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Skirted Foundation, Performance, Mechanism, and Limitations: A Review Study

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ABSTRACT

Semi-deep foundations are a viable option when the soil under the foundation is loose and extended to a significant depth, also, when traditional methods of improvement are not feasible applying piles would not be a practical choice due to their high cost and time-consuming installation process. Skirted foundations are a sort of semi-deep foundation that can penetrate the soil to a depth that is twice their width. Skirted foundations, in which a vertical or inclined wall surrounds one or more sides of the soil mass under the footing, are recommended methods to increase the soil's bearing capacity. The walls work to reduce settlement while enhancing load capacity and failure depth in soils with low shear strength. This paper discusses the previous experimental and numerical investigations conducted on skirted foundations. Various factors were considered, including soil type, degree of saturation, soil properties, skirt depth, and width, soil-skirt interaction, and different scenarios of applied loads such as inclination and eccentricity. These studies have effectively shown that skirted foundations are very successful in reducing sliding, overturning, and settlement while also increasing foundation stability, soil capacity, and uplift capacity.

Keywords: Semi-Deep foundation, Skirted foundation, Bearing capacity, Settlement, Confinement, Finite element.

1. INTRODUCTION

Bearing capacity and settlement are important factors in geotechnical engineering. The researchers developed a range of methods to improve the performance of geotechnical structures and soil characteristics. Applying these methods can be difficult due to their high cost and the constraints imposed by site conditions. The development of bearing capacity theory highlights the importance of the general shear failure mechanism in determining the bearing capacity of a foundation on a homogeneous layer of soil. It is observed that as the total length of the failure surface increases, the foundation's bearing capacity. The length of the failure surface can be increased by either widening or deepening the foundation. This

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suggests that attaching structural skirts to the edges of shallow foundations could potentially extend the failure surface under loading. In this instance, it has been demonstrated that the skirted foundation is a vulnerable technique for increasing bearing capacity and lowering footing settlement when it rests on the ground. Stated differently, this approach enhances the footing's resilience to shear, stiffness, and elasticity as well as the supporting soils **(Joseph and Anju, 2018; Jawad et al., 2019)**.

Because of their economic advantages, skirted foundations have been demonstrated to be a valuable alternative to more conventional foundation systems such as piles in a variety of soil types. **(Al-Aghbari, 2007; El Wakil, 2010; Thakare and Shukla, 2016).**

The term "skirted foundation" refers to shallow foundations with angled or vertical plates attached to the foundation called "skirts" that are immersed into the soil without any excavations, encircling the underlying soil to restrain it **(Thakare and Shukla, 2016).** Since skirts can prevent soil from moving under the foundation laterally, as illustrated in **Fig. 1**, they are a very useful tool for enhancing bearing capacity.

The shallow foundation failure occurs when the soil beneath the foundation experiences shear failure, leading to the collapse of the foundation. When the foundation is loaded, the soil beneath it moves sideways by shear failure, as studied by (**Albusoda and Salem,2012; Al-busoda and Salman,2013).**

The aim behind this paper is to do an extensive survey on the previous experimental and numerical investigations conducted on skirted foundations and reach a recommendation on the performance of this type of footing.

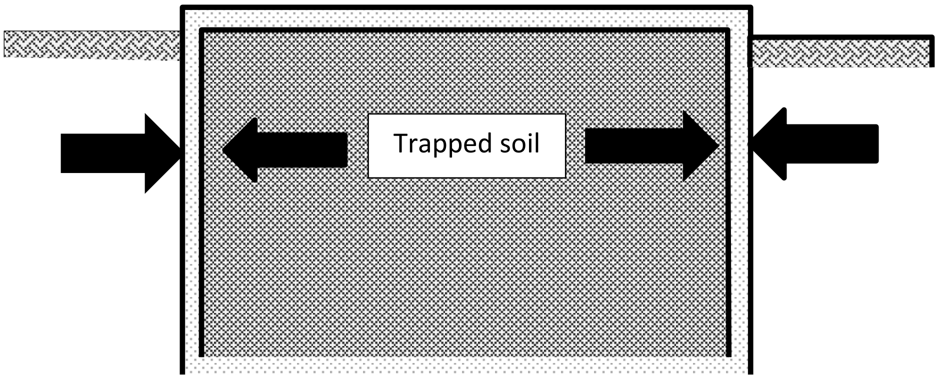


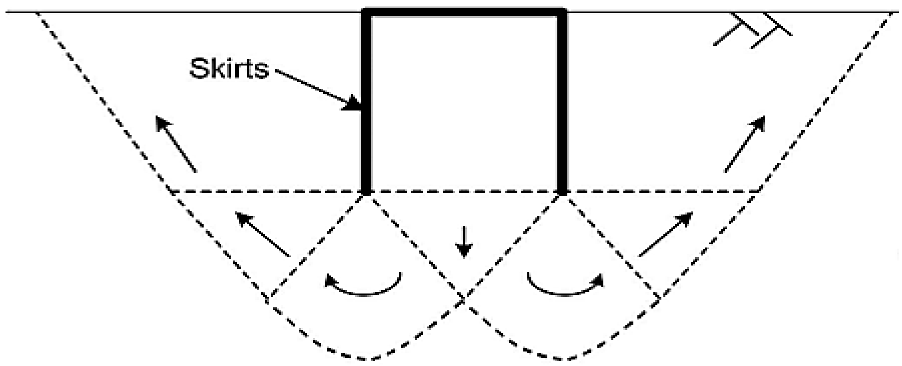
Figure 1. The mechanism of soil confinement due to using skirts

