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Improving Bearing Capacity by Skirted Foundation: A Review Study

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ABSTRACT

The difficulty that faces the geotechnical engineers how to find the alternative and effective method to improve bearing capacity and reduce foundation settlement. Therefore, the skirt is considered one of the methods to improving the shallow foundation bearing capacity on different soil. The mechanism of skirt work is confinement soil below the foundation and decrease settlement of the foundation. Soil engineers are worked to devise this method as an alternative to pile foundation for conventional buildings. This paper reviews most of these studies of skirted foundations with different types of soil including laboratory tests, field tests, centrifuge models, numerical method and theoretical analysis; these studies are used in investigation the behaviors skirted foundations.

1. Introduction

The shallow foundation failure occurs owing to the soil shear failure below the foundation. When the load is applied to a foundation, the soil below the foundation is moved sideways by shear failure. By confining the soil under the foundation, such failure can be effectively controlled and thus the failure mechanism. Thus by providing a skirt, the load from the superstructure is transferred to the strata below the bottom of the skirt as shown in (Fig. 1).

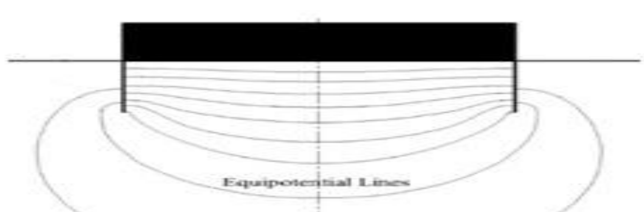

Fig. 1 Mechanism of load transfer inside the soil

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The skirt is preferred over the traditional pile foundations and diaphragm walls owing to the economic advantages that arise from the simpler construction approaches, the lower costs of installation, saving time, labor, and energy.

2. Literature Review

Studies of the skirt included sandy soil and clay soil. Some researchers have also suggested that the skirt can be worked under static and dynamic loads. Offshore hydrocarbon projects are the first to use structural skirts in the early 1970s to support the structures. At this time, the term skirted foundations is utilized to define shallow foundations with vertical or inclined thin structural elements fixed along its edges, called “skirt” to increase the bearing capacity and/or provide scour protection which penetrate the soil and surround one or more sides of the soil underneath the foundation and thus constrain its lateral movement.

(Bransby & Randolph, 1998) mentioned that skirts can be used in offshore foundation applications, but there is a major problem which is protecting steel skirts from wear.

(Hu et al., 1999) investigated a skirted offshore circular foundation upon a non-uniform soil. Structural skirts are considered one of the most important methods to support offshore structures even in loose soil on account of economic feasibility, short installation time, and also satisfactory performance under cyclic loading.

(Watson & Randolph, 1997) observed that the skirt execution below the foundation and came to a conclusion that the skirted foundations can be considered as a good solution for replacing deep foundations in weakened soils.

(EL Wakil, 2013) pointed out that the benefits of skirts in loose sand outweigh as compared to the skirted foundation rest upon the medium and dense sand. The results indicated that the bearing capacity rose by up to (6 - 25) times for the skirted circular foundation upon the sand.

(Al-aghbari & Mohamedzein, 2004) and (EL Wakil, 2010) mentioned that the reduction in the settlement of foundation and the improvement of bearing capacity on sand relies on several factors, such as properties of structural skirts, shape of the foundation, and interface conditions between sand and skirt.

(Al-Aghbari & Mohamedzein, 2018) aforesaid that the skirts have been utilized to improve the bearing capacity of the circular foundation positioned on dune sand and decrease the settlement. Depending on such promising outcomes, the bearing capacity is greatly augmented by about 470% at 1.25 B depth of the skirted foundation. From these results of experimental work, the researchers have proposed the modified bearing equation (Eq. 1) for the circular foundation.

$$q_{ult} = \gamma(D_f + D_s)\, N_q\, s_q d_q + 0.5\, \gamma\, B'\, N_\gamma s_\gamma d_\gamma F_\gamma \quad (1)$$

Where:

s_q and s_γ are shape factors, D_f is the foundation depth below the level of ground, D_s is the depth of skirt below the foundation as shown in (Fig. 2), d_q and d_γ are the depth factors, B' is the whole foundation and skirts width (B + 2Bs), where Bs is the skirt thickness, N_q and N_γ are the functions of the effective angle of internal friction Ø, and F_γ is the factor of skirt $F_\gamma = F_{\gamma f} F_{\gamma d}$ ($F_{\gamma f}$ is the surface friction factor of skirt, and $F_{\gamma d}$ is the depth factor of skirt).

