Numerical and Experimental Analysis of R.C. Strip Footings

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ABSTRACT: Unlike most structures, the construction of bearing walls structures does not necessarily require using a lot of steel in reinforced concrete strip footings, but these structures can be constructed using light steel reinforcement. This paper aims at analyzing reinforced concrete strip footings with light steel reinforcement, as foundation system of bearing walls structures, which are widely used in Egypt, as an alternative solution to reduce the construction cost of buildings. In this paper, the effect of load value on the dimensions and capacity of strip footings is studied numerically and experimentally. A numerical model for the non-linear analysis of strip footing-soil interaction problem based on the finite and infinite element was implemented. A computer program was developed to model the strip footing-soil system. The material's non-linearity of the reinforced concrete strip footing taking into account the non-linear stress-strain relation of concrete. In addition, The Modified Duncan-Mohr-Coulomb model was used to simulate soil non-linearity. The obtained numerical results were compared with the experimental results and a good agreement was observed. Design charts are proposed and presented for structural designers in order to calculate R.C. strip footing dimensions according to load capacity.

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INTRODUCTION

The demand to construct economic structures increases to solve the housing problem in Egypt. The solution of this problem requires using innovative and untraditional ideas and techniques such as using a bearing wall construction system with reinforced concrete strip footings with light steel reinforcement, which are commonly used in Egypt. A vital element in promoting the return back to the bearing walls system is decreasing the amount of the used steel in R.C. foundations. The design of safe and economical footings depends manly on the knowledge of the actual contact pressure distribution as well as the internal stresses developed [1].

Previous researches studied the influence of interaction between reinforced and plane concrete strip footings and soil beneath it on the distribution of contact pressure and internal stresses [1-11]. However, in the present paper, the effect of dimensions of the R.C. strip footing with light steel reinforcement, on the capacity of the strip footings were considered. Soil-structure interaction will be considered through the use of finite element analysis of both the R.C. strip footings and the soil beneath it, taking into consideration the non-linearity of concrete and the underneath soil by using Duncan-Mohr-Coulomb Modified Model [12-17].

EXPERIMENTAL PROGRAM

A series of experiments were performed in the present study to investigate the influence of the dimensions of strip footings with light steel reinforcement on their capacity.

Description of specimens:

Details of the concrete specimens used in the present investigation were illustrated in reference [11]. Each specimen having dimensions as shown in Fig.1, was reinforced with 4ϕ8 mm normal mild steel as the main reinforcement, while 4ϕ6 mm were used as the secondary reinforcement.

The proportions of the concrete mixture by weight were 1 (cement): 3.8 (gravel): 1.75 (sand): 0.55 (water). The 28-day concrete compressive strength and elastic modulus of the concrete were 300 kg/cm^2 and 255 x 10^3 kg/m^2, respectively.

Elastic light timber pieces resting on large casted base were used to simulate the elastic soil. Any details of the test set-up were illustrated in reference [11].

Effect of model parameters on the strip footing behavior:

In this research parametric study was carried out to investigate the effect of different model parameters on the strip footing bearing capacity. These parameters include the model thicknesses (t) and (t_p) as shown in Fig. 1 and Table 1.

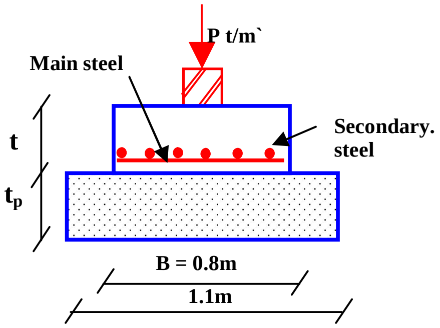


Fig. 1: Typical dimensions of the tested model.

Tested strip footings with different dimensions were subjected to gradually increasing vertical load up to failure.

