Improvement ratio and behavior of bearing capacity factors for strip skirt footing model resting on sand of different grain size distribution

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Abstract. Plain strain model tests were performed on beds of sands with different particle size distribution (Coarse, Medium and Fine) prepared at loose state (Relative density D_r of 30%). A strip footing model with skirt was placed on the bed of sand and loaded vertically up to failure at different ratios of skirt depth to width D/B of (0.5, 1.0, 1.5, 2, and 3). The applied stress increments and the corresponding settlements were measured. The improvement ratio due to different skirt depth and the behavior of bearing capacity parameters N_γ and N_q at each depth were evaluated and compared with some theoretical approaches. The test results revealed that the improvement ratio increased linearly up to D/B of 1.5 then reduced. Two factors were introduced into the general bearing capacity equation where used to evaluate bearing capacity of skirt footing, their values are about 1.6 for skirt ratio ranged between 0.5 to 1.5, and 1.25 for skirt ratio more than 1.5. Also, it is found that the N_γ parameter for $D/B=0$ were very close to Vesic proposal for fine and medium grain size distribution, while it's close to Biarez proposal for coarse sand. The behavior of N_q parameter with different skirt ratio shows slight increase up to D/B of 1.5 then decrease with increasing D/B ratio for different grain size distribution. While the behavior of theoretical N_q parameter (depending on angle of internal friction values) shows a linear increase with skirt ratio for different grain size distribution.

1 Introduction

Ultimate bearing capacity theories for shallow footings are available since the proposals of Terzaghi in (1948), and its modifications by Meyerhof (1951, 1963), Hansen (1970), Vesic (1973) etc. These theories depend on the shear resistance of the soil beneath the footing. It is known that from the mechanism of shear failure for a footing resting on a homogenous layer the bearing capacity increase with the increasing total length of the failure surface to give higher shear resistance. This can be produced by increasing the width or the depth of foundation. Skirt foundation can be used to increase the depth of footing then increase the length of failure surface that would develop under central vertical loading condition and improve the bearing capacity of the foundation. These skirts are expected to constrain the soil between them and thereby improve foundation performance equivalent to that a foundation embedded to the depth of the skirt tips. Skirts form closed space at which soil is restrained laterally; it works with the skirt as one unit to transfer the loads to the soil at the level of the skirt tip.

So, the skirted foundation transfers the load to a high depth, in comparison to a surface foundation, which mobilizing higher load bearing capacity. Skirted foundations were first used in early 1970's as a supporting unit for floating structures in offshore hydrocarbon projects. Nowadays, skirted foundation is

adopted for bridges, marine structures and where water scouring is a major issue.

The ultimate bearing capacity of a centrally loaded strip footing of width (B) is normally calculated from the well known Terzaghi's formula^[1] as shown in figure (1), which in the case of cohesionless soils ($c=0$) gives:

Fig. 1. Mechanism of bearing capacity failure in soil under a rough rigid strip footing subjected to vertical load proposed by Terzaghi (1943)

$$Q_{ult} = \gamma D_f N_q + 1/2 B \gamma N_\gamma \quad \text{-----} \quad 1$$

Where: Q_{ult} and γ are the ultimate bearing capacity and unit weight of the soil respectively; N_q and N_γ are bearing capacity factors which depend on the angle of

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internal friction. D_f represents the depth of the foundation base below ground level.

Most of geotechnical engineers accept the method of superposition which adopted for estimation the ultimate bearing capacity. For rough continuous foundation Meyerhof^[2] solution for estimation N_q parameter is:

$$N_q = e^{(\pi \tan \phi)} \tan^2 \left(45 + \frac{\phi}{2} \right) \quad \text{----- 2}$$

This is found an acceptance from most of Geotechnics. While there is a wide controversy considered over the theoretical values of N_γ Meyerhof suggested that N_γ could be approximate as:

$$N_\gamma = (N_q - 1) \tan (1.4\phi) \quad \text{----- 3}$$

Hansen^[3] proposed an approximate relationship for N_γ in the form:

$$N_\gamma = 1.5(N_q - 1) \cot \phi \tan^2 \phi \quad \text{----- 4}$$

Vesic^[4] suggested that:

$$N_\gamma = 2(N_q + 1) \tan \phi \quad \text{----- 5}$$

Biarez et al.^[5] also recommended the following relationship for N_γ :

$$N_\gamma = 1.8(N_q - 1) \tan \phi \quad \text{----- 6}$$

He shows that the reason for several theories used to estimate N_γ factor and the few of correlation with the experimental values is due to the difficulty in choosing a representative value of the soil angle of internal friction (ϕ) for estimating the bearing capacity. So, it is suggested plain strain soil angle of internal friction (ϕ_p) instead of (ϕ_t) (triaxial) to estimate the bearing capacity.

