# Behavior of Arched Strip Footings under Bearing Walls Structures

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**ABSTRACT:** The construction of bearing walls structures does not necessarily require using reinforced concrete plane strip footings, but these structures can be constructed using arched plain and reinforced concrete strip footings. This paper aims at analyzing plain and reinforced concrete arched strip footings, as foundation system of bearing walls structures, as an alternative solution to reduce the construction cost 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 were studied 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 was implemented. A computer program was developed to model the arched strip footing-soil installation. The material and geometrical non-linearity of the concrete strip footing taking into account the non-linear stress-strain relation of concrete and presence of cracking were also considered. In addition, Duncan-Mohr-Coulomb Modified model was used 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 were proposed and presented for structural designers in order to calculate arched P.C & R.C strip footing dimensions according to soil type and vertical load for such strip footings which considerably cost less than traditional bearing walls construction system.
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**Keywords:** Structural design, Plain and reinforced concrete, Arched Strip footing, Non linear - Finite element

## 1. Introduction

The continuous increase in population, in addition to housing problems in Egypt led to a considerable demand for construction and consequently, an increase in the construction cost of new structures. 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, which have been already used in Egypt may contribute in the reduction of construction cost. The bearing walls system decreases the amount of used steel in R.C. foundations. Strip footings are commonly of reinforced concrete and sometimes of brick or stone laid just under the walls of older buildings. Previous researches have described the influence of interaction between reinforced and plain concrete plane, arched and 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 of using R.C and P.C. arched strip footing dimensions and the increase of its supported vertical loads on the internal stresses of strip footing and soil stresses were considered. Soil-structure interaction will be considered through the use of finite element analysis of both P.C. and R.C arched strip footing and soil beneath it, taking into consideration the non-linearity of concrete and the soil by using Duncan-Mohr-Coulomb Modified Model [9-12].

## Finite Element Model

In the present paper, different types of elements were used to model the problem in order to obtain the internal stresses and crack pattern in the arched strip footing and stresses in the foundation soil. The bar element was used to model the steel reinforcement. A simple bilinear stress-strain curve is 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 were used in two cases. The first one was used 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 is a linear, elastic and brittle material in tension, and elasto-plastic in compression. The concrete has a very limited capacity in resisting tension, and is therefore allowed to crack when the principle stresses exceed the permissible tensile stress ($\sigma_t$). The second type of element was used to model the soil media, taking into consideration the non-linearity 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. A computer program was developed specially for this study in which the considered linear and non-linear finite and infinite elements of the model were implemented.

**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 was constructed as shown in Fig. (1-a) for the model, which has dimensions as shown in Fig. (1-b). Non-linear performance was assumed for the strip footing material with a concrete compression strength $\sigma_c$ = 300 kg/cm$^2$ and allowable tensile concrete strength ($\sigma_t$) = 10% of $\sigma_c$ according to the Egyptian code [15]. The minimum of steel reinforcement area is taken in R.C. arched strip footing.

Parametric study was carried out to investigate the effect of different model parameters on the arched strip footing-soil interaction behavior. These parameters include the thickness (t) and 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 thickness of strip footing was expressed 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') were investigated in the analysis. Two types of soil; silty clay, and silty sand were considered in this study to represent the cases of weak and stiff soil. The properties of these soils are presented in table 1. A particular soil is defined by eight parameters: K, n, $R_f$, C, $\phi_o$ and $\Delta\phi$ to define the tangential modulus ($E_t$); and $K_b$ and $m_b$ to define the bulk modulus ($B_t$). These parameters are determined from the obtained results of conventional triaxial tests [11 & 12].

