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THE ANALYSIS BEHAVIOUR OF ARCHED STRIP FOUNDATIONS

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ABSTRACT: - The construction of bearing walls structures does not necessarily require for using plane strip reinforce concrete footings. These structures can construct by using present simple arched plain and reinforced concrete strip footings on silty clay and silty sand soil using finite element. This paper aims at analyzing plain and reinforced concrete arched strip footings, as foundation system of bearing walls structures, as an alternative solution to the construction of buildings. The effect of soil type, arched strip footing's height and the bearing walls vertical load on the dimensions and capacity of arched strip footings study in this paper. A numerical model for the non-linear analysis of arched strip footing-soil interaction problem based on the finite and infinite element implement. A computer program develops to model the arched strip footing-soil installation. The material and geometrical non-linearity of the concrete strip footing takes into account the non-linear stress-strain relation of concrete and presence for cracking also considers. In addition, Duncan-Mohr-Coulomb Modified model uses to simulate soil non-linearity. The obtained numerical results were compared with the traditional method in designing of strip footings commonly used by structural engineers.

Design charts propose and presented for structural designers in order to calculate arched P.C & R.C strip footing dimensions according to type of soil and vertical load such strip footings which consider the cost less than traditional bearing walls construction system. The thickness of strip footing expresses in a non-dimensional ratio (t/B), where (B) is the breadth of the strip footing, with three ratios of 0.1, 0.2, and 0.3 respectively. The height of the arched strip footing was expressed in a non-dimensional form (h/B) with three ratios of 0.1, 0.2 and 0.3 respectively. Four different values of vertical load (P = 20t/m', 30t/m', 40t/m' & 50t/m') investigate in the analysis. Two types of soil; silty clay, and silty sand consider in this study to represent the cases of weak and stiff soil. This result leads to exceptionally low cost up to 30% and safe structures than in case of plane strip footing. The present investigation shows some results that the minimum etc.

Keywords: *Plain and reinforced concrete, Arched Strip footing, silty clay and silty sand soil, Nonlinear - Finite element*

1. INTRODUCTION

Rewrite what? Do you mean here! The solution of the increasing in construction cost problem requires for using an innovative and untraditional ideas and techniques such as using plain and reinforced concrete arched strip footings as a foundation system for bearing walls building. The bearing walls system decreases the amount of use steel in R.C. foundations. Strip footings are commonly reinforced concrete and brick or stone just laid under the walls of older buildings. The influence of interaction between reinforces, plain concrete plane, arched, folded strip footing and soil beneath it on the distribution of contact pressure and internal stresses [1, 8]. However, in the present paper, the effect for using R.C and P.C.

arched strip footing dimensions and the increases of. Its supports vertical loads on the internal stresses of strip footing and soil stresses consider. Soil-structure interaction considers through the use of finite element analysis of both P.C., R.C arched strip footing, soil beneath it, for taking into consideration the non-linearity of concrete and the soil by using Duncan-Mohr-Coulomb Modified Model [9,12].

2. FINITE ELEMENT MODEL

In the present paper, different types of elements use to model the problem in order to obtain the internal stresses, crack pattern in the arched strip footing and stresses in the foundation soil. The bar element has used to model the steel reinforcement. A simple bilinear stress-strain curve has used in steel reinforcement to show the yield stress in tension and compression which depended on the type of the used steel bars [10 & 14].

Plain strain isoperimetric four-node quadrilateral elements has used in two cases. The first one uses to model the strip footing tacking into consideration the non-linearity of concrete [9&10]. The material model represents elements of concrete in biaxial stress states and provides the cracking and crushing patterns of concrete. The basic prerequisite for performing non-linear analysis of concrete has a linear, elastic and brittle material in tension, and elasto-plastic in compression. The concrete has very limited capacity in resisting tension, and therefore allow to crack when the principle stresses exce the permissible tensile stress (st).

The second type of element uses to model the soil media, take for into consideration the nonlinearity of soil by using Duncan-Mohr-Coulomb Modified Model [9, 11 & 12]. Finally, the outer boundaries of the soil media were modeled by left and right two-node infinite elements, which describe the soil continuity [9 & 13].Derivation of the basic numerical equations corresponding to various elements was previously presented by [9,14]. Therefore employment of such elements in simulating the footing-soil problem can model real problems.

The purpose of this study computer program has specially developed for this study in which the considered linear and non-linear finite and infinite elements of the model have implemented.

3. EFFECT OF DIFFERENT MODEL PARAMETERS ON ARCHED STRIP FOOTING - SOIL INTERACTION BEHAVIOR

For the analysis of arched strip footing-soil interaction problem, a finite-infinite element mesh has constructed as shown in Fig. (1-a) for the model, which has dimensions as shown in Fig. (1-b). Nonlinear performance has assumed for the strip footing material with a concrete compression strength sc = 300 kg/cm2 and allowable tensile concrete strength (st) = 10% of sc according to the ACI 318-11 code [15]. The minimum of steel reinforcement area has taken in R.C. arched strip footing. Parametric study has carried out to investigate the effect of different model parameters on the arched strip footing-soil interaction behavior. These parameters include the thickness (t), height (h) of the R.C&P.C arched strip footing, the vertical load on the strip footing (P) and the soil type respectively. The properties of these soils are presented in table 1.

A particular soil has defined by eight parameters: K, n, R**f**, C, Df to define the tangential modulus (E**t**), K**b** and mb to define the bulk modulus (B**t**). These parameters determine from the obtained results of conventional triaxial tests [11,12].

