Analysis of negative skin friction distribution on a single pile

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ABSTRACT

Negative skin friction (NSF) is the downward shear stress distributes along the pile's shaft. NSF may lead to pile's material cracks or in some cases might pull out the piles from the pile cap. NSF occurred when the settlement of the adjacent soil is larger than pile's settlement, which makes the soil pull down the pile until arriving the point of equilibrium; Neutral plane location (NPL). After reaching this, point the skin friction changes from negative to positive. Studying the mechanism of NSF distribution is so important when designing the pile foundations in clay layers. Many factors play a major rule in mobilizing the negative shear stresses along pile's shaft. In this paper, a parametric study will be carried on to examine the distribution of NSF and the changing in the NPL. The study model will be validated first by comparing the numerical results with field test measurements. Then a numerical parametric study based on two soil models will be carried on. The location of the neutral plane will be determined for different cases of parameters and designing equations will be formed to help the designing engineers. Graphs show the NSF and excess pore water distribution in addition to soil settlements along the pile's length will be obtained. According to the parametric study results, it can be concluded that the thickness of the soft clay layer and the percentage of the pile's length impeded into the bearing layer impact the neutral plane location. Moreover, changing the soil mechanical properties affects the (NSF) distribution.

Keywords: Negative skin friction, pile, shear stress, the coefficient of slenderness, neutral plane.

1 INTRODUCTION

Pile foundation has been used and universally accepted as the traditional form of foundation 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. In many circumstances, settlement of the surrounding soil might take place, thus it will provide no support to the pile. As a matter of a fact, it will act in reverse sense, in terms of resistance, by comparison with the normal situation. Further, if the downward movement of the surrounding soil exceeds the pile settlement, the pile will resist the soil movement and hence an extra load will be transferred to it in addition to the external axial load. It has been found that the down drag load due to surcharge loading on the surrounding soil can exceed the ultimate capacity of a pile Bjerrum et al (1965). Moreover, the excessive settlement associated with the down drag can cause vital damages to the superstructure of a building (Brand et al (1975). The shear stresses generated on the pile shaft by virtue of the soil settlement will be negative in sign, and accordingly the terms "negative skin friction" and "down drag load" are used. In this paper, a numerical model will be carried out using (PLAXIS-2D). A parametric study for different cases will be conducted and the location of the neutral plane will be determined for each case.

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 ($\theta$`) and dilatancy angle (ϕ)

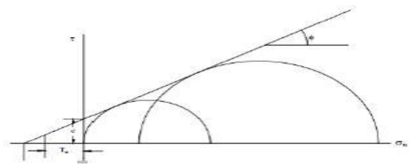

Fig. 1. Failure envelop of Mohr-Coulomb

2.2 Field loading test in Changsha, China

W. -T. Lu et al (2005) 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 5m layer of the 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.

Table 1. Soil mechanical properties.

Soil type	Depth (m)	γ (kN/m3)	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	4.08.7	20.0

Table 2. Pile material properties.

