Journal of Engineering Research

Volume 6 | Issue 1 | Article 3

2022

Numerical analysis of group effect on dragload on piles subjected to negative skin friction

Mohsen Saad

Numerical Analysis of Group Effect on Dragload on Piles Subjected to Negative Skin Friction

Marwan Shahin [1], Ahmed Farouk [2], and Mohsen Saad [3]

[1] Professor Structural Eng. Department, Faculty of Engineering, Tanta University, Tanta, Egypt
Email: marawan.shahin@f-eng.tanta.edu.eg
[2] Assistant Structural Eng. Department, Faculty of Engineering, Tanta University, Tanta, Egypt
Email: drafarouk@f-eng.tanta.edu.eg
[2] M.SC. Student, Faculty of Engineering, Tanta University, Tanta, Egypt
Email: MohsenM.Saad@gmail.com

Abstract- **In this paper, the group effect on dragload on pile group subjected to negative skin friction is studied. The effect of pile spacing, pile location in a group and pile number is studied using finite element program PLAXIS 3D. Single pile, 2x2 pile groups and 3x3 pile groups with pile spacing 2d and 3d existing in soft clay layer overlying dense sand layer are used in this parametric study. A layer of fill is used as a load on the layer of soft clay resulting in soil consolidation which causes increase in axial load on piles "dragload" due to negative skin friction along the piles. The results from parametric analysis showed that the group effect on dragload is relevant to pile spacing, piles number and pile location within pile groups. Results showed that the reduction in dragload due to group effect decreases with the increase in pile spacing. Results also showed that center piles had the most significant group effect on reduction of dragload followed by edge piles and corner piles respectively.**

Keywords: **Negative Skin Friction, Group Effect, Pile Spacing, Soft Clay, PLAXIS 3D.**

I INTRODUCTION

Piles are used to transfer the load acting on them from structures to the bearing soil by end-bearing resistance and to the surrounding soil by development of positive skin friction as a result of the downward relative movement of the pile with respect to the surrounding soil. When soil surrounding pile settlement is larger than pile settlement negative skin friction is induced. This happens when piles are constructed through soft soil or in consolidating ground. Dragload is the load transferred to a pile from negative skin friction as defined by Fellenius (1998). Dragload on piles due to negative skin friction can be estimated by theoretical approaches such as the effective stress approach (β-method) which used to estimate dragload by multiplying the effective overburden pressure by a constant ($\beta = k_o \tan\Phi$). NAVFAC (1982) recommended that values of β varied from 0.2 to 0.25 for clay.

Lee et al. (2002) performed 3D-numerical analysis to investigate the dragload and the group effect in pile groups, the results showed that groups with close pile spacing had more group effect than groups with wide pile spacing and they reported that in pile groups, the inside piles have more group effect than the outside piles and the more number of piles in a group the more group effect and vice versa. Lam et al. (2009) carried out centrifuge model tests and a series of axi-symmetric and 3D-numerical analysis for center piles surrounded by eight smaller sacrificing piles in 3x3 pile groups with pile spacing 5d and 6d, the results showed that the maximum drag load transferred to center pile in a group with pile spacing 5d was less than the maximum drag load transferred to center pile in a group with pile spacing 6d and it revealed that the closer the pile spacing, the greater the shielding effect.

Tan and Fellenius (2016) performed a 3D-numerical analysis for 6x6 pile group, the results showed that the inner piles had less dragload than the outer piles. Results also cocluded that numerical analysis is a suitable method for computing the reduced dragload on inner piles and this can be used for a more economical design of pile groups.

II. PROBLEM DEFINITION

Figure 1 shows the soil profile used in the study which consists of a layer of fill of 2m thick underlain by a soft clay layer of 23m thick that overlying a layer of dense sand of 15m thick. The ground water table is at the top of soft clay layer. The analysis for this study were performed on single pile, 2x2 pile groups and 3x3 pile groups with pile length (L) = 26m, pile diameter (d) = 1m and pile spacing (S) = 2d and 3d. In this study, the effect of pile spacing and pile location within pile group is investigated considering the parameters presented in Table 1, and 2 respectively. Figures (2-a) and (2-b) show pile group arrangement and pile locations, a, b and c refers to corner, edge, and center respectively. Tables 1, 2, 3 and 4 illustrate the properties of soil and pile used in this study after Hong (2013).

