



PERFORMANCE OF SKIRTED CIRCULAR SHALLOW FOOTINGS RESTING ON SANDY SOIL UNDER INCLINED LOADS

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ABSTRACT

Experimental tests were conducted to study the behavior of skirted foundations rested on dry medium sandy soil subjected to vertical and inclined loads. To achieve this goal, a small-scale physical model was designed and performed which contained an aluminum circular footing (100 mm) in diameter and (10 mm) in thickness and skirts with different heights, local medium poorly graded dry sand is placed in a steel soil container (2 mm) thick with internal dimensions (1000 mm x 1000 mm in cross section and 800 mm in height). The main objective of this study was to evaluate the response of skirt attached to the foundation at different skirt (L/D) ratios (0.0, 0.5, 1.0 and 1.5) and is subjected to point load at different angles of inclination (θ) (90 °, 80 °, 70 ° to 60 °) varying with the horizontal. In all tests, the relative density of sand was kept constant and equal to (60%). Four tests were conducted on a foundation without a skirt, for comparison reasons, and twelve tests were conducted on a skirt attached to foundation. The results showed that with decreasing the angle of inclination of load with the horizontal the load carrying capacity decreased due to increase the horizontal component of applied load which leads to increase the shear stresses under the foundation, however that effect decreases with increase the skirt height.

KEYWORDS: Skirt foundation, Circular Shallow footing, Medium dry Sand; Bearing Capacity of shallow Footing; Physical Model Tests.

1. INTRODUCTION

Civil engineers have adopted many methods in recent years to enhance the carrying capacity of vertical and lateral loads and to reduce rotation, sliding and settling for foundations supported by different methods on soils; for example, soil reinforcing, deep compaction, grouting, etc. Some of these methods may be expensive, restricted and difficult to implement. In addition to improving the overall performance of the foundation system, geotechnical engineers in the field of soil structure interaction are trying to find alternative methods to enhance vertical and lateral bearing capacity and reduce rotation, sliding and structured settlement.

The use of skirts to confine soil is one of the most alternative ways to improve soil capacity and reduce the rotation of foundations.

Skirted foundations have great features that make them suitable for the construction of structures with economic promise that involve heavy loads and poor soil conditions. Because of economic benefits, it has proven to be competitive alternatives to more traditional foundation solutions like piles in different types of soil, resulting in cost savings through material reduction and installation time consumption. It is also utilized in soil with low surface strength as an alternative to deep foundation (Al-Aghbari, 2007; Salih and Joseph, 2010; El Wakil, 2013; Thakare and Shukla, 2016).

In this study, the behavior of the skirt footings subjected to various inclination load angles utilizing circular footings sizes of diameter 100 mm along with various skirt length (0, 0.5D, D and 1.5D) will be investigated through a laboratory model with a dimensions of (1000) mm length, (1000) mm width and 800 mm depth.

2. LITERATURE REVIEW

Last decade, many researchers tried to study the behaviour of skirt foundation and its effects on the load capacity and can be summarized as:

Saleh et al. (2008) carried out numerical analysis and Laboratory work was performed to study the behavior of one-sided skirted foundation subjected to an inclined and an eccentric load. he was found, the skirt foundations in which inclined or vertical wall surrounding one or more sides of a soil mass under the foot leads to confining the underlying soil and creates a soil resistance on the skirt side that helps the foundation resist sliding.

El Wakil, (2010) investigated the performance of skirt foundation subjected to horizontal loads by implemented laboratory tests on a circular skirted foundation. It was searched for the effect of the skirt length and the relative density of sand. The results illustrated that there was a

significant improvement in the horizontal bearing capacity of shallow footing due to utilizing the skirts. It was founded that the capability of the skirt footing to resist horizontal pressures increments with the increments in the skirt length up to 1.5 and sand relative density also. It was found that the skirt converted the failure state of footing from sliding to a rotational mechanism.

Golmoghani-Ebrahimi and Rowshanzamir, 2013) conducted laboratory tests to assess the bearing capacity of footing with the skirt. They concluded the effect of skirt stiffness by utilizing three sorts of skirts at thickness of 1mm, 3mm and 5 mm and the effect of skirt length on the bearing capacity of skirted footing by utilizing three various length ratios ($L/B = 0.5, 1$ and 1.5). The results refer to that utilizing skirts can improve the bearing capacity of the footing up to 3.68 times depending on the skirt, the geometry of the foundation, structural qualifications, soil properties.

Krishna et. al., (2014) a series of experimental model tests to analyse the load carrying capacity of a square footing resting on sandy soil. Hollow container made of steel plates were utilized to confine the soil laterally. The effect of sand relative density, embedment depth of foundation ratio and varying confinement depth was investigated. The results showed that load carrying capacity increments when the embedment depth increases, it was greatest at ($D_e/D=0.5$) for all sand relative densities.

Ali, (2016) Conducted theoretical work to analyse the performance of a model strip foundations placed on dry sandy soil under the impact of the eccentric inclined pressure with varying embedding ratios (D_f / B) varying from (0-1), depending on a numerical assessment performed utilizing finite element program (Plaxis 3D Footings). The findings show that, with the increase of the angle of inclination (α) and the ratio of eccentricity (e / B), the bearing capacity of the strip footing is considerably reduced.