Where:

$$E_t = KP_a\left(\frac{\sigma_3}{P_a}\right)^n\left[1-\frac{R_f(1-\sin\phi)(\sigma_1-\sigma_3)}{2C\cos\phi+2\sigma_3\sin\phi}\right]^2 \quad (1)$$

$\sigma_3$ = Minimum principal stresses in compression.
$\sigma_1$ = 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).

$$= \frac{(\sigma_1-\sigma_3)_f}{(\sigma_1-\sigma_3)_u}.$$

C = Cohesion intercept, units as $P_a$.

$$\phi = \phi_\circ - \Delta\phi\log_{10}\left(\frac{\sigma_3}{P_a}\right).$$

$\phi_o$ = Friction angle, radians.
$\Delta\phi$ = Reduction in $\phi$ for 10-fold increase in $\sigma_3$.

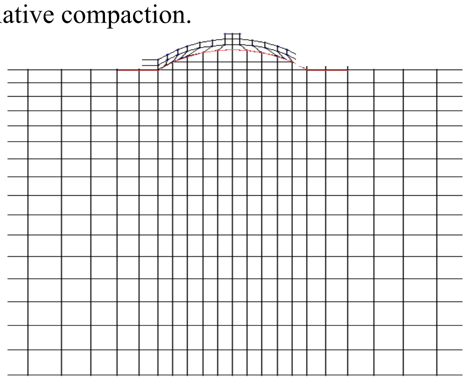
$$B_t = K_b P_a\left(\frac{\sigma_3}{P_a}\right)^m \quad (2)$$

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

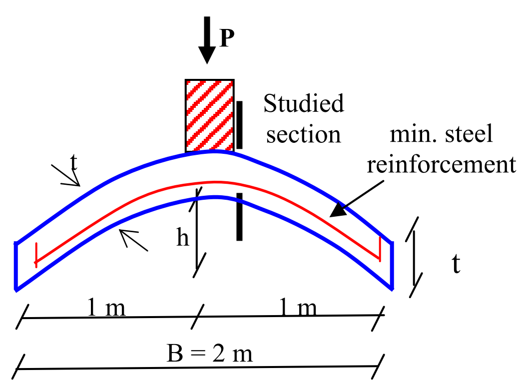
**Table 1:** Soil parameters for hyperbolic model proposed by (Duncan) [11&12]

| Unified classification | rc % | $\gamma$ t/m$^3$ | $\phi_0$ 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.