2. FAILURE MODES OF THE SKIRTED FOUNDATION

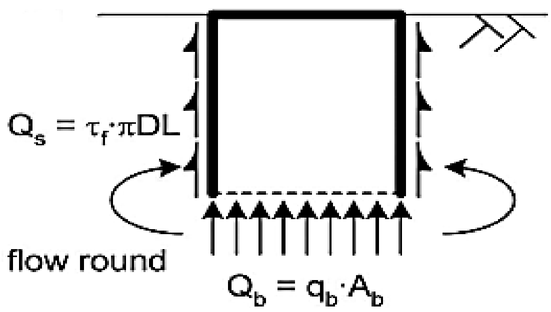
(Schneider and Senders, 2010) categorized three modes of failure in skirted foundations shown in **Fig. 2**

- Shallow failure mechanism: by adding skirts, the shallow foundation collapse mechanism is redirected to stronger and deeper soil layers. More resistance is provided by the failure surfaces' extension into the earth above the foundation.
- Plugged deep failure mechanism: The skirted foundation's flow round mechanism creates resistance along its sides ($Q_s = \tau_f \pi D L$), where τ_f is the unit shaft friction along the side, D is the diameter and L is the skirt length and at its base ($Q_b = q_b \cdot A_b$) where q_b is the end bearing force and A_b is end bearing area. If the internal shaft friction (Q_s) of the plug is less than the end bearing resistance (Q_b), and there is a gap between the top plate of the skirt foundation and the internal soil that allows for plug movement, then the foundation will be able to move.

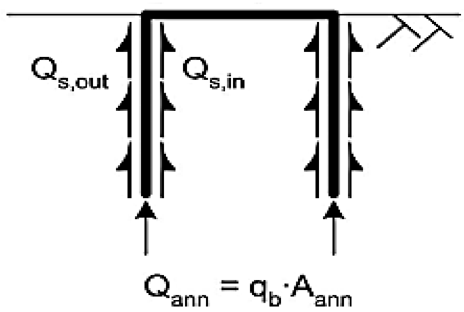
- coring deep failure mechanism: end bearing resistance (qb) is observed on the skirted foundation's annulus only, while the ultimate vertical resistance is influenced by both internal and external shaft friction



a. Shallow failure mechanism



b- Plugged deep failure mechanism



c- coring deep failure mechanism

Figure 2: Failure modes for skirted foundations. **(Schneider and Senders, 2010)**

3. BEARING CAPACITY OF THE SKIRTED FOUNDATION

(Terzaghi, 1943) derived one of the first equations used to determine the bearing capacity. The equation for strip footing placed on sandy soil and subjected to vertical load at the center is derived, as shown in **Fig. 3.**

$$q_{ult} = \gamma D_f N_q + 0.5\gamma B N_\gamma \quad (1)$$

Where:
q_{ult} = the ultimate bearing capacity
γ = soil unit weight
D_f = depth of footing
B = width of footing
Nq and Nγ are factors of the bearing capacity given by **(Terzaghi, 1943)**

Also, the load-carrying capacity Eq. (2) for a square foundation proposed by **(Terzaghi,1943)** is:

$$q_{ult} = \gamma D_f N_q + 0.4\gamma B N_\gamma \quad (2)$$

The load-carrying capacity Eq. (3) for the circular foundation was proposed by **(Terzaghi,1943)** also:

$$q_{ult}=\gamma D_f N_q + 0.3\gamma B N_\gamma \quad (3)$$

Where, B in eq. (3) is the footing diameter.
Based on the equations above, the vertical bearing capacity of skirted footing can be estimated.

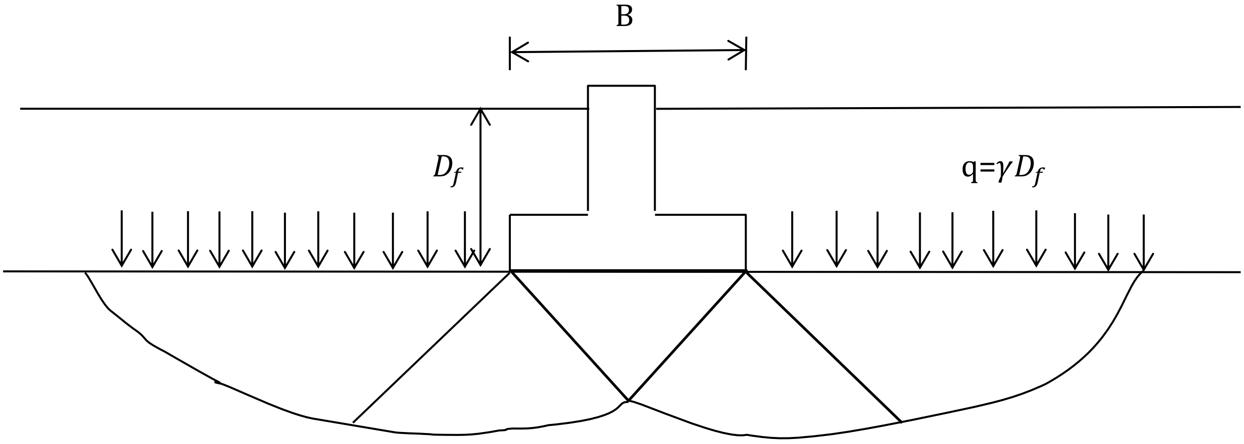


Figure 3. Failure mode in soil under a rough rigid strip footing subjected to vertical load. **(Terzaghi, 1943)**

For shallow strip foundations with structural skirts resting on sandy soil under central vertical loads **(Al-Aghbari and Mohamedzein, 2004**) proposed two modifications to the equations above:
1- Assuming that the soil located over the lower edges of the structural skirt is considered a surcharge as shown in **Fig. 4**
2- A skirt factor (F_γ) should be introduced into the second part of the general equations.

