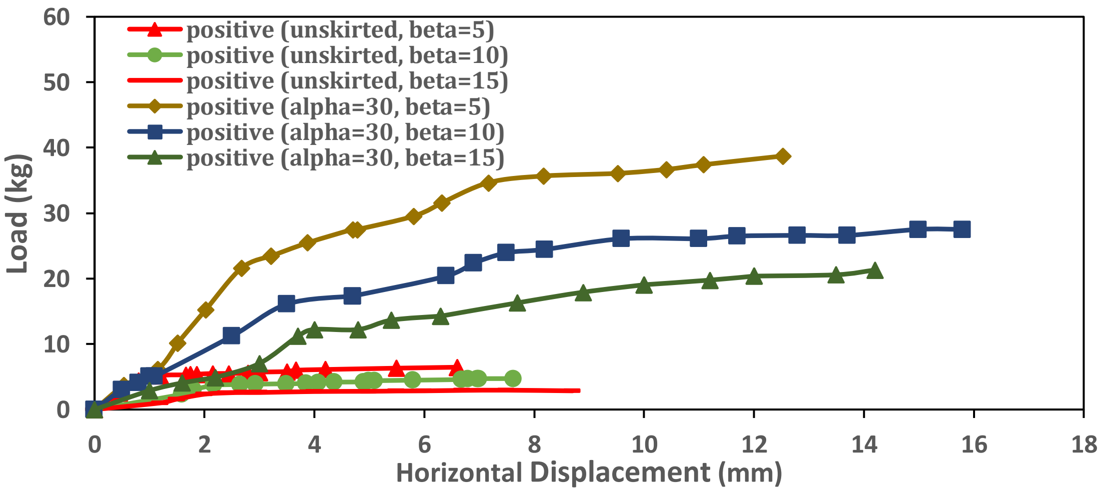


Figure 21. Load-horizontal displacement with e/B=0.1 for positively inclined loading.

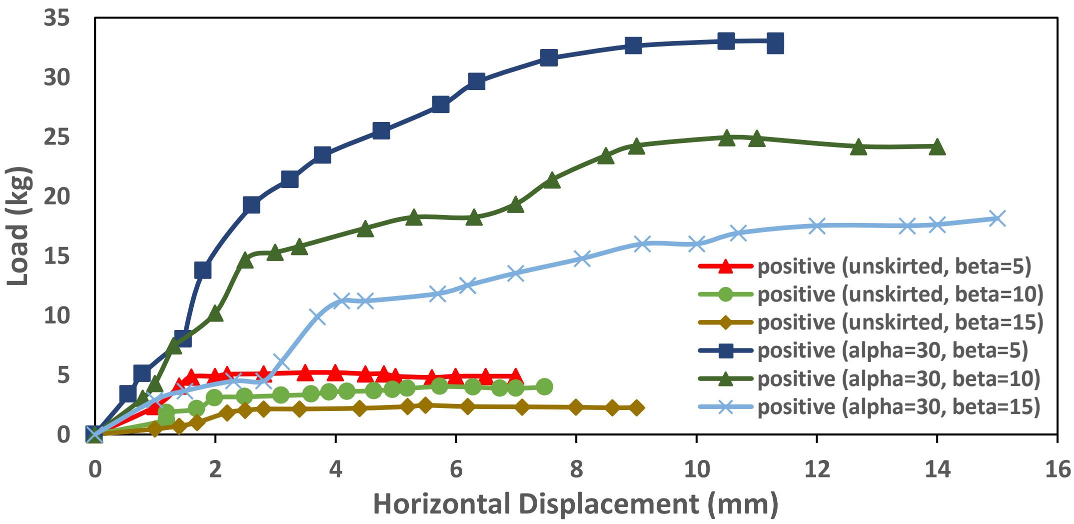


Figure 22. Load-horizontal displacement with e/B=0.15 for positively inclined loading.

The load-horizontal displacement From **Figs. 17** to **22** showed that the horizontal displacement of the skirted foundation is greater than that of the unskirted foundation, and this is due to an increase in the bearing capacity of the soil at failure load. The load on the unskirted foundation leads to a high settlement and is accompanied by a small horizontal displacement. Increasing the load angle significantly impacts the horizontal displacement, so it works to increase it for all cases. In some cases, the effect of the load angle may be reduced after failure with eccentric. For example, negative eccentric-inclined load with Ds was 0.5 B, the beta was 15, and e was 0.05 B. The effect of eccentric for a skirted and unskirted foundation for negative cases is more than positive. Horizontal displacement for negative eccentric-inclined load decreases with increasing eccentricity at the same load angle (beta).