Table 1. Details and dimensions of the tested models

No	**t (m)**	**t_p(m)**	**B(m)**	**t/B**
M1	0.15	0.15		0.1875
M 2	0.2	0.15		0.25
M 3	0.25	0.15	0.8	0. 3125
M 4	0.3	0.15		0. 375
M 5	0.35	0.15		0.4375
M 6	0.40	0.15		0.5
M 7	0.45	0.15	0.8	0.5625
M 8	0.5	0.15		0.625
M 9	0.15	0.2		0.1875
M 10	0.2	0.2	0.8	0.25
M 11	0.25	0.2		0.3125

Figures 2 and 3 show that the ultimate ($P_{u)}$ and failure ($P_{f)}$ load are affected by the thickness-breadth (t/B) ratio which increase as (t/B) ratio increases due to increasing the stiffness of strip footing. The value of P_u increases up to 10% as t_p increased due to increase the relative stiffness between the strip footing and the soil foundation as shown in Fig 3.

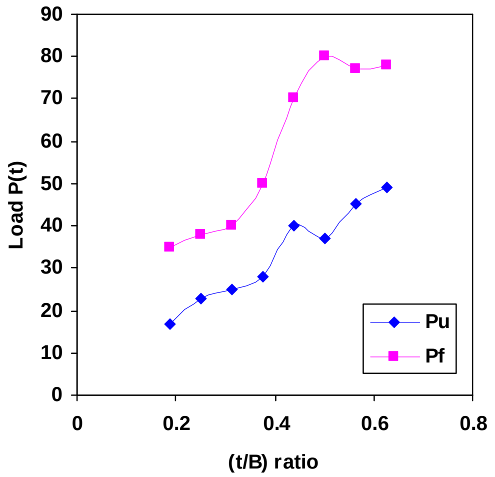


Fig. 2. Effect of thickness-breadth (t/B) ratios on the capacity of the tested R.C strip footing.

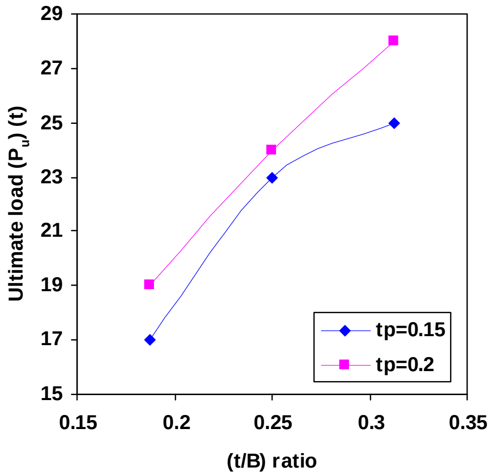


Fig. 3. Effect of thickness-breadth (t/B) ratios on the capacity of tested R.C. strip footing at the change of (t_p) thickness.

PROPOSED FINITE ELEMENT MODEL

In the present study, F.E.M. is used with different types of elements to model the problem in order to obtain the internal stresses and crack pattern in the tested strip footings as well as stresses in the foundation soil. The bar element was used to simulate the steel reinforcement. A simple bilinear stress-strain curve is used to model steel reinforcement.

Plane strain isoparametric 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 [12&13]. 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 as shown in Fig (4).

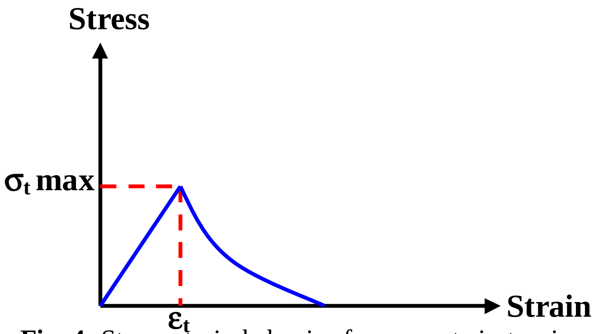


Fig. 4: Stress-strain behavior for concrete in tension.