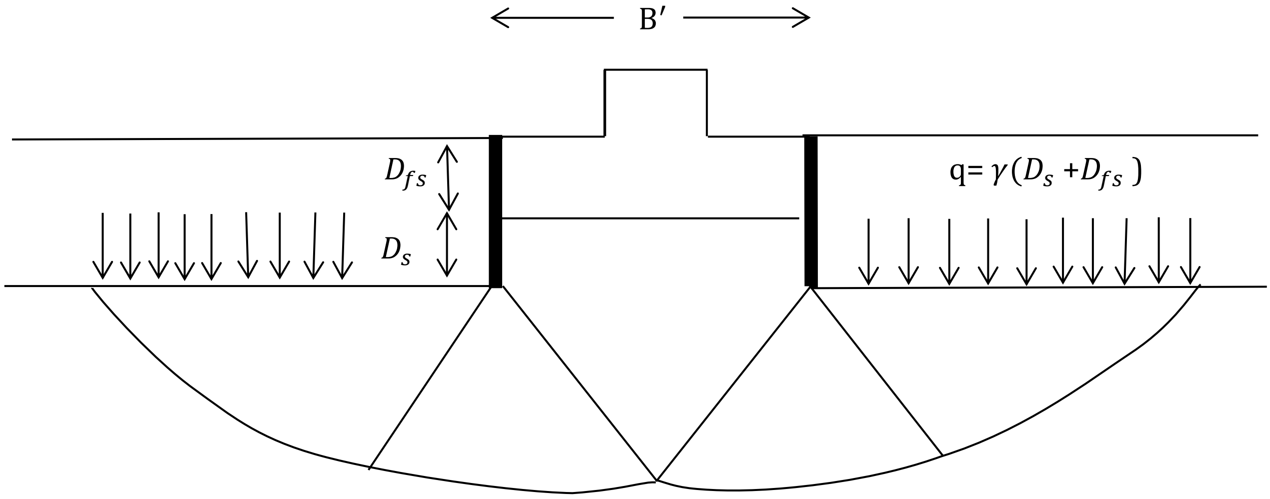


Figure 4. Failure mode in soil under continuous footing with structural skirt subjected to vertical load. (**Al-Aghbari and Mohamedzein, 2004)**

The equations (4-6) for strip, square, and circular are shown below respectively:

$$q_{ult} = \gamma\left(D_{fs} + D_s\right)N_q + 0.5\gamma B' N_\gamma F_\gamma \quad (4)$$

$$q_{ult} = \gamma\left(D_{fs} + D_s\right)N_q + 0.4\gamma B' N_\gamma F_\gamma \quad (5)$$

$$q_{ult} = \gamma\left(D_{fs} + D_s\right)N_q + 0.3\gamma B' N_\gamma F_\gamma \quad (6)$$

Where:
F_γ= Skirt factor
D_{fs}= Foundation base depth below the ground level
D_s = Depth of the skirt below the base of the foundation
B' = Total width of the foundation equals to (B + $2t_s$)
t_s: skirt thickness

They found that the skirt factor (F_γ) can be determined from Eq. (7):

$$F_\gamma = 1.15\ [0.4+0.6(\frac{tan\emptyset\prime}{tan\delta_f})][0.57+0.1(D_s\text{B}')+0.37(\frac{tan\delta_s}{tans_f})][1.2\text{-}0.002D_r] \quad (7)$$

Where:
$\emptyset'$= Effective angle of internal friction
δ_f = Friction angle at foundation base
δ_s = Friction angle at sides of the skirt
D_r = Relative density in percent

4. EXPERIMENTAL AND NUMERICAL STUDIES ON SKIRTED FOUNDATION

4.1 Experimental Studies.

Extensive research has been conducted on skirted foundations in soil mechanics. Offshore field and onshore laboratory tests were conducted by **(Tjelta and Haaland, 1993)** in sandy soil to study the skirted foundation concept. They found that the skirted foundation proves its efficiency against the traditional foundation. An experimental study utilizing electrokinetic was carried out by **(Micic et al., 2003)** to enhance the load–carrying capacity of circular skirted foundations embedded in soft marine sediments. The results showed increased bearing capacity up to three times after treatment. **(Yun and Bransby, 2003)** performed Several centrifuge model studies to examine the combined vertical, horizontal, and moment loading behavior of skirted foundations lying on drained loose sand. The tests revealed that the skirted foundation enhanced its lateral capacity by 3-4 times compared to the raft foundation, even under drained circumstances. Their findings also revealed that the Failure mechanism changes from sliding to rotating. **(El Sawwaf and Nazer ,2005)** used laboratory model studies to concentrate on the impact of soil confinement by circular skirted foundations on granular soil. They found that increasing the vertical and horizontal bearing capacity is due to soil confinement. **(AL-Aghbari and Mohamedzein, 2006)** carried out A series of research facility tests to concentrate on the impact of round-skirted establishment on sandy soil. The use of the skirted foundation was found to increase the bearing capacity obviously and lessen the settlement of a surface footing by up to 11 % compared with the footing without skirts. Research center tests were directed **(Al-Aghbari, 2007)** at skirted roundabout establishments laying on sand to concentrate on how the skirted foundation affects the settlement. Using the skirted foundation reduces the settlement.