Material	Length (m)	Diameter (mm)	γ (Kn/m3)	E (GPa)
Pile	1.86	18.4	4.61	24.5

Note: υ=0.3

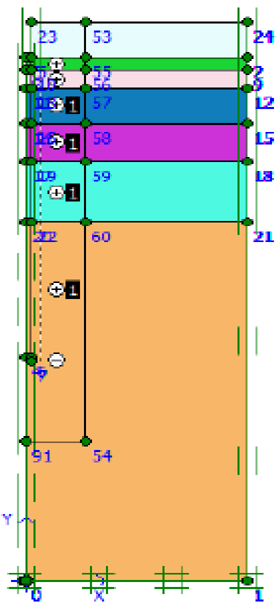

Fig. 2. An analytical model of the field test

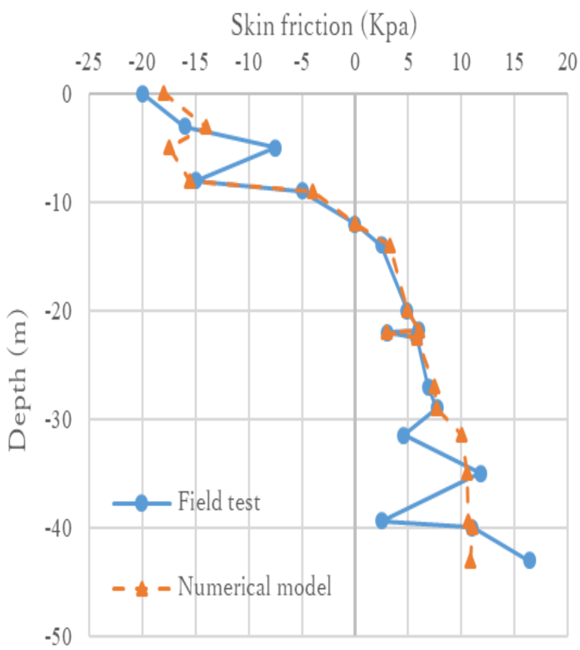

Fig. 3. Comparison between field test measurements and analytical results

3 PARAMETRIC STUDY

3.1 Soft Clay Layer Thickness (H)

In this parametric study, the thickness of the soft clay layer will be changed from 5m to 25m. The length of the pile is constant (L=30m). Fig. 4 shows the distribution of the skin friction along the pile length. Fig.5. shows the change in the NPL.

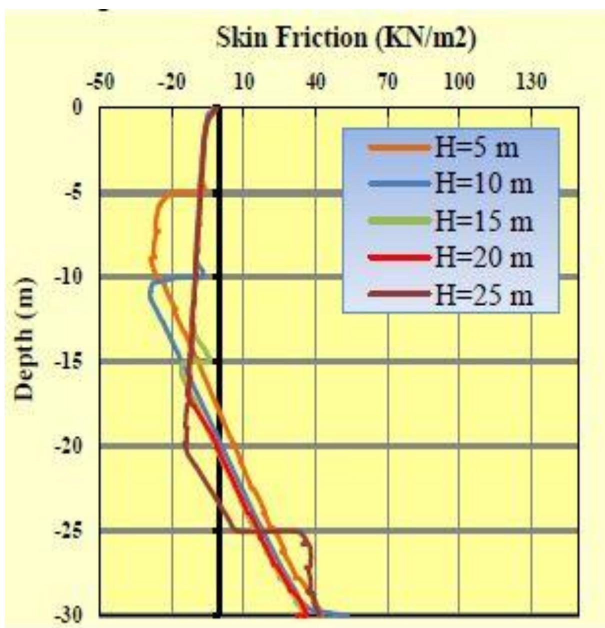

Fig. 4. Skin friction distribution along the pile length with changing the soft clay layer thickness

