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SETTLEMENT AND DEFORMATION PATTERN OF MODELED WOODEN PILES IN CLAY

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Abstract

This paper presents the results of laboratory experimental investigation on settlement and deformation pattern of modeled wooden square and circular piles in clay. The modeled piles were sawn, sharpened and carved from strong wood obtained from Minsk, Belarus. The configurations of circular section consist of 20mm and 200mm for diameter and length respectively. The square section is 20 x 20 mm, with a length of 200 mm. Single pile as well as pile groups of 2x2 (4 piles) with centre to centre spacing (a) = 4d, and 3x3 (9 piles) with centre to centre (a) = 3d, were driven into clearly marked layered clay soils differentiated by moisture and density of w = 20%, γ = 17 kN/m^3 for the weak; w = 10%, γ = 19 kN/m^3 for the strong), and a third layer of reinforced weak soil having reinforcing bars placed in it. The tests were conducted in a specially designed testing equipment/tank. The loadings were applied at the rates of 0.01, 0.05, 0.1 and 1mm/min. The modeled piles were subjected to axial compressive loads and the effect on the settlement of the soils in the inter-pile spacing, as well as those under and around the piles were evaluated. Pile displacement increased linearly with the applied loads. The pile axial capacity increases with the loading rate. The initial settlements of square piles are generally higher than in circular piles, but the latter gives higher over-all settlement than the former. Lateral deformations decrease with increase in distance from the pile, and outward radial deformations around the pile decrease downwards along the pile depth.

KEYWORDS: Settlement; Compressive Loads; Deformation; Wooden Piles; Clay.

Introduction

Vertical piles resist lateral loads or moments by deflecting laterally until the necessary reaction in the surrounding soil is mobilized [1]. The piles penetration depth (length) depends on the magnitude of the applied load and type of soil. The rate of application of external load affects the strength of cohesive soils [2]. For a group of piles, it would be expected that the strain level will increase as the pile-soil interface is approached, and thus, the stiffness of the soil at the pile-soil interface is smaller than that between the piles at some distance from the pile shafts. Simplified distributions of the soil modulus with distance from the pile shafts may be assumed, especially with a steady rate of load application. It has been demonstrated that the presence of the stiffer soil between the piles can lead to a significant reduction in the interaction factor between two piles [3]. The result has been viewed to be in agreement with the results of field tests on pile group in clay [4]. Soil within a few pile diameters can undergo large shear deformations. The pile driving process can potentially generate large stresses and deformations in the nearby soils [5]. For many cohesive clay soils which tend to be highly sensitive to remolding, this leads to significant loss of strength in the short term. Observations of settlement and deformation of piles under load do not only present scientific interest for the geotechnical engineer, but also an indication of the long term behavior of the construction and the overall functionality of the project [6]. One of the common mean of analyzing pile group behavior is by use of interaction factor method which was described by [7], otherwise known as the principle of superposition. A simplified expression for the interaction factor, which enables easier computational analysis of group settlement of piles, was later developed by [8]. For estimation of pile settlement, the key geotechnical parameter is the stiffness of the soil. The settlement of a pile group can differ significantly from that of a single pile at the same loading rate. The presence of soft compressible layers below the pile tips can result in substantial increase in the settlement of a pile group, despite the fact that the settlement of a single pile may be largely unaffected by the compressible layers. The larger the group (i.e. the width of the pile group), the greater is the effect of the underlying compressible layer on settlement ([9], [10] and [11]).

The behaviors of piles are usually investigated with pile load test in the field. However, the high cost of conducting full-scale pile tests in the field and the inherently high variability of the field conditions make them impractical for research purposes. Therefore, model tests are usually used for investigating the behavior of piles [2].

A review of literatures on the effect of loading on pile behavior among others, revealed that, as the loading increases, the axial capacity of single piles in clay soils increases ([12], [13] and [5]). Due to the interaction of neighboring piles in group, the behavior of pile group is geometrically different from that of single pile under applied load. Investigating the deformation magnitude and pattern of modeled circular piles in clay under different rates of loading therefore, will be of practical importance.

This paper therefore, presents the results of a series of modeled pile tests on the settlement and deformation pattern of square and circular wooden piles conducted in the research laboratory, Geotechnical and Environmental Engineering department, Belorussian National Technical University, Minsk, Belarus. The model piles were subjected to axial compressive loads at incremental rates of 0.01, 0.05, 0.1 and 1mm/min respectively. The clay soil was pulverized and mixed to desired water contents of 10%; bulk densities of 17 kN/m^3 and 19 kN/m^3 for weak modeled and strong modeled layers of clay respectively. The weak layers were also reinforced with reinforcing bars. The load-displacement responses, as well as settlement of these piles were investigated. This investigation is essential in the calibration and validation of analytical techniques to predict the changes in the properties of the underlined soil under loading, especially those around the piles.

