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Behavior of Shallow Skirted Footing under Different Loading Conditions, Compression, Uplift, and Lateral: A Review Study

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ABSTRACT

Bearing capacity of soil is one of the important matters that occupies the minds of geotechnical engineers, especially in weak soils. In the field of geotechnical engineering, soil improvement is one of the most commonly used techniques. However, difficulties in implementation and increased costs have also caused scientists to look for more efficient and effective techniques. Many researchers as one of the innovative and promising alternatives have identified using skirts beneath shallow foundations in recent years. Their research has demonstrated the effectiveness of this method in treating the condition of the soil beneath the foundation, including enhancing bearing capacity vertically and laterally by 470% and 6.6 times, respectively, and reducing settlements by 186% and reducing rotation, slipping, and the shallow foundation's uplift capacity by 397.7% on diverse soil types. For offshore constructions such as jack-up unit structures, wind turbine foundations, oil and gas plants, tension leg platforms, bridge foundations, and transmission towers, it was discovered that skirted foundations might be a formidable rival to conventional foundation types. The results obtained from this review indicate that there are many methods for improving problematic soils to increase their bearing capacity, uplift capacity, and reduce settlement, but all of these methods are largely related to the economic aspect and the feasibility of their implementation on-site. This study demonstrated that the use of skirting is very cost-effective, as it is a successful alternative to deep foundations in problematic soils and offshore conditions. In addition, the effectiveness of a skirt depends on factors such as length, depth, relative density, and its suitability for various soil types (e.g., sandy, clayey, liquefiable, and gypseous). Optimal skirt depth-to-width ratios improve the stability of foundations exposed to inclined and lateral loads.

Keywords: Skirted foundation, Bearing capacity, Settlement, Soil improvement, Uplift capacity.

1. INTRODUCTION

To construct safe and stable structures, one of the basic concepts of geotechnical engineering is to stabilize the soil on which construction is being done. In weak and loose soils,

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geotechnical engineers have a greater responsibility to ensure the necessary stability for the structures. This stability is primarily related to the soil's bearing capacity, settlement, and uplift capacity. It is thought that improving the soil is the best technique to accomplish the aforementioned objectives. Improved soil can be achieved by a variety of techniques, which vary in terms of how they are implemented, efficiency, durability, improvement percentage, and cost. The use of skirted shallow foundations is an applicable and effective approach, serving as a significant alternative to deep foundations like piles and diaphragm walls. Economic benefits stem from simplified construction methods, reduced installation costs, and savings in time, labor, and energy. **(Appolonia et al., 1968)** investigated the impact of altering the inclined angled skirt attached to the foundation resting on sandy soil; the compressibility of the sand diminished as the inclination angle of the skirt developed from 0° to 30° vertical. A skirted foundation was developed by **(Rao and Narhari, 1979),** suggesting that using a skirt was appropriate and generally helpful when the settling was limited to a particular load. It was also noted that the compressibility value is the main constant when the skirt inclination angle is between 30° to 45°. To improve the soil, a granular pile encircled by skirts was utilized; it was discovered that this method has a lot of promise for usage with structures that are vulnerable to settling and heavy loads **(Ranjan and Rao, 1985)**.

Sandy soil locations are more likely to have shallow foundations **(Hogervorst, 1980; Tjelta et al., 1990; Tjelta, 1994; Tjelta, 1995; Bye et al., 1995).** Concrete skirted foundations have been employed as anchoring systems for tension leg platforms (TLPs) **(Stove et al., 1992; Dyvik et al., 1993).** Steel-skirted foundations have effectively served as a substitute for pile foundations in jacket structures **(Tjelta and Haarland, 1993; Bye et al., 1995)**. Skirted foundations are a cost-effective substitute for deep foundations.

This research examines numerous studies on skirted foundations across various soil types, encompassing laboratory, field, centrifuge models, numerical methods, and theoretical analyses tests; these investigations assess the behavior of skirted foundations.

2. IMPROVED SOIL

Soil bearing capacity and reducing the rate of settlement are the main issues that geotechnical engineers focus on. Due to the difference in soil composition, which leads to a difference in soil bearing capacity and the rate of settlement under the influence of the loads imposed on it, it is always expected that designers will encounter some types of weak soils. Researchers have developed many methods through which soil bearing capacity can be increased and the settlement rate reduced, such as (geogrid reinforcement, grouting, and stone columns, etc.).

The design of a reinforced shallow foundation has been approached theoretically **(Binquet and Lee, 1975)**. **(Al-Mosawe et al., 2008; 2010)** investigated the overall behavior of utilizing geogrid reinforcement to improve the soil. The results showed that when single-layer reinforcement was utilized, there was an ideal depth of reinforcement embedment at which the bearing capacity was at its highest. **(Al-Mosawe et al., 2009)** presents the results of a comparison between the laboratory model tests utilized to investigate the bearing capacity of a square footing on geogrid-reinforced loose sand. The overall behavior of employing the geogrid to improve the soil was investigated by examining the influence of various parameters. Results demonstrate that the bearing capacity of loose sand can be estimated using the theoretical equation. Liquid asphalt stabilization of gypseous soil was investigated by **(Sarsam et al., 2011)**. According to the test results, stabilizing gypseous soil enhanced its C.B.R. value, permeability, rebound consolidation, shear strength, compressibility, cohesion, and unconfined compressive strength. Shear failure of the soil below the footing causes the foundation to collapse, which is known as shallow foundation failure. The soil beneath the foundation shifts sideways due to shear failure when it is loaded, as demonstrated by research by **(Albusoda and Salem, 2012; Al-busoda and Salman, 2013)**. The behavior of the reinforced gypseous soil embankment model subjected to cyclic loading was examined by **(Sarsam et al., 2013). (Fattah et al., 2015)** studied the characteristics of clay stabilized using lime-silica fume mix under ring footing subjected to inclined loads.

(Shakir, 2017) carried out laboratory tests to treat an undisturbed soil sample with 30% gypsum using varying ratios of MC-30 lump asphalt. Test results indicated that the overall stability of 25 mm of asphalt-treated soil may be attained at a vertical tension below the requisite value for natural soil. The thickness of the asphalt-treated layer beneath the proposed foundation significantly influences the soil's bearing capacity. The optimal enhancement in bearing capacity was observed at 9% of MC-30 lump asphalt and a depth corresponding to the width of the foundation.

(Al-Hadidi and AL-Maamori, 2019) Conducted experimental tests to enhance gypseous soil with a gypsum content of (42.5%) using a mixture of soil-cement in different weight ratios. The results showed that a 10% cement ratio reduces soil collapse by 86.5% and that the minimum time required for treatment is 14 days. Rigorous examinations were performed by **(Saeed and Rashed, 2020)** to analyze the alterations in the geotechnical characteristics of natural soil stabilized by using construction and demolition waste (CDW). The results indicate a reduction in the swelling potential of the expansive soil, accompanied by a significant increase in unconfined compressive strength value, reaching up to three times its original value. The findings suggest that CDW is a cost-effective approach for soil stabilization while also being a sustainable approach to recycling construction debris and addressing the ongoing demand for additional landfill space. **(Bachay and Al-Saidi, 2022)** investigate that the ideal number of geogrid reinforcing layers, the optimum geogrid layer number is found to be 4. Studies by **(Al-Saidi et al., 2022)** investigated how injection affected the consolidation settlement of soft clayey soil**. (Mohammed and Al- Saidi, 2023)** examined the influence of eccentric-inclined forces on the performance of ring footings situated on both treated and untreated loose sandy soil. The test results showed that as the ratio of eccentric-inclined loading force to the footing radius increases, the carrying capacity of the footing decreases. The results of the test indicated that at angles of inclination equal to 5, 10, and 15, the enhancement of load-bearing capacity was by (115, 126, and 131%), respectively. The issue of saturated soil liquefaction during earthquakes employing stone columns is addressed by a series of analytical solutions conducted by **(Arefpanah and Sharafi, 2024)**.

Under specific circumstances, sandy soil enhanced using stone columns undergo to a centrifuge test. Accelerating the leakage of maximal intercellular pore pressure through stone columns can partially or wholly mitigate the possibility of liquefaction induced by earthquake stress. The accuracy of the proposed formula for figuring out how much stone column foundations settle is supported by how closely the estimated settlement matches the results from the centrifuge test.

3. FAILURE MECHANISM OF SKIRTED FOUNDATION UNDER LOADING STATES

(Mana et al., 2012) categorized the three modes of failure in skirted foundations. The PIV technique was employed by utilizing semi-circular foundation models surrounded by skirts of varying depth-to-width ratios to examine the kinematics controlling undrained failure under vertical tension, along with compression loads.

(a) A reverse end bearing mechanism utilizing external soil and the included confined soil was activated in the uplifting test, even with foundations exhibiting a low L/D ratio = 0.1.

(b) Variations in the kinematic mechanisms at breakdown have been observed in compression and uplift for a certain depth-to-width ratio.

i- Less deep processes were associated with failure in the uplifting instead of in compression.

ii- A descending soil region under the foundations, suggestive of a Prandtl-kind mechanism, was observed in compression, while a combination of Prandtl- and Hill-kind mechanisms, exhibiting slight deformations within the confined soil, was identified in the uplifting.

iii- The failure mechanisms were identified on three surfaces during the uplifting process for each L/D ratio examined, whereas limited failure mechanisms were noted for L/D > 0.3 in cases of failure under compression.

(c) The disparities in breakdown processes during tension and compression can be ascribed to a confluence of gradual breakdown impacts and the effects of soil self-weight.

Three types of collapse in skirted foundations were classified **(Schneider and Senders, 2010)**, as illustrated in **Fig. 1.**

1- Failure mechanism of Shallow footing: The incorporation of a skirt shifts the failure process of the shallow foundation to deeper soil strata, perhaps including more robust soils. **Fig. 1a.** Further resistance arises from the expansion of surface failure via the soils above the foundation **(Skempton, 1951; Gourvenec et al., 2006)**.

