Numerical Investigation of the Bearing Capacity Factor and Behavior of Footing Bonded by a Wall

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Abstract: - This research presents a numerical study of a footing bounded by a concrete wall at one of its edges resting on sandy soil and subjected to axial static loading. The effect of wall depth (d/b) and distance from the edge (h/b) of footing were studied as a percentage of the footing width was changed several times, the optimum value was selected. Therefore the value of the bearing capacity factor $N\gamma$ for the optimum values of the ratio of (d/b and h/b) was obtained by changing the value of soil friction angle. The results show that the behavior of stress and strain in general is linear at low stress level, whereas stress increases, the strain generated increases, the strain is irregular under the foundation and that the value of the required stresses to generate strain increases with increasing depth below the foundation. Increasing the ratio of depth (d/b) leads to an increase in the value of the stresses required to generate the strain within soil as well as note when the ratio (d/b) exceeds (1/2) of no significant change occur in the value of stress and strain The presence of the wall at the edge of footing leads to a reduction in the strain generated within the soil by not less than (40%) and the optimum value of the ratio of (h/b) when the wall is linked to edge of the footing in other words (h/b=0). The bearing capacity factor ($N\gamma$) for bounded footing increases with increasing the angle of internal friction of the soil.

Keywords: foundation; concrete wall; sandy soil; static load; Plaxis program.

1. Introduction

Structural skirts are walls linked or fixed at specified distance to the edges of shallow foundations to improve their bearing capacities. **[6]** studied the effects of skirt stiffness and depth on the bearing capacity of footing models. The test results were then compared with various bearing capacity equations, it was found that using structural skirts may improve the footing bearing capacity up to (3.68) times depending on the geometry and structural specifications of the skirts and footings.

[3]. (2013) show that the Skirts are used to improve the bearing capacity of shallow foundation on sandy soil by constraining the soil beneath and containing the plastic flow of soil. They are used as an alternative to deep foundations in soils with low strength at the surface.

[4]. (2014) presented the results of laboratory model tests carried out to study the effect of footing diameter on load carrying capacity of skirted footing. The footings of four diameters (40 mm, 60 mm, 80 mm and 100 mm) were used on loose sand having embedded skirt inside. The skirts of UPVC pipe of different diameters (46, 59, 71 and 85 mm) were inserted in the sand centrally in a model test tank filled with sand, the results show. It was found that the skirt restricts the lateral displacement of sand leading to a significant improvement in the response of the footing.

[1] studied the behavior of foundations with structural skirts adjacent to a sand slope and subjected to earthquake loading. The effect of the adopted skirts to safeguard foundation and slope from collapse is studied. The skirts effect on controlling horizontal soil movement and decreasing pore water pressure beneath foundations and beside the slopes during earthquake was investigated. This technique is investigated numerically using finite element analysis.

[5] investigated the behavior of model footings bounded by a wall of different depths and located at different distances from the footing resting on sandy soil. Test results show that the presence of the wall affects remarkably the bearing capacity, leading to improvement in the bearing capacity with different percentages according to the distance of the wall from the edge of footing and depth of wall, due to the increase in the soil confinement underneath the footing. **[2].** (2015) studied a ten story reinforced concrete building resting on raft foundation with two panels represented as two dimensional model with and without skirts. This technique is analyzed numerically using finite element analysis of two dimensional plane strain program PLAXIS, dynamic module. A series of models were analyzed at different skirt depths below the foundation level. The results showed that the skirts have a great effect on controlling the horizontal deformation for the subgrade and superstructure. **[7]** presented a study on lateral loading tests performed to shed some lights on the performance of rectangular skirted footings. It was found that increase in the number of skirts and D/B ratio increased the ultimate lateral load carrying capacity of footings significantly. Locations of skirts with respect to loading direction also have significant effect on the ultimate lateral load carrying capacity of shallow footings. Load carrying capacity of footing increases with increase in inclination of load in plan.

The objective of the present work is to carry out numerical analysis on footings bounded by concrete walls for the purpose of knowledge of the impact of the wall on the bearing capacity of footing and reduce the strain generate in the soil mass.

2. Research Methodology

The research method is designed to find the maximum stresses that generate less strain in the soil mass for the bounded foundation by changing the engineering geometry of the model and friction angle of sandy soil. The changing of engineering geometry is represented by:

1- The ratio of depth of wall to width of footing (d/b).
2- The ratio of distance between wall and edge of footing to width of footing (h/b).

