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EXPERIMENTAL STUDY OF THE BEHAVIOR OF THE CONVEX CONTACT SHAPE STRIP FOOTING ON SAND

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Received 10 July 2012; accepted 4 August 2012

ABSTRACT

The behavior of the strip footing on sand was deeply studied in many publications. They were trying to improve this behavior through many techniques. These improvements include the using of geogrid and geotextile reinforcement, skirts on the sides of the footing to elongate the contact surface of the footing with soil. None of these studies had implemented in the effect of the contact shape of the footing on its behavior. In this present experimental study, it is intended to observe the behavior of the convex strip footing on sand with different strip footing contact shapes. A series of experiments using different convex strip footing contact shapes, are carried out on sandy soil. The results showed that the increase in the strip footing contact areas, did not increase the bearing capacity, but decreases the ultimate bearing capacity load from about 30% to 60%. Also with sever convex curve, the ultimate load decreases seriously.

Keywords: Convex footing, sand, bearing capacity

1. Introduction

The behavior a particular soil, under a shallow footing, was investigated theoretically, using the concept of plastic equilibrium [1]. Many studies on footings resting on sand have been widely carried out and the relevant theory for the calculation of ultimate bearing capacity is available since the proposal of Terzaghi [2]. Many investigators [3,4,5] had modified Terzaghi equation by the addition of several correction factors such as depth, shape and inclination factors.

The general shear failure mechanism of bearing capacity theory of a foundation resting on a sandy layer increases with the increase of the total length of the failure surface which mobilizes higher shear resistance [6].

Increase in length of the failure surface can be produced by increasing the width of the foundation or increasing the depth of the foundation using skirts [6,7]. The structural skirts fixed to the edges of shallow foundations to increase the length of failure surface could develop under central vertical loading condition and therefore improves the bearing capacity of the foundations resting on sand Fig (1).

The objective of this experimental study is investigating the effect of increasing the length of contact surface of the strip footing, on the ultimate load or maximum bearing capacity. The length of the contact surface was designed curved and convex downward. The curved part has different curved types.

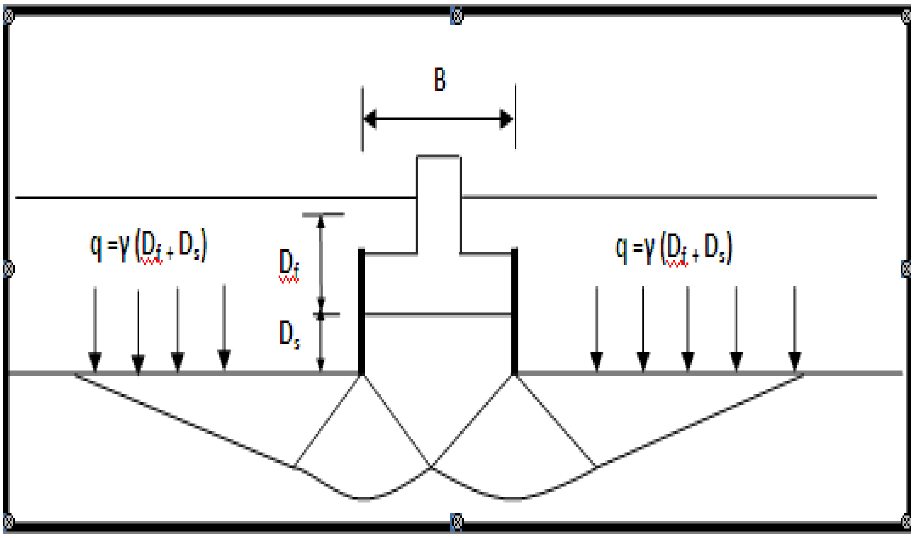

Fig. 1. Bearing failure mechanism using Skirts

1.1. Review of bearing capacity equations

The equation for calculating the ultimate bearing capacity of shallow strip foundation bearing on a homogeneous layer of sand and subjected to central vertical loading as shown in Figure (2). This equation has the following form [3]:

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

where:

q_{ult} = Ultimate bearing capacity

γ = Unit weight of the soil

D_f = Foundation depth

B = Foundation width

N_q and N_γ are bearing capacity factors

Values for N_q and N_γ are given by Terzaghi [8] in terms of the peak angle of internal friction (φ).