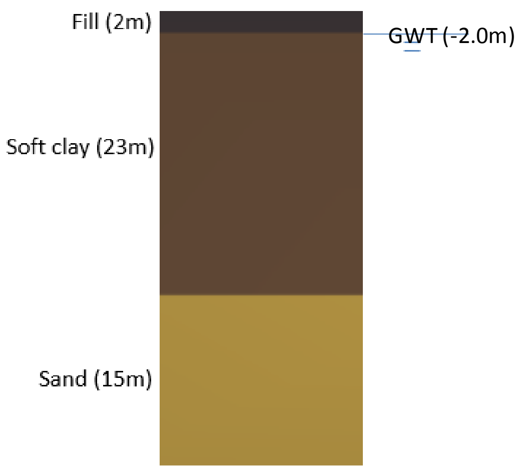
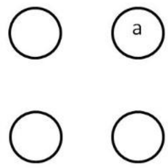
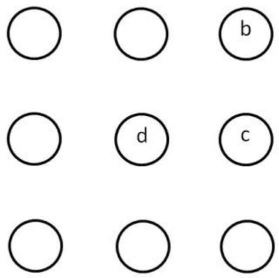


Fig. 1: The soil profile



(a) Pile group 2x2 arrangement



(b) Pile group 3x3 arrangement
Fig. 2: Pile group arrangment

Table 1: Material Properties of Piles (After Hong, 2013)

Parameters	Unit	Values
Material model		Elastic model
γ	(kN/m^3)	25.00
E	(kN/m^2)	30e6
υ	(-)	0.2

Table 2: Material Properties of Fill (After Hong, 2013)

Parameters	Unit	Values
Material model		Hardening soil
Material type		Drained
γ_{unsat}	(kN/m^3)	20.00
γ_{sat}	(kN/m^3)	20.00
K_x	(m/day)	0.864
K_y	(m/day)	0.864
K_z	(m/day)	0.864
e_{init}	(-)	0.50
e_{min}	(-)	0.00
e_{max}	(-)	999.00
c_k	(-)	1E15
E_{50}^{ref}	(kN/m^2)	15000.00
E_{oed}^{ref}	(kN/m^2)	15000.00
power (m)	(-)	0.50
c_{ref}	(kN/m^2)	0.10
φ	$(^o)$	35.00
ψ	$(^o)$	0.00
E_{ur}^{ref}	(kN/m^2)	45000.00
$\upsilon_{ur}^{(nu)}$	(-)	0.200
p^{ref}	(kN/m^2)	100.00
cincrement	(kN/m^2)	0.00
yref	(m)	0.00
Rf	(-)	0.90
Tstr.	(kN/m^2)	0.00
R_{inter}	(-)	1.00
Interface permeability		Neutral

III. FINITE ELEMENT MODELING

Plaxis 3d was used to perform numerical analysis for this analysis. The hardening soil model was used for the soil and piles were simulated as embedded piles. An embedded piles is a pile composed of beam elements that can be placed in the sub-soil by means of special interface elements. Gwee Boon Hong (2013) used a value of R_{int} equals to 1 to yield a β value of 0.25. A single pile and two 3x3 pile groups with pile spacing 2d and 3d with pile length (L) = 26m, pile diameter (d) = 1m and pile spacing (S) = 2d and 3d were used in this analysis. The geometry of the Finite Element soil model adopted for this analysis is 50 m in depth and 50 m in width and Length to satisfy the boundary condition of side and base effect. Figures 4 and 5 show 3D finite element mesh for single pile and pile groups respectively.

Table 3: Material Properties of Soft Clay (After Hong, 2013)

Parameters	Unit	Values
Material model		Hardening soil
Material type		Undrained
γ_{unsat}	(kN/m^3)	16.00
γ_{sat}	(kN/m^3)	16.00
K_x	(m/day)	0.001
K_y	(m/day)	0.001
K_z	(m/day)	0.001
e_{init}	(-)	0.5
e_{min}	(-)	0.00
e_{max}	(-)	999.00
c_k	(-)	1E15
E_{50}^{ref}	(kN/m^2)	2000.00
E_{oed}^{ref}	(kN/m^2)	2000.00
power (m)	(-)	1.00
c_{ref}	(kN/m^2)	0.10
φ	$(^o)$	22.00
ψ	$(^o)$	0.00
E_{ur}^{ref}	(kN/m^2)	6000.00
$\upsilon_{ur}^{(nu)}$	(-)	0.200
p^{ref}	(kN/m^2)	100.00
cincrement	(kN/m^2)	0.00
yref	(m)	0.00
Rf	(-)	0.90
Tstr.	(kN/m^2)	0.00
R_{inter}	(-)	1.00
Interface permeability		Neutral

