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Static interaction in soil – pile - cap system using three-dimensional analysis

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ABSTRACT

A value of interaction load along the pile shift in the pile foundations design is an important factor in calculation of the bearing capacity and consequently, not taking the interaction load into consideration cased an increase in the piles lengthy and then cost increased. In this paper, was studying the effect of skin friction on behavior of soil- raft foundation, (soil -single pile – cap) system and (soil – 2 piles group- cap) system is investigated and analyses using Abaqus software (is a 3D finite element). Parameters studied were raft footing thickness, length of square concert pile in the (soil-single piles –cap) system, the spacing ratio in the (soil-2 piles –cap) system. It was intended to investigated the skin friction distribution around the pile shaft for the (soil-single piles –cap) and (soil-2 piles –cap) system. The results showed that the mobilized interaction among raft footing and clay soil caused increases in raft capacity and reduce the value of vertical settlement compared with frictionless soil raft model and the interaction load value (skin friction) increased with increasing in raft thickness. The percentage of the increases in load capacity due to interaction mobilized was 43% compared with frictionless case. There was a clear difference in capacity load for mobilized interaction case compared to the absence of interaction between single pile and cap with soil. This increase was clear when the length of pile is more than 10 m, and this increased reaches about 67%. The distribution of interaction load along the pile shaft is linear where the interaction load is equal to zero at the head of the pile. The interaction load begins to increase when the length of pile increases. Highest value for interaction load was at the end of pile.

Keywords: Finite elements, pile, interaction, raft foundation, three-dimensional analysis.

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1 Introduction

Foundation system is the most important aspect for a civil engineering project. For a safe, efficient, and economic project of the foundation system designing should be carefully and properly. For that, the system of foundation design is considering as the most important and critical stage before starting any construction project. Until recently, most of the foundation engineers used shallow foundations (rafts) and deep foundations (piles) each one separately. Now, geotechnical engineers preferred to use these two systems together. Geotechnical engineers through combining these two systems provided the important parameters for designing to obtain safely and more economical solution. Several authors studied piled raft foundation in experimental and analytical work by different materials such as concrete model Katzenbach et al.in [1] steel model Fleming et. al in [2] and aluminum model Park et al in [3].

Liu and Novak in [4]:worked on the static interaction of the pile-soil used finite and infinite elements combination models.
Prakoso et al. in [5]: stated the results of the piled-raft foundation for elastic linear. Also, nonlinear plane strain for the piled-raft used models of finite element. The influences of the capacity compression of the raft and the pile group on the settlements, bending moments, and raft- pile ratio of the transfer load evaluated.
Maharaj in [6] : presented the results of the ultimate capacity load in the flexible raft was improved related to increase in soil modulus and length of pile using the analysis of three nonlinear dimensional finite element for raft-piled foundation. Found that when increasing modulus of soil and length of pile the ultimate capacity load for raft flexibility will be improved. Also, it increased the modulus of soil reduced the overall settlement and increased differential settlement.
Tan et al. in [7] : worked on the influence of use raft-pile system for different lengths of pile in a very soft clay for a building of five story. The implemented of a monitoring scheme for a structure was successfully.
Zhao et al. in [8]: worked on piled raft foundation to develop a method for calculated settlement for pile composite (short and long).
Ye et al. in [9]: worked on a number of numerical analyses models used an FEM by DBLIVE software for simulated the soil properties.
Fioravante in [10];[12] & Rasouli et al. in [11] worked on the Several tests used centrifugal model exploited the load mechanism transfer in the disconnected rafts piles state.
Poulos et al. in [13]: stated the design of the pile raft required fewer piles in comparison to the design of the pile group to reach the same requirements for settlement and capacity.
Zhang and Shi in [14]: the cushion pile-piercing model was constructed, as calculation method for soil–pile interaction. The models used to propose a theoretical calculation method for the ratio of the-stress of the soil-pile.
Al-Shayea and Zeedan in [15]: presented way to design raft foundation used model of three dimension for all parts of the structure individually and considering the interaction of the soil structure. Clarifying a relationship between the raft thickness and the number of design parameters including type of soil using charts.
Fattah et al. in [16]: found from the finite element analysis that the dissipation of the pressure excess pore water beneath piled raft foundation resulted from considerably affects the foundation final settlement. Attention must be paid for the settlement-time variation. Behavior of the settlement for unpile raft showed a shaped bowl for settlement being the maximum value at center. The raft curvature degree for vertical load increased with the decreased of the raft thickness.
Fattah et al. in [17]: found that when the pile group with small (less than 4), no contribution evident of raft to load carrying capacity. Load failure for pile raft consisted of nine piles was 100% approximately greater than group of pile without raft have the same number of piles. The difference increased to about four times for 16 pile group. Piles worked effectively as settlement reducers when the number of piles greater than 6 in comparison to the number of piles less than 6.
Tradigo et al. in [18]: the accuracy and applicability for the embedded pile to DP rafts in the first time was studied. In the embedded pile method and in the solid pile method settlement value was noted were nearly the same value.
In this paper, a model is constructed for studying the skin friction effect on behavior of raft footing, soil -single pile – cap system, and soil - 2piles group- cap by modeling and analyses the work using Abaqus software (is a three-dimensional finite element analyses software). Parameters that will be studied are thickness of the raft foundation to obtain the optimum value will give the maximum value of the bearing capacity and the minimum settlement value with and without assigning interaction properties and obtain the value and distribution of skin friction under the raft for optimum value of thickness. In addition, the length of square concert pile is changed to obtain the optimum value which will give the maximum bearing capacity and minimum value of settlement with and without assigning interaction properties and obtain the value and distribution for friction of the skin around the pile shaft for optimum value of length of pile.

