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Effect of Tie Beam Dimensions on Vertical and Horizontal Displacement of Isolated Footing

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Abstract*— This study aims to investigate the effect of tie beam dimensions (length and height) connecting two isolated footings on the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions. In the present study, a finite element package of a PLAXIS 3D version 1.1.3.16 (a finite element code for soil and rock analysis) has been used to investigate the behavior of two isolated footings of different dimensions connected with tie beam. The dimensions of left footing are fixed LL= (1.0 X 1.0B) and the right footing dimensions are variable LR= (1.0 X 1.0B), (1.0 X 1.5B) and (1.0 X 2.0B). The width of the two footings is fixed (B=1.0m). The thicknesses of the two footings are variable (t=0.3B, 0.4B, 0.5B and 0.6B). The tie beam between footings has variable lengths (Ltie =0.5B, 1.0B, 1.5B and 2.0B). The height of the tie beams is variable (h=1.0t, 1.5t, 2.0t and 2.5t) and the width of tie beam is fixed (b=0.25m). All of the above assumptions have done with variable effect of depth of footing (df =0.0B, 0.5B, 1.0B and 1.5B). In addition, the angle of internal friction in sandy soil has been taken (Ø=30°, 35°, 40°and 45°). However, cohesion for clayey soil has been taken as (c=10, 15, 20 and 25) KN/m2. It was found that the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions increases with increasing the length of tie beam. Also, the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions decreases with increasing the angle of internal friction in sandy soil as well as cohesion in clayey soil. The vertical displacement in Y-direction (settlement) and horizontal in X and Z directions decreases with increasing the height of tie beam. Increasing the depth of footings leads to decreasing the vertical displacement in Y-direction (settlement) as well horizontal in X and Z directions.

Keywords*— *Tie Beam; isolated footing; soil structure interaction; spacing; deflection; plaxis 3d; stresses.

I-INTRODUCTION:

A soil shear failure can result in excessive building distortion and even collapse. However, it is necessary to investigate both base shear resistance (ultimate bearing capacity) and settlements for any structure. In many cases settlement criteria controls the allowable bearing capacity. Fellenius, B. H. and Altaee, A., (1994) compared the magnitude of the settlement of a footing in sand to the settlement of a different size footings in the same sand. The settlement were considered to be proportional to the density of the sand. Results of finite element analysis of settlement for footings of three sizes placed in two different sand types show that the settlement in sand is a direct function of neither footing size nor soil density. Briaud, J., and Gibbens, R., (1999) tested five square spread footings ranging in size from 1 to 3 m. The load tests were up to 150 mm of settlement. They were all embedded 0.75 m in a medium dense, fairly uniform, silty silica sand. Load-settlement curves are presented, as well as creep curves relating settlement and time under a constant load. Since the soil mass was instrumented with telltales and inclinometers, vertical and horizontal movements in the soil mass were obtained as a function of depth and lateral extent. Khalil, A. A., (2000) investigated the soil structure interaction analysis of two isolated footings connected by tie beam or by a wall supported on a strip footing. The finite element method was used to investigate the problem. Three dimensional solid elements were used to represent the footings, beam and columns. Winkler model was used to represent soil. A parametric study included beam depth, soil stiffness, soil nonuniformity and the level of the tie beam relative to the footing was performed. The effects of these parameters on the distribution of the loads between the tie beam and the footings and the relative settlement as well as the stresses in the tie beam were investigated. Elsamny M.Kassem, et.al. (2002) measured the settlement of footing in sandy soil at field by using plate load tests with different sizes of rigid plates (Diameter B = 300mm, B =455mm and B = 610mm). The settlement has been measured at ground surface and at different depths, (B/4, B/2, and B). The measurements were underneath the center of the plate as well as the sides. The shape of called settlement isobars have been determined under different applied stresses. In addition, the settlement under the same stresses was calculated using elastic theory. Ezz- Eldeen, H. A. (2006) investigated cooperation between footings and tie beams to transfer the vertical loads of column to supporting soil. The tie beam dimensions (depth and length), vertical position of tie beam (in footings level or above footings surface) and the footing depth as well as soil type with or without upper tie beam were the different investigated parameters for centric and eccentric footings. The finite element technique is used to perform the analysis for the problem. Commercial package "COSMOS/M version 2.6" is used. Footings, beams, upper tie beams and columns were modeled using three-dimensional eight–node solid concrete elements. Soil is modeled using one dimensional two nodes linear spring elements. Percentage of loads carried by all tie beams to total load increases by increasing tie beam length and depth and decreases by increasing the bearing capacity of soil (q_a). Elbatal, S. A. (2008) presented three models, isolated footings connected with beams, grid strip footing and raft foundation. The parameters and criteria have been used in the research are the effect of foundation thickness, the effect of soil types and effect of superstructure types and its number of floors on contact pressure distributions under foundation and distribution of column loads. Computer program