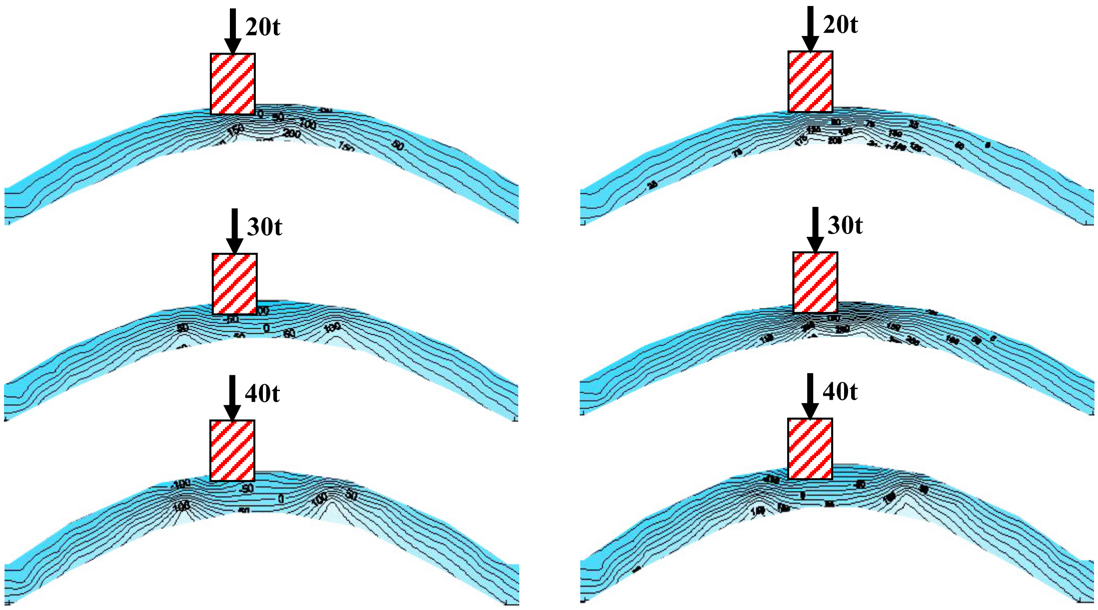


(1-a)Proposed finite-infinite element mesh



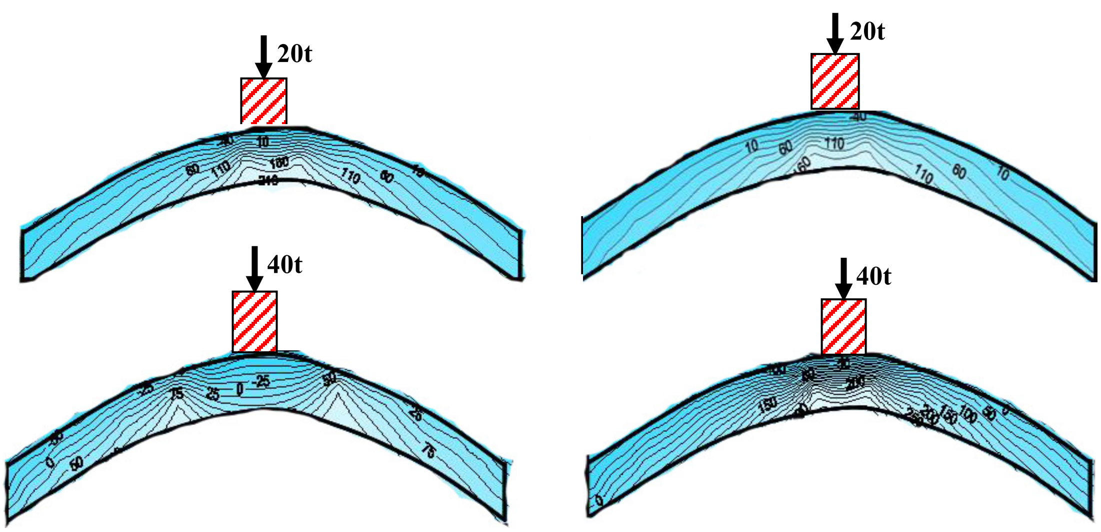

(1-b) Dimension of P.C and R.C arched strip footing.

**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 ($\sigma_x$) contour in R.C. & P.C arched strip footing at ratio (t/B) = 0.1, ( h/B) = 0.2 and silty clay soil.

