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Evaluation conduct of deep foundations using 3D finite element approach

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Abstract: In most practical situations, the pile either include circular or rectangular cross-section. The pile with circular cross-sectional shape usually analyzed in previous studies and little for the second type. While, no studies included comparison between those common types to understand and recommend which is batter for case of deep foundations. Therefore, this study is mainly deal with the vertical pile response under vertical load (i.e. no horizontal loads) when take into account the shape factor. To achieve the objective of this research, 3D finite element approach has been used to simulate the whole deep foundation case study. This study includes many factors, such as pile depth that measured below ground surface, soil strength parameter and soil types. It can be seems that little influence of shape factor on the vertical performance of deep foundation. Therefore, it can be recommended that if no any source of lateral load, it can be used any type and it is depending only on cost of pile types.

Keywords: Deep Foundation, Shape, Vertical Load, Pile Depth, Soil Type

1. Introduction

In fact, from long time ago the projects at that time were mainly containing deep foundation. Therefore and due to the projects been huger and this mean the deep foundation should be magnified to carry these mega structures in case of shallow foundation are not suitable (Prakash and Sharma 1990).

Usually the deep foundation is very expensive compared with other types of foundation like shallow foundation or mat foundation. Therefore it is not easy to select these types of foundation. Thus, this type of project needs more accurate results of soil investigations and soil profile. Depend on this and load condition the number of piles and its arrangement can be fixed. In this case, the piles can reduce the settlement that maybe occurred during loading of certain mega structure (Bowles et al. 1997).

Consequently, this research is mainly included the deep foundation settlement and earth resistance under vertical load only. The study take into account the cross sectional shape of pile. In addition the depth of pile from ground surface. The free-headed pile condition is also taken in this research. Finally the soil with different layers is used to represent the case closed to the actual projects. The objective of this research has been achieved according to the problem statements. The results section is included all important assessment of such deep foundation cases.

2. Methodology

In this study the linear elastic model has been used to represent the concrete part of the pile group. While, Mohr-Coulomb model has been used to represent the surrounded soil. This model is based on soil parameters that are known in most practical situations Johnson et al. [9, 10]. Pile-structure interface has been represented using 16-node interface elements. Interface elements consist of eight pairs of nodes.

PLAXIS 3D has been used for this study, in this program the 3D meshes is formed and this consisting of 16-nodes wedge element as shown in Figure 1. The pile cross sections for both circular and rectangular section are take D=1m and W=1m, respectively. In addition the depth of pile is represented by L and measured from ground surface that taken for four values (i.e. 10m, 15m, 20m and 25m). The soil mass that used in this study is cube and all dimension are depends on the pile geometry. For example the lateral dimension is 20 times pile diameter in both sides, while the vertical dimension is equal to pile depth plus 5 times the pile diameter under bottom of pile.

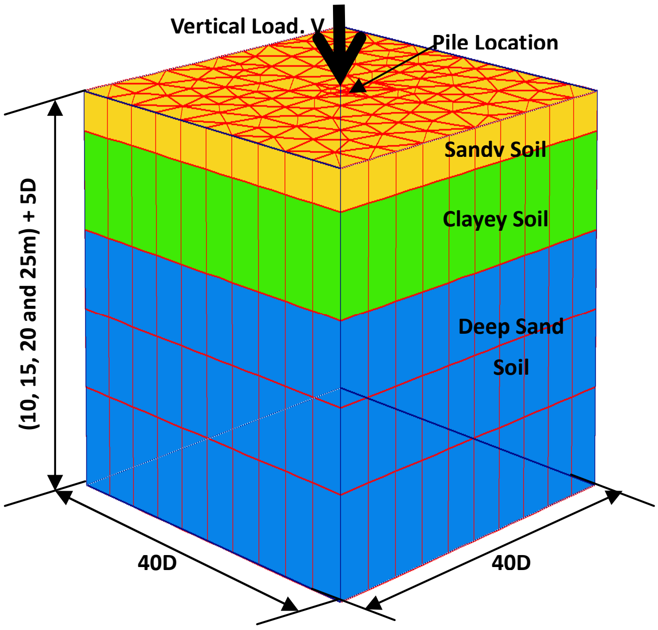

Figure 1 *Three dimension finite element mash for single pile and surrounded soil mass*

