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STRAINING ACTIONS OF FOOTINGS CONNECTED WITH TIE BEAMS RESTING ON REPLACED SOIL

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Abstract*—the straining actions variation of foundations located on soil replacement are an important factors affecting the foundation design and construction. Soil replacement may be refer to topography of the location or/and accidents like a failure of slops or retaining structures and environmental soil conditions. Uneven soil density induces structural, functional and operational and designing problems. In the present study, a non-linear finite element PLAXIS 3D FOUNDATION analysis is used to investigate the Straining actions of two square footings connected with tie beams resting on replaced soil. The aim of the present study is investigating and analyzing the effect of the interaction between natural soil deposit, soil replacement density and length and foundations. Three different densities of sand soil replacement are used. Four different groups for the geometry of the replaced soil are taken into account related to the density of both of soil 1(natural deposit) and soil 2 (replaced soil). For each group, the length of replaced soil (X) is varied as 7B, 6B, 5.5B, 5B and 4B. Vertical displacements of soil and foundations, Bending moments and shear force along the tie beam length. In addition the Bending moment in the two direction X & Y (M11 & M22) induced in the footings have been determined. Frome the obtained results, it is noticed that Variation of replaced soil density change final straining actions of footings and tie beams. In addition Variation of replaced soil must be considered in foundation deign to avoid error in design. However, In case of the natural soil deposit is dense, increasing the density of the replaced soil increases the maximum moment in X direction (M11) in footings but has no significant effect on maximum moment in Y direction (M22) in footings. Also, in case of the natural soil deposit is loose, increasing the density of the replaced soil has no significant effect on maximum moment in X and Y directions (M11 & M22) in footings*

Keywords*—straining actions; tie beam, soil/structure interaction; replacement; soil; density; displacements; design; plaxis.*

1. INTRODUCTION

In Egyptian new cites, actually the ground is not flat according to the topography of the location. Cut and fill or soil replacement processing may be applied to straightening the ground. Cut and fill may be lead to replaced soli layers under foundations. Also, compaction of soil layers may be lead to replaced soil in horizontal directions as shown in figure (1). Furthermore, accidents like a failure of slops or retaining structures and environmental conditions may often cause a local soil weakness underneath a certain part of the foundation. Uneven settlement induces structural, functional and operational problems. Also, error in execution of non-retaining the adjacent Neighbour structures as shown in figure (2). Connecting isolated footing with tie beam is an important requirements in this manners and affecting foundation design in these cases. Borowicka, H., (1939) obtained solution for the distribution of contact pressure beneath a smooth strip foundation subjected to uniform pressure, and also smooth strip foundation subjected to central line load. Rowe, R..K. and Boker, J.R. (1980) investigated the behaviour of circular footings resting on a replaced elastic soil with a crust. The stiffness of the crust is assumed to be either constant or to decrease with depth, whereas the stiffness of the underlying soil increases linearly with depth. Effect of layer depth, crust depth, and the rate of variation of stiffness within the crust and the underlying soil upon the settlement profile were Considered. Sedra, G. Y. (1983) studied groups of isolated footings connected with tie beams using the subgrade method. The formula of the element stiffness matrix and the values of the factors were developed. The Settlement, the bending moment and shearing force have been obtained. Aly, A. H., (1990) examined the behavior of isolated footings connected with beams by using the following groups: (i) three isolated footings in one direction, (ii) four isolated footings in one direction, (iii) five isolated footings in one direction, and (iv) five isolated footings in two perpendicular directions. The studied parameters were the type of soil, Rigidity of tie-beams, Distance between footings, presence and absence of tie beams, and number and arrangement of footings. Khalil, A. A., (2000) used the finite element method to investigated the soil structure interaction analysis of two isolated footings connected by

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tie beam or by a wall supported on a strip footing. 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 effect of these parameters on the distribution of the loads between the tie beam and the footings, the relative settlement and the stresses in the tie beam was investigated. Elbatal, S. A. (2008) evaluated the foundation design by using three models, isolated footings connected with beams, grid strip footing and raft foundation. The parameters and criteria have been used in this research are the effect of foundation thickness, the effect of soil types and effect of superstructure types and its number of floors on the followings: (i) Contact pressure distributions under foundation, (ii) Contact pressure values under points and (iii) Distribution of column loads. Parametric study has been done for isolated footings connected with beams and for grid strip footing as well as raft foundation without considering superstructure effect and with considering superstructure effect. The finite element technique was used to perform the analysis for these models. Computer program "COSMOS/M version 2.6" was used. Al-Omari, R. R. and Al-Ebadi, L. H. (2008) studied theoretically the effect of tie beams on settlement, moments and shear developed in the foundation. Grid foundation consisted of nine footings is selected in the study. Three-dimensional nonlinear finite element analyses have been conducted. The soil has been assumed to follow the Drucker-Prager rate independent plasticity criterion. The parametric study conducted involved the effects 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. Almasri A. H., Taqieddin. Z. N., (2011) investigated the effete tie beam on structural resistance to settlement using finite element analysis of three dimensional structural models. Results indicate that tie beam has efficiency to decrease differential settlement under both static and dynamic loads. Abd-Elsamee, W.N. (2012) Conducted a field tests to investigate the cooperation between tie beams and footing depth using two steel rigid plates (one is square and one is circular). The plates have a finished thickness of 32 mm. The effect of footings size with dimension (1.00 x 1.00 x 0.50) m, (2.00 x 2.00 x 0.50) m and (3.00 x 3.00 x 0.50) m has been investigated. Settlement was found to be sensitive to the tie beam length connected footings. It was also notes 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 one unit. Elsamny, M.K., et al. (2012) conducted an investigation to study the cooperation between footings and tie beams to transfer the vertical loads to the supporting soil. Effect of tie beam length and surcharge on settlement of soil are investigated. Finite element computer program two-dimensional finite element was used to simulate theoretically tie beam and foundations settlements (finite element package of the PLAXIS version 7.2.) A theoretical formulii have been presented to calculate the settlement for the square and the rectangular footings with tie beam including surcharge effect. Elsedeek, M. B., (2013) investigated the effect of tie beam length, Width and overlap- stress on settlement of foundation. Square concrete footings has been used with dimension (B x B x d) where (B) is footing width and was taken (1,1.5,2 m). Width of tie beam (b) was taken equal to (0.25, 0.3,40,50 and 0.75 m). Tie beam length has been taken varying from B till 3B with same footing depth equal 0.5 m. Effect of overlap stress as well as tie beam length and width has been determined. Also, efficiency of tie beam length and width on overlap stress has been obtained. An equation is presented to compute the overlap stress zone in case of existing of tie beam. The width of overlap stress zone in case of existing tie beam has been found to be equal to (1.6-1.75) B.