Where:

$$E_t=KP_a\,(\sigma_3/P_a)^n\,[1-(R_f\,(1-\sin\emptyset)(\sigma_1-\sigma_3)\,/\,2C\cos\emptyset+2\,\sigma_3\sin\emptyset]^2 \qquad (1)$$

σ_3 = Minimum principal stresses in compression.

σ_1 = Maximum principal stresses in compression.

P_a = Atmospheric pressure.
K = Modulus number, dimensionless.
n = Modulus exponent, typical range (-1.0 to 1.0).
R_f = Failure ratio, typical range (0.5 to 0.9).

$$(\sigma_1 - \sigma_3)_c / (\sigma_1 - \sigma_3)_u \quad (2)$$

C = Cohesion intercept, units as Pa.

$$Ø = Ø_0 - \Delta Ø \log_{10} [\sigma_3 / P_a] \quad (3)$$

f_o = Friction angle, radians.
D_f = Reduction in f for 10-fold increase in s3.

$$B_t = K_b P_a [\sigma_3 / P_a]^{m_b} \quad (4)$$

K_b = bulk modulus number (dimension-less)
m_b = bulk modulus exponent, typical range (0.0 to 1.0)

Figs. 2 & 3 show the normal stress (sx) contours (t/m^2) for P.C&R.C arched strip footing at ratios (t/B) = 0.1, (h/B)=0.2 (as recommended in [4]), for various values of vertical loads on silty clay and silty sand soil. It has noticed that the intensity of the stress contours have affected by the steel reinforcement, type of soil and the increasing of the applied load. This intensity decreases in R.C arched stripe footing by 20% lower than in case of plain concrete arched strip footing. However, the tensile normal stress increases as the vertical load increases up to failure, especially at the zone just under the bearing wall, because of the increase of the bending moment. The redistribution of stresses occurre at the beginning of cracking up to failure at P = 30 t/m' , p=40t/m in P.C.& R.C. arched strip footing resting on silty clay soil respectively and the starting for cracking increases at P = 40 t/m and P = 50 t/m when the soil became stiffer as shown in Figs. 4 & 5. From the above results the arched strip footing capacity increase to about 25% as the relative stiffness between strip footing and soil foundation increases. The vertical normal stress (sy) contours (t/m^2) in the two types of soil have plotted in Fig. 6 under the P.C. and R.C. arched strip footing. It has clear to case of R.C. arched strip footings,(sy) decreases up to 15% than in case of plain concrete arched strip footing as the soil became stiffer; due to the increase in the relative stiffness between the footing and the soil foundation.

For the P.C. and R.C. arched strip footing, the factor of safety of normal stress in concrete (F.O.S.) is expressed in a dimensionless form (tall t_{max} s / s) where tall s ha the allowable tensile strength given in the ACI 318-11 code [15] and t_{max} s has the maximum tensile normal stress at a studied section, as shown in Fig. 1-b. The factor of safety (F.O.S.) has plotted against the thickness-breadth ratio (t/B) & the height-breadth ratio (h/B) for the used two soil types as shown in Figs. 7 and 9. It has clearly indicated that the F.O.S. to increases as the (t/B) ratio increases and the soil becomes stiffer due to the increase in the relative stiffness between footing and soil. On the other hand, it has decrease from 10% to 50% as the vertical load increases as shown in Figs. 7 and 9. From Fig. 8 it has clearly indicated that the F.O.S slightly increase as the (h/B) ratio increase up to (h/B) = 0.2 either than, or because of it decreases the decrease in the arch effect and reduce the relative stiffness between footing and soil.

For the P.C. & R.C arched strip footing, the relation between the vertical load and the ratios (t/B) for the two soil types, at factor of safety equal 2 (as usually use in the traditional design method) and h/B = 0.2 has plotted in Figs. 10 as a design charts. It has shown that the minimum thickness-breadth (t/B) ratio at P = 50 t/m' have equal to 0.3 for P.C arched strip footing and (t/B) = 0.25 for R.C arched strip footing when it was changed the soil from sand to clay due to the relative stiffness between footing and the sand soil. Comparing this results with the results from references [3] it has found that the decrease in min. thickness breadth (t/B) ratio is about 30% i.e. the cost decrease to 30% in case of arched strip footing than in case of plane strip footing. From Fig. 10 the structural designers can use these charts to calculate P.C and R.C arched strip footing dimensions according to load capacity.

5. CONCLUSION

For using of P.C & R.C. arched strip footings as a foundation type of bearing walls structures have studied numerically by using the finite element method.

In this paper, a non-linear analysis of an arched strip footing and the underlying soil has performed. Various parameters which affect the R.C and P.C. concrete strip footing-soil interaction behavior have investigated, such as the thickness, height-breadth ratios of the R.C and P.C arched strip footing, the vertical load values on the bearing walls, and the soil type. Based on the proposed numerical analysis, a computer program has developed. The proposed results of analysis has showed the possibility for using plain concrete arched strip footing for bearing wall structures. The plain concrete arched strip footings were able to sustain the imposed vertical loads up to 50 t/m^2. The F.O.S. has increased as the (t/B) ratio increases and the soil becomes stiffer due to the increase in the relative stiffness between footing and soil. Comparing this results with the results from references [3] it is found that the decrease in min. thickness breadth (t/B) ratio has about 30% i.e. the cost decrease to 30% in case of arched strip footing than in case of plane strip footingT the present results of investigation has showed that the minimum safe thickness -breadth ratios of P.C&R.C. arched strip footing under P=50 t/m' load is (t/B) = 0.3 and 0.25 respectively at (h/B) =0.2 when change the soil from sand to clay due to the relative stiffness between footing and the sand soil. The Fig. 10 considers useful for the designers to design the P.C and R.C arched strip footings as a foundation system for bearing walls structures.