Experimental Investigation

The soil investigated in this study was wet clay samples obtained from a site around Uruccha, at the outskirt of Minsk province of Belarus. Comprehensive laboratory investigations were then carried out on the conditioned clay in order to determine its settlement, deformation pattern and response to incremental loading when modeled wooden square and circular piles were driven through it.

The soil samples were consolidated in a specially constructed multipurpose steel tank with the dimensions of 1100 x 250 x 600 mm for length, width and depth respectively. It has a relatively rigid steel framework support (Fig. 1). It has a one sided steel panel having open and close apertures for drained and undrained tests. The frontal panel (other side) is made with transparent plastic fiber, which is strong enough to withstand consolidation pressure and strikes. The transparent strong plastic allows proper monitoring of sample's state during the test as well as ensures visual observation of failures in the tested soils in terms of depression, heaving or wobbles. Temporary makings can be made on the transparent plastic panel depending on the desired volume of work. Thereafter, the pulverized, air-dried and conditioned clay was placed in the test tank in three layers; strong, weak and reinforced weak layers. The weight of clay required to obtain a unit weight of 19 kN/m^3 (strong) or 17 kN/m^3 (weak) were packed into the test tank in lifts, with the interface between the lifts being made uneven, to reduce the bedding effects, and clearly marked to give room for proper monitoring during loading and unloading.

The load is transferred to the soil by a weight hanger with a lever arm. The hanger consists of a lower and upper cross beams and a cantilevered beam with a pin connection at one end and a cradle for weights at the free end. The load is applied by placing slotted dead weights on the cradle. The cantilever beam connecting end is designed with a load factor of 10 i.e. the actual load transferred to the soil through the connecting plate being 10 times the load on the cradle (Fig. 1).

To achieve the desired densities layer by layer, consolidation pressure was applied through the upper surface layer. The testing tank was then made rigid and ready for pile driving. Modeled square and circular piles were then driven through the soil, and the pile cap was put in place (Figs. 2 and 3). The pile cap was then connected by the fulcrum under the loading arm. Soil deformation was monitored and readings of settlement were taken at certain time intervals until the relationship between settlement and the logarithm of time became nearly horizontal.

The test piles were subjected to axial compressive loads until the allowable pile settlement of 0.1d (10% of pile diameter i.e. 2 mm) is reached or exceeded in line with the submission of [14] and [15], also commented on by [16] and [17]. The settlement of the clay was measured by means of a dial gauge, which was connected to the upper plate (Fig. 1). The load was then increased at the rate of 0.01, 0.05, 0.1 and 1mm/min. The settlement was taken with time until the time when the settlement change was insignificant. For each pile group, the tests were repeated for the three soil conditions separately and the three combined.

Figure 1. Tank Set up and Load Application on the Soil

Figure 2. Pile driven into Clay Soil in the Tank

Figure 3. Settlement Measurement on Dial gauge

Discussion of Test Results

For ease and convenience of work with the testing tank, group efficiencies were pre-determined and pile spacing of 4d and 3d were adopted for the 2 x 2 (4 piles) and 3 x 3 (9 piles) respectively. A total of 30 tests (15 a piece for the square and circular piles) were conducted in the laboratory. The results of critical cases were evaluated and thus presented.

The result of some of the geotechnical properties of the clay investigated is shown in Table 1. The samples used can be described as soft clay which is slightly over consolidated in it wet state having 0 cohesion and less than zero liquidity index (modeled).

Table 1. Some Geotechnical Properties of the Clay Sample

Parameters	**Modeled strong clay** (γ = 19 kN/m^3, w = 10%)	**Modeled weak clay** (γ = 17 kN/m^3, w = 20%)
Specific gravity of solids	2.66	2.66
Liquid Limit (%)	23	25
Plastic Limit (%)	17	19
Plasticity Index (%)	6	6
Liquidity Index (%)	$I_L < 0$	0.3
Void ration (e)	0.51	0.84
Cohesion (kPa)	20	0
Angle of internal friction (φ^o)	25	33

Load-settlement curves at different loading conditions for both square and circular piles are shown in figures 4 - 7. Generally, pile displacements increased with increment in loading. While the 2 x 2 (4 piles) group with 4d spacing and 3 x 3 (9 piles) with 3d spacing behaved similarly as a result of group efficiency influence, the single pile showed an isolation effect, although with smaller settlement. The reinforced weak clay behaved similar to strong modeled clay in it response to deformation and pile displacement under load.