2 Testing program and numerical model

2.1 Definition of the model geometry

The three-Dimensional (3D) models are simulated in Abaqus program of the soil – pile – cap system consists of a solid element which is used to represent the cap (raft footing), pile and soil, the model idealization shown in Figure 1. The model geometrical dimensions are presented below.

- Cubic clayey soil body: area (50X50 m) with depth 60 m.
- Square raft foundation with dimensions (5 x 5 m).
- Pile with length (10, 15 and 20 m), square cross section and both the single and the group of piles situated at the soil cubic center.

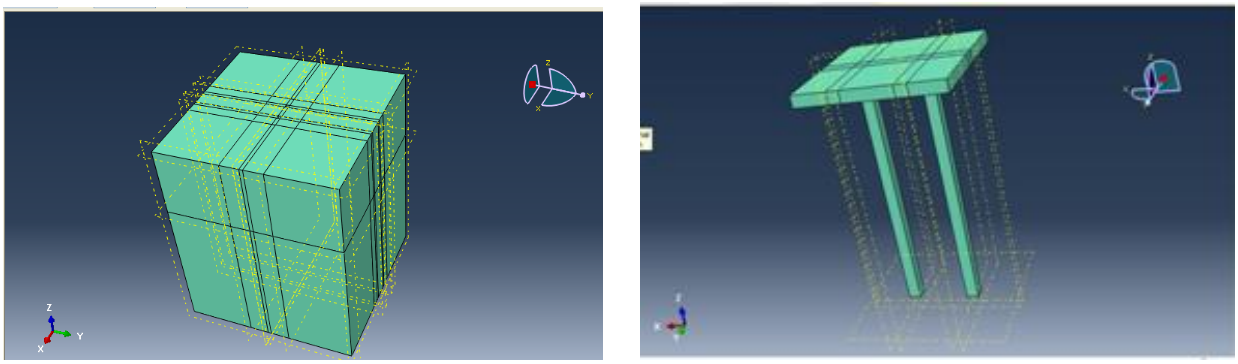

Figure 1. Geometry of soil body and 2-piles – cap

2.2 Properties of material

Table 1 showed the material properties for each individual portion of model like: raft footing, piles, and layers of clay soil. The pile and pile cap assumed to behave as linear elastic linear. Also, soil material behavior was simulating use material model modified Drucker-Prager (elasto-plastic). In Tables 2 and 3 are listed in the data and the factors are used to explain the behavior of the soil and the hardening cap using Abaqus software.

Table 1. Pile and raft properties

Property	Value
Modulus of elasticity, kPa	$2x10^7$
Poisson's ratio	0.17
Unit weight, kN/m^3	24

Table 2. Soil parameters used for Abaqus software

Parameter	Value
Eccentricity of cap (R)	0.9
Ratio of flow stress (k)	1
Yield surface for Initial cap	0
Radius of transition surface	0.04

Table 3. Yield stress values and volumetric strain

Yield stress, kPa	Volumetric plastic strain, %
300	0
400	0.03
600	0.06

2.3 Parts assembly, assigning interaction properties and mesh choosing

Figure 2 obtained the interaction effect between surfaces for determining the interfaces behavior. It needed to be assigned the properties, also setting the normally relative motions between surfaces. Rough is an interaction behavior tangentially. In other word no slip can occur, the relative velocity among surfaces equal to zero. In this case, it was assumed that the interaction among pile and soil is rough for clarifying assuming a full adhesion among the concrete surface and sand. In Abaqus, a mesh of model type C3D8R used with 8-node linear hexahedral element and the total number of elements is (22392) as shown in Figure 3.