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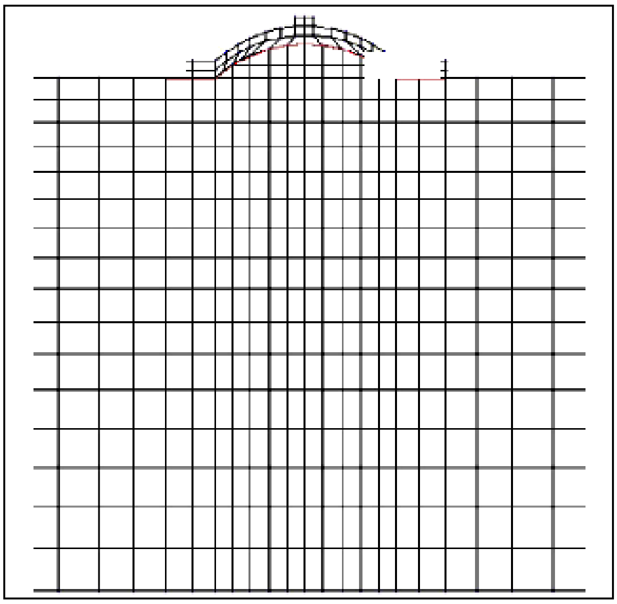
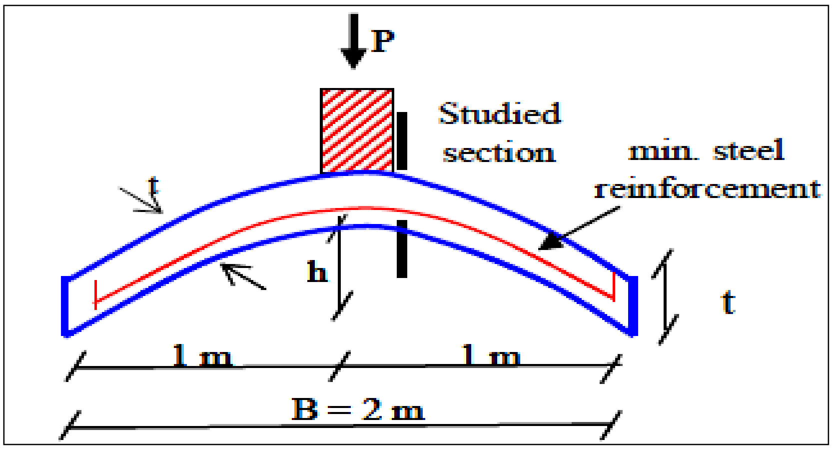
Table 1. Soil parameters for hyperbolic model proposed by (Duncan) [11, 12]

Unified classification	rc %	γ t/m^3	ϕ_0 deg	$\Delta\phi$ deg	C t/m^2	K	n	R_f	K_b	m_b
Silty sand	90	2.002	32	4	0.0	300	0.25	0.7	250	0
Silty Clay	85	1.922	30	0	0.488	60	0.45	0.7	50	0.2

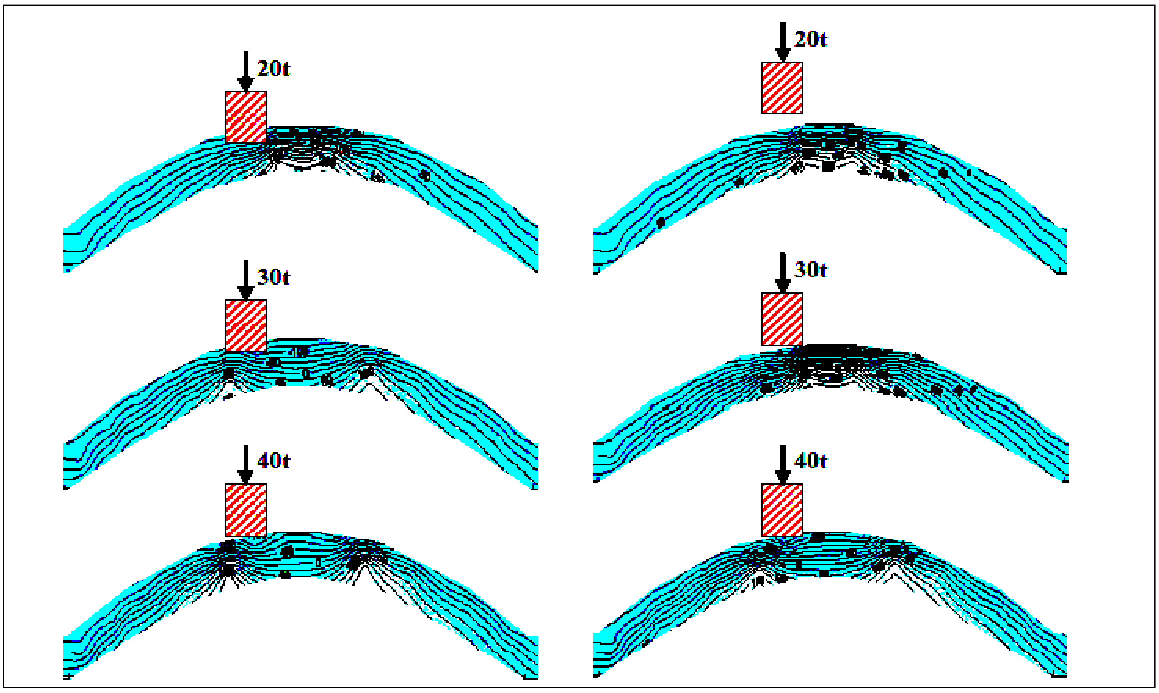
rc: Relative compaction.



