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Research Article

Analysis of Settlement of Soils around Axially Loaded Tapered Piles in Compressive Clay of Minsk Region

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Abstract: Presented in this research paper are the results of a comprehensive investigation on the analysis of settlement of soils around axially loaded tapered piles in compressive clay soil. The results show the influence of tapering of the circumferential dimension of instrumental piles on the magnitude, pattern and orientation of settlement of soils around loaded modeled wooden and reinforced concrete piles bored into compressive clay soil. With the same pile spacing (η), while a reduced tapering angle (α) gives a less depth of failure zone, it produces a larger horizontal displacement of soil than corresponding piles with a higher tapering angle. Settlement of tapered piles among other things is influenced by the tapering angle (α) relative to the diameter of the pile, and this effect increases with incremental depth of pile penetration into compressive clay soil. In addition, pile cap settlement is 5-10 % higher in tapered piles with lower tapering angle.
Keywords: Settlement; Tapered piles; Loading; Deformation, Compressive clay.

INTRODUCTION

When pile is penetrated in a downward frictional mode, a failure zone is developed along the soil-pile interface which partly upheaves laterally and disturbs the soil below the pile tip. Partly consolidation develops around soil-pile interface when soil compresses elastically below the critical depth [1].

Based on the strength of their digenetic bonds, clay and clay-shale have been grouped into 3: i) over consolidated plastic clay with weak or no bond; ii) over consolidated plastic clay with well-developed digenetic bonds and iii) over consolidated plastic clay with strongly-developed digenetic bonds [2]. Clay around Minsk region falls into the third category [3].

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, the greater is the effect of the underlying compressible layer on settlement [4, 5].

Soil within a few pile diameters can undergo large shear deformations, especially when installed by driving. The pile driving process can potentially generate large stresses and deformations in the nearby soils [6]. 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 [7]. For piles in stiff fissured clay, an empirical reduction factor of the undrained shear strength has been established to decrease with greater pile base diameter and is greater for driven than for bored piles. The ultimate unit skin friction of piles in a given sand or clay is practically independent of the pile diameter [8, 9].The collapsibility properties of a highly porous layered soil diminish with depth, from 2-3% to 1 - 1.5%, while the unit bearing capacity of bored piles reduces 2-3 times on the average [10].The lateral deformation of piles decreases with increase in distance from the pile center line, while outward radial deformations recorded around the pile decreases downwards along the length [11]. The skin friction and radial stress are highly influenced by tapered piles compared with conventional piles. The tapering and wedging effects are responsible for increase in normalized skin friction and normalized lateral stresses. Taper-shaped piles offer a larger resistance than the cylindrical piles [1, 12].

In pile foundations design, evaluation of the pile deflection, which is closely related to its settlement under load, in addition to estimating the ultimate pile capacity to satisfy the serviceability requirements is a necessity [13]. Obtaining the settlements of piles under loads is a key factor to understanding its behavior and response to deformation and utmost functionality. The foregoing therefore, explains the relevance of this investigation.

This paper therefore, presents the results of a series of modeled pile tests on the settlement analysis of tapered piles conducted in the research laboratory, Geotechnical and Environmental Engineering department, Belarusian National Technical University, Minsk, Belarus. The field tests were conducted at Shabani, an outskirt of Minsk, Belarus. The load-displacement responses, as well as settlement of soils around these piles were investigated. This investigation is essential in the understanding of calibration and validation of analytical techniques of tapered piles, especially when predicting the changes in the properties of the underlined soil, particularly those around the piles' immediate vicinity.

MATERIAL AND METHODS

Detailed laboratory investigations were conducted on clay samples taken from a site around Shabani, an outskirt of Minsk province of Belarus. The clay soil was conditioned in order to determine its settlement under axial compressive load when modeled wooden tapered piles were bored in to it.

The clay soil was pulverized and mixed to desired water contents of 10%; bulk densities of 18kN/m^3. Consolidated in a specially constructed multipurpose test tank, (Fig. 1), the soil samples were properly pulverized. The tank has a relatively rigid steel framework support, with a one sided steel panel having open and close apertures for drained and undrained tests. The frontal panel is made with transparent plastic fiber, which is strong enough to withstand consolidation induced 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. The weight of clay required to obtain a unit weight of 18kN/m^{3}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.

After layer by layer densities were achieved, axial compressive load was applied through the upper surface layer. The testing tank was then made rigid and ready for pile installation by boring. Modeled wooden tapered piles were then bored 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.