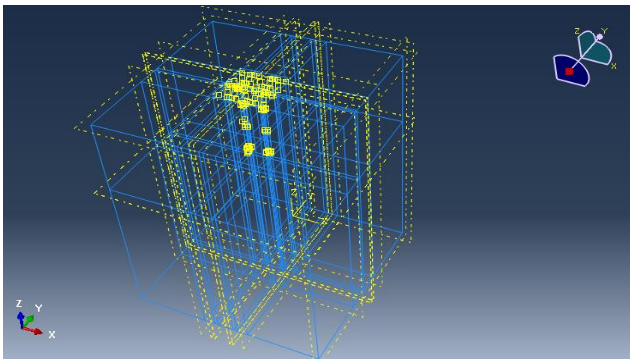

Figure 2. Assembly parts of model and assigning interaction properties

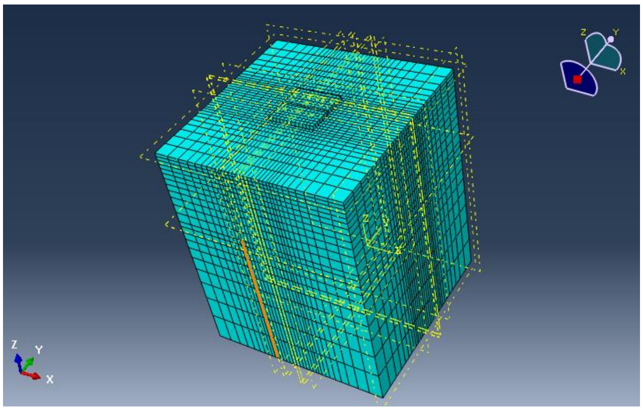

Figure 3. The meshing of the model

2.4 Applied loads and boundary conditions steps

Figure 4 showed the great steps of applying incremental of static (general). At the concrete cap node center, the load is applied. Assuming a boundary conditions are displacement and rotation for preventing movement in all sides direction (x, y) with fixing bottom model movement.

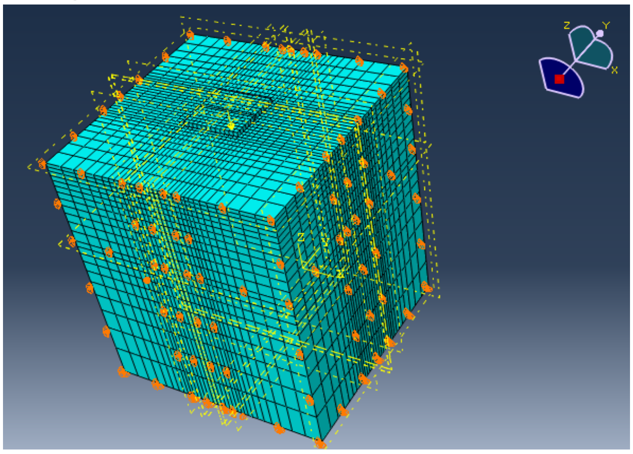

Figure 4. Defining loads and boundary conditions

3 Results and discussion

3.1 Effect of soil-raft interaction

Some model of the concrete footing with soil which is modelled with different thickness (t = 0.25, 0.5 and 1 m) at the case of interaction is presented or not. In Figures 5and 6 the analysis results are shown. In general, it could indicate increased load capacity with increasing in raft thickness due to increase in the rigidity (EI) value of raft footing. When the interaction is mobilized between raft footing and the clay soil, it cases to increase in raft capacity and reduced in the value of vertical settlement compare with frictionless soil raft model.