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"COSMOS/M version 2.6" finite element technique has been used to perform the analysis for these models. Al-Omari, R. R. and Al-Ebadi, L. H. (2008) presented theoretically the effect of tie beams on settlement, moments and shear developed in the foundation. Three-dimensional nonlinear finite element analyses have been conducted. The soil has been assumed to follow the Drucker-Prager rate independent plasticity criterion. The detailed results indicated that the tie beams reduce the total and differential settlements of footings. El-Samny,M.K. et.al. (2010) determined the Young's modulus "Es" of cohesionless soil at surface under footings with and without surcharge in field for graded sand samples. The tests have been conducted in field by using plate load test. The settlement has been measured under different stress levels at the surface along the center line of the plate as well as the edge of the plate. Also, the settlement has been measured under different applied stresses. The Young's modulus of elasticity can be determined for any solid material and represents a constant ratio of stress and strain. Elsamny, M.K., et al (2011) presented investigation to determine the settlement value and displacement of soil shape under footings. The results indicated that for cohesionless soil the square footing whose dimension is (305x305) mm gives settlement value less than those for the rectangular dimensions (305x610) mm. Mahdy, M. (2011) presented a test setup used to measure the settlement and the shape of displacement of soil under two different types of rigid plates connected with tie. Graded sand is used all through the tests. The settlement has been measured at surface and at different depths (B/2, B and 1.50 B where B = width of plates) with and without surcharge. It was found that the settlement of cohesionless soil for square plate with dimensions (305 x 305) is less than the settlement of rectangular plate with dimensions (305 x 610) mm. However increasing tie length increases the settlement of both square and rectangular footing. Elsamny, M. K., et al (2012) investigated the effect of tie beam length and surcharge on settlement of soil is the different parameters. A theoretical formulii has been presented to calculate the settlement for the square and the rectangular footings with tie beam including surcharge effect. Farouk, M. (2012) presented a study based on the determination of displacement field under footings connected with tie beams. An empirical formula to determine the settlement for two footing connected with tie beam has been obtained. A finite element package, PLAXIS version 7.2 was used to determine the displacement field of cohesion less soil as well as the settlement under footings. It was found that the settlement under footings increases with increasing tie beam length. In addition, footings not connected with tie beam exhibit more settlement than footings connected with beams. Elsedeek, M. B. (2013) investigated the effect of tie beam length and width on overlap- stress and settlement of foundation. Effect of overlap stress as well as tie beam length and width has been determined. An equation was presented to compute the overlap stress zone in case of existing of tie beam. Also, it was found that the settlement increases with increasing the length of tie beam which is clear after the effect of overlap stress zone. The settlement of footings decreases with increasing tie beam width. Also, it was found that the settlement after the effect of overlap stress zone increases with increasing the length of tie beam.

II- FINITE ELEMENT ANALYSIS:

A computer program has been used in the present investigation for the proposal a three-dimensional finite element model in order to simulate theoretically tie beams and foundations displacement. A finite element package of a PLAXIS 3D version 1.1.3.16. (a finite element code for soil and rock analysis) has been adopted. The numerical model presented as a 3D problem with three dimensions element of 15-node triangular elements is used to present the soil elements as shown in fig. (1). the beams are presented with 3-node beam elements and the floor elements are presented with 6-node triangles elements. The stress-strain behavior of the soil was modeled as the Mohr-coulomb model.

In the present study, a theoretical analysis has been done for two isolated footings connected with tie beam with different dimensions. The dimensions of left footing are fixed LL= (1.0 X1.0B) and the right footing has variable dimensions LR= (1.0 X 1.0B), (1.0 X 1.5B) and (1.0B X 2.0B). The width of the two footings is fixed (B=1.0m) and the thicknesses of the two footings are variable (t=0.3B, 0.4B, 0.5B and 0.6B). The tie beam between the two footings has variable lengths (Ltie=0.5B, 1.0B, 1.5B and 2.0B). The tie beam height is variable (h=1.0t, 1.5t, 2.0t and 2.5t) and the width of tie beam is fixed (b=0.25m). The angle of internal friction in sandy soil is taken as (Ø= 30.0°, 35.0°, 40.0° and 45.0°). However, cohesion for clayey soil has been taken as (c=10, 15, 20 and 25) KN/m2. All of the above assumptions have done with variable effect of depth of footing (df = 0.0B, 0.5B, 1.0B and 1.5B). The details and variations of the selected parameters are listed in the table (1) and fig. (2).

TABLE (1) INVESTIGATED CASES OF STUDY

Problem No.	Footings Dimensions			Tie beam		
	LL	LR	t	Ltie	b	h
1	1.0 X1.0B	1.0 X1.0B	0.3B, 0.4B, 0.5B, 0.6B	0.5B	0.25B	1.0t, 1.5t ,2.0t, 2.5t
2		1.5 X1.0B				
3		2.0 X1.0B				
4		1.0 X1.0B	0.3B, 0.4B, 0.5B, 0.6B	1.0B		1.0t ,1.5t ,2.0t, 2.5t
5		1.5 X1.0B				
6		2.0 X1.0B				
7		1.0 X1.0B	0.3B, 0.4B, 0.5B, 0.6B	1.5B		1.0t, 1.5t ,2.0t ,2.5t
8		1.5 X1.0B				
9		2.0 X1.0B				
10		1.0 X1.0B	0.3B, 0.4B, 0.5B, 0.6B	2.0B		1.0t, 1.5t ,2.0t, 2.5t
11		1.5 X1.0B				
12		2.0 X1.0B				

Where: LL: left footing dimensions, LR: Right footing dimensions, t: Thickness of the footing, B: footing breadth, Ltie: Tie beam length, b: tie beam breadth, h: height of tie beam

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TABLE (2) MATERIAL PROPERTIES FOR SOIL LAYERS

Parameters	Name	sandy soil	clayey soil	unit
Material model	Model	Mohr-coulomb	Moher-coulomb	-
Material behavior	Type	Drained	Drained	-
unsaturated soil weight	γunsat	17	16	KN/m3
saturated soil weight	γsat	20	18	KN/m3
Poisson ratio	υ	0.3	0.35	-
Cohesion	c	-	10,15,20 & 25	KN/m2
Friction angle	Ø	30,35,40 & 45	-	°

The structural model is shown in figures (3), (4) and (5). The material properties for the sandy and clayey soil are shown in table (2).

