Effect of Loading Rate on the Settlement of Axially Loaded Modeled Square and Circular Piles in Clay

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***Abstract*- This paper presents the results of experimental investigations of the effect of loading rate on deformation and settlement of axially loaded modeled square and circular piles in clay. The modeled piles were sawn, sharpened and carved from strong wood. The configurations of both square and circular section consist of 20 mm and 200 mm for diameter and length respectively. 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 layer, and w = 10%, γ = 19 kN/m^3 for the strong layer), with a third layer of reinforced weak soil having reinforcing bars placed in it. The tests were conducted in a specially designed testing equipment/tank. At the loading 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 soils in the inter-pile spacing, as well as those under and around the piles were evaluated. The pile axial capacity increases with the loading rate. Also, the relationship between applied load and pile displacement within the load bearing limit was observed to be linear. The initial settlements of square piles are generally higher than circular piles, but the latter gives an over-all settlement of 14 - 18% higher than the former.**

Keywords*- *Loading Rate; Settlement; Compressive Loads; Deformation; Wooden Piles; Clay

I. INTRODUCTION

The rate of application of external load affects the strength of cohesive soils [1]. 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 [2]. The result has been viewed to be in agreement with the results of field tests on pile groups in clay [3]. 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 [4]. For many cohesive clay soils which tend to be highly sensitive to remoulding, this leads to significant loss of strength in the short term. Several laboratory studies have shown that the undrained shear strength of clay increases with the rate of loading ([5-15]).

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) is, the greater the effect of the underlying compressible layer on settlement ([16] and [17]).

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 [1].

A review of studies on the effect of loading rate on pile behavior among others, revealed that, as the loading rate increase, the axial capacity of single piles in clay soils increases ([18], [19] and [1]). Due to the interaction of neighbouring 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 presents the results of a series of modeled pile tests on the effect of loading rate on the settlement of axially loaded 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 different incremental rates of 0.01, 0.05, 0.1 and 1 mm/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 layers 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.

II. EXPERIMENTAL INVESTIGATION

The soils investigated in this study were clays samples obtained from a site around Uruccha, a layout on 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 of 1.1 m length, 0.25 m width, and 0.6 m height supported by a relatively rigid steel framework (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 fibre, 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 (Fig. 2). 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.

Fig. 1 Load Application on Soil in the Tank

Fig. 2 Pile Driven into Clay in the Tank

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 and Fig. 2).

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. 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.

Fig. 3 Settlement Measurement on Dial gauge

The modeled 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 [20]. The settlement of the clay was measured by means of a dial gauge, which was connected to the upper plate (Fig. 3). The load was then increased at the rate of 0.01, 0.05, 0.1 and 1 mm/min. The settlement was taken with time until when the settlement change became insignificant. For each pile group, the tests were repeated for the three soil conditions separately and the three combined. General visual observations were also carried out through the transparent panel.

III. DISCUSSION OF EXPERIMENTAL RESULTS

For the convenience of investigation and experimental work with the testing tank, pile group efficiencies were pre-determined and the spacing 4 d, and 3 d were adopted for the 2 x 2 (4 piles) and 3 x 3 (9 piles) respectively.

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

TABLE I SOME GEOTECHNICAL PROPERTIES OF THE CLAY SAMPLE

Parameters (average)	**Modeled strong clay** (γ = 19 kN/m^3, w = 10%)	**Modeled weak clay** (γ = 17 kN/m^3, w = 20%)
Specific gravity of solids	2.67	2.67
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
Modulus of Deformation (kPa)	8.5	5.4

Load-settlement curves at different loading rates 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 3 d 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 layers behaved similar to strong modeled clay layers with respect response to deformation and pile displacement under load.