In the present study, the effect of relative position of a new compacted soil layer on soil structure interaction behavior and footings and tie beam design of an existing two footing connected with tie beam is investigated.

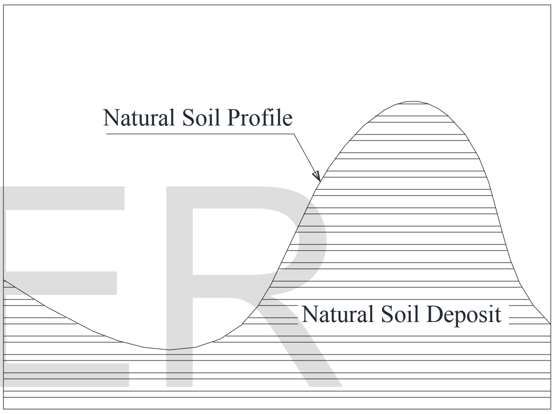

Fig. 1(a). Natural Soil Deposites In Most egyption New Cities

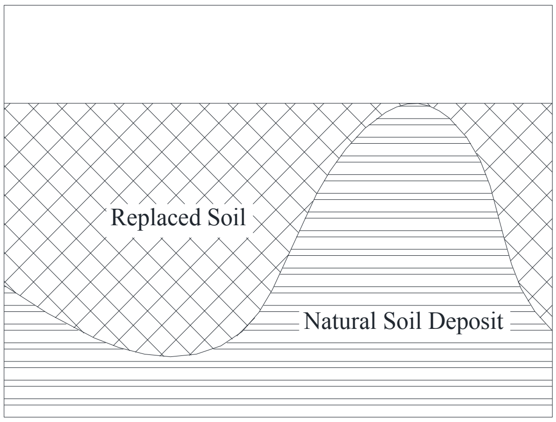

Fig. 1(b) .replaced soil (surface equalization)

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Fig. 2.(a). error in execution (non-retaining the adjacent Neighbour structures)

Fig. 2.(b). error in execution (non-retaining the adjacent Neighbour structures)

Fig. 2. Compacted replaced soil (non-retaining the adjacent Neighbour structures)

2. Analysis Details

In the present study a finite element package of the PLAXIS 3D FOUNDATION is used to simulate a Non-linear numerical model to study the effect soil structure interactions on the behavior of two square footings connected with tie beam located on replaced soil. The aim of the present study is investigating and analyzing the effect of soil structure interaction effect on straining actions and foundation design of footings connected with tie beam resting on replaced soil. Three different densities of sand soil are used and presented as Mohr-Coulomb model. Table I shows the properties of the selected soil. Two square footings with dimensions (B x B) equal (2.0m x2.0m) and separated with 2B from center to center as shown in figure (3) are simulated. Properties of the used footings are shown in table II. The two footings are connected with tie beam with cross section 0.25x0.5 m in the same depth of foundation. Table III shows the properties of the tie beam. Column's load is taken 800 kN for each column. Depth of foundations is selected 1B as shown in figure (4). Four different groups for the geometry of the replaced soil are taken into account related to the density of both of soil 1 and soil 2. Group I: soil 1 is taken as dense sand while soil 2 is chosen as medium sand, Group II: soil 1 is taken as dense sand while soil 2 is chosen as loose sand, Group III: soil 1 is taken as loose sand while soil 2 is chosen as dense sand and Group IV: soil 1 is taken as loose sand while soil 2 is chosen as medium sand as shown in table IV. For all groups, the profile of soil 2 is taken with inclined angle 45^{o} with the horizontal plane as shown in figures (5 and 6). For each group, the length of replaced soil (X) is varied as 7B, 6B, 5.5B, 5B and 4B as shown in figures (7 and 8). Vertical displacements of soil and foundations, Bending moments and shear force along the tie beam length. In addition the Bending moment in the two direction (M_{11} & M_{22}) induced in the footings have been determined.

Table 1. Material Properties of the Soil and the Interface

Parameter	Soil Type			Unit
	Loose sand	Medium sand	Dense sand	
Material model	Mohr-Coulomb			-------
Type of material behavior	Drained			-------
Dry soil weight (γ_{unsat})	16	17	18	KN/m^3
Wet soil weight (γ_{sat})	20	20	20	KN/m^3
Young's modulus (E_{ref})	20000	40000	60000	KN/m^2
Poisson ratio (ν)	0.35	0.33	0.30	-------
Friction angle ($\emptyset$)	29	33	37	-------
Dilatancy angle (ψ)	0	3	7	-------

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TABLE 2. MATERIAL PROPERTIES OF THE FOOTINGS

Parameter	Name	Value	Unit
Type of behavior		Linear	-------
Thickness	d	0.5	m
Weight	γ	25	kN/m^3
Young's modulus	E	$21x10^6$	KN/m^2
Shear modulus	G	$8.75x10^6$	KN/m^2
Poisson's ratio	ν	0.2	-------

TABLE 3. MATERIAL PROPERTIES OF THE TIE BEAM

Parameter	Name	Value	Unit
Type of behavior		Linear	-------
cross-section area	A	0.125	m^2
Weight	γ	25	kN/m^3
Young's modulus	E	$21x10^6$	KN/m^2
Moments of inertia (against horizontal bending)	I_2	$6.51x10^{-4}$	m^4
Moments of inertia (against vertical bending)	I_3	$2.60x10^{-3}$	m^4
Moments of inertia (against oblique bending)	I_{23}	0	m^4
Poisson ratio	ν	0.2	-------

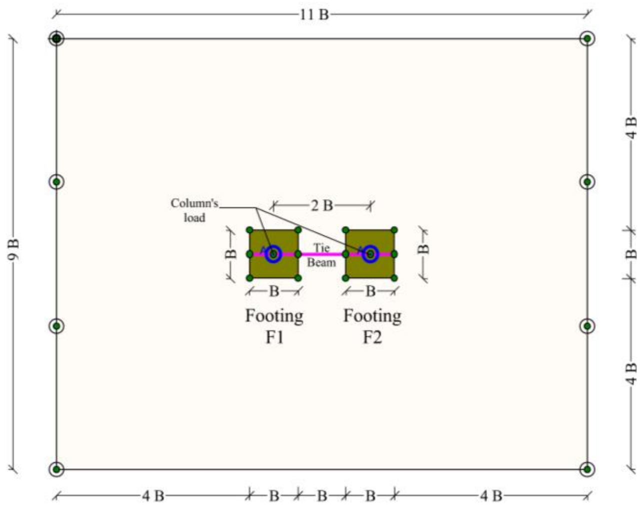

Fig. 3. Dimensions of the numerical model in plane view.