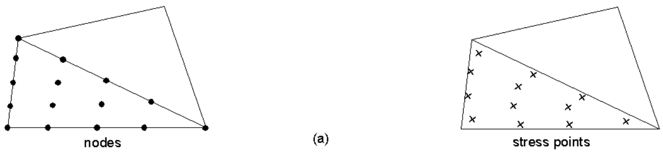

Fig. (1): Nodes and stress points of elements for 15-node triangular elements

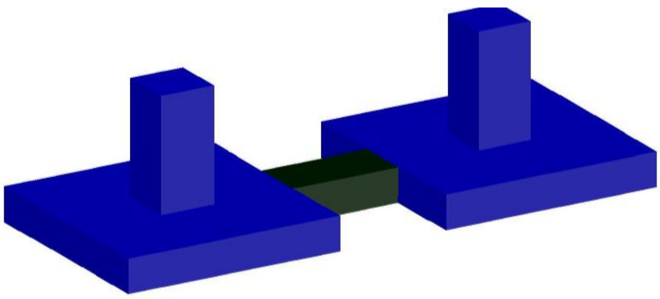

Fig. (2): Two footings connected with tie beam

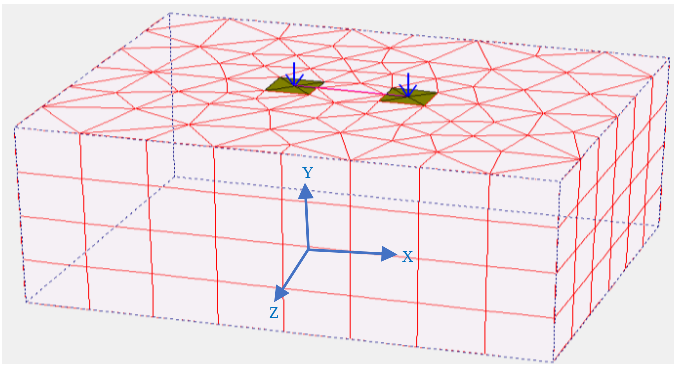

Fig. (3): Structural model with tie beam in 3-D at df=0.0B, (LL=LR=1.0 X1.0B) m and Ltie=1.5B

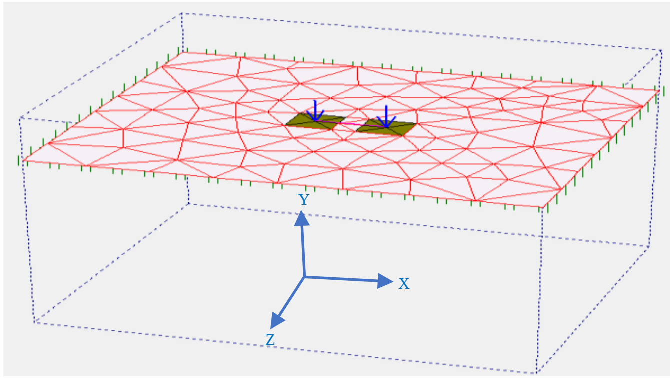

Fig. (4): Structural model with tie beam in 3-D at df=1.5B, (LL=LR=1.0 X1.0B) m, and Ltie=0.5B

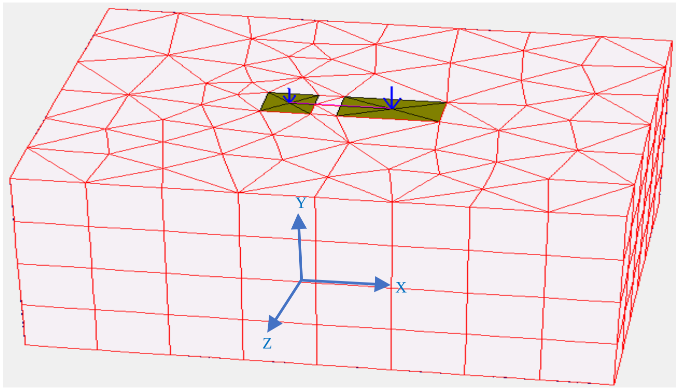

Fig. (5): Structural model with tie beam in 3-D at df=0.0B, (LL=1.0X1.0B), (LR=2.0X1.0B) and Ltie=0.5B

III-THEROTICAL RESULTS:

The theoretical results involve the followings:

a- Deformed mesh.

b- Vertical displacement in Y-direction (settlement) in soil at different depths (0.0B, 0.5B, 1.0 B and 1.5B).

c- Horizontal displacement in soil under footings in both X and Z directions.

The obtained results of selected examples for different cases are shown in figures (6 to 27) as follows:

i. Figures (6), (7) and (8) show the deformed mesh of soil and the vertical displacement in Y-direction (settlement) in the soil as contour line and shading for two footings (LL=LR=1.0 X1.0B) m and Ltie=0.5B, h=1.0t, t=0.3B, df= 0.0B and Ø=30°. From these figures, it can be shown that the two footings act as combined one.