The factors be studied in this research are summarized in Table.1.

Table 1. Factors studied in the research.

Model	Parameter			
	Width of footing, (b, m)	(Depth/ width) ratio, (d/b)	(Distance / width) ratio, (h/b)	Friction angle, (Ø°)
Model 1	18	0	---	30
Model 2	18	1/3	0	30
Model 3	18	1/2	0	30
Model 4	18	2/3	0	30
Model 5	18	1/2	1/6	30
Model 6	18	1/2	1/3	30
Model 7	18	1/2	0	10
Model 8	18	1/2	0	20
Model 9	18	1/2	0	30
Model 10	18	1/2	0	40
Model 11	18	1/2	0	50

3. Finite Element Analysis

The models of the bounded footing and soil was built using 3-D finite element model in Plaxis program as shown in Fig. 1. The model was built for the bounded footing of the geometric changes that were explained in Table 1. The soil type is sand composition with dimensions (75x75x40 m) and the depth of ground water was defined at (2 m) from the level of the ground surface. The Mohr Coulomb was used to define the sandy soil behavior. The bounded footing where it was considered to be stiff, in other words the footing and wall is simulated by terms of non-porous linear elastic volume elements.

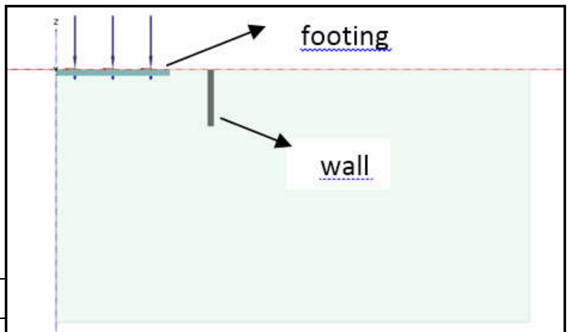

Fig. 1 The front view of 3-D model of bounded footing.

3.1 Representation of selection parameters in the program

After completion of the model for each of the bounded footing and soil dimensions, properties of the materials for both the bounded footing and soil must be defined. The bounded footing will be represented by the concrete, while the soil will be represented by sand. Table 2 shows the properties of the footing and sand materials.

Table 2. Properties of materials.

parameter	Name	Sand	Skirted footing	wall	unit
General					
Material model	Model	Mohr-column	Liner-elastic	Liner-elastic	--
Drainage type	Type	Drained	Non-porous	Non-porous	---
Unit weight	γ_t	17	24	24	kN/m^3
Parameters					
Young modulus (constant)	È	1x10^4	23500	23500	kN/m^2
Poisson's ratio	ν	0.3	0.15	0.15	---
Cohesion constant	C	10	---	---	kN/m^2
Friction angle	Ø	30	---	---	°
Dilatancy angle	ψ	0	---	---	°
Initial					
$k_\circ$ determination	---	Automatic	Automatic	Automatic	-
Lateral earth pressure coeff.	K_0	0.5	1.0	1.0	-

3.2 Staged construction and calculations

Several models of footing were built with and without wall were considered. Then the phases that will pass during the calculations were defined, the phases can be defined by the initial phase, building phase and then loading phase. The load applied is vertical static load and the value is range from (100 - 300 kN/m^2) for cases mentioned in Table 1. And the calculations are done to extract the results. **Fig. 2** shows the bounded footing at the loading phase.

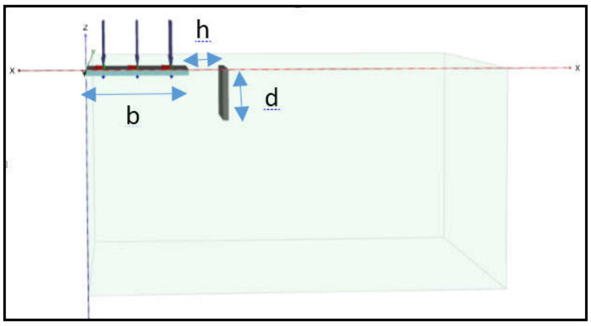

Fig. 2 The geometry of the model at loading phase.