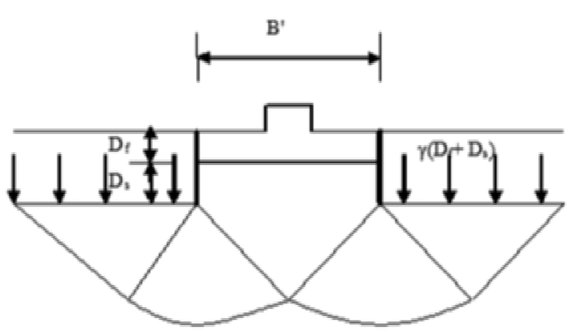

Fig. 2 Failure mechanism of bearing capacity with skirted foundation

(Byrne et al., 2002) reported consequences based on a lab study of the monotonic loading response of the skirted shallow foundations upon sand, with a special focus upon the loads related to the wind turbines problem. This study involved changing the skirt length compared to the foundation diameter and changing the mineral and sand density. The outcomes of the tests of the vertical bearing capacity were stated. Then, a comparison was made with the results taken from simple theoretical expressions based on the standard formula of bearing capacity.

Tests of a series of centrifuge models have been achieved by (Yun & Branby, 2003) to study skirted foundation response on the soil of loose sand subjected to vertical displacement, horizontal displacement, also flexural load combinations. The trials stated so that skirted foundation horizontal capacity increased 3-4 approximately times that obtained in the plane foundation. Besides, the researchers remarked that the mechanism of foundation failure changes from the mode (sliding) to the mode (rotational).

(El Sawwaf & Nazer, 2005) performed the lab model tests of the soil confinement effect upon the conduct of the model footing that rests upon a sandy soil. The results showed that the circular footing bearing capacity can be increased remarkably through confining the soil. It is reached that this strengthening, which prevents the soil lateral displacement under the footing, results in a noticeable enhancement in the response of footing. It is noticed that the bearing capacity of the model of footing sitting upon the confined sand increases with the normalized cell diameter (d/D) (diameter of the cell/diameter of the footing), up to a certain (d/D) value. Beyond that, the ratio of bearing capacity decreases with the (d/D) ratio. Adopting the soil confining may lead to upgrade the bearing capacity to 17 times that of the non-confining soil. The best advantage of the confinement of soil can obviously be determined when the ratio of (d/D) is (1 - 2). The utmost enhancement in the bearing capacity occurs at a ratio of (d/D) nearly (1.4) for various confining cells heights.

(Punrattanasin, 2009) studied skirted foundations on a sandy soil with two types of loading: vertical load and combined vertical-horizontal load. Results elucidated that the peak capacities of the skirted foundation under the combined vertical-horizontal load are higher than the square footing.

(Tripathy, 2013) performed the lab model tests to investigated the lateral stability and vertical load bearing capacity of the skirted footing with different relative densities and different L/D (skirt length to diameter ratio). The results proved that the raise in load carrying capacity of skirted foundation has been occurred both with the increase in relative density of sand and skirt depth. In horizontal loading test at higher relative intensity, the stress reaches the peak value at lower strain and sudden failure occurs. But at a lower relative density, the peak is stress occurs at relatively high stress.

(Ebrahimi & Rowshanzamir, 2013) found that when using skirted foundation lead to improvement the load carrying capacity of foundation up to 3.68 times depending on the structural specifications and geometry of the skirts and foundation, soil conditions and skirt-soil and foundation- soil interfaces.

(Dawarci et al., 2014) presented the experimental research of a multi-edges footing resting on a sandy soil without structural skirts.

(Haider & Mekkiyah, 2018) reported consequences based on a lab study of the monotonic loading response of the skirted shallow foundations on sand with different skirt depth 0.5D to 1.5D and different circular diameters. The results showed that the bearing capacity of foundation increases with increase depth skirted as well as diameter of foundation.

A wide analysis of software addressing the validated model results has been presented by (Yun & Bransby, 2007), (Saleh, et al., 2008), (Gourvenec & Jensen, 2009), (Mana, et al., 2013), and (Pusadkar & Bhatkar, 2013). In these studies, the finite element (FE) analysis helped in best understanding and specifying the failure plan of the skirted foundation with and without a skirt.