The second type of elements was used to model the soil media, taking into consideration the non-linearity of soil by using Modified Duncan-Mohr-Coulomb Model [12, 13 & 14]. The application of Duncan model in representing the soil media makes deficient modeling of soil behavior in tension ignores soil stiffness [14]. Mohr-Coulomb model is better in representing the behavior of soil in tension by performing redistribution of stresses; it has the drawback of assigning the same stiffness to the soil allover the whole analysis. Thus, a modified procedure is suggested to combine the merits of both models and overcome their drawbacks. This proposed procedure uses the relations of Duncan [14 & 15] when the soil is in compression, that means the stiffness is varied according to the state of stresses, but when the soil satisfies the failure criteria the model redistributes the stresses according to Mohr-Coulomb model.

Proceeding on the solution for displacements and stresses, the element having state of stresses outside the failure's envelope is treated, as shown in Fig. (5), as an elastic-perfectly plastic material. The Mohr-Coulomb is accounted for according to Equ. (1). Values of redistribution loads are then added to the loads of the next increment as follows:

$$F = \sigma_m \sin\phi + \sigma` \left(\frac{\cos\ \theta}{\sqrt{3}} - \frac{\sin\theta \sin\phi}{3} \right) - C\cos\phi \tag{1}$$

Where:

F= Failure criterion, dimension as stresses.

ϕ = Friction angle, degree.

σ_m = Mean stress,

$\sigma`$ = Deviator stress,

θ = The lode angle which measure of the angular position of stress point.

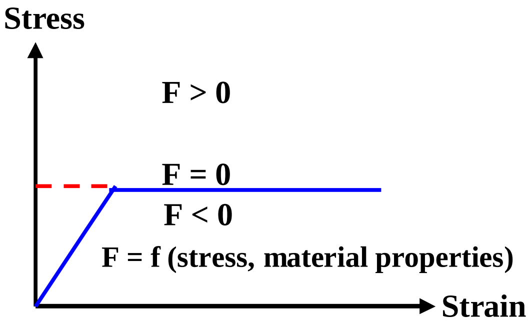


Fig. 5: Elastic-perfectly plastic stress-strain behavior.

Finally, the outer boundaries of the soil media were modeled by left and right two-node infinite elements, which describe the soil continuity [12 & 16].

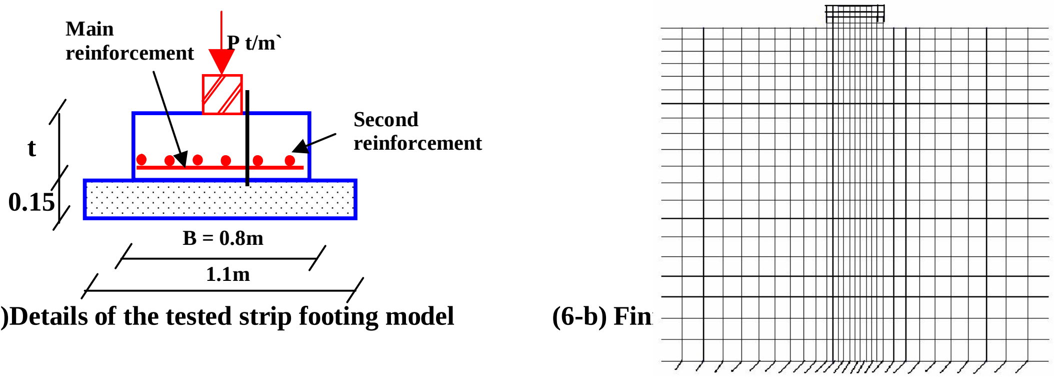
Derivation of the basic numerical equations corresponding to various elements was previously presented [12]. Therefore employment of such elements in simulating the footing-soil problem can model real problems. A computer program was used for this study in which the considered linear and non-linear finite and infinite elements of the model were implemented.

VERIFICATION OF THE MODEL

A verification study was carried out to test the validity of the proposed model predications against available solutions.

The obtained experimental results were used to validate the proposed finite element modeling of the present study of the first eight experimental models as shown in Table1. The obtained numerical results were compared with the experimental results. Loading and layout of the model footings are shown in Fig 6-a. The finite-infinite element mesh is shown in Fig.6-b. Non-linear performance was assumed for the R.C.- strip footings with concrete compressive strength f_{cu}= 300 k/cm^2. After many trials to simulate the soil which used in the experimental test, Silty clay soil was considered, and its properties are presented in Table.2.