The SRF (the settlement of skirted footing S_s over the settlement of skirtless footings S_f) was in the range of 0.1 to 1 in the case of using the skirted foundation depending on the applied loads and the skirt length. **(Villalobos, 2007)** studied the impact of skirted foundations on sandy soil experimentally. It was concluded that the bearing capacity increased with skirt length. **(Acosta-Martinez et al., 2008)** performed Centrifuge tests to concentrate on the way of behaving of skirted foundations laid on clay under both uplift and compression loads. This research indicates that using a skirted foundation enhances the resistance to the uplift and compression loads. The way of behaving of the skirted square foundation resting on the sand was conducted by **(Al-Aghbari and Dutta, 2008)** in the laboratory taking into consideration the roughness of the foundation base. The results indicated that the square footing's bearing capacity experiences a significant increase ranging from 11.2% to 70%. The results also indicated that the bearing capacity improvement is reduced as the base roughness of the footing increases. Also, the settlement reduction factor (SRF) varied between 0.11 and 1.0, depending on the applied load and skirt depth ratio. **(Punrattanasin, 2009)** tested the vertical and horizontal capacities of square and circular sheet pile foundations under varying sand densities**.** Research findings indicated that the ultimate bearing capacity of square and circular sheet pile foundations with an equivalent contact area on the ground provides a similar horizontal or vertical maximum bearing capacity and sheet-piled footings have greater vertical and horizontal bearing capacity than square footings without sheet piles. The research laboratory studies focused on the behavior of circular skirted footings laying on the sand under horizontal loads while examining the impact of relative density and skirt length were directed by **(El Wakil, 2010).** The outcomes showed that the horizontal capacity to resist lateral stresses increases with the skirt length and relative density and the failure mode changed from sliding to rotational mode due to using skirted foundation. The cylindrical footing of different diameters (40, 60, and 100mm) on sandy soil tested by **(Tripathy, 2013)** with different skirted depths (0.4, 0.6, 1.2, 1.5 and 2D) for smooth and rough conditions, different relative densities (30, 45, 60, 75 and 90%) with vertical and horizontal loads. The findings indicated that increasing the bearing capacity due to using the skirted foundation in the range of 11.2 to 30 % according to skirt, footing, and soil properties. The study presented data and interpretations indicating an increase in the ultimate bearing capacity with factors such as the size of the footing, the length of skirts, and the relative density of sand. Also, the rough-skirted foundation is better than the smooth-skirted foundation to minimize settlement and boost bearing capacity.

(Wakil, 2013) performed a laboratory test on the effectiveness of circular skirt footing on the sand with footing diameter (D) equal to (75,100 and 150 mm), the skirt length taken from (0 D to 1.5 D), and relative density (35, 65, and 90%). It was investigated that bearing capacity ratios BCR (a skirted foundation's bearing capacity over that of an unskirted foundation) are inversely related to the relative sand density and directly proportional to skirt-to-footing-diameter ratios. Skirted foundations do not significantly affect the footing behavior when the relative density of the sand is more than 65%. In this study, the skirted circular footing increases the ultimate load of shallow footings up to 6.25 times. Skirted strip foundations installed on soft clay soil were tested experimentally by **(AL-Qaissy and Muwafak, 2013)** to determine the impact of embedment ratio on bearing capacity improvement. The findings revealed that enhancing the load-carrying capacity by increasing the skirt depth. It was discovered in this study that a ratio of 0.5 between the depth and width of the skirt was the most optimal. Laboratory tests were performed by **(Davarci et al., 2014)** on skirted foundations taking into account the geometry of the foundation (H, +, T, and square shaped), footing size, and relative density. In this study, the findings showed that all shapes exhibit close values of bearing capacity in case of having the same surface area. The bearing capacity increases as the surface area increases for any type of soil (loose or dense). **(Fattah et al., 2014)** carried out an experimental study to concentrate on the way of behaving of bounded square footing on sandy soil with two relative densities (33 and 56%). Factors such as wall depth, footing width, and distance from wall to footing are taken into account in the study. A significant impact on bearing capacity values is due to the existence of the walls. The tests also revealed that When a square footing is bounded by walls, the maximum improvement in its bearing capacity is 43.3% in loose sand, at (h/B=0.5) and (d/B=2) while In medium sand, with the same ratios of (h/B = 0.5) and (d/B = 2), the maximum improvement in bearing capacity can reach 56.6%, where h is the distance between skirt wall and nearest foundation edge, and B is the footing width, while d is the skirt depth.

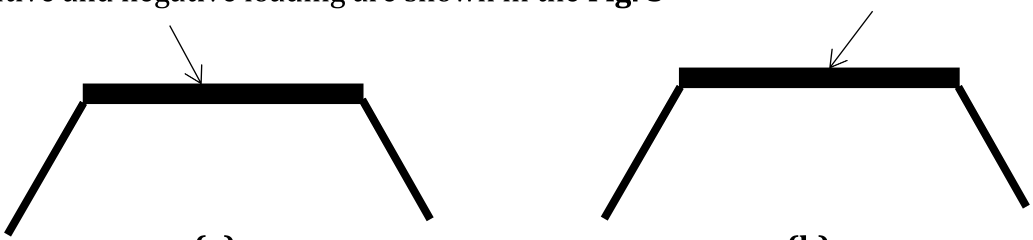
Considering the thickness, skirt length, and shape of the footings, an experimental study carried out by (**Vijay et al., 2016)** to research the effect of a skirted foundation on c-Φ soils. They discovered that increasing the skirt thickness and skirt length improves the bearing capacity. The footing's shape dramatically influences the bearing capacity of c-Φ soils. Using skirted foundations is more beneficial with square foundations rather than circular and rectangular foundations.

(Thakare and Shukla, 2016) investigated the influence of skirt depth, load inclination, and variations in skirt length on the performance of rectangular skirting footings subjected to lateral loads. The results demonstrated that augmenting the quantity of skirts improved the lateral load-bearing capacity. Increasing the skirt length to footing width ratio from 0.5 to 2 results in a three hundred percent increase in horizontal capacity. Moreover, when the inclination increases, the load-carrying capacity of the footing also increases. In a study conducted by **(Kannan and Chezhiyan, 2016)** a circular foundation with a diameter of 90 mm was tested on poorly graded sand. The researchers examined the ratios of skirt depth to footing width, which were 1, 1.5, 2, and 2.5. The increase in skirt depth to footing width ratios from 1 to 2.5 resulted in a significant 6.6 times increase in horizontal capacity, clearly demonstrating the relationship between these two factors. Furthermore, it was discovered that the utilization of a skirted foundation altered the mode of failure from sliding to rotational. **(Prasanth and Kumar, 2017)** carried out a laboratory examination on the effect of relative density and skirt depth on sand- based circular skirted foundations. It became concluded that a useful manner to enhance the bearing capacity and reduce the settling is to apply the skirted foundation. The circular footing of various diameters (75, 100 and 150) and different skirted lengths equal to (75,100 and 150 mm) was examined by (**Renaningsih et al., 2017)** on sandy soil. They found out that the skirt depth to footing width ratio and the ultimate bearing capacity are straightforwardly corresponding. In addition, on similar skirt lengths and diverse footing diameters, it's obvious that the skirt depth to footing width ratio and ultimate bearing capacity are conversely corresponding. Laboratory tests with a circular footing of various widths and diameters with partially skirted lengths have been conducted **(Hanani and Listyawan, 2017)**. The findings proved that circular footings' bearing capacity is increased and settling effects are decreased through partially skirted that is linked to them. Meanwhile, the ultimate bearing capacity will increase proportionately to the period of the partial skirt, thinking about that the diameter of the circular footings remains constant. Experimental research was made by **(Khatri et al., 2017)** on skirted footings that had been placed on sand and subjected to a vertical load. The shapes tested were square and rectangular, and the depths of the skirts ranged from 0.25 B to 1 B. The relative densities taken into consideration have been 30, 50, 70, and 87 %. The findings indicated that growing the depth of skirts improves the bearing capacity.

