Numerical Analysis Using Elastic–Plastic Soil Model for a Single Pile in Clay Layer to Examine the Effect Surcharge Loading on the Distribution of Skin Friction

T. Awwad, S. Al Kodsi, V. Ulitsky, A. Shashkin and L. Awwad

Abstract Loading the ground surface next to the pile head is the main reason for the soil layers' settlements. According to the relative movement between the pile and soil, skin friction along the pile's shaft is distributing. In this paper, a numerical modeling will be carried out using finite elements technique to examine the pile-soil loading combination on the distribution of skin friction. The model is elastic–plastic relationship between stress and strain and is first validated by comparing the numerical results with the ones obtained from a full-scale loading field test. A parametric study will be conducted herein using different cases of loading on both pile and the ground surface. The value of the surcharge load and the type of loading will be discussed and their effect on the location of neutral plane; point of equilibrium will be examined.

Keywords Neutral plane · Skin friction · Single pile · Parametric study · Elastic–plastic model

1 Introduction

Pile foundations are traditional form of foundations in bad subsoil conditions. Friction pile is usually installed in a compressible soil layer beyond the reach of any incompressible bearing strata at its tip, thus it transmits the loads to the surrounding soil mainly through the pile's shaft. A relative movement between pile and the soil

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leads to mobilize shear stresses along the interface between pile and adjacent soil. Moreover, the excessive settlement associated with the down drag can cause vital damages to the superstructure of a building [1]. Terzaghi and Peck [2] assumed full mobilization of shear strength along the pile-soil interface up to the pile toe for a single pile, or along the perimeter of pile group. Therefore, the neutral point (point of zero shear stress) is assumed to be located at the bearing stratum of the pile. Indraratna et al. [3] suggested that in order to minimize the negative skin friction, piles may be driven few weeks, or a month later after the surcharge load is applied on the ground surface. Poorooshasb et al. [4] studied the case of a single pile of circular cross-section considering an axisymmetric problem with a surcharge pressure on the underlying clay layers. Hanna and Sharif [5] conducted a study on piles driven into clay and subjected to indirect loading through the surcharge applied symmetrically on the surrounding area. The study was based on a numerical model using finite element technique and the soil was assumed to follow a linear elastic-perfectly plastic stress–strain relationship, which defined by Mohr–Coulomb failure criterion. The objective of this paper is to study the factors affecting the distribution of NSF along the pile length besides the examination of the access of pore water pressure and the change in NPL. Field tests of a single pile in clay layers will be presented herein to compare the field measurements with the analytical modeling.

2 Model Validation

2.1 Soil Constitutive Model

The soil was modeled to behave as a linear elastic-perfect plastic material, and its yield function is defined by Mohr–Coulomb criterion. The model is used usually because of its reasonable accuracy, simplicity and widely used in practice. The basic parameters required for the elastic perfectly plastic model includes Modulus of elasticity (E), Poisson ratio (υ), Cohesion (c'), angle of internal friction (θ') and dilatancy angle (ψ) (Fig. 1).

Fig. 1 Failure envelope of Mohr–Coulomb

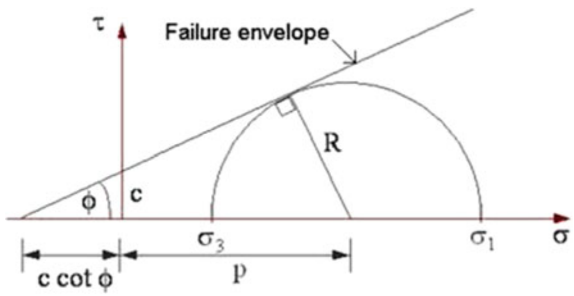


Table 1 Soil mechanical properties

Soil type	Depth (m)	γ (kN/m^3)	E (MPa)	C (kPa)	θ
Clay	1.86	18.4	4.61	24.5	8.7
Mud clay	2.54	18.3	7.55	8.4	6.3
Clay	4.86	20.0	9.39	37.3	16.7
Silt	5.70	19.0	10.01	15.6	21.0
Silty clay	8.70	18.2	6.08	14.7	15.3
Silty sand	20.00	19.5	28.25	4.0	20.0

Table 2 Pile material properties

Material	Length (m)	Diameter (mm)	γ (kN/m^3)	E (GPa)
Pile	1.86	18.4	4.61	24.5

Note $\upsilon = 0.3$

2.2 *Loading Test in Changsha, China*

Lu et al. [6] carried out a field test in Changsha city in China to investigate the negative skin friction. Groundwater level was at 0.6 m and a cast in place concrete pile was used with 43 m in length and 1 m in diameter. A (5 m) layer of embankment was constructed in the field test site. The mechanical properties for the soil profile are shown in Table 1. The properties of the pile material are shown in Table 2.