2-Plugged deep failure mechanism: In the case of deep skirts illustrated in **Fig. 1b,** a rounded flow mechanism could develop at the bottom of the skirted foundation, with resistance activated at the base (Qb=qb.Ab), where qb denotes the end bearing force and Ab signifies the end bearing area. Furthermore, resistance occurs alongside the shafts of the skirt foundation (Qs = τfπDsLs), in which (τf) indicates the unit shaft friction along the skirted foundation's side, (Ds) represents the diameter, and (Ls) is the skirt length at its base. Should a vacuum be present between the upper plate of the skirting foundation and the resistance (Qb).

3- Coring deep failure mechanism: This failure process, illustrated in **Fig. 1c**, may transpire. In such a case, the resistance of the end bearing (qb) is exclusively located on the ring of the skirted foundation, whereas both interior and exterior shaft friction helped with the ultimate vertical resistance. The interior soil must allow for plug movement, and the plug resistance (interior shaft friction, Qs, in) must be inferior to the end bearing.

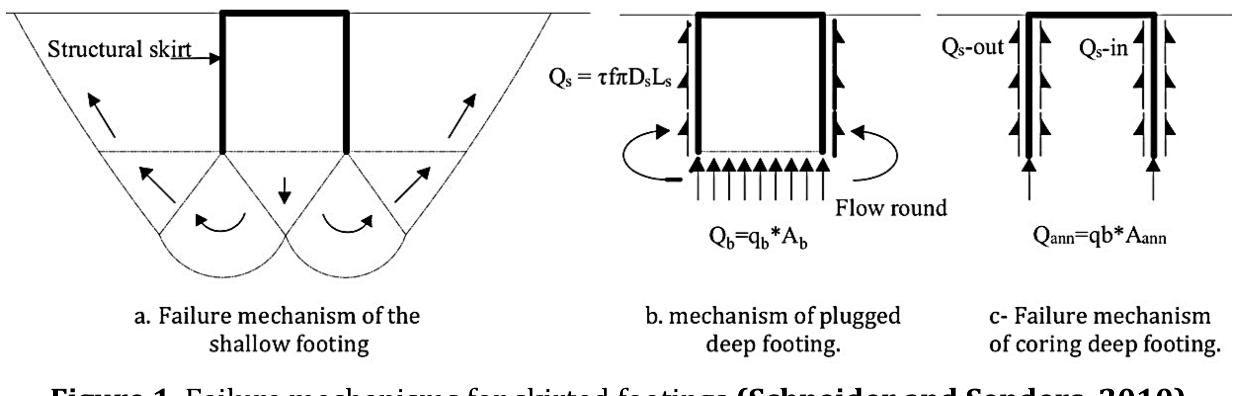

Figure 1. Failure mechanisms for skirted footings **(Schneider and Senders, 2010)**

4. APPLICATIONS OF SKIRTED FOUNDATION

In the case of non-marine structures, one of the newest methods for strengthening a foundation is the skirted foundation, which has been researched in isolated foundations. A "skirt" is a wall or walls that encircle a foundation, are attached to the foundation's bottom portion, and function together as a single unit to contain dirt between the walls while distributing the structural weight to the soil.
According to **(Thakare and Shukla, 2016)**, skirts are structural barriers made of steel or concrete that are thin, vertical, or angled to stop slides from failing on their side. Skirts were worn over a shallow base of square, rectangular, and circular forms. Because it saves time and requires fewer materials and installation techniques, this foundation is reasonably priced. Gradually, these foundations take the place of the expensive foundation.
The main difference was the marine structures in which shallow foundations reinforced with skirts were used. (Tension leg platforms, Foundation for bridges, Jacket unit structure, Gravity-based structures, Foundation for wind turbines, and Petroleum gas and oil plants) **(Tripathy, 2013)**.

5. BEARING CAPACITY OF SKIRTED SHALLOW FOUNDATION

Comprehensive studies have been undertaken on skirted foundations within the realm of soil mechanics. Offshore field and onshore laboratory experiments were performed by **(Tjelta and Haaland, 1993)** on sandy soil to investigate the skirted foundation concept.
(House and Randolph, 2001; Byrne and Cassidy, 2002) also employed this strategy. Assuming that both terms are independent is a typical procedure.
The skin-friction term for a strip footing in uniform-strength soil for skirted foundations with confined soil inside the skirts will rely on the strength of the soil, ∅, the interface roughness term, δ, and the embedment ratio L/D:

$$\mathrm{Vs} = Ks\sigma v' tan\delta \tag{1}$$

(Al-aghbari and Mohamedzein, 2004) A modified version of the classical (**Terzaghi, 1943)** bearing capacity formula Eq.(2) was suggested for strip footings with skirts resting on dense sand. It was assumed that the soil positioned above the lower edges of the skirt is regarded as a surcharge, necessitating the application of the skirt factor ($F\gamma$) Eq.(3). The suggested formula is predicated on a failure surface that resembles Terzaghi's **Fig. 2**.

$$Q_u = \gamma Hf\ Nq + 0.5\gamma BN\gamma \tag{2}$$

Where: Q_u= the ultimate bearing capacity, γ = soil unit weight, Hf = depth of footing, B = width of footing, Nq and Nγ are factors of the bearing capacity

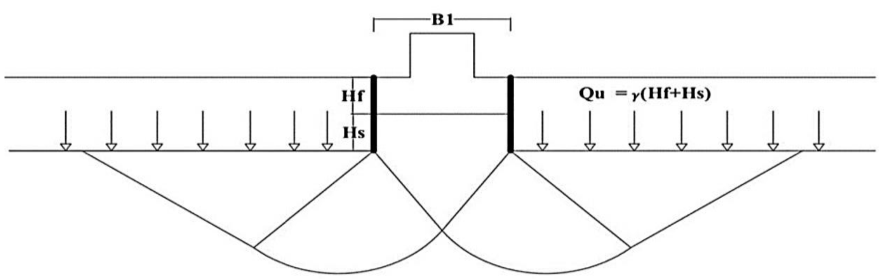

Figure 2. Failure of bearing capacity of soil beneath a strip footing with vertically loaded structural skirts (**AL-Aghbari and Mohamedzein, 2004**)

The proposed equation is:

$$Q_u = \gamma(H_{fs} + H_s)N_q + 0.5\text{B}1\gamma N_\gamma F_\gamma \quad (3)$$

Where: $F\gamma$= Skirt factor, Hfs= Foundation base depth below the ground level, Hs = Depth of the skirt below the base of the foundation, B1 = Total width of the foundation equals to (B + 2ts), ts: skirt thickness. The skirt factor ($F\gamma$) can be calculated by Eq. (4):

$$F\gamma = 1.15\ [0.4+0.6(tan\emptyset' tan\delta f)][0.57+0.1(Ds\text{B}')+0.37(tan\delta s tansf)][1.2\text{-}0.002Dr] \quad (4)$$

Where: $\emptyset'$= Effective angle of internal friction, δf = Friction angle at foundation base, δs = Friction angle at the sides of the skirt, R.D = Relative density in percent

(Ebrahimi and Rowshanzamir, 2013) discovered that the incorporation of skirts can enhance the footing carrying capacity by as much as 3.68 times, contingent upon the geometrical and structural variables of the skirts and footings, as well as the features and circumstances of the soil at both the soil-skirt and soil-footing interactions. Similar to the axial bearing capacity of a pile, the total bearing capacity, Vo, of a skirted foundation can be divided into two parts. The pile's end bearing and the exterior skin friction are Vb and Vs, respectively:

$$\text{Vo} = \text{Vb} + \text{Vs} \quad (5)$$

6. PREVIOUS STUDIES ON SKIRTED FOUNDATIONS

A review of earlier studies on the behavior of skirted foundations is conducted. The objective of the literature review is to identify the contributions that scholars have made to the actions of skirted foundations constructed on cohesionless soil and clay soil. These papers will review previous experimental and theoretical research and studies that used the skirted foundation to improve the soil's bearing capacity, reduce settlement, and increase the soil's resistance to uplift and lateral forces.

6.1 Skirted Foundation under Vertical Loads

A laboratory model for the skirted foundation was constructed by **(Giri, 1994)** four plates surround the footing, and a vibrated eccentric load is applied on the footing; the results show that the compressibility decreases with increasing inclination angle of the skirt. It is believed that using skirts during undrained loading increases the carrying capacity of foundations by retaining dirt between them **(Tani and Craig, 1955; Bransby and Randolph, 1998)**. Structural skirts have historically been utilized in marine constructions and other environments where uncontaminated water poses challenges **(Watson and Randolph, 1998; Bransby and Randolph, 1998; Randolph, 1999)**. Several investigators have examined the functionality of these foundations by numerical analysis programs and physical modeling tests, and they have documented enhanced behavior **(Watson and Randolph, 1997; Bransby and Randolph, 1999; Villalobos, 2006; Villalobos, 2007)**.

(Watson and Randolph, 1997) noted that skirt implementation beneath the foundation and concluded that skirted foundations serve as an effective alternative to pile foundations in compromised soils. **(Bransby and Randolph, 1998)** observed that skirted shallow footing can be employed with the foundation of offshore applications; however, a major concern is the safeguarding of steel skirts against wear. **(Randolph et al., 1999)** examined a skirted circular offshore foundation situated on heterogeneous soil. Structural skirts are regarded as a crucial way for supporting offshore structures, even on loose soil, due to their economic viability, rapid installation, and adequate performance under cyclic loads.

When an eccentric load is applied to the footing, the use of a vertical skirt with a square-skirted footing resting on cohesionless soil will reduce tilt to nearly zero, according to research done using the ANSYS software package **(Mahiyar and Patel, 2000).** Research by **(Ortiz, 2001)** suggested installing a vertical skirt around the foundation; the outcome revealed a 20% improvement in bearing capacity as well as a 20% reduction in settlement. Outcomes from a laboratory study on the action of skirted shallow footings on cohesion-less soil under monotonic loading were presented by **(Byrne et al., 2002)**, with a focus on stresses pertinent to the wind turbine challenge.