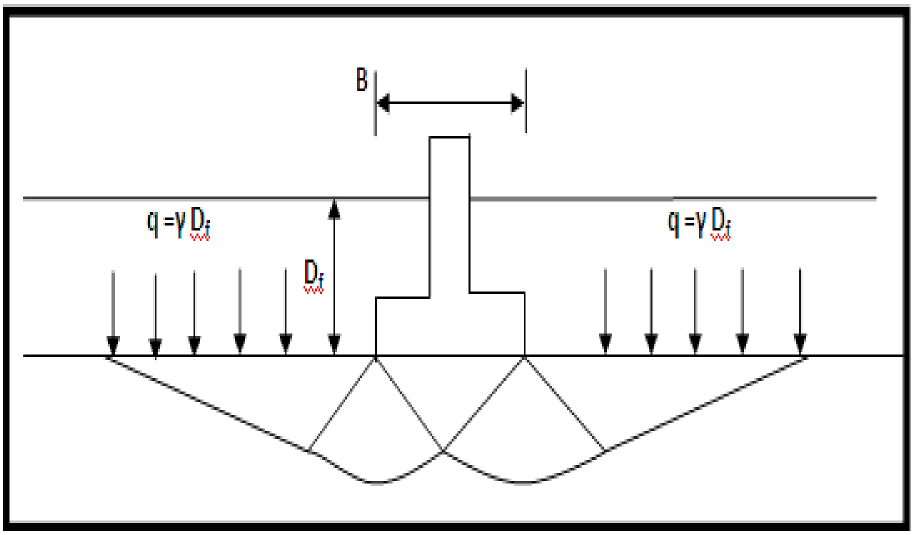

Fig. 2. Bearing capacity failure mechanism for strip footing

Bearing capacity failure mechanism in soil under a rough rigid continuous foundation subjected to vertical central load is proposed by [3,4,5]. For shallow strip foundation with structural skirts resting on dense sand and subjected to central vertical load Figure (1), modifications to the general ultimate bearing capacity equation are required [6,8].

1.2 Sources of approximations in the bearing capacity equations

The approximations involved in the derivation and use of the ultimate bearing capacity q_{ult} , given in Equation (1), may be summarized as [9]:

1. The soil mass is assumed to be purely homogeneous and isotropic, while the soil in nature is extremely heterogonous and anisotropic.
2. The shear strength of soil within a depth D, from the surface is neglected.
3. There may be three types of failure modes;
 (i) General shear failure.
 (ii) Local shear failure.
 (iii) Punching shear failure.

As shown in figure (2), the theoretical considerations behind Equation (1), correspond only to the general shear failure mode, which is typical for soils of low compressibility, such as dense sands and stiff clays. In the local shear failure, only a partial state of plastic equilibrium is developed with significant compression under the footing .In the punching shear mode, however, direct planar shear failures occur only along the vertical directions around the edges of the footing. Therefore, equation (1) is no longer applicable for soils of high compressibility, such as loose sand, which may undergo either the local shear or the punching shear failures. Consequently, the results of equation (1) will only be approximate for such soil.

4. The ultimate bearing capacity calculations are very sensitive to the values of shear strength parameters, which are determined in the laboratory using ‘undisturbed’ soil samples, which may not necessarily represent the true conditions in the site.
5. A factor of safety of 3 is used normally, in order to obtain the allowable bearing capacity, q_a , which contains a significant amount of reserve strength in it. This high factor of safety represents the degree of uncertainties in determining the real soil conditions.

2. Experimental work

2.1 Test procedures

The original strip footing (O) was 50 mm breadth and 40 mm depth, and 250 mm perpendicular length. The other strip footings A , B , C and D were the same as the original strip footing (O), but with 20 mm straight depth, while the rest of depth is curved in cross section. All the strip footings are manufactured from rigid timber. All tests were carried out on the surface of the homogeneous medium dense sand. The height of sand in the tank was 650 mm placed in a rectangular steel tank with inside dimension of 1000, 750 and 254 mm for length, width and depth respectively. All sides of the tank were made from steel plates with thickness 3 mm except the front side which was made from Perspex of 10 mm thickness to observe the behavior the sand during loading. Each side of the tank was braced with stiffeners to avoid lateral displacement during soil placement in the tank. The original strip footing was driven 20 mm in the sand to be stable during loading, while for the other footings, only the curved part driven in the sand.