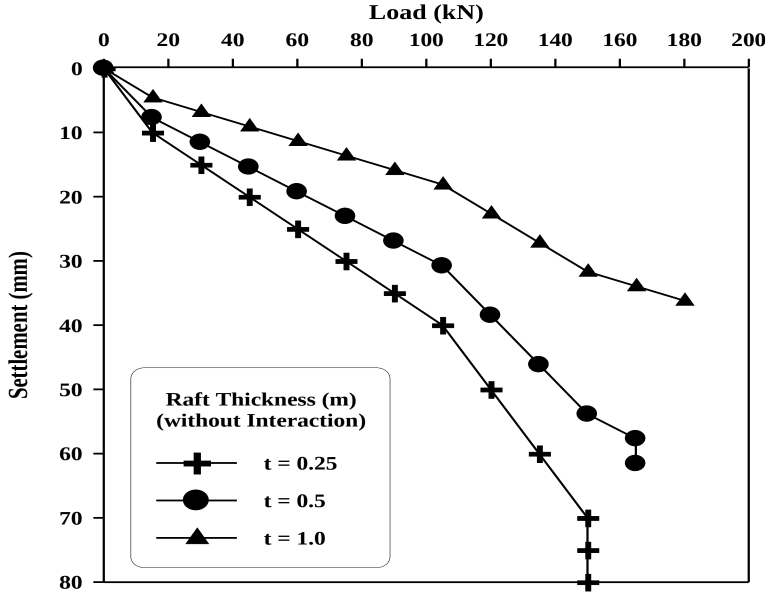

Figure 5. The load capacity versus settlement at different raft footing thickness at frictionless case.

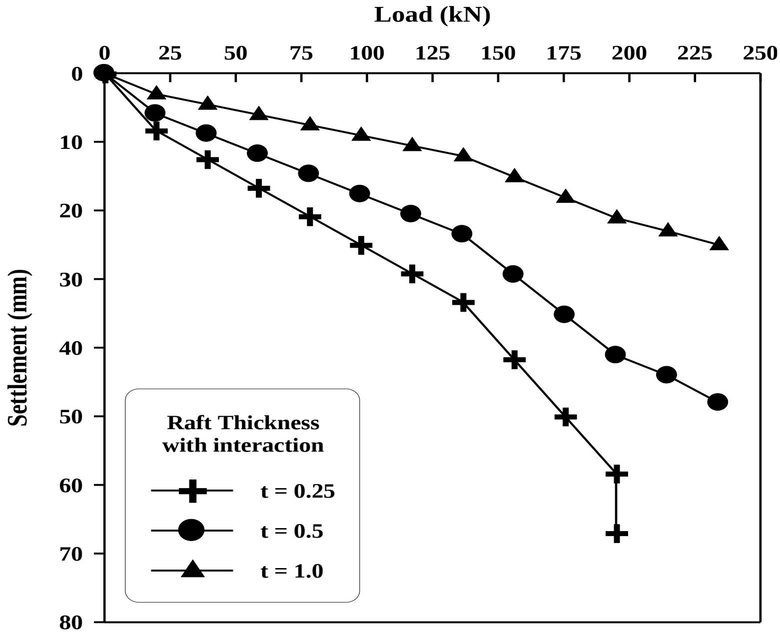

Figure 6. The load capacity versus settlement at different raft footing thickness at interaction case.

To show the mobilizing friction (interaction effect) effect between footing base and clay soil on the load capacity of the footing, a relation was drawn between the maximum load and the footing thickness in the case of the interaction if modeled or not as shown in Figure 7. The results showed that the interaction load value (skin friction) increased with the raft thickness increasing and the percentage increases in the capacity of load due to mobilized interaction was 43% compared with frictionless case.

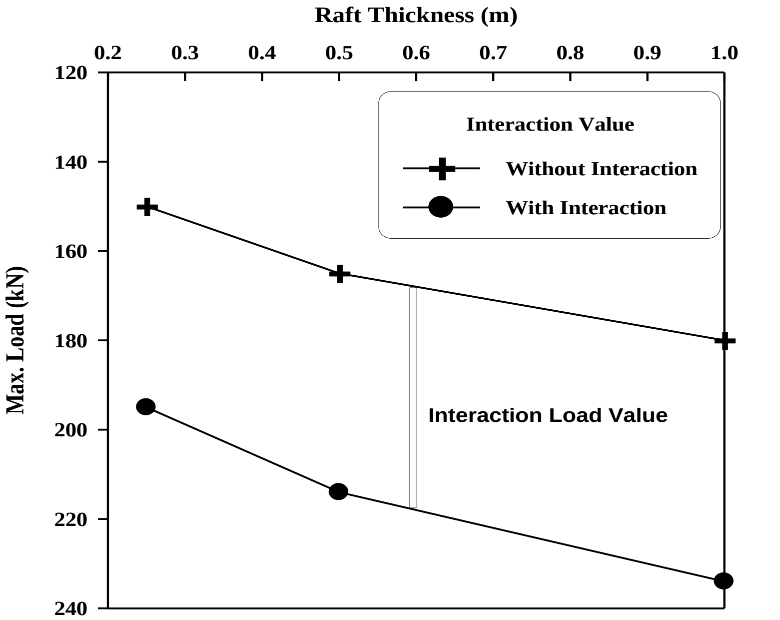

Figure 7. The maximum load capacity versus footing thickness

Figure 8 illustrated the distribution of interaction load under the base of the footing at footing thickness (t =1.0 m). It can be seen tha the non-distribution uniform of the load interaction under the footing base. It is noticed that the highest value of the load interaction is below the middle of the footing and then begin to decrease as it approaches the edge of the footing.