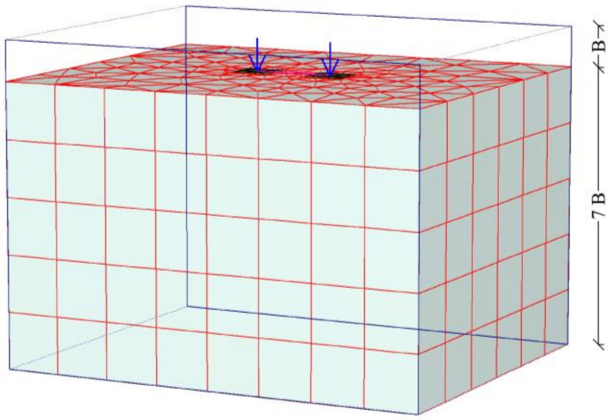

Fig. 4. Dimensionsof the numerical model in 3-D view.

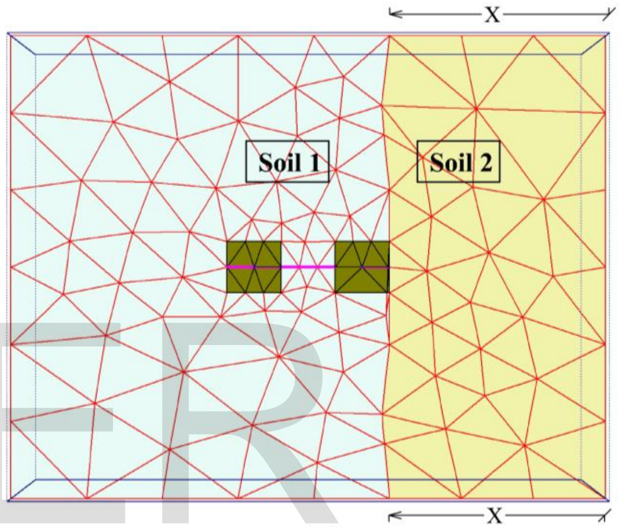

Fig. 5. Model geometry in plane view.

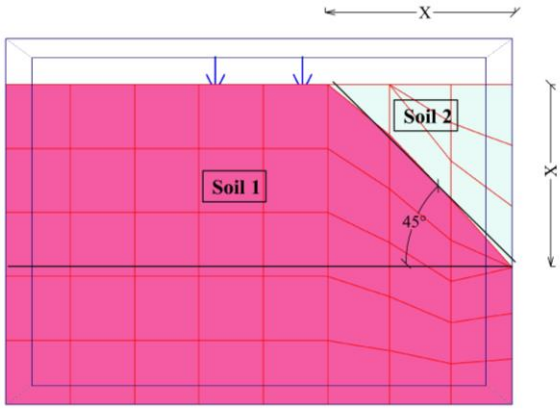

Fig. 6. Model geometry in elevation view.

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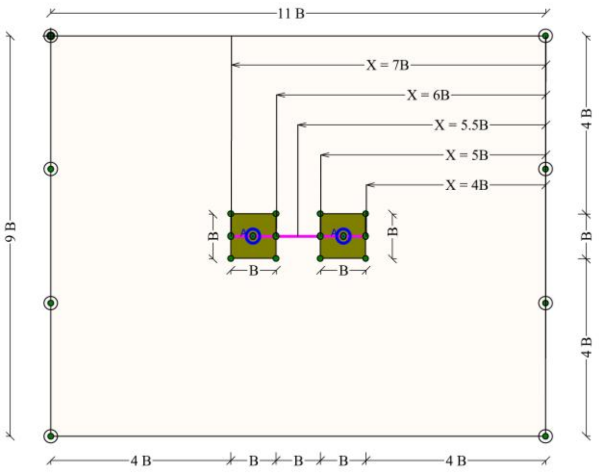

Fig. 7. Variation of the length of replaced soil (X) in plane view.

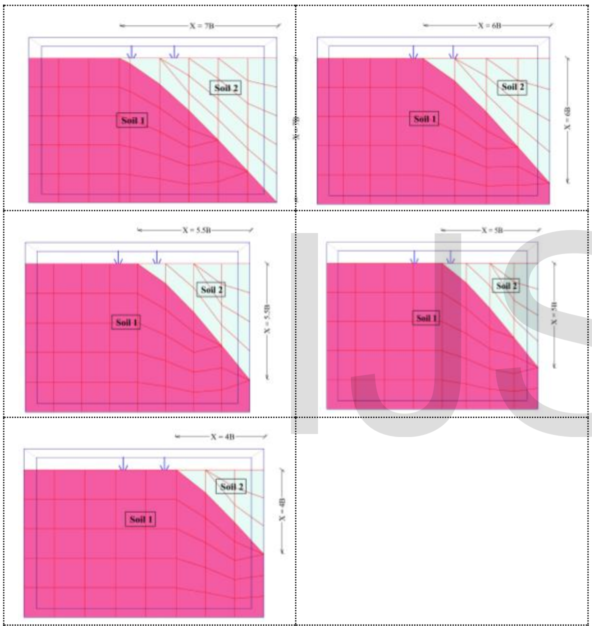

Fig. 8. Variation of the length of replaced soil (X) in

TABLE 4. MODEL GEOMETRY AND DIMENSIONS

Code	Group	Soil 1	Soil 2	X
001	Control	Dense		-----------
002		Medium		-----------
003		Loose		-----------
1A1	Group I	Dense	Medium	7 B
1A2				6 B
1A3				5.5 B
1A4				5 B
1A5				4 B
1B1	Group II	Dense	Loose	7 B
1B2				6 B
1B3				5.5 B
1B4				5 B
1B5				4 B
2A1	Group III	Loose	Dense	7 B
2A2				6 B
2A3				5.5 B
2A4				5 B
2A5				4 B
2B1	Group IV	Loose	Medium	7 B
2B2				6 B
2B3				5.5 B
2B4				5 B
2B5				4 B

3. NUMERICAL RESULTS

The theoretical results involve the followings:

a- Bending moment along tie beam length.

b- Shear force along tie beam length.

c- maximum absolute bending moments on tie beam.

d- maximum absolute shear force on tie beam

e- bending moment at the centre of both footings

f- vertical displacement profile in soil

The analysis of the results is classified as follows:

i. Effect of spacing (X) of the replaced soil on the bending moment along the tie beam length:

Figure (9) shows copmparison between the beanding moment along tie beam length due to soil types under isolate footings connected with tie beam.