Foundation was placed centrally across the width of the tank. The central vertical loads were applied by positioning the tank under a test loading frame. The load on the strip footing was applied by manual screw jack. A load cell measures the applied load and a dial gauge to measure the displacement of the footing. The experimental model is shown in Figure (3). The relative density proposed for sand was 70%. Compaction is controlled by adjusting the height of the sand layer and the weight of soil required for each layer. Every layer is compacted carefully by hand rod timber to achieve the required density. This compaction method was calibrated with different variations of sand densities.

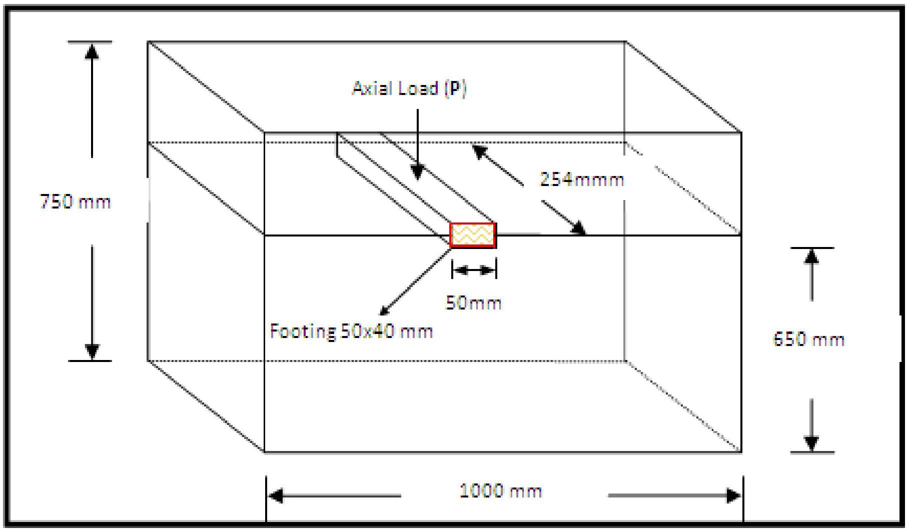

Fig. 3. The dimensions of the experimental model

2.2. Soil used in the experimental model

The sand used in the experiments, was medium dense sand with a particle size ranges approximately from 0.1 to 5.0 mm, with a mean particle diameter of 0.82 mm. The sand was placed in the tank Figure (3), with a uniform dense state using a relative density of 70%. The peak angle of internal friction for the dense sand was determined. The properties of the used sand are shown in Figure (4) and Table (1).

2.3 Strip footing used in the study

Five rigid timber strip footings were prepared. One represents the normal strip footing with flat contact with sand named original (O). The other four tested footings were chosen with different convex contact shapes. Each footing cross section consists of two parts. The upper part is a rectangle and lower part is formed as curved piece in its cross section. The curved strip footings and their engineering properties, curved lengths, and curved areas, are shown in Figures (5,6) and Table (2).

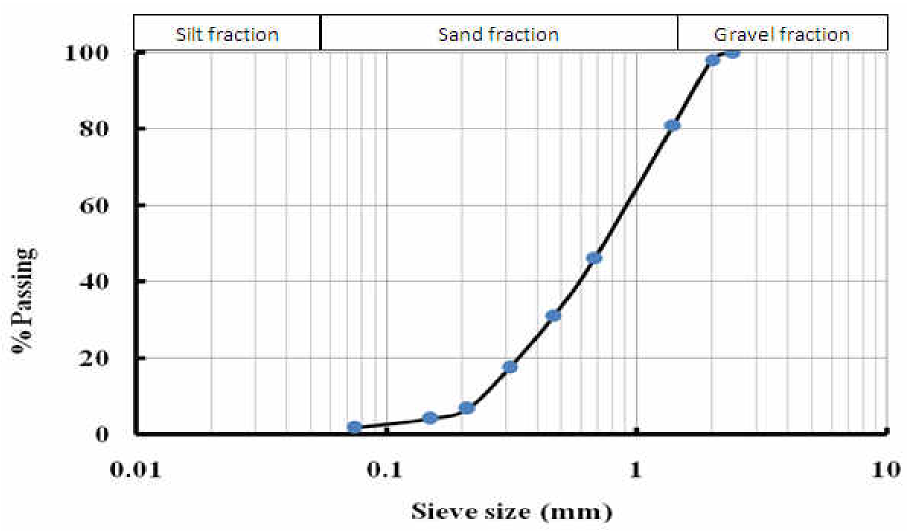

Fig. 4. Particle size distribution of the used sand

Table 1
Mechanical properties of the used sand

Property	D_{10} mm	D_{30} mm	D_{60} mm	C_u -------	C_c --------	$\gamma_{d\,max}$ t/m^3	$\gamma_{d\,min}$ t/m^3	R_d %	φ^o
Value	0.25	0.45	0.9	3.6	0.9	1.92	1.57	70	35