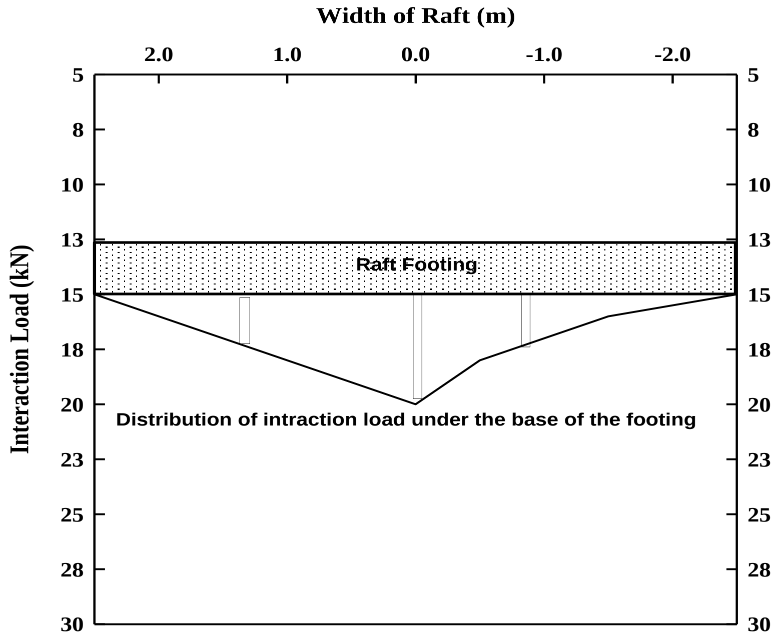

Figure 8. The variation of interaction load under the base of the footing

3.2 Soil-single pile – cap interaction system

Figures 9 and 10 showed the effect of soil-pile-cap system interaction on the settlement and the load capacity when the pile length is changed from (L = 5 to 10 and 15 m). In general, increasing the pile length cases to an increase in load capacity with reduction in the settlement for system of soil – pile-cap. It can be seen from above figures, there is a clear differences in the capacity load in the case of mobilized interaction compared to the absence of interaction between the pile and cap with soil, and this increase is clear when the length of pile is more than 10 m and that this increase reaches about 67%.

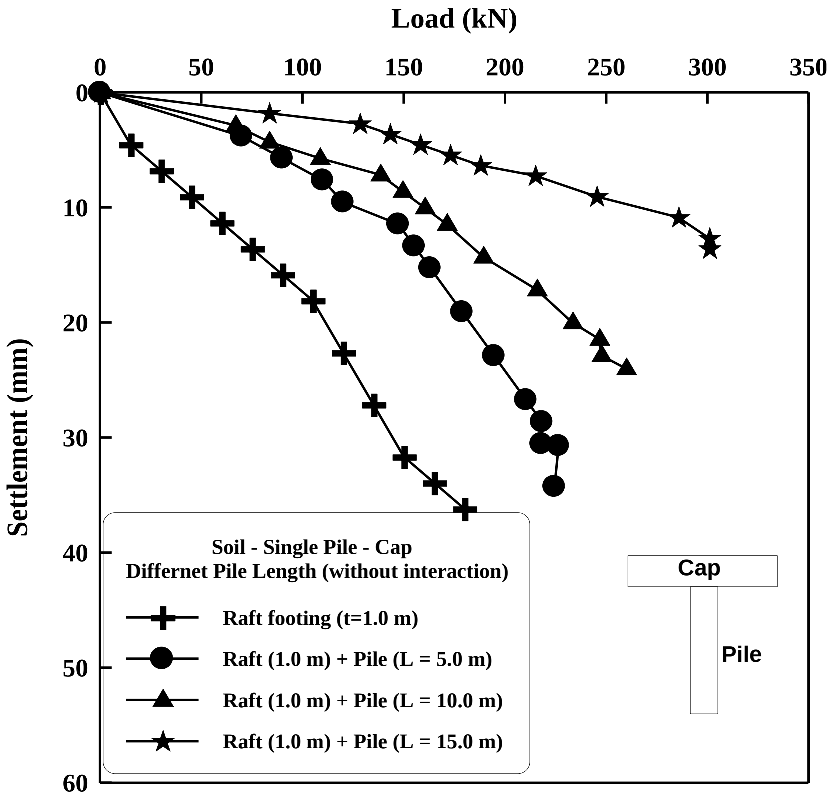

Figure 9. Load versus settlement when interaction is not modeled for different pile lengths