4. Results and discussion

In order to determine the value of stress – strain below the foundation, (9 points) were chosen below the foundation and at different depths. These points were divided into three group each group contains (3 points) the first and third group below the edges of footing and the second group below the center of the footing as shown in **Figs. 3 and 4.** The names and coordinates of these points are as follows at the edges of the footing of the following points at the first edge A(0, 0, -2), B (0, 0, -4) and C (0, 0, -6) at the second edge G (18,0, -2), H (18, 0, -4) and I (18, 0, -6) at the central of the footing the following points D (9, 0, -2), E (9, 0, -4) and F (9, 0, -6), respectively.

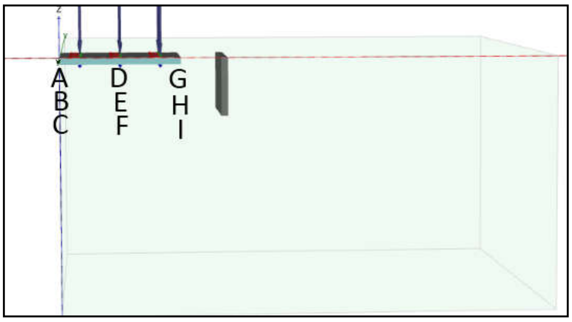

Fig. 3 The names of the points below the footing.

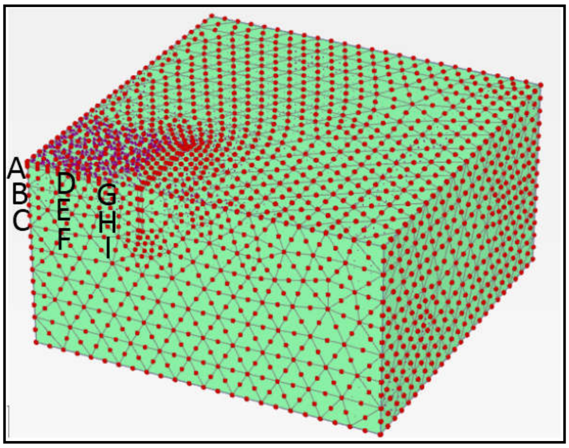

Fig. 4 The points below the footing.

Figs. 5 to 7 show the total vertical stress versus the total vertical strain in the points referred to above. It can be concluded from the figures that the behavior of stress and strain in general is linear at low stress level, whereas the stress increases, the strain generated increases. It is clear that the value of the required stresses at the shallow depth is small to generate the strain while at greater depths, it is noticed there is increase in the value of the required stresses to generate strain within soil where it can be seen from figures that the stress to generate the strain changes from (40 to 100 kN/m^2) when the depth change from (2 to 6m).

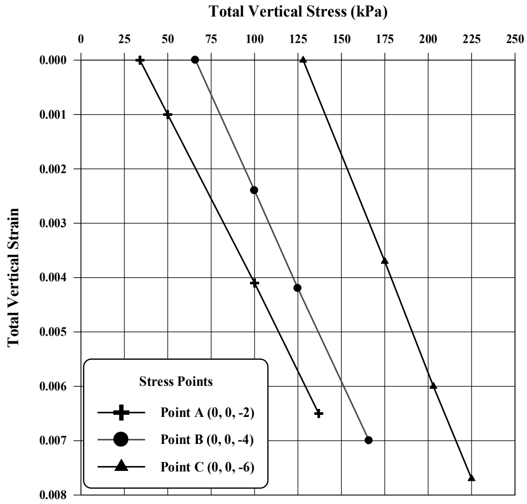

Fig. 5 Vertical stress versus the vertical strain at stress points A, B and C at Ø=30º

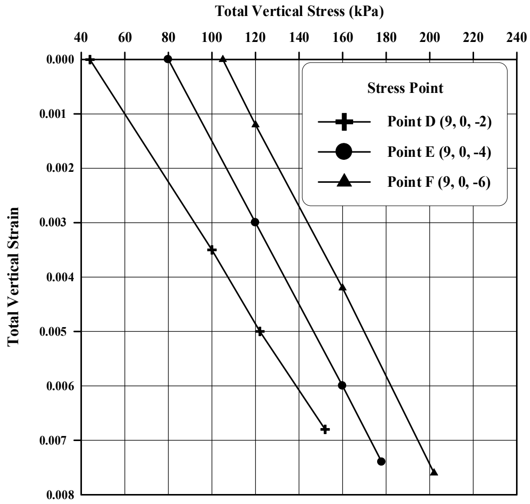

Fig. 6 Vertical stress versus the vertical strain at stress point D, E and F at Ø=30º