A particular soil is defined by eight parameters: K, n, R_f, C, F_o and $\Delta\phi$ to define tangential modulus (E_t); and K_b and m_b to define bulk modulus (B_t). These parameters are determined from the results of conventional tri-axial test [14, 15].



(6-a)Details of the tested strip footing model

(6-b) Fin

Fig. (6): Details and layout of the proposed model footing.

Table 2 Soil parameters for hyperbolic model proposed by (Duncan) [14&15]

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.

Tested strip footing with light steel reinforcement was subjected to gradually increasing vertical load up to failure. Figure 7 shows the comparison between the experimental results and predicated crashed load -thickness curve using the numerical model developed in this study. Where crashed load (P_c) is the load at which the initial crack appears. Numerical results were found to be nearest to those given in the experimental investigations. The crack pattern predicted in the finite element analysis also was found to be nearest to those presented in the experimental investigation as shown in Fig.8 & photo 1. However, the obtained results of the proposed F.E analysis are slightly higher than that of the laboratory experiments. The difference is about 10%. However both the experimental and F.E models clearly show that the crashed load increases as the thickness-breadth (t/B) ratio increases because of increasing the footing bearing capacity. Also, the results show that the minimum thickness-breadth (t/B) ratio of the R.C. strip footing with light steel reinforcement under P= 40t/m$^-$ is (t/B)=0.6.

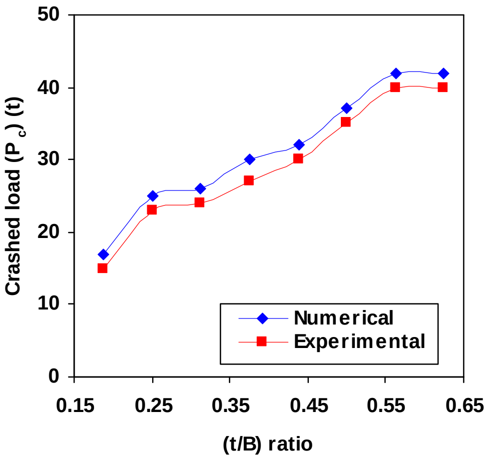


Fig.7 Comparison between experimental and numerical results.

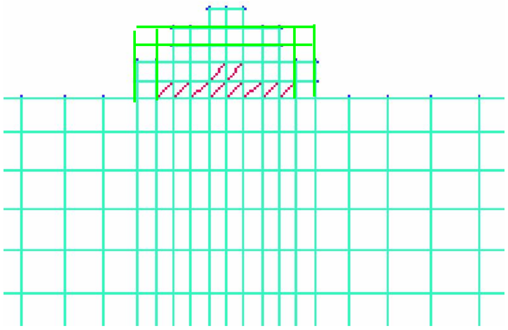


Fig. 8. Crack pattern of the numerical model.