Pusadkar and Navkar, (2016) A series of Laboratory load tests were carried to study model square footing efficiency under eccentric, inclined and eccentric-inclined loading on unreinforced sand to assess ultimate bearing capacity, settlement, and horizontal displacement behaviour. The ratio of eccentricity (e / B) and angle of inclination (α) varied from 0 to 0.2 and from 0° to 30° . Results indicate that square footing's ultimate bearing capacity reduces as load eccentricity and inclination of load increases, as well as the horizontal deflection increases as load inclination increase

[Khatiri et. al., \(2017\)](#) Various combination of parameters was studied such as Sand with different relative density was utilized ($D_r = 30\%$, 50% , 70% , and 87%), They utilized a footing with a width of (50 mm) and (60 mm), length/width ratio of (1 and 2) and The depth of the skirt was varied from $0.25 B$ to $1.0 B$, to examined the stress-settlement behaviour and bearing capacity of rectangular and square skirted foundation placed on sandy soil and subjected to the vertical pressure through the laboratory experimental tests. The results appeared that utilize of skirt improves the bearing capacity of foundation remarkably. The enhancement in bearing capacity was noted approximately linearly proportional to the depth of the skirt. The enhancement in bearing capacity of skirt foundation over foundation without skirt was noted in the range of 33.3% to 68.5% , 68.9% to 127% and 146.7% to 262% for a skirt depth of $0.25 B$, $0.50 B$ and $1.0 B$ respectively. The skirt foundation was found more effective in the sandy soil of relative density 30% and 50% than that of relative density 70% and 87% .

3. EXPERIMENTAL TESTS AND MATERIALS USED

3.1. Steel Container

The soil container, manufactured for this research as square section of 1000 mm in length and 800 mm in depth. three sides in addition to the base were made of a steel plate with a thickness 3 mm, while the fourth side was made of plastic glass with a thickness 6 mm, the aim of utilizing glass is to let better watching of soil homogeneity as well reference marks were utilized to assist with the creation of the required soil model. The dimensions of The steel container were big sufficient to overcome the boundary condition effects on the footings reaction ([Nazier, 1996](#)), while the width of the soil bin was approximately 8 times the diameter of the biggest footings and the depth under a tallest skirt was 3.5 times a diameter of the biggest footings.

3.2. Sand

This experimental investigation was carried out using locally available sand. The sand was washed and dried before the test and then sieved through (4.75) mm sieve. The particle size distribution of the sand used is illustrated in [Fig. 1](#). Laboratory characterization tests Which were conducted consisted of sieve analysis test, maximum and minimum index density, specific gravity, direct shear box tests. The information of these properties of the sand are listed in [Table 1](#). The sand is classified as SP (i.e. poorly graded sand) according to the Unified Soil Classification system (USCS). Classification of sand according to relative density is medium dense sand.

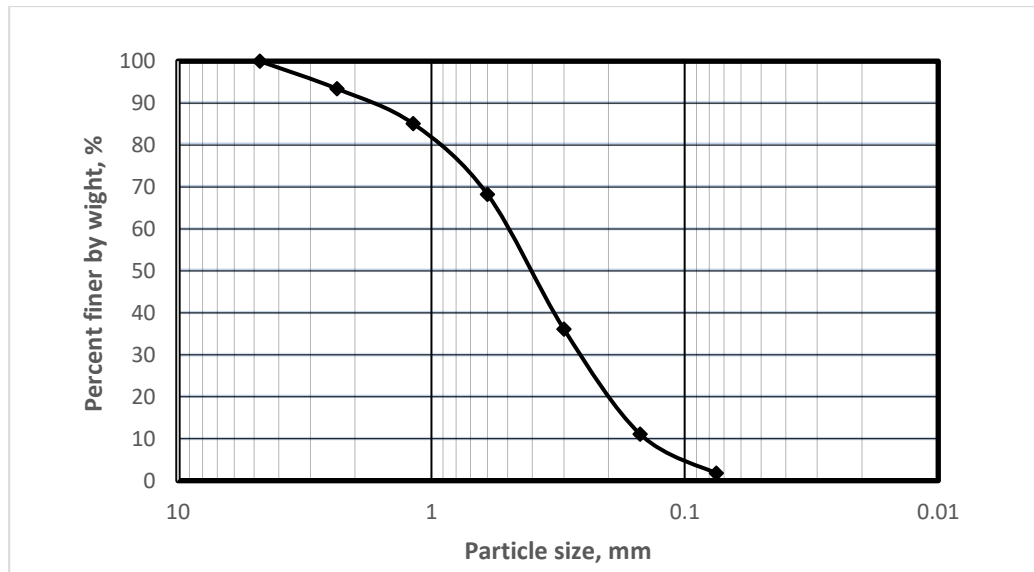


Fig. 1. Grain size distribution of the sand.

Table 1. Physical properties of the sand used

Property	Value
D_{10}	0.14 mm
D_{30}	0.26 mm
D_{60}	0.52 mm
Coefficient of Uniformity (C_u)	3.72
Coefficient of Curvature (C_c)	0.93
Specific Gravity (G_s)	2.65
Angle of Internal Friction (ϕ)	35.94°
Max. Dry Unit Weight (γ_{dmax})	17.34 kN/m ³
Min. Dry Unit Weight (γ_{dmin})	14.56 kN/m ³
Dry Unit Weight in Test (γ_d)	16.1 kN/m ³
Relative Density of Sand During Test (D_r)	60 %

3.3. Foundation Models

Circular foundation was used with diameters ($D = 100$ mm) with a thickness of (10 mm), it was made of aluminum to resist the large stresses placed on them as shown in [Plate 1](#). In this study, D_{50} is (0.36 mm); therefore, D/D_{50} is greater than (100) for the smallest foundation diameter. Consequently, influence of particle size of sandy soil on the test results is avoided.



Plate 1. Foundation models.

3.4. Skirts

Aluminium cylinders are used in the lengths of $0.5D$, $1.0 D$ and $1.5D$ open on both sides and hollow inside and have internal diameters (100) mm to act a skirt in the present study. These skirts were utilized to confine the sand laterally beneath the circular foundation model have a diameter equal to (100mm). The thickness of all skirts was constant and equal to 5 mm, as shown in [Plate 2](#). The foundation was placed on the top of the skirt and was attached to the base by the bolt.



Plate 2. Types of Skirts used.

3.5. Test set up

The test set up contains square test tank such as a soil container, steel loading frame, loading system (manual press, load cell, digital weighing indicator), raining System.