The analytical model is shown in Fig. 2. A comparison between the field test measurements and the numerical model results for the skin friction distribution is shown in Fig. 3.

3 Study Model

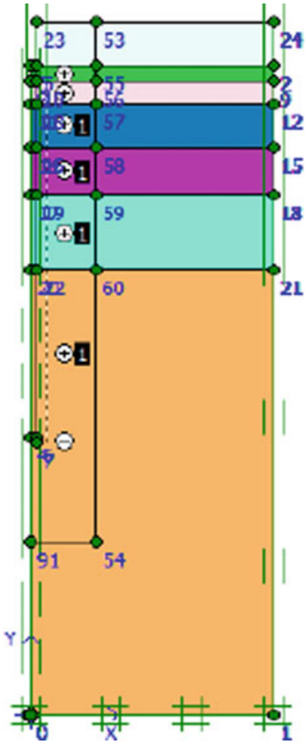
The study model is a driven concrete pile in two types of clay layers. The upper layer is a soft clay while the bearing is a stiff clay layer. Tables 3, 4, 5, 6, 7 and 8 show the soil and pile properties for the study model (after Azizul Hoque [7]).

4 Parametric Study

The parametric study will be based on changing the surcharge load (Table 9).

Surcharge Load (q) is the distribution load applied on the upper soil surface near to the pile which mobilize the negative skin friction along the pile length. Figure 4

Fig. 2 Analytical model of the field test



shows the distribution of skin friction along the pile length and Fig. 5 shows the changing in the location of neutral plane versus the changing in surcharging.

5 Conclusion

In this paper, finite element technique was used to carry on the parametric study to simulate the case of a single driven pile in clay layers. The ground surface next to the pile is under surcharging and according to the parametric study results, it can be concluded that the location of the neutral plane goes deeper when the surcharge load, increases. It is recommended not to overloading the ground surface next to the pile with a long term surcharging when the NSF is expected.

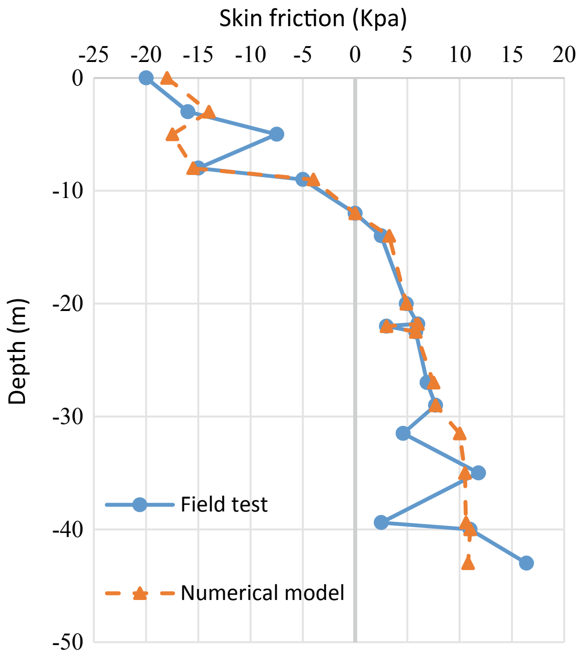


Fig. 3 Comparison between field test measurements and analytical results

Table 3 Properties of the clay used for Mohr–Coulomb (cohesion ratio 0.2)

Soil type	Soft clay	Medium stiff clay
γ_{unsat} (kN/m^3)	14	–
γ_{sat} (kN/m^3)	15.5	19
c' (kPa)	10	50
ϕ'	15	20
E (kPa)	5000	38,000
ν	0.2	0.25
k_x (m/day)	8.0×10^{-4}	4.0×10^{-4}
k_y (m/day)	8.0×10^{-4}	4.0×10^{-4}

Table 4 Properties of the clay used for Mohr–Coulomb (cohesion ratio 0.3)