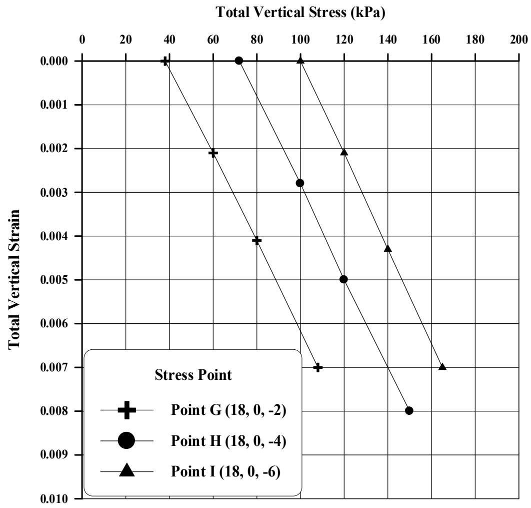

Fig. 7 Vertical stress versus the vertical strain at stress point G, H and I at Ø=30º.

Fig. 8 shows at a specified value of the applied and transferred stress within the soil, the generated maximum vertical strain decreased with increased depth, also can be seen that an increase in the value stresses at the same depth leads to an increase in the strain generated at that depth. The figure show clearly at a depth of (2 m) at point G the strain is reduced from (0.007 to 0.0021) when the stress value reduce from (100 to 50 kPa). The effect of using the wall at the edge of the footing starts to decrease when increasing the depth below the footing where it can be seen at the depth (4 m) at point H the strain is reduced from (0.0028 to 0) when the stress value reduce from (100 to 50 kPa).

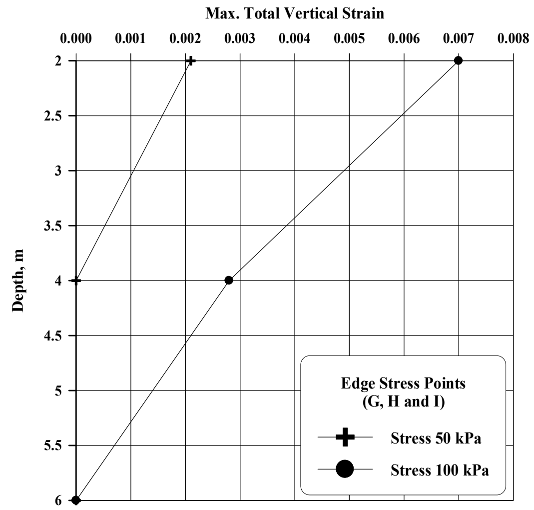

Fig. 8 Max. total vertical strain versus depth at Ø=30º.

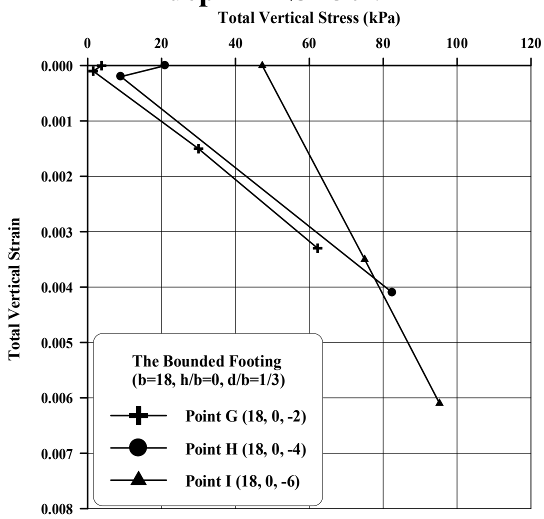

Fig. 9 The total vertical stress versus the total vertical strain at (h/b=0 and d/b=1/3) and Ø=30º.

Figs. 9 to 11 show the stress-strain relation for the bounded footing when the distance between the footing edge and the wall is (h/b=0) the depth of the wall is changed from (d/b= 1/3, 1/2, 2/3).The figures show that increasing the ratio of depth (d/b) leads to an increase in the value of the stresses required to generate the strain within soil as well as note when the ratio (d/b) exceeds (1/2), no significant change occurs in the value of stress and strain, in other words that the optimum ratio of (d/b) is (d/b=1/2).