Visible observations from the testing tank transparent panel (fig. 8), showed eaves, depression and total settlement of modeled test piles, which varies with the differences in pile spacing shown in figs. 10 and 11. The failure bulb and deformation zones of a single pile are shown in fig. 9. Averagely, the depth of zone 1 is about 3d from the lateral surface of pile; zone 2 has a depth of 2.5 d, while zone 3 ends at about 2d from the pile tip, (d is pile diameter).

Lateral deformations decrease with increase in distance from the pile, and outward radial deformations recorded around the pile decreases downwards.

As the loading regime is gradually increased up to 100 percent from 0.01-1.0 mm/min, the deformation in the bearing soil shown in figures 4 - 7 revealed that, the axial compressive capacity of the pile group, in terms of axial load applied, increase linearly with loading rate up to the bearing point. For a single pile, increase in loading rate produced a quicker deformation and increase pile displacement.

The initial settlement of circular piles is lower than that of square piles. This may be explained by wider contact surface area and less negative friction. However, as the loading rate increases, circular piles penetrate further with higher settlement and deformation than square piles, figs. 10 and 11. Fig. 7 clearly shows that for a given loading rate, the settlement of square piles is lower for a corresponding load. This was practically proven in the three modeled soil conditions of strong, weak and reinforced-weak clay.