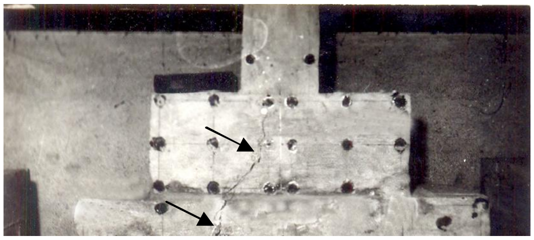


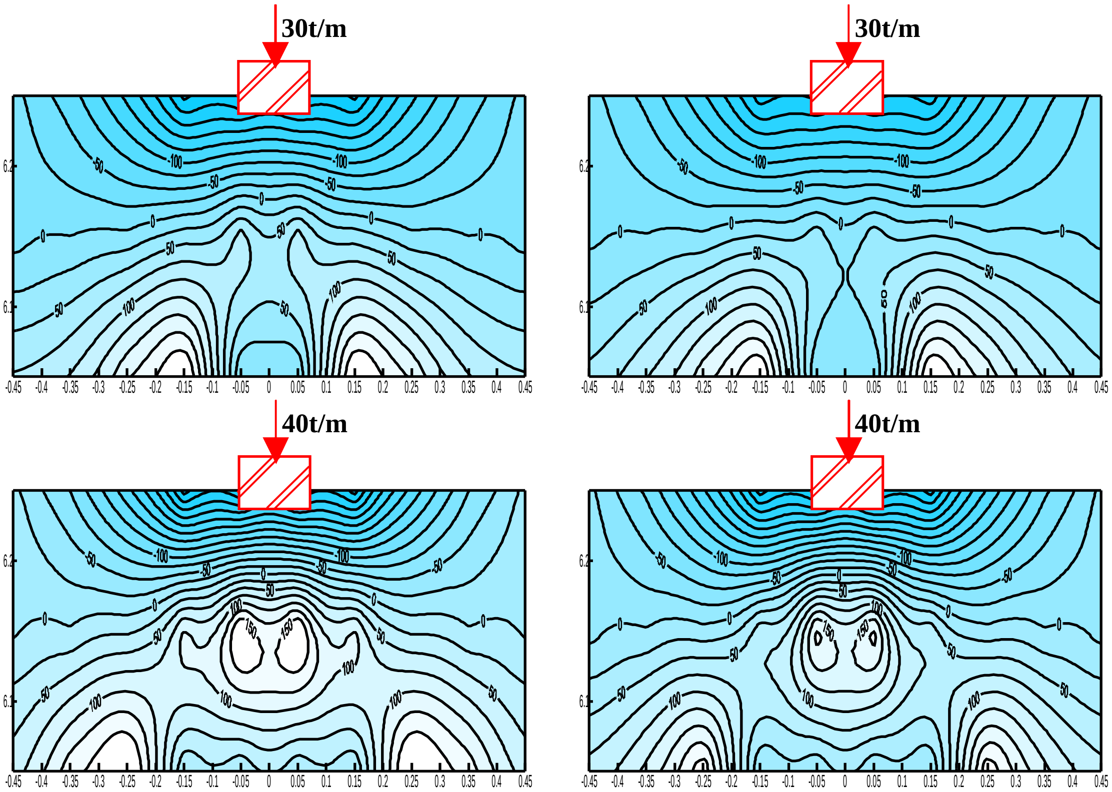
Photo 1. Cracks of the tested model

Numerical Analysis and Results.

For the analysis of strip footing-soil interaction problem, a finite-infinite element model was constructed as shown in Fig (6-b) for the model, and has dimensions as shown in Fig (6-a).Area of steel reinforcement was assumed 1% of concrete area. Non-linear performance was assumed for the strip footing material with a compressive strength (f_{cu}) = 250 kg/cm^2 and allowable tensile strength (f_t) = 10% of (f_{cu}) according to the Egyptian code ECP 203-2007[18].

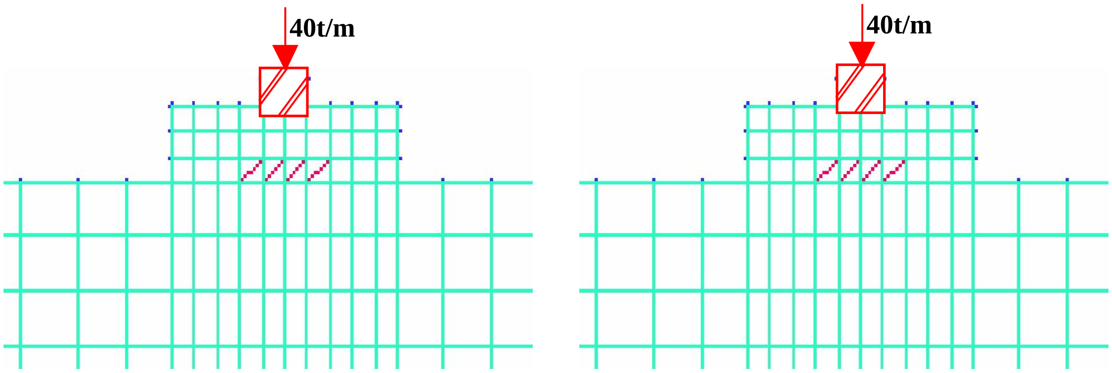
Parametric study was carried out to investigate the effect of different model parameters on the R.C strip footing-soil interaction behavior. These parameters include the thickness of strip footing (t), the vertical load on the strip footing (P) and the soil type. The thickness of R.C. strip footing was expressed in a non-dimensional form (t/B), where (B) is the breadth of the R.C strip footing, with eight ratios as shown in the top of Table 1. Five different values of vertical load (P = 20t/m', 30t/m', 40t/m', 50t/m' & 60t/m$^-$) were investigated in the analysis. Tow types of soil; silty clay and silty sand were considered to represent the cases of weak and stiff soil. The properties of these soils were presented in Table 2.