3. Results and discussion

3.1. Test conditions

- The load on each footing is applied till reaching footing failure.
- All footings have 20 mm height above the sand bed.
- The relative density of the used sand is 70% for all testes.
- Three results for each footing and the average is calculated.
- The load settlement curve for each footing is drawn.

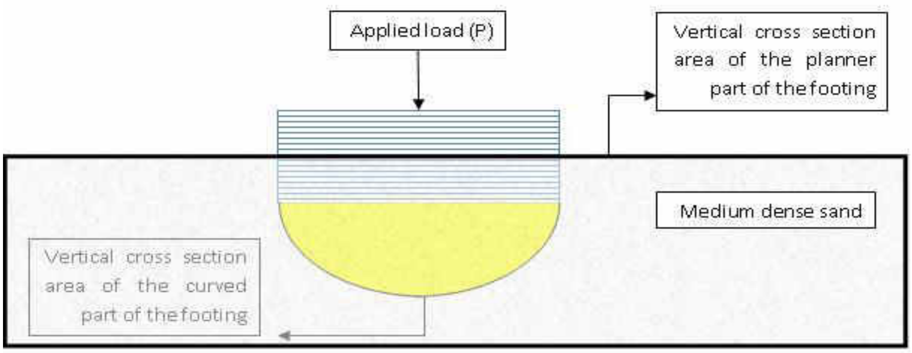

Fig. 5. Schematic diagram illustrating the vertical cross sectional area of the curved and planner part of the footing