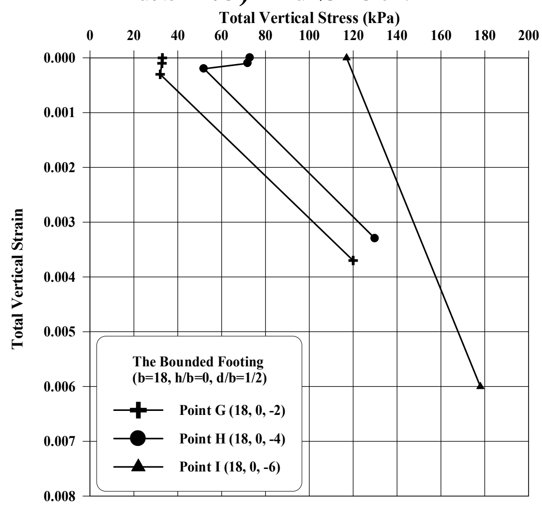

Fig. 10 The total vertical stress versus the total vertical strain at (h/b=0 and d/b=1/2) and Ø=30º.

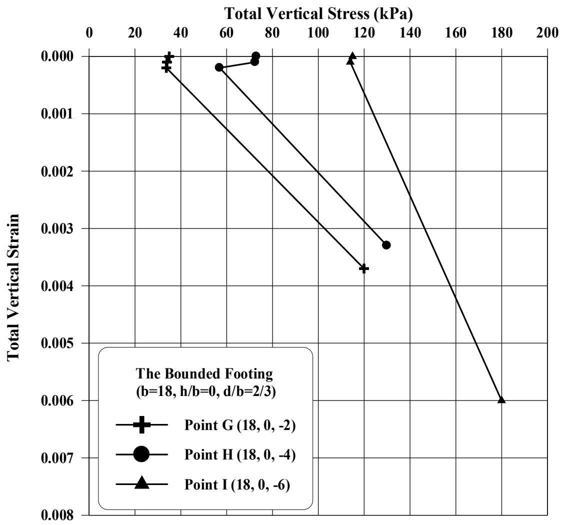

Fig. 11 The total vertical stress versus the total vertical strain at (h/b=0 and d/b=2/3) and Ø=30º.

Fig. 12 shows that the decrease in strain generated by the use of the wall compare to the footing without a wall for (d/b =1/2 and 2/3) at (h/b=0). It can be noticed that the reduction percentage of strain is defined as:

$$Rs = \frac{s - s*}{s*} \; x \; 100\% \qquad \text{-------} \; (1)$$

Where:
Rs = reduction percentage of strain
s = strain at d/b (1/2 or 2/3)
s*= strain at d/b=1/3
d/b = ratio of depth of wall to width of footing.

The reduction percentage of strain increases linearly with increase of the stress required when the depth of the points to be read changed from (2 to 6 m) below the footing. The results above show that the presence of the wall at the edge of footing leads to a reduction in the strain generated within the soil by not less than (40%). The effect of the presence of the wall at the edge of footing highlights clear at a shallow depth where the rate of reduction in strain is more than to the reduction in strain at deep depths below the footing.

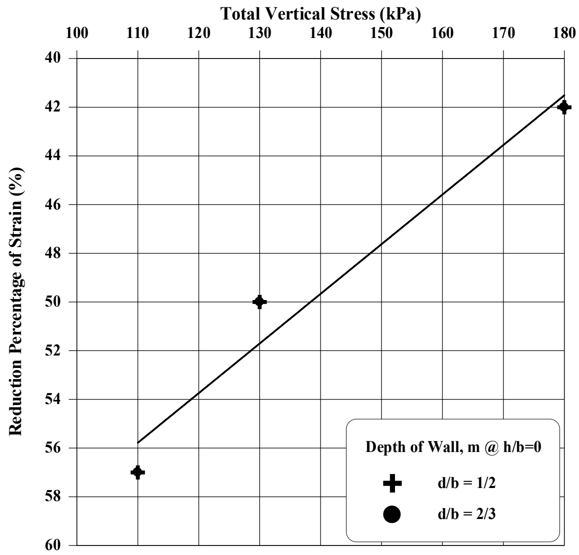

Fig. 12 The total vertical stress versus the reduction percentage of strain (%) at (h/b=0) and Ø=30º.

Figs. 13 and 14 show the results of the total vertical stress versus the total vertical strain at the optimum depth of wall (d/b=1/2) and change the value of distance between the wall and edge of footing from (h/d = 1/6 to 1/3). The results show that the increases in the ratio of (h/b) leads to increases in generated strain within soil and the optimum value of the ratio of (h/b) when the wall is linked to the edge of the footing, in other words (h/b=0). The increase in the ratio of (h/b), the strain will be reduce to the same depth when the wall approaches the edge of the foundation, note that need at point G stress value (120, 110 and 118) to generate strain in the soil (0.003, 0.007 and 0.0053) when the value of h/b change from (0, 1/6 and 1/3), respectively.