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Figures (10) to (13) show copmparison between the beanding moment along tie beam length due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1.

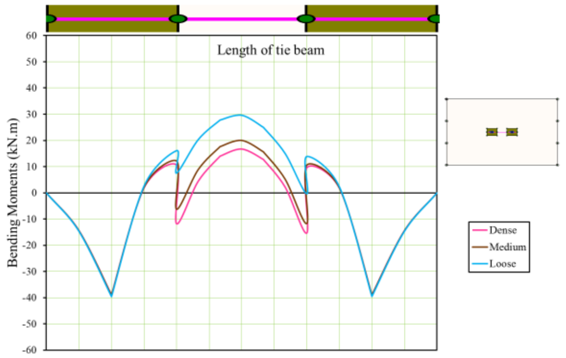

Fig. 9. Comparison between bending moments along the axe of tie beam for control group.

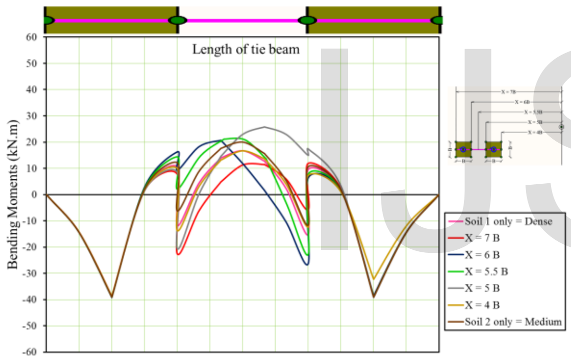

Fig. 10. Comparison between bending moments along the axe of tie beam for group I (soil 1 = Dense & soil 2 = Medium).

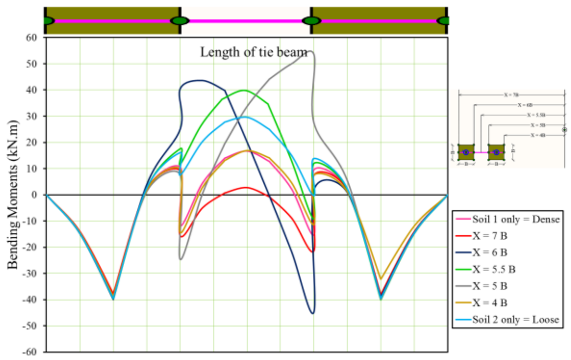

Fig. 11. Comparison between bending moments along the axe of tie beam for group II (soil 1 = Dense & soil 2 = Loose).

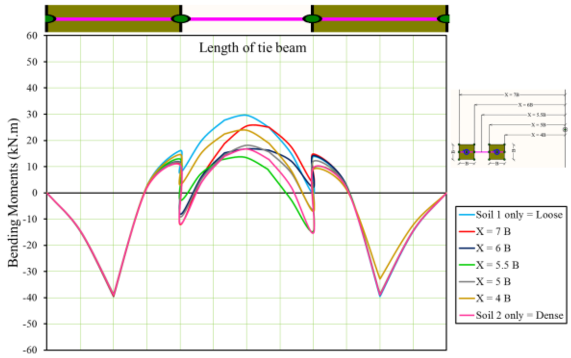

Fig. 12. Comparison between bending moments along the axe of tie beam for group III (soil 1 = Loose & soil 2 = Dense).

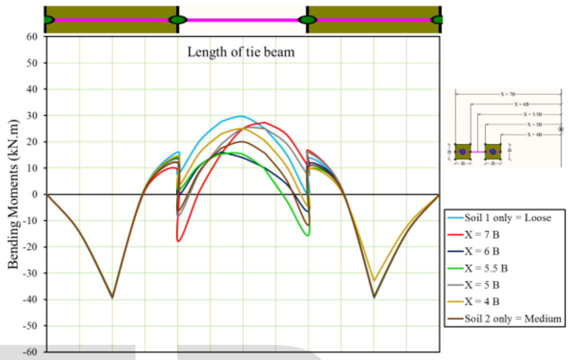

Fig. 13. Comparison between bending moments along the axe of tie beam for group IV (soil 1 = Loose & soil 2 = Medium).

ii. Effect of spacing (X) of the non-homogeneous soil on the shearing force along the tie beam length:

Figure (14) shows copmparison between the shearing force along tie beam length due to soil types under isolate footings connected with tie beam.

Figures (15) to (18) show copmparison between the shearing force along tie beam length due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1.

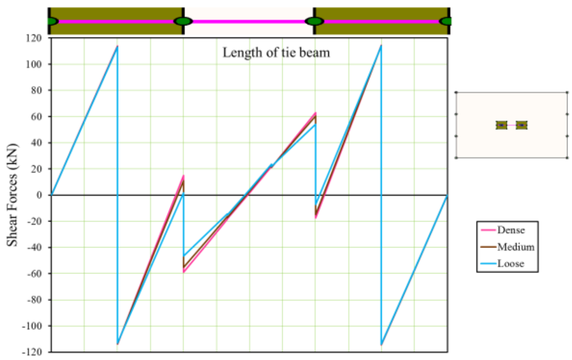

Fig. 14. Comparison between shear forces along the axe of tie beam for control group.

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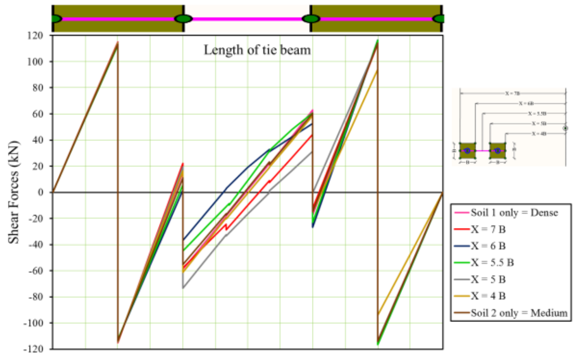

Fig. 15. Comparison between shear forces along the axe of tie beam for group I (soil 1 = Dense & soil 2 = Medium).