Table 4: Material Properties of Dense Sand (After Hong, 2013)

Parameters	Unit	Values
Material model		Hardening soil
Material type		Drained
γ_{unsat}	(kN/m^3)	20.00
γ_{sat}	(kN/m^3)	20.00
K_x	(m/day)	0.864
K_y	(m/day)	0.864
K_z	(m/day)	0.864
e_{init}	(-)	0.50
e_{min}	(-)	0.00
e_{max}	(-)	999.00
c_k	(-)	1E15
E_{50}^{ref}	(kN/m^2)	200000.00
E_{oed}^{ref}	(kN/m^2)	200000.00
power (m)	(-)	0.50
c_{ref}	(kN/m^2)	20.00
φ	$(^o)$	38.00
ψ	$(^o)$	0.00
E_{ur}^{ref}	(kN/m^2)	600000.00
$\upsilon_{ur}^{(nu)}$	(-)	0.200
p^{ref}	(kN/m^2)	100.00
cincrement	(kN/m^2)	0.00
yref	(m)	0.00
Rf	(-)	0.90
Tstr.	(kN/m^2)	0.00
R_{inter}	(-)	1.00
Interface permeability		Neutral

IV. VALIDATION

In the beginning, the finite element model was validated using the model of single pile which was simulated by Gwee Boon Hong in 2013 using the PLAXIS 2D program to carried out a parametric study on single piles subjected to negative skin friction. The soil properties adopted in his model are illustrated previously in tables 1, 2, 3, and 4. Figures 5 and 6 show the results of the numerical analysis carried by (Hong, 2013) and the 3D finite element results respectively. It has been found that, there is a good agreement with two results is obtained.

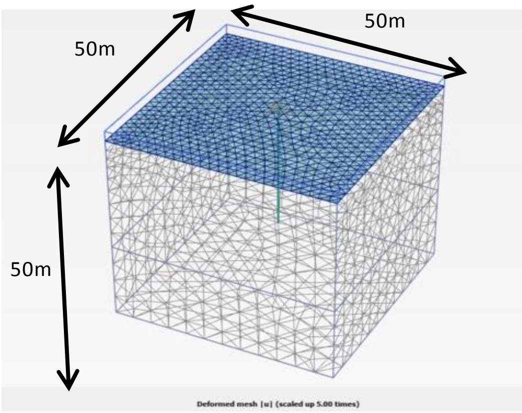


Fig. 3: Finite element mesh used in the analysis of single pile.

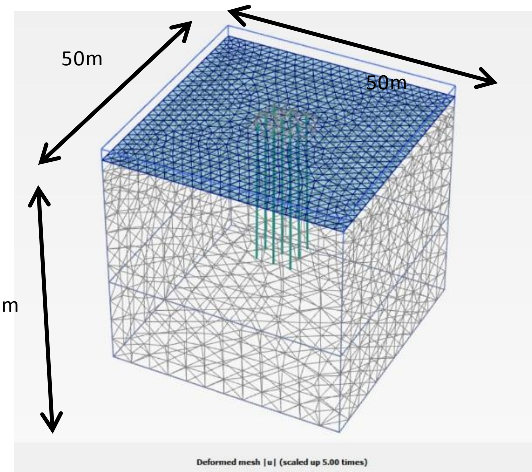


Fig. 4: Finite element mesh used in the analysis of pile groups.

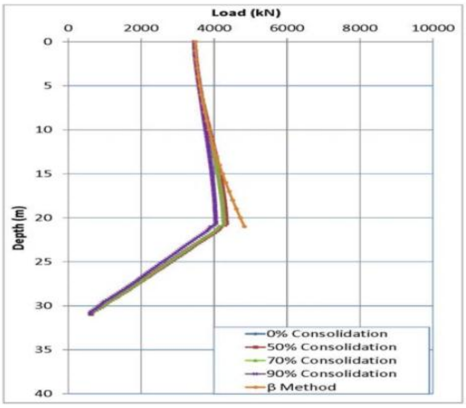


Fig. 5: Dragload along pile (After Hong, 2013).

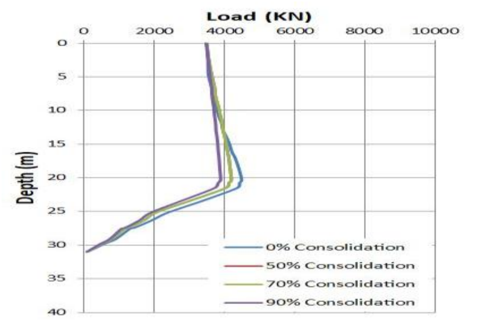


Fig. 6: Dragload along pile in current study.