Skirted foundations are constructed from steel, metal or concrete material, with a relatively thin plate or wall beneath the perimeter, hence the name, and a top raft serving as the foundation. Skirted foundations are a successful substitute for surface, pier, and pile foundations in various offshore applications such as wind turbines, oil platforms, offshore industrial, and jacket structures **(Andersen et al., 2005).**

(El Sawwaf and Nazer, 2005) carried out laboratory model tests to explore the impact of soil plugging on the performance of a model footing installed on sandy soil. The results indicated that restricting soil can substantially boost the bearing capacity of circular footings. It is determined that this strengthening results in a discernible enhancement in the footing's performance by preventing the soil's lateral displacement beneath it. By using soil confining techniques, the bearing capacity of the soil can be increased 17 times higher than that of non-confining soil. The maximum increase in carrying capacity for different confining cell heights is observed at a ratio of (L/D) about equal to 1.4.

(Al-Aghbari and Mohamedzein, 2006) implemented an experiment to examine how circular footings behave while their skirt is lying on sand. The experimental study's findings showed that this kind of reinforcement alters the footing's load-displacement behavior and raises its bearing capacity. Skirt factors are utilized in the basic formula of bearing capacity for shallow circular foundations on sandy soil; they are proposed to account for the variables affecting the bearing capacity. It was discovered that using skirts lessens surface foundation settlement relative to their absence. When subjected to a working load of 50% of the ultimate bearing capacity, surface footing settling can be reduced to 11% in contrast to a footing devoid of a structural skirt. The ideal structural skirt length may fluctuate based on certain factors, including soil type, moisture content, footing dimensions, and loading conditions on the footing. The soil wedge constructed below the foundation is subsequently utilized to measure the static equilibrium and load-carrying capacity. The length of the slip surface lines directly influences the load-carrying capacity; longer slip surface lines yield make more bearing capacity. Augmenting the footing width or embedment depth can extend the length of slip lines **(Das, 2007)**.

The circular foundation settlements, both with and without structural skirts, are examined by **(Al-Aghbari, 2007)**. It was discovered that using skirts significantly affects how much sand settles and how the foundation behaves under stress and pressure. It was suggested to use a settlement reduction factor (SRF), which accounts for the effect of various factors on settlements. The findings showed that the SRF decreases as the stress increases at a given depth. When skirts are utilized, settlement can be reduced more effectively by 0.1 to 1. It was determined that the employment of skirts to lessen footing settlement on dense sand is beneficial. **(Martinez et al., 2008)** conducted laboratory tests to investigate the behavior of a shallow circular skirted footing has (diameter D=20m) and a skirt (depth Hf =6m) under compression and uplift loading. The results demonstrate that pullout capacity is less resistant than its compression reaction; hence, vigilance is warranted in planning for uplift. **(Saleh et al., 2008)** investigated the performance of a vertical foundation with a structural skirt and an angled skirted foundation on one or multiple sides when subjected to an angled and eccentric load. The results demonstrate that the skirted foundation's sloped or vertical wall restrains the underlying soil and provides resistance to lateral sliding along the skirt side **Fig. 3**.

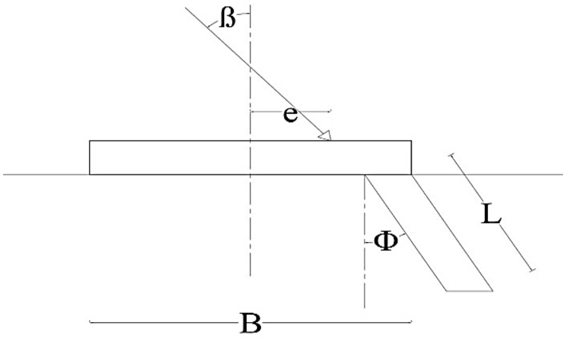

Figure 3. Variables employed in the test (**Saleh et al., 2008**).

(Azzam and Nazir, 2010) examined the bearing capacity of a 100 mm-diameter circular footing sitting on clay, both with and without skirts. According to the study, adopting circular footing with skirts could improve the carrying capacity at the footing's failure. A viable approach to extend the length of slip surface lines is to employ structural skirts that encapsulate the soil beneath the footing **(Ebrahimi and Rowshanzamir, 2013)**. A few scholars looked at the effect of skirts on footings in clay soil using experimental and software studies. **(AL-qaissy and Muwafak, 2013)** presented an experimental investigation on skirted foundations in clay soil. In this study, different structural skirt depths with an L/B ratio of (0-2). The experimental outcomes indicated that the use of a skirt in soft clay can improve the bearing capacity; the best results were obtained with an L/B ratio of 0.5.
To investigate the impact of foundation diameter on the load-bearing capability of skirted foundation placed on sand, **(Pachauria et al., 2014)** conducted lab model tests. Four different diameter foundations were applied on loose sand with an embedded skirt. The skirts of different diameters are inserted into the sand. Results demonstrated that the bearing capacity increased when the foundation diameter was increased, while the skirt diameter remained constant. **(Vijay et al., 2016)** conducted an experimental study to determine the bearing capacity of (square, circular, and rectangular) skirted footings with varying sizes, resting on c-ø soils and subjected to vertical loads. The findings indicate that utilizing a square-skirted foundation produces the greatest effects on lowering settling and increasing load-bearing capability. **(Ali, 2016)** used a numerical program test (3D Plaxis) to explore the action of a strip foundation model resting on dry sandy soil under the influence of eccentric inclined loads with varying embedment ratios (L /B) from (0-1). The findings are displayed on **Fig. 4.**

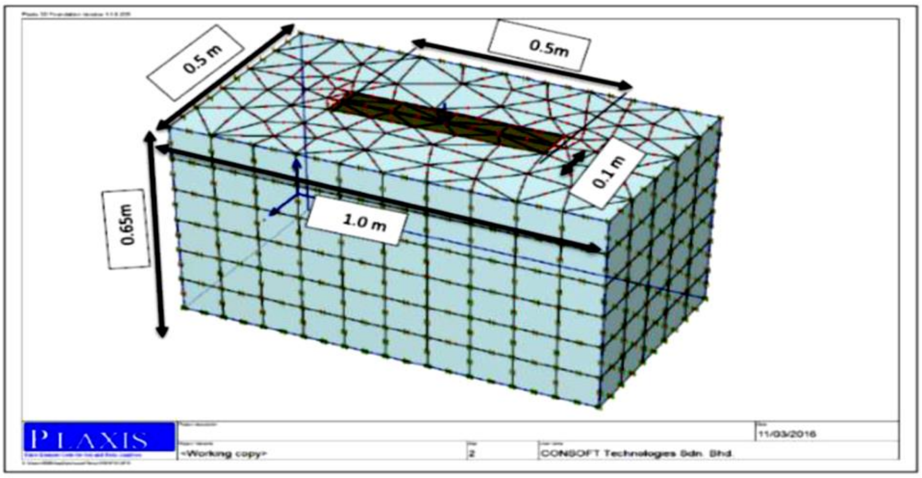

Figure 4. Mesh limit shape when footing **(Ali, 2016)**

The outcomes showed that when the eccentricity ratio (e/B) and inclination angle (β) grow, the strip foundation's bearing capacity is considerably reduced. Additionally, the impact of the inclined angle on the footing's ultimate carrying capability shows that at L/B and e/B equal zero, the carrying capability of the footing is decreased by the increase (β). In this scenario, the ultimate capacity is reduced for L/B equal 0.5 and e/B equal zero. Also, in cases where L/B equals 1 and e/B equals zero, the footing capacity is decreased. That means with the model footing positioned at a specific depth below ground level, the consequences of sliding and overturning owing to eccentric inclined load are reduced.

(Prasanth and Kumar, 2017) indicated that a circular skirted foundation lying on sand and subjected to a vertical load has a higher load-carrying capacity as the skirt length to foundation diameter (L/D) ratios are 0.4, 0.8, 1.2, 1.6, and 2. The use of a skirt also reduces settlement rate and increases the bearing capacity ratio (B.C.R.), which increases when relative density (R.D) and (L/D) ratios rise. A circular skirted foundation located on sand, exposed to perpendicular stresses, was examined by **(Renaningsih et al., 2017)** to boost the ultimate bearing capacity; the findings indicate that increasing skirt depth caused an increase in bearing capacity by up to 470%. **(Khatri et al., 2017)** conducted laboratory tests to examine the bearing capacity and load-settlement behavior of square and rectangular skirting foundations that were subjected to a vertical load while resting on sand. A foundation with (L=B) and widths of (50 and 60) mm was utilized. Various relative densities of sand equal (30%, 50%, 70%, and 87%) were employed. The level of skirt was adjusted between (0.25B - 1.0 B). The application of a skirt considerably increases the foundation's carrying capability, according to the results. The bearing capacity enhancement was found to be approximately linearly correlated with the depth of the skirt.

(Listyawan and Kusumaningtyas, 2018) studied the bearing capacity of a circular skirted foundation with a diameter of (75,100,150) mm and varying skirt depth (L) that was resting on clay and exposed to perpendicular force. Findings show that incorporating a skirt to a circular footing can reduce settlement and increase bearing capacity. The behavior of a skirted foundation supported on sandy soil, exposed to a vertical load was examined by **(Abd Ali, 2018)**. The findings reveal that the implementation of a skirt enhances the load-carrying capacity of a shallow footing resting on sandy soil.

A collection of experiments conducted on sandy soil by **(Ahidashti et al., 2019)** to evaluate how the skirted foundations respond to liquefaction caused by upward seepage. According to the study findings, high pore pressure in sand lowers the bearing capability of the footings.