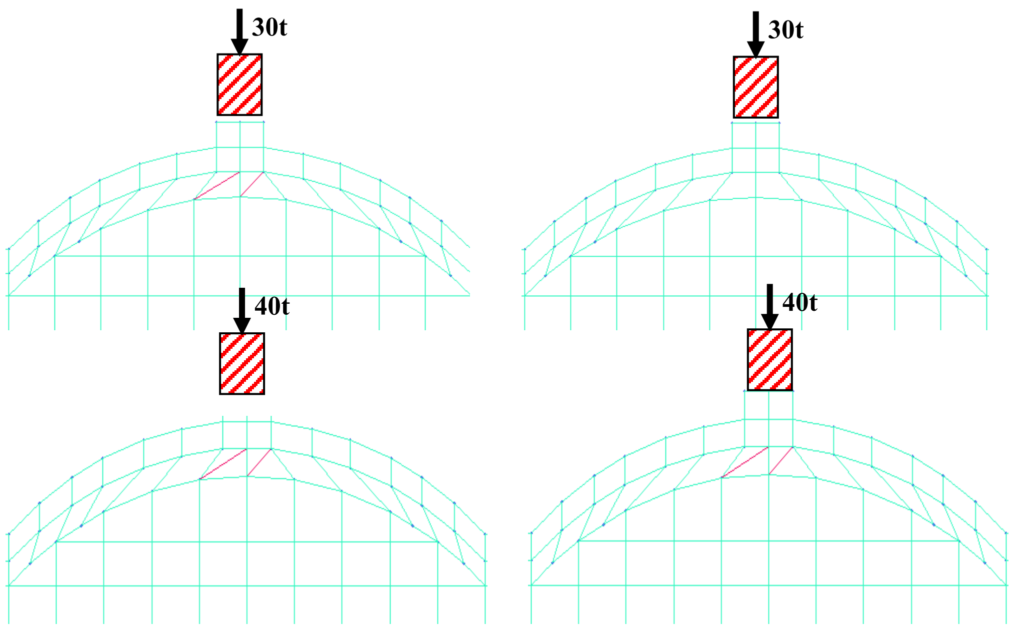



(3-a) P.C. arched strip footing (3-b) R.C. arched strip footing

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

**Results and Discusions**

Figs. 2 & 3 show the normal stress ($\sigma_x$) contours (t/m$^2$) for P.C&R.C arched strip footing at ratios (t/B) = 0.1 and (h/B)=0.2 (as recommended in [4] ), for various values of vertical loads on silty clay and silty sand soil. It is noticed that the intensity of the stress contours are 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 occurred at the beginning of cracking up to failure at P = 30 t/m' and p=40t/m in P.C.& R.C. arched strip footing resting on silty clay soil respectively and the beginning of cracking increases at P = 40t.m and P = 50t/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($\sigma_y$) contours ($t/m^2$) in the two types of soil are plotted in Fig. 6 under the P.C. and R.C. arched strip footing. It is clear that, in case of R.C. arched strip footings,($\sigma_y$) 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.

