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Procedia Engineering 57 (2013) 83 – 88

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013

Laboratory Investigation of Load Incremental Effect on the Deformation of Clay Under Axially Loaded Modeled Circular Piles

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Abstract

This paper presents the results of recent experimental investigation of load incremental effect on the deformation of clay under axially loaded modeled wooden circular piles in clay. The modeled piles consist of 20 mm diameter, 200 mm length, made up of single pile, 4 No pile group of 2×2 with centre to centre a = 4d, and 9 No pile group of 3×3 with centre to centre a = 3d, were driven into clearly marked layered clay soils differentiated by w = 20%, γ = 17 kN/m^3 for the weak; w = 10%, γ = 19 kN/m^3 for the strong) while the third class of reinforced weak layer had hollow reinforcing bars placed in it. The tests were conducted in a specially designed testing equipment/tank. The modeled piles were subjected to axial compressive loads at incremental rate of 0.01, 0.05, 0.1 and 1mm/min respectively. A linear relationship was observed between the load incremental rate and pile axial capacity and pile displacement, which were also visible from the increase in the radius of curvature of the displaced/deformed soil from the pile centre-line.

Keywords: loading increment; compressive loads; deformation; settlement; circular piles; clay.

1. Introduction

The strength of cohesive soils is affected by the rate at which the external load is applied [1]. 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 [2]. For many cohesive clay soils which tend to be highly sensitive to remolding, 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 [3–13].

Compressibility and rate of consolidation decrease with decreasing in dielectric constant of organic fluids, whereas permeability increases [14], [15]. Shear strength of montmorillonite decreases with increasing in dielectric constant in the range 1–80 [16]. Unsaturated soils are generally near the ground surface and are commonly over consolidated due to environmental effects.

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 on pile behavior, ultimate pile capacity and pile group revealed that they were scanty and limited. As the loading rate increase, the axial capacity of single piles in clay soils increases [1], [17], [18]. 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.

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doi:10.1016/j.proeng.2013.04.013

This paper presents the results of a series of modeled pile tests on the effect of loading rate on deformation of circular piles conducted in the Geotechnical and Environmental Engineering post graduate research laboratory, Belorussian National Technical University, Minsk, Belarus. The model piles were subjected to axial compressive loads at different increment rates of 0.01, 0.05, 0.1 and 1mm/min respectively. The load-displacement response, axial capacity, and group efficiency and spacing in a group were also 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. 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 and strong modeled layers of clay respectively. The weak layers were also reinforced with hollow reinforcing bars of 150 mm diameter.

2. Experimental investigation

The soils used in this study were clays samples obtained from dogged site around Uruccha, Minsk province of Belarus. A comprehensive laboratory investigation was then carried out on the conditioned clay in order to determine its deformation pattern and response to incremental loading when modeled wooden 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 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 by hand in the test tank in three layers, of strong, weak and reinforced weak layers. The weight of clay required for the first layer to obtain a unit weight of 19 kN/m^3 (strong) or 17 kN/m^3 (weak) was packed into the test tank by hand in lifts, with the interface between the lifts being made uneven, to reduce the bedding effects, and clearly marked to allow for proper monitoring during 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 times the load on the cradle being the actual load transferred to the soil through the connecting plate.

After the consolidation pressure was applied to achieve the desired densities layer by layer, the testing tank was made rigid. Circular piles were then driven through the soil, and the pile cap was put in place. 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. 1. Multipurpose testing tank set up

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 [19]. The settlement of the clay was measured by means of a dial gauge, which was connected to the upper plate. 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.

3. Discussion of test results

From previous knowledge that, increase in spacing between piles, reduces the overlapping area, and hence increases the group efficiency, and for the convenience of work with the testing tank, group efficiencies were already pre-determined and the spacing 4d, and 3d fixed for 2×2 (4 piles) and 3×3 (9 piles) respectively.

The result of some of the geotechnical properties of the clay investigated is shown in Table 1, which can be described as soft clay that can be 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

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	2.66	2.66
Liquid Limit (%)	23	25
Plastic Limit (%)	17	19
Plasticity Index (%)	6	6
Liquidity Index (%)	$I_L < 0$	0.3
Void ration (e)	0.6	0.9
Cohesion (kPa)	20	0
Angle of internal friction (φ°)	25	33

From Figs 3–5, pile displacements increased with increment in loading. While the 2×2 (4 piles) group with 4d spacing and 3×3 (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.

Lateral deformations decrease with increase in distance from the pile, and outward radial deformations were recorded around the pile shaft which decreases downwards. Visible observations from the testing tank transparent panel (Fig. 6), showed eaves, depression and total settlement of modeled piles.

With gradual load incremental rate of up to 100 percent from 0.01–1.0 mm/min, the deformation in the bearing soil shown in Figs 8 and 9 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 Fig. 7.

