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Effect of Overlap Stress as Well as Tie Beam Length and Width on Settlement of Isolated Footings Using Finite Element

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Abstract

Effects of tie beam length, width and overlap stress on settlement of foundations have been investigated. In this investigation square concrete footings have been used with dimensions (B × B × d) where (d) is footing depth and (B) is footing width (1, 1.5, 2 m). Width of tie beam (b) has been taken equal to 0.25, 0.30, 0.40, 0.50 and 0.75 (m). Tie beam length (L) has been taken varying from B till 3B with same footing depth = 0.50 m. Effect of overlap stress on settlement as well as effect of tie beam width and length on settlement has been determined. Also, the efficiency of tie beam length and width has been obtained. An equation is presented to compute the overlap stress zone in case of existing tie beam. It is found that the settlement increases with increasing the length of tie beam which is clear after the effect of the overlap stresses zone. The width of overlap stress zone case of existing tie beam has been found to be equal to (1.6 - 1.75) B. The settlement of footings decreases with increasing tie beam width. It is found that the settlement after the effect of the overlap stress zone increases with increasing the length of tie beam.

Keywords

Effect; Overlap Stress; Tie Beam Length and Width; Settlement; Isolated Footings; Finite Element

1. Introduction

Settlement can be defined as the permanent downward displacement of the foundation. There are two basic types of settlement. The first type of settlement is directly caused by the weight of the structure. The second basic type of settlement of a building is caused by secondary influence, which may develop at a time long after the completion of the structure. This type of settlement is not directly caused by the weight of the structure. How-

ever, soil is usually considered as a heterogeneous material with settlement behavior that is hard to be predicted with any great accuracy.

One practical way to improve settlement resistance is to increase the structural stiffness in the vertical direction by using reinforced concrete tie beams. These beams usually connect isolated footings and sometimes even strip footings.

In practice, differential settlements between footings are generally controlled, not by considering the differential settlement itself, but by controlling the total settlement predicted by analysis using an estimate of the soil elasticity.

Some of the Methods Used to Calculate the Effect of Tie Beam between Footings

Fenton *et al*. (2003) [1] presented their reports on a Monte Carlo investigation in which a spatially variable soil mass is simulated and virtual samples taken at a small number of locations are used to determine the required footing width. The resulting footing is then placed on the simulated soil mass and the actual settlement computed using the finite element method.

Al-Omari *et al*. (2008) [2] investigated theoretically the effect of tie beams on settlement, moments and shear developed in the foundation. A case study is selected as of grid foundation composed of nine footings. The parametric study conducted involved the effect of tie beams proportion, tie beams soil contact and an induced soil weakness beneath parts of the total foundation area. The detailed results indicated that the tie beams reduce the total and differential settlements of footings but this restriction is often on the expense of increasing the shear and moment particularly in the central footing. However, the settlement reduction may be considered invaluable in view of avoiding the excessive stresses in beams and slabs of the superstructure.

Farrokhzad *et al*. (2011) [3] presented as analysis of foundation accomplished by using the pure displacement-based finite element method.

Mahdy *et al*. (2011) [4] presented as test setup used to measure the settlement and the shape of displacement of soil under two different types of rigid plates connected with tie. Results indicate that the settlement of cohesionless soil for square plate with dimensions (305×305) is less than the settlement of rectangular plate with dimensions (305×610) mm. However, increasing tie length increases the settlement of both square and rectangular footing.

Amin *et al*. (2012) [5] presented investigate how tie beams between footings can improve structural resistance to settlement using finite element analysis of three dimensional structural models. In addition, seismic analysis is run to investigate tie beams behavior under earthquake loading in enhancing structural performance of foundation system. Results indicate that tie beams can reduce differential settlement greatly under both static and dynamic conditions.