The loading system which consists of the manual press fixed on base moving within the track located in the horizontal beam and the two columns, which are used to apply the axial load or inclined loading according to the angles required by the search. The maximum pressure that can be applied through a manual press is approximately (2 tons). the load cell was a compression/tension “SEWHA, Korea” type: SS300_2T model S-beam is utilized to measure a pressure. It is manufactured of the stainless steel - LS300, locally calibrated, with the

maximum capacity of (2 tons). For displaying the magnitude of the load the digital weighing indicator is utilized for displaying the magnitude of the pressure, SI4010 model "SEWHA, Korea", with an input sensitivity of 50 gm, which was calibrated in the University of Babylon. The sand raining technique was utilized in which the sand is allowed to rain during air at a controlled rate of discharge and specific height of pour to obtain uniform densities, thus assure homogeneity of sand formation and recreate the sand at the the specified relative density.

The utilize of this technique for getting the desired relative density has been recommended by a lot of researchers (Fretti et. al., 1995; Madabhushi et. al., 2006; Al-Saffar, 2015) .By utilizing the raining method, any density at the maximum/minimum density range can be accomplished by controlling the intensity and the height of down of the sand (Walker and Whitaker, 1967; Butterfield and Andrawes, 1970; Hanna, 1981).

The raining apparatus consists of a steel frame, the cone with the hole size of (25mm) linked to the hand lever by steel rope to allow the cone to move upward, the lateral movement of the cone was accomplished by hand. A piece of the net (diameter of the opening is 10 mm) was position in the exit of the cone to decrease the effect of the particles (Ali, 2012).

Plate 3. shows the experimental setup used to preformed the tests.

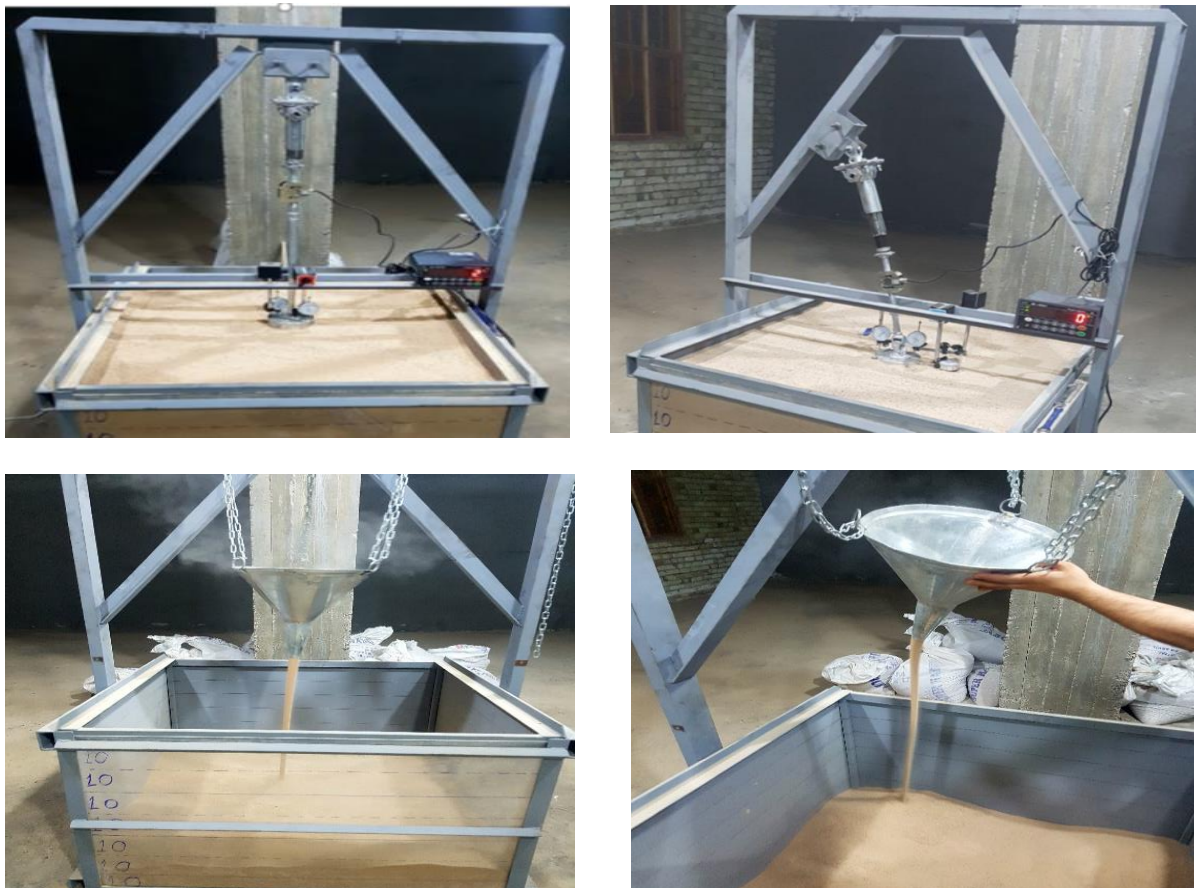


Plate 3. Test Set up frame and loading system.

3.6. Preparation of Sand Bed

To arrange the sand in a uniformly and homogenous for the state of relative density (60%), the sand is positioned in the model of the steel tank in eight layers, the final height of each layer is around (10 cm) to get final total height of sand 80 cm.

The sand deposit was arranged by utilizing the raining technique way. This technique was specifically designed and developed to get a uniform deposit with the required density. Various values of relative density are given by utilizing several heights of the sand fall. A lot of researchers utilized this technique as (Turner and Kulhawy, (1987); Jawad, (2009)).

The elevation of the free drop of the sand can be controlled by setting the height of the raining apparatus with regard to the sand tank. To calculate the relationship between density and height, the number of attempts have been implementation of with varying elevations of a drop. It was observed when the elevation of drop increased the density of sand is increased. in order to attain the selected relative density of (60%), the height of the free fall will be (415 mm).

4. RESULTS AND DISSUASION

A series of (16) experimental tests were carried out to determine the behavior and to analyses the response of shallow foundation, in addition to skirt foundation resting on medium dense sandy soil with relative density (60%) subjected to vertical and inclined loads.