Figures.9 -12 show the normal stress (σ_x) contours (t/m^2) and crack patterns for R.C. strip footing at (t/B) = 0.375 & 0.625 respectively for various values of vertical loads for different tow types of soil. It is noticed that the tensile normal stress increases as the vertical load increases up to crack, especially at the zone just under the bearing wall, because of increasing the bending moment as shown in Figs.10&12. However, it decreases to 10% as the soil became stiffer. The redistribution of stresses occurred at the beginning of cracking at P = 40 t/m' for (t/B)=0.375 and P= 60t/m' for (t/B)=0.625 respectively, as shown in Figs.9 & 11.



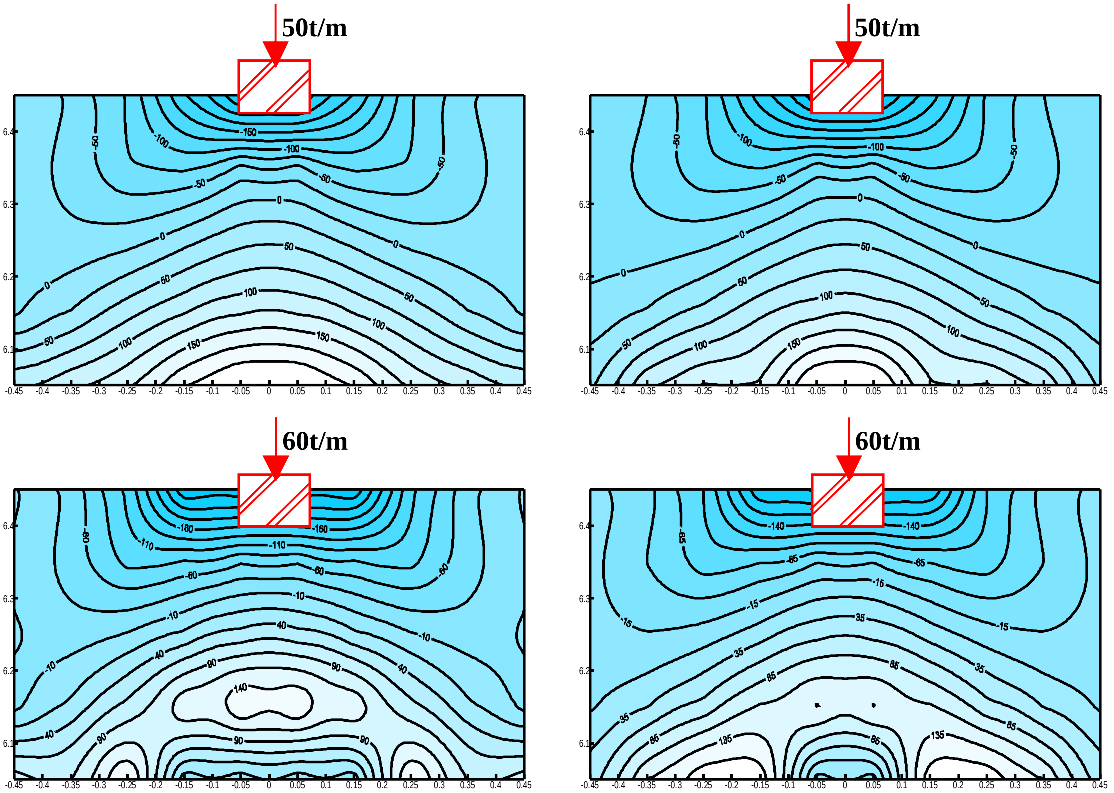
(a) Silty clay **(b) Silty sand**

Fig. 9. Effect of load increasing on the normal stress (σ_x) contour in strip footing at ratio (t/B) = 0.375, for different two types of soil.



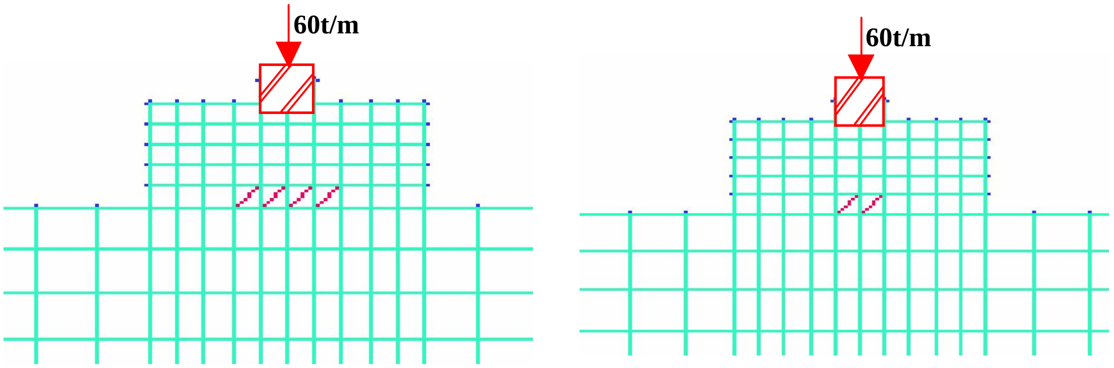
(a) Silty clay **(b) Silty sand**

Fig. 10. Crack pattern for strip footing at ratio (t/B) = 0.375, for different two types of soil.



(a) Silty clay **(b) Silty sand**

Fig. 11. Effect of load increasing on the normal stress (σ_x) contour in strip footing at ratio (t/B) = 0.625, for different two types of soil.



(a) Silty clay **(b) Silty sand**

Fig. 12. Crack pattern for strip footing at (t/B) = 0.625 for different two types of soil.

The results of the considered cases are plotted in Fig. 13, where the factor of safety is expressed in dimensionless form ($f_{t_{all}} / \sigma_{t_{\max}}$) where f_{tall} is the allowable tensile strength given in the Egyptian code and $\sigma_{t_{\max}}$ is the maximum tensile normal stress at studied section, as shown in Fig.6-b. The factor of safety (F.O.S.) is plotted against vertical load (P) for (t/B) ratios for the used tow soil types. It is clearly indicated that the F.O.S. increases as the (t/B) ratio increases and the soil became stiffer due to increase the relative stiffness between footing and soil. On the other hand, it decreases by about 10% as the vertical load increases. Figs. 13 indicate that the maximum vertical load at (t/B)=0.625 at factor of safety equal 2 is P = 30 t/m' which increase to P= 33 t/m$^-$ when the soil became stiffer. From the above results, it is clear that the concrete compressive strength affect on the (t/B) ratios which decreases as the concrete compressive- strength increases.