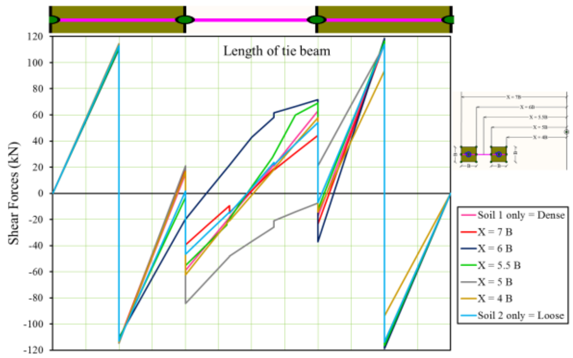

Fig. 16. Comparison between shear forces along the axe of tie beam for group II (soil 1 = Dense & soil 2 = Loose).

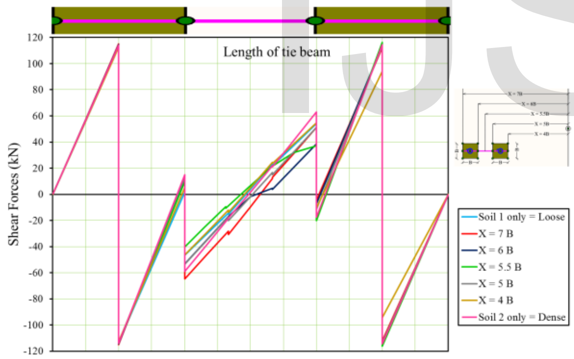

Fig. 17. Comparison between shear forces along the axe of tie beam for group III (soil 1 = Loose & soil 2 = Dense).

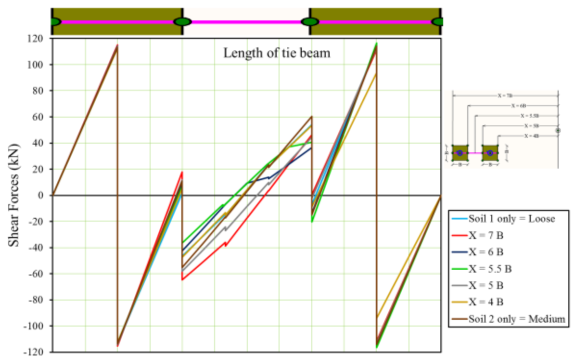

Fig. 18. Comparison between shear forces along the axe of tie beam for group IV (soil 1 = Loose & soil 2 = Medium).

iii. Effect of spacing (X) of the replaced soil on the absolute maximum bending moment along the tie beam length:

Figures (19) to (22) show copmparison between the absolut maximum bending moment along tie beam length due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1.

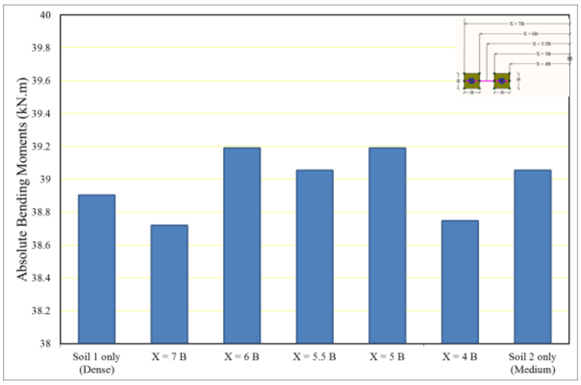

Fig. 19. Comparison between maximum absolute bending moments along the axe of tie beam for group I (soil 1 = Dense & soil 2 = Medium).

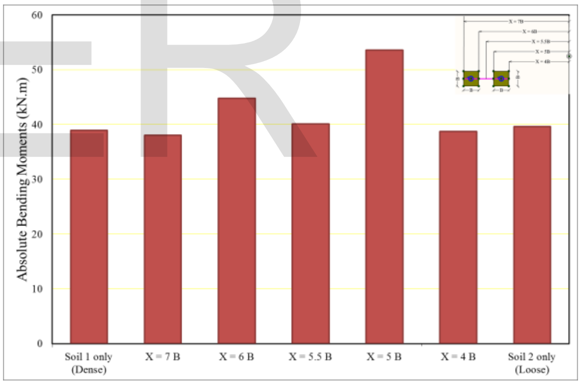

Fig. 20. Comparison between maximum absolute bending moments along the axe of tie beam for group II (soil 1 = Dense & soil 2 = Loose).

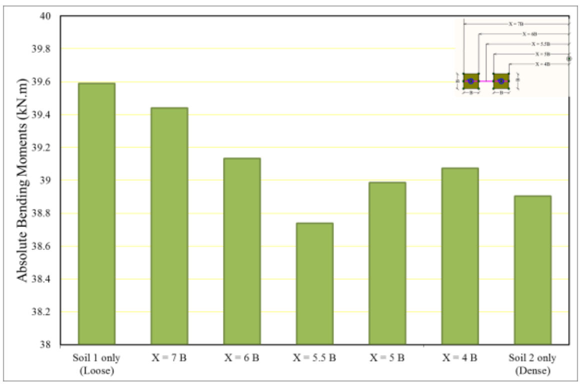

Fig. 21. Comparison between maximum absolute bending moments along the axe of tie beam for group III (soil 1 = Loose & soil 2 = Dense).

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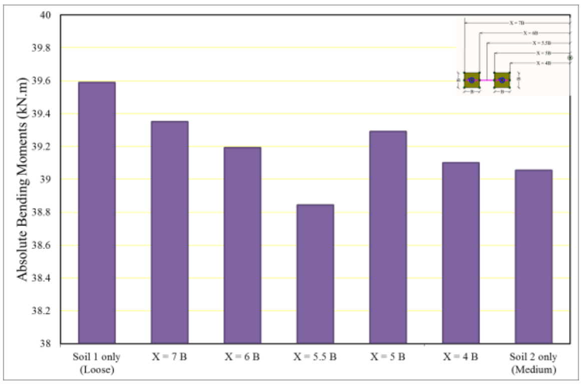

Fig. 22. Comparison between maximum absolute bending moments along the axe of tie beam for group IV (soil 1 = Loose & soil 2 = Medium).

iv. Effect of spacing (X) of the replaced soil on the absolute maximum shear force along the tie beam length:

Figures (23) to (26) show copmparison between the absolut maximum shear force along tie beam length due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1.