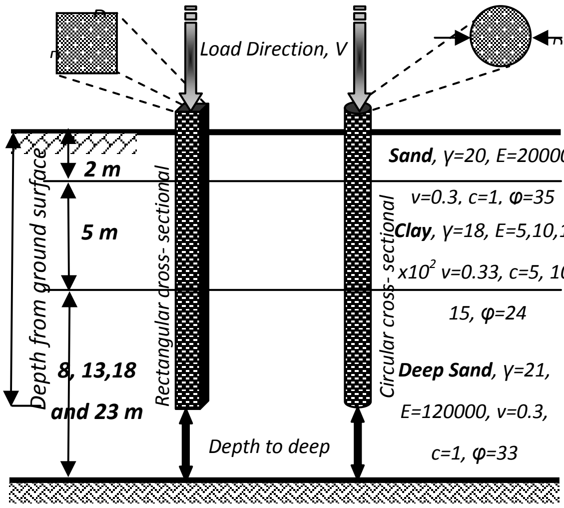

Figure 2 *plan and profile views of an idealized prototype*

3. Results and Discussions

This case of deep foundation that included both the piles and surrounded soil in addition to the pile-soil interaction has been deal with using numerical method. This numerical method was included three-dimensional finite element approach. In fact this method is usually used to solve the complex systems. Therefore to achieved the objective of this study, the study include different amount of loading and this is represented the low intensity of loading to high intensity of load. In addition to evaluate both, shape factor and soil profile.

In this part, the significance of showing a necessary assessment is customary. A major study is completed on the vertical pile response under pure vertical load and also achieved using changing model parameters of the material of structural part like geometric dimension of the pile; for example by changing the depth of piles as well as specification of surrounded soil the properties of three layers for example the Poisson's ratio, Cohesion intercept and angle of internal friction. Furthermore, this manuscript correspondingly involved, vertical pile displacement when the foundation carry only pure vertical load as well as the investigation likewise consist the evaluation of load-settlement relationship for layered soil.

Figure 2 shows plan and profile views of an idealized prototype of vertical pile with diameter and width, D and depth from ground surface L. Assumed that the pile tip is at the ground surface level. The soil is suggested as mutli-layered soil type. The water table assumed reached to the ground surface. This case is closed to real and also represent the worst situation of such type of foundation.

Commonly, the material of whole geotechnical system such as concrete part and the surrounded soil are influenced on the response of such deep foundations. In addition the dimension of piles such as depth from ground surface and cross section value are also one of the key of the behavior of deep foundation.

Correspondingly the soil properties such as cohesive intercept and Young modules are similarly necessary to modern research. In the face of the statement that these elementary properties are simple to be documented as important, their influence on vertical response is further problematical to quantify. The research achieved the influence of pile and soil specifications when the pile is carry only pure vertical load. Totally necessities that involved in this manuscript are completed by numerical investigation of the vertically loaded piles and cover the subsequent limitations: (a) the vertical load were begin from small intensity of 20% from maximum vertical load and reached to 100% from the expected vertical load. (b) two pile cross-sectional shapes (usual circular shaped and rectangular shaped). (c) three layer soil profile was used with sandy soil in upper part, and then clayey soil at the middle and the deep sand in the bottom of soil skeleton. (e) the pile depth measured from ground surface was 10m, 15m, 20m, and 25m. The analysis consists of modeling of single pile using linear-elastic model with 15-node wedge elements. The cross-section of the pile is circle and rectangular with a diameter and width of 1.0m, respectively. The drained soil condition was used in this study which represents the case of dissipation of pore water pressure (i.e. the end of consolidation stage). The baseline soil parameters used for the analysis of vertical loaded pile were included Unit weight (γ'), Young's modulus (E'), Poisson's ratio (ν'), Cohesion intercept (c') and angle of internal friction (ø') are all described by detail inside Figure 2. The axial pile settlement and soil resistance due to the axial load is always influenced by axial load intensity and soil as well as depth from ground surface. Figures 3 and 4 were presents the effect of vertical load magnitude and soil parameter on the settlement response of pile along the pile length for four piles of pile depths. For the pile depth more than 15m, give a significantly great quantity of vertical settlement for the equal value of vertical loading. The settlement among the pile is usually in the direction of load (assumed negative).

