Enhancement of The Behaviour of Laterally Loaded Vertical Piles Embedded in Clayey Soil

Marawan M. Shahien[1], Ahmed M. Nasr [1], Ahmed Farouk[1] and Mohamed HArfoush[2]

Faculty of Engineering, Tanta University, Egypt
E-mail: Marawan.shahin@f-eng.tanta.edu.eg , amanasrg@hotmail.com, drafarouk@f-eng.tanta.edu.eg
[2] *Faculty of Engineering, Mansoura University, Egypt*
E-mail: eng_mohamedharfoush@hotmail.com

***Abstract*-One of the most important problems is the construction on a soft clay soil, which extends over many areas in Egypt, Construction on a soft clay soil requires the use of deep foundations. In most of the cases the pile lateral capacity isn't satisfied due to the upper soft clay layers. Thus, there is a need to enhance the lateral load behavior of the pile. This paper is to study the enhancement of the lateral behavior of piles by replacing the upper layers of soft clay with dense sand. A series of laboratory tests were conducted on a single pile in soft clay soil. The upper clay layer around the pile was removed and replaced with compacted dense sand and the tests were repeated. The model pile used in this study was made of smooth hollow steel pipe. The outer diameter and wall thickness were 21 and 1.8 mm, respectively. Results indicated that the improvement of laterally loaded pile behavior was found to be strongly dependent on the replaced layer depth and replaced layer extension around the pile in dense sand. Results of experimental investigations were used to extract the lateral load-lateral displacement (P-Δ) curves.**

Keywords: Soft Clay, Model Tests, Laterally loaded pile.

I. INTRODUCTION

Lateral loads for piles are produced by seismic events, wind, wave action, ship impact, traffic, and land slide forces. The lateral resistance of a pile is controlled by the stiffness and the strength of the material of the pile and the soil surrounding the upper portion of the pile. In most situations, the soil surrounding the upper portion of the pile is too weak to sustain the design lateral loads. Thus there is a need to increase the lateral resistance of the pile or groups of piles. Such an increase may be achieved by either increase number of piles or increase pile diameter. Alternatively, an economic way to increase the lateral resistance is to improve the soil surrounding the upper portion of the pile Rollins and Brown, 2011 [1] and Faro et al., 2015[2].

Ground improvement has the ability to increase the lateral resistance of the pile by increasing the passive resistance of the soil surrounding the upper portion of the pile. The ground improvement techniques have the potential for being more cost-effective and reducing construction time. In spite of this fact, such techniques are rarely implemented in practice. Further, there are relatively few tests or records available in the literature to guide engineers in evaluating the actual effectiveness of this approach. In addition, there is no standard or methodology to aid engineers in designing increase of lateral resistance with surface ground improvement. There are specific improvement methods for each soil type, whether it is loose cohesionless soil or soft cohesive soil and these methods are provided by Michell 1981 [3], Tershai and Juran 2000 [4] and ASCE 1997 [5]. Furthermore, there are number of case histories that add a new hole in the sight, such as the cases provided by Brown et al. (1987 [6], 1988 [7]), Mokwa and Duncan 2001 [8], Rollins et al. 2005 [9], Cole and Rollins 2006 [10], Rollins, Snyder et al. 2010 [11], Rollins, Gerber, and Kwon 2010 [12] , Rollins and Nasr 2010 [13] , and Gerber et al. 2010 [14].

This paper presents a series of lateral load-displacement analysis performed to investigate the influence of replacing the upper layer around the pile with dense sand on the lateral behavior of piles embedded in soft clay sites. The purpose of this analysis is to provide guidance on the depth and lateral extent of the improved upper layer around the pile to provide the soil properties required to significantly increase the lateral pile behavior. Results and conclusions of the study are presented below.

II. EXPERIMENTAL SETUP

A series of laboratory model tests were conducted in a mild steel tank with length of 500 mm, width of 500 mm and height of 700 mm. The dimensions of the tank were chosen to ensure that the failure wedge around the model piles did not extend up to the walls (Prakash, 1962 [15]) . A schematic elevation view of the test configuration is illustrated in Fig. 1.