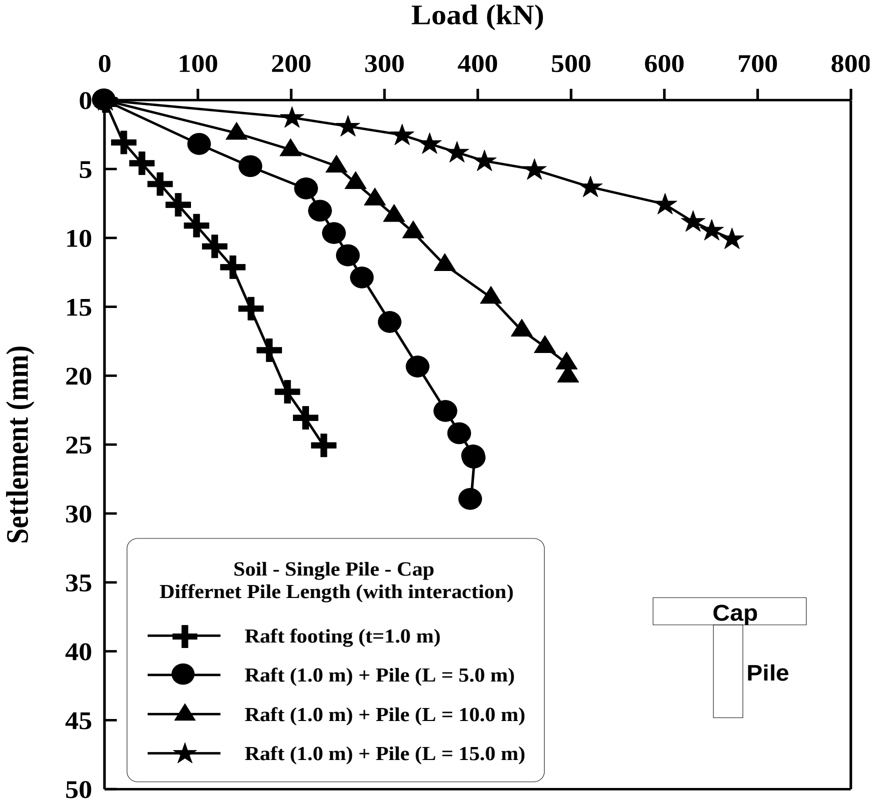

Figure 10. Load versus settlement when interaction is mobilized using different pile lengths

Figure 11 obtained the maximum load variation pile length on the soil – pile – cap system, in the case of friction or its absence. It can be seen clearly that the interaction load value increased with increasing the length of pile and also it is clear in the interaction load when the length of the pile is more than 10 m.