In 2004, Aghbari and Mohamedzein^[6] performed laboratory model test on skirted strip foundation on dense sand and found that the use of structural skirts can improve the bearing capacity by a percent of 1.5 to 3.9 depending on the geometrical and structural properties of the skirts and foundations, soil characteristics and interface condition of soil skirt foundation system as in figure(2). They suggested adding a skirt factor, F_γ , to Terzaghi bearing capacity equations (see equation 7). They mentioned that skirt factor is a function of foundation base friction factor, skirt depth factor, skirt side roughness factor, skirt stiffness factor, and soil compressibility factor. Nevertheless, they reported that the skirt factor ranges from 1.3 to 1.5. They mentioned also, no factor is included the first part (N_q term) of the general equation because the effect of the skirt can be accounted for by the skirt depth.

Fig. 2. Mechanism bearing capacity failure in soil under strip footing with skirt subjected to vertical central load (Based on Terzaghi (1943) assumptions)

$$Q_{ult} = \gamma(D_{fs} + D_s) N_q + 1/2 B' \gamma N_\gamma F_\gamma \quad \text{----- (7)}$$

Where: D_{fs} represents the depth of foundation base below ground level, D_s denotes the depth to the lower edge of the skirt at footing tip, B' shows the total width of foundation including skirts and the skirt thickness.

Sawwaf and Nazer (2005)^[7] studied the effect of skirt confinement on the bearing capacity of sand and have found an improvement in bearing capacity as 17 times as that without skirt confinement.

In 2007, Aghbari and Mohamedzein^[8] performed tests on circular skirted footing models resting on sand. The results showed that the use of skirts improved the bearing capacity by a factor up to 3.

Eid et al. 2009^[9] performed laboratory study on footing load test in sand and concluded that the existence of walls, which surrounded a surface foundation, significantly reduces its settlement and increases its bearing capacity.

El-Wakil 2013^[10] reported that 1.3 times increase in bearing capacity of thin wall foundations in dense sands when the wall to width ratio is increased from 0.5 to 1.

Amr Z. EL Wakil (2013)^[11] performed eighteen laboratory tests on circular footings of different diameters and different skirt lengths. They found enhancement in bearing capacity of footing with the skirt was increased by about 6.25 times than the footing without the skirt. They studied the effect of relative density of sand and skirt length on bearing capacity of shallow footings

Mahmood and Huda (2013)^[12] present study to investigate the behavior of skirted strip model footing founded on beds of soft clays and to evaluate the improvement values in bearing capacity. A series of laboratory model tests were performed to determine the optimal vertical capacities of skirted foundation within different skirted embedded depth (D/B) ratio ranged between (0.0-2.5). It is found that the appropriate skirted embedded depth as the skirt depth to foundation width of 0.5 ($D/B=0.5$).

P.K. Jain et. al., (2014)^[13] presents the result of load tests conducted on a circular footing resting on confined sand to study the influence of cylindrical skirts with different heights and diameters in medium dense

sand. The comparison was made between the results of unconfined case and confined case. It is concluded that the pressure corresponding to 5 mm settlement (i.e. 10% S/D ratio), increases appreciably by confining the sand with skirts and it is due to that skirt restricts the lateral displacement of the sand underneath the footing, thus resulting in appreciable improvement.

Pavan and Oruna (2016)^[14] presents experimental results by utilizing 50 mm square footing on the sand which is maintained at a relative density of 47% and confining cells of varying length (50 mm, 75 mm, 100 mm, 125 mm & 150 mm) are used. The obtained results indicate that load carrying capacity of footing increases as the length of confinement increases.