The load is transferred to the soil by a weight hanger with a lever arm. The hanger consists of a pair of 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. Axial compressive load applied though the pile group centerline produce settlement and external convex eaves on the underside of pile cap (Fig. 2).

The field tests were performed on 4 No tapered piles with tapering angles (α) of 1.43^{o}and 0.95^0, and group efficiency of 0.85 and 0.95 at two test points respectively. Static loads were applied and maintained using a hydraulic jack (of 200T capacity) and were measured with a load cell as shown in Fig. 3. Reaction to the jack load is provided by a steel frame that is attached to an array of steel H-piles located at least 1.5m away from the test piles. Pile cap settlements were measured relative to a fixed reference beam using 2 dial gauges. Displacement/settlement of soils around the piles measurements were made in reference to the pile cap using 5 dial gauges, Fig. 4. The settlements were recorded for each loading increment at an interval of 15 minutes or the time when the movement of the indicator on the dial gauges becomes insignificant.

The modeled test piles (tapered) were instrumented with strain gauges connected to the stylishly perforated steel cone-heads by string-pulley (for static resistance) with censors to the pile centerline. The steel cone-heads with series of springs connected to the indicators were installed in the soils around the piles at depths 0.2m, 0.5m, 1.0m 1.5m, and the 5thone at 0.2m outside the pile cap.

The modeled tapered 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 [4, 14-16]. The settlement of the clay was measured by means of a dial gauge, which was connected to the upper plate (Fig. 1). The settlement was taken with time until the time when the settlement change was insignificant.

Fig. 1: Testing tank for the laboratory work

Fig.2: Testing tank for the laboratory work

Fig.3: Hydraulic jack for field test loading

Fig. 4: Dial gauges for Settlement Reading

RESULTS AND DISCUSSION

Summary of laboratory results for the geotechnical properties of the compressive clay is presented in Table-1 below. It shows a high void ration (e) and cohesion with maximum values of 1.92 and 30 kPa respectively, which indicated the compressibility of the sample. It does not drain readily and may absorb water by capillary action with resulting loss in strength.

Deformation and settlements observed in the disturbed soil particles (failure zone) below the pile tip, with its effective length measured from the tip of the pile to the point of maximum curvature below its tip. It increases radially outward from the pile centerline, and is greater in tapered piles with lower tapering angle. However, the overall depth of failure zone is higher around piles with higher tapering angle(Figs. 5 and 6), a scenario similar to the findings of Manandhar *et al*. [17].

Table 1: Summary of Geotechnical properties of the investigated clay sample

Parameters	**Values for the Sample**	High void ratio (e) and cohesion indicate the compressibility of the clay sample
Density **γ** (kN/m^3)	18	
Moisture content (**w**)	10	
Specific gravity of solids	2.63	
Liquid Limit (%)	23 - 29	
Plastic Limit (%)	17 - 19	
Plasticity index (%)	5 - 10	
Liquidity Index (%)	0.1 – 0.3	
Void ratio (**e**)	0.70 - 1.92	
Cohesion (kPa)	25 - 30	
Angle of internal friction (**φ**^{o})	7 - 18	
Modulus of Deformation **E** (kPa)	7.5 - 13	