4. CONCLUSIONS

This study examines the impact of square-inclined skirted foundation under eccentric-inclined loading on loose sand. The effectiveness of skirts on square footing was assessed through a series of experimental tests. The research mentioned above leads to the following conclusions:

1. Using a skirt leads to a decrease in tilting, an increase in the angle of the skirt angle (alpha) at the same load, and a reduction in the horizontal displacement for both negative and positive eccentrically inclined loading. Using an inclined skirt decreases tilting from (2.3% to 0.66%) with 0.15 B, load angle (beta) was 15°, alpha=30° For negative case. Using an inclined skirt leads to a decrease in tilting from (10% to 2%) with e was 0.15 B, load angle (beta) was 15°, and alpha was 30° For the positive case.
2. For negative eccentric-inclined loading when the load angle (beta) is increased, the tilting before and after failure load decreases for all eccentricity.
3. The negative sign for some cases in the load-tilting curve indicates that the base of the skirt foundation turns in the opposite direction to the load.
4. For positive eccentric-inclined loading, the tilting increases with the increase in eccentricity, and when the load inclination increases, the skirted and unskirted foundations tend to slide and then turn over simultaneously. For the same load angle

(beta), when the eccentricity increases, the foundation slides for a moment before continuing to overturn, and this indicates that with increasing eccentricity, the sliding decreases.

5. The horizontal displacement of the skirted foundation is greater than that of the unskirted foundation.
6. The load on the unskirted foundation leads to a high settlement and is accompanied by a small horizontal displacement.
7. Increasing the load angle significantly impacts the horizontal displacement, so it works to increase it for all cases. In some cases, the effect of the load angle may be reduced after failure with eccentric. For example, negative eccentric-inclined load with Ds was 0.5 B, the beta was 15, and e was 0.05 B.
8. Horizontal displacement for negative eccentric-inclined load decreases with increasing eccentricity at the same load angle (beta).

NOMENCLATUR

Symbol	Description	Symbol	Description
Alpha	Skirt angle inclination, degree	Dr	Relative density
B	Footing width, mm	LVDT	Linear variable distance transducer
Beta	Load angle, degree		

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Credit Authorship Contribution Statement

All the authors have read and approved the manuscript. The 1st author, Ghazwan Salah Alhalbusi Writing – original draft of the manuscript. The 2nd author, A'amal A.H. Al-Saidi, reviewed and edited the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Al-Saidi, A.A.H., 2009. Evaluation The Behaviour of Reinforced Loose Sand under Inclined Loading. *Journal of Kerbala University*, 7(3), pp.98–108.

Acosta-Martinez, H.E., Gourvenec, S.M., and Randolph, M.F., 2008. An experimental investigation of a shallow skirted foundation under compression and tension, *Soils and Foundations*, 48(2), pp. 247–254. Doi:10.3208/sandf.48.247.

Al-busoda, B.S., and Salman, R., 2013. Bearing capacity of shallow footing on compacted filling dune sand over reinforced gypseous soil. *Journal of Engineering*, 19(5), pp. 532–542. Doi:10.31026/j.eng.2013.05.01.

Al Mosawe M.J., Al-Saidi, A.A, Jawad, F.W.,2008. Improvement of soil using geogrids to resist eccentric loads. *Journal of engineering*, 14(4). pp. 3198-3208. Doi:10.31026/j.eng.2008.04.25

Al Mosawe MJ, Al Saidi A.A., Jawad FW., 2010. Bearing capacity of square footing on geogrid reinforced loose sand to resist eccentric load. *Journal of Engineering,* 16(2). pp. 4990-4999. Doi: 10.31026/j.eng.2010.02.17.

Abd-Alhameed, H.J., and Albusoda, B.S., 2022. Impact of eccentricity and depth-to-breadth ratio on the behavior of skirt foundation rested on dry gypseous soil. Journal of the Mechanical Behavior of Materials, 31(1), pp. 546-553. Doi:10.1515/jmbm-2022-0057.

AL-Kinani, A.M., and Ahmed, M.D., 2020. Field study of the effect of jet grouting parameters on strength based on tensile and unconfined compressive strength. In IOP Conference Series: Materials Science and Engineering, 737(1). pp. 012083. IOP Publishing. Doi:10.1088/1757-899X/737/1/012083.

Albusoda, B.S., and Al-Anbary, L.A., 2016. Performance assessment of pile embedded in expansive soil. *Al-Khwarizmi Engineering Journal*, 12(2), pp.1-9. Doi:10.1155/2021/5582197.

Aljuari, K., Fattah, M., and Alzaidy, M., 2023. Behavior of circular skirted footing on gypseous soil subjected to water infiltration. *Journal of the Mechanical Behavior of Materials*, 32(1), P. 20220252. Doi:10.1515/jmbm-2022-0252.

ASTM D 2049-64, 1969. Standard Test Methods for Calculation of Relative Density. Annual Book of ASTM standards. American Society for Testing and Materials, Philadelphia, United States.

ASTM D 4253, 2016 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.

ASTM D 4254, 2006 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.

ASTM D3080/D3080M, 2011. Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM International, West Conshohocken, PA.

ASTM D6913/D6913M, 2017. Standard test methods for particle-size distribution (graduation) of soils using sieve analysis. Chonshohocken, PA: ASTM International.

ASTM D854, 2014. Standard test methods for specific gravity of soil solids by water pycnometer. ASTM International, West Conshohocken, PA, www.astm.org.

Bieganousky, W.N., and Marcuson, W.F., 1976. Uniform placement of sand. *Journal of Geotechnical Engineering Div.* , ASCE, 102(GT.3), pp. 229-233.