The model used in this study was also validated by a field case study. Indrartna et al. (1992) reported a long-term full-scale measurements and performed numerical analysis of negative skin friction induced on two piles with pile length (L) = 26m, pile diameter (d) = 1m due to a 2m thick embankment within 265 days. One of the piles was coated by bitumen and the second was uncoated. Tables from 5 to 11 show the soil and pile properties from the field study carried by Indrartna et al. (1992). Figure 7 shows the field measurements ant the results of the numerical analysis of the dragload transferred to the uncoated pile after 265 days by Indrartna et al. (1992) and the 3D finite element results and it also has been found that, there is a good agreement between them. Consequently, the FEM is capable of predicting the behavior of the problem under investigations.

Table 5: Material Properties of Pile (After Indrartna et al., 1992)

parameters	unit	values
Material model		Elastic model
ɣ	(kN/m^3)	15
E	(kN/m^2)	30e6
υ	(-)	0.2

Table 6: Material Properties of (After Indrartna et al., 1992)

parameters	unit	values
Material model		Hardening soil
ɣ	(kN/m^3)	17.00
K_x	(m/day)	1.00
K_y	(m/day)	1.00
K_z	(m/day)	1.00
E	(kN/m^2)	50000.00
power (m)	(-)	0.50
c	(kN/m^2)	0.00
φ	(^{o})	30.00
υ	(-)	0.200
R_{inter}	(-)	1.00

Table 7: Material Properties of Weathered Crust (After Indrartna et al., 1992)

parameters	unit	values
Material model		Hardening soil
ɣ	(kN/m^3)	17.00
K_x	(m/day)	0.008
K_y	(m/day)	0.008
K_z	(m/day)	0.008
E	(kN/m^2)	6500.00
power (m)	(-)	1.00
c	(kN/m^2)	0.00
φ	(^{o})	25.00
υ	(-)	0.200
R_{inter}	(-)	0.65

Table 8: Material Properties of Soft Clay (After Indrartna et al., 1992)

[

parameters	unit	values
Material model		Hardening soil
ɣ	(kN/m^3)	15.50
K_x	(m/day)	0.008
K_y	(m/day)	0.008
K_z	(m/day)	0.008
E	(kN/m^2)	7000.00
power (m)	(-)	1.00
c	(kN/m^2)	5.00
φ	(^{o})	13.00
υ	(-)	0.200
R_{inter}	(-)	1.00

Table 9: Material Properties of Medium Clay (After Indrartna et al., 1992)

parameters	unit	values
Material model		Hardening soil
γ	(kN/m^3)	19.00
K_x	(m/day)	0.004
K_y	(m/day)	0.004
K_z	(m/day)	0.004
E	(kN/m^2)	8750.00
power (m)	(-)	1.00
c	(kN/m^2)	10.00
φ	(^{o})	16.00
υ	(-)	0.200
R_{inter}	(-)	0.85

Table 10: Material Properties of Stiff Clay (After Indrartna et al., 1992)

parameters	unit	values
Material model		Hardening soil
γ	(kN/m^3)	19.50
K_x	(m/day)	0.004
K_y	(m/day)	0.004
K_z	(m/day)	0.004
E	(kN/m^2)	20000.00
power (m)	(-)	0.80
c	(kN/m^2)	60.00
φ	(^{o})	30.00
υ	(-)	0.200
R_{inter}	(-)	0.70

Table 10: Material Properties of Stiff Clay (After Indrartna et al., 1992)

parameters	unit	values
Material model		Hardening soil
γ	(kN/m^3)	20.00
K_x	(m/day)	1.00
K_y	(m/day)	1.00
K_z	(m/day)	1.00
E	(kN/m^2)	55000.00
power (m)	(-)	0.50
c	(kN/m^2)	0.00
φ	(^{o})	35.00
υ	(-)	0.200
R_{inter}	(-)	1.00

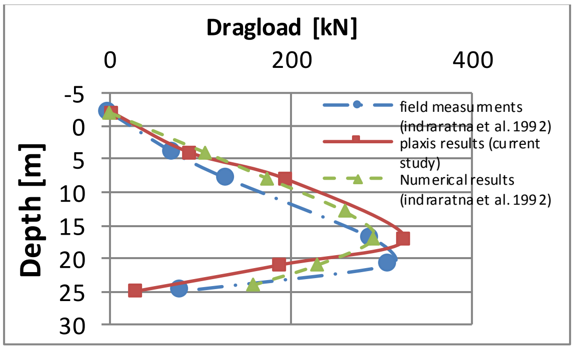


Fig. 7: Measured and numerical results of dragload along uncoated pile.