Findings show that enlarging the footing's breadth and skirt length was positively correlated with its ability to support loads in liquefiable soils. Experimental studies were carried out by **(Abdulhasan et al., 2020)** on skirted foundations placed on sandy soil with exclusive skirt depths (0D to 1.5 D) and circular foundations with implemented loads at different angles of inclination (90, 80, 70 to 60) degrees with the horizontal. The load in relation to the footing diameter ratio with the horizontal and skirt depth.
An experimental study was performed to assess the efficiency of a square skirted foundation in comparison to a square shallow footing placed on soil that had the properties of dry gypseous soil and an R.D of 33% **(Abd-Alhameed and Albusoda, 2023)**. Thus, a skirted footing improves the ability to sustain weight while reducing the amount of sinking. By employing a depth of skirt approximately 1.5 times the width of the footing, carrying capability may be enhanced by as much as 190% while reducing settling by more than 186%. When the eccentric loading (e) was 8mm and the skirt's length was 1.5mm, the bearing capacity increased by 120%. Similarly, once the eccentricity loading was 17mm and the skirt length was 1.5mm, the settlement grew by upwards of 105%.
A series of experiments were conducted using a T-shaped skirting design to investigate the effects of different sand densities, from 30% to 60% and from 0.25 to 1.5, on the skirt depth. According to the study's findings, using T-skirts improves the soil's capacity to support loads while reducing settling. The test findings show that when the relative density is at 30%, the improvement is clearly visible. A comparison of the t- and h-shaped structures. Studies have indicated that a T-shaped structure may support more weight than an H-shaped structure. Experimental research was conducted by **(Alhalbusi and Al-Saidi, 2023)** to examine the behavior of sloped skirting foundations on sandy ground. The ideal skirt angle was found to be equivalent to 30, yet the load-carrying capacity rises as the skirt angle increases. Positive and negative loading are depicted in **Fig. 5**. Positive loading is more effective than negative loading in terms of boosting bearing capacity and reducing settling.

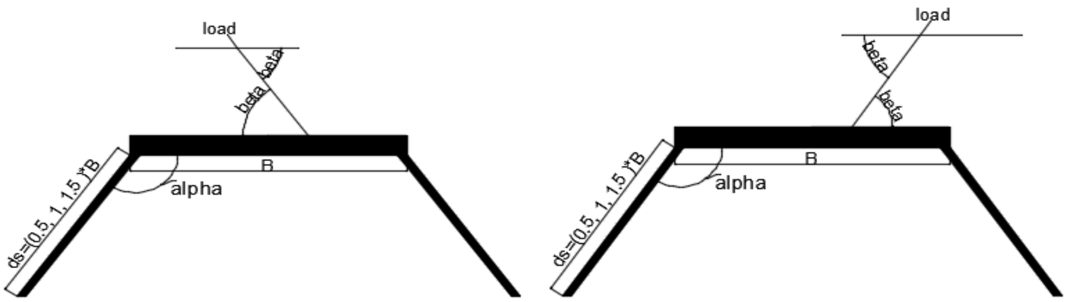

Figure 5. Skirt footing subjected to eccentric-inclined forces exposed to (a) negative, (b) positive inclination **(Alhalbusi and Al-Saidi, 2023)**

Employing both physical testing and software modeling, a strip-skirted footing was tested to assess the load-carrying capacity by using slag columns situated on sand **(Mohammadizadeh et al., 2023)**. The outcomes of the data analysis showed that the load-carrying capacity of strip footing was significantly boosted with the use of slag columns, whether or not they included geotextile reinforcement. It was discovered that utilizing slag columns with reinforcing geotextile enhanced their carrying capacity by four times, whereas using slag columns without reinforcement increased it by 2.5 times. Furthermore, the bearing capacity increased by almost 3.75 times when the skirt foundation was used in place of the strip footing. Evaluating the efficacy of skirting foundations by the utilization of

numerical approaches is prevalent in the field of geotechnical engineering due to the mechanical and geometrical complications of most issues **(Al dabi and Albusoda, 2024)**.
Based on the reviewed results, the embedment ratio of skirted footings placed on sand ranging from 1.5 to 2 has outstanding effectiveness under vertical loading conditions.

6.2 Skirted Foundation under Uplift Loads

No official guidelines are available for the uplift capacity of shallow skirted footings. However specific design recommendations agree that momentary suctions due to moving loads might facilitate the movement of enhanced capacities; industry guidelines advise depending exclusively on the combination of submerged mass of the footing and skirt friction **(Det Norske Veritas (DNV), 1992; American Petroleum Institute (API), 2000; International Standardisation Organisation (ISO), 2002; Martinez et al., 2008)**.
The pullout capability of skirted foundations in sand has been calculated theoretically by **(Houlsby et al., 2005; Senders, 2008; Lehane et al., 2014; Sawicki et al., 2016**). Numerical programs were carried out by **(Rahman et al., 2001; Zhou et al., 2008; Mana et al., 2014; Thieken et al., 2014**; **Shen et al., 2017)**.
(Das, 1978) reported the model test results for determining the pullout capacity of square and rectangular clay foundations. Aluminum plates with a thickness of 3.18 mm were used to create the model foundations. The test plates had length-to-width ratios ranging from one to five. Breakout factors have been used to present the empirically obtained net uplifting loads **(Vesic, 1971)**. Examined the differences between shallow and deep foundation conditions in terms of the critical embedment ratio and breakout parameters. The results of the current program, together with model studies carried out by other researchers, indicate that the breakout factor of foundations situated at a relatively shallow depth rises in a linear fashion with the embedment ratio, reaching approximately 6. The rate of rise steadily diminishes after approximately 6, peaking at the key embedment ratio. The critical embedment ratio for square and circular foundations ranges from roughly 3 for soft clay to roughly 7 for medium and stiff clays.
The critical embedment ratio rises as the foundation's length-to-width ratio does in a given clay. When L/B is more than 4,

$$(L/B)\ \mathrm{cr(Rectangular\ foundation\}}=1.\ 6\ (L/\ B)\ \mathrm{cr(Square\ foundation\}} \quad (6)$$

The net ultimate pullout capability of rectangular footings in sandy soil as determined by laboratory model tests, was presented by **(Das and Jones, 1982)**. The rectangular foundations were built with length-to-width ratios ranging from one to five. In medium, dense, and loose sands, tests were performed. According to Meyerhof and Adams **Fig. 6** the crucial embedment ratio for square foundations is roughly equal to that which rises with the level of sand compaction. As the foundation's length-to-width ratio rises, so does the critical embedment ratio for a given level of sand compaction. Provided is a method for calculating the factor of uplift, which determines the net ultimate uplift load force for foundations that are deep. The extent of sand compaction raises the foundation's crucial ratio of embedment. The reported values of (L/B)cr (square foundation) in this test program typically fall within the range that Meyerhof and Adams propose. The embedment of the critical ratio for horizontal foundations rises as (L/B) ratio of the plate rises and the degree of soil compaction stays constant. The Meyerhof and Adams fundamental equation's uplift factor for shallow foundations compares quite well to the experimental findings. For shallow foundations at shallow depths, their relation can be articulated as:

$$Qu = \mathrm{W} + \mathrm{Wa} + \gamma D_f^2 (2S_F B + Lf - B) K_u \tan\,\phi \quad (7)$$

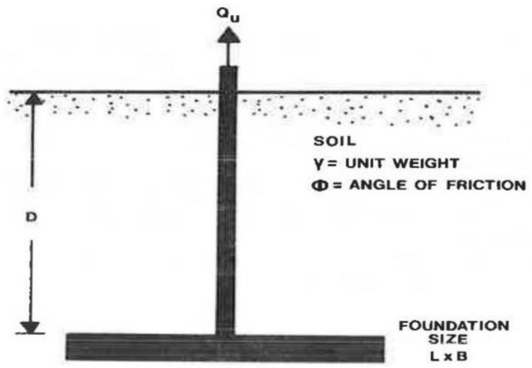

Figure 6. Parameter for ultimate uplift capacity of rectangular footings (**Das and Jones, 1982**)

(Lieng and Bjorgen, 1995) indicated that even a minor puncture, relative to the overall mudmat surface, can result in a substantial decrease in ultimate uplift capacity. Field experiments indicated a lowering of almost half a percent in uplift capacity with a perforation ratio of 3%, known as the plan area of perforating holes relative to the overall area. Skirted foundations also have uplift capacities of similar magnitude to their bearing capacity **(Watson and Randolph, 1997),** as suction within the skirt on pull-out leads to an inverse bearing capacity mechanism.

(Merifield and Sloan, 2006) carried out a thorough numerical analysis utilizing limit analysis theorem-based finite element techniques. The techniques produce trustworthy break-out factor estimations with an accuracy of ±5%, which helps to achieve the objective of enhancing soil anchor design procedures. It was discovered that the capacity of vertical anchors was significantly impacted by the roughness of the anchor interface. Reducing the interface roughness from perfectly rough to perfectly smooth can result in a 67% decrease in anchor capacity. It was discovered that the impact of anchor roughness lessened as the embedment ratio increased, and it was particularly noticeable in dense soils with large friction angles (≥ 40°).

(Singh et al., 2007) varied the pullout speed from (1.4-21.0) mm/min to investigate the influence of pullout speed on the uplift performance of plate anchors embedded in soft saturated clay. The breakout force and suction force variations with the speed of draw and embedment depth are shown. The pace at which the undrained strength of clay and anchor capacity increase is correlated with the rate of strain. To estimate the breakout capability of anchors, an empirical equation that takes the rate of pull into account has finally been proposed. (**Martinez et al., 2008)** Report on the results of testing a clay-skirted footing exposed to compression and uplift utilizing a beam centrifuge. The effects of consolidation stress level and stress history on undrained capacity and sustained load response are reported in this study, which looks at both rapid and protracted loading. The result highlights how sensitive uplift resistance is to loading history and provides information on long-term load responses by demonstrating that the undrained pullout capacity is approximately 70% of the compressive capacity.

The resistance of shallow skirting foundations to uplift for marine structures exposed to overturning or buoyant pressures is investigated by **(Martinez, 2010).** Demonstrates the experimental findings of a number of model experiments conducted at the beam centrifuge apparatus. The results were used to investigate how uplift resistance is enhanced by the slow dissipation of negative excess pore pressures. Also, **(Martinez, 2010)** studied one-way and two-way concentric cyclic loading effect on the behavior of the footing-soil system. Outcomes indicated that cyclic loading causes residual pullout displacement and reduced stiffness; however, prior cyclic loading can enhance the undrained and sustained pullout capacity under monotonic loading conditions.