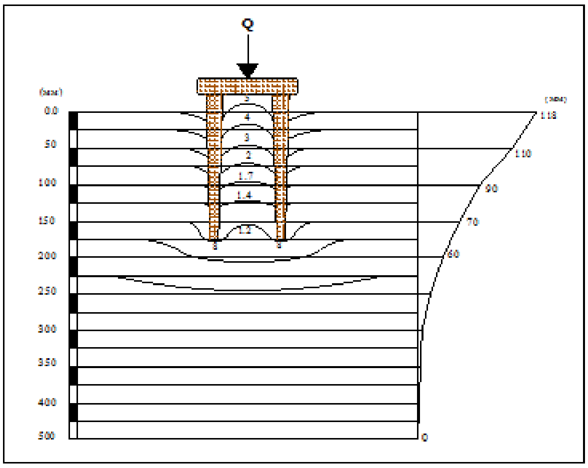

Fig. 5: Settlement of piles with α of 1.43°

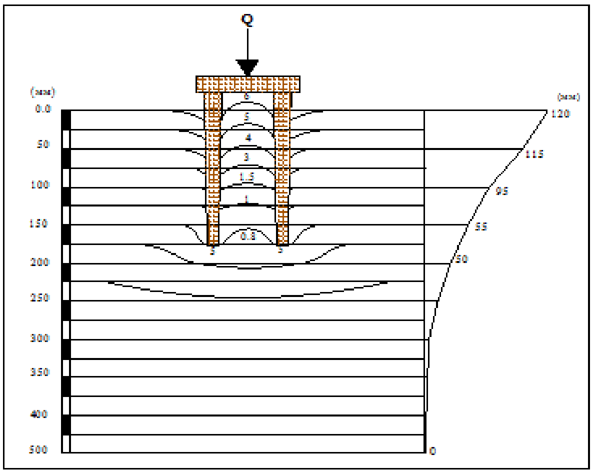

Fig.6: Settlement of piles with α of 0.95°

The Load-settlement curves for modeled tapered piles tested in the laboratory are shown in (Figs. 7 and 8). Soils around tapered piles with higher tapering angle (α) show less settlement (5-10% lower) at the initial period of loading. However, they reacted further to load and produced a generally higher settlement and deformations in soils closer to and around the pile tip with a depth of failure tip influence zone 10 times the pile diameter, while those with less tapering angle is 7.5 times their diameter. Pile cap settlement is 102% and 110% higher than soil settlements around tapered piles with tapering angles of 1.43^0 and 0.95^0 respectively.

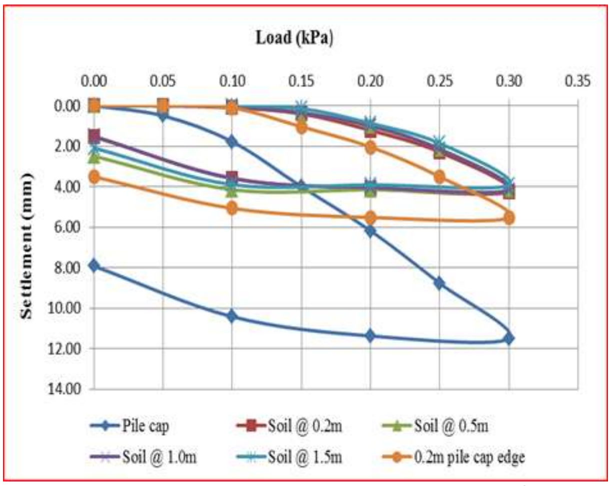

Fig.7: Settlement of soils with α of 1.43°

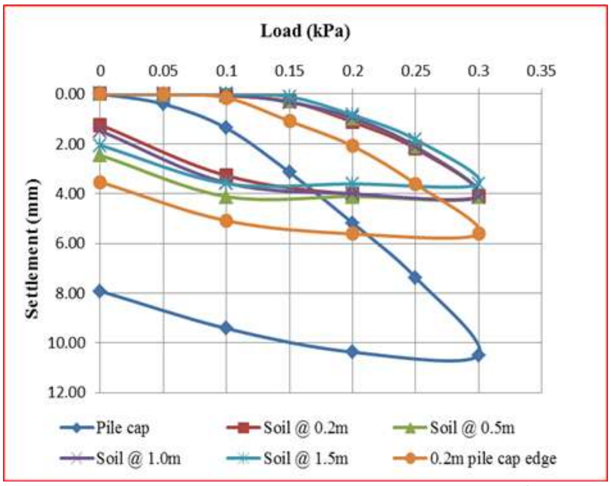

Fig. 8: Settlement of soils with α of 0.95°

The stress distribution and deformation pattern of the pile cap-soil interface during loading and unloading on the field is shown in (Figs. 9 – 12). Figs. 9 and 10 showed the horizontal displacement and settlement variation at a depth of 1.2m below the pile cap, the vertical variation of displacement of soil under pile cap line of piles with tapering angle α=1.43^0, the settlement variations for the corresponding tapered piles with α=0.95^0 are shown in (Figs. 11 and 12) below.