(Bransby & Randolph, 1999) observed that the circular foundation is better than the strip foundation, when the (FE) technique is employed for investigating the skirted foundation

(Mahmood et al., 2019) studied the skirted foundations effectiveness upon a problematic soil (submerged gypseous, dry gypseous soil). The experimental test used to find the best L/D ratio (Length /Diameter) of the skirted foundation for obtaining the ultimate bearing capacity upon a dry and saturated collapsible gypseous soil. The results proved that the skirt can be used in gypsum soil. Where, the bearing capacity increased from 1.92 to 2.27. These increments depend on the characteristics of gypseous soil, and the geometric properties of the skirted foundation. The results evidence refers to increasing the depth of penetration of the skirt leads to the intersection of failure lines below the foundation with a skirt and their influence does not reach the soil surface and this drove to confining soil block to reach maximum capacity.

Through the presentations suggested by researchers, the circular foundation was used via (El Sawwaf & Nazer, 2005) and (Al-Aghbari, 2007), the rectangular footing was applied by (Khatri, et. al., 2017), the strip footing was utilized by (Al-aghbari & Mohamedzein, 2004), and the square footing was exercised by (Al-Aghbari & Dutta, 2008) and (Eid, 2013). Most of these researches have studied the structural skirts resting on the sandy soil under static load.

Some researchers conducted experimental and software studies for investigating the skirt influence upon the foundations at clay soil. The experimental research of skirted foundation on clay soil has been presented by (AL-qaissy & Muwafak, 2013). This study includes using different structural skirts depth D/B ratio (skirt depth to foundation width) 0-2. The results of tests showed that the structural skirt foundation in the soft clay has ability to increase bearing capacity and the best result occurs at 0.5 D/B ratio.

(Rezazadeh & Eslami, 2017) investigated the skirted foundation on clay soil under vertical loading as a part of combined loading (vertical, horizontal, and moment) by the experimental and finite element method. The study includes using geometries considering of embedded depth of skirted foundation, and different soil strength. The results showed that the failure is changed from a general shear to a punch shear failure. the comparison of the finite element results with the experimental results that increasing the D/B ratio (skirt depth to foundation width) will lead to an increase in the difference between bearing capabilities calculated by finite element and experimental due to ignoring the important role of skin friction in the perimeter of the larger skirt depth.

(Listyawan, et al., 2017) investigated the skirted foundation effect on a clay soil under a vertical load. Nine experiment tests were carried out on the circular foundation with different skirt lengths and different diameters of foundation. The results of the tests evinced that the skirts are very effective to increase the bearing capacity and decrease the foundation settlement which is noted on the same load 1 kN Generally, it is found that the longest skirt has the best bearing capacity at constant settlement 3 mm.

Despite the significance of the skirt to decrease the settlement and raise the foundation bearing capacity under static load, but under dynamic load, there is a poverty of such studies.

(Alzabeebee, 2020) have tried to estimate the influence of the skirted strip foundation on dynamic response under vertical vibration. The 2-D finite element model is developed for the investigation of reducing the settlement of the foundation when using the skirts. The results 2-D finite element method showed that the effect of skirts on the settlement is very important to enhanced settlement reduction. It may be worth noting that the decrease in the settlement is dependent on the frequency of the machine, depth of skirts, and density of the soil.

3. Conclusions

Through many studies (laboratory tests, field tests, centrifuge models, numerical method and theoretical analysis) carried out by many researchers in order to investigate the effect of the skirted foundation on different types of soil (sand, gypseous sand soil, and clay soil) and under the influence of different loads (vertical static load, dynamic load), the following conclusion was reached:

- On the basis of these promising results, the skirt can be considered a reliable technology to raise the foundation bearing capacity at different types of soils
- When the skirted foundation depths increases, this will lead to a reduction in the foundation settlement and raise the bearing capacity because of confining soil under the foundation transferring stress to deeper.
- Improvement of the bearing capacity depends on several factors such as properties of structural skirts, the shape of the foundation, and interface conditions between soil and skirt.
- Through papers, it is found that the effect of the skirt is greater on sandy soils than on clayey soils.
- the benefits of skirts in loose sand outweigh as compared that the skirted foundation resting on medium and dense sand
- For clay soil, some researchers have pointed out the best result occurs at a 0.5 D/B ratio.
- The skirt can be used in problematic soils (gypsum soils) as it reduces the settlement and increases the bearing capacity depending on the gypseous soil characteristics, and the geometric properties of the skirted foundation.

References

Abdulrasool, A. S. (2017). Effect of sand wall stabilized with different percentages of lime on bearing capacity of foundation. *International Scholarly and Scientific Research & Innovation*, 11(2),166-169.

Al-Aghbari, M. Y., & Mohamedzein, Y. E. (2004). Bearing capacity of strip foundations with structural skirts. *Geotechnical and Geological Engineering*, 22(1), 43–57.