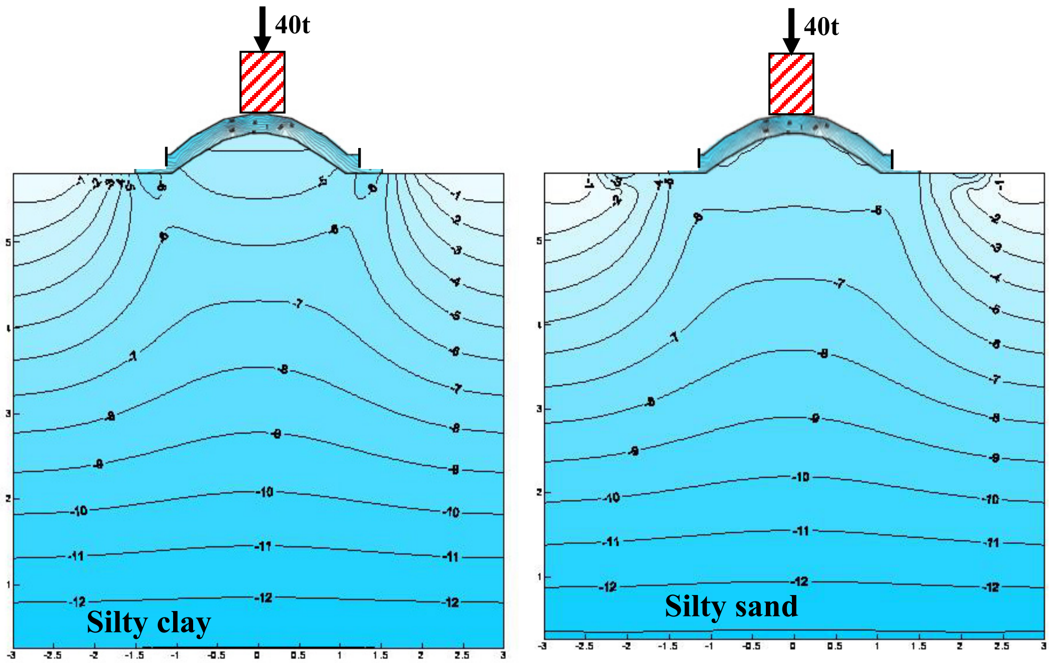



(4-a)P.C. arched strip footing (4-b)R.C. arched strip footing

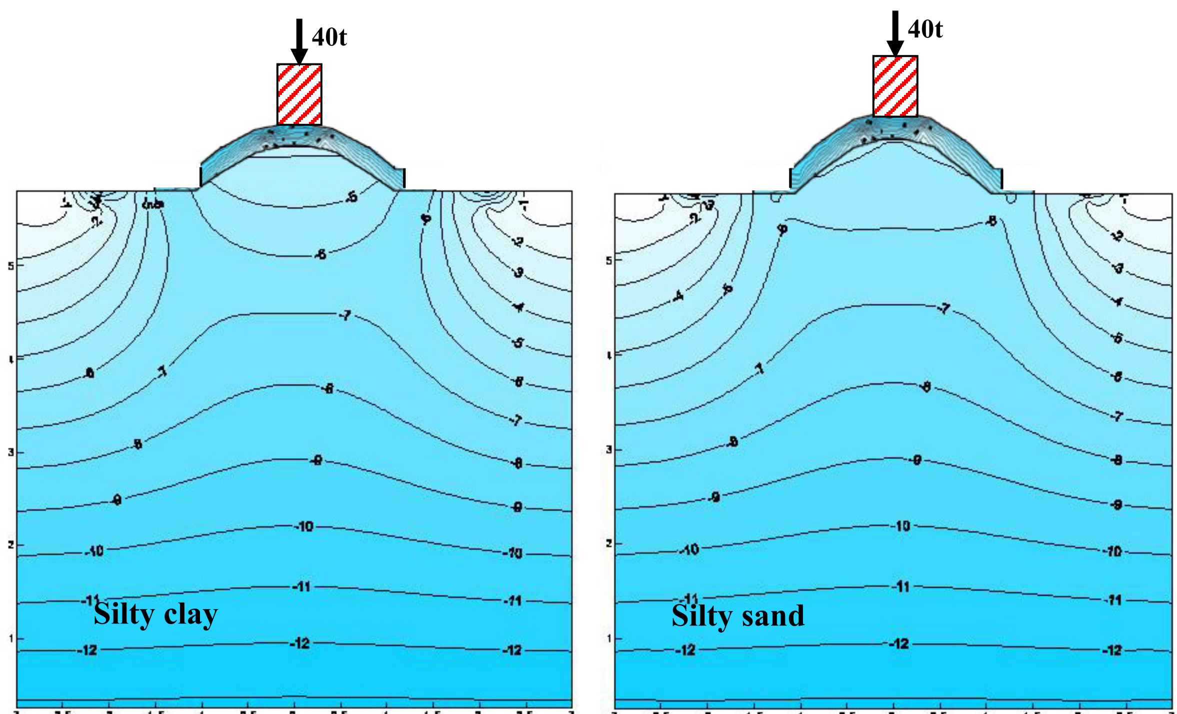
**Fig. 4.** Crack pattern for P.C. & R.C. arched strip footing for different loads at ratio (t/B) = 0.1 ,( h/B) = 0.2 and silty clay soil.


(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 ($\sigma_y$) contours under the P.C. & R.C arched strip footing at P = 40 t/m, (t/B) = 0.1 &( h/B) = 0.2.

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 ($\sigma_{t_{all}} / \sigma_{t_{max}}$) where $\sigma_{t_{all}}$ is the allowable tensile strength given in the Egyptian code [15] and $\sigma_{t_{max}}$ is the maximum tensile normal stress at a studied section, as shown in Fig. 1-b. The factor of safety (F.O.S.) is 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- 9. It is clearly indicated that the F.O.S. 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 decreases from 10% to 50% as the vertical load increases as shown in Figs. 7 - 9. From Fig. 8 it is clearly indicated that the F.O.S slightly increased as the (h/B) ratio increase up to (h/B) = 0.2 then it decreases because of the decrease in the arch effect.