A shallow foundation has a size (100 mm) resting on the top surface of sand bed was subjected to vertical and inclined loads in three different angles (80,70,60) degrees with the vertical, as well as three different skirt length with ratio (0.5,1.0,1.5) of foundation diameter were added to foundation and were subjected to the same applied loads.

4.1 Failure Criteria

The failure load of shallow foundation can be defined as the maximum load at which unlimited excessive displacement of the foundation occurred without any increase in an applied load.

4.2 Load-Settlement Behaviour

The load-settlement relationships and the ultimate load of foundations with and without skirts were obtained. four tests were carried out on foundation without skirt as a reference test for comparison purposes.

Figs. 2, 3, 4 and 5, respectively represent load-settlement curves for vertical load component for smooth circular skirted footing and for foundation without skirt is shown in the same graphs with at different inclination angles (θ).

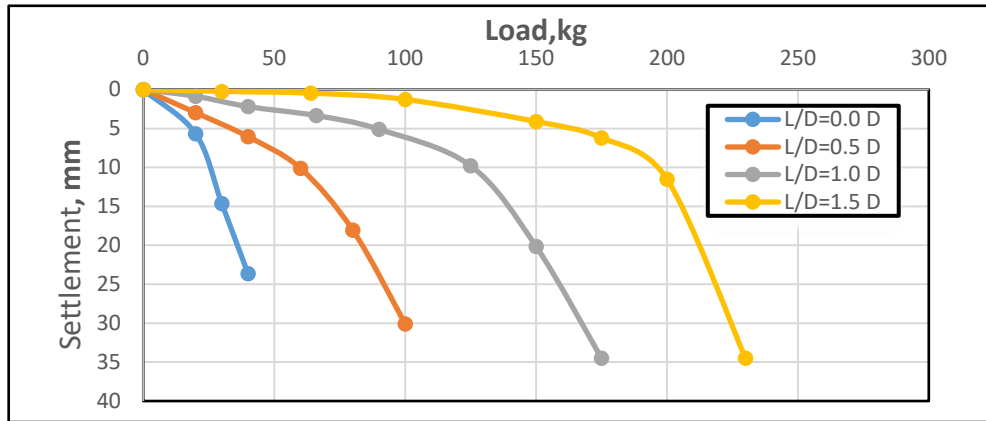


Fig. 2. Load vs. foundation settlement relationship with angle ($\theta=90^\circ$) resting on sand

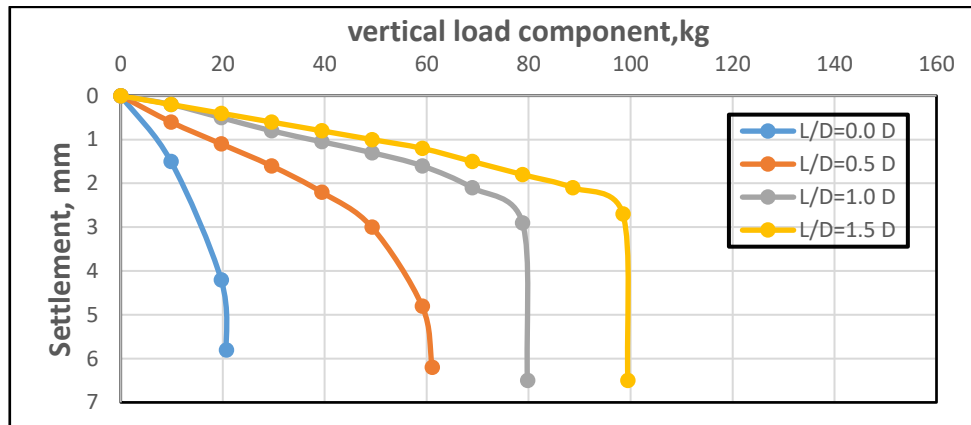


Fig. 3. Load vs. foundation settlement relationship with angle ($\theta=80^\circ$) resting on sand

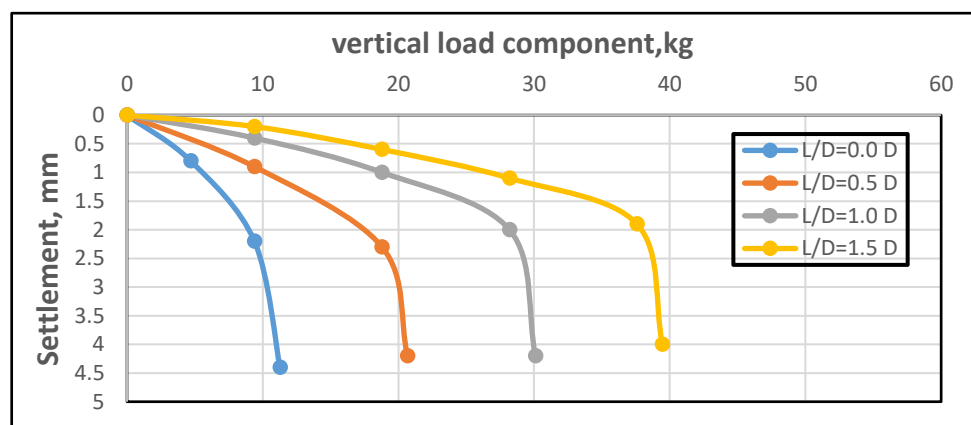


Fig. 4. Load vs. foundation settlement relationship with angle ($\theta=70^\circ$) resting on sand

