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ORIGINAL RESEARCH PAPER

Effect of groundwater on the displacements of axially loaded pile in clayey soil

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ABSTRACT

The displacement of a loaded pile could be vertical (axial) or horizontal (lateral); these displacements are sensitive to groundwater presence within the soil mass. This paper presents a theoretical study to investigate vertical and horizontal displacement of piles embedded in a clayey soil for different levels of groundwater under the ground surface. The study was performed using the commercial finite element package PLAXIS-3D. Three diameters of the concrete piles were considered: 0.5, 0.75 and 1 m, and were subjected to 1,000 kN axial load. The effect of 0, 5, 10, 15 and 20 m groundwater along the 20 m pile in length from the ground surface on the vertical and horizontal displacements was investigated. The results indicated that the vertical and horizontal displacements increase when the ground water level increases towards the base of pile. Also, there is a significant increase in the horizontal displacement up to 15 m of groundwater level from ground surface and decreased at levels from 15 to 20 m.

KEYWORDS

pile displacement, pile in clay, pile in PLAXIS, axially loaded pile, pile under groundwater

1. INTRODUCTION

1.1. General

Pile foundations are widely used to transmit the loads from the superstructure through weak soil to the stiffer soil or rock. Therefore, the reliability of pile-supported structures depends principally on the behavior of the pile [1].

Publication [2] studied the effect of partially saturated soil on piles behavior. Imperial College Finite Element Program (ICFEP) was used to conduct an analysis of a single pile embedded in a partially saturated soil. The results of the analysis highlighted the partial saturation and fluctuations of groundwater level effect on the behavior of a single pile. Groundwater level effect on pile behavior was studied also for a pile of high-rise building in London. The study showed that the pile capacity and settlement for many loads and water tables are completely different when partially or fully saturated models were used.

Paper [3] used two model piles to investigate the vertical pile loads at acceleration of 50 g on a model of centrifuge tests. The pile tip displacement gave the neutral plane to device upward thereby the negative skin resistance was reduced. The negative skin resistance decreased when the spacing of the pile diameter ratio decreases and when the number of neighboring piles increases. The results yielded an acceptable agreement within the results of centrifugal models. The results also indicated that water regenerate in a downward will rapidly mitigate the axial capacity of pile induced by negative skin resistance.

Paper [4] used a finite element method to simulate lowering of the water table, which occurs when water is guided up from aquifers with the comparison with data from the Hanoi land, where groundwater has been guided for many years. It was concluded that a reasonable indicator could be made of field behavior. Migration of the observed ground was then used in combination with pile analysis program, which can compute moments and displacements in the piles due to ground migration. It was found that the migrations induced by lowering of the groundwater could result in high moments in piles, and that leads to a structural distress.

Publication [5] formulated physical models in a test chamber having of 250 mm in diameter with control of axial and lateral stresses to replicate in-situ stress levels. Cylindrical piles (25 mm in diameter) and H-piles of the same size were pushed through an upper sand layer on the centerline, and then through the clay layer all the way down to the underlying sand layer. Sand layers were a minimum of 100 mm in thickness; while the clay had a thickness from 25 to 200 mm. Cylindrical piles were effectively sealed during driving through the clay layer with a thickness of 2 or more the pile diameters. This sealing process preserves the integrity of the layer acting as an aquitard. The results indicated that the pile driving process may be visualized as if an equivalent additional seepage pathway would be created in a column of overlying soil, which passes through the clay, although the amounts of soil overlain, which was pushed down through the clay layer was relatively small. The clay deformations observed in the models were naturally ductile. The study also revealed that heavily over-consolidated and fissured clays could have different conclusions as compared to ductile clay.

Paper [6] presented the benefit of using micropiles, the construction of micropile was conducted also. The conclusions appeared that the use of micropiles increase the bearing capacity of foundation and decrease the settlement problems in the site.

Paper [7] modeled the behavior of a single pile and examined in PLAXIS 3D package. The soil parameters resistance of pile adopted as an input values. The aim of the study was to find the exact determination of load-settlement relationship by the use of subgrade reaction and the interface models with the comparison of results of field tests.