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 used in the traditional design method) and h/B = 0.2 is plotted in Figs. 10 as a design charts. It is shown that the minimum thickness-breadth (t/B) ratio at P = 50 t/m' are equal to 0.3 for P.C arched strip footing and (t/B) = 0.25 for R.C arched strip footing. Comparing this results by the results from references [3] it is 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 the above charts the structural designers can use this charts to calculate P.C and R.C arched strip footing dimensions according to load capacity.

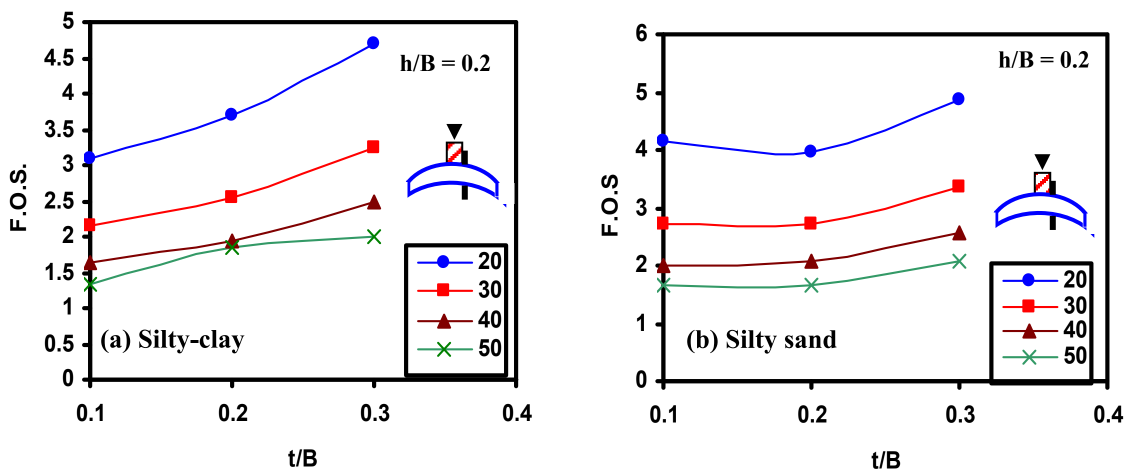



**Fig. 7.** Effect of thickness-breadth (t/B) ratio of P.C footing on the F.O.S at different load values for the two types of soil.

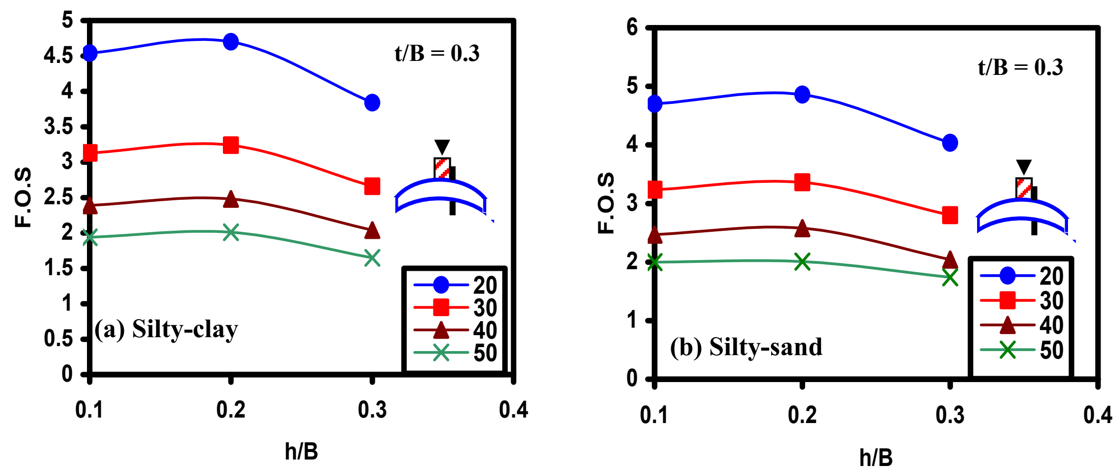



**Fig. 8.** Effect of height-breadth (h/B) ratios of P.C footing on the F.O.S at different load values for the two types of soil.