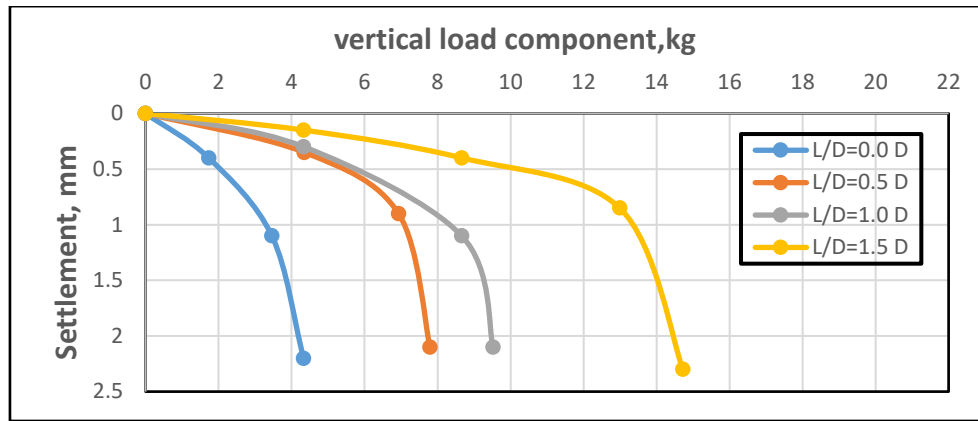


Fig. 5. Load vs. foundation settlement relationship with angle ($\theta=60^\circ$) resting on sand

It can be noted from these figures, that the use of skirt under footing improves the shallow Foundation performance by enhancing the capacity of shear resistance before failure, as well as reducing the settlement of the footing for different inclination angles (θ). For example, the capacity of shear resistance was increased from (40) kg, (20.68) kg, (11.27) kg and (4.33) kg for footing without skirt to (230) kg, (99.46) kg, (39.46) kg and (14.72) kg for footing with skirt having (L/D) ratio equal to (1.5), respectively. This action is due the fact that, the addition of skirt to shallow footing confines the soil beneath the foundation which leads the confined soil to behave as a part of rigid foundation and starts to work as one unit to transfer a part of foundation load into a deeper zone, in addition to that the increasing in skirt height increases the area which is subjected to friction in both inside and outside face of the skirt as well as transform part of load to deeper distance by skirt tip where the confined pressure is higher.

The ratio of improvement in capacity of shear resistance for different skirt heights and different load inclinations with respect to shallow footing without skirt is illustrated in Table 2.

Table 2. The percentage improvement in failure load for a foundation with different inclination load angles (θ)

L/D ratio	% improvement in failure load for different inclination load angles			
	$\theta=60^\circ$	$\theta=70^\circ$	$\theta=80^\circ$	$\theta=90^\circ$
0	-	-	-	-
0.5	1.79	1.83	2.5	2.95
1	2.19	2.67	3.86	4.37
1.5	3.39	3.5	4.81	5.75

4.3 Load-Horizontal Displacement Behaviour

The load-horizontal displacement relationships and the lateral capacity of shear resistance of foundations with and without skirts were obtained. three tests were carried out on foundation without skirt as a reference test for comparison purposes.

Figs. 6, 7 and 8, respectively represent load-horizontal displacement curves for horizontal load component for smooth circular skirted footing and for foundation without skirt is shown in the same graphs with at different inclination angles (θ).

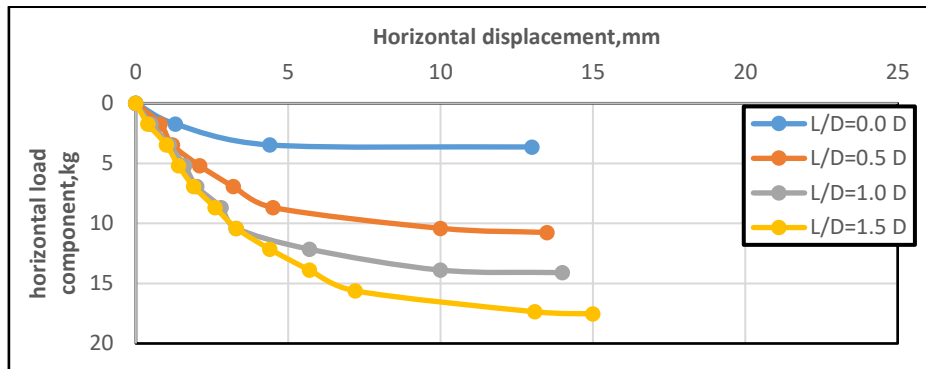


Fig. 6. Load vs. horizontal displacement relationship with angle ($\theta=80^\circ$) resting on sand

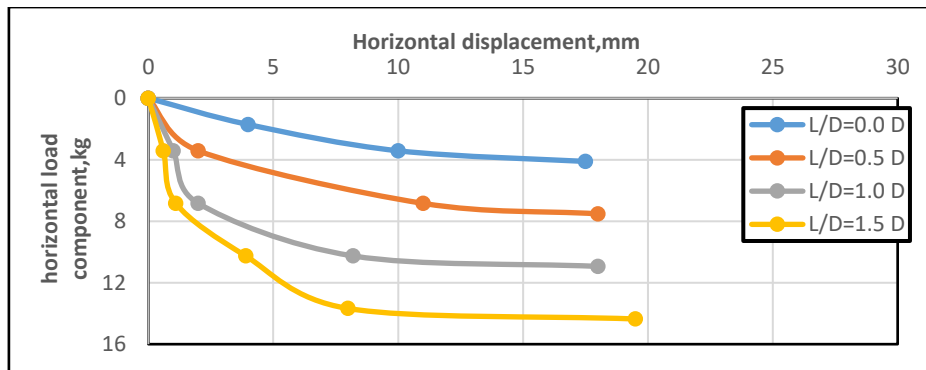


Fig. 7. Load vs. horizontal displacement relationship with angle ($\theta=70^\circ$) resting on sand