Laboratory experiments are being conducted on square and circular foundation models by **(Koorala et al., 2012).** Analytical solutions for both square and circular flat foundations were compared with the results regarding their uplift capacities. The uplift force and upward displacement of two foundation models, one circular and one square, were evaluated in dry sand at three different depths. An analytical solution's uplift capability was compared to the experimentally acquired uplift force versus upward displacement characteristics. Theoretical and practical data together lead to the conclusion that square foundations have a stronger elevating capacity than circular foundations at all depths. For both kinds of foundations, the embedding depth of the foundation increases the uplifting capability as well. The angle between the vertical plane and the failure plane is over half of the soil's friction angle, which is another significant finding. A novel concept is put forth for improving the geometry of skirted foundations. To investigate this, numerical research has been done by **(Ahmadi and Ghazavi, 2012)** to determine the skirted foundations' load-carrying capacity with non-vertical walls about the vertical axis. Studies' findings indicate that when the wall face angle about the vertical direction increases, so does the bearing capability of skirting foundations. Furthermore, larger displacements are necessary to obtain the greater pull-out bearing capacity.

Several centrifuge model experiments are conducted by **(Li et al., 2013)** to define the pullout strength of mudmats having a rectangular shape situated on mildly kaolin clay under consolidated conditions. The research examines the pullout capacity and suction formed at the foundation invert affected by perforation, with skirt length and eccentricity uplift. The results indicate that the eccentric and central pullout of mudmats exhibit distinct mechanisms of failure, leading to an irregular distribution of pore water pressure at the foundation invert. Conversely, holes do not modify the mechanism of failure; they merely affect the intensity of the suction produced. Skirted shallow foundations' undrained reaction to uplift and compression has been modeled by **(Chatterjee et al., 2013)** using large deformation finite element analysis. When foundation displacement increases, either in tension or compression, there are alterations in the ratio of embedding and the local soil shear strength in operation. These are known as large deformation effects. Centrifuge model testing shows that these variations in shape affect the mobilization load- carrying capacity and the kinematic mechanisms determining failure under undrained uplift and compression. The findings demonstrated that the undrained uplift resistance for a skirted foundation implanted in a somewhat over-consolidated clay with a ratio of embedding of (L = 0.3D) for undrained compression was just 70% of the capacity.

(Landlin and Chezhiyan, 2017) tested a model skirt foundation that was smaller than the real prototype. The uplift forces were subjected to the shallow skirted foundation at variable

(L/D) ratios over sea sand (loose) under both dried and immersed situations. Ten experimental works were conducted on a model of shallow skirt footings, and the outcomes were examined. The pullout resistance decreases with submersion, and the ultimate pullout load increases as the L/D ratio increases. The soil within the skirt and the skirt's own weight combine to comprise the remaining load. Results clearly show that when the increased L/D ratio when immersed, the uplift resistance will increase. The ultimate uplift resistance for the skirt has an L=2.5D was found to be 57.86 N. With L=0.5D, this is roughly five times more than the skirt's max resistance of 11.76 N. In dry conditions, the pullout capacity rises by roughly 391.7% when the ratio of L/D goes from 0.5 to 2.5.

According to **(Kulczykowski, 2020)**, the different rates of displacement, from (5 – 450) mm/sec, affected the final uplift capacity, the vacuum pressure within the skirt compartment, and the extraction period by using single gravity 1g model testing on a shallow skirted footing established on sandy soil and exposed to a strength of rapid uplift loads. Results indicate that the rate of displacement had minimal impact on the relationship between stresses and foundation displacement, but it had a substantial impact on the amount of suction under the foundation lid and the uplift resistance. For every experimental displacement rate, the suction-displacement curve and the uplift capacity-displacement curve had comparable forms.

Based on the reviewed results, the embedment ratio of skirted footings placed on sand, ranging from 1.5 to 2.5 has outstanding effectiveness under uplift loading conditions.

6.3 Skirted Foundation under Lateral Loads

A centrifuge model was used by **(Yun and Bransby, 2003)** to study how skirted footings behaved on loose sand (at drained conditions) subjected to blended loads (horizontal, vertical, and moment stresses). According to the test results, the raft footing had a horizontal bearing capacity that was roughly (3-4) times less than that of the foundation with a skirt.

(El Wakil, 2010) Conducted laboratory testing on a circular skirted foundation to analyze the performance of the foundation under lateral loading. The influence of the skirt's length and the relative density of the sand was investigated. Results showed that the use of the skirts significantly increased the shallow foundations' ultimate horizontal bearing capability. It was discovered that the more the skirt length is increased up to 1.5, the more capable skirted foundations are of withstanding lateral loads; the same is true for the relative density of the sand. The skirt altered the failure mechanism of the foundation from slipping to rotating. The performance of foundations situated on sand with differing relative densities is influenced by the proportion of skirt length to diameter.

In order to determine the bearing capacity of a square foundation supported on sand, **(Krishna et al., 2014)** conducted experimental tests. The sand was contained laterally using hollow steel plate boxes. It examined the effects of altering the sand relative density, confinement depth, and embedment depth of the foundation ratio. Findings demonstrated that load-bearing capacity grows with confinement depth; it reached its maximum value at (L=2B), and it raises with increased embedment depth; for all sand relative densities, it reached its maximum at (L=0.5 D).

(Kannan and Chezhiyan, 2016) indicated that skirt foundations represent an alternate solution to pile foundations for offshore buildings, including wind turbines and oil rigs. An experimental work was conducted to determine the lateral load-bearing capacity of circular skirted footings with varying L/D ratios on loose submerged sand, utilizing a model bucket foundation. The results revealed that the lateral load-bearing capacity of the skirt foundation increases with an increase in the L/D ratio (6.6 times greater for L/D = 2.5 compared to L/D = 1.0), and the mechanism of failure transitions from sliding to rotation beyond a certain threshold value.

(Deshmukhthe et al., 2017) investigated the efficacy of equal skirted strip footings. The criteria examined included the ratio of embedding of the skirt and the ratio of the footing distance from the crest to the footing width. The findings of tests indicate that an increase in skirt depth and an increase in the distance from the crest to the footing width greatly enhance the ultimate lateral load-bearing capacity of footings by up to 250%.

(Barari and Ibsen, 2018) formulated a work-hardening plasticity model for the moment and horizontal force resultants related to the displacements of offshore suction caissons. A series of cyclic lateral loads tests were conducted on small-scale models. The impact of cyclic lateral loads on the lateral secant stiffness of the bucket is examined, employing a function to analyze it in relation to permanent displacements. The bucket stiffness is augmented with the number of cycles, regardless of the load characteristics, which contradicts conventional strategies to address this intricate issue.

(Rezazadeh and Eslami, 2018) explored the shallow skirted foundation resting on clayey soil subjected to vertical forces as a combined force (vertical, horizontal, and moment) using experimental tests and a finite element technique. Geometries that account for the different soil strengths and the skirting foundation's embedded depth are used in the analysis. The results showed that punching shear had replaced general shear as the failure type. Analysis of the experimental and finite element results indicates that a rise in the D/B ratio amplifies the discrepancy between the experimental and finite element bearing capacities, as skin friction plays a significant role at the outer boundaries of the deeper skirt.

The impact of lateral load applications on a skirted rectangular footing situated on sandy soil in different states was examined by experimental means **(Jawad et al., 2019)**. The factors that are being studied are the depth of the skirt (d) and the distance between the footing and the skirt (h). The conclusions suggest that the wall's nearness to the footing (L/B = 0), considerably increases bearing capacity and lowers lateral displacement for a shallow skirted foundation. It was discovered that it will lose its effectiveness if the ratio (L/B) is more than one. **(Joybari et al., 2023)** examined the efficacy of shallow skirted foundations having a square shape subjected to seismic and static compression loads through numerical analysis programs and modeling physical techniques.

The findings demonstrate that the incorporation of skirts improves the load-bearing and settling characteristics of the foundation’s surface on sandy soil, with enhancements correlating positively with increased skirt depth. The data show that the use of skirts is an excellent method for decreasing movement and vertical accelerations, strengthening foundation strength, and markedly improving the structure's response to seismic forces. The findings of experimental work correspond with numerical analysis, confirming its applicability for the designs of large-scale systems.

The load carrying capacity of skirted foundations under VH composite loading, influenced by geographical variability of undrained shear strength and embedment ratio, was examined by **(Mancer et al., 2024)** to conduct Monte Carlo simulations in conjunction with arbitrary finite element limit analysis OptumG2 program was utilized. Investigated the random study of bearing capacity and failure envelopes, emphasizing the influence of the spatial relationship on undrained shear forces. The study investigates the lateral extent of variation and the soil strength variation index, uncovering previously undiscovered sites. Recent findings highlight the influence of a rigid base on vertical bearing failure envelopes and offer

direction for evaluating the vertical bearing capability of shallow skirted foundations. Based on the results reviewed, the embedment ratio of skirted footings placed on sand, ranging from 1.5 to 2 has outstanding effectiveness under lateral loading conditions.
After looking at all previous studies on the use of structural skirts under shallow foundations and achieving impressive results in the engineering and economic aspects under compressive and lateral loading conditions, it was noted that there is a significant lack of research that dealt with the uplift loading condition. Therefore, it can be suggested to conduct experimental and theoretical research to study the effect of using the skirt and the extent of its contribution to improving the uplift capacity. It is recommended to use different parameters such as geometric shape, skirt length, soil type, soil condition (dry or saturated), materials from which the skirt is made, the condition of the skirt surfaces (rough or smooth), and the conditions of uplift loading (inclined or vertical). The most important point is to develop theoretical equations to calculate the uplift capacity of the skirt due to the lack of those laws, as indicated previously.