(1-a)Proposed finite-infinite element mesh



(1-b) Dimension of P.C and R.C arched strip footing.
Fig. 1. Dimensions and layout of the arched strip footing.



(2-a) P.C. arched strip footing (2-b) R.C. arched strip footing

Fig. 2. Effect of load increasing on the normal stress (sx) contour in R.C. & P.C arched strip footing at ratio (t/B) = 0.1, (h/B) = 0.2 and silty clay soil.

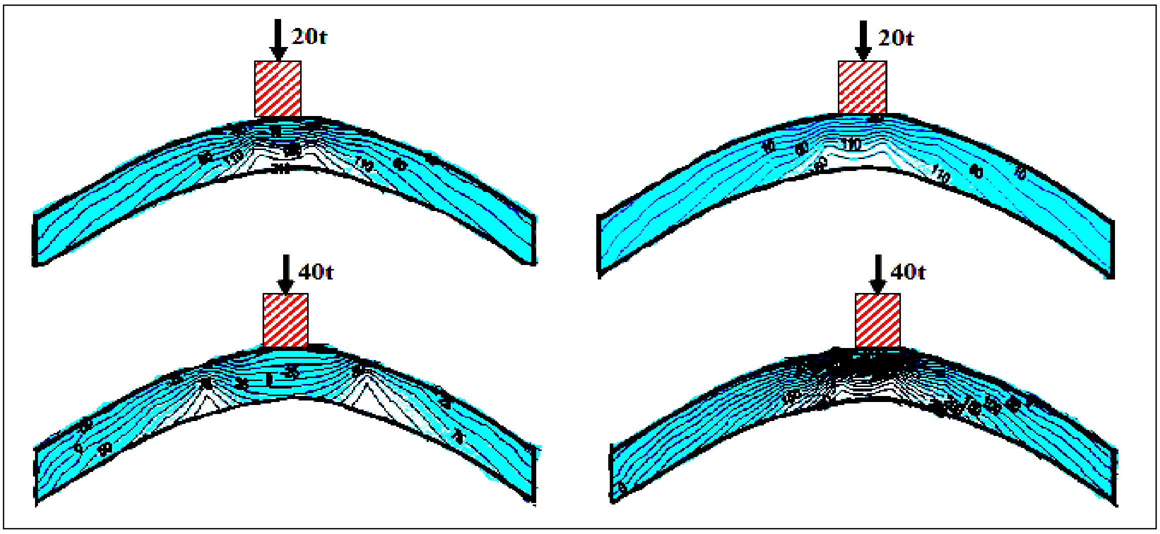
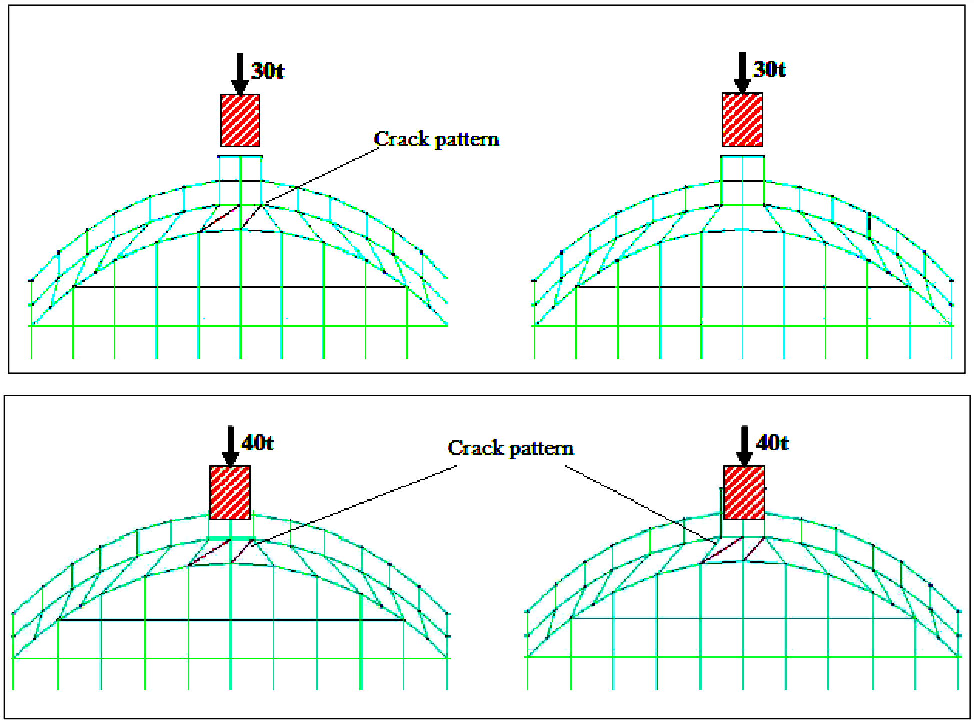
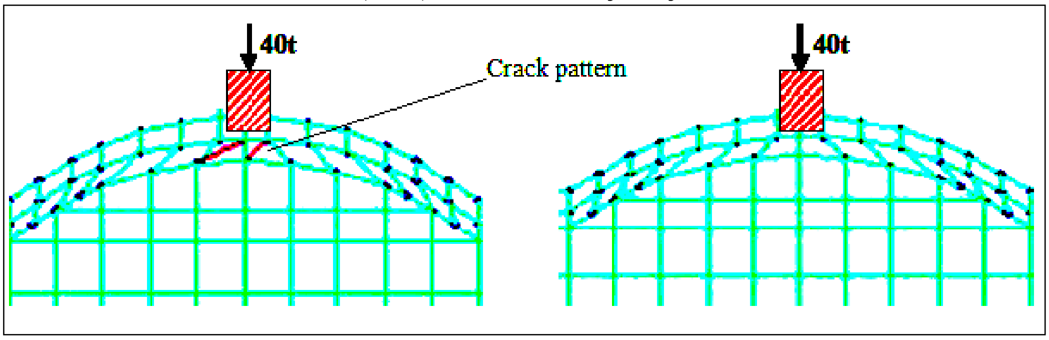