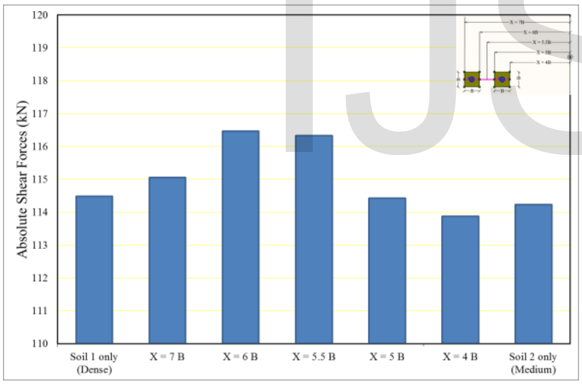

Fig. 23. Comparison between maximum absolute shear forces along the axe of tie beam for group I (soil 1 = Dense & soil 2 = Medium).

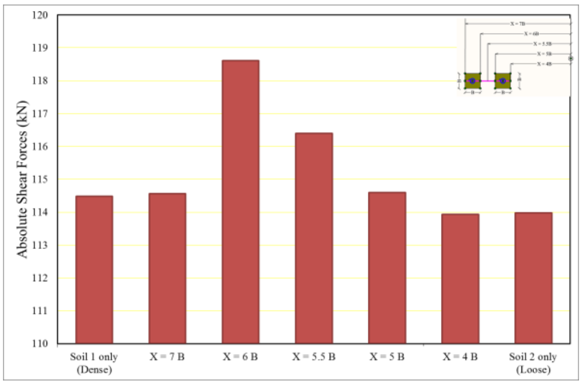

Fig. 24. Comparison between maximum absolute shear forces along the axe of tie beam for group II (soil 1 = Dense & soil 2 = Loose).

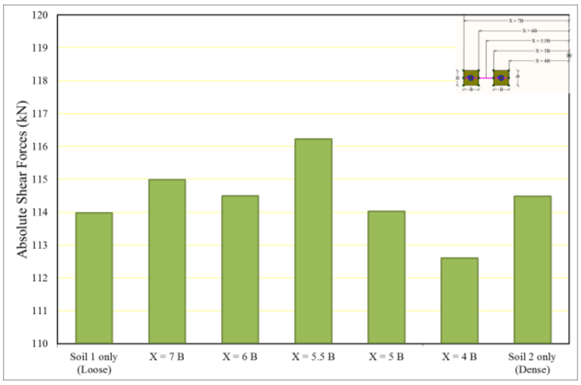

Fig. 25. Comparison between maximum absolute shear forces along the axe of tie beam for group III (soil 1 = Loose & soil 2 = Dense).

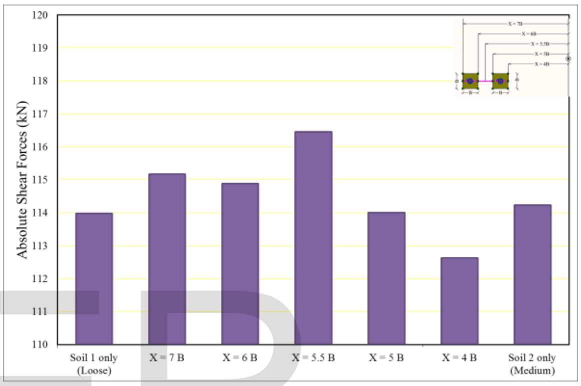

Fig. 26. Comparison between maximum absolute shear forces along the axe of tie beam for group IV (soil 1 = Loose & soil 2 = Medium).

v. Effect of spacing (X) of the replaced soil on the bending moment at the centre of both footings (F1 & F2):

Figures (27) to (30) show copmparison between the bending moment at the center of both footings (F1 & F2) due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1.

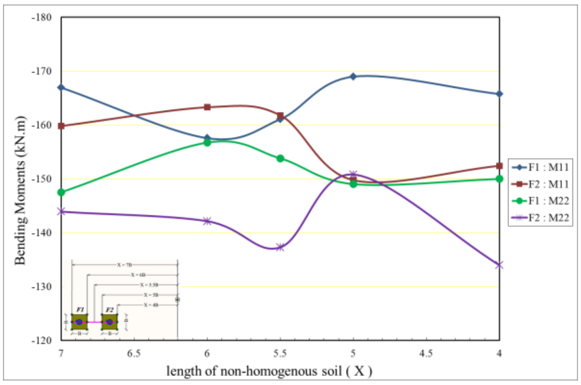

Fig. 27. The relasionship between length of replaced soil (X) and bending moments in both X & Y directions (M11 & M22) at the center of both footings (F1 & F2) for group I (soil 1 = Dense & soil 2 = Medium).

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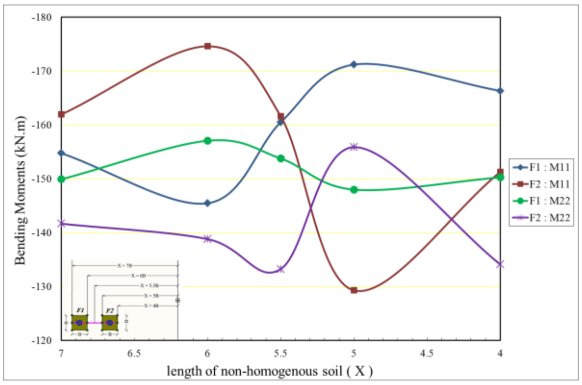

Fig. 28. The relasionship between length of replaced soil (X) and bending moments in both X & Y directions (M11 & M22) at the center of both footings (F1 & F2) for group II (soil 1 = Dense & soil 2 = Loose).

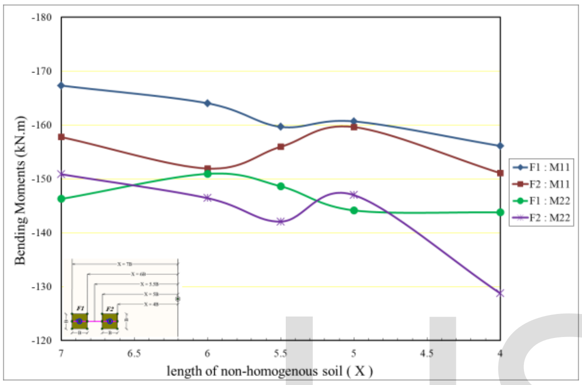

Fig. 29. The relasionship between length of replaced soil (X) and bending moments in both X & Y directions (M11 & M22) at the center of both footings (F1 & F2) for group group III (soil 1 = Loose & soil 2 = Dense).