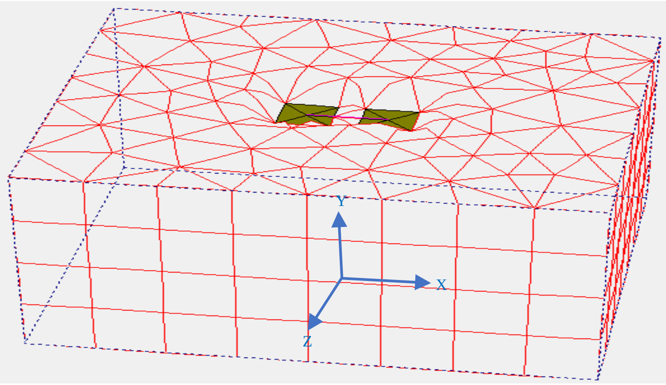

Fig. (6): Deformed mesh of soil in 3-D for (LL=LR=1.0 X1.0B) m, Ltie=0.5B, h=1.0t, t=0.3B, df=0.0B and Ø=30°

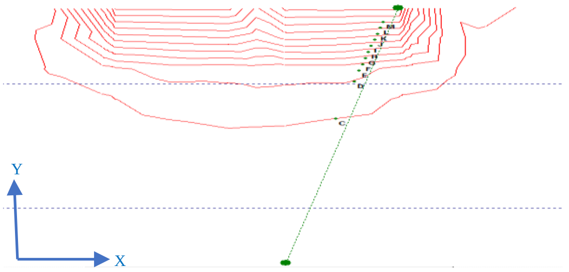

Fig. (7): Vertical displacement as contour line for (LL=LR=1.0 X1.0B) m, Ltie=0.5B, h=1.0t, t=0.3B, df=0.0Band Ø=30°

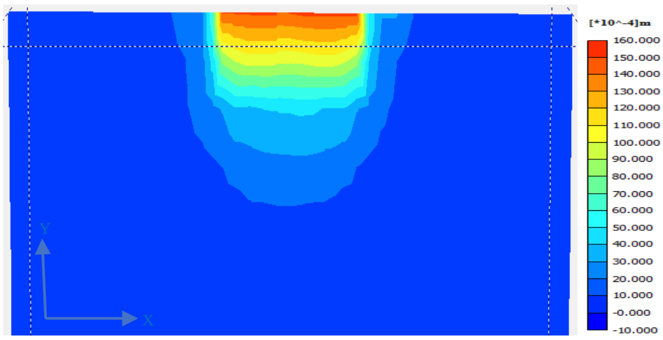

Fig. (8): Vertical displacement as shading for (LL=LR=1.0 X1.0B) m, Ltie=0.5B, h=1.0t, t=0.3B, df=0.0Band Ø=30°

ii. Figures (9), (10) and (11) show the deformed mesh of soil and the vertical displacement in Y-direction (settlement) in the soil as contour line and shading for two footings (LL=1.0X1.0B) m, (LR=2.0X1.0B) m and Ltie = 1.5B, h=1.0t, t=0.3B, df = 0.0B and Ø=30°.From these figures, it can be shown that the two footings act as separated footings.

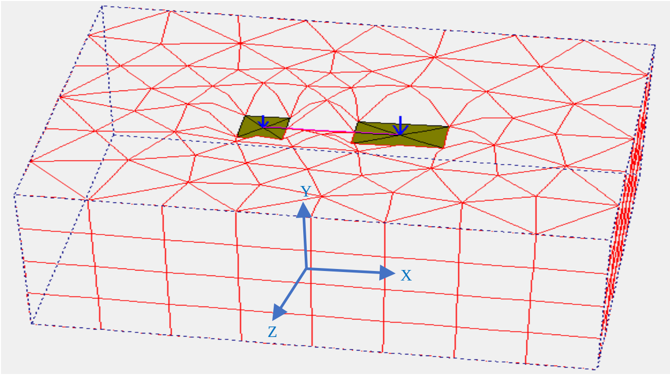

Fig. (9): Deformed mesh of soil in 3-D for (LL=1.0X1.0B) m, (LR=2.0X1.0B) m, Ltie=1.5B, h=1.0t, t=0.3B, df=0.0Band Ø=30°

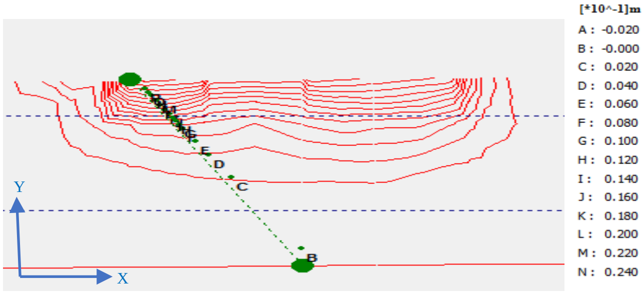

Fig. (10): Vertical displacement as contour line for (LL=1.0X1.0B) m, (LR=2.0X1.0B) m, Ltie=1.5B, h=1.0t, t=0.3B, df=0.0Band Ø=30°

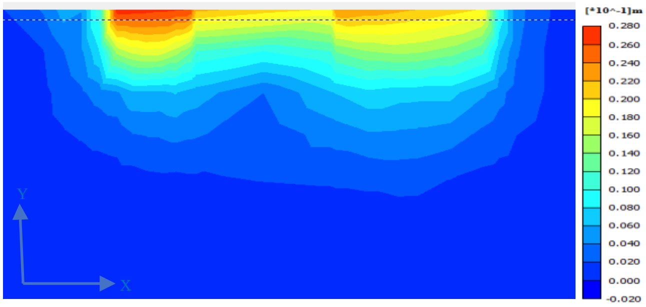

Fig. (11): Vertical displacement as shading for (LL=1.0X1.0B) m, (LR=2.0X1.0B) m, Ltie=1.5B, h=1.0t, t=0.3B, df=0.0Band Ø=30°

iii. Figures (12), (13) and (14) show the relationship between angle of internal friction and the vertical displacement in Y-direction (settlement) and horizontal displacement in X and Z directions under square right footing connected with square left footing. The two footings are connected with different tie beam length (Ltie = 0.5B, 1.0B, 1.5B and 2.0B) at depth of footing (df = 0.0B), h=1.0t, t=0.3B. These figures show that the vertical displacement in Y-direction(settlement) and horizontal displacement in X and Z directions decreases with increasing angle of internal friction up to Ø ≤ 36°and in cases of Ø > 36° no significate effect on the vertical displacement in Y-direction(settlement) as well as horizontal displacement in X and Z directions.