Abd-Elsamee (2012) [6] investigated the cooperation between tie beams and footing depth. Field tests have been conducted by using the plate load test. This study presented two steel rigid plates (one is square and one is circular) were used. The settlement has been calculated from the actual settlement of plate (0.30×0.30) m measured at field. Settlement was found to be sensitive to the tie beam length connected footings. It was also found that the settlement under footings connected with tie beam decreases with decreasing tie beam length. However, footings connected with short tie beams are found to work as combined footings.

Elsamny *et al*. (2012) [7] presented cooperation between footings and tie beams to transfer the vertical loads to the supporting soil. The investigated parameters are the effect of tie beam length and surcharge on settlement of soil.

Elsamny *et al*. (2012) [8] [9] presented the effect of foundation depth on the settlement for isolated footings connected with tie beam.

Farouk *et al*. (2012) [10] presented the displacement field under footings connected with tie beams. The relationships between the angle of internal friction and the settlement of cohesionless soil under the two rigid square plates connected with different lengths of tie beam under different stresses and different depths. Also the relationships between the stress and settlement at different angle of internal friction and different depths are studied. Results indicate that the settlement under footings increases with increasing tie beam length. However, it was found also, that the two footings connected with tie beam act as one footing up to tie beam length equal to (1.25) B.

The finite element method is numerical procedure for obtaining solution to many of the problems encountered in engineering analysis. In this study the author used finite element method for utilizing discrete elements to ob-

tain the joint displacement of soil under isolated footings with and without tie beam in different cases of width and length of tie beam. The effect of tie beam length on settlement of foundations as well as tie beam width has been investigated.

2. Finite Element Analysis

Three dimensional models of two isolated footings with and without tie beam in different cases of width and length of tie beam have been investigated. Every footing carries concentrated load 100, 225 and 400 (KN) at the width of footing (B) = 1, 1.5 and 2 (m) respectively. These loads give the same stress under footings.

A finite element package, PLAXIS 3D, 2D version 8.2 is used to determine the effect of tie beam length and width on settlement under footings as well as the effect of overlap stress on settlement. Dimensions of all elements are presented in **Table 1** at all cases of dimensions. In order to simplify analysis, both martials (foundation concrete and soil) were assumed to be homogeneous, with properties listed in **Table 2**.

Two structure models are constructed as shown in the **Figures 1** and **2**; one without tie beam and other with tie beam. The first one has three cases; distance between the two footings equals B, 1.5B, 2B, 2.25B, 2.50B and 3.00B where (B) is the width of isolated footing. The second model has six cases also; the length of tie beam equal B, 1.5B, 2B, 2.25B, 2.50B and 3.00B. However, every case has three tie beam's width (b) = (0.25, 0.30, 0.40, 0.50, 0.75) m. Full contact is assumed between the soil elements and footings elements. The lower surface of soil layer is fixed against translations and rotations as boundary conditions.

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Table 1. Model geometry and dimensions.

Case	Geometry	Depth (m)	Width (m)	Length (m)	Distance (m)
General	Soil layer	6	8	20	-
General	footing	0.50	1 , 1.5 , 2	1, 1.5, 2	-
Control-1, 2, 3, 4, 5, 6	footing	0.50	1 , 1.5 , 2	1, 1.5, 2	(1, 1.5, 2, 2.25, 2.5, 3)
1	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	B	B
2	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	1.5 B	1.5 B
3	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	2 B	2 B
4	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	2.25 B	2.25 B
5	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	2.50 B	2.50 B
6	Tie beam	0.50	0.25, 0.3, 0.4, 0.5, 0.75	3.00 B	3.00 B

Table 2. Material properties.