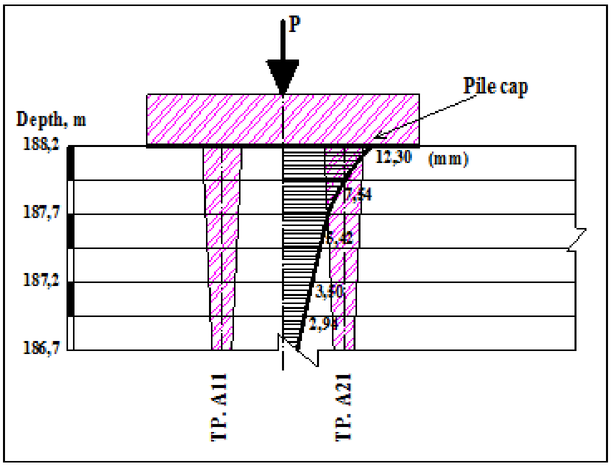

Fig.9: Vertical Settlement with α of 1.43°

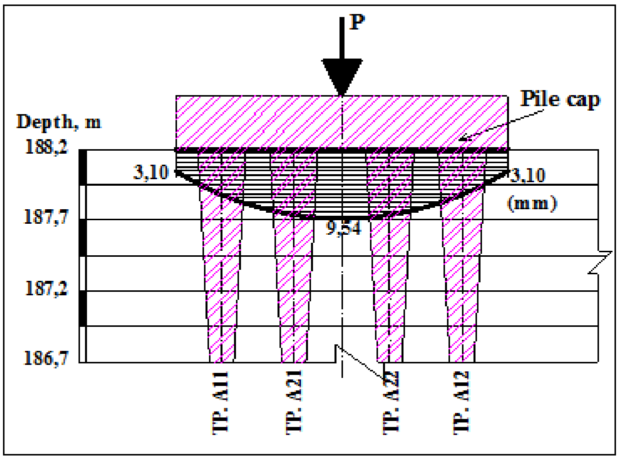

Fig.10: Horizontal Settlement with α of 1.43°

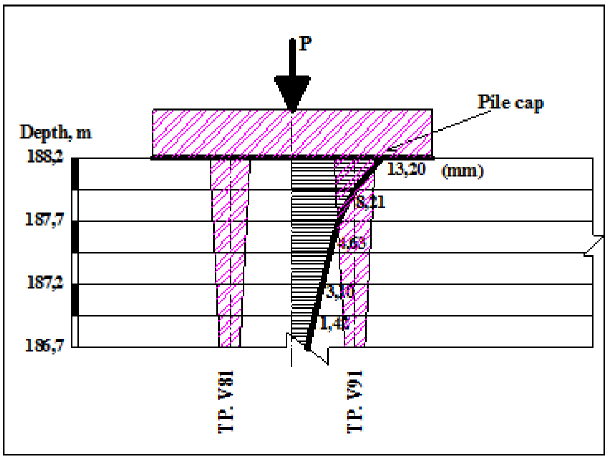

Fig.11: Vertical Settlement with α of 0.95°

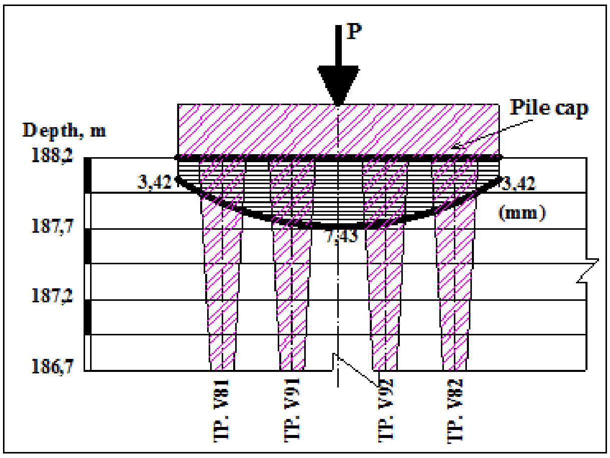

Fig.12: Horizontal Settlement with α of 0.95°

CONCLUSION

The settlement of soil around tapered piles bored into compressive clay soil obtained from the outskirt of Minsk region, when subjected to compressive axial loads have been investigated. The results of the study showed that in compressive clay, tapered piles with lower tapering angle have a higher soil resistance (5-10% higher) close to the soil surface with less toe effect on settlement of soil around the piles. The convex eaves, which is due to pile effect is more pronounced at deeper depth of penetration into the soil. The average depth of failure zone for tapered piles with pile spacing (η) of 0.95, and tapering angle (α) $0.95^0$is 7.5 times pile diameter, whereas it's 10 times diameter of piles when the tapering angle is increased 1.43^0.Settlement of tapered piles among other things is influenced by the tapering angle relative to the diameter of the pile, and this effect increases with incremental depth of pile penetration into compressive clay soil. Pile cap settlement is 5-10% higher in tapered piles with lower tapering angle.

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