Furthermore, the skirted foundation technique is greater useful for low relative densities of sandy soils. They additionally found in this study that the skirted foundation has the ability to increase bearing capacity as much as 262%. The behavior of circular footings under vertical stresses with different diameters (75, 100, and 150 mm) and different skirt lengths (0, 100, and 150 mm) on clayey soil was examined in experimental tests conducted by **(Listyawan and Kusumaningtyas, 2018)**. The results indicate that the skirt effectively reduces foundation settlement on clay. The research indicates that increasing the ratio of skirt depth to footing width can lead to reduced settlement and increased load capacity. To discover how skirted foundations work, **(Gnananandarao et al., 2018)** ran experiments considering the foundation geometry form (H and square shaped), skirt depth, and relative density. The H-shaped skirted foundation performance is better than the square skirted foundation as the findings discovered. In addition, the usage of the skirted foundation is a most advantageous manner to enhance the loose soil. The performance of a circular skirted foundation on sandy soil was examined by using **(Sajjad and Masoud, 2018).** Bearing capability and settlement have been considered about the subsequent foundation parameters: diameter, relative density, skirt depth, and roughening. The bearing capacity and settling can be effectively improved through the inclusion of skirts as concluded from the results. Skirt depth and roughness are directly proportional to increased bearing capacity and reduced settlement of shallow foundations, whereas relative density has a diverse effect. Moreover, Shallow foundations may have their ultimate bearing capacity increased by five times, and settlement can be minimized to 8% due to using the skirted foundations. **(Mahmood et al., 2018)** performed laboratory tests to find the optimum embedment ratio (L/D) which exhibits maximum bearing capacity for gypseous soil with varying relative densities. The findings showed that there is a direct relationship between the improvement in bearing capacity and skirt length to footing width (L/D) and this embedment ratio is directly correlated to the relative density. In this study, a specific case surfaced when L/D = 3 in medium relative density, the bearing capacity is less than the bearing capacity of L/D = 2. Finally, Peak failure appears at high dry relative density in the range (0-2) of L/D ratio and the failure occurs like a general shear failure. otherwise, at (L/D = 3), there is no peak failure. An increase in confining pressure with depth causes the failure to occur like a local shear failure. The purpose of laboratory experiments carried out by **(Abd Ali, 2018)** was to study the impact of different skirt depths and diameters on circular skirted foundations placed on dry and saturated sandy soil. The tests took into account the state of open-end skirted foundation and closed-end skirted foundation. They revealed that the foundation with a circular skirt is constant directly with both the foundation diameter and the depth of the skirts. In addition a ,Foundation with a closed-end skirt can exhibit higher improvement in comparison with an open-end skirt.