3.1. Influence of Pile Length

The influence of pile length on the vertical pile settlement was calculated by a fixed pile diameter (or width) and changing on the pile length from 10m, to 25m. In addition, two pile shape (i.e. circular and rectangular). The soil and pile parameters were kept unchanged. The influence of pile depth and shape on the vertical pile settlement was shown in Figures 3 and 4. A comparison for four pile depth of pile under five load intensities namely, 20%, 40%, 60%, 80% and 100%, were completed. At the small load amount, very little variations were detected on the vertical pile settlement with respect to the pile depth.

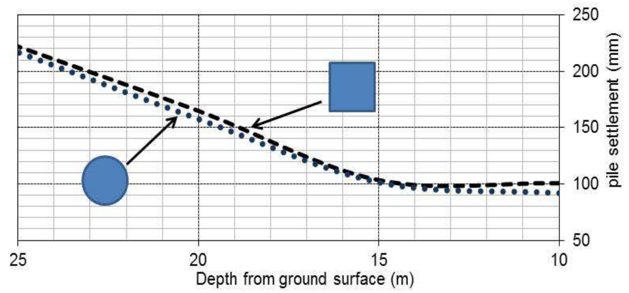

Figure 3 *Predicted pile-head settlement vs. pile slenderness ratio for different pile shapes*

An equation have been developed according to the design curves to compute the amount of settlement as a function of both pile depth and pile diameter (D) under the effect of the vertical loads, given in the form of:

$$\delta = A\ln\left(\frac{L}{D}\right) - B$$

Where **δ** is pile head settlement, L is pile length and D is pile diameter. A is equal to 134.8 and B is equal to 282.7 for circular cross sectional pile shape. While A is equal to 138.37 and B is equal to 239.3 for rectangular cross sectional pile shapes.

3.2. Shape Factor

Two cross sections have been considered in which has been compare the response of rectangular/square and circular piles. Figure 4 shows the vertical pile settlement of 10, 15, 20, 25m circular pile shape with 1m diameter and of 10, 15, 20, 25m rectangular pile shape with 1m x 1m.