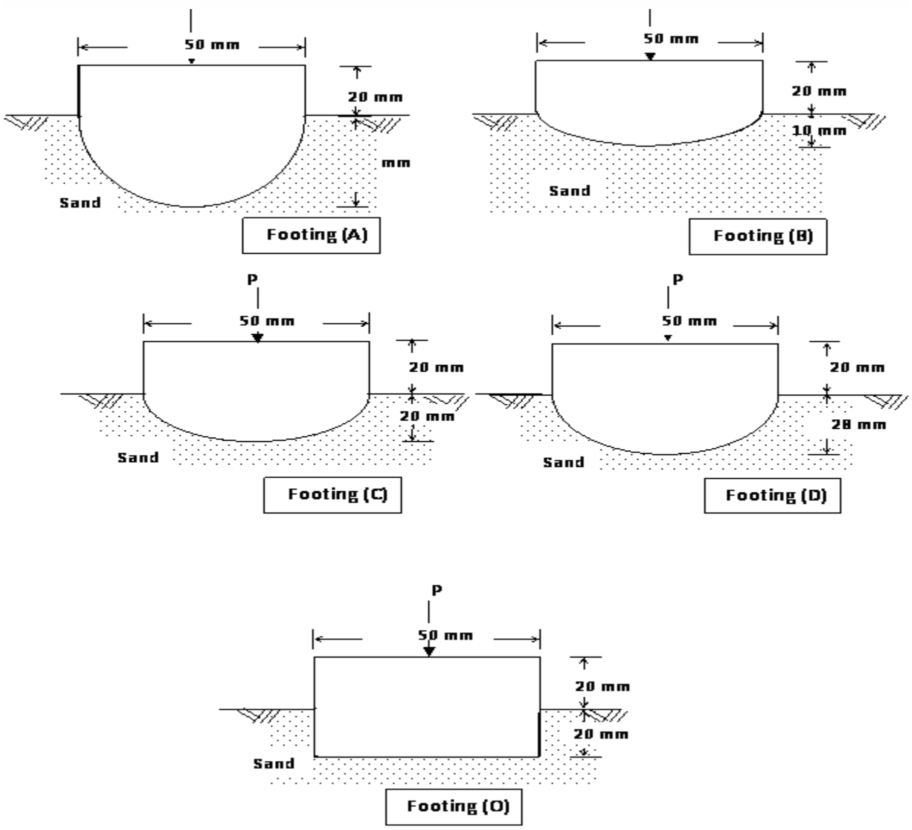

Fig. 6. The sketch section of the curved footing

Table 2
Strip footings and their engineering properties

Footing	Equation of the curved part of the footing	Length of the curved part (cm)	Vertical cross sectional area of the curved part cm^2
O	-----------	0.0	0.0
A	$y = 0.5x^2$	8.20	9.62
B	$y = \sin x$	5.46	3.16
C	$y = \sqrt{0.4(25-4x^2})^{0.5}$	6.94	7.60
D	$y = \sqrt{0.5x^3}$	7.48	8.00

3.2. Result analyses

From the analyses of the ultimate bearing capacity, it is obvious from the curves in Figures (7,8) that the maximum ultimate load occurs under the original strip footing (O) which has a flat contact. Referring to the convex curved contact strip footing, the maximum bearing capacity occurs with strip footing B which is very close to the flat contact surface as shown in Figure(8) . Footings C, D and A have a descending order in the ultimate load, they have 97.8, 81.5 and 69.2 kgf respectively.

Figure (9), represents the relation between the ultimate load and the length of the curved part of the footing. The ultimate load decreases with the increase of the length of the curved part of the footing section.

Figure (10), represents the relation between the ultimate load and the vertical cross sectional area of the curved part of the footing section. The ultimate load decreases with the increase of the vertical cross sectional area of the curved part.

In the present study, the strip footing was designed using curved contact instead of flat contact in the lower part of the footing base. This curved section of the footing contributes in accelerating the formation of the punch cone, under the strip footing. The behavior of the strip footing with curved contact shape with soil is similar to the stresses zones generated under the footing as a result of the applied loads. The shape of the footing cross section is approaching from the punching zone generated under any footing during load application. This can be the reason of the bearing capacity decrease when using strip footing with curved contact shapes.

Referring to the relation of the curved depth with the ultimate load Figure (11), it is found that the increase in curved part depth is accompanied by a decrease in the ultimate load and vice versa. This action is caused by the severe curvature which generated from the depth increase of the curved part.

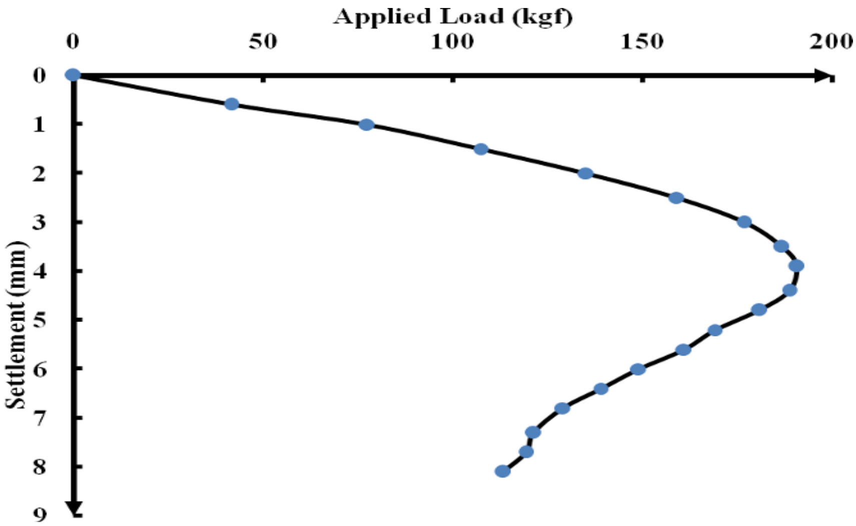

Fig. 7. Load-settlement curve for footing (O)