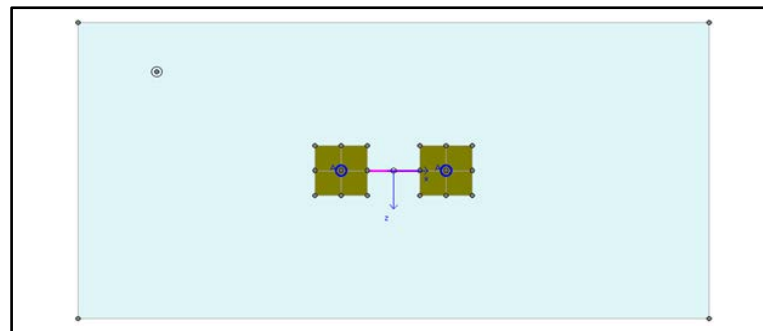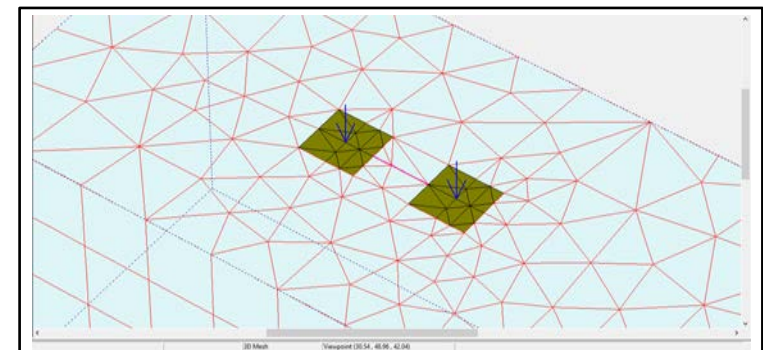| Property	Foundation concrete	Soil
Modulus of elasticity (KN/m^2)	22,000,000	13,000
Poisson ratio	0.20	0.30
Unit weight (KN/m^3)	25	17
Angle of friction (ϕ)	-	32
Cohesion (c) (KN/m^2)	-	0.00
Bearing capacity (KN/m^2)	-	187.3
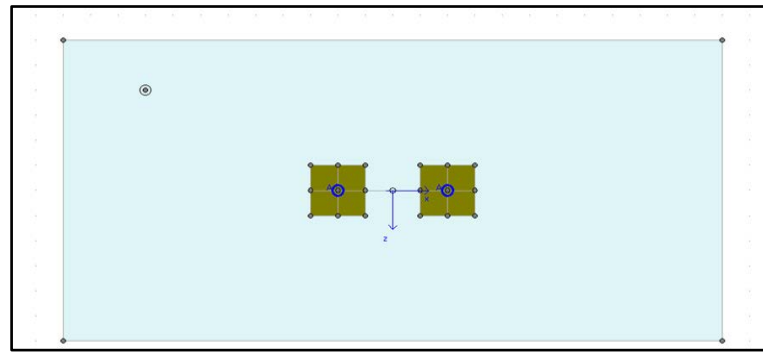
(a)
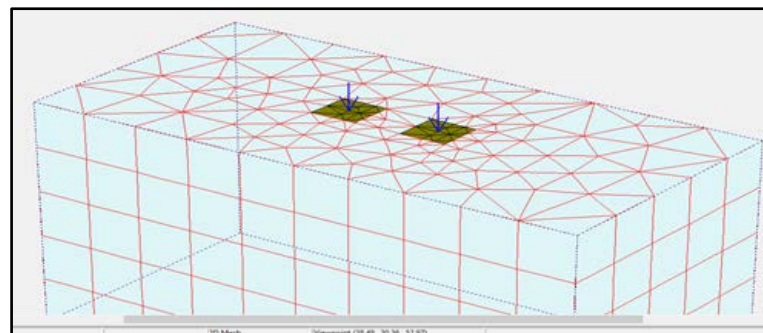
(b)

Figure 1. (a) Structural model without tie beam in 2D; (b) Structural model without tie beam in 3D.

(a)

(b)

Figure 2. (a) Structural model with tie beam in 2D; (b) Structural model with tie beam in 3D.

3. Results and Discussion

Tie beam width has an effect on the reduction in settlement of footings especially at the zone of the overlap stress. This does not mean that any increase in the width lead to decrease in the settlement of footings. However, there is a relationship between the ratio of increase in tie beam width, footing width and settlement of footings.