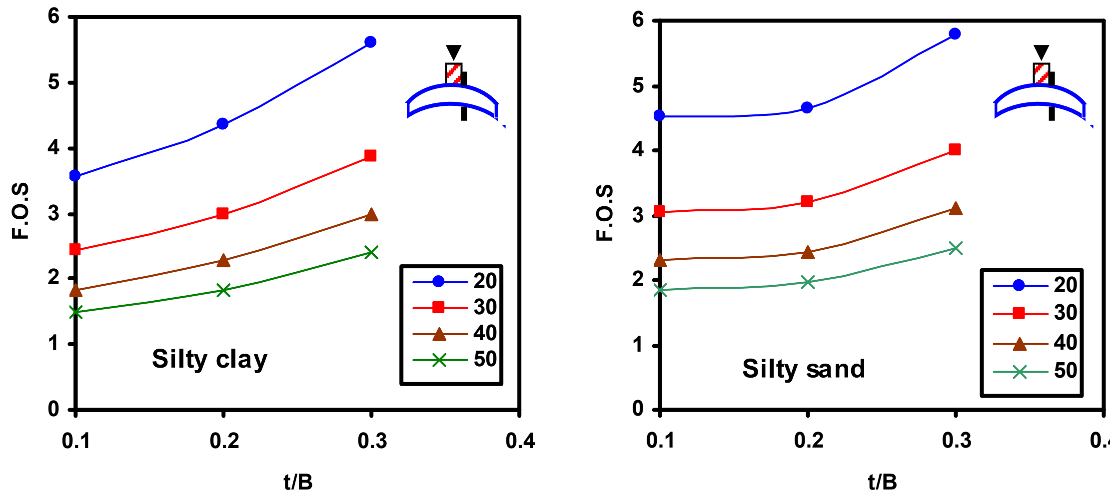



**Fig. 9.** Effect of thickness-breadth (t/B) of R.C arched strip footing ratios on the F.O.S at different load values for the two types of soil at h/B = 0.2.

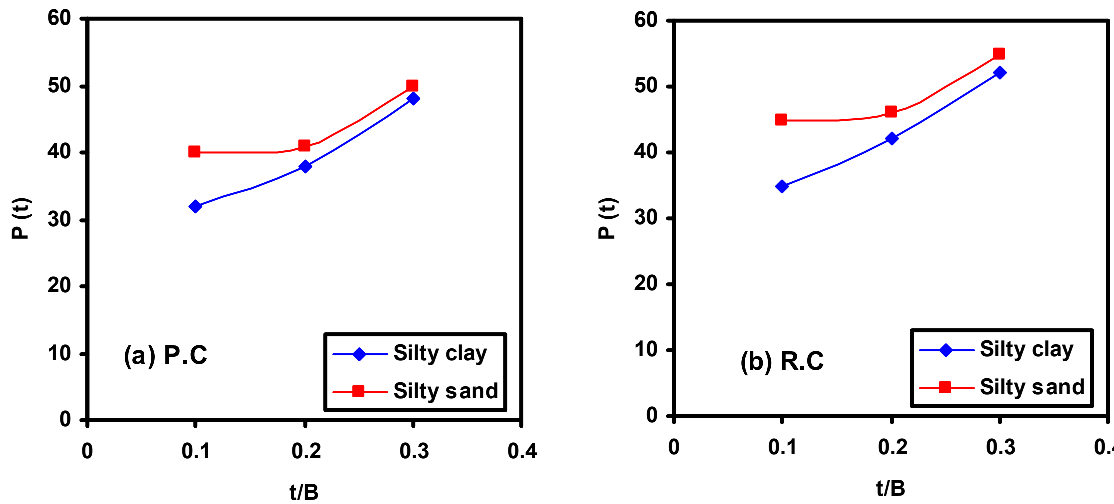



**Fig. 10.** Relation between load (P) and (t/B) ratios at t/B = 0.2 for to types of soil at factor of safety=2.

**Conclusion**

Using of P.C & R.C. arched strip footings as a foundation type of bearing walls structures were studied numerically using the finite element method. In this paper, a non-linear analysis of an arched strip footing and the underlying soil is performed. Various parameters which affect the R.C and P.C. concrete strip footing-soil interaction behavior have been investigated, such as the thickness and 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 been developed.