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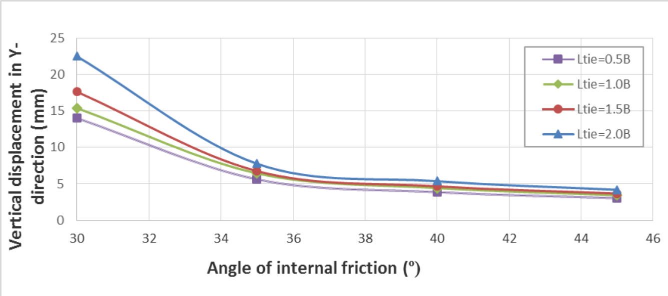

Fig. (12): The relation between angle of internal friction and vertical displacement in Y-direction for different tie beam lengths, df=0.0B, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

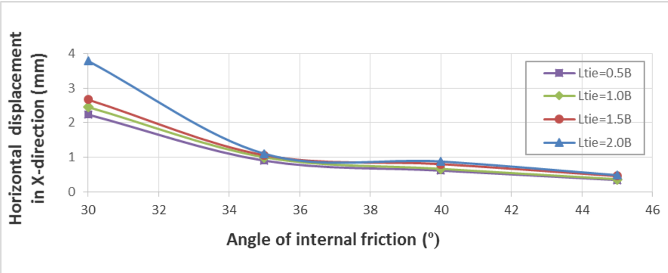

Fig. (13): The relation between angle of internal friction and horizontal displacement in X-direction for different tie beam lengths, df=0.0B, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

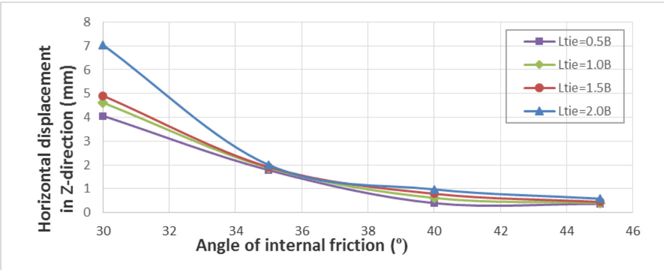

Fig. (14): The relation between angle of internal friction and horizontal displacement in Z-direction for different tie beam lengths, df=0.0B, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

iv. Figures (15), (16) and (17) show the relationship between depth of footing and the vertical displacement in Y-direction (settlement) and horizontal displacement in X and Z directions under square right footing connected with square left footing. The two footings are connected with different tie beam length (Ltie = 0.5B, 1.0B, 1.5B and 2.0B), h=1.0t, t=0.3B, and Ø=30°. These figures show that the vertical displacement in Y-direction (settlement) and the horizontal displacement in X and Z directions decreases with increasing depth of footing up to df≤1.0Band in cases of df >1.0B no significate effect on the vertical displacement in Y-direction (settlement) and horizontal displacement in X and Z directions.

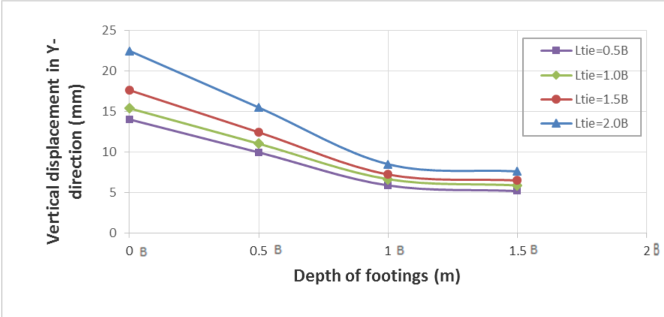

Fig. (15): The relation between depth of footing and vertical displacement in Y-direction for different tie beam lengths, Ø=30º, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

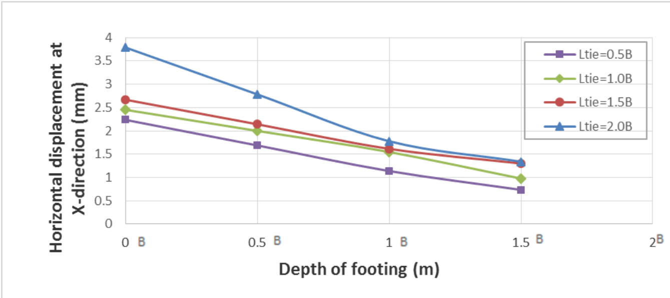

Fig. (16): The relation between depth of footing and horizontal displacement in X direction for different tie beam lengths Ø=30º, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