7. CONCLUSIONS

1- There are many methods for improving soils with low bearing capacity, which are effective for increasing soil bearing capacity and reducing the rate of settlement, but they remain governed by the economic cost and the possibility of implementation on the site.
2- The use of shallow skirt foundations is a suitable alternative to deep foundations as they are cost-effective and provide adequate safety for structures
3- The effectiveness of the skirt depends on a set of parameters such as skirt length, depth, and soil relative density, and its suitable to use in both sandy and clayey, liquefiable and gypseous soils.
4- The optimal values of skirt depth-to-diameter ratios (e.g., L/D and D/B) are essential for achieving maximum skirt performance. The optimal values of footing placed on sand were (2 ,2.5, and 2) for vertical, uplift, and lateral loading conditions, respectively.
5- The use of shallow footings has been shown to improve stability under lateral and inclined loads, transforming the failure mechanisms from sliding to rotation.
6- The bearing capacity, uplift capacity, settlement, and vertical displacement of a foundation resting on different types of soils are significantly impacted by the usage of skirts beneath the foundations. The maximum bearing capacity improvement was 470% and reduced settlement by 186% under compression loading conditions, for the lateral loading condition was 6.6 times more than the unskirted footing, and for the uplift loading condition was 391.7%.
7- The geometrical and structural characteristics of the foundation and skirt determine how well the soil improves.
8- To determine the behavior of shallow foundations of varying sizes, the improvement in uplift capacity and the decrease in vertical displacement that results from the application of skirts.
9- Eccentric uplift demonstrated a significantly higher impact on diminishing uplift capacity compared to holes; however, the advantage diminishes with increased skirt embedment.
10- The rate of displacement during rapid uplift significantly influences suction pressure and uplift resistance, yet the load-displacement connection stays comparatively consistent across varying displacement rates.
11-A significant lack of research on the impact of using a structural skirt with shallow foundations and how to improve uplift capacity.

NOMENCLATURE

Symbol	Description	Symbol	Description
B	Footing width, m.	Hs	Depth of the lower edge of the skirt below the foundation base, m.
B1	Total foundation width with skirts equals to (B + 2ts), m.	ts	Skirt thickness, m.
C	Soil cohesion, kPa.	N_q, N_γ	Bearing capacity factors,
C.B.R	California bearing ratio	Qu	Cross ultimate bearing capacity, kPa
D	Diameter of Footing, m.	Sf	Shape factor
ɵ	Angle of the shearing zone, deg.	V_o	total bearing capacity
h	distance between the footing and the skirt	W	Effective weight of soil, kN
L	Length of skirt, m.	Wa	Effective weight of footing, kN
Ku	Uplift coefficient	$\sigma v'$	Total effective stress at the skirt level
Ks	Coefficient of lateral stress,	δ	Angle of friction between the skirt and soil, m.
L/Bcr	Critecal embedment ratio	BCR	Bearing capacity ratio
Lf	Length of footing, m.	γ	unit weight of the soil, kN/m^3
Fγ	Skirt factor	e	Load eccentricity, m.
Hf	Depth of the foundation	β	Angle of load inclination, deg.
Hfs	Depth of the foundation base below ground level, m.	Ø	Angle of internal Friction, deg.

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Credit Authorship Contribution Statement

Aqeel Jaafar AL-zubaidi wrote the original draft of the manuscript. 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

Abd Ali, L., 2018. Performance of skirted foundations supported on sand soil subjected to vertical loads. M.Sc. thesis, Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.

Abd-Alhameed, H.J., and Al-Busoda, B.S., 2023. Experimental study on the behavior of square-skirted foundation resting on gypseous soil under inclined load. *Journal of Engineering*, 29(3), pp. 27-39. https://doi.org/10.31026/j.eng.2023.03.03

Abdulhasan, O., Mustafa, F., and Al-Zuhairi, A., 2020. Performance of skirted circular shallow footings resting on sandy soil under inclined loads. *Kufa Journal of Engineering*, 11(2), pp. 10-27. https://doi.org/10.30572/2018/KJE/110202

Acosta-Martinez, H.E., Gourvenec, S.M., and Randolph, M.F., 2010. Effect of gapping on the transient and sustained uplift capacity of a skirted foundation in clay. *Soils and Foundations*, 50 (5), pp. 725–735. https://doi.org/10.3208/sandf.50.725

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. https://doi.org/10.3208/sandf.48.247

Ahidashti, R.A., Barari, A. and Haddad, A., 2019. Insight into the post-liquefaction behavior of skirted foundations. In *Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions*, pp. 1106-1113.

Ahmadi, M. and Ghazavi, M., 2012. Effect of skirt geometry variation on uplift capacity of skirted foundation. In *ISOPE International Ocean and Polar Engineering Conference* (pp. ISOPE-I). ISOPE. pp. 695-699.

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. https://doi.org/10.31026/j.eng.2025.05.05.

Al Mosawe M.J., Al Saidi A.A., Jawad F.W., 2010. Bearing capacity of square footing on geogrid reinforced loose sand to resist eccentric load. *Journal of Engineering*, 16(2). pp. 4990-4999. https://doi.org/10.31026/j.eng.2010.02.17

Al-Aghbari, M. Y. 2007. Settlement of shallow circular foundations with structural skirts resting on sand. *the Journal of Engineering Research*, 4(1), pp. 11-16.

Al-Aghbari, M. Y. and Mohamedzein, Y. A., 2004. Model testing of strip footings with structural skirts. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, 8(4), pp. 171-177.

Al-Aghbari, M. Y. and Mohamedzein, Y. A., 2006. Improving the performance of circular foundations using structural skirts. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, 10(3), pp. 125-132.

Al-busoda, B.S. and Salem, L.A.K., 2012. Bearing capacity of shallow footings resting on dune sand. *Journal of Engineering*, 18(03), pp. 298-308. https://doi.org/10.31026/j.eng.2012.03.02.

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. https://doi.org/10.31026/j.eng.2013.05.01

Al-Hadidi, M. TH and AL-Maamori, Z.N.H. 2019. Improvement of earth canals constructed on gypseous soil by soil cement mixture, *Journal of Engineering*, 25 (3). pp. 23-37. https://doi.org/10.31026/j.eng.2019.03.03

Alhalbusi, G.S., and Al- Saidi, A. A., 2023. Enhancing the ability of the square footing to resist positive and negative eccentric inclined loading using an inclined skirt. *E3S Web of Conferences,* 427(01020). https://doi.org/10.1051/e3sconf/202342701031

Ali, A.M., 2016. Evaluation of bearing capacity of strip foundation subjected to eccentric inclined loads using finite element method. *Journal of Engineering*, 22(8), pp. 86-102.

Al dabi S.K., and Albusoda B.S., 2024. Skirted Foundation, Performance, Mechanism, and Limitations: A Review Study. *Journal of Engineering,* 30 (10). pp. 102-121. https://doi.org/10.31026/j.eng.2024.10.06

Al-Mosawe, M.J., Al-Saidi, A.A., and Jawad, F.W., 2009. Comparison between analytical solution and experimental results for reinforced loose sand. *6th Engineering Conference, College of Engineering*. University of Baghdad, Vol. 1, pp. 296-304

AL-Qaissy, M., and Muwafak, H., 2013. Experimental study on the behavior of skirted foundation resting on soft clayey soils. *Engineering and Technology Journal*, 31(20), pp. 434-443. https://doi.org/10.30684/etj.2013.83854

Al-Saidi, A.A., Al-Juari, K.A.K., and Fattah, M.Y., 2022. Reducing the settlement of soft clay using different grouting materials. *Journal of the Mechanical Behavior of Materials*, 31(1), pp. 240–247. DOI:10.1515/jmbm-2022-0033

American Petroleum Institute (API), 2000. RP2A: Recommended practice for planning, designing, and constructing fixed offshore platforms. Washington DC.

Andersen, K.H., Murff, J.D., Randolph, M.F., 2005. Suction anchors for deepwater applications. *Proceedings of the International Symposium on Frontiers in Offshore Geotechnics (ISFOG)*, Perth, Western Australia, vol. n/a, pp. 3–30**.**

Appolonia, D.J.D., Appolonia E.D., and Brisette, R.F.,1968. Settlement of spread footings on sand. ASCE *Journal of Soil Mechanics and Foundations Division*, 94(3), pp. 735-760. https://doi.org/10.1061/JSFEAQ.0001137

Arefpanah.S., and Sharafi, A., 2024. Analytical and experimental study of the improvement of stone column composite foundations under shaking effect. *Proceedings of the Institution of Civil Engineers Ground Improvement*, 177 (4), pp. 255-272.

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 Engineering*, 28(12), pp. 18-33. https://doi.org/10.31026/j.eng.2022.12.02

Barari A., and Ibsen L.B., 2018. A Macro-element approach for non-linear response of offshore skirted footings. *New Prospects in Geotechnical Engineering Aspects of Civil Infrastructures*, *GeoChina,* pp. 127–139.

Binquet, J., and Lee K.L., 1975. Bearing capacity tests on reinforced earth slabs. *Journal of Geotechnical Engineering Division*, ASCE, 101 (12), pp. 1241-1255. https://doi.org/10.1061/AJGEB6.0000219

Bransby, M.F., and Randolph, M.F., 1999. The effect of skirted foundation shape on response to combined V-M-H loadings. *International Journal of Offshore and Polar Engineering* 9(3), pp. 214–218.

Bransby, M.F., and Randolph, M.F., 1998. Combined loading of skirted foundations. *Geotechnique*, 48, (5), pp. 637-655. https://doi.org/10.1680/geot.1998.48.5.637

Bye, A., Erbrich, C., Rognlien, B., and Tjelta, T. I., 1995. Geotechnical design of bucket foundations. In *the Offshore Technology Conference*, Houston, Texas. https://doi.org/10.4043/7793-MS

Byrne, B. W., Villalobos, F., Houlsby, G. T., and Martin, C. M., 2002. Laboratory testing of shallow skirted foundations in sand. In *Proceedings of British Geotechnical Association International Conference on Foundations*, Dundee, 2, pp. 161-173.