These relationships between the effect of tie beam length and width are illustrated in **Figures 3-5**. From these relationships, it is clear that the value of the settlement decreases after the tie beam width (b) reaches 0.50 m. Also, it is shown that the settlement increases by increasing the length of tie beam. However, this relationship is clear after the zone of the effect of overlap stress under isolated footing faded. This zone can be computed by the following equation:

$$d = (0.96 - 0.55B) \times B / \tan(45 - 0.5\phi) \tag{1}$$

where:
   d: End of zone effect of overlap stress (m).
   B: Width of footing (m).
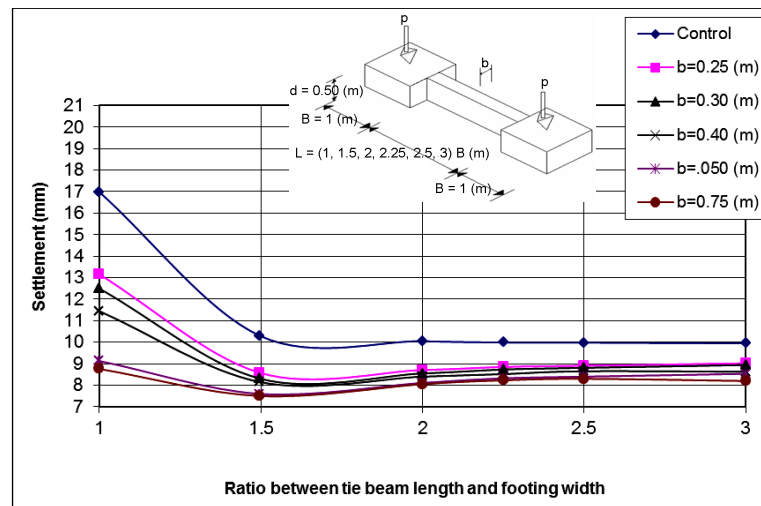 ϕ: Angle of friction in sand.

Figure 3. Effect of ratio between tie beam length and footing width on settlement at width of footing (B) = 1.00 (m).
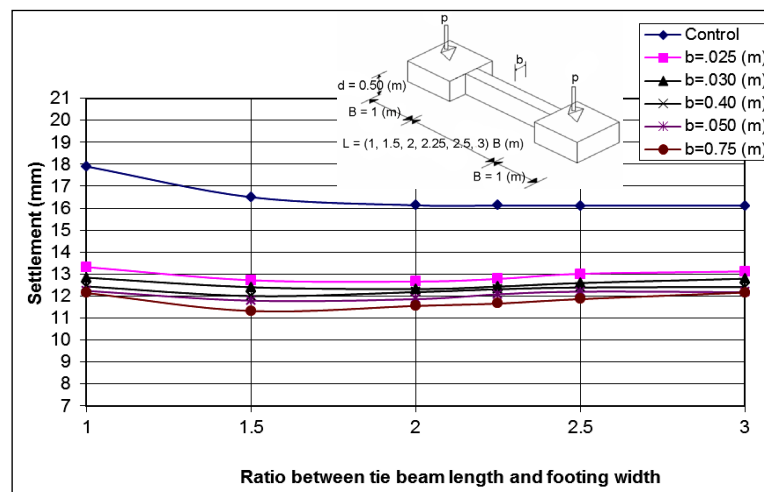

Figure 4. Effect of ratio between tie beam length and footing width on settlement at width of footing (B) = 1.50 (m).

By applying this equation in the present analysis the followings can be obtained:

At (B) = 1.00 (m): d = 1.65 m;

At (B) = 1.50 (m): d = 2.39 m;

At (B) = 2.00 (m): d = 3.10 m.

Settlement of isolated footings without tie beam is illustrated in **Figure 6** when distance between footings (D) = B, 1.5B, 2B, 2.25B, 3B and (B) = 1, 1.5 and 2 m. The vertical displacement contours is shown in **Figure 7** for structural model without tie beam and the deformation in meshes of soil are shown in **Figures 7** and **8**.