In order to verify the effect of grain size distribution incorporated with the behavior of bearing capacity factors through loading skirt footing with the different skirted ratio, model tests were performed simulating the plain strain condition to avoid any effect of the shape of the footing.

2 The soil used

Poorly graded sand of rounded particles was used as a natural soil in the present study. The sand was sieved to obtain different grain size distribution (fine, medium and coarse) according to (ASTM D 422-02). Table (1) shows physical soil properties for the sand. Figure (3) shows the grain size distribution curve, according to the Unified Soil Classification System (USCS), the sand is classified as poorly graded sand with symbol (SP).

Table (1): Physical properties of the soils used.

The Properties	Fine sand	Medium Sand	Coarse Sand	Specification
Effective size D_{10} , (mm)	0.18	0.56	1.90	ASTM D 422 ^[4]
D30 , (mm)	0.23	0.76	2.15	
D60 , (mm)	0.27	1.02	2.25	
Coefficient of curvature, C_c	1.08	1.01	1.08	
Coefficient of uniformity, C_u	1.50	1.82	1.18	
Soil classification (USCS)	SP	SP	SP	
Specific gravity, G_s , @20°C	2.68	2.65	2.61	ASTM D 854 ^[3]
Maximum dry unit weight γ_{max} , (kN/m ³)	16.6	17.45	16.41	ASTM D 4253 ^[5]
Minimum dry unit weight γ_{min} , (kN/m ³)	13.6	14.8	13.8	ASTM D 4254 ^[6]
Dry unit weight (γ_d) (kN/m ³) at D.R. 30%	14.5	15.5	14.4	
Max. void ratio, e_{max}	0.94	0.75	0.85	-
Min. void ratio, e_{min}	0.61	0.49	0.59	-
Angle of internal friction(ϕ°) at D.R. 30%	32.5	33.3	31.7

density of 30%. The soil surface is scraped and leveled by a sharp edge tool to get flat surface.

4.2 Foundation model:

Foundation model has divide into two parts; strip model footing and the skirted structure. A mild steel plate of 4 cm width, 40 cm length which gives L/B 1:10 (strip footing), and 1cm in thickness was employed to simulate the proposed shallow strip model footing. The plane strain condition was assumed in all model tests carried out during this study. The structural skirted introduced here to embracing the shallow foundation model was acted via utilizing a jacket made from rigid steel plate with a length of 25 cm, 4 cm width and 0.3 cm in thickness. It is fixed to the edges of steel strip footing through a threaded hole in the center of the footing to allowed rigid connection with the auxiliary of four screw bolts as shown in plate(2).

The steel jacket was holed vertically at an equal spacing to get different (D/B) ratios of (0,0.5,1.0,1.5,2, and 3) with various skirted depth were take into consideration via conversion the location of the screw bolts.

Plate 2. The steel jacket skirt footing model

5 Presentation and discussion of test results

5.1 Bearing Capacity Ratio

Three loading tests were performed for each type of different grain size distribution with different D/B ratio. Average load-settlement values been revealed the behavior of skirted foundation rested on loose sand. The normal foundation case without skirted that employed as a reference case by which a comparative study can be done. Ultimate bearing capacities at failure detected to show the variation of bearing capacities due to existence skirted structure. The load-settlement measurement

continuous beyond failure point and followed by unloading stages. Failure commonly pointed as the q_{ult} recorded by settlement of 10% regarding foundation width.

Figures (4, 5, and 6) deduced that the q_{ult} at failure for different grain size distribution (Coarse, Medium, and Fine sand) at different skirt ratio of (0.0, 0.5, 1.0, 1.5, 2.0, and 3.0) respectively. It is represented a comparative figures summarized the vertical bearing capacities for various cases considered.

Fig.4. Applied pressure vs settlement for **loose Coarse** sand at different skirted ratio

Fig. 5. Applied pressure vs settlement for **loose Medium** sand at different skirted ratio

Fig.6. Applied pressure vs settlement for **loose Fine sand** at different skirted ratio

The theoretical improvement ratio of ultimate bearing capacity due to increasing in depth (same as the depth of skirt ratio) shows in figure (7). The figure shows a liner increase in bearing capacity ratio due increase in depth for all the particle size distribution. Coarse graded sand demonstrate higher improvement ratio, while medium graded sand demonstrate lower improvement ratio.