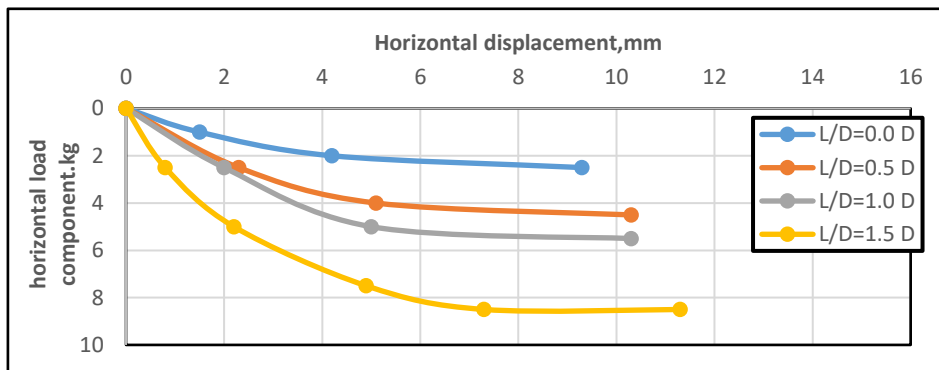


Fig. 8. Load vs. horizontal displacement relationship with angle ($\theta=60^\circ$) resting on sand

It can be noted from above figures, that the use of skirt under footing improves the shallow Foundation performance by enhancing the lateral capacity of shear resistance before failure, as well as reducing the horizontal displacement of the footing for different inclination angles (θ). For example, the lateral capacity of shear resistance was increased from (3.64) kg, (4.11) kg and (2.5) kg for foundation without skirt to (17.53) kg, (14.36) kg and (8.5) kg for foundation with skirt having L/D ratio equal to 1.5, respectively. This action is due to the foundation on the surface is free and unrestrained from each the direction of soil, the foundation will be subjected to a sliding impact as a result of the influence of the horizontal component that causing a horizontal force to decrease of entire stability of foundation and displacement it to the side. When the skirt foundation is constructed beneath the foundation at a certain depth into the soil, the skirt foundation will confine by the surrounding soil and the foundation will be considerably resist against sliding action, this refers to existence of passive forces exerted on the foundation base as a result of adjacent soil. The magnitude of passive forces increases with increasing skirt length and lead to improving the ultimate lateral load.

The ratio of improvement in lateral capacity of shear resistance for different skirt heights and different load inclinations with respect to shallow footing without skirt is illustrated in [Table 3](#).

Table3. The percentage improvement in failure load for a foundation with different inclination load angles (θ)

L/D ratio	% improvement in failure load for different inclination load angles		
	$\theta=60^\circ$	$\theta=70^\circ$	$\theta=80^\circ$
0.0	-	-	-
0.5	1.79	1.83	2.5
1.0	2.19	2.67	3.86
1.5	3.39	3.5	4.81

4.4 Effect of Skirt Length

To assess the influence of the skirt length on the behavior of the shallow footing be subjected to vertical as well as inclined loads.

This improvement in the capacity of shear resistance for both vertical and horizontal load components is expressed by utilizing a non-dimensional parameter called the improvement ratio (IR) and clarify the effect of changing of the skirt height as shown in Figures (9,10) respectively.

This parameter is defined as the ratio of the skirted footing failure load to the shallow footing (without skirt) failure load for different load inclinations.

Note that $IR = 1$ refers to the skirt-free footing state (i.e. $L / D = 0$).

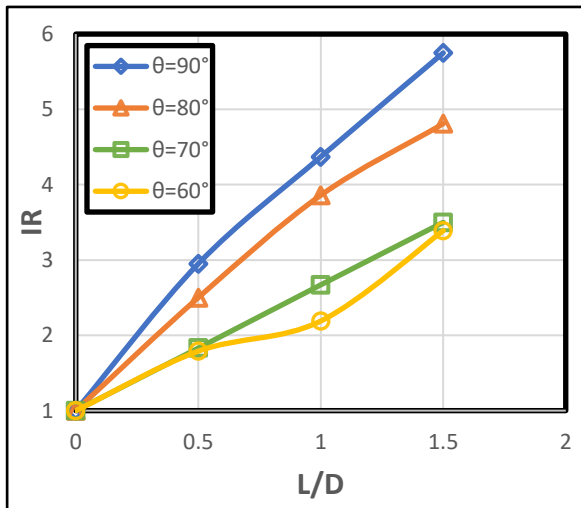


Fig. 9. Variation of IR with L/D ratios for vertical load component with different inclination load angles

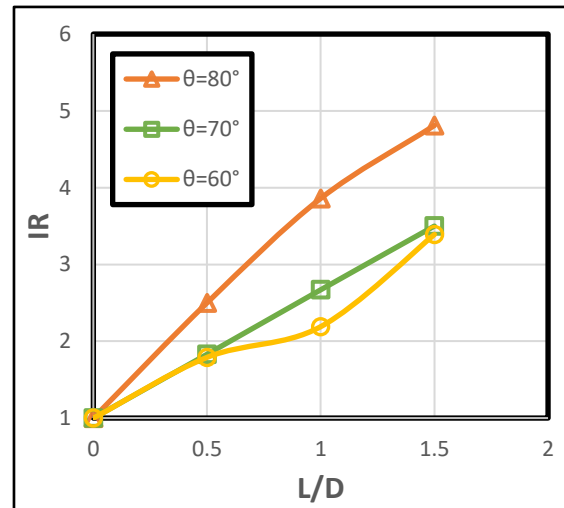


Fig. 10. Variation of IR with L/D ratios for horizontal load component with different inclination load angles

Figures above also show that the impacted of increasing skirt length on the IR is observed to be most significant at $L/D=1.5$ for each foundations size, this mean if skirt length equals to 1.5 of foundation diameter (i.e. $L/D=1.5$) then the foundation performs better.

The increase in skirt length results in an increase in the surface area of the skirt- foundation system; therefore, the base load will be transferred to a deeper depth leading to an increase in the improvement ratio and a decrease in the settlement. Thus it is possible to obtain higher ultimate loads.

4.5 Effect of Load Inclination on Skirt Performance

When the skirt foundation is constructed beneath the foundation at a certain depth into the soil, the skirt foundation will confine by the surrounding soil and the foundation will be considerably resist against sliding action, therefore the responsible about the lateral resistance is a work of vertical load and a friction. The lateral force is significantly dependent on the friction between the foundation and the soil and vertical component of loading. Therefore, when angle of inclination increases, the horizontal component increases, the vertical component and the friction between the skirt and the soil decreases, causing a decrease in the ultimate lateral load and the final vertical load.