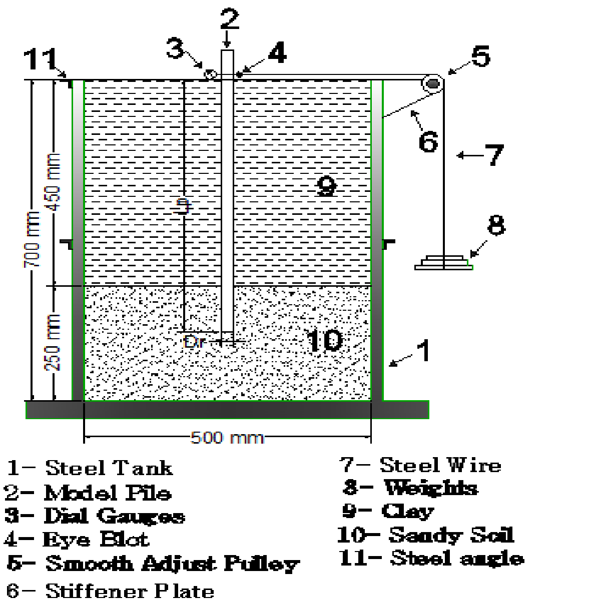


Figure 1. Schematic elevation view of test configuration (not to scale).

The model pile used in this study was made of smooth hollow steel pipe. The outer diameter and wall thickness were 21 and 1.8 mm, respectively. Embedment length (Lp) of the pile was 550 mm. The pile was considered to be long elastic pile.

III. TESTING PROCEDURE

The clay layer used in the model was prepared by using available Egyptian Kaolin. The Kaolinite powder was mixed with water at a water content of 22% in a concrete mixer for 15 minutes to achieve an undrained shear strength equal to 16kPa.

To investigate the influence of soil replacement on lateral pile behavior, the pile was placed in its position and a medium sand layer of unite weight 17 kN/m3 was placed at the bottom of the tank up to the level of pile tip The clay was then placed in 50 mm thick layers over the base sand and around the pile up to the surface level and left for 24 hours.

After 24 hours, two dial gauges were placed on the thin plate welded to the single pile head at constant spacing from the pile center. Then the lateral load was applied incrementally at approximately the soil surface through a smooth pulley until failure was reached. Each load increment was maintained constant until the pile lateral deflection had stabilized. The average displacement reading was taken for plotting the load displacement graphs.

IV. TESTING PROGRAM

The variables considered in this study included the thickness of improved soil and the lateral extent of the improved soil. Firstly, a pile embedded in uniform soft clay was tested under lateral load and was considered to be the reference case. Then, 13 tests were carried out to investigate the dense sand replacement effect on the lateral behavior of piles. Tests were conducted at various depths (Z) of 1.2 D, 2.4 D, 3.6 D and 4.8 D. The effect of sand depths was studied at various lateral extents of (5Dx5D), (10Dx10D), (15Dx15D) and (25Dx25D), the lateral extents of the compacted dense sand layer were kept constant for all depths.

Table (1). Model tests program

Replacement layer depth (Z)	Z = 2.4 D Z = 3.6 D Z = 4.8 D
Replacement layer extent (X)	X = 5D×5D X = 10D×10D X = 15D×15D X = 25D×25D

A. *Results and Discussions*

In the present study and according to AASHTO (2004)[16] , the ultimate lateral load capacity (H_u) is defined as the lateral load corresponding to the lateral displacement equal to 12.5 % of the pile diameter at the pile head.

Initially, an investigation of the behavior of a single pile embedded in uniform soft clay and under lateral load was conducted to provide the necessary reference data for the purpose of comparison. Figure 2 shows the lateral-load verses lateral displacement for single pile embedded in uniform soft clay soil.