V. FINITE ELEMENT RESULTS

Figure 8 presents the variation of dragload with the pile depth for piles in 2x2 pile groups with 2d and 3d pile spacing compared to single pile. The figure shows that the dragload transferred to the piles in a group was less than the dragload transferred to the single pile. It can be noted that piles in group with 2d pile spacing exposed to less magnitude of dragload than piles in group with 3d pile spacing. Maximum values of dragload were 2691, 2353 and 2500 kN for single pile, piles in group with 2d pile spacing and piles in group with 3d pile spacing respectively.

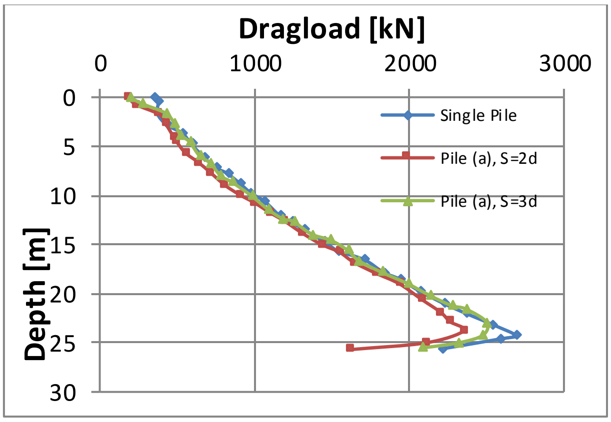


Fig. 8: Dragload along piles in 2x2 pile groups.

Figure 9 presents the variation of dragload with the pile depth for piles in 3x3 pile groups with 2d and 3d pile spacing compared to single pile. The figure also shows that the dragload transferred to the piles in a group was less than the dragload transferred to the single pile and piles in group with 2d spacing exposed to less magnitude of dragload than piles in group with 3d pile spacing. It can be noted from figures (7) and (8) that piles in 2x2 pile group are exposed to more magnitude of dragload than piles in 3x3 pile group Maximum values of dragload were 2091, 1594 and 471 kN for corner, edge and center piles in group with 2d spacing respctively and 2329, 2066 and 1466 kN for corner, edge and center piles in group with 3d spacing respctively.

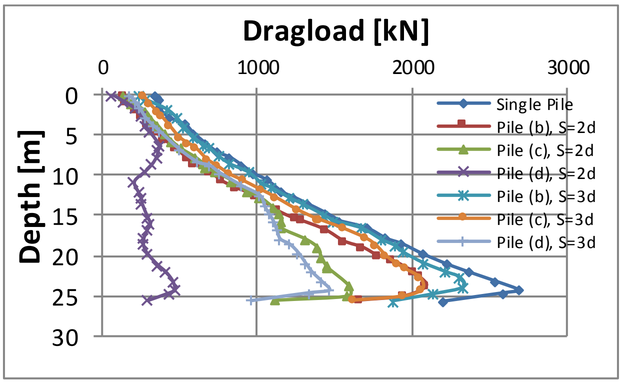


Fig. 9: Dragload along piles in 3x3 pile groups.

VI. DISCUSSION

In this discussion, the influence of group effect on dragload in pile groups subjected to negative skin friction is represented in terms of relative reduction in dragload (P_r). C. J. Lee and Charles W. W. Ng (2004) defined and expressed the relative reduction in dragload due to group effect (P_r) by the following equation:

$$P_r = (P_{max,s} - P_{max,g})/P_{max,s}$$

Where P_{max}=maximum dragload and s and g represent a single pile and piles in a group respectively. Figure 10 presents the variation of relative reduction in dragload (P_r) with pile spacing for piles in 2x2 and 3x3 pile groups with 2d and 3d pile spacing. It can be noted that piles in 2x2 pile groups had less magnitude of relative reduction in dragload (P_r) than piles in 3x3 pile groups. In case of 3x3 pile groups center piles had the most significant magnitude of relative reduction in dragload (P_r) followed by edge piles and corner piles respectively, as shown in figure 10. In all series of pile groups, it can be generally noted that the values of relative reduction in dragload (P_r) decrease pile spacing with the increase of pile spacing. Values of relative reduction in dragload (P_r) were 12.6% and 7.1% for piles in 2x2 pile groups with 2d and 3d pile spacing respectively, 22.3%, 40.8% and 82.5% for corner, edge and center piles in 3x3 pile group with 2d spacing respectively and 13.5%, 23.2% and 45.5% for corner, edge and center piles in 3x3 pile group with 3d spacing respectively.