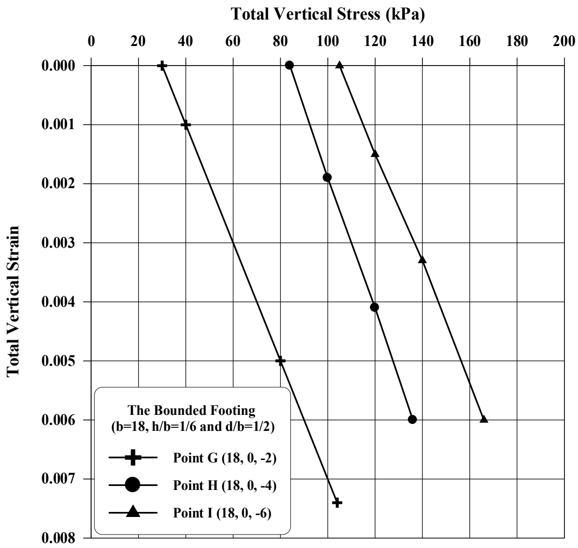

Fig. 13 The total vertical stress versus the total vertical strain (h/b= 1/6 and d/b=1/2) and Ø=30º.

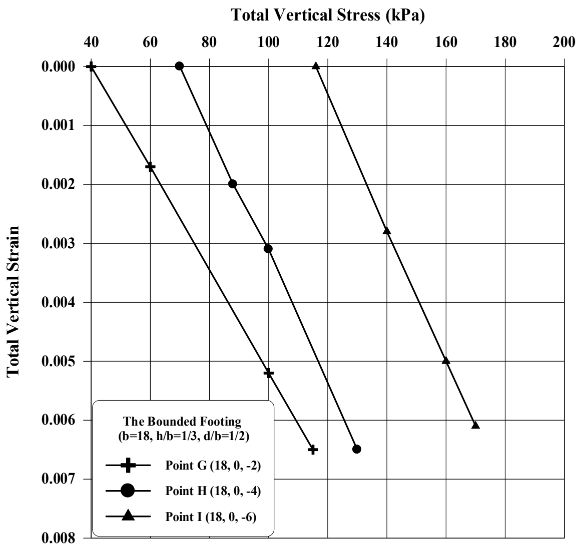

Fig. 14 The total vertical stress versus the total vertical strain (h/b= 1/3 and d/b=1/2) and Ø=30º.

Fig. 15 shows the relationships between the measured maximum strain with depth at which the value of the ratio (h/b) is changed from (h/b=0, 1/6 and 1/3) and the stress level is (100 kPa). It can be seen from the figure that the maximum strain generated when the value of ratio (h/b=0) is less than the strain generated at the other ratio of (h/b), especially at the shallow depths. This indicates that the ideal ratio at (h/b=0) when the wall is more effective at the edge of the footing to reduce the strain and as the ratio of (h/b) increases leads to the effectiveness of the wall to treat the generated strain starting with decreases. It can be seen at point (H) at depth of (4 m) below the footing, the amount of reduction in strain decrease compare to the impact of the wall at Point (G) at depth of (2m) in other words the strain reduce from (0.003 to 0.002) when the ratio of (h/b) change from (1/3to 0). There is no noticeable effect on strain when the depth is (6 m) or more.

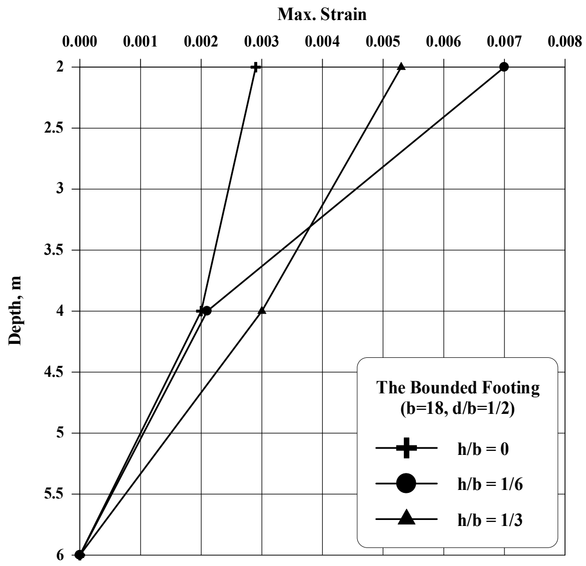

Fig. 15 Max. strain versus depth with different (h/b) at (b=18and d/b=1/2) and Ø=30º.