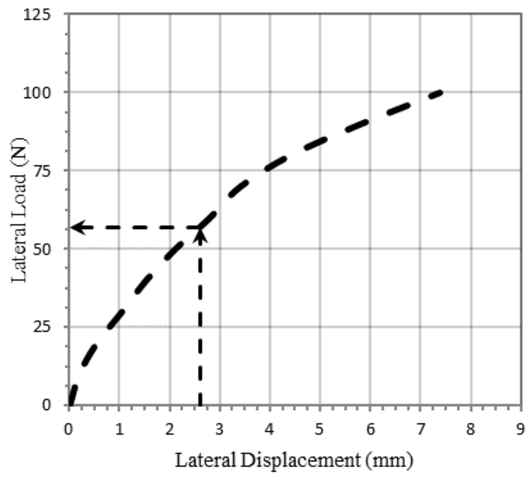


Figure 2. Load-Displacement curve for single pile in soft clay

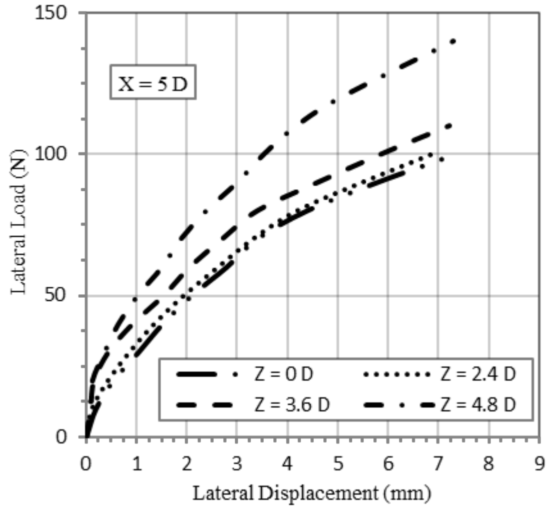
To investigate the effect of replacing the upper layer around the pile with compacted dense sand, a series of tests were performed extent for the improved upper layer. The lateral load verses lateral displacement curves for different lateral extents of compacted sand layer at each depth are shown in Figure 3.

Figure 3 shows that there is no significant improvement in the pile lateral capacity by increasing the improved lateral extent around the pile from 5 D to 25 D when the improved depth equal to 2.4 D. The lateral force required to display the pile 2.6 mm increase from 57 N with no improvement to 60 N, 62 N, 65 N and 65 N for lateral soil extent equal to (5Dx5D), (10Dx10D), (15Dx15D) and (25D x 25D) respectively.

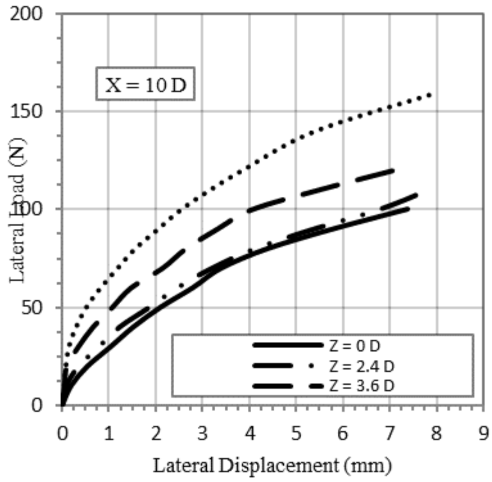
It is clear from Fig. 3 that the pile lateral capacity clearly improved when the lateral extent around the pile is between (15D x 15D) and (25Dx25D). The pile lateral capacity increases by about 53% and 70 % respectively, at improved soil depth equal to 3.6 D. while the pile lateral capacity increases by about 96 % and 144% respectively, at improved soil depth equal to 4.8 D. Thus, it should be noted that increasing the lateral behavior of the pile can be achieved by increasing the lateral extent from 15D to 25D (7.5 D to 12.5 D in front of the pile), that's agree with the observation made by Rollins and Brown (2011)[1] that the lateral extent required to develop the passive resistance of the soil around the pile is 10D in front the pile.

Also it should be noted that both improved soil lateral extent and improved soil depth are two important factors that affect the pile lateral capacity. The pile lateral capacity of pile can be enhanced by replacing the upper portion around the pile with compacted dense sand with lateral extent from 15 D to 25 D and soil depth from 3.6 D to 4.8 D.

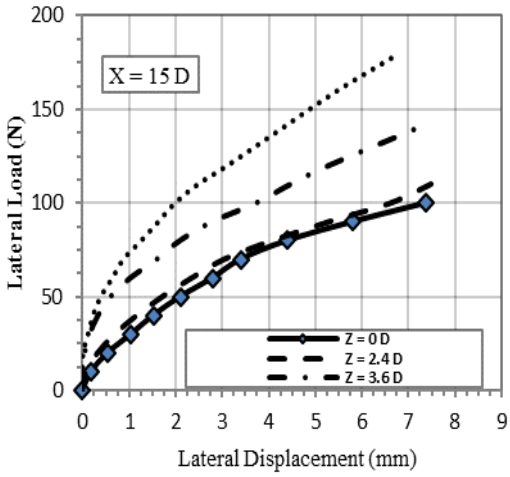
Figures 4 and 5 show the tests results for pile embedded in uniform clay and results of replacing the upper layer with compacted dense sand at various depth and varies extent respectively.