Normally, the shallow foundation which subjected to inclined load will be under effect two components of loads, horizontal and vertical forces. The vertical component was checked for the capacity of shear resistance as illustrated in Figs. 11, 12, and 13. As for the lateral force, the model foundation will be subjected to sliding impact This means horizontal displacement, causing to decrease of entire stability of foundation as illustrated in Figs. 14, 15, and 16.

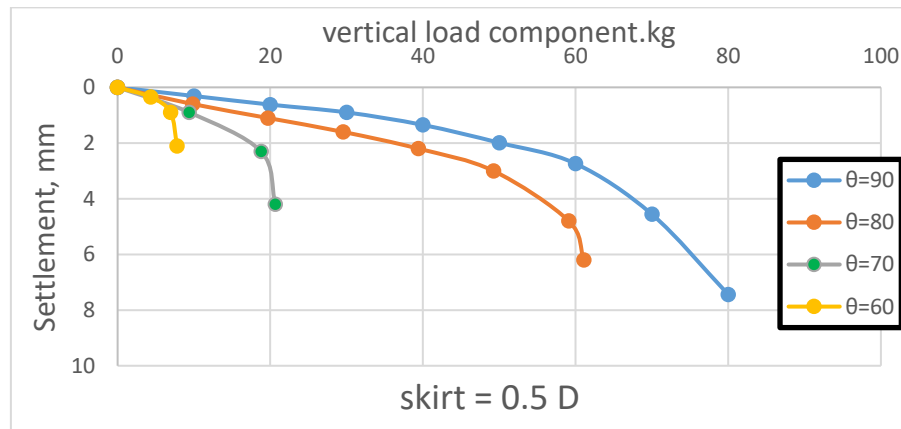


Fig. 11. relationship between vertical load component vs Settlement with constant skirt ratio equal (0.5 D) under effect different inclination angles

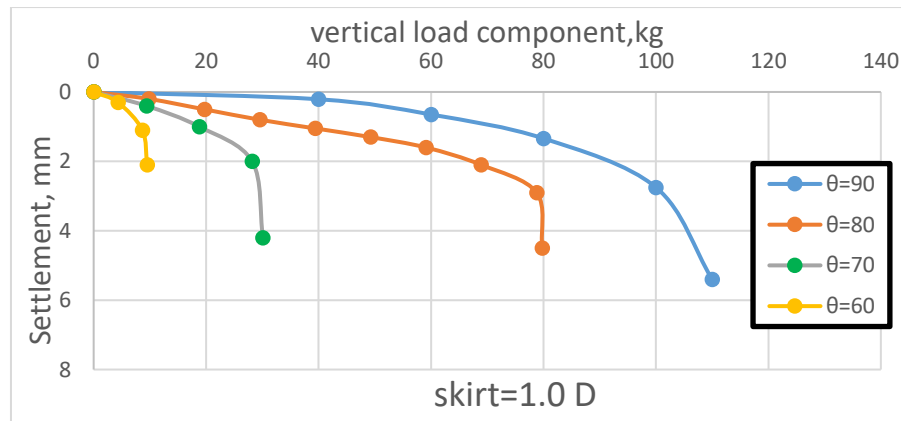


Fig. 12. relationship between vertical load component vs Settlement with constant skirt ratio equal (1.0 D) under effect different inclination angles

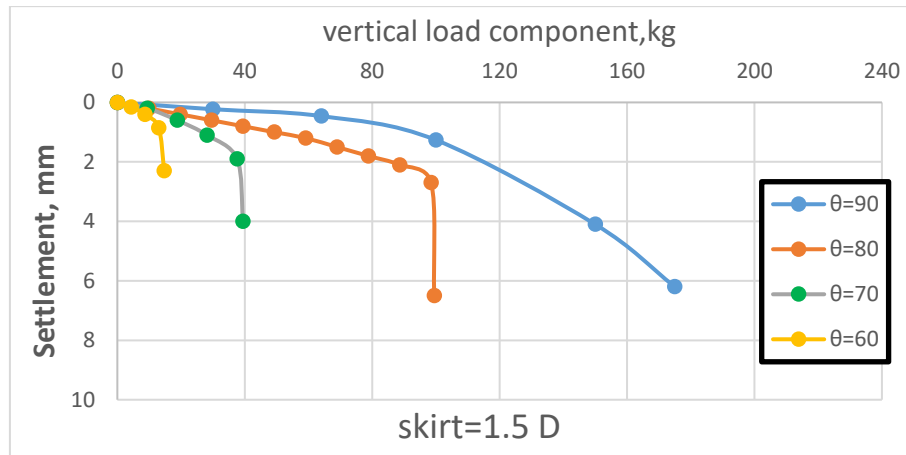


Fig. 13. relationship between vertical load component vs Settlement with constant skirt ratio equal (1.5 D) under effect different inclination angles

As was expected, a maximum value of the load that the skirt foundation can be reached at the state of (i.e. $\theta = 90^\circ$) (i.e. $\theta = 90^\circ$) and skirt ratio equal (1.5 D). It is noticed that the capacity of shear resistance decreases as the inclination angle increases and embedment ratio decreases. It is noted that, the capacity of shear resistance of foundation is influenced with the embedment ratio moreover the inclination angle. This justification is attributed to the fact that the amount of reduction in the shallow foundation bearing capacity is greater than that of cases where the model foundation is installed at a deeper distance ($L/D > 0$).