Fig. 3. Effect of load increasing on the normal stress (sx) contour in R.C. & P.C arched strip footing at ratio (t/B) = 0.1, (h/B) = 0.2 and silty sand soil.



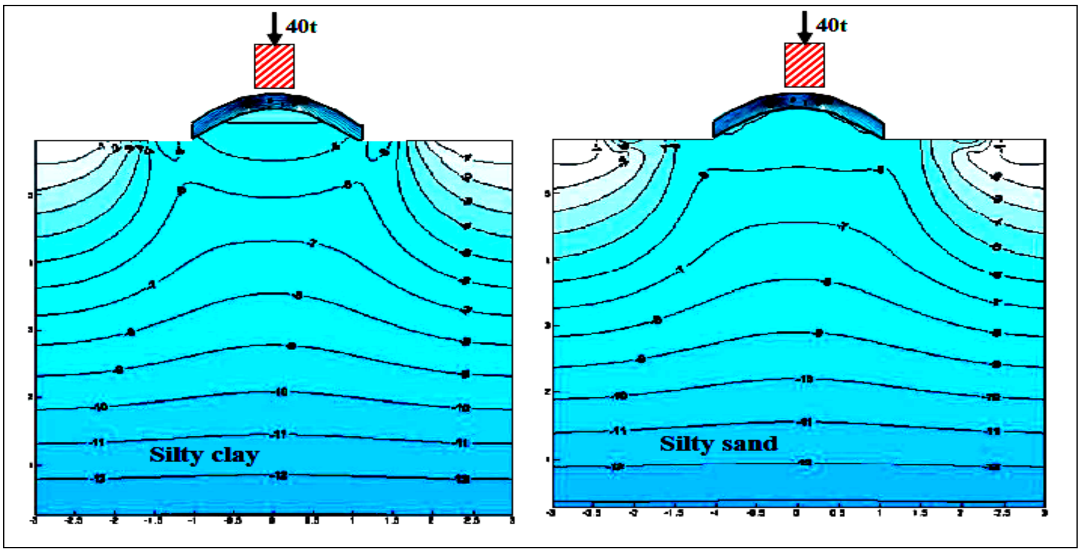
(4-a) P.C. arched strip footing (4-b) R.C. arched strip footing

Fig. 4. Crack pattern for P.C. & R.C. arched strip footing for different loads at ratio (t/B) = 0.1 ,(h/B) = 0.2 and silty clay soil.

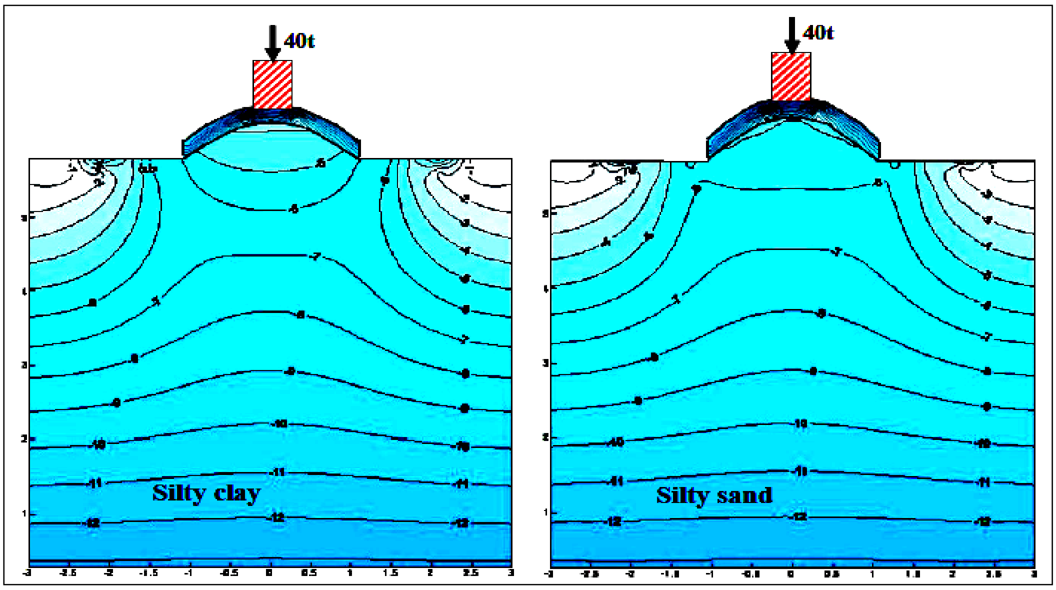


(5-a)P.C. arched strip footing (5-b)R.C. arched strip footing

Fig. 5. Crack pattern for P.C. & R.C. arched strip footing for different loads at ratio (t/B) = 0.1 ,(h/B) = 0.2 and silty sand soil.