Fig. 16 obtains the results of the stress strain of bounded footing at (b=18, h/b=0, d/b=1/2) when the soil friction angle changes from (10, 20, 30, 40 and 50◦), respectively. It can be seen from the figure that as the friction angle increases, the stresses increase and the strain generated decreased. In order to draw the relationship between the soil friction angle and bearing capacity factor (Nγ) obtained from the **Hansen equation (2**) after the input value of the ultimate stress obtained from numerical analysis when the soil friction angle changes from (10, 20, 30, 40 and 50◦), respectively at strain value (0.01)**.** The bearing capacity factor (Nγ) for the bounded footing increases with increasing interior friction angle of the soil.

q_u=cNcSc+DγNqSq+0.4γBNγSγ -(2)

where:

c= cohesion=0 for sand soil, and

D = depth of footing = 0 at the surface of the footing.

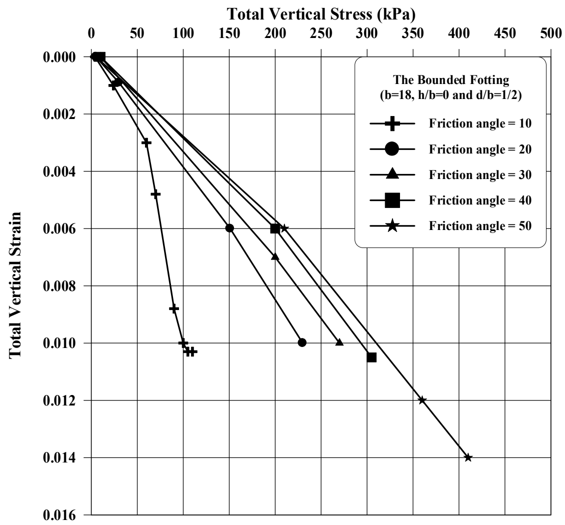

Fig. 16 Vertical stresses with vertical strain at different friction angles.

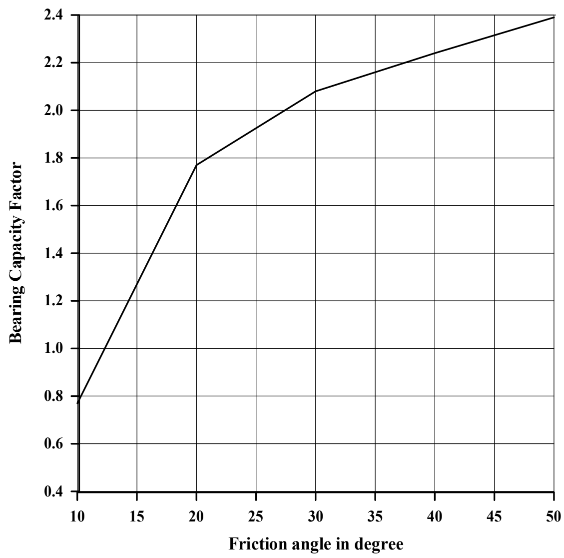

Fig. 17 Variation of the Nγ with different friction angles of soil.

The deformation and stress shapes extracted from the program after calculation process can be shown in Figs. 18 and 19.

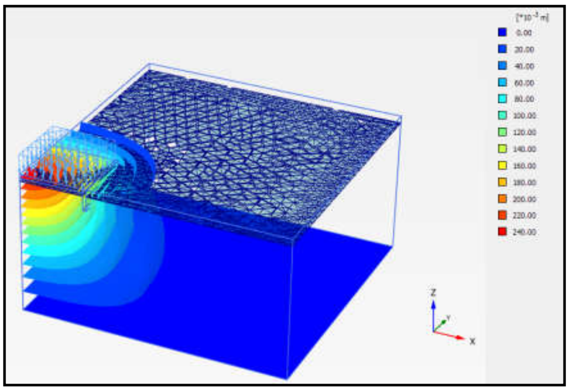

Fig. 19. Full contour of deflection (h/b=0 and d/b=1/2).