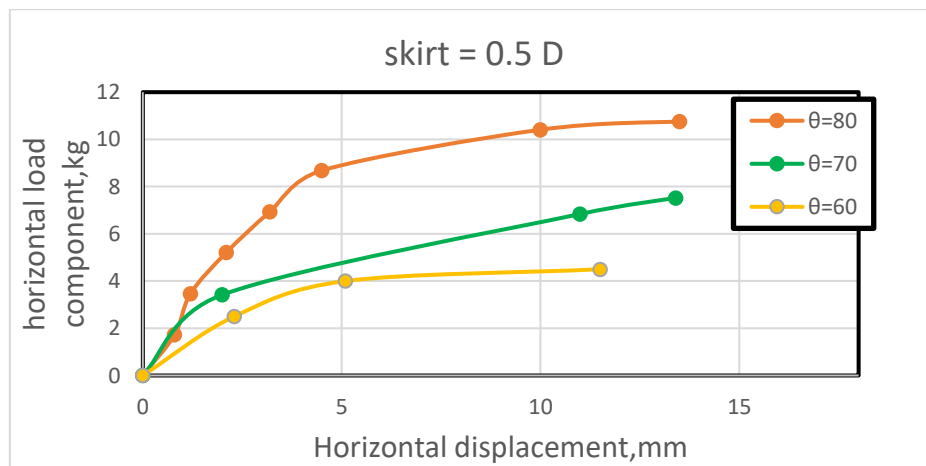


Fig. 14. relationship between horizontal load component vs Horizontal displacement with constant skirt ratio equal (0.5 D)

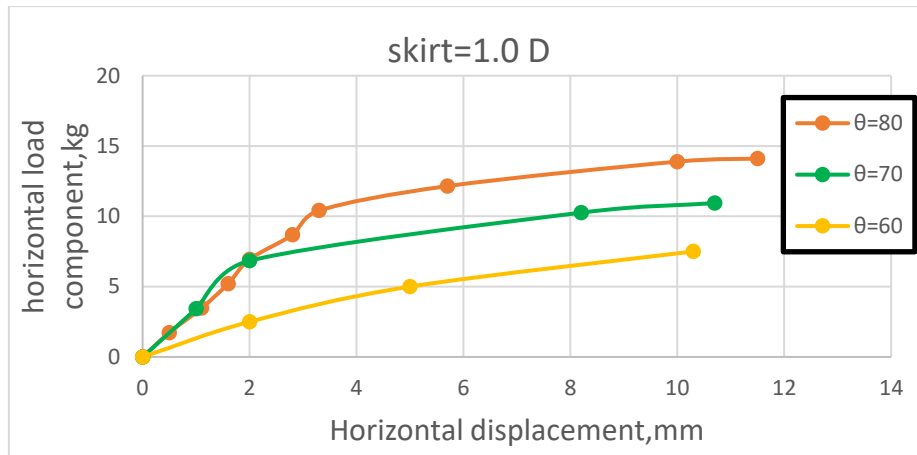


Fig. 15. relationship between horizontal load component vs Horizontal displacement with constant skirt ratio equal (1.0 D)

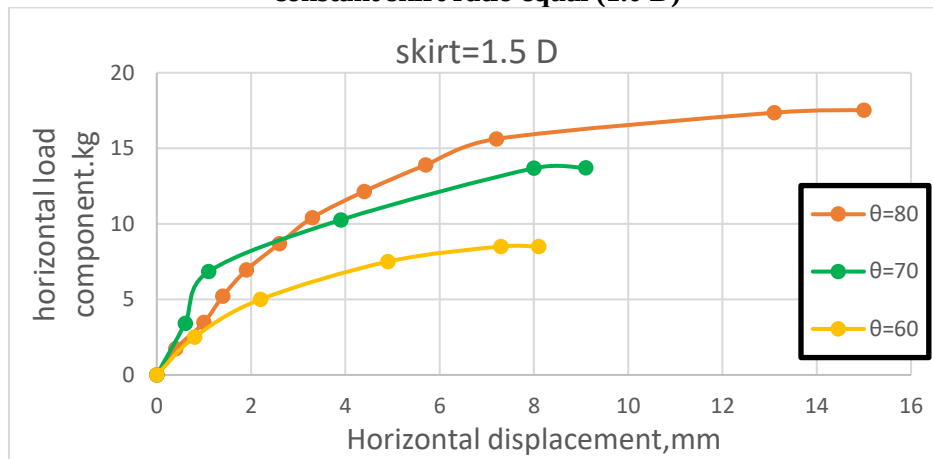


Fig.16. relationship between horizontal load component vs Horizontal displacement with constant skirt ratio equal (1.5 D)

The maximum lateral load value that the skirt footing can be reached is, as expected, equal in the case of (i.e., $\theta = 80$) and skirt ratio (1.5 D). It is noted that the lateral capacity of shear resistance decreases as the angle of inclination increases, and ratio of embedding decreases. It is observed that, in addition to the angle of inclination, the lateral capacity of shear resistance of the foundation is affected by embedding ratio. This justification is attributed to the fact that, when the skirt foundation is installed at a greater distance, the amount of reduction in the lateral bearing capacity of the shallow foundation is higher than that of the state ($L/D > 0$).

5. CONCLUSIONS

Based on this study's experimental work, the main conclusions are outlined below.

1. The skirt foundation when subjected to pure vertical load, the capacity of shear resistance increases with increase in (L/D) ratio, the settlement decreases with increase the (L/D) ratio.

2. The capacity of shear resistance for vertical and horizontal component of the skirt foundation increases with increase in both (L/D) ratio and the angle of inclination of load with the horizontal.
3. The settlement and horizontal displacement for vertical and horizontal component decreases with increase the (L/D) ratio and its increases with decrease the angle of inclination of load with the horizontal.
4. Increasing the skirt length lead to improving load-settlement behavior. The rate of improvement increases with increase the angle of inclination of load with the horizontal and reached its maximum value at skirt length (L/D) ratio equal to 1.5.
5. The effects of sliding and overturning due to inclined load are minimized when the skirt footing is placed at a certain depth below ground level, the failure mode changes from sliding to rotation.
6. The finite element method (FEM) PLAXIS 3D, gives a good insight and helps in understanding the behavior of soil supporting a skirted footing under different loading conditions. The FEM is capable of predicting the load – settlement response to a good level of accuracy. However, as in experimental work, the numerical result is higher than the actual results of plate loading test.

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