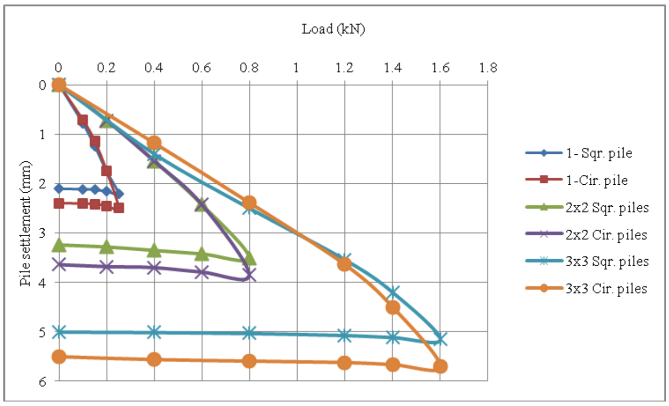

Fig. 4 Load – Settlement Curve for Loading rate 0.01 mm/min

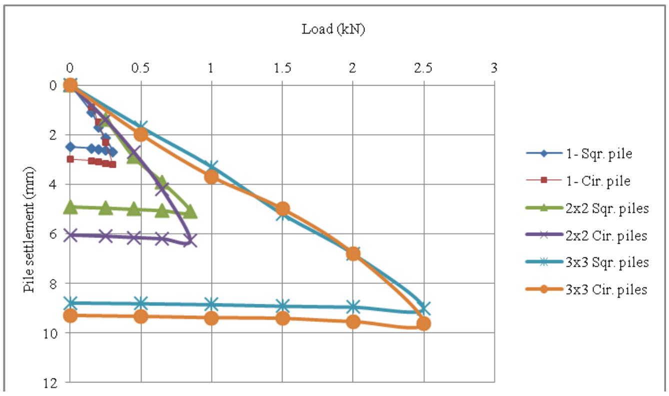

Fig. 5 Load – Settlement Curve for Loading rate 0.05 mm/min

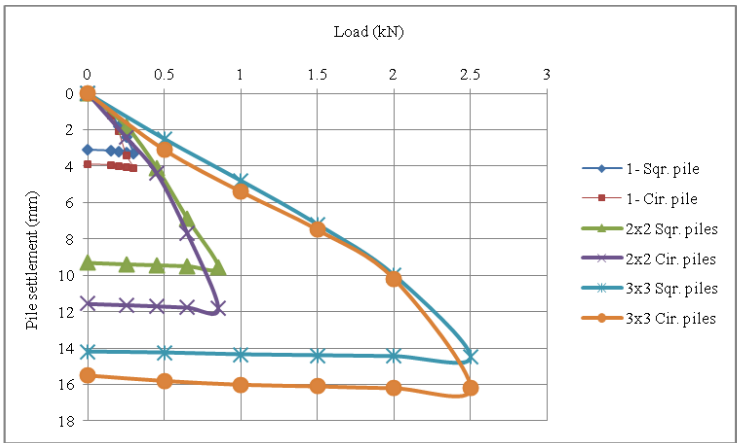

Fig. 6 Load – Settlement Curve for Loading rate 0.1 mm/min

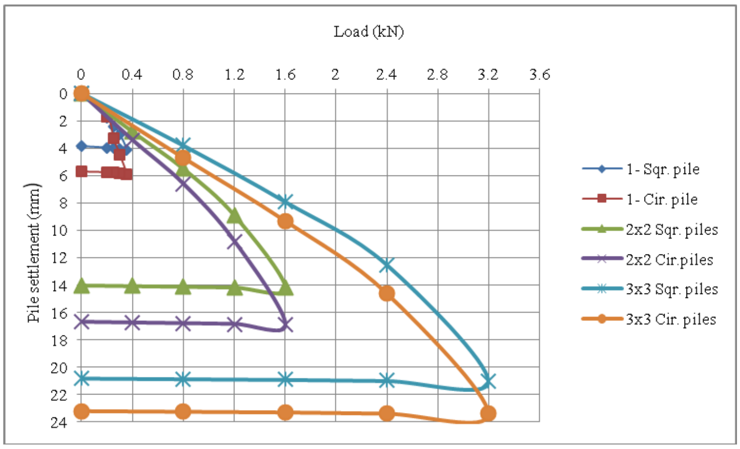

Fig. 7 Load – Settlement Curve for Loading rate 1.0 mm/min

Visible observations are shown through the transparent panel of the testing tank (Fig. 8). It shows eaves, depression and total settlement of modeled piles, which varies with the differences in pile spacing, as amplified in Figs. 9 and 10.

Lateral deformations decrease with increase in distance from the pile, and outward radial deformations recorded around the pile increased downwards along the pile length Figs. 9 and 10.