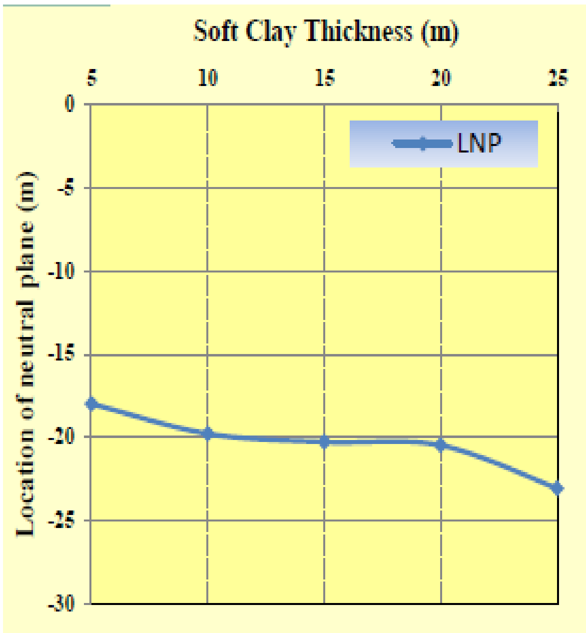

Fig.5. The change in the NPL due to the changing in soft clay layer thickness

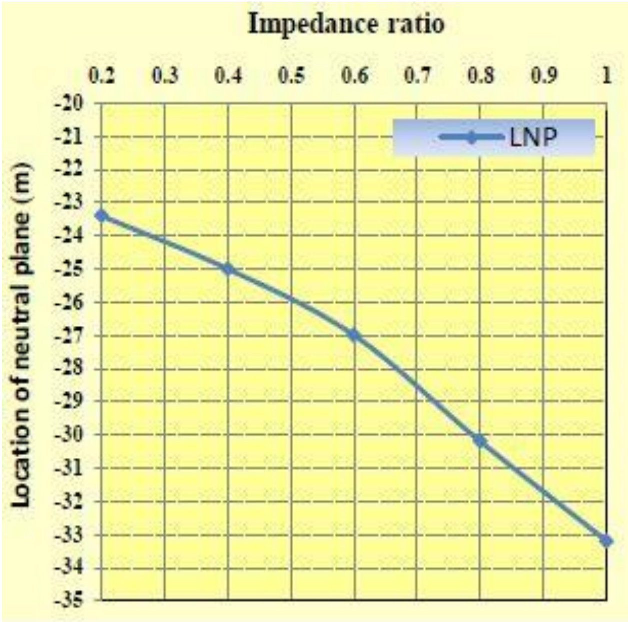

Fig.7. The change in the NPL due to the changing in the impedance ratio

3.2 Impedance Ratio (i)

Impedance ratio represents the percent of the pile length penetrates the medium stiff clay to the height of the soft clay layer that is equal to 25m. It has been used five different values for impedance ratio (0.2, 0.4, 0.6, 0.8, 1). Fig. 6. Shows the distribution of NSF

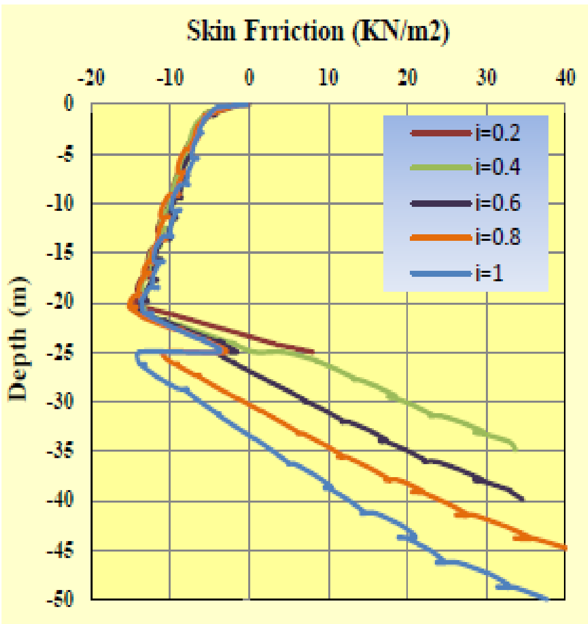

Fig.6. Skin friction distribution along the pile length with changing the impedance ratio

3.3 Cohesion Ratio (C)

This parameter represents the effect of changing the mechanic properties between the two layers of clay on the negative skin friction. It has been used five different values for the cohesion ratio (0.2, 0.3, 0.4, 0.5, 0.6) which represent the percent of soft clay layer's cohesion to medium stiff clay layers'. Fig (6) shows the distribution of skin friction along the pile length while Fig (7) shows the changing in the location of the neutral plane versus the changing in the cohesion ratio.

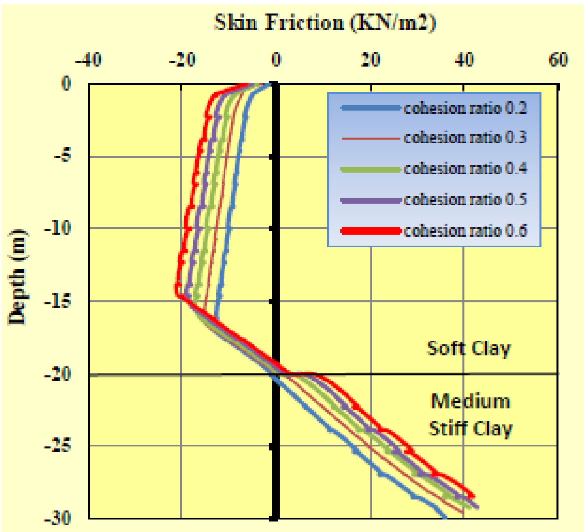

Fig.8. Skin friction distribution along the pile length with changing the Cohesion ratio