The results of settlement without and with tie beam at footing width (B) = (1, 1.50 and 2) m and different tie beam width and length are shown in **Tables 3-5**. The reduction in settlement due to tie beam as percentage of the total settlement (tie beam efficiency) are shown in **Figures 9-11**. These figures show that the efficiency of tie beam is reduced by increasing tie beam length at any width of tie beam.

However, the efficiency (η) can be computed from following equation:

$$\text{Efficiency}(\eta) = \frac{\left(\text{Settlement without tie beam} - \text{Settlement with tie beam}\right)}{\text{Settlement without tie beam}} \times 100 \qquad (2)$$
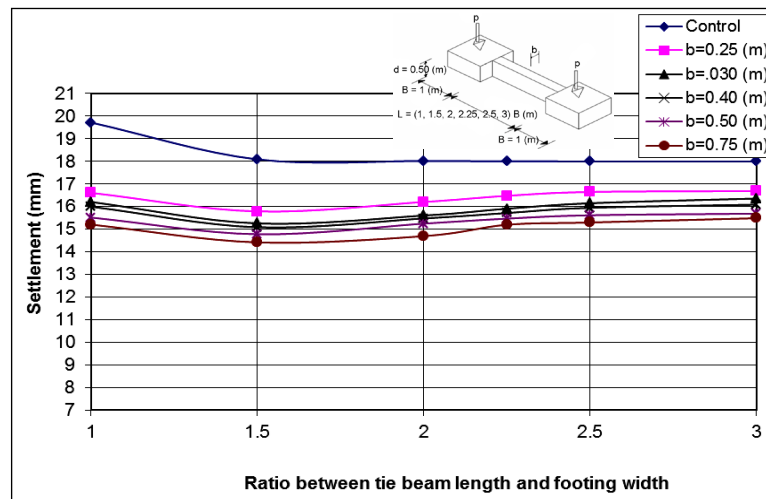

Figure 5. Effect of ratio between tie beam length and footing width on settlement at width of footing (B) = 2.00 (m).
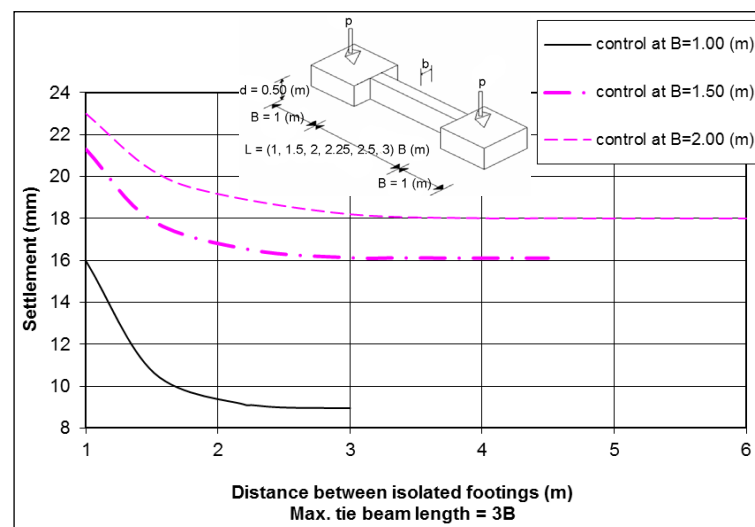