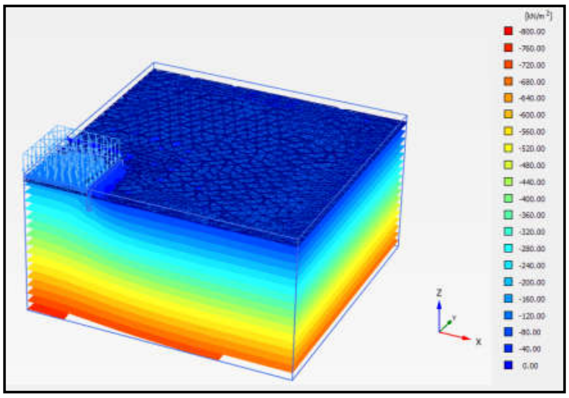

Fig. 19 Full contour of stress (h/b=0 and d/b=1/2).

5. Conclusions

- The behavior of stress and strain below the footing in general is linear, where as stress increases, the strain generated increases.
- The value of the required stresses at the shallow depth is small to generate the strain while at greater depth, an increase in the value of the required stresses takes place to generate strain within soil.
- The strain is irregular under the foundation and that the value of the required stresses to generate strain increases with increasing depth below the foundation.
- Increasing the ratio of depth (d/b) leads to an increase in the value of the stresses required to generate the strain within soil as well as note when the ratio (d/b) exceeds (1/2) of no significant change occur in the value of stress and strain, in other words, the optimum ratio of (d/b) is (d/b=1/2).
- The reduction percentage of strain increases linear with the stress. The presence of the wall at the edge of footing leads to a reduction in the strain generated within the soil by not less than (40%). The effect of the wall at the edge of footing appears clearly at a shallow depth.
- The increase in the ratio of (h/b) leads to increase in generated strain within soil and the optimum value of the ratio of (h/b) when the wall is linked to edge of the footing (h/b=0).
- As the friction angle increases, the stresses increase and the strain generated decreased.
- The bearing capacity factor (Nγ) for bounded footing increases with the angle of internal friction of the soil.

6. References

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دراسة عددية عن معامل قابلية التحمل والتصرف لأساس محدد بواسطة جدار

د. فارس وليد جواد

وزارة التعليم العالي والبحث العلمي / دائرة الاعمار والمشاريع

أ.د. محمد يوسف فتاح

الجامعة التكنولوجية / قسم هندسة البناء والإنشاءات

الخلاصة:- البحث يقدم دراسة عن الاساس المحدد بواسطة جدار كونكريتي عند احدى حافاته جالس على تربة رملية مسلط عليه حمل ساكن محوري. تم دراسة تأثير عمق الجدار والمسافة بين الجدار وحافة الاساس كنسبة مأخودة من عرض الاساس بحيث هذه النسبة تتغير عدة مرات لايجاد القيمة المثلى لهذه النسبة وكذلك تم حساب قيمة معامل التحمل ($N\gamma$) بالنسبة للقيمة النسب المثلى التي تم استخرجها لكل من عمق الجدار وبعد الجدار عن حافة الاساس بتغير زاوية الاحتكاك الداخلي للرمل. اظهرت النتائج ان علاقة التصرف بين الاجهاد المسلط والانفعال المتولد علاقة خطية حيث كلما زاد الاجهاد المسلط زاد قيمة الانفعال المتولد داخل التربة وان الانفعال المتولد في التربة الاسفل الاساس يكون غير منتظم حيث كلما زاد عمق زاد قيمة الاجهاد المراد لتوليد الانفعال داخل التربة ان زيادة نسبة عمق الجدار تؤدي الى زيادة في قيمة الاجهادات المطلوبة تسليطها لتوليد الانفعال داخل التربة حيث لوحظ ان زيادة هذه النسبة اكثر من (2/1) لاوجود لتغير في قيمة الجهادات والانفعال المتولد. ان استخدام الجدار عند افة الاساس يؤدي الى تقليل في نسبة الانفعال المتولد داخل التربة بما لايقل عن (40 %) وان النسبة المثلى لمسافة الجدار عن حافة الاساس هي (b/h=0) وان معامل التحمل الاقصى ($N\gamma$) يزداد بزيادة زاوية الاحتكاك التربة.

الكلمات المفتاحية: اساس، جدار كونكريتي، تربة رملية، حمل ساكن، برنامج Plaxis .