Considering the relative density and (L/D) ratio laboratory tests were performed by **(Joseph and Anju, 2018)** to study the behavior of circular skirted foundations lying on sandy soil. It was concluded that using the skirted foundation is beneficial in sandy soil with a relative density of less than 60 %. The maximum bearing capacity ratio (BCR) in this study was reported when the skirt depth to footing diameter (L/D) ratio was kept at 1.46. Considering the relative density and (L/D) ratio laboratory assessments had been performed by **(Joseph and Anju, 2018)** to study the behavior of circular skirted foundations lying on sandy soil. It was concluded that the usage of the skirted foundation is beneficial in sandy soil with a relative density of less than 60 %. The maximum bearing capacity ratio (BCR) on this study at was pronounced while the skirt depth to footing diameter (L/D) ratio was kept at 1.46. The reaction of a skirted rectangular footing resting on the sandy soil of various states to lateral applications of loads was experimentally investigated on this research by **(Jawad et al.,2019)**. The parameters under research include the spacing between the footing and the skirt (h), as well as the skirt depth (d). The consequences indicate that the wall's nearness to the footing (h/b = 0), where b is the footing width, notably increases bearing load and decreases lateral movement for a skirted footing. It was found that when the ratio (h/b) is greater than one, it will become ineffective. A collection of experimental investigations on sandy soil achieved by **(Ahidashti et al., 2019)** to assess the behavior of skirted foundations in reaction to upward seepage-triggered liquefaction. High pour water pressure in sand reduces the skirted foundation's bearing capacity, consistent with the take a look at results. The results additionally indicated improving the foundation's bearing capacity in liquefiable soils was proven to be connected with increasing the foundation's width and skirt length. Experimental research on skirted foundations on sandy soil with exclusive skirt depths (0D to 1.5 D) and circular foundations with implemented loads at distinct angles of inclination (90, 80, 70 to 60) degrees with the horizontal was conducted by (**Abdulhasan et al., 2020)**. The load with the horizontal and skirt depth to footing diameter ratio. Laboratory tests were completed by **(Santhoshkumar and Ghosh, 2020)** to concentrate on the way of behaving of skirted foundations under seismic loads in cohesionless soils. In this study, during seismic events, skirted foundations experience less reduction in bearing capacity. **(Gnananandarao et al., 2020)** explored the square, plus and double box-shaped skirted foundations sitting on sandy soil for entirely and partially rough interface footing, the skirted depth can differ from 0.25 B to 1.5 B, and the relative density can be considered to be 30% or 60%**.** The footing's geometry increases load-bearing capacity and decreases settlement as concluded from the results. Compared to rough interface footing, partially rough interface footing increased bearing capacity to a greater level. Finally, the settlement reduction factors for footing with the skirt varied from 0.16 to 1.0, depending on the strain applied and the skirt depth ratio. A model test of a square-skirted foundation on sandy soil was tested by **(Parmar and Patel, 2021)**. The parameters like skirt length, skirt angle (30, 45, 60 and 90), and depth of placement were considered. The results indicated that increasing in depth of placement increases the bearing capacity for all skirt lengths and angles. The effect of placement is more predominant in 30-skirt angled footing. As the skirt length increased effect of an increase in bearing capacity is predominant for 45 skirt angled footing. **(Al-Aghbari et al., 2021)** demonstrated how skirted foundations can improve the performance of shallow footings under both vertical and inclined loading conditions. **(Vijay et al., 2022)** proposed a composite skirted ground reinforcement system to mitigate the liquefaction in liquefiable soils. This system not only reduces incoming ground vibrations to the foundation but also reduces the generation of pore water pressure in these soils. Skirted strip footing resting on sandy soil in three cases (dry, fully saturated, partially saturated) was tested by **(Mahmood et al., 2022)** for different relative densities and different skirted depths (L/B). The optimum state for having the best load-carrying capacity for the skirted foundation is partially saturated followed by a dry state and a fully saturated state as revealed in the study. A T-shaped skirted footing was examined experimentally by **(Gnananandarao et al., 2023)** with the changing of skirt depth and relative density. The optimum benefit of using skirts can be obtained in case of a partially rough state and 30% relative density as concluded from the findings. They also found out the settlement decreases as the skirt length increases. **(Abd-Alhameed and Albusoda, 2023)** performed an experimental study on the skirted foundation on dry and saturated gypseous soil with different skirt depths (0 B to 1.5 B) and three shapes (square, square two–room, double–row square) skirted foundation with the size of (50 and 100) mm width. The experimental outcomes showed the impact of utilizing a skirt to upgrade the presentation of the square foundation by developing the load-carrying capacity and minimizing the settlement of the foundation.

The developing rate increases with increasing foundation width and skirt depth. For saturated gypseous soil, the development ratio is smaller as compared with dry soil situations. **(Abd-Alhameed and Al-busoda, 2023)** completed a review study to evaluate the performance of the skirt foundation. It was concluded that a skirted foundation can be more durable than other conventional foundation types, and in conditions wherein the soil's carrying capacity is poor, it is probably a more beneficial choice than a deep foundation. Typically, offshore structures use skirted foundations. Due to its ability to preserve water from penetrating the underlying soil, the skirt reduces soil erosion. By making a resistance against sliding by the skirt side, it functions to contain soil between the skirt walls. Laboratory tests were examined by **(Aghadadashi et al., 2023)** to estimate the effectiveness of skirted foundations in saturated sandy soils subjected to varying levels of excess pore water pressure. Using a skirted foundation was found to be an effective strategy for mitigating the consequences of excessing pore water pressure. **(Alhalbusi and Al-Saidi, 2023)** studied the behavior of inclined skirting foundations on sandy ground experimentally. The load-carrying capacity increases as the skirt angle increases but the optimum skirt angle was found to be equal to 30. When it comes to increasing bearing capacity and lowering settlement, positive loading works better than negative loading, the positive and negative loading are shown in the **Fig. 5**



(a) **(b)**

Figure 5. Foundation exposed to eccentric-inclined loadings with skirt subjected to (a positive (b) negative inclination (**Alhalbusi and Al-Saidi, 2023)**

On sandy soil reinforced with geo-grid layers, the performance of square footings that are loosely skirted was evaluated by **(Kirtimayee and Samadhiya, 2023).** Many parameters were studied such as skirt depth, number and distances of geogrid layers, and vertical loads with different eccentricities. There was a decrease in settlement and an improvement in bearing capacity with the insertion of geogrid horizontal reinforcements. As the skirt depth increased, the load intensity also increased, reaching its maximum value at d/B= 2 for a spacing of 0.25B under both loading conditions.

4.2 Numerical Studies.

The numerical method is essential for analyzing skirted foundations in the geotechnical engineering field because of the mechanical and geometrical complexity of most problems. Finite element analysis was conducted by **(Bransby and Randolph, 1999)** to identify the behavior of strip footings with shallow embedment in undrained, nonuniform soil under vertical, moment, and horizontal loading.The analysis showed that embedment depth affected the bearing, moment, and horizontal capacity of the footing significantly. The vertical capacity and the behavior of skirted foundations on typically consolidated undrained soil were the focus of mathematical and practical testing made by **(Yun and Bransby, 2007)**. The investigations demonstrated that if the soil inside the skirts was completely stiff and the skirt depth was the same as the embedment depth, the vertical capability of the skirting foundation in usually consolidated undrained soil could be computed. **(Mana et al., 2013)** studied the behaviour of internal skirted foundations by using finite element analysis under vertical, horizontal, and moment loads on soil stiffness while taking skirt embedment into account. The analysis indicated that as the skirt depth increases, fewer internal skirts are needed to maintain soil plug rigidity. Surface, pier, and skirted foundations lying on the sand were analyzed numerically by **(Eid, 2013)** to find out how they behaved under axial loading, taking shear strength characteristics, foundation size, and skirt depth into account. For the same width and depth, skirted foundations and pier foundations exhibit close values of bearing capacity and settlement. The depth of the skirt is proportionate to the improvement in bearing capacity, while the relative density of sand has an inverse relationship. Also, the results showed that in case of having a skirt depth to footing width ratio equal to 2, the reduction in settlement may exceed a value of 70%. **(Azzam, 2015)** used finite element evaluation to take a look at the behavior of a skirted foundation next to a sand slope when seismic loading was carried out on a 4-story reinforced concrete structure that sits on a raft foundation.