Fig. 8 Testing Tank showing Eaves, Depression and Settlement of Piles

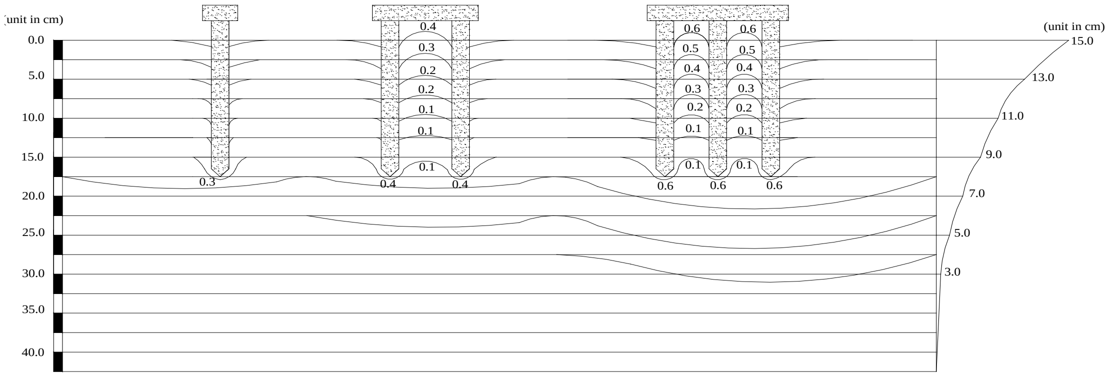

Fig. 9 Deformation of Soils around Square Piles under Load

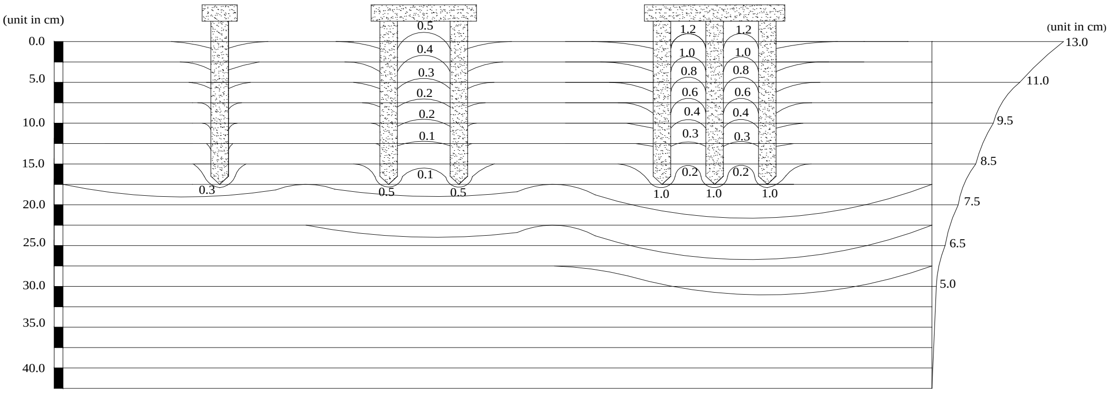

Fig. 10 Deformation of Soils around Circular Piles under Load

As the loading rate is gradually increased up to 100% from 0.01 mm/min to 1.0 mm/min, the deformation in the bearing soil shown in Figures 5 - 8 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 square piles is higher than that of circular piles. This may be explained by increase 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. 9 and 10. Fig. 7 clearly shows that for a given loading rate, the settlement of circular piles is higher for a corresponding load. This is practically proven in the three modeled soil conditions of strong, weak and reinforced-weak clay.

IV. CONCLUSIONS

From the results of laboratory investigations on the effect of loading rate on the settlement of axially loaded modeled square and circular piles in clay obtained from a site in Uruccha, a layout in the outskirt of Minsk province in Belarus, the following conclusions are drawn:

- Pile displacement increases with increase in loading.
- Outward radial deformations around the pile shaft increases downwards with depth along the pile length.
- Lateral deformations decrease with increase in distance from the pile centre.
- The initial settlement of circular piles is lower than that of square piles, but as the load increases circular piles produce a generally higher settlement than the square piles by approximately 14 -18%.
- Increment in loading significantly affects the compressive axial capacity of modeled piles in group.
- Linear relationship exists between the loading rate and pile axial capacity as well as deformation of modeled piles.
- The settlement of modeled piles (especially wooden) in clay responses linearly to steadily increasing loading rate.

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