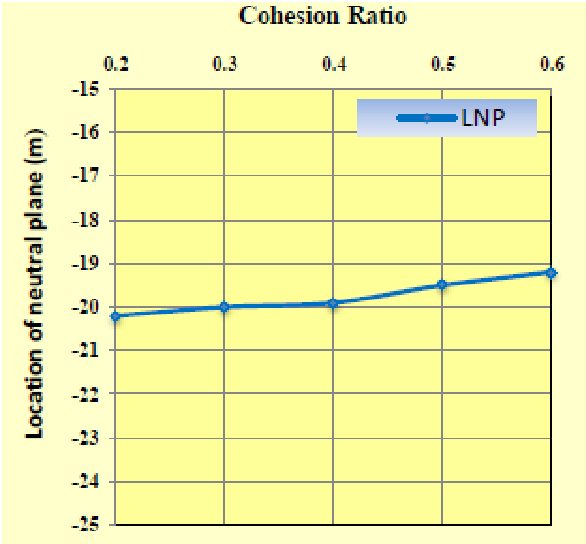

Fig.9. The change in the NPL due to the changing in the cohesion ratio

4 CONCLUSION

NSF produces due to the settlements of the pile and the adjacent soil. Usually, when the pile is driven into a clay layer, its settlement will be larger than the soil leading to produce positive shear stresses along the pile's shaft. In case of applying a surcharge load on the surface next to the pile head, the settlements of the adjacent soil may become larger than the pile's depending on the value of the surcharging and a negative shear stress distribution will occur along the pile's shaft.

In this article, two parameters impact has been studied through the parametric study and it can be concluded that:

1. The location of the neutral plane (LNP) varies due to the change in the soft clay layer thickness. When the soft clay layer becomes thicker, the neutral plane goes deeper which means that the part of the pile induced by NSF becomes bigger.

2. The impedance ratio has an impact on the (LNP) and the NSF distribution. The neutral plane moves downwards as the value of the impedance ratio is higher.

3. Changing the mechanical properties of the soft clay layer raises the (LNP) and as a result, the part of the pile induced by (NSF) will be smaller.

REFERENCES

Awwad T. and Kodsi S.A. (2017). A comparison of numerical simulation models to determine the location of the neutral plane. Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering. pp 1947 – 1950.

Awwad T., Mussabayev T., Tulebekova A., Jumabayev A. (2019). Development of the computer program of calculation of concrete bored piles in soil ground of Astana city. International Journal of GEOMATE 17 (60), pp.176-182.

Awwad T., Shakhmov Z.A., Lukpanov R.E., Yenkebayev S.B. (2019) Experimental Study on the Behavior of Pile and Soil at the Frost Condition. In: El-Naggar H., Abdel-Rahman K., Fellenius B., Shehata H. (eds) Sustainability Issues for the Deep Foundations. GeoMEast 2018. Sustainable Civil Infrastructures. Springer, Cham, pp 69-76,

Awwad T., Yenkebayev S.B., Tsigulyov D.V., Lukpanov R.E. (2019) Analysis of Driven Pile Bearing Capacity Results by Static and Dynamic Load Tests. In: El-Naggar H., Abdel-Rahman K., Fellenius B., Shehata H. (eds) Sustainability Issues for the Deep Foundations. GeoMEast 2018. Sustainable Civil Infrastructures. Springer, Cham, pp 77-84.

Bjerrum, L. and Johanessen, I. J. (1965). Measurement of the compression of a steel pipe to rock due to the settlement of the surrounding clay. Proc. 6th ICSMFE, MONTREAL, vol. 2, pp.261-264.

Brand, E. W. and Luangdilok, N., (1975). A long-term foundation failure caused by dragdown on piles. Proc. 4th S.E. Asian Conf. Soil Eng., Kuala Lumpur, pp 4.15-4.24

Indraratna, B., Balasubramaniam, A. S., Phamvan, P. and Wong, Y. K. (1992). Development of negative skin friction on driven piles in soft Bangkok clay. Can.Geotech. J., 29, pp.393 – 404.

Kodsi, S.A., Oda, K. & Awwad, T. (2018), "Viscosity effect on soil settlements and pile skin friction distribution during primary consolidation," International Journal of GEOMATE, Dec. 2018 Vol.15, Issue 52, pp.180 -187.

Mohammad Azizul Hoque (2006). Coupled consolidation model for negative skin friction on piles in clay layers. A Thesis in the Department of Building, Civil an Environmental Engineering, Concordia University, Montreal, Quebec, Canada.

W.-T.Lu, W.Leng, and Y.-H. Wang (2005), “In-situ tests on negative friction resistance of abutment piles in soft soil,” Chinese Journal of Geotechnical Engineering, vol. 27, no. 6, pp. 642-645, 2005.