Soil confinement by skirt inclusion can be considered an effective approach to limiting the acceleration of the slope and the foundation throughout earthquakes and keeping soil deformation under control. **(Sarma, 2016)** used finite element analysis to assess the performance of skirted and unskirted raft foundations. They discovered that skirted raft foundations are superior to unskirted ones in terms of bearing capacity and settlement. Finite element analysis was adopted by **(Toma-Sabbagh et al., 2018)** to carry out an analytical investigation on the behavior of two Spread foundations of different sizes with different sheet pile depths (0.5B, B and 1.5B) and different distances from sheet piles (0.1B, 0.5B and 0.75B) to find out the best distance between the sheet pile and the foundation. The best distance between the sheet piles and the foundation is observed to be 0.5B. **(Lee et al., 2020)** finished a chain of mathematical examinations at the skirt length alongside exceptional conditions of sand-over-clay deposits to mitigate punch through on sand-over-clay deposits. The degree of mitigation becomes improved through expanding the skirt length. 2D finite element model was created, verified, and applied to have a look at the efficiency of using skirts as a technique to decrease the settlement of a strip foundation under machine vibrations. To investigate the performance of skirted rectangular combined footing, finite element modeling is used by **(Naik et al., 2020)**. The skirted rectangular combined foundation has been studied and observed to be one of the powerful strategies to improve the foundation. **(Aljuari et al., 2023)** performed a study take a look at to examine the stableness of circular skirted footings on gypseous soil beneath environmental loads. They take a look at used numerical calculations to analyze the settling of the footings at some stage in loading, infiltration, and collapsing stages. Finite element analyses were achieved using the commercially available software program GEO-STUDIO. The study takes into consideration the stage of gypseous soil and the ratio of skirt depth to footing diameter (d/D). The study discovered the significant effect of each soil stage and the skirt embedment ratio on the ultimate bearing capacity and settlement of weak soil. A homogeneous settlement was observed underneath the skirted footing, with no signs of differential settlement. The effect of skirting ring footing resting on soft clay soil under dense sand soil was investigated by **(Dutta and Khatoon, 2023)** using finite element analysis. It was determined that each the sand density and clay cohesion improve the footing's carrying capacity. Research performed by **(Ahmad, 2023)** to study an effective approach for improving the bearing capacity and reducing settlement of soft clay soil using a two-dimensional finite element model. The study compared the performance of skirt sand piles to reinforced cement piles. Specifically, the point of interest became on analyzing skirt sand piles with thick sand cores and closed tubes placed underneath a circular shallow foundation. The foundation became supported with the aid of a steel plate of appropriate dimensions, alongside reinforced cement piles of various lengths. The study mainly checked out those structures in non-drained conditions. The calculations have been accomplished using PLAXIS 2D software program, and a sequence of finite element analyses had been achieved. The efficiency of skirt sand piles exceeds that of deep cement piles. Moreover, increasing the length of SSP skirt sand piles has a more pronounced impact on improving bearing capacity compared to increasing the length of deep cement piles. As a result, the failure modes of piles with skirt sand were determined. It was observed that when skirt sand piles were tied into clayey soils, the failure mode was a general shear failure in the underlying sandy soil layer. The effect of the buried pipe under the skirted foundation was performed by **(Mohammadizadeh et al., 2023)** using finite element analysis. Using the skirted foundation can enhance the performance of the foundation and reduce the effect of cavities. The load-carrying capacity and settling of the foundation near slopes were investigated by **(Mohammadizadeh et al., 2023)** using numerical analysis of skirt foundations. The impact of skirt depth, angle, skirt depth to footing width (L/B) ratio, soil cohesion, and foundation surface roughness under vertical loading was considered. The outcomes revealed that surface roughness and skirt angle increase the bearing capacity and reduce the settlement, and when the (L/B) ratio increases to 2.5 times the bearing capacity increases up to 58%.

Extensive investigations on skirted foundation combining numerical and experimental methods in order to confirm the model test findings and explore configurations that have not been modeled in experiments. Mathematically and experimentally tests were conducted by **(Saleh et al., 2008)** to investigate the behavior of one-sided strip-skirted foundations under eccentric and inclined loads as shown in **Fig. 6**