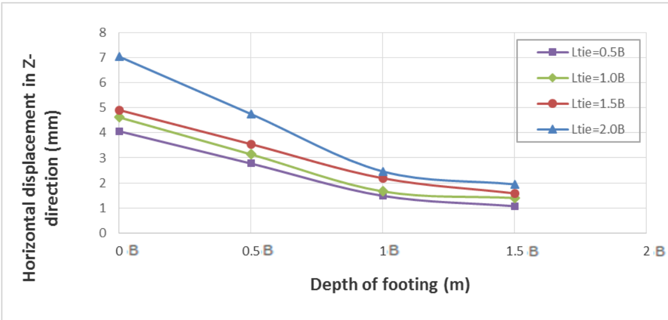

Fig. (17): The relation between depth of footing and horizontal displacement in Z-direction for different tie beam lengths Ø=30º, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

v. Figures (18) and (19) show the relationship between length of tie beam and vertical displacement in Y-direction(settlement) and horizontal displacement in Z-direction under square right footing connected with square left footing, the two footings connected with tie beam and have different depth of footings, h=1.0t and Ø=30°. These figures show that the vertical displacement in Y-direction (settlement) and horizontal displacement in Z -direction increases with increasing length of tie beam. In addition increasing depth of footings decreases vertical as well as horizontal displacements.

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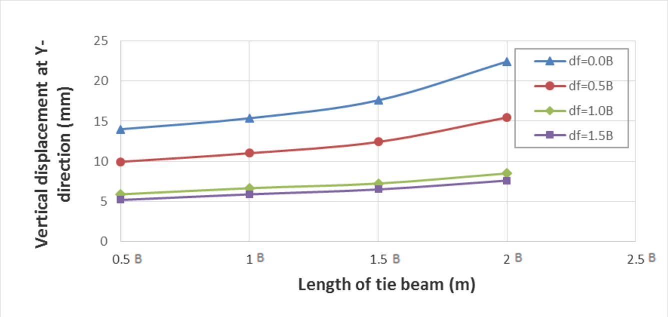

Fig. (18): The relation between length of tie beam and vertical displacement in Y direction for different depths of footing, Ø=30º, h=1.0t, df=0.0B and (LL=LR=1.0 X1.0B) m

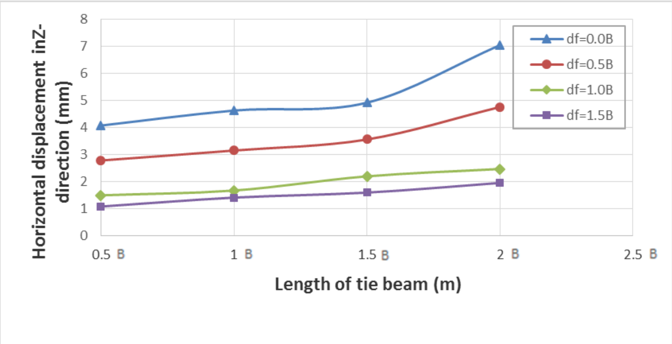

Fig. (19): The relation between length of tie beam and horizontal displacement in Z direction for different depths of footing, Ø=30º, h=1.0t, df=0.0B and (LL=LR=1.0 X1.0B) m

vi. Figures (20) and (21) show the relationship between thickness of footing and the vertical displacement in Y-direction (settlement) and horizontal displacement in X direction under square right footing connected with square left footing. The two footings are connected with tie beam and have different thickness of footings (t=0.3B, 0.4B, 0.5B and 0.6B) at depth of footing (df = 0.0B), h=1.0t and Ø=30º. These figures show that footing thickness have no significate effect on the vertical displacement in Y-direction (settlement) as well as horizontal displacement in X -direction.

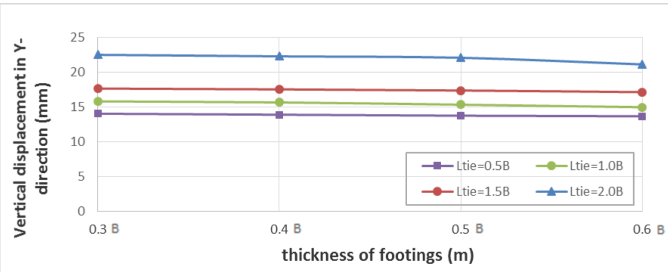

Fig. (20): The relation between thickness of footing and vertical displacement in Y direction for different tie beam lengths, Ø=30º, h=1.0t, df=0.0Band (LL=LR=1.0 X1.0B) m

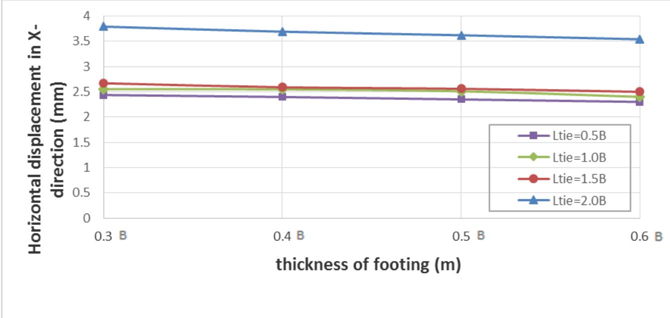

Fig. (21): The relation between thickness of footing and horizontal displacement in X direction for different tie beam lengths, Ø=30º, h=1.0t, df=0.0Band (LL=LR=1.0 X1.0B) m

vii. Figures (22) and (23) show the relationship between cohesion of soil and the vertical displacement in Y-direction (settlement) and horizontal displacement in X direction under square right footing connected with square left footing. The two footings are connected with different tie beam length (Ltie=0.5B, 1.0B, 1.5B and 2.0B) at depth of footing (df = 0.0B), h =1.0t, t = 0.3B. These figures show that the vertical displacement in Y-direction (settlement) and horizontal displacement in both directions increases by increasing the length of tie beam and increases by decreasing the cohesion of soil up to (C≤20KN/m2) and in case of (C>20KN/m2) no significate effect on vertical displacement in Y-direction (settlement) and horizontal displacement in both directions.