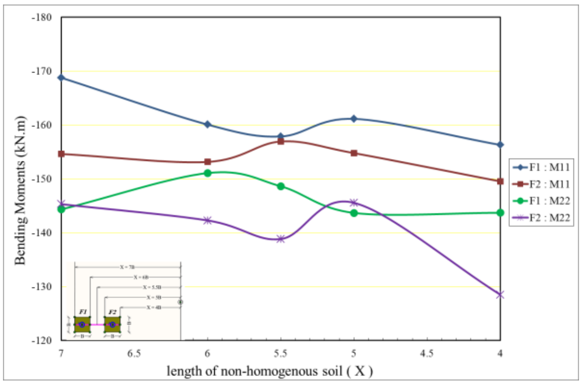

Fig. 30. The relasionship between length of replaced soil (X) and bending moments in both X & Y directions (M11 & M22) at the center of both footings (F1 & F2) for group IV (soil 1 = Loose & soil 2 = Medium).

vi. Effect of spacing (X) of the replaced soil on the bending moment at the centre of both footings (F1 & F2):

Figures (31) to (34) show copmparison between the bending moment at the center of both footings (F1 & F2) due to soil types compinations (dense, medium and loos sand) under isolate footings connected with tie beam and effect of X span of soil 2 to soil 1 as aparchart.

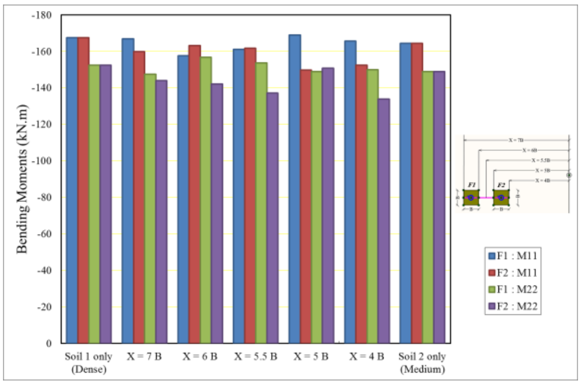

Fig. 31. Comparison between bending moments in both X & Y directions (M11 & M22) in the center of both footings (F1 & F2) for group I (soil 1 = Dense & soil 2 = Medium).

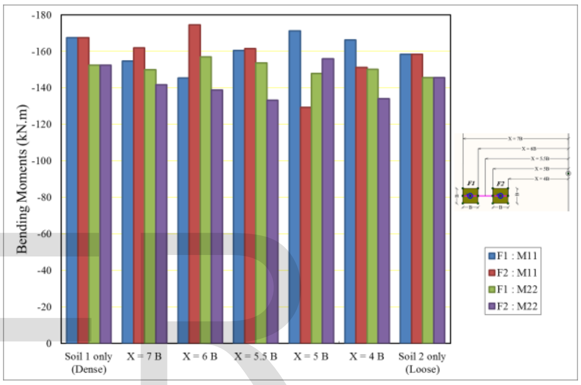

Fig. 32. Comparison between bending moments in both X & Y directions (M11 & M22) in the center of both footings (F1 & F2) for group II (soil 1 = Dense & soil 2 = Loose).

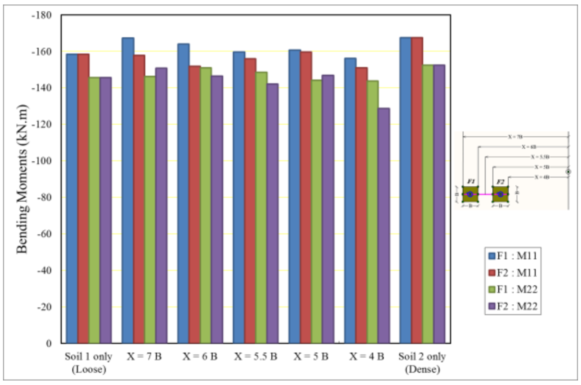

Fig. 33. Comparison between bending moments in both X & Y directions (M11 & M22) in the center of both zfootings (F1 & F2) for group III (soil 1 = Loose & soil 2 = Dense).

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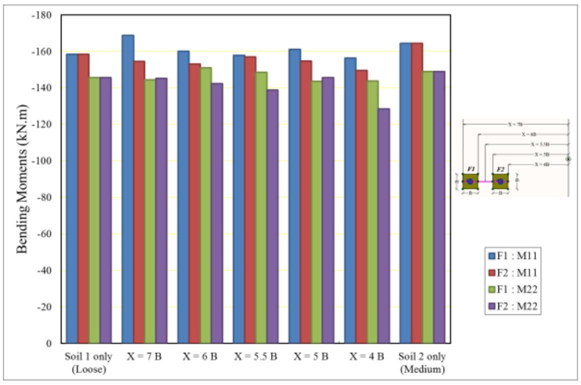
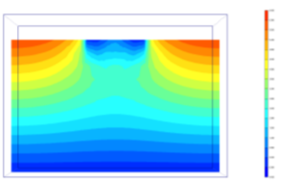
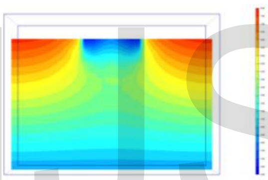


Fig. 34. Comparison between bending moments in both X & Y directions (M11 & M22) in the center of both footings (F1 & F2) for group IV (soil 1 = Loose & soil 2 = Medium).

vii. Effect of soil types on the vertical displacement profile in soli:

Figure (35) shows vertical displacement profile in soil for cases of footings connected with tie beam resting on dense, medium and loose sand.


a. Dense sand


b. Medium sand

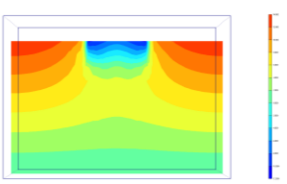
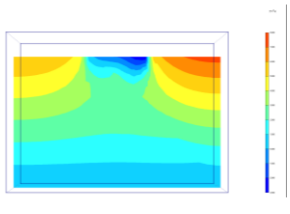
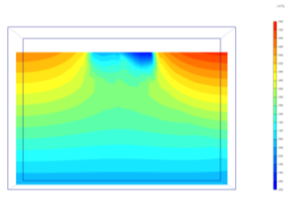
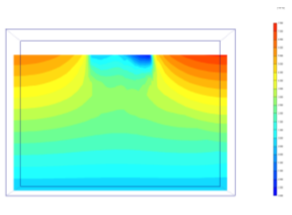

c. Loose sand

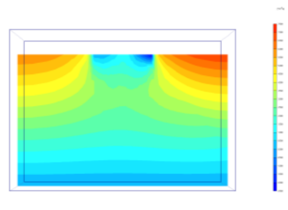
Fig. 35. Vertical displacement in soil for control group