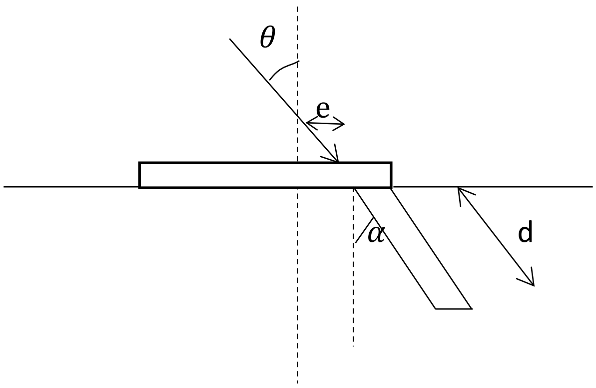


Figure 6. Parameters used in the analysis **(Saleh et al., 2008)**

The experimental results showed that lengthening the skirt improves the load-settlement behavior and improves the lateral resistance to sliding. The impact of load inclination angle on the load-settlement behavior of skirted footing is significantly more noticeable when the skirt length to footing width is (d/B=0.25). By increasing the skirt length to (d/B = 0.50), sliding failure was successfully avoided. The bearing capacity ratio BCR increased with the increase in skirt length, load eccentricity and load inclination angle and reached its optimal value of about 5.5 at skirt length of (d/B = 0.5). The FEM provided higher values than the experimental results. **(Thakur and Dutta, 2020)** implemented An experimental and numerical examination to estimate the maximum load capacity of unskirted, singly, and doubly skirted hexagonal foundations on three different types of sand S1 (D_{10} = 0.14), S2 (D_{10} = 0.45) and S3 (D_{10} = 1.45) . The experimental outcomes indicated that the skirted hexagonal footings had the best bearing capacity on sand S3, followed by using sands S2 and S1. Moreover, double-skirt foundations showcase a larger development in bearing capacity in contrast with the singly and unskirted ones. The results obtained numerically were similar to the experimental results for the hexagonal footings on sands (S1, S2, and S3). Numerical and physical studies carried out by **(Günay and Çinicioğlu, 2023)** to investigate the behavior of the Box-Shaped Deep Foundation (BSDF) and Conventional Piled Raft Foundations (CPRF) taking into consideration many parameters such as surface roughness, load level soil conditions, and embedment ratio (D/B). Box-shaped Deep Foundations are better than Conventional Piled Raft Foundations. The results of a mathematical and experimental study indicate that the addition of skirts improves the bearing capacity and settlement behavior of surface foundations on sand (**Bashir et al., 2023)**.

5. CONCLUSIONS

The following conclusion was reached after comprehensive numerically and experimentally studies into the behavior of skirted foundations on various soil types (sand, gypseous soil, and soft clayey soil) under various loading conditions and parameters

1- The vertical and horizontal bearing capacity for static and dynamic conditions has increased and the settlement has decreased with using a skirted foundation compared to that without a skirt due to soil confinement under the foundation which will transfer the stresses to the deeper zone.
2- The improvement in bearing capacity and reduction in settlement depends on many factors such as skirt depth to footing width ratio, soil type, shape of footing, footing surface area, skirt thickness, relative density, number of skirts, skirt–footing roughness, depth of footing placement, loading conditions (eccentricity and inclination), footing size , soil cohesion , skirt distance from the footing and interface conditions between soil and skirt.
3- Skirted foundations provide homogeneous settlement under the foundation thus used to prevent differential settlement.
5- For sandy soil, the effect of skirts vanished at a relative density equal to or more than 60%.
6- The settlement reduction SRF due to using the skirts was found in the range (0.1-1).
7- The skirted foundation can be used to modify the failure mode from sliding to rotational.
8- The use of geogrid skirts appears to be a viable option for enhancing the effectiveness of footings under eccentric and inclined loading conditions.
9- All shapes (circular, rectangular, square, and multi-edge shapes) have close horizontal and vertical bearing capacities when they have the same surface area. Also, the bearing capacity and settlement values of skirted foundations and pier foundations are similar when they have the same width and depth
10- When the ratio of the distance between the skirts and the surface foundation over the footing width exceeds one, the skirts lose their effectiveness.

NOMENCLATURE

Symbol	Description	Symbol	Description
B	Foundation width, m.	L	Skirt length, m.
B'	Total foundation width with skirt, m.	q	Uniform surcharge, kPa
BCR	Bearing capacity ratio	q_{uilt}	Ultimate bearing capacity, kPa
c	Soil cohesion, kPa.	S	Settlement, mm.
D	Footing diameter, m.	S_f	Settlement of unskirted foundation
D_s	Skirt depth, m.	S_s	Settlement of skirted foundation, mm.
D_f	Foundation depth	S_q, S_γ	Shape factors in bearing capacity equation
e	Load eccentricity, m.	α	Angle of inclination, deg.
$F_{s\gamma}$	Skirt factor	β	Batter angle, deg.
d	Depth of wall, m.	δ_f	Angle of friction at base of foundation Uniform, deg.
h	Distance between footing and wall	∅	Friction angle between soil particles, deg.
IR	Improvement ratio	γ	Unit weight of soil, kN/m^3
N_q, N_γ	Bearing capacity factors	ϴ	the angled of the shearing zone, deg.

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Credit Authorship Contribution Statement

All the authors have read and approved the manuscript. The 1st author, Sajjad Kamel Wrote the original draft of the manuscript. The 2nd author, Bushra Suhale, 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.

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الاساس ذو الحواف، الاداء، الالية، والمحددات: دراسة مراجعة

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خلاصة

الاساسات شبه العميقة هي خيارات قابلة للتطبيق عندما تكون التربة تحت الاساس رخوة الى عمق مؤثر وتكون الطرق التقليدية لتحسين التربة غير قابلة للتطبيق، كذلك يكون استخدام الركائز خيار غير عملي بسبب تكلفتها العالية والوقت المستهلك في عملية الانشاء. الاساسات ذات الحواف هي نوع من الاساسات شبه العميقة والتي تمتلك القابلية على اختراق التربة بمقدار ضعفي عرضها. الاساسات ذات الحواف والتي تتألف من حوائط عمودية او مائلة تحيط جهة واحدة او أكثر من جهات التربة المتواجدة تحت الاساس، تعتبر طريقة معتد بها لتحسين قدرة تحمل التربة. هذه الاساسات تساعد في تقليل الهبوط وكذلك تحسين زيادة مقدار الحمل وعمق الفشل في الترب التي تمتلك مقاومة قص قليلة. هذه الورقة تناقش البحوث العملية والنظرية السابقة التي تمت لغرض دراسة تأثير هذا النوع من الاساس. العديد من العوامل تم اخذها بنظر الاعتبار مثل نوع التربة، درجة الاشباع، خواص التربة، عمق وعرض الحواف، التداخل بين الحواف والتربة، وظروف التحميل المختلفة مثل الميلان واللامركزية. اظهرت هذه الدراسات كفاءة الاساسات ذات الحواف في تقليل الانزلاق، الانقلاب والهبوط وفي نفس الوقت زيادة استقراريه الاساس، تحمل التربة ومقاومة الرفع

الكلمات المفتاحية: الاساس شبه العميق، الاساس ذو الحواف، قدرة التحمل، هبوط، حصر، العناصر المحددة، دراسة تجريبية.