Figure 6. Effect of distance between footing on settlement without tie beam at footing width (B) = 1, 1.50 and 2 (m).
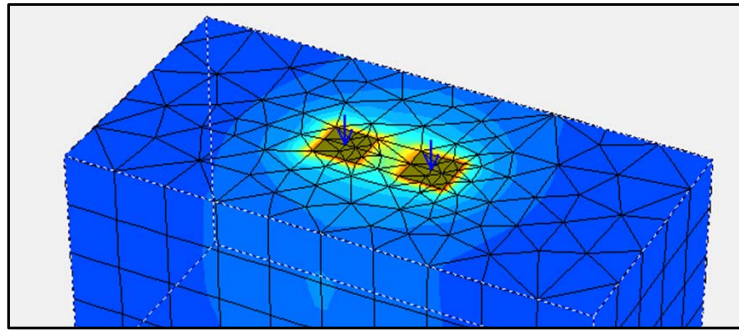
Figure 7. Effect of distance between footing on settlement without tie beam at footing width (B) = 1, 1.50 and 2 (m).
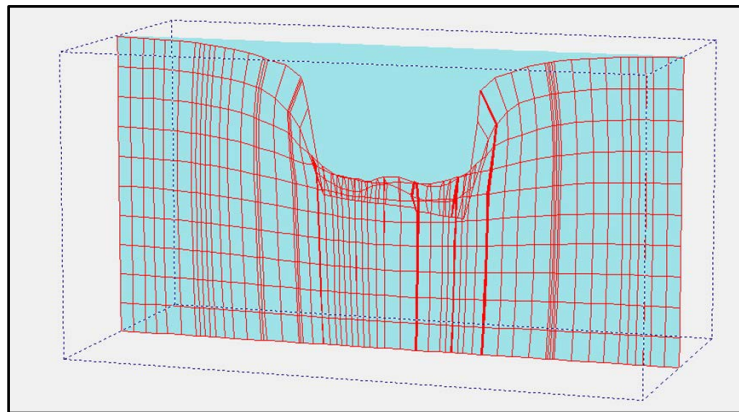

Figure 8. The deformation in meshes of soil due to the settlement.
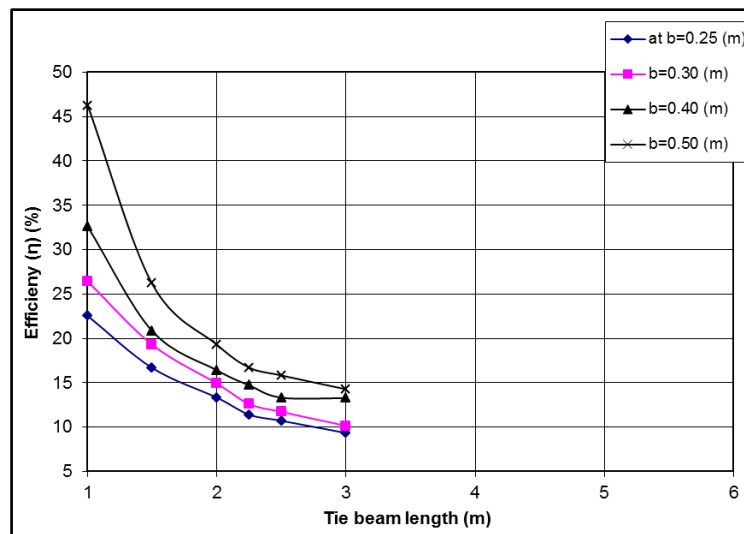

Figure 9. Effect of tie beam length on efficiency at width of footing (B) = 1.00 (m).

4. Conclusions

1) The effect of tie beams in improving foundation resistance to settlement has been investigated under static loading.

2) It was found that the settlement of isolated footing decreases with increasing tie beam width (B).

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Table 3. Settlement of foundations in case without tie beam.

L (m)	Sett. (mm) without tie beam at B =1.0 (m)	Sett. (mm) without tie beam at B = 1.5(m)	Sett. (mm) without tie beam at B = 2.00 (m)
L = 1.00 B	16.99	17.90	19.72
L = 1.50 B	10.30	16.50	18.09
L = 2.00 B	10.05	16.13	18.02
L = 2.25 B	9.99	16.12	18.01
L = 2.50 B	9.98	16.11	18.00
L = 3.00 B	9.95	16.11	18.00

Table 4. Settlement of foundations in case with tie beam.