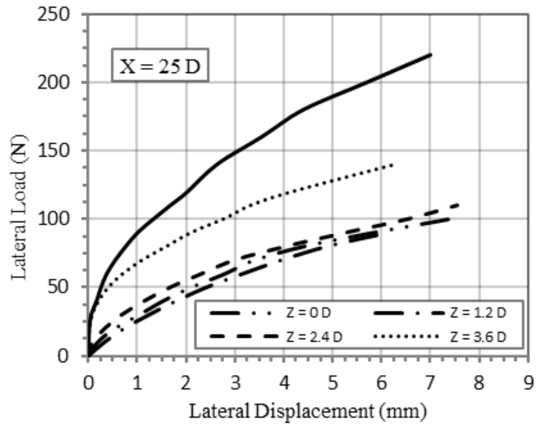
(A) Load-displacement curves for various depths at lateral extent equal to 5 D



(B) Load-displacement curves for various depths at lateral extent equal to 5 D



(C) Load-displacement curves for various depths at lateral extent equal to 15 D



(D) Load-displacement curves for various depths at lateral extent equal to 25 D

Figure 3. Lateral load versus lateral constant lateral extent (X) = (5, 10, 15and 25) D for various depths (Z)

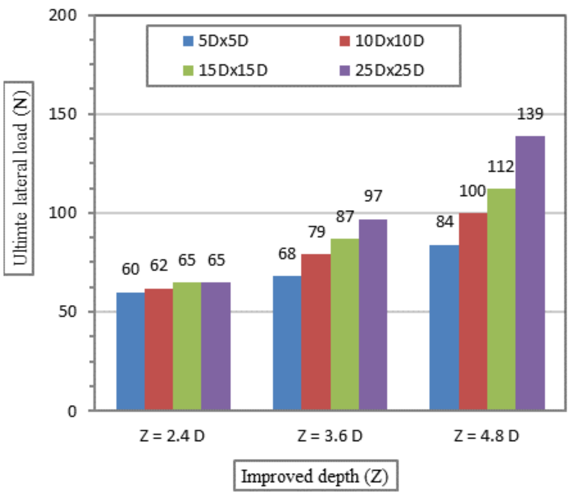


Figure 4. Variation of ultimate lateral load versus improved sand depths.

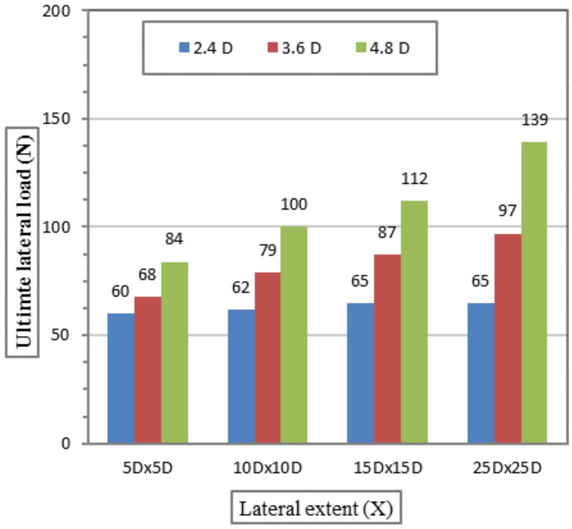


Figure 5. Variation of ultimate lateral load versus improved sand lateral extent.

V. CONCLUSIONS

In this study a series of laboratory tests was performed to study the effect of soil improvement techniques on the lateral behavior of piles. The experimental study was carried out for various thickness (Z) and lateral extent (X) of the improved soil around the piles. Based on this experimental results, the following conclusions can be drawn.

1- The increase in the pile lateral capacity is a function of the combined effect of the depth and lateral extent of the replaced layer, as well as the shear strength of the replaced upper layer.
2- It is clear that using compacted sand near the ground surface did not improve the piles lateral capacity.
3- Increasing the depth of compacted dense sand around a single pile to 3.6 D and 4.8 D, improves the pile lateral capacity by 70% and 144 % respectively.
4- The kinematics of lateral failure is detected by displacement and crack propagation around the piles system.
5- Soil improvement over such a limited extent can be an economically viable option for improving the piles lateral performance.

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