Fig. 7. Theoretical Improvement bearing capacity ratio vs. different depth ratio

The measured improvement ratio as a consequence to the presence of a skirt evaluated for different skirted depth with different grain size distribution at the same relative density shows in figure(8). The figure shows that the improvement ratio (ultimate bearing capacity of skirt foundation to the ultimate bearing capacity of footing at the soil surface) increasing linearly, up to D/B about 2.0 then the improvement ratio was reduced. The coarse sand of the lowest angle of internal friction revealed higher improvement ratio than medium and fine grain size. Same as the fine sand of angle of internal friction lower than medium grain size revealed a higher improvement ratio. That means the soil of lower angle of internal friction when packed through the skirt revealed a higher improvement.

Fig. 8. Improvement bearing capacity ratio vs. skirted depth ratio

Figure (9) shows the net improvement ratio of using skirt than that without skirt at the same depth ratios of the skirt. The figure shows a linear increase of ultimate bearing capacity when using skirt up to skirt ratio about 1.8, at which is the optimum increment ratio occurs, after that the improvement ratio will be decreased. Coarse graded sand gives a higher net improvement ratio, about 2.7 times than that footing without skirt at (D/B) ratio of 1.5. While medium graded sand gives a lower improvement ratio about 1.9 times than that footing without skirt at the same (D/B) ratio.

Fig. 9. Net improvement ratio of bearing capacity for skirt footing than that without skirt at the same depth ratio

From the above analysis of improvement ratio due to using skirt foundation it's concluded to introduce skirt improvement factor in order to determine the ultimate bearing capacity of strip footing with skirts. A factor of 1.6 will introduce to the general bearing capacity equation for skirt ratio (D/B) up to 2.0 and 1.25 for skirt ratio more than 2.0.

Figure (10) shows the improvement ratio for the strip footing model without skirt (theoretical improvement bearing capacity ratio as shown in fig.7) multiplied by skirt factor of 1.6 for D/B less than 2.0 and 1.25 For D/B more than 2.0. The figure shows that the values of improvement ratio as approximately the same as that of the improvement ratio for skirt strip footing from experimental results as shown in (fig. 8).

Fig. 10. Theoretical Improvement bearing capacity ratio vs. different depth ratio multiplied by skirted factors

5.2 Behavior of bearing capacity factors

5.2.1 Variation of N_γ :

Figure (11) shows the variation of theoretical N_γ with the angle of internal friction ϕ of different particle size distribution for different authors according to equations no. (3, 4, 5, and 6) comparing with the measured values from the experimental model for $D/B=0$. The results show that the measured N_γ parameters were very close to Vesic proposal for fine and medium grain size distribution, while it's close to Biarez proposal for coarse sand.

Fig. 11. Behavior of measured and theoretical N_γ parameter of different authors with different angle of internal friction

In general the theoretical N_γ values are all below the experimental values. The general remark that may be drawn is that most of the theories provide conservative results. At the present stage and because measured values are close to Vesic proposed, it will be adopted for calculating N_q parameter according to eq.(5).

Figure (12) shows the behavior of N_γ parameter with skirt ratio, the figure demonstrate that there is a little effect on N_γ values at skirt ratio up to 1.5 but when skirt ration increase N_γ reduced.

Fig. 12. Behavior of measured N_γ parameter with different skirt ratio for different grain size distribution

5.2.2 Variation of N_q :

Figure (13) shows the variation of N_q versus angle of internal friction (ϕ) for coarse, medium, and fine graded sand determined from the ultimate bearing capacity of experimental model tests for different skirt ratio (D/B) of (0.5, 1.0, 1.5, 2.0 and 3) by adopting equation no. (1) and Vesic proposal for N_q . The figure shows a conservative value of N_q when compared with those obtained from the model tests. Also it shows that N_q values for skirt ratio of 0.5 to 1.5 are close to each other and reduced with increasing this ratio.

Fig.13. Behavior of N_q parameter for different skirt ratio with angle of internal friction

Figure (14) shows the behavior of N_q parameter with different skirt ratio for different grain size distribution. The figure shows that a little change of N_q parameter for skirt ratio range between 0.5 to 1.5 for all the different grain size distribution, while it decrease with increasing this ratio. This is may attributed to the increase the stress outside the footing area with increasing the skirt depth, where N_q parameter is concerned with the soil above the skirt tip.