L (m)	Sett. (mm) with tie beam at B = 1.00 (m)				Sett. (mm) with tie beam at B = 1.50 (m)				Sett. (mm) with tie beam at B = 2.00 (m)			
b (m)	0.25	0.30	0.40	0.50	0.25	0.30	0.40	0.50	0.25	0.30	0.40	0.50
L = 1.00 B	13.16	12.50	11.45	9.13	13.32	12.84	12.44	12.24	16.61	16.21	16.00	15.52
L = 1.50 B	8.58	8.31	8.15	7.60	12.72	12.40	12.00	11.79	15.79	15.26	15.09	14.78
L = 2.00 B	8.71	8.55	8.40	8.11	12.66	12.32	12.18	11.86	16.21	15.61	15.48	15.25
L = 2.25 B	8.85	8.73	8.52	8.32	12.78	12.43	12.31	12.08	16.48	15.91	15.72	15.47
L = 2.50 B	8.91	8.81	8.65	8.40	13.01	12.59	12.39	12.20	16.65	16.15	15.95	15.62
L = 3.00 B	9.02	8.94	8.63	8.53	13.12	12.79	12.41	12.18	16.69	16.36	16.09	15.69

Table 5. Tie beam efficiency (η).

L (m)	Efficiency (η) at B = 1.00 (m) (%)				Efficiency (η) at B = 1.50 (m) (%)				Efficiency (η) at B = 2.00 (m) (%)			
b (m)	0.25	0.30	0.40	0.50	0.25	0.30	0.40	0.50	0.25	0.30	0.40	0.50
L = 1.00 B	22.50	26.43	32.6	46.30	25.60	28.30	28.30	30.50	15.80	17.80	18.90	21.30
L = 1.50 B	16.70	19.32	20.90	26.20	22.90	24.80	24.80	27.30	12.70	15.60	16.60	18.30
L = 2.00 B	13.30	14.93	16.40	19.30	21.50	23.60	23.60	24.50	10.00	13.40	14.10	15.40
L = 2.25 B	11.40	12.61	14.70	16.70	20.70	22.90	22.90	23.60	8.50	11.70	12.70	14.10
L = 2.50 B	10.70	11.72	13.30	15.80	19.20	21.80	21.80	23.10	7.50	10.30	11.40	13.20
L = 3.00 B	9.30	10.15	13.30	14.30	18.60	20.60	20.60	23.00	7.30	9.10	10.60	12.80

3) The settlement after the effect of the overlap stresses zone increases with increasing the length of tie beam.

4) The efficiency of tie beam reduces with increasing the length at any width of tie beam.

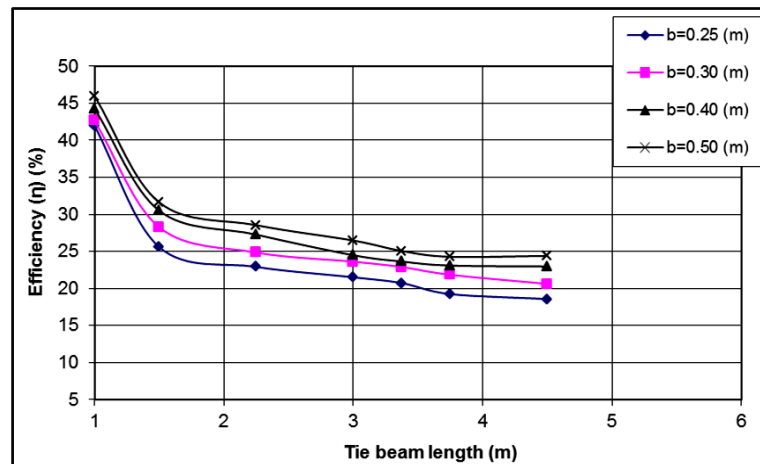5) The width of overlap stress zone was found to be from (1.6 - 1.75) B.

