JP&M Engineering
Journal of Petroleum and Mining Engineering

Experimental and Numerical Analysis of the performance of pile group subjected to downdrag force before loading

Mohamed N. Elsiragy[*a], Azzam, W. Ragab[b] and Ali H. Mahfouz[3]

[a]Civil Engineering Dept., Faculty of Engineering, 6th October University, Egypt
[b]Faculty of Engineering, Tanta University, Tanta, Egypt
[c]Geological and Geophysical Engineering Dept., Faculty of Petroleum and Mining Engineering, Suez University, Suez-Egypt

*Corresponding author e-mail: mohamed.nabil.eng@o6u.edu.eg

Article Info

Received 4 Jan. 2023
Revised 17 Mar. 2023
Accepted 19 Mar. 2023

Keywords

Single pile; pile group; downdrag force; Nevagate skin friction; group efficiency

Abstract

Negative skin friction is the most common problem in the design and construction ofpile foundations in soft ground when the soil next to piles moves down more than thepile. Three main reasons cause negative skin friction, first is increase of verticalstress, second is development of additional compressive force, third is excessive ofpile settlement, these problems cause difficulty in construction and maintanance.Failure of the pile foundation from the servicability point of view might occur due tonegative skin friction. It has been concluded that less dragload occurs in piles in agroup due to pile-soil-pile interaction. In this research an exprimntal model for pilegroup installed in soft clay bed is carried out. The effect of downdrag force on pilegroup has studied with the varaible of piles spacing ratio, S/D, and the drainage stateof the clay stratum. Weather single or double drainage are also investigated atdifferent piles groups. Finally a comparison between single pile and pile group withthe same case of loading is studied to shed some light on the group effect.The resultswere numerically validated and verfied to study the obtained load values at diifrentcase. There is a good agreent between exprimental and numerical results. Also the thenumerical anaysis is helpd in better understand the induced drage loads and piledeformation. It also demnstrated that, the higher cohesion has a higher dragload. Forcase of Cu =30kPa, the dragload for pile group of spacing S =4D, 3D are 1.22, 1.05time of single pile.

Introduction

Negative skin friction is the most common problem in design and construction of pile foundations in soft soil when the surrounded soil to piles moves down more than the pile. The drag load is time dependent because it is related to the magnitude of excess pore water pressure. The dissipation of excess pore water pressure results in: (a) settlement to the soil which means increase in soil–pile relative movement, and (b) increase in the pile–soil interface strength associated with the increase soil which means increase in soil–pile relative movement Mahfouz, A. (2011) and Mahfouz et al. (2016), in soil effective stress according to Fellenius (1999). Ohannessenand Bjerrum (1965), Fellenius (1972, 2006), Blanchetetal. (1980), Bozozuk, and Indraratnaetal (1992), performed field measurements on instrumented piles. These measurements revealed that the drag load value may be large enough to cause pile structural failure. Also, the down drag may lead to serviceability problems. Lee et al. (2001) mentioned that most current design approaches are based on simplified methods which are not satisfactory. Little and Ibrahim 1993 stated that predictions presented by engineers in worth memorial symposium failed to estimate drag load within a range of 98-515% of the observed value. It is worth mentioning that the drag loads reduced in piles in a group due to pile-soil-pile interaction. Thomas (1999) showed that the group effect in case of down drag for most situations is relatively small. Lee et al. (2001) mentioned that ordinary pile foundation design where elastic analysis reasonably estimates pile behaviour, soil yielding is to be developed at the interface due to large soil movement and hence large shear strain. Nishi and Esashi1982 proved that slip occurs on the interface of single pile. Chow et al. (1996) reported that the effect of the slip at the pile-soil interface governs the group effect. Lee et al. (2001) concluded that piles subjected to down drag forces should be installed as deep as possible to a stiff layer. They also mentioned that the group effect depends on slipping at the soil-pile interface which is governed by the surface loading, pile spacing, and interface friction. Finally they concluded that the reduction of dragload due to group effect is found to be 10-40% in case of 3x3 group. Li and Lam (2001) performed a study of a project involving the use of driven piles where ground settlement occurs due to dewatering for construction of a tunnel. If the conventional methods were applied for calculating the negative skin friction, NSF, the additional load might exceed the allowed pile load. Li and Lam (2001) described an alternative approach to pile design depending on the neutral point by assuming that a pile shaft positive friction occurs at a lower potion of the pile stem embedded into the soft stratum. The pile load equation to be modified in the form P+NSF<2Pall , where P is the applied load, NSF is the negative skin friction, and Pall is the allowable pile load.

On the other hand the modern studies were supported the experimental investigation using finite element analysis by a variety of computer program. Numerical modeling is one of the powerful tools available to both researchers and engineers. The time varying negative skin friction NSF problem can be simulated numerically. Kuwabara and Poulos (1989); Lee et al. (2002); Lee and Ng (2004); Jeong et al. (2004); Comodromos and Bareka (2005); Hanna and Sharif (2006); Ng et al. (2008); Chen et al. (2009); Lam et al. (2009) and El-Mossallamy et al., (2013) have performed numerical analysis to study the response of a pile subject to NSF. The development of axial load is modelled numerically.