1.2. Scope of study

Piles are commonly used to transmit vertical forces, generated from super structure. However, in some instances the principal function of pile is to transmit the lateral loads. In many cases, in addition to the vertical forces, the movement of loaded pile can be vertical and horizontal, so these movements must be taken into consideration especially when the pile embedded in a clay soil with the absence of water. This paper presents a theoretical study to investigate vertical and horizontal movements of piles embedded in clayey soil for different locations of Ground Water (GW) under Ground Surface (GS). The study was performed using PLAXIS-3D software. Three diameters of massive concrete piles models of 0.5, 0.75 and 1 m subjected to 1,000 kN axially load are adopted. The groundwater effect of 0, 5, 10, 15 and 20 m along the 20 m pile length from GS on the vertical and horizontal displacements was investigated. The relationship between the GW level and pile diameter was presented also.

2. PROBLEM FORMULATION

2.1. PLAXIS 3-D software

PLAXIS 3D is a three-dimensional finite element analysis software designed to quantify the deformations in geotechnical engineering. This package handles various simulations involving complex geotechnical models and construction processes utilizing robust and sophisticated geotechnical assumptions. Two distinct modes can be defined with PLAXIS 3D: the geometry of the soil and the geometry of the structures. These modes are intended for soil and structural modeling. 3D solid models can be created by intersection and mesh generation. In addition, the staged constructions mode assists in simulating the construction and excavation processes through activating and deactivating clusters of soil volume and structural masses, load application, water table change, etc. The output results consist of a full visualization suite tools to check the details of the inner 3D soil-structural model [8].

2.2. Problem formulation in PLAXIS-3D software

The case study was formulated in PLAXIS as it is shown in Fig. 1. The pile length was taken equals to 20 m embedded in a 20 m clay soil layer resting on 10 m dense sandy soil. Axial load of 1,000 kN was applied on the pile and it considered as a constant value throughout the study. The properties of soil layers and concrete pile are presented in Table 1.

2.3. Parametric study

The effect of GW level under the GS on the vertical and horizontal displacement of a pile under the axial load was investigated. The depth of water table was adopted as (0, 5, 10, 15 and 20 m (the pile length and the layer are equal). The outside interface (skin friction) of pile was ticked in the toolbox of PLAXIS as it is shown in Fig. 2. Stress around the pile after running the phases in PLAXIS-3D software is shown in Fig. 3.

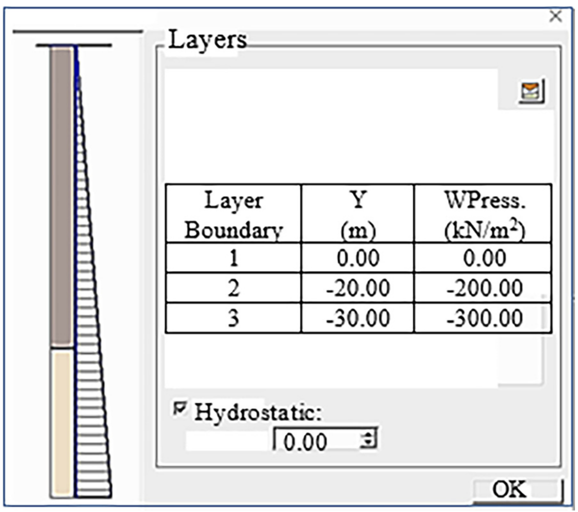

Fig. 1. Case study formulation in PLAXIS-3D software

Table 1. The properties of soil layers and concrete pile

Property	Clay	Sand	Pile
Material model	Mohr-Coulomb	Mohr-Coulomb	Linear elastic
Material type	Drained	Drained	Non-porous
γ_{unsat} (kN m^{-3})	19	17	–
γ_{sat} (kN m^{-3})	20	18	–
γ (kN m^{-3})	–	–	25
Es (kN m^{-2})	50,000	40,000	60,000,000
Y	0.3	0.3	0.2
Ø	0	40	–
c (kN m^{-2})	150	5*	

*PLAXIS cannot accept zero value.