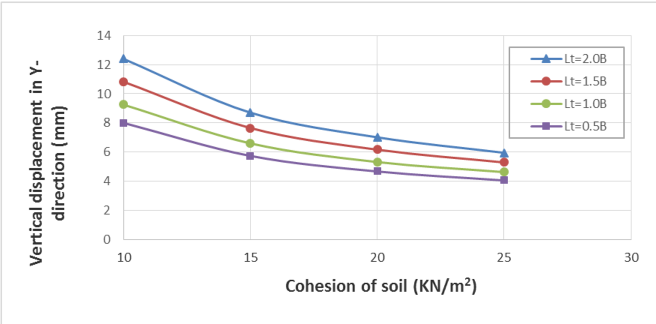

Fig (22): The relation between cohesion of soil and vertical displacement in Y- directiont for different tie beam lengths, df=0.0B, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

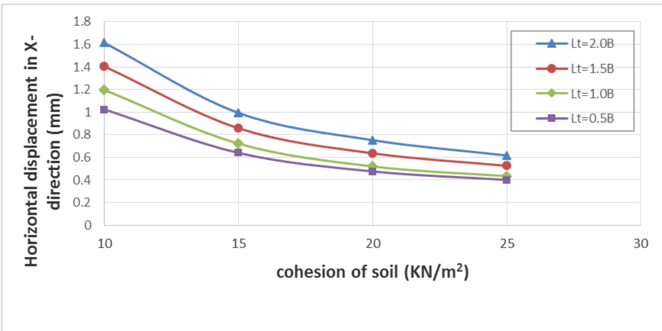

Fig. (23): The relation between cohesion of soil and horizontal displacement in X direction for different tie beam lengths, df=0.0B, h=1.0t, t=0.3Band (LL=LR=1.0 X1.0B) m

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viii. Figure (24) shows the relationship between length of tie beam and vertical displacement in Y-direction (settlement) under right footing at df = (1.5B), (LL=LR=1.0 X1.0B), (Ø=30º), (t=0.3B) and different heights of tie beam where h= (1.0t, 1.5t, 2.0t and 2.5t). This figure shows that vertical displacement in Y-direction (settlement) decreases with increasing height of tie beam.

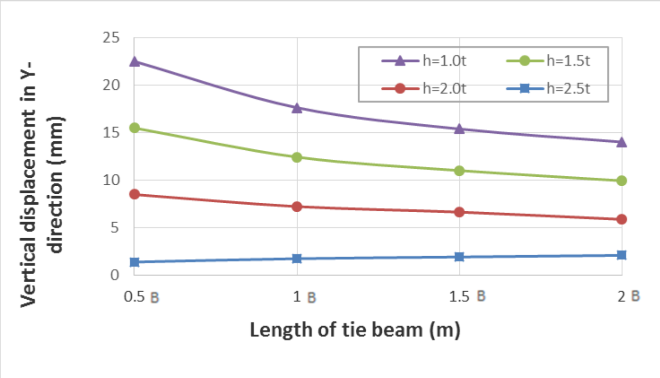

Fig. (24): The relation between length of tie beam and vertical displacement for different height of tie beam, t=0.3, df=1.5Band (LL=LR=1.0 X1.0B) m

ix. Figures (25) and (26) show the relationship between angle of internal friction and the vertical displacement in Y-direction(settlement) and horizontal displacement in Z direction under right footing at df= (1.5B), (LL=LR=1.0 X1.0B), (t=0.3B), (Ltie=0.5B) and different height of tie beam where h= (1.0t,1.5t,2.0tand 2.5t). These figures show that vertical displacement in Y-direction (settlement) and horizontal displacement in Z direction decreases with increasing height of tie beam.

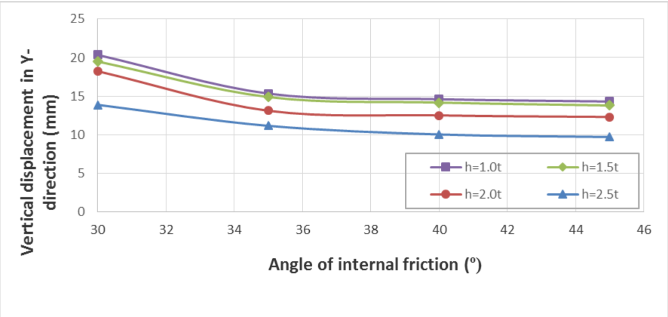

Fig. (25): The relation between angle of internal friction and vertical displacement for different height of tie beam, t=0.3, Ltie=0.5B, df=1.5Band (LL=LR=1.0 X1.0B) m

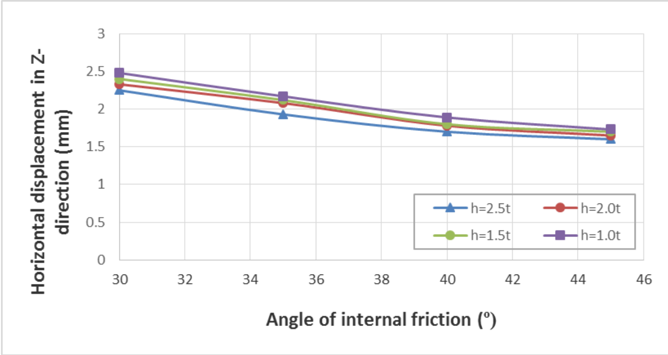

Fig. (26): The relation between angle of internal friction and horizontal displacement in Z-direction for different height of tie beam, t=0.3, Ltie=0.5B, df=1.5Band (LL=LR=1.0 X1.0B) m

x. Figure (27) shows the relationship between angle of internal friction and displacement in Y, X and Z directions under rectangular right footing connected with square left footing. The two footings are connected with tie beam. This figure shows that the vertical displacement in Y-direction(settlement) and horizontal displacement in X and Z directions decreases with increasing angle of internal friction up to Ø≤36ºand in cases of Ø>36º no significate effect on the vertical displacement in Y-direction(settlement) and horizontal displacement in X and Z directions.