Byrne, B.W., and Cassidy, M.J., 2002. Investigation the response of offshore foundations in soft clay soils. In *Proceedings of 21st International Conference on Offshore Mechanics and Arctic Engineering,* 4. pp. 263-275. https://doi.org/10.1115/OMAE2002-28057

Chatterjee, S., Mana, D.S., Gourvenec, S., and Randolph, M.F., 2014. Large deformation numerical modeling of the short-term compression and uplift capacity of offshore shallow foundations. ASCE *Journal of Geotechnical and Geoenvironmental Engineering*. 140(3). https://doi.org/10.1061/(ASCE)GT.1943-5606.0001043

Das, B.M., 2007, *Theoretical foundation engineering*, originally published: Amsterdam, Elsevier Science c1987.

Das, B.M., 2017. *Shallow Foundations Bearing Capacity and Settlement*, 3rd Edition.

Das, B.M., and Jones, A.D., 1982. Uplift capacity of rectangular foundations in sand. Transportation Research Record. https://onlinepubs.trb.org/Onlinepubs/trr/1982/884/884-009.pdf

Das. B.M., 1978. Model tests for uplift capacity of foundations in clay. *Soils and Foundations*, 18(2). pp. 17-24. https://doi.org/10.3208/sandf1972.18.2_17

Det Norske Veritas (DNV), 1992. Classification notes No. 30.4, *Foundations*.

Deshmukh P.S., Thakare S.W., and Dhatrak A. I., 2017. Performance of equal skirted strip footing resting on sand slope subjected to lateral load. *International Journal of Advance Research, Ideas and Innovations in Technology,* 3(2).

Dyvik, R., Andersen, K.H., Hansen, S.B., and Christophersen, H.P., 1993. Field tests of anchors in clay, I: Description. *Journal of Geotechnical Engineering,* ASCE, 119(10), pp. 1515-1531. https://doi.org/10.1061/(ASCE)0733-9410(1993)119:10(1515)

El Sawwaf, M., and Nazer, A., 2005. Behavior of circular footings resting on confined granular soil. *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, 131(3), pp. 359-366. https://doi.org/10.1016/j.hbrcj.2014.03.011

El Wakil, A.Z., 2010. Horizontal capacity of skirted circular shallow footings on sand. *Alexandria Engineering Journal*, 49(4), pp. 379-385. https://doi.org/10.1016/j.aej.2010.07.003

Esmaeili, K., Eslami, A., and Rezazadeh, S., 2018. Semi-deep skirted foundations and numerical solutions to evaluate bearing capacity. *Open Journal of Geology*, 8(06), pp. 623. https://doi.org/10.4236/ojg.2018.86036

Fattah , M.Y., Al-Saidi, A.A., and Jaber, M.M., 2015. Characteristics of clays stabilized with lime-silica fume mix. *Italian Journal of Geosciences*, 134(1), pp. 104–113. https://doi.org/10.3301/IJG.2014.36

Giri, P., 1994. Performance of Skirted Foundation in Sand Subjected to Vibrations. *Proceedings of the 13th International Conference on Soil Mechanics and Foundation Engineering ICSMFE*, New Delhi, India, pp. 787- 790.

Golmoghani-Ebrahimi, S., and Rowshanzamir, M.A., 2013. Experimental evaluation of bearing capacity of skirted footings. *Civil Engineering and Architecture*, 1(4), pp. 103-108. https://doi.org/10.13189/cea.2013.010401

Gourvenec, S., Randolph, M.F., and Kingsnorth, O., 2006. Undrained bearing capacity of square and rectangular footings. *International Journal of Geomechanics*, ASCE. 6(3), pp. 147-157. http://dx.doi.org/10.1061/(ASCE)1532-3641(2006)6:3(147)

Hogervorst, J.R., 1980. Field trials with large diameter suction piles. In the *Offshore Technology Conference, Houston, Texas.* https://doi.org/10.4043/3817-MS

Houlsby G.T., Kelly R.B., and, Byrne B.W., 2005. The tensile capacity of suction caissons in sand under rapid loading. *Proceedings of the International Symposium on Frontier in Offshore Geotechnics*, ISFOG, *Perth*, pp. 405–410.

House, A.R., and Randolph, M.F., 2001. Installation and pull-out capacity of stiffened suction caissons in cohesive sediments. *Proceedings of the 11th International Offshore and Polar Engineering Conference IOSPE, Stavanger, Norway*, pp. 574-580.

Hu, Y., Randolph, M.F, and Watson, P.G., 1999. Bearing response of skirted foundation on nonhomogeneous soil. *Journal of Geotechnical and Geoenvironmental Engineering*, 125(11), pp. 924–935. https://doi.org/10.1061/(ASCE)1090-0241(1999)125:11(924)

International Standardisation Organisation (ISO), 2002. Petroleum and natural gas industries: Offshore structures: Part 4: *Geotechnical and foundation design considerations*. International Organisation for Standardisation 19900.

Jawad, F.W., Al-Ameri, A.F.I., and Yasun, A.S., 2019. Experimental investigation of skirt footing subjected to lateral loading. *The Open Civil Engineering Journal*. 13(1). http://dx.doi.org/10.2174/1874149501913010020.

Joybari, H.M, Afzalirad, M., Hosseinzadeh, Z., and Naveen, B P., 2023. Behavior of skirted foundations under vertical load by numerical and physical modeling methods. *Arabian Journal of Geosciences*, 16(661). DOI:10.1007/s12517-023-11759-6.

Kannan M., and Chezhiyan S., 2016. Lateral capacity of skirt foundation on loose submerged sand. *International Journal of Chemical Sciences*, 14(S1), pp. 295-301.

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. https://doi.org/10.12989/gae.2017.12.4.689

Koorala S.K.D.C.P, Kumara M.K.S.N., Edirisinghe E.A.L., and de Silva L.I.N., 2012. Investigation on Uplift Capacity of Shallow Foundations on Cohesionless Soil. *Proceedings of the Civil Engineering Research for Industry Symposium (CERIS)*, pp. 22-25. http://dl.lib.uom.lk/handle/123/17921

Krishna, A., Viswanath, B., and Keshav, N., 2014. Performance of square footing resting on laterally confined sand. *International Journal of Research in Engineering and Technology*. 3(6), pp. 110-114.

Kulczykowski. M., 2020. Experimental investigation of skirted foundation in sand subjected to rapid uplift. *Archives of Hydro-Engineering and Environmental Mechanics*, 67 (1–4), pp. 17–34. https://doi.org/10.1515/heem-2020-0002

Landlin G., and Chezhiyan S., 2014. Behavior of skirt foundation on loose sea sand with pullout loading under dry and submerged conditions. *International Journal of Civil Engineering and Technology (IJCIET)*, 8 (4), pp. 1897–1904.

Lehane, B.M., Elkhatib S., Terzaghi S., 2014. Extraction of suction caissons in sand, *Geotechnique*, 64 (9), pp. 735–739. https://doi.org/10.1680/geot.14.T.011

Li, X., Gaudin. C., Tian. Y., and Cassidy. M. J., 2013. Effect of perforations on uplift capacity of skirted foundations on clay. *Canadian Geotechnical Journal*, 51(3). https://doi.org/10.1139/cgj-2013-0110

Listyawan, A.B., and Kusumaningtyas, N., 2018. Bearing capacity of circular skirted footing on clay soil. In *IOP Conference Series: Materials Science and Engineering*, 403(1), P. 012019. https://doi.org/10.1088/1757-899X/403/1/012019.

Mahiyar, H., and Patel, A.N., 2000. Analysis of angle-shaped footing under eccentric loading. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, 126(12), pp. 1151-1156. https://doi.org/10.1061/(ASCE)1090-0241(2000)126:12(1151)

Mana, D.S.K, Gourvenec, S.M, Randolph. M.F., and Hossain, M.S., 2012. Failure mechanisms of skirted foundations in uplift and compression. *International Journal of Physical Modelling in Geotechnics,* 12 (2). pp. 47-62. https://doi.org/10.1680/ijpmg.11.00007

Mancer, F., Bouaicha, A., Chwała, M., and Mabrouki, A., 2024. Probabilistic assessment of bearing capacity of skirted foundation under combined loadings with a rigid base. *Geological Journal*, 59(9), pp. 2609-2622. https://doi.org/10.1002/gj.5008

Merifield, R.S., and Sloan, S.W., 2006. The ultimate pullout capacity of anchors in frictional soils. *Canadian Geotechnical Journal*, 43 (8), pp. 852–868. https://doi.org/10.1139/t06-052

Mohammadizadeh, M., Nadi, B., Hajiannia, A., and Mahmoudi, E., 2023. The undrained vertical bearing capacity of skirted foundations located on slopes using finite element limit analysis. *Innovative Infrastructure Solutions,* 8 (121). https://doi.org/10.1007/s41062-023-01070-4

Mohammed Ali, J.Y., and Al-Saidi, A.A., 2023. Optimum reinforcement depth ratio for sandy soil enhancement to support ring footing subjected to a combination of inclined eccentric load. *Journal of Engineering*, 29 (11). pp .95-108. https://doi.org/10.31026/j.eng.2023.11.06

Nazir, A.K., and Azzam, W.R., 2010. Improving the bearing capacity of footing on soft clay with a sand pile with/without skirts. *Alexandria Engineering Journal*, 49(4), pp. 371–377. https://doi.org/10.1016/j.aej.2010.06.002

Ortiz, J.M.R., 2001. Strengthening of foundations through peripheral confinement. *Proceedings 15th International Conference on Soil Mechanics and Geotechnical Engineering, Netherlands*, 1, pp. 779-782.

Pachauria, D.K., Kumar, R., and Jain, P. K., 2014. Behaviour of circular footing resting on skirted loose sand. *International Journal of Advanced Engineering Research and Studies*, 3(IV), pp. 10-12.