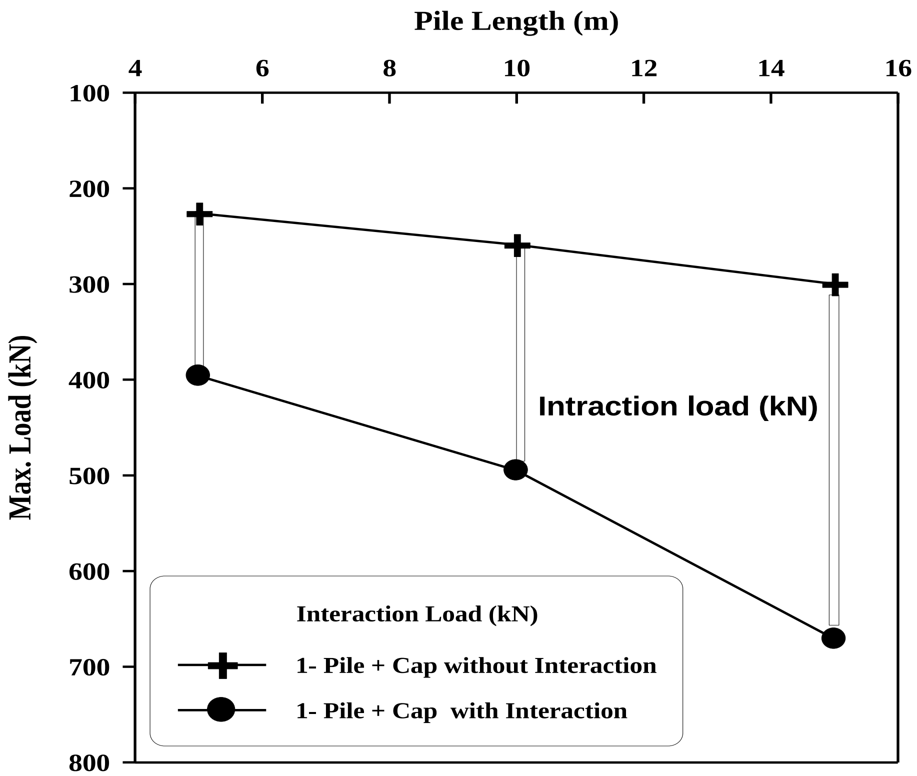

Figure 11. Maximum load capacity versus pile length

The distribution of the interaction load (skin friction) along the pile shift can be presented as in Figure 12. It could be observed that the nearest distribution of load interaction along the shaft pile should be linear distribution where the load interaction is equal to (zero) when the depth is equal to zero (at the pile cap) and the interaction load begins to increase as the pile length increases and highest interaction load value is at the end of pile, in other words, the interaction load value depends mainly on the length of the pile.

Figure 12. Distribution of interaction load along the pile shift

3.3 Effect of spacing ration in soil-piles-cap system

Figure 13 showed the load capacity of soil-2 piles – cap system with variation of the spacing ratio (s/d) between the piles (s/d =1.5, 2.5, 3.5 to 4.5). The results showed that increasing the spacing ratio from (1.5 to 2.5 and 3.5) leads to increase in the value of interaction load and the highest value of the interaction load recorded when the spacing ratio between piles is (s/d =3.5) and the lowest value of interaction load is recorded when the spacing between piles is more than (s/d = 4.5).

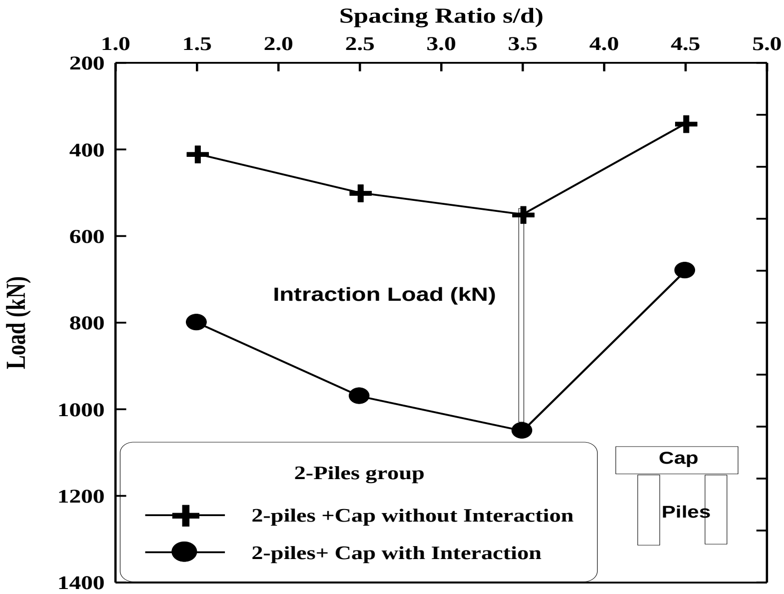

Figure 13. Pile load capacity versus spacing ratio for soil-2-piles-cap system

The distribution of interaction load around the pile shaft of the two piles in the soil-2-piles – cap system when the spacing ratio (s/d = 3.5) is presented in Figure 14. It showed the distribution of interaction load is approximately linear where the lowest value of load interaction is obtained when the length of the pile is equal to (zero) and the load of interaction begins to increase with increasing the pile length to the greatest value at the pile end. From above figure, it can be noted that no overlapping occurs with the interaction load distributed along the shift of the two piles, which leads to this spacing ratio (s/d=3.5) being the best spacing ratio giving the highest interaction load and maximum bearing capacity of the (soil – 2 piles – cap) system.