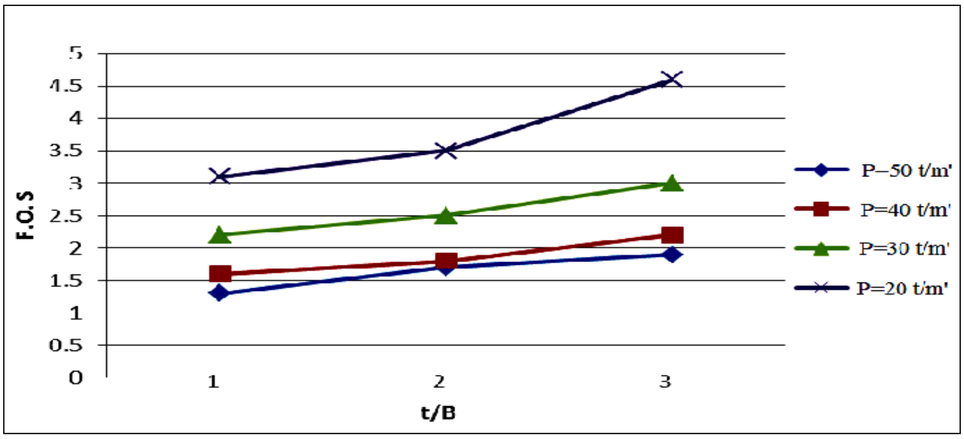


(6-a) P.C. arched strip footing

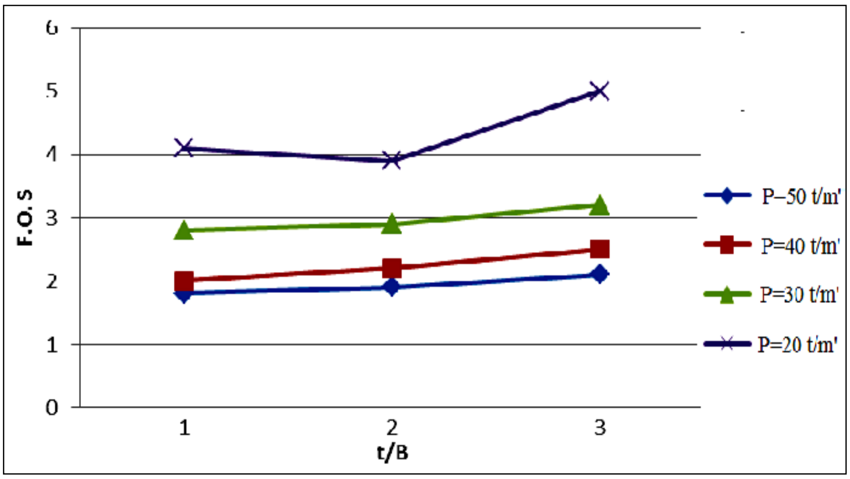


(6-b) R.C. arched strip footing

Fig. 6. Effect of type of soil on the vertical stress (sy) contours under the P.C. & R.C arched strip footing at P = 40 t/m, (t/B) = 0.1 &(h/B) = 0.2.