At the present state, the figure indicates that no effect of N_q values obtained from the model tests on the skirt ratio. It shows that a slight increase up to

$D/B=1.5$ then N_q value will tend to decrease close to the theoretical values.

Fig. 14. Behavior of measured N_q parameter with different skirt ratio for different grain size distribution

6 Conclusions:

The following conclusions were drawn from the model tests of strip footing with skirt resting on loose sand of different particle size distribution:

1. The theoretical improvement ratio of ultimate bearing capacity due to increase in depth shows a linear increase in bearing capacity ratio for all particle size distribution of the sand used.
2. The improvement ratio of skirt footing increase linearly, up to D/B of 1.5 then the improvement ratio decreased.
3. The net improvement ratio of using skirt foundation than that without skirt at the same depth ratio of the skirt shows a linear increase of ultimate bearing capacity up to skirt ratio of 1.7, at which is the optimum increment ratio occurs, after that the improvement ratio will be decreased.
4. Coarse graded sand gives a higher improvement ratio than that of fine and medium sand, about 2.6 times than that footing without skirt at (D/B) ratio of 1.5. While medium graded sand gives a lower improvement ratio about 1.8 times than that footing without skirt at the same (D/B) ratio.
5. To determine the ultimate bearing capacity of strip footing with skirts rested on loose sand, multiply the general bearing capacity equation by skirt factor (f_s) of 1.6 for skirt ratio (D/B) ranged between 0.5 to 1.5 and by 1.25 for skirt ratio more than 1.5.
6. The measured N_q parameters were very close to Vesic proposed for fine and medium grain size distribution, while it's close to Biarez proposed for coarse sand.
7. N_q values obtained from the model tests for skirt ratio of 0.5 to 1.5 are close to each other and reduced with increasing this ratio.
8. Behavior of N_q parameter has a little effect for skirt ratio of 0.5 to 1.5 for all different grain

size distribution, while it decreases with increasing this ratio.

References

1. K. Terzaghi, "Theoretical soil mechanics". New York: John Wiley (1943).
2. G.G. Meyerhof, Canadian Geotech. J. **15**(4): 593.(1978).
3. J.B. Hansen, Bulletin No. 28, Danish Geotechnical Institute, Copenhagen(1970).
4. A.S. Vesic, J. Soil Mech. Found. Div., ASCE, **99**(1): 45. (1973).
5. J. Biarez, M. Burel, and B. Wack. "Contribution à l'étude de la force portante des fondations", in Proc., V Intl. Conf. Soil Mech. Found. Eng., Paris, France, 1: 603. (1961).
6. M.Y. Al-Aghbari, and Y.E-A. Mohamedzein, Geotechnical and Geological Engineering,**22**(1):43-57(2004)..
7. M.El. Sawwaf, and A. Nazer, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, **131**(3), 359-366(2005)..
8. M.Y. Al-Aghbari ,the Journal of Engineering Research , **4**, No.1 11-16 (2007).
9. T. Hisham, O. Alansari, A. Omar, M. Abdelfattah, N. Mohannad and A. Husam , Canadian Geotechnical Journal,vol. **46**, 438-453(2009).
10. A. Z. El.Wakil. "Horizontal capacity of skirted shallow footings on sand." Alexandria Eng. Journal (2010).
11. A. Z. EL Wakil , Alexandria Engineering journal vol.**52**, pp.359-364(2013).
13. M. R. Mahmood and H. Muwafak "Experimental Study the behavior of Skirted Foundation Rested on Soft Clayey Soils" 1st International Conference for Geotechnical Engineering and Transportation ICGTE in15-24/4/2013 Eng. & Tech. Journal , Vol. **31** , Part (A),No. 20,(2013).
13. P.K. Jain et.al" Effect of skirt on pressure settlement behavior of model circular footing in medium dense sand " Chandrawanshi, et al., International Journal of Advanced Engineering Technology E-ISSN 0976-3945.(2014)
14. H. M. Pavan, T. Aruna. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 03 Issue: 07 | July- (2.16).