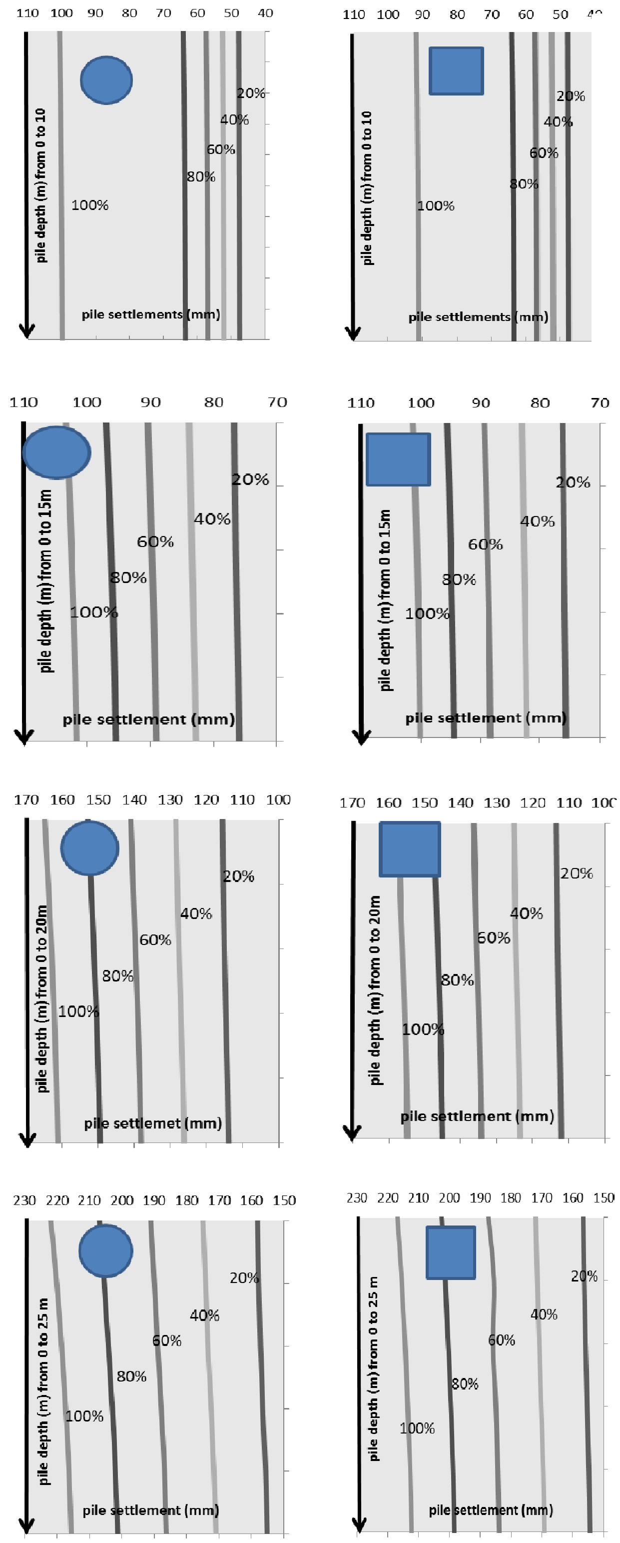

Figure 4 *Influence of axial load magnitude on the pile settlement*

The circular and rectangular piles were subjected to 20%, 40%, 60%, 80% and 100%. Correspondingly plotted in the figures were the responses of a pile with the same properties and loads. Comparison the results of two shapes has been done and it can be founded the settlement of the rectangular piles is less than those of the circular piles, but this comparison was very little. Although the vertical force profiles with depth were almost independent of the shape.

3.3. Design Curves

The Load-Settlement curves expected from finite element at head of pile for this case study were shown in Figure 5. From this figure, the load settlement curves predicted from finite element analysis for the pile with depths of 10, 15, 20, 25m with circular and rectangular pile shape show different responses based on shape. It can be seems that the curves shows the more differences from two shapes in case of 10m depth and 100% load intensity.

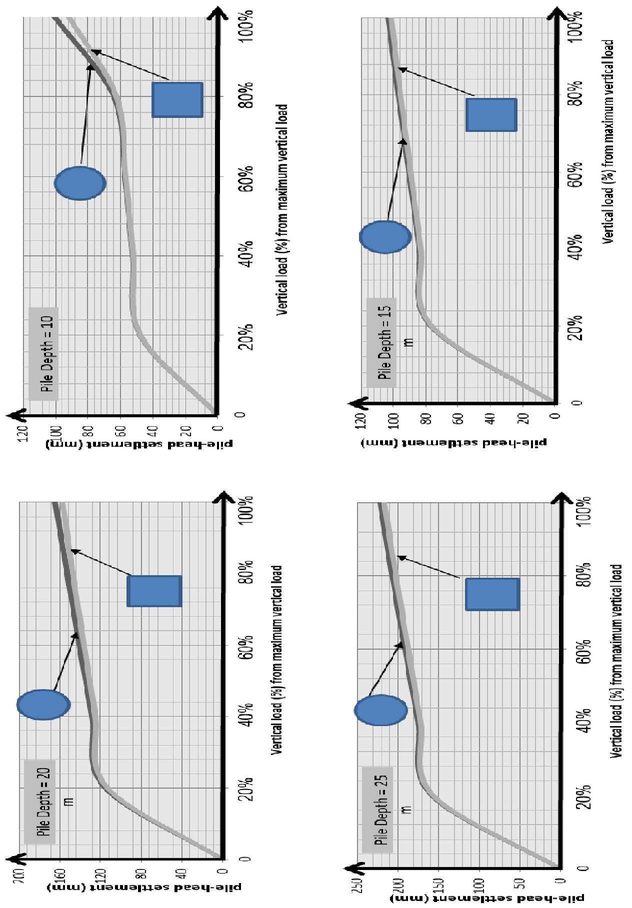

Figure 5 *Predicted Load-settlement curves for different pile shape*

3.4. Influence of Cohesion Intercept

The soil properties are one of the key aspects affecting the performance of vertically loaded pile than any other geotechnical factors. The main well-known parameter for cohesive soil is cohesion intercept (c). In this part, the effect of this factor on the vertical pile settlement has been discussed for the vertically loaded pile situation.

The effect of the cohesion intercept (c) of middle soil layer on the pile settlement was assessed by test various magnitudes. Three different cohesion intercepts (i.e. 5, 10 and 15) has been used in this part. These values were tested separately and drawn together for the five load magnitudes and two shapes of pile (i.e. circular and rectangular).