Prasanth, T., and Kumar, P.R., 2017. A study on the load-carrying capacity of skirted foundation on sand. *International Journal of Science and Research*, 6(6), pp. 2231-2235. http://dx.doi.org/10.21275/ART20174885

Rahman M.S., Wang, J., Deng, W., and Carter, J.P., 2001. A neural network model for the uplift capacity of suction caissons, *Computers and Geotechnics*, 28 (4), pp. 269–287, https://doi.org/10.1016/S0266-352X(00)00033-1

Ranjan, G., and Rao, B.G., 1985. Settlement analysis of skirted granular piles. *Journal of Geotechnical Engineering Division*, 111(11), pp. 1264-1280.

Rao, B.G., and Narhari, D.R., 1979. Skirted soil plug foundation. *Proceedings 6th Asian Regional Conference on Soils, Singapore*, pp. 319-322.

Renaningsih, R., Satria, I.F., Susanto, A., and Listyawan, A.B., 2017. Method to increase the ultimate bearing capacity of skirted circular footing. In *AIP Conference Proceedings* (Vol. 1855, No. 1). AIP Publishing. http://dx.doi.org/10.1063/1.4985458

Saeed, S.B., and Rashed, K.M., 2020. Evaluating the uses of concrete demolishing waste in improving the geotechnical properties of expansive soil. *Journal of Engineering*, 26(7), pp. 158-174. https://doi.org/10.31026/j.eng.2020.07.11

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), pp. 1-33.

Sarsam, S.I., Al-Saidi, A.A., and Al-Khayat, B.H., 2011. Implementation of gypseous soil-asphalt stabilization technique for base course construction. *Journal of Engineering,* 17(5), pp. 1066-1076. https://doi.org/10.31026/j.eng.2011.05.03

Sarsam, S.I, Al- Saidi, A.A., and Mukhlef, O.J., 2013. Behavior of reinforced gypseous soil embankment model under cyclic loading. *Journal of Engineering*, 19(7), pp. 830-844. https://doi.org/10.31026/j.eng.2013.07.05

Sawicki, A., Wachowski, Ł., and Kulczykowski, M., 2016. The pull-out capacity of suction caissons in model investigations. *Archives of Hydro Engineering and Environmental Mechanics*, 63 (2–3), pp. 157–171, DOI: https://doi.org/10.1515/heem-2016-0010

Schneider, J.A., and Senders, M., 2010. Foundation design – a comparison of oil and gas platforms with offshore wind turbines, *Journal of the Marine Technology Society*, 44(1), pp. 32-51. https://doi.org/10.4031/MTSJ.44.1.5

Senders M., 2008. Suction caissons in sand as tripod foundations for offshore wind turbines, PhD Dissertation, *School of Civil and Resource Engineering. University of Western Australia*.

Shakir, Z.H., 2017. Improvement of gypseous soil using cutback asphalt. *Journal of Engineering*, 23 (10), pp. 44–61. https://doi.org/10.31026/j.eng.2017.10.04

Shen K., Zhang, Y., Klinkvort R.T., Sturm H., Jostad H.P., Sivasithamparam N., and Guo Z., 2017. numerical simulation of suction bucket under vertical tension loading. *Offshore Site Investigation Geotechnics, 8th International Conference Proceeding*, 10, pp. 488–497. https://doi.org/10.3723/OSIG17.488

Singh, S.P., Tripathy, D.P., and Ramaswamy, S.V., 2007. Estimation of uplift capacity of rapidly loaded plate anchors in soft clay. *Marine Georesources and Geotechnology*, 25(3-4), pp. 237-249. https://doi.org/10.1080/10641190701699376

Skempton, A.W., 1951. The bearing capacity of clays. In *Proceedings of the Building Research Congress, Vol. 1, pp. 180–189*.

Stove, O.J., Bysveen, S., and Christophersen, H.P., 1992. New foundation systems for the Snorre development. *Proceedings Offshore Technology Conference, Houston*, OTC 6882, pp. 75-83.

Tani, K., and Craig, W.H., 1995. Bearing capacity of circular foundations on soft clay of strength increasing with depth. *Soils and Foundations*, 35(4), pp. 21–35. https://doi.org/10.3208/sandf.35.4_21

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.

Thieken K., Achmus, M, Schröder, Ch., 2014. On the behavior of suction buckets in sand under tensile loads. *Computers and Geotechnics*, 60, pp. 88–100. http://dx.doi.org/10.1016/j.compgeo.2014.04.004

Tjelta, T.I., 1995, Geotechnical experience from the installation of the Europipe jacket with bucket foundations. In the *Offshore Technology Conference, Houston, Texas*. https://doi.org/10.4043/7795-MS

Tjelta, T.I., Aas, P.M., Hermstad, J., and Andenaes, E., 1990. The skirt piled Gullfaks C platform installation. In the *Offshore Technology Conference, Houston, Texas*. https://doi.org/10.4043/6473-MS

Tjelta, T.L., 1994. Geotechnical aspects of bucket foundations replacing piles for the Europipe 16/11-E jacket. In the *Offshore Technology Conference, Houston, Texas. 70*. https://doi.org/10.4043/7379-MS

Tjelta, T.I., and Haaland, G., 1993. Novel foundation concept for a jacket finding its place. In *Offshore Site Investigation and Foundation Behaviour: Papers presented at a conference organized by the Society for Underwater Technology and held in London, UK, September 22–24,* pp. 717-728*.* Springer Netherlands. https://doi.org/10.1007/s42452-020-2239-9

Tripathy, S., 2013. Load carrying capacity of skirted foundation on sand. PhD thesis, *National Institute of Technology, Rourkela.*

Vesic, A.S., 1971. Breakout resistance of objects embedded in the ocean bottom. *Journal of the Soil Mechanics & Foundations Division*. ASCE, 97(9), pp. 1183-1205. https://doi.org/10.1061/JSFEAQ.0001659

Vijay, A., Akella, V., and Bhanumurthy, P.R., 2016. Experimental studies on bearing capacity of skirted footings on C-Φ soils. *International Journal of Research Engineering Technology*, 5(14), pp. 5-9. https://doi.org/10.1007/978-981-15-3254-2_9

Villalobos, F.A.J., 2006. Model testing of foundations for offshore wind turbines. PhD thesis, Oxford University, Oxford, UK.

Villalobos, F., 2007. Bearing capacity of skirted foundations in sand. In *VI Congreso Chileno de Geotecnia, Valparaiso*.

Watson, P.G., and Randolph M.F., 1997. Vertical capacity of caisson foundations in calcareous sediments. *Proceedings of the 7th International Offshore Polar Engineering Conference, Honolulu. International Society of Offshore and Polar Engineers (ISOPE), Hawaii, USA, Vol. 1*, pp. 784–790.

Watson, P.G., and Randolph, M., 1998. Failure envelopes for caisson foundations in calcareous sediments. *Applied Ocean Research*, 20(5), pp. 83-94. https://doi.org/10.1016/S0141-1187(98)00008-X

Yun, G.J., and Bransby, M.F., 2003. Centrifuge modeling of the horizontal capacity of skirted foundations on drained loose sand. In BGA International Conference on Foundations: Innovations, observations, design, and practice: *Proceedings of the international conference organized by British Geotechnical Association and held in Dundee, Scotland on 2–5th September 2003,* pp. 975-984*.* Thomas Telford Publishing.

Zhou X.X., Chow Y.K., and Leung C.F., 2008. Numerical modeling of the breakout process of objects lying on the seabed surface. *Computers and Geotechnics*, 35(5), pp. 686–702. https://doi.org/10.1016/j.compgeo.2007.11.004

الأساس ذو الحواف تحت مختلف حالات التحميل، الضغط، والرفع، والتحميل الجانبي: دراسة مراجعة

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الخلاصة

تُعد قدرة تحمل التربة من أهم الأمور التي تشغل بال المهندسين الجيوتقنيين، وخاصةً في الترب الضعيفة. وفي مجال الهندسة الجيوتقنية، يُعد تحسين التربة من أكثر التقنيات شيوعًا. إلا أن صعوبات التنفيذ وارتفاع التكاليف دفعت العلماء إلى البحث عن تقنيات أكثر كفاءة وفعالية. وقد حدد العديد من الباحثين في السنوات الأخيرة استخدام التنانير أسفل الأساسات الضحلة كأحد البدائل المبتكرة والواعدة. وقد أثبتت أبحاثهم فعالية هذه الطريقة في معالجة حالة التربة أسفل الأساسات، بما في ذلك تعزيز قدرة التحمل رأسيًا وأفقيًا بنسبة 470% و6.6 مرة على التوالي، وتقليل الهبوط بنسبة 186%، وتقليل الدوران والانزلاق وهبوط المنشآت، بالإضافة إلى قدرة الأساسات الضحلة على مقاومة الرفع بنسبة 397.7% لأنواع مختلفة من التربة. وفي المنشآت البحرية، مثل هياكل وحدات الرفع، وأساسات توربينات الرياح، ومحطات النفط والغاز، ومنصات الأرجل الشدّية، وأساسات الجسور، وأبراج النقل، فقد اكتُشف أن الأساسات ذات التنانير قد تُشكل منافسًا قويًا لأنواع الأساسات التقليدية. تشير النتائج التي تم الحصول عليها من هذه المراجعة إلى وجود العديد من الطرق لتحسين التربة ذات المشاكل لزيادة قدرتها على التحمل وقدرتها على مقاومة الرفع وتقليل الهبوط، ولكن جميع هذه الطرق مرتبطة إلى حد كبير بالجانب الاقتصادي وجدوى تنفيذها في الموقع. أظهرت هذه الدراسة أن استخدام القاعدة (التنورة) فعال للغاية من حيث التكلفة، حيث إنه بديل ناجح للأساسات العميقة في التربة ذات المشاكل والظروف البحرية. بالإضافة إلى ذلك، تعتمد فعالية القاعدة على عوامل مثل الطول والعمق والكثافة النسبية وملاءمتها لأنواع التربة المختلفة (مثل الرملية والطينية والقابلة للتميع والجبس). تعمل النسب المثلى لعمق القاعدة إلى عرضها على تحسين استقرار الأساسات المعرضة للأحمال المائلة والجانبية.

الكلمات المفتاحية: أساسات ذات قاعدة، قدرة تحمل، هبوط، تحسين التربة، قدرة الرفع.