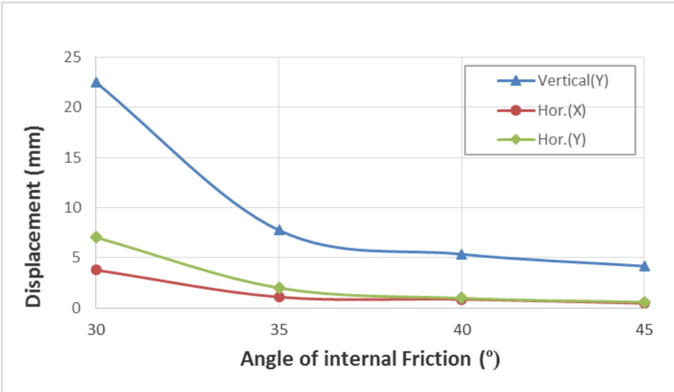

Fig (27): The relation between angle of internal friction and displacement for different displacements, t=0.3, h=1.0t, df=0.0B, Ltie=0.5B and (LL=1.0X1.0B) m, (LR=2.0X1.0B) m

xi. Figures (28) and (29) show the relationship between depth of footing as well as cohesion and displacement in Y, X and Z direction under square right footing connected with square left footing. The two footings are connected with tie beam (Ltie=0.5B, 1.0B, 1.5B and 2.0B). These figures show that the effect of depth of footing and cohesion on vertical displacement in Y –direction (settlement) is higher than the horizontal displacement in X and Z directions.

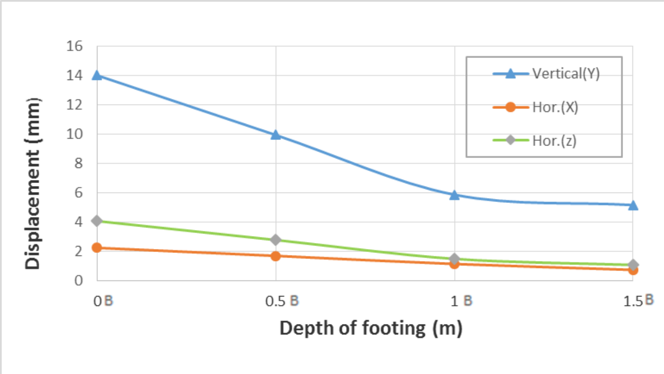

Fig. (28): The relation between depth of footing and displacement for different displacements, t=0.3, h=1.0t, Ø=30º, Ltie=2.0Band (LL=LR=1.0X1.0B)m

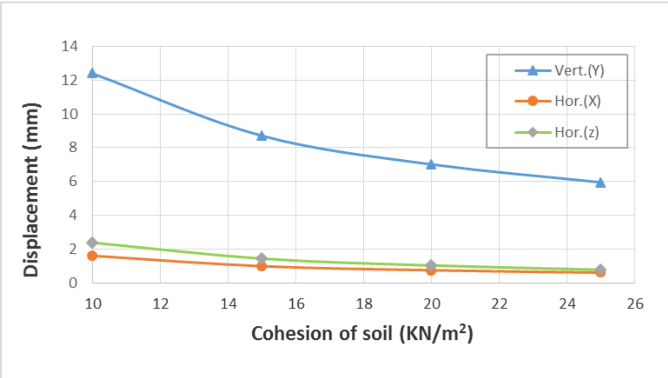

Fig. (29): The relation between cohesion of soil and displacement for different displacements, t=0.3, h=1.0t, Ltie=0.5B,df=0.0Band (LL=LR=1.0X1.0B)m

IX. CONCLUSIONS

From the present study, the followings are concluded:

i. The vertical displacement in Y-direction under footing (settlement) and the horizontal displacement in both X and Z directions increases with increasing the length of tie beam.

ii. The vertical displacement in Y-direction under footing (settlement) and the horizontal displacement in both X and Z directions increases with decreasing the height of tie beam.

iii. The vertical displacement in Y-direction and the horizontal displacement in X and Z directions decreases with increasing depth of footing up to df≤1.0Band in cases of df>1.0B no significate change in the vertical displacement in Y-direction (settlement) and horizontal displacement in X and Z directions.

iv. The vertical displacement in Y-direction(settlement) and horizontal displacement in X and Z directions decreases with increasing angle of internal friction up to Ø≤36ºand in cases of Ø>36º no significate change in the vertical displacement in Y-direction(settlement) as well as horizontal displacement in X and Z directions.

v. The vertical displacement in Y-direction (settlement) and horizontal displacement in X and Z directions increases by decreasing the cohesion of soil up to (C≤20KN/m2) and in case of (C>20KN/m2) no significate effect on vertical in Y-direction (settlement) and horizontal displacement in both X direction.

vi. No significate effect of footing thickness on vertical displacement in Y-direction (settlement) as well as horizontal displacement in X and Z directions.

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