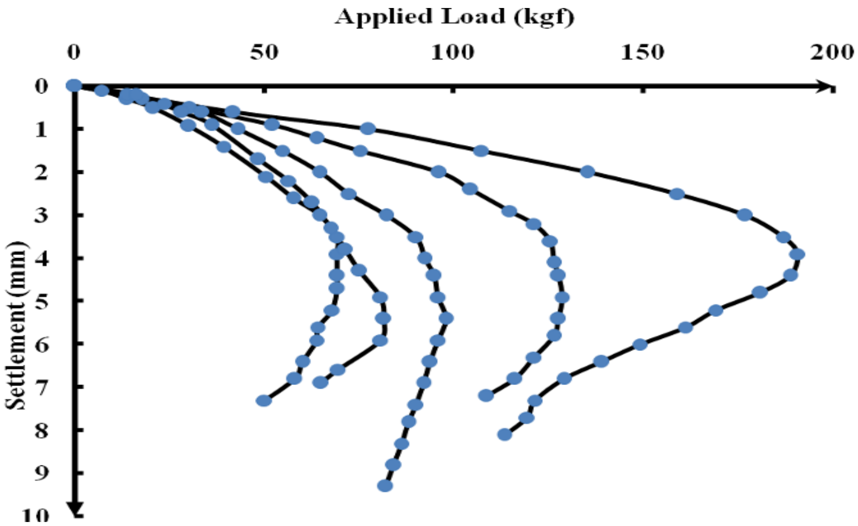

Fig. 8. Load settlement curve for all footings

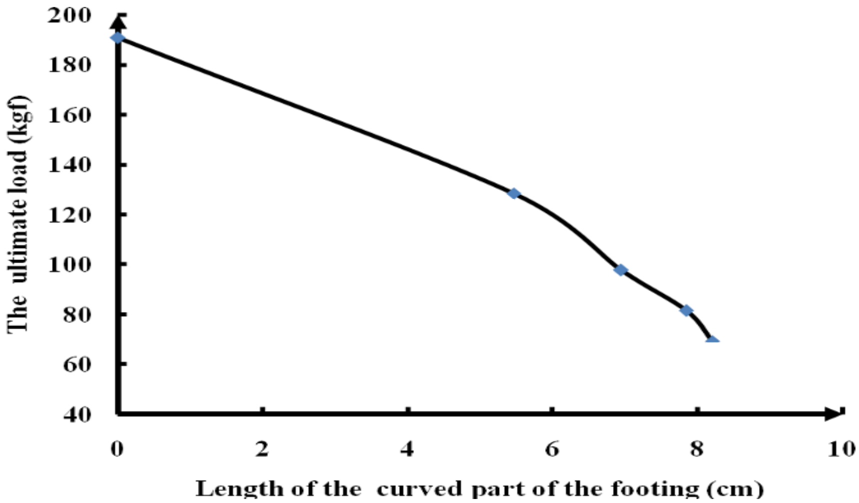

Fig. 9. The length of the curved part with the ultimate load

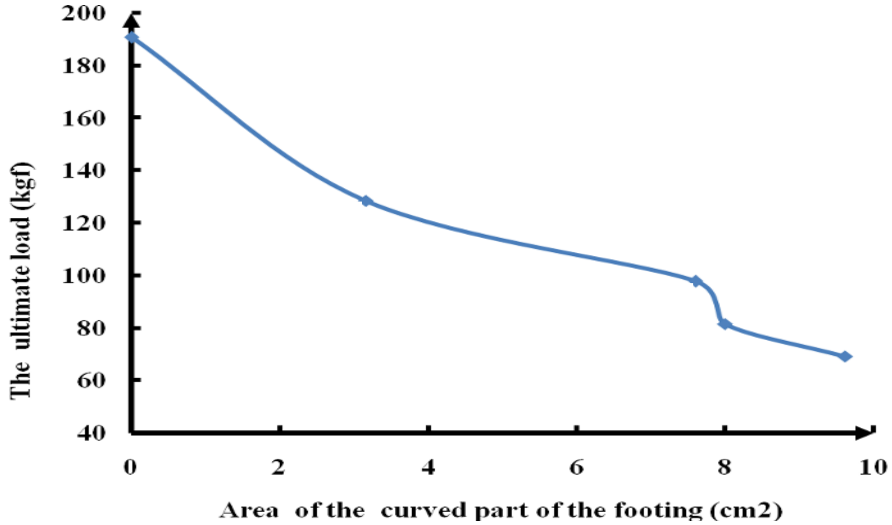

Fig. 10. The vertical cross sectional area of the curved part and the ultimate load