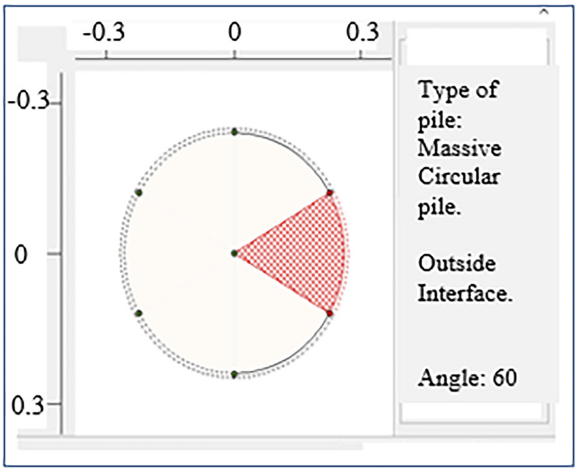

Fig. 2. Pile tool box in PLAXIS-3D software

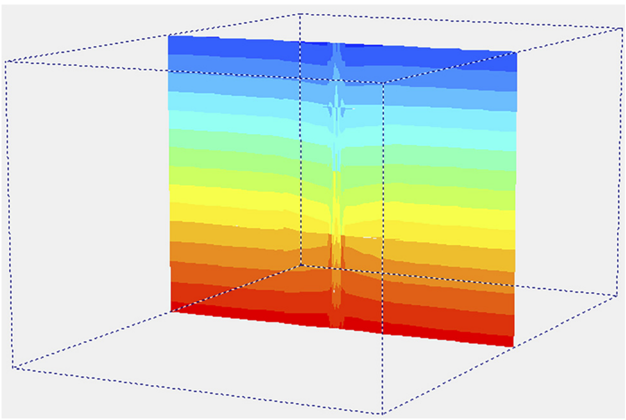

Fig. 3. Stress around the pile after running the phases in PLAXIS-3D software

3. RESULTS AND DISCUSSION

3.1. Effect of groundwater depth on vertical displacement

The effect of groundwater level (in figures noted as WT) on the vertical displacement of the piles (0.5, 0.75 and 1 m) in diameter and $L = 20$ m formulated in PLAXIS according to the case study presented in previous section under a constant load of 1,000 kN is shown in Figs 4–6. From these figure it