Figure 6 shows the influence of the cohesion intercept with pile depth on the pile response. It can be seen that the cohesion intercept affected on the vertical pile settlement. Figure 6 shows the vertical pile settlement with the depth. The pile settlement changed when the value of cohesion intercept was different from c=5 to c=15. Finally, Figure 7 shows the predicted Load-settlement curves under the effect of different cohesive intercept of the soil (i.e. circular pile shape and rectangular pile shape) under the effect of cohesion intercept value (c) at depths of (z=15m) where Large effect of the cohesion intercept value can be observed at 100% Less effect of (c) occurred when the 30% .

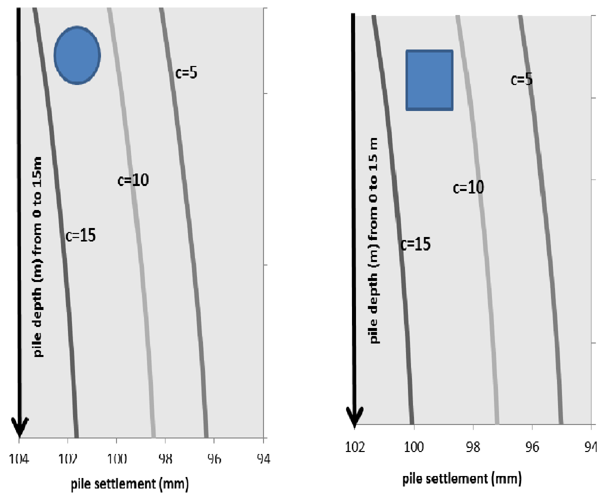

Figure 6 *Influence of the cohesive intercept on the pile settlement*

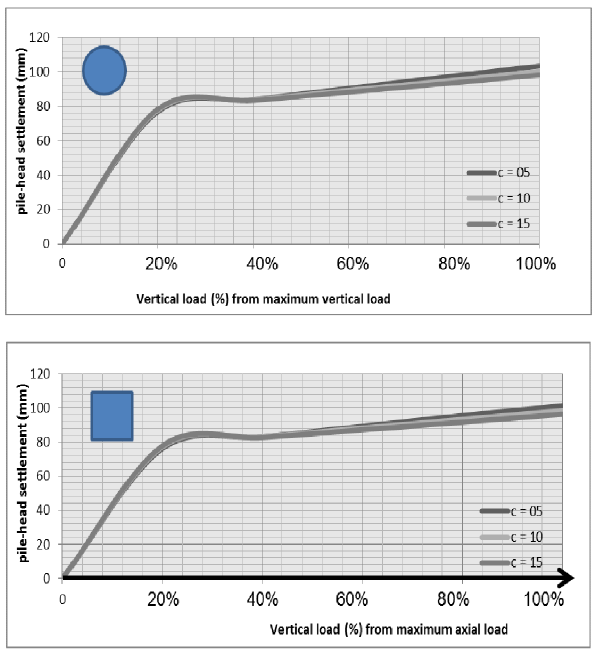

Figure 7 *Predicted Load-settlement curves under the effect of different cohesive intercept of the soil*

3.5. Influence of Modulus Elasticity of the Soil (E)

The vertical pile settlement observed from different magnitudes of Elastic Modulus (E) and from two different shapes was illustrated in Figure (8) at the middle layer. This results for pile depth of 15m only. This can be used to predict all other depths (e.g. 10m, 20m and 25m). Shown in Figure 8 was the measured pile settlement with depth for the pile length of 15m for both used shapes. It was observed the pile with low value of modulus elasticity of the soil (E) settles higher and more critical than the pile with high value of modulus elasticity of the soil (E). Therefore, the pile in the second case supported additional vertical load compared with the pile in the first case. Although, piles with rectangular cross section settles lesser then circular pile shape.

The load settlement curve resulted from this simulation at depth (z=15m) for two cross sectional shapes were illustrated in Figure 9. It can be found that the performance of pile with various elastic modulus of surrounded soil (E) is usually influenced by vertical load. Therefore the piles were sensitive to magnitudes of elastic modulus of the soil (E) in different depths.