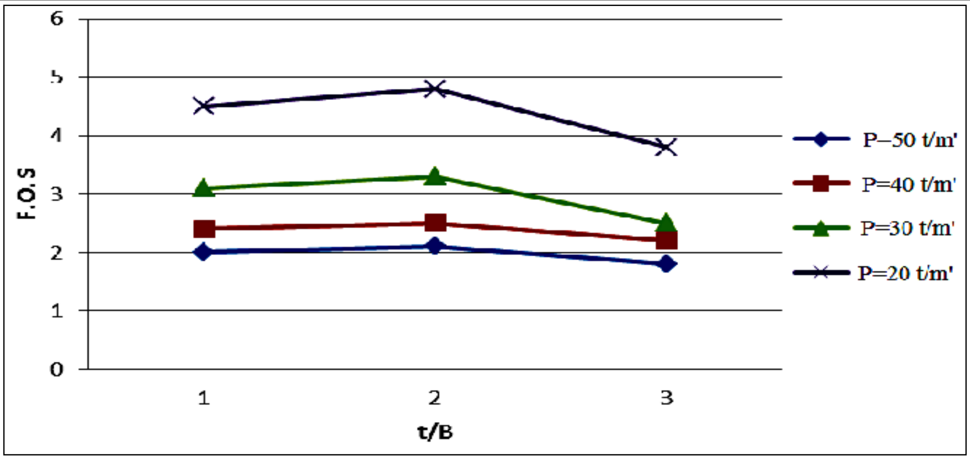


a) Silty-Clay

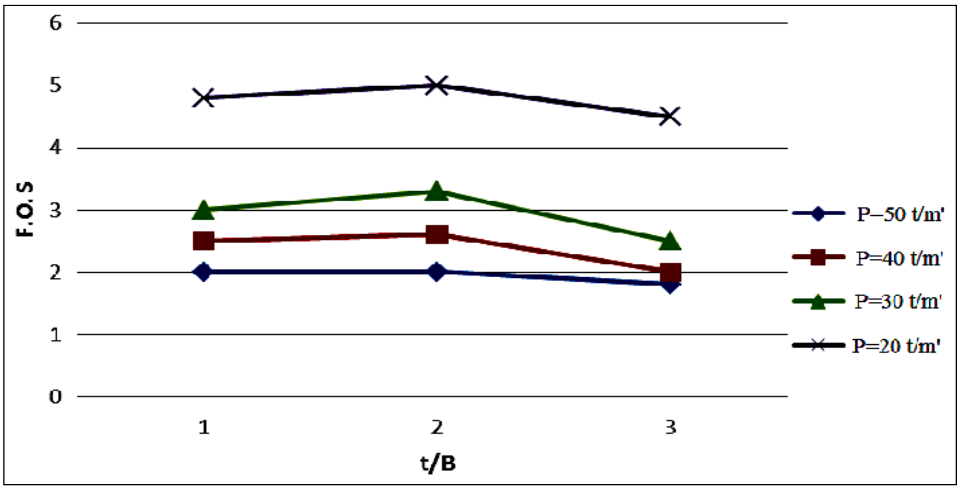


b) Silty-Sand

Fig. 7. Effect of thickness-breadth (t/B) ratio of P.C footing on the F.O.S at different load values for the two types of soil for (h/B = 0.2).

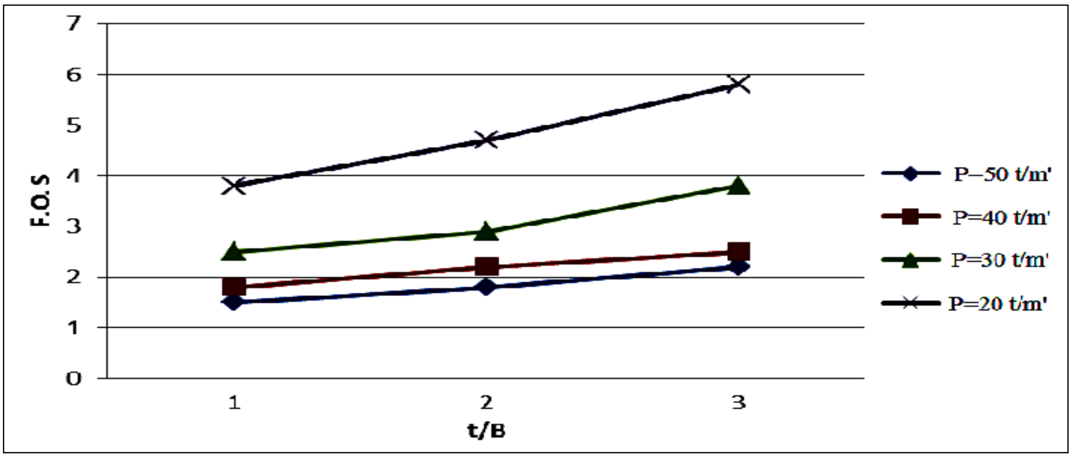


a) Silty – Clay

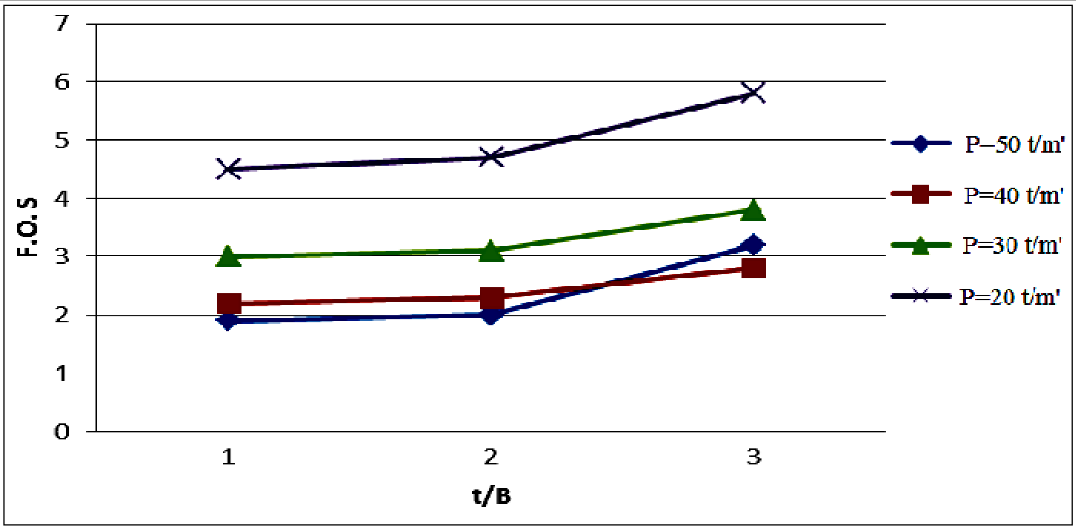


b) Silty-Sand

Fig. 8. Effect of height-breadth (h/B) ratios of P.C footing on the F.O.S at different load values for the two types of soil for (t/B=0.3).