Figures (36) to (39) show vertical displacement profile in soil for cases of footings connected with tie beam resting on non hemogeniouse soil (dense, medium and loose sand) and effect of X span of soil 2 to soil 1 as abar chart.


a. X = 7B


b. X = 6B


c. X = 5.5B


d. X = 5B

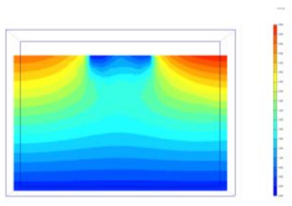
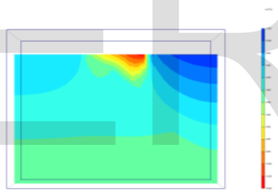
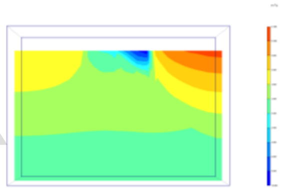
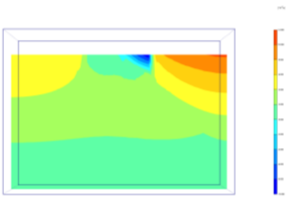
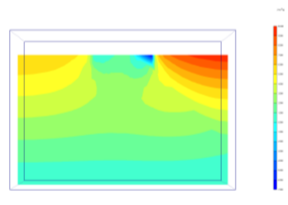

e. X = 4B

Fig. 36. Vertical displacement in soil for group I (soil 1 = Dense & soil 2 = Medium).


a. X = 7B


b. X = 6B


c. X = 5.5B


d. X = 5B

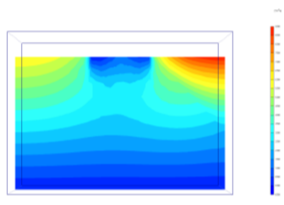

e. X = 4B

Fig. 37. Vertical displacement in soil for group II (soil 1 = Dense & soil 2 = Loose).

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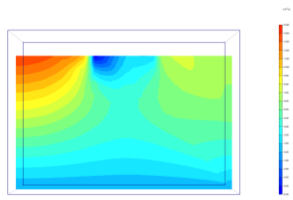
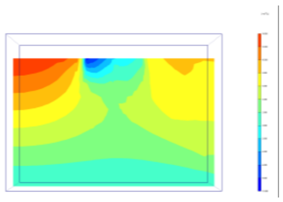
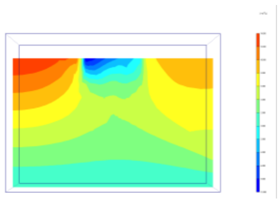


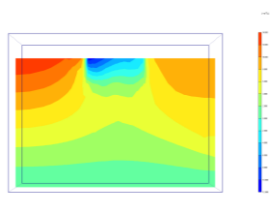
a. X = 7B



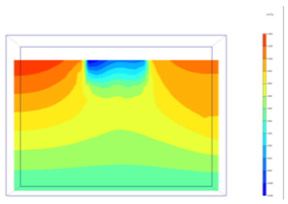
b. X = 6B



c. X = 5.5B

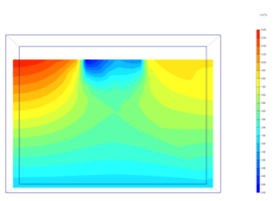


d. X = 5B

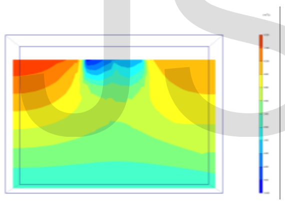


e. X = 4B

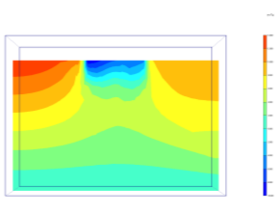
Fig. 38. Vertical displacement in soil for group III (soil 1 = Loose & soil 2 = Dense).



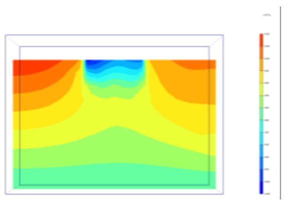
a. X = 7B



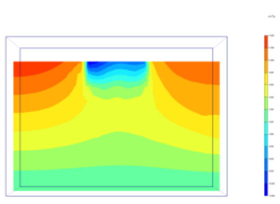
b. X = 6B



c. X = 5.5B



d. X = 5B



e. X = 4B

Fig. 39. Vertical displacement in soil for group IV (soil 1 = Loose & soil 2 = Medium).

4. Conclusions

From the present investigation, when comparing the results, the followings are concluded:

- Variation of replaced soil density change final straining actions of footings and tie beams
- Variation of replaced soil density lead to considerable vertical differential displacement and settlement of footings.
- Variation of replaced soil must be considered in foundation deign to avoid error in design.
- In case of replaced dense soil to loose soil, decreasing the length of replaced soil decreases the bending moments in both X &Y directions of footings.
- In case of replaced loose soil to dense soil, decreasing the length of replaced soil decreases the bending moments in both X directions of footings.
- In case of replaced loose soil, decreasing the length of replaced soil decreases the absolute maximum shear force along the tie beam length.
- In case of the natural soil deposit is dense, increasing the density of the replaced soil increases the maximum moment in X direction (M11) in footings.
- In case of the natural soil deposit is dense, increasing the density of the replaced soil has no significant effect on maximum moment in Y direction (M22) in footings
- In case of the natural soil deposit is loose, increasing the density of the replaced soil has no significant effect on maximum moment in X and Y directions (M11 & M22) in footings
- In case of the natural soil deposit is dense, increasing the density of the replaced soil decreases maximum moment and shear force of tie beam for in case of length of replaced soil ≥ 6B but almost has no significant effect in case of ≤ 5.5B
- In case of the natural soil deposit is loose, increasing the density of the replaced soil has no significant effect on the maximum bending moment and shear force of the tie beam.
- Future study for repair and strengthening of foundation resting on replaced soil with variable density must be applied.

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