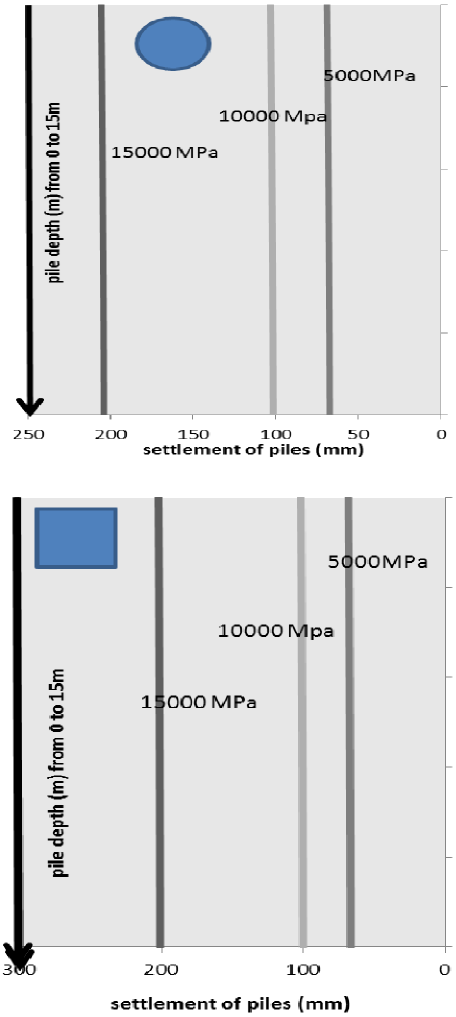

Figure 8 *Influence of the modulus of elasticity on the pile settlement, pile depth= 15,*

4. Conclusion

The shape factor influence on the deep foundation assessment has been presented in this study in case of vertical load only. The observation mainly included pile-settlement and vertical reaction as a function of depth for the following aspects: different pile depths, soil properties (Young modulus E′, cohesive intercept c′,) of layered soil and the magnitude of the applied vertical force.

1. This study supported the fact that the pile settlement is usually influenced by the vertical load intensities and surly influenced by depth.
2. The shape factor is little influence; the pile capacity of square shape is more than the capacity resulted from circular shape with low differences.
3. It is recommended that it can be used any shape of pile in case of pure vertical load.
4. The length of pile is major influence on the vertical response of the pile. This can used to increase of pile capacity and decrease the piles numbers in same group.
5. The cohesion intercept and the modulus of elasticity of layered soil profile were also affected on the lateral pile response. This is also can be used to decrease the number of piles in specific group.

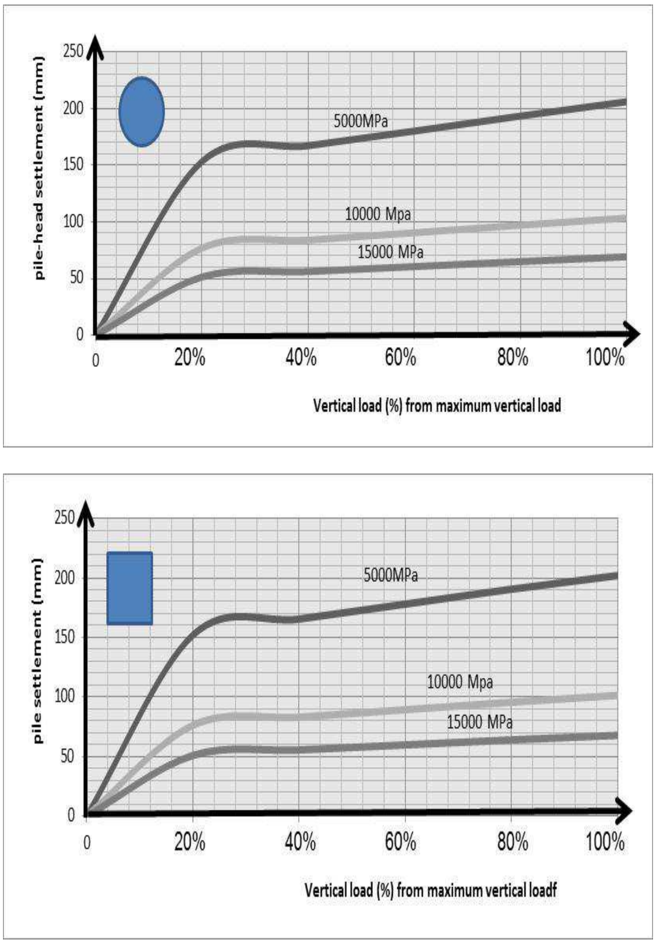

Figure 9 *Predicted Load-settlement curves under the effect of modulus of elasticity of the soil*

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