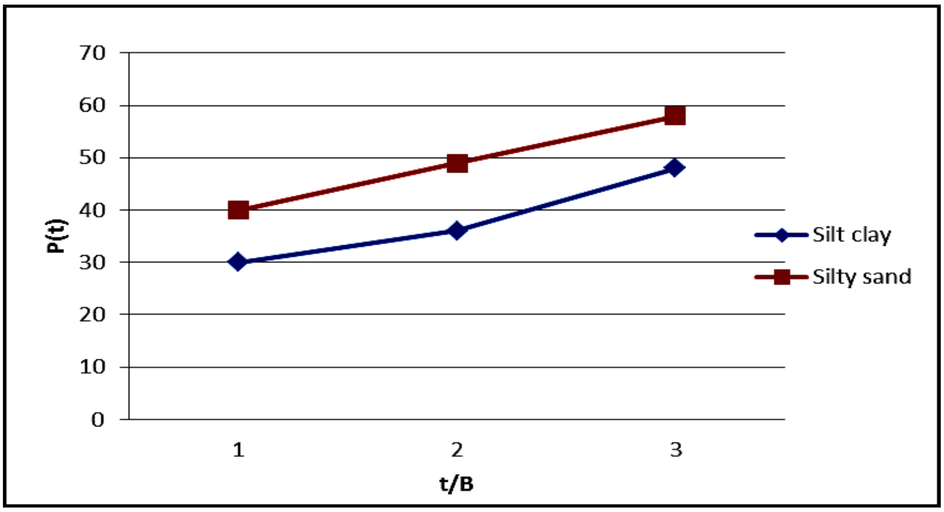


a) Silty- Caly

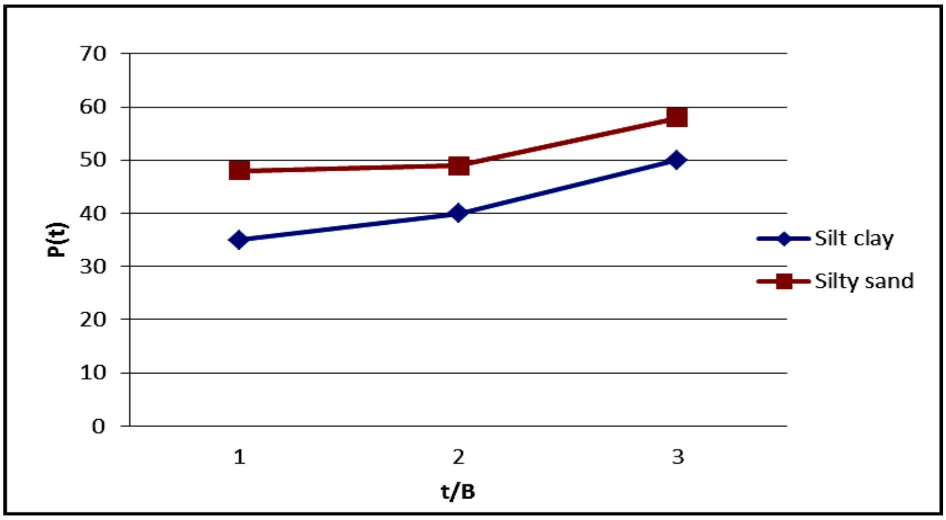


b) Silty- Sand

Fig. 9. Effect of thickness-breadth (t/B) of R.C arched strip footing ratios on the F.O.S at different load values for the two types of soil at h/B = 0.2.



a)**P.c**



b)**R.c**

Fig. 10. Relation between load (P) and (t/B) ratios at t/B = 0.2 for to types of soil at factor of safety=2.

تحليل السلوك للاسس المقوسة

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الخلاصة:

المنشأت المتكونه من الجدران ليس بالضرورة ان تستند فقط على اسس من الكونكرت المسلح المستوية المفردة ولكن يمكن ان تستند على الاسس الكونكرتية المسلحة و الغير مسلحة المقوسة. و في هذا البحث كان الهدف دراسة الاسس الكونكرتية المسلحة و الغير مسلحة المقوسة تحت المنشأت كأسلوب بديل لتقليل التكاليف. وتم دراسة تأثير التربة الطينية و الرملية على الاساس بستخدام العناصر المحددة. اهداف هذا البحث هي تحليل الاسس الكونكريتية المسلحة و الغير مسلحة كطريقة بديلةللاسس العادية.

تم دراسة تاثير نوع التربة و مواصفات الاساس من حيث السمك و عرض و ارتفاع القوس على مدى تحمل الاساس المقوس. ثم التحليل اللاخطي للاساس المقوس المفرد و التربة و منطقة الاتصال بين التربة و الاساس باستخدام العناصر المحددة. ثم اخذ بعين الاعتبار التحليل اللاخطي لمادة و خواص الكونكريت و دراسة الاجهادات الداخلية و الشقوق المتولدة من جراء الحمل. ثم استخدام طريقة Duncan-Mohr-Coulomb Modified لتحليل سلوك الترب و المقارنة بالطرق التقليدية المستخدمة بتصميم الاسس.

المخططات التصميمية توضح ان الاسس الكونكريتية المقوسة المسلحة و الغير مسلحة تكون نسبة الكلفة اقل من الاسس التقليدية. حيث ان سمك الاساس المستخدم بالنسبة للعرض يكون بين 0,1 و 0,2, الى 0,3 و ارتفاع قوس الاساس المفرد يكون كنسبة من العرض الاساس من 0,1 و 0,2 و 0,3 ثم استخدام اربع انواع احمال من (20و30و40و50) طن/م^2 من اجل التحليل الاساس. ثم استخدم نوعين من التربة رملية و طينية و معرفة التربة القوية و الضعيفة.

والنتائج توضح ان الكلفة تقل بنسبة 30% من الاسس التقليدية مع المحافظه على قوة تحمل الاساس.