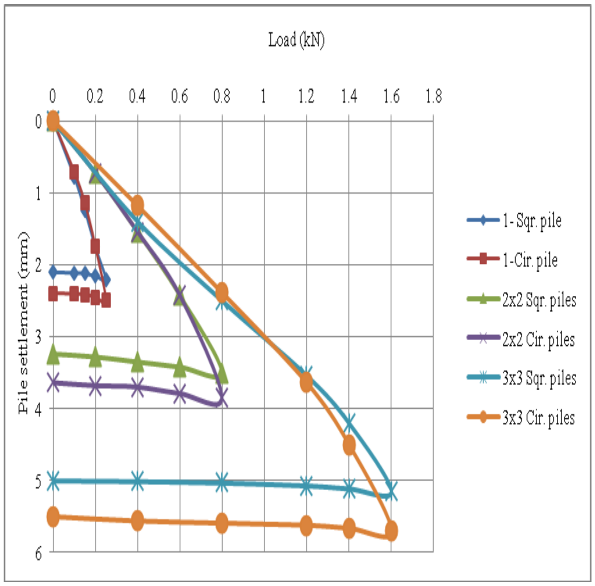

Figure 4. Load-Settlement curve for loading rate 0.01 mm/ min

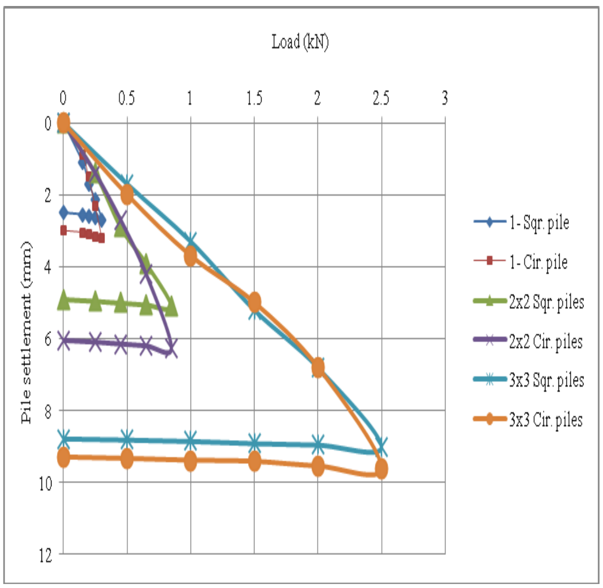

Figure 5. Load-Settlement curve for loading rate 0.05 mm/ min

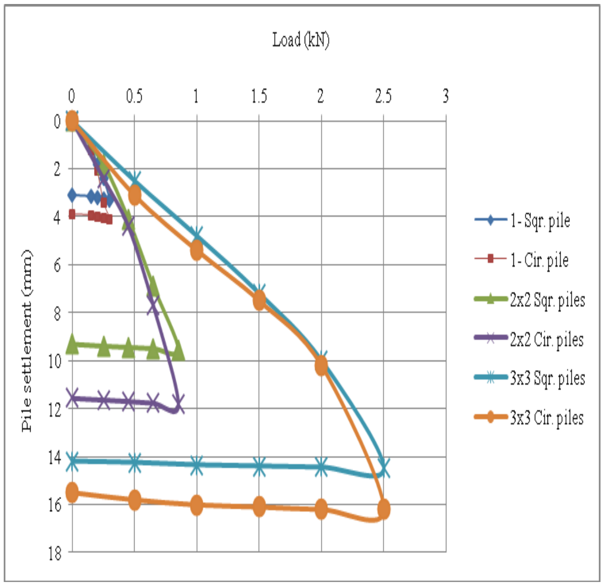

Figure 6. Load-Settlement curve for loading rate 0.1 mm/ min

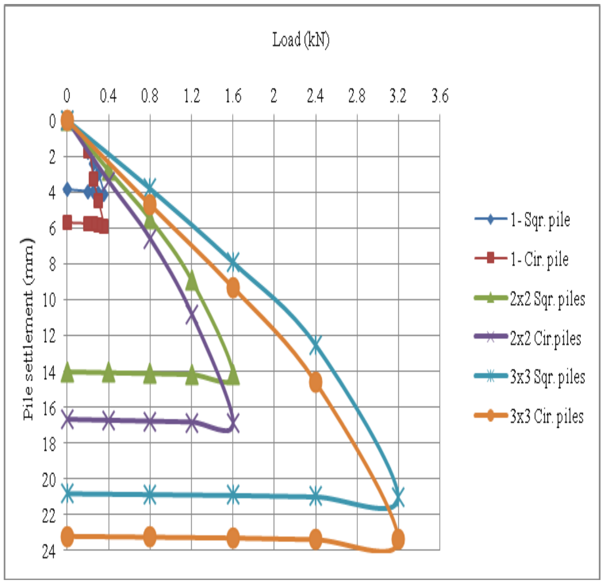

Figure 7. Load-Settlement curve for loading rate 1.0 mm/ min

Figure 8. Testing Tank showing eaves, depression and settlement of piles

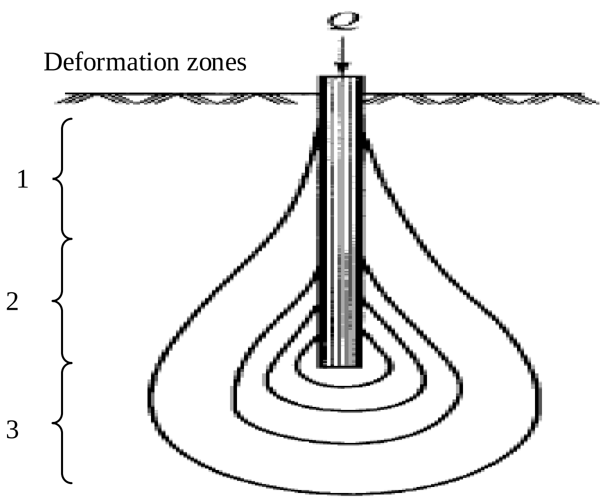

Figure 9. Failure bulb and Deformation Zones of a Single Pile

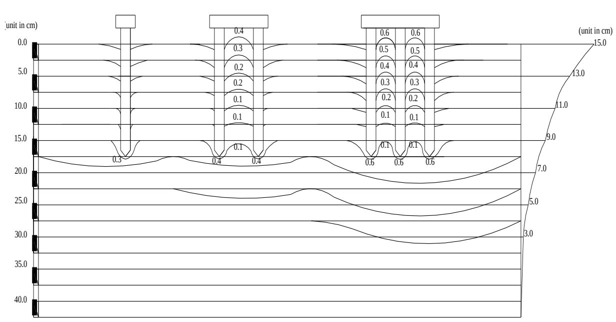

Figure 10. Deformation of Soils around Square Piles

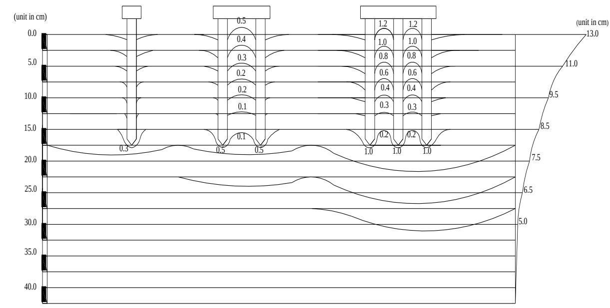

Figure 11. Deformation of Soils around Circular Piles

Conclusions

From the results of experimental investigation of settlement and deformation pattern of modeled square and circular piles in clay obtained from a site in Uruccha, Minsk province of Belarus, the following conclusions are drawn:

Lateral deformation of pile decrease with increase in distance from the pile centre. Outward radial deformations around the pile shaft decreases with depth.

The initial settlement of square piles is higher than that of circular piles. However, as the load increases circular piles produce a larger overall settlement than the square piles.

Increment in loading significantly affects the compressive axial capacity of modeled pile group in clay. Pile displacement increases with increase in applied load.

Three zones of deformation are clearly shown in the tested loaded piles; zone 1 of about 3d from pile lateral surface under the pile cap; zone 2 of about 2.5d along the pile length; and zone 3 around and under the pile tip with a depth of about 2d.

Acknowledgments

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Biography

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