Figure 10. Effect of tie beam length on efficiency at width of footing (B) = 1.50 (m).
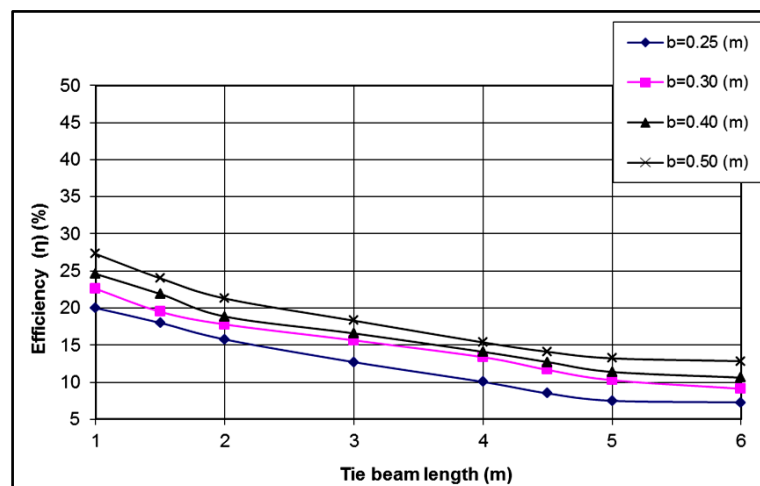

Figure 11. Effect of tie beam length on efficiency at width of footing (B) = 2.00 (m).

Acknowledgements

References

[1] Fenton, G.A., Zhou, H., Jaksa, M.B. and Griffths, D.V. (2003) Reliability Analysis of a Strip Footing Designed against Settlement. *Applications of Statistics and Probability in Civil Engineering*, **129**.

[2] AL-Omari, R.R. and AL-Ebadi, L.H. (2008) Effect of Tie Beam on Settlements and Moments of Footings. *The* 12*th International Conference of International Association for Computer Method and Advances in Geomechanics* (*IACMAG*), Goa, 1-6 October 2008.

[3] Farrokhzad, F. and Jchoabbasti, A. (2011) Assessing the Load Size Effect in the Soil under Single Foundation Using Finite Element Method. *International Journal of Soil Science*, **6**, 209-216. http://dx.doi.org/10.3923/ijss.2011.209.216

[4] Mahdy, M. (2011) Settlement of Soil under Different Types of Foundations. Ph.D. Thesis, Faculty of Engineering, Al-Azhar University, Cairo.

[5] Almasri, A.H. and Taqieddin, Z.N. (2012) Finite Element Study of Using Concrete Tie Beams to Reduce Differential Settlement Between Footings. *Proceedings of the* 13*th WSEAS International Conference on Mathematical and Com-*

putational Methods in Science and Engineering, 112-116.

[6] Abd El-Samee, W.N. (2012) Effect of Tie Beam Length and Depth of Isolated Footings on Settlement of Granular Soils. *Al-Azhar University Engineering Journal*, **7**, 965-988.

[7] Elsamny, M.K., Abd Elsamee, W.N., Ezz-Eldeen, H.A. and Abo-Alanwar, M. (2012) Settlement of Footings Connected with Tie Beams. *Civil Engineering Research Magazine*, **34**.

[8] Elsamny, M.K., Ibrahim, M.A., Elsedeek, M.A. and Farouk, M. (2012) Effect of Tie Beam Length on Displacement Field for Shallow Foundations. *Al-Azhar University Engineering Journal*, **34**.

[9] Elsamny, M.K., Ibrahim, M.A., Elsedeek, M.A. and Farouk, M. (2012) Experimental Investigation on Settlement under Isolated Footings Connected with Tie Beam. *Al-Azhar University Engineering Journal*, **34**.

[10] Farouk, M. (2012) Displacement Field for Shallow Foundations. Ph.D. Thesis, Faculty of Engineering, Al-Azhar University, Cairo.