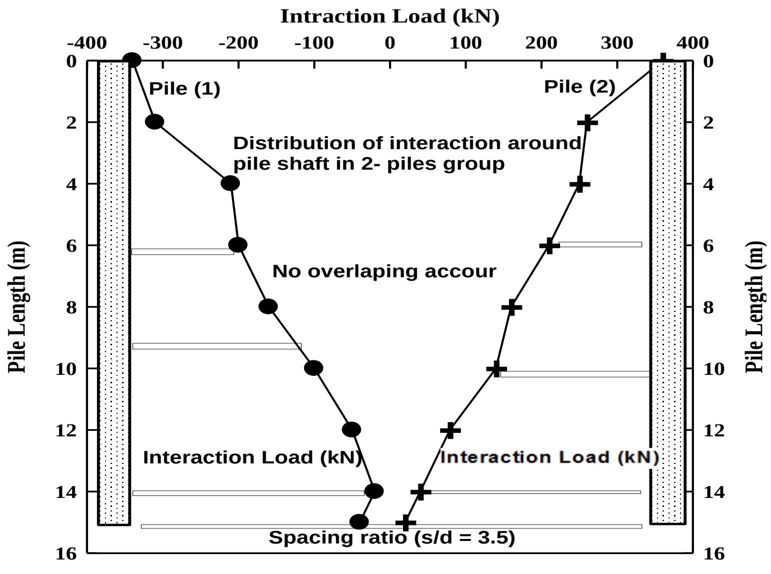

Figure 14. Distribution of interaction laod for soil-2-piles-cap system

Figure 15. Illustrated the deformed shape of raft footing resting on the clayey soil and (soil- single piled – cap) system under static concentrated vertical load.

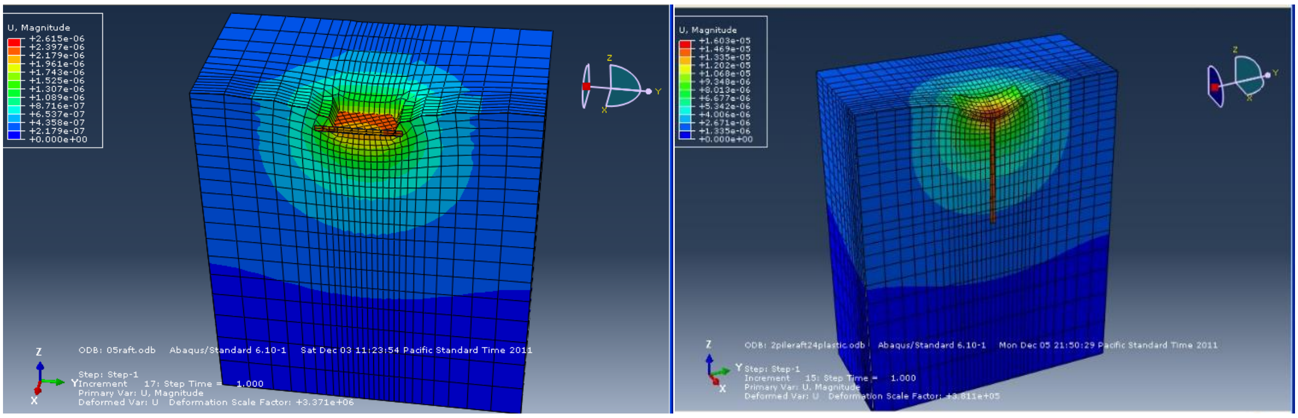

Figure 15. Deformed shape of raft footing and (soil- single piled – cap) system

4 Conclusions

- The interaction mobilized between raft footing and the clay soil causes increases the capacity of raft with the reduce in the value of vertical settlement compare with frictionless soil raft model. The interaction load value (skin friction) increases with increasing the thickness of raft. The percentage increases in the load capacity due to mobilized interaction which is 43% compared with frictionless case.
- There is a clear difference in capacity load in the mobilized interaction case compared to the absence of interaction between the single pile and cap with soil, and this increase is clear when the length of pile is more than 10 m and this increase reaches about 67%.
- The nearest distribution of interaction load along the pile shaft is where the interaction load is equal to (zero) at the length head and the interaction load begins to increase related to the increases of pile length. The highest load value of interaction is at end of the pile.
- It increases the spacing ratio from 1.5 to 2.5 and 3.5 in (soil – 2- piles- cap) system leads to increase in the value of interaction load and the highest value of the interaction load is obtained when the spacing ration between piles is (s/d =3.5).
- The lowest value of interaction load is recorded when the spacing between piles is more than (s/d = 4.5), no overlapping occurs with the interaction load distributed along the shaft of the two piles, the spacing ratio (s/d=3.5) is the best which gives the highest interaction load and maximum bearing capacity of (soil – 2 piles – cap) system.

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