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

Al-Aghbari, M. Y., & Dutta, R. K. (2008). Performance of square footing with structural skirt resting on sand. *Geomechanics and Geoengineering*, 3(4), 271–277.

Al-Aghbari, M. Y., & Mohamedzein, Y. E. A. (2018). The Use of Skirts to Improve The Performance of a Footing in Sand. *International Journal of Geotechnical Engineering*, 1-8.

Al-qaissy, M., & Muwafak, H. (2013). Experimental study on the behavior of skirted foundation rested on soft clayey soils. *Engineering and Techechnology Journal*, 31(20), Part (A), 435- 443.

Al-zabeebee, S. (2018). Dynamic response and design of a skirted strip foundation subjected to vertical vibration. *Geomechanics and Engineering*, 20(4), 345-358.

Bransby, M. F., & Randolph, M. F. (1998). Combined loading of skirted foundation. *Geotechnique*, 48(5), 637–655.

Bransby, M. F., & 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), 214–218.

Dawarci, B., Ornek, M., & Turedi, Y. (2014). Analysis of multi-edge footings rested on loose and dense sand. *Period Politech Civil Engineering*, 58(4), 355–370.

Ebrahimi, S. G., & Rowshanzamir, M .A. (2013). Experimental evaluation of bearing capacity of skirted footings. *Civil Engineering and Architecture* ,1(4),103-108.

Eid, H. T. (2013). Bearing capacity and settlement of skirted shallow foundations on sand. *International Journal of Geomechanics*, 13(5), 645-652.

EL Wakil, A. Z. (2010). Horizontal capacity of skirted circular shallow footings on sand. *Alexandria Engineering Journal*, vol. 49, 379–385.

EL Wakil, A. Z. (2013). Bearing capacity of skirt circular footing on sand. *Alexandria Engineering Journal*, vol. 52, 359–364.

Gourvenec, S., & Jensen, K. (2009). Effect of embedment and spacing of cojoined skirted foundation systems on undrained limit states under general loading. *International Journal of Geomechanics*, 9(6), 267–279.

Haider, L., & Mekkiyah, H. M. (2018). Response of skirted foundations resting on dry medium dense sand. *Civil Engineering Journal*, 4(6), 1193-1205.

Hu, Y., Randolph, M. F, & Watson, P. G. (1999). Bearing response of skirted foundation on nonhomogeneous soil. *Journal of Geotechnical and Geoenvironmental Engineering*, 125(11), 924–935.

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

Listyawan, A. B., Renaningsih, & Kusumaningtyas, N. (2017). Bearing capacity of circular skirted footing on clay soil. *1st International Conference on Engineering and Applied Technology*, doi:10.1088/1757-899X/403/1/012019.

Mahmood, M. R., Fattah, M. Y., & Khalaf, A. (2018). Experimental study on bearing capacity of skirted foundations on dry gypseous soil. *International Journal of Civil Engineering and Technology (IJCIET)*, 9(10), 1910–1922.

Mahmood, M. R., Fattah, M. Y., & Khalaf, A. (2019). Experimental investigation on the bearing capacity of skirted foundations on submerged gypseous soil. *Marine Georesources & Geotechnology*, 38(10), 1151-1162.

Mana, D. S. K., Gourvenec, S. M., & Martin, C. M. (2013). Critical skirt spacing for shallow foundations under general loading. *Journal of Geotechnical and Geoenvironmental Engineering*, 139(9), 1554–1566.

Pusadkar, S. S., & Bhatkar, T. (2013). Behaviour of raft foundation with vertical skirt using plaxis 2d. *International Journal of Engineering Research and Development*, 7(6), 20–24.

Rezazadeh, S., & Eslami, A. (2017). Bearing capacity of semi-deep skirted foundations on clay using stress characteristics and finite element analyses. *Marine Georesources & Geotechnology*, 36(6), 625-639.

Saleh, N. M., Alsaied, A. E., & Elleboudy, A. M. (2008). Performance of skirted strip footing subjected to eccentric inclined load. *Electronic Journal of Geotechnical Engineering*, 13(F), 1–13.

Tripathy, S. (2013). *Load carrying capacity of skirted foundation on sand*. MS Thesis, National Institute of Technology, Rourkela, India.

Watson, P. G., & Randolph, M. F. (1997). Vertical capacity of caisson foundations in calcareous sediments. *International Society of Offshore and Polar Engineers (ISOPE),* vol. 1, 784–790.

Yun, G., & Bransby, M. F. (2007). The undrained vertical bearing capacity of skirted foundations. *Soils and Foundations*, 47(3), 493–505.