Results of the proposed analysis showed the possibility of 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 . This result could lead to exceptionally low cost up to 30% and safe structures than in case of plane strip footing.

Results of the present investigation 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 at factor of safety 2 according to Egyptian code E.C.P.205-2007.

The charts in Fig. 10 are 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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**References**


1. Roy R., K. Bhattacharya and S.C. Dutta, 2005."*Behavior of Grid Foundation under static Gravity Loading*" IE (I) Journal. Cr. 85, pp. 261-268
2. Huat B.B.K, , T.A. Mohammed, A.A.A. Abang Aly and A.A. Abdullah, 2007. "Numerical and field study on triangular shell footing for low rise building" International Journal of Eng. and Technology,4,( 2):194-204,.
3. Abdel-Salam S.S., E.A. Elshamy and H.E. ABd-**El**-Mottaleb, 2008. "*Analysis of Plain Concrete Strip Footings as a Foundation of Bearing Walls Structures*". Ain Shams Journal of Civil Engineering A S J C E, 2(1): 1-12
4. Eman A El-Shamy and Sayed abdel-Salam, 2002. "*Non Linear Analysis of Arched Strip Footing*", Military Technical College. International Conf. on Civil Eng and Arch. Eng, 4th ICCAE Conf. 16-19 May.
5. Nainan P. Kurian and VM Jayakrishna Devaki, 2005. "*Analytical Studies on the Geotechnical Performance of Shell Foundations*", Can. Ceotech. J. 42(2): 562-573.
6. Abdel-Salam, S. S., 1989. "*Analysis of Reinforced Folded Strip Footing*", Third Arab Structural Eng. Conf, U.A.E.
7. Adel Hanna and Mohamed Abdel-Rahman , 1998. *"Experimental Investigation of Shell Foundations on Dry Sand*". Can Geotech. J. 35(5): 847-857,.
8. Adel Hanna and Mohamed Abd EL-Rahman, 1990. "*Ultimate Bearing Capacity of Triangular Shell Strip Footings on Sand*". (ASCE) Journal of Geotechnical Engineering, 116,(12): 1851-1863
9. Hanaa E. Abd-Elmottaleb,2005. "*Earthquake Nonlinear Modeling of R.C. Buildings Including Foundation-Soil Interaction*", Ph.D. Thesis, Structural Eng. Dept. Zagazig University.
10. Smith, I.M. and Groiffiths, D.V., "*Programming the Finite Element Method*", John Wiley and Sons Inc., New York, 1988.
11. Duncan, J. M., Byrne, P., Wong, K. S. and Mobry, P., 1978. "*Strength, Stress-Strain and Bulk Modulus Parameters for Finite Element Analysis of Stresses and Movement in Soil Masses*", Report N°. UCB/GT/78-02, Department of Civil Engineering, University of California, Berkeley, Co..
12. Duncan, J.M., 1980. "*Hyperbolic Stress-Strain Relationships. Proc. of Workshop on Limit Equilibrium, Plasticity and Generalized Stress-Strain In Geotech Eng*". McGill Univ. May 28-30.
13. Angelou, T. A., 1991. "*Infinite Element-Theory and Applications*", J. Computers and Structures, 41(5): 959-962.
14. Zeinkiwiez, O.C., 1977."*The Finite Element Methods*", 3rd Edition, McGraw-Hill, London,.
15. Egyptian Code of practice and design for concrete. Structures ECP-203. 2007, The Housing and Building National Research Center of Egypt, ECP 203-2007, Cairo, Egypt.


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