Soil type	Soft clay	Medium stiff clay
γ_{unsat} (kN/m^3)	14	–
γ_{sat} (kN/m^3)	15.5	19
c' (kPa)	15	50
ϕ'	15	20
E (kPa)	6000	38,000
ν	0.2	0.25
k_x (m/day)	7.5×10^{-4}	4.0×10^{-4}
k_y (m/day)	7.5×10^{-4}	4.0×10^{-4}

Table 5 Properties of the clay used for Mohr–Coulomb (cohesion ratio 0.4)

Soil type	Soft clay	Medium stiff clay
γ_{unsat} (kN/m^3)	14.5	–
γ_{sat} (kN/m^3)	16	19
c' (kPa)	20	50
ϕ'	15	20
E (kPa)	7000	38,000
ν	0.2	0.25
k_x (m/day)	7×10^{-4}	4.0×10^{-4}
k_y (m/day)	7×10^{-4}	4.0×10^{-4}

Table 6 Properties of the clay used for Mohr–Coulomb (cohesion ratio 0.5)

Soil type	Soft clay	Medium stiff clay
γ_{unsat} (kN/m^3)	14.5	–
γ_{sat} (kN/m^3)	15.5	19
c' (kPa)	25	50
ϕ'	15	20
E (kPa)	8500	38,000
ν	0.2	0.25
k_x (m/day)	6.5×10^{-4}	4.0×10^{-4}
k_y (m/day)	6.5×10^{-4}	4.0×10^{-4}

Table 7 Properties of the clay used for Mohr–Coulomb (cohesion ratio 0.6)

Soil type	Soft clay	Medium stiff clay
γ_{unsat} (kN/m^3)	15	–
γ_{sat} (kN/m^3)	16.5	19
c' (kPa)	30	50
ϕ'	15	20
E (kPa)	10,000	38,000
ν	0.2	0.25
k_x (m/day)	6.0×10^{-4}	4.0×10^{-4}
k_y (m/day)	6.0×10^{-4}	4.0×10^{-4}

Table 8 Properties of the pile material

Material	Pile
Length (m)	30
Diameter (mm)	500
γ (kN/m^3)	24
E (kPa)	30,000,000
ν	0.3

Table 9 Parametric study cases

Case	Value
Surcharge load (q)	14–112 kN/m^2

Fig. 4 Distribution of negative skin friction along the pile

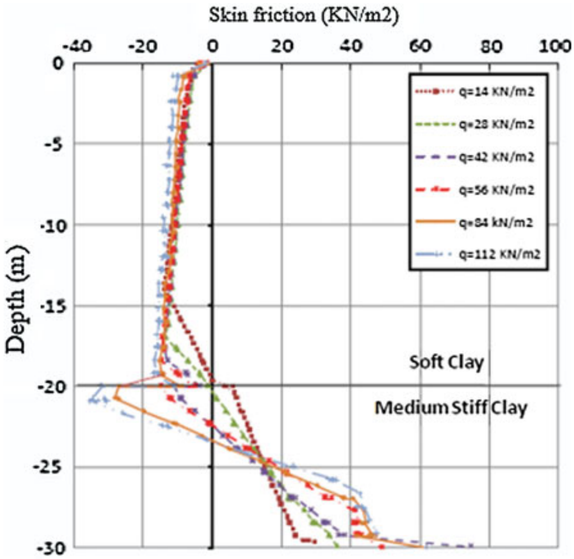
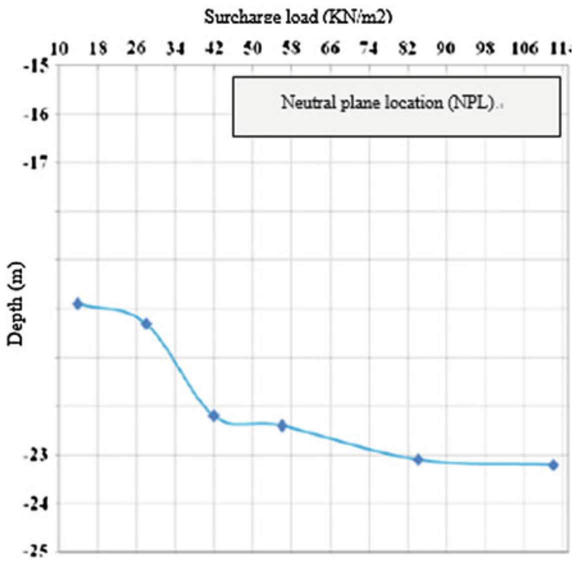


Fig. 5 Changing in the location of neutral plane versus the changing in surcharge load



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