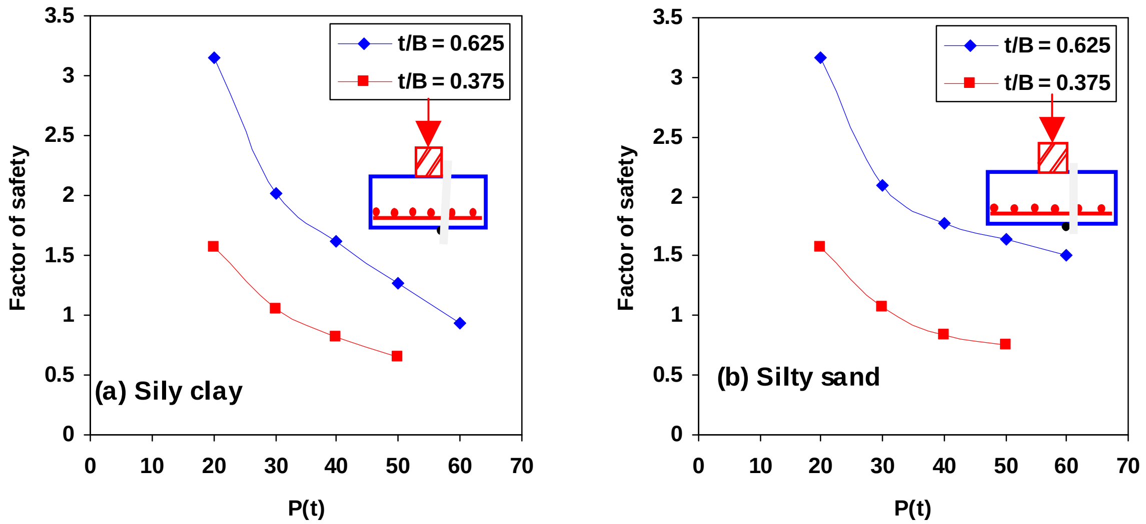


Fig. 13. Effect of vertical load values on the F.O.S at different (t/B) ratios for different two types of soil.

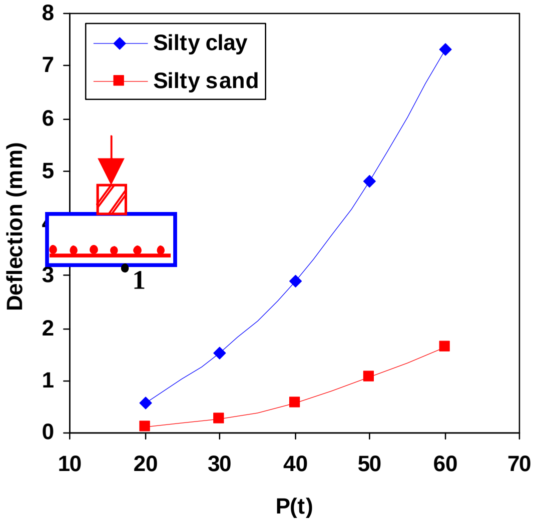


Fig. 14. Load-deflection curve for (t/B) = 0.625 for different two types of soil.

The relation between the vertical load and the maximum deflection at point 1 at the strip footing for different two types of soil is plotted in Fig.14. It is indicated that the deflection affected by the vertical load and the type of soil. Where increases up to 30% as the vertical load increases. However, the deflection decreases about 3 times when the soil became stiffer.

6. CONCLUSION

Using of R.C. strip footings with light steel reinforcement as a foundation system of bearing walls structures was studied numerically and experimentally. In this paper, a non-linear analysis of the R.C. strip footings and the underlying soil is performed. Various parameters which affect the strip footing-soil interaction behavior have been investigated, such as the thickness-breadth ratio of the R.C. strip footing. Vertical load values on the bearing walls, type of soil and type of concrete mix. Based on the numerical analysis, a computer program has been developed. The numerical results were verified also with the experimental results and good agreement is obtained.

Results of the proposed analysis showed the possibility of using R.C strip footings with light steel reinforcement as foundation system of bearing wall structures, which able to sustain the imposed vertical loads up to 40 t/m^{-}. This result could lead to exceptionally low cost and safe structures.

Numerical results showed also that the minimum safe thickness-breadth ratio of the R.C. strip footing under imposed vertical load 40 t/m^{-} is $t/B = 0.6$. And the compressive strength of the used concrete mix is recommended to be equal to 300 kg/cm^2.

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