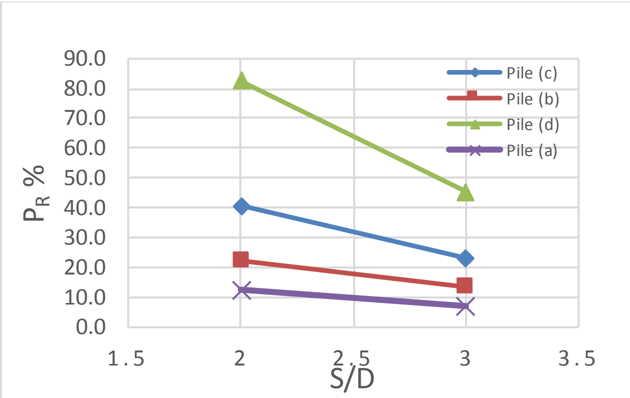


Fig. 10: Variation of P_r with pile spacing (S/D) for 2x2 and 3x3 pile groups.

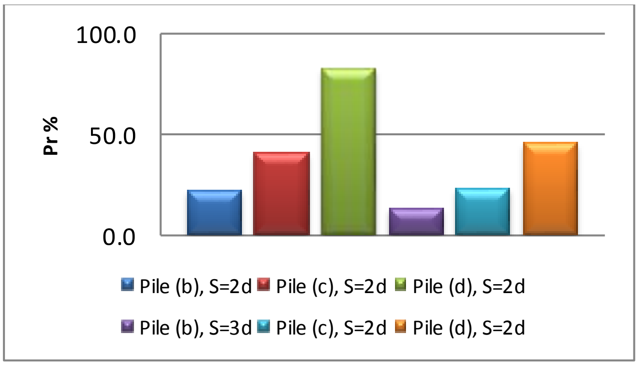


Fig. 11: Variation of P_r for different pile locations in 3x3 pile groups.

VII. CONCLUSION

Piles situated in consolidating ground are exposed to negative skin friction that resulted in increase in axial load acting on piles "dragload". In pile groups, piles are exposed to less magnitude of dragload than single piles due to group effect. The group effect is investigated in this study using the finite element program PLAXIS 3D. The following conclusions can be extracted from the analysis of results:

1. The magnitude of reduction in dragload due to group effect is relevant to pile spacing, pile number and pile location within a group.
2. The more the pile number in a group, the more the reduction in dragload.
3. The magnitude of reduction in dragload decreases with the increase in pile spacing.
4. Inner piles in a group have more magnitude of reduction in dragload than outer piles.

REFERENCES

[1] Fellenius, B. H. (1998), Recent advances in the design of piles for axial loads, dragloads, downdrag, and settlement, Proceedings of a Seminar by ASCE and Port of New York and New Jersey, April 1998, 19p.
[2] Gwee Boon Hong (2013-11-29). Numerical Study on Negative Skin Friction of Single Pile.
[3] Lam SY, Ng CWW, Leung CF, Chan SH (2009) Centrifuge and numerical modeling of axial load effects on piles in consolidating ground. Can Geotech J 46:10–24.
[4] Lee, C. J. and Ng, W. W. (2004). “Development of downdrag on piles and pile group in consolidating soil.” J. Geotech. Geoenviron. Eng., Vol. 130, No. 9, pp. 905–914, DOI: 10.1061/(ASCE)1090-0241(2004)130:9(905).
[5] Lee, C. J., Bolton, M. D., and Al-tabbaa, A. (2002), Numerical modeling of group effects on the distribution of dragloads in pile foundations, Geotechnique, Vol. 52, No. 5, pp. 325-335.
[6] NAVFAC (1982), Foundation and earth structures. Design manu al 7.2, U. S. Department of the Navy, Virginia.
[7] Plaxis 3D reference manual version 2013.
[8] Tan, S.A. and Fellenius, B.H., 2016. Negative skin friction pile concepts with soil-structure interaction. ICE Geotechnical Research Journal, UK. Paper 16.00006. pp 1-11.