Bachay H.A., and Al-Saidi A.A., 2022. The optimum reinforcement layer number for soil under the ring footing subjected to inclined load. *Journal of Engineer*ing, 28(12). pp., 18-33. Doi:10.31026/j.eng.2022.12.02.

Bashir, K., Shukla, R., and Jakka, R.S., 2022. Lateral capacity of skirted footing resting on level ground. in *Lecture Notes in Civil Engineering*. pp., 59-66. Doi:10.1007/978-981-16-5673-6_5.

Fazel, A.H.S., and Bazaz, J.B., 2020. Behavior of eccentrically inclined loaded ring footings resting on granular soil. *International Journal of Engineering, Transactions B: Applications*, 33(11), pp. 2146–2154. Doi:10.5829/ije.2020.33.11b.04.

Gnananandarao, T., Dutta, R.K. and Khatri, V.N., 2020. Model studies of plus and double box shaped skirted footings resting on sand. International Journal of Geo-Engineering, 11, pp.1-17. Doi:10.1186/s40703-020-00109-0.

Gnananandarao, T., Onyelowe, K.C., Khatri, V.N., and Dutta, R.K., 2023. Performance of T-shaped skirted footings resting on sand. *International Journal of Mining and Geo-Engineering,* 57(1), pp. 65-71. Doi:10.22059/IJMGE.2022.340418.594955

Cheng, Y., Cai, X., Mo, H., and Gu, M., 2023. Numerical analysis on the behavior of floating geogrid-encased stone column improved foundation. *Buildings*, 13(7), p.1609. Doi:10.3390/buildings13071609

Hadi, D.H., Waheed, M.Q., and Fattah, M.Y., 2021. Effect of piles number on the behavior of piled raft foundation. *Engineering and Technology Journal*, 39(7), pp.1080-1091. Doi: 10.30684/etj.v39i7.1795

Jawad, F.W., 2009. Improvement of loose sand using geogrids to support footing subjected to eccentric loads. MSc. Thesis, University of Baghdad, Iraq.

Khatri, V.N., Debbarma, S.P., Dutta, R.K., and Mohanty, B., 2017. Pressure-settlement behavior of square and rectangular skirted footings resting on sand. *Geomechanics and Engineering*, 12(4), pp.689-705. Doi:10.12989/gae.2017.12.4.689.

Kirtimayee, B., and Samadhiya, N.K., 2022. Behavior of loose geogrid skirted square footing resting on reinforced sand subjected to eccentric and inclined loading. *Indian Geotechnical Journal*, 52(4), pp. 895–906. Doi:10.1007/s40098-022-00624-0.

Lepcha, O.N., Deb, P., and Pal, S.K., 2023. Parametric studies on skirted foundation resting on sandy soil. *Lecture Notes in Civil Engineering*, 296, pp. 297–309. Doi:10.1007/978-981-19-6513-5_26.

Pusadkar, S.S., and Tejas Bhatkar, M., 2013. Behaviour of Raft Foundation with Vertical Skirt Using Plaxis 2d. *International Journal of Engineering Research*, 7(6), p. 20. www.ijerd.com.

Saha Roy, S. and Deb, K., 2017. Bearing capacity of rectangular footings on multilayer geosynthetic-reinforced granular fill over soft soil. *International Journal of Geomechanics*, *17*(9), p.04017069. Doi:10.1061/(asce)gm.1943-5622.0000959.

Sajjad, G., and Masoud, M., 2018. Study of the behaviour of skirted shallow foundations resting on sand. *International Journal of Physical Modelling in Geotechnics*, 18(3), pp. 117–130. Doi:10.1680/jphmg.16.00079.

Saleh, N.M., Alsaied, A.E., and Elleboudy, A.M., 2008. Performance of skirted strip footing subjected to eccentric inclined load. *Electronic Journal of Geotechnical Engineering*, 13 F(January 2008).

Sasikumar, A., 2008. Behaviour of circular skirted footing resting on sea sand. *International Research Journal of Engineering and Technology*, 9001, pp. 6–8.

Satria, I.F., Susanto, A., and Listyawan, A.B., 2018. Method to increase ultimate bearing capacity of skirted circular footing method to increase ultimate bearing capacity of skirted. In *AIP Conference Proceedings*, 1855(1). AIP Publishing. Doi:10.1063/1.4985458.

Terzaghi, K., 1943. Theoretical Soil Mechanics, Wiley, New York.

Thakare, S.W. and Shukla, A.N., 2016. Performance of rectangular skirted footing resting on sand bed subjected to lateral load. International Journal of Innovative Research in Science, Engineering and Technology, 5(6), pp.11075-11083. Doi:10.15680/IJIRSET.2015.0506182.

Örnek, M., Çalişici, M., Türedi, Y. and Kaya, N., 2021. Investigation of skirt effect on eccentrically loaded model strip footing using laboratory tests. Soil Mechanics and Foundation Engineering, 58(3), pp.215-222. Doi:10.1007/s11204-021-09731-1.