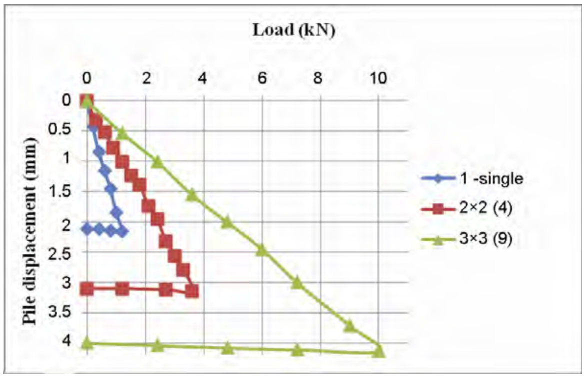

Fig. 2. Load – displacement curve for piles in strong modeled clay

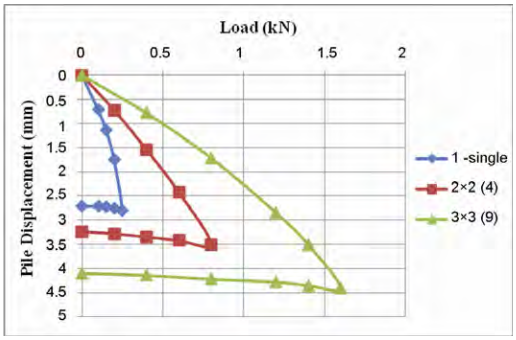

Fig. 3. Load – displacement curve for piles in weak modeled clay

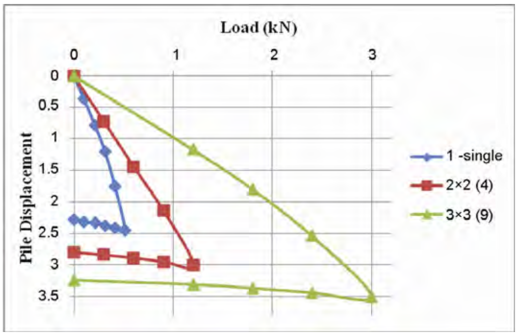

Fig. 4. Load – displacement curve for piles in reinforced weak modeled clay

Fig. 5. Testing tank showing eaves, depression and settlement of piles

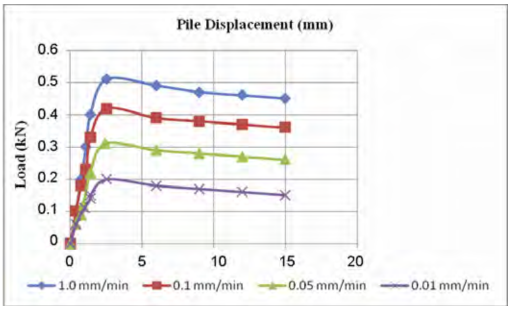

Fig. 6. Incremental effect on Load – displacement curve for 1(single) pile

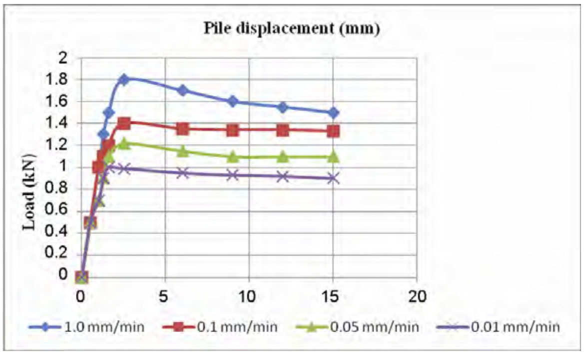

Fig. 7. Incremental effect on Load – displacement curve for (2×2 – 4d) pile group

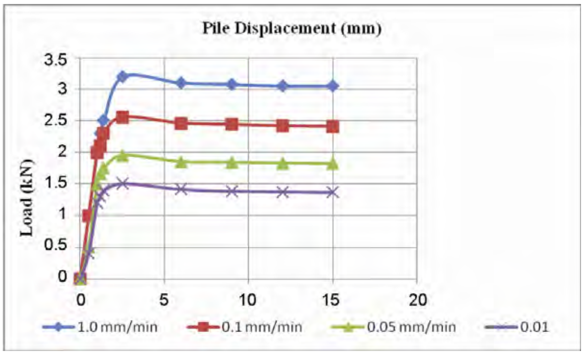

Fig. 8. Incremental effect on Load – displacement curve for (3×3 – 3d) pile group

4. Conclusions

From the results of laboratory investigations of load incremental effect on the deformation of modeled circular piles in clay in Uruccha, Minsk province of Belarus, the following conclusions are drawn:

- Lateral deformations of clay decrease with increase in distance from the pile centre.
- Outward radial deformations were recorded around the pile shaft which decreases downwards.
- Increment in loading significantly affects the compressive axial capacity of modeled group piles.
- Linear relationship exists between the loading rate and pile axial capacity and deformation.
- Lateral displacements in the model tests exhibited roughly similar trends to those generally observed in the field.

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