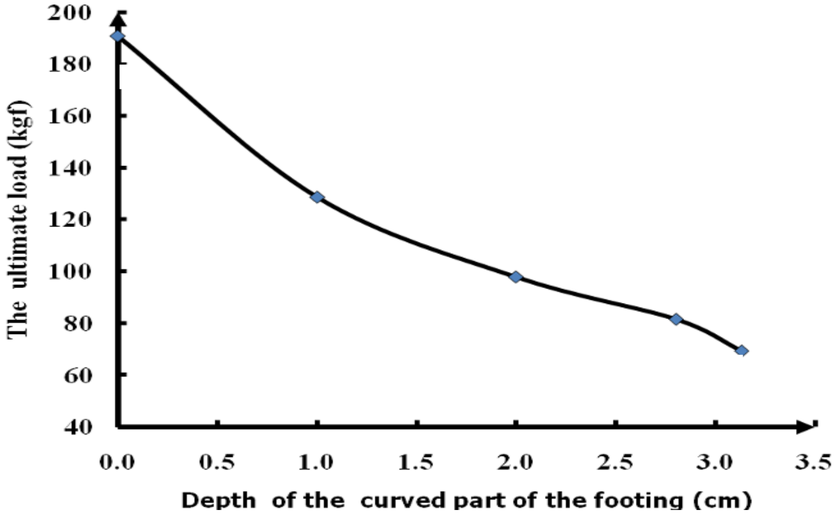

Fig. 11. Depth of the curved t part of the footing with the ultimate load

4. Conclusions

1. The curved contact shapes of strip footings decrease the ultimate load by about 30% to 60%.
2. When the curvature of the strip footing reaches to be flat, the ultimate load reaches to be equal to the case of the original flat contact footing.
3. As the area, length and depth of the curved part of the footing, increase, the ultimate load decreases.
4. The flat contact surface of the strip footing is the suitable and effective shape which gives the more accurate and maximum ultimate load.

References

[1] Reissner,"Concerning the Earth Pressure Problem", Proc.1st Int. Congress of Applied Mechanics, Delft, pp. 295–311.,1924.

[2] Terzaghi, K., " Theoretical Soil Mechanics" John Wiley & Sons, New York.,1943

[3] Hansen, J. B. "A Revised and Extended Formula for Bearing Capacity" Bulletin No.28, Danish Geotechnical Institute, Copenhagen, pp. 5–11.,1970.

[4] Meyerhof, G. G., "Some Recent Research on the Bearing Capacity of Foundations", Can.Geotech. J.,1, pp. 16–26.,1963.

[5] Vesic, A. S., “Analysis of Ultimate Loads of Shallow Foundations”, J. of Smfed, ASCE, 99, pp. 45–73.,1973.

[6] Al-Aghbari, M. Y. S., "Bearing Capacity of Shallow Strip Foundation With Sructural Skirts Resting on Dense Sand", Ph.D. Thesis, University of Strathclyde, Glasgow, UK.,1999.

[7] Hu, Y., Randolph, M. F. and Watson, P. G. "Bearing Response of Skirted Foundation on Non-homogeneous Soil", Journal of Geotechnical and Geo-environmental Engineering, ASCE,125(11), pp. 924–935.,1999.

[8] Bransby, M. F. and Randolph, M. F. "Combined Loading of Skirted Foundation", Geotechnique,48(5), pp. 637–655.,1998.

[9] Semih S. Tezcan, et al., “Allowable Bearing Capacity of Shallow Foundations Based on Shear Wave Velocity" Geotechnical and Geological Engineering 24: pp. 203–218, 2006.

دراسة سلوك الأساس الشريطي المحدب علي التربة الرملية

ملخص:

كتبت دراسات كثيرة لتحسي سلوك الأساس الشريطي علي الرمل. منها استخدام الألياف الصناعية في تسليح طبقات التربة أسفل الأساس وأيضا استخدام ساندات جانبية علي جانبي الأساس (Skirts)لتطويل السطح المحتك من الأساس بالتربة .في الدراسة الحالية استخدمت مجموعة من الأساسات المحدبة ناحية التربة لمعرفة هل تعطي هذه التقنية تحسنا في الأحمال التي يمكن أن تتحملها التربة أم لا. من التجارب المعملية التحميلية علي رمل متوسط الـ دمك اتضح ان هذه الأساسات المحدبة تقلل من قيمة أقصي حمل تتحمله التربة بمقدار من 30% الي 60%. و لهذا لا ينصح باستخدام هذه الأساسات المحدبة.