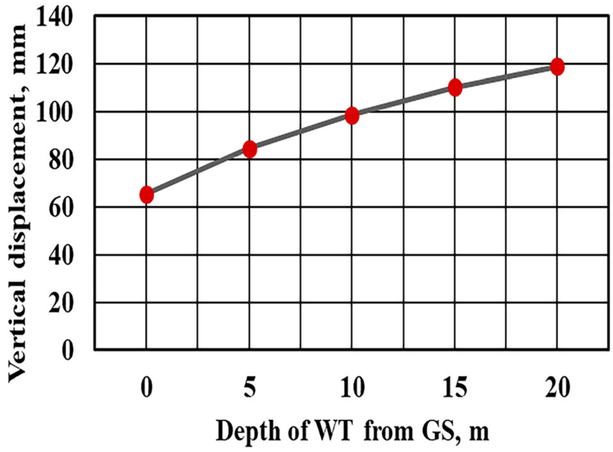

Fig. 4. Depth of WT and vertical displacement relationship for $D = 0.5$ m

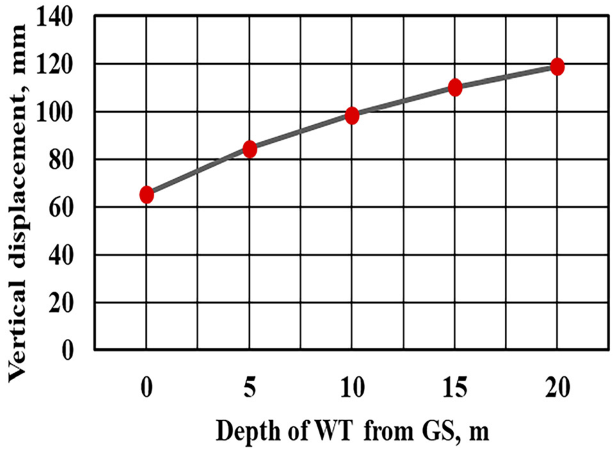

Fig. 5. Depth of WT and vertical displacement relationship for $D = 0.75$ m

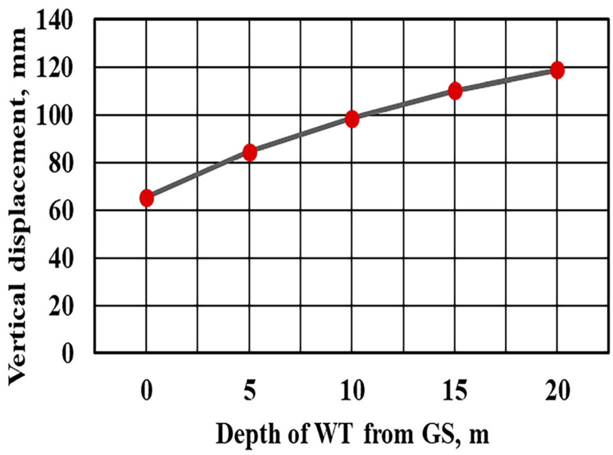

Fig. 6. Depth of WT and vertical displacement relationship for $D = 1$ m

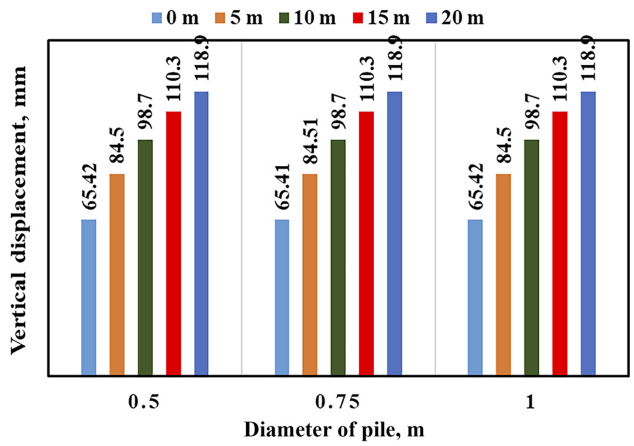

Fig. 7. Depth of WT and vertical displacement relationship for all diameters

can be seen that the vertical displacement of the pile increase when the groundwater level increase from the ground surface (groundwater towards to the lower) under the same load. This increasing in vertical settlement or displacement can be visualizes as a result of decreasing in uplift pressure due to water (decreasing in water head on the base and the surface of pile). Figure 7 shows the relationships for all diameters used, it can be seen that the values are equals for each depth in all diameters within the chosen load. The equalities in displacements for each depth for all diameters can be attributed to the small value of the load (1,000 kN) chosen to keep the smaller pile diameter from reaching a failure state.

3.2. Effect of groundwater depth on horizontal displacement

For the same case study values, the relationships between the groundwater depth and the horizontal displacement for all pile diameters are investigated. The relationships are presented in Figs 8–10. The horizontal displacement increase when the groundwater lowered downwards. The horizontal displacement may be occurring because of the weakness of

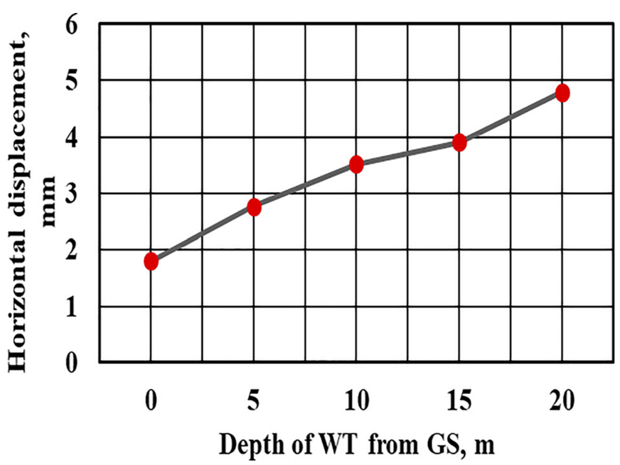

Fig. 8. Depth of WT and horizontal displacement relationship for $D = 0.5$ m

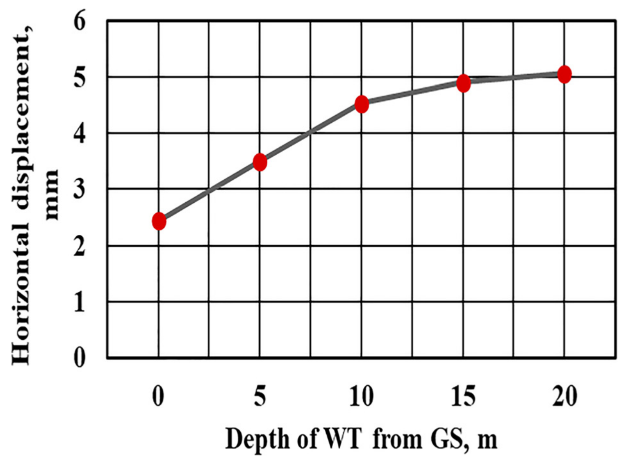

Fig. 9. Depth of WT and horizontal displacement relationship for $D = 0.75$ m

the upper soil particles. So the values can be considered small with the comparison of vertical displacement but they are not equals for each diameter of pile as appear for vertical displacement. Figures 11 and 12 show the relationships on the same chart, the values of horizontal displacement for each pile diameter different from each diameter to others.

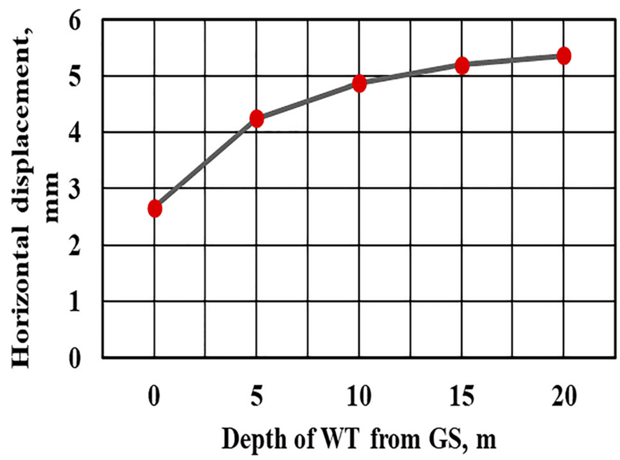

Fig. 10. Depth of WT and horizontal displacement relationship for $D = 1$ m

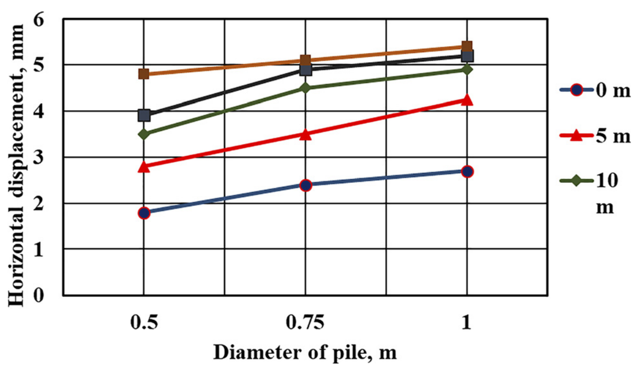

Fig. 11. Depth of WT and horizontal displacement relationship for all diameters

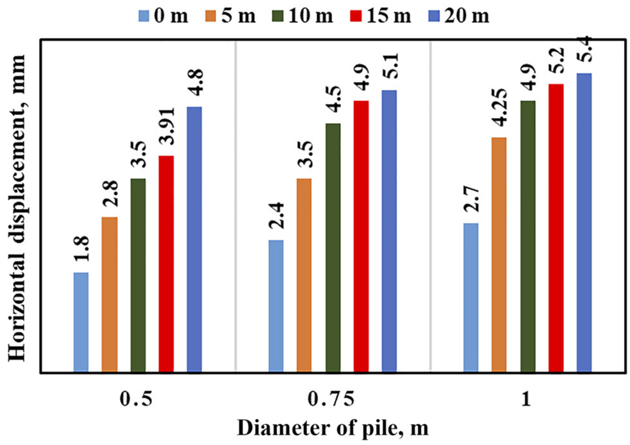

Fig. 12. Depth of WT and horizontal displacement relationship for all diameters

4. CONCLUSIONS

This paper investigated the effect of the depth of groundwater level from ground surface on the vertical and horizontal displacement of pile embedded in a clayey soil. Three pile diameters 0.5, 0.75 and 1 m were taken and a 20 m in length under a constant 1,000 kN axial load using PLAXIS-3D software. The pile is embedded in a clay soil to a depth of 20 m resting on a 10 m dense sand layer. The depths of groundwater were taken as 0, 5, 10, 15 and 20 m from ground surface.

Many conclusions from this study can be drawn as in the following:

1. The vertical displacement increase when the ground water level increase towards the base of pile;
2. The vertical displacement did not affect when the pile diameter varies from 0.5 to 1 m under the used load;
3. The horizontal displacement increase when the ground water level increase towards the base of pile;
4. The horizontal displacement increase when the pile diameter increase for all depths of groundwater;
5. The vertical displacement increase regularly when the depth of groundwater increase from ground surface;
6. Horizontal displacement up for 15 m of groundwater level from ground surface has a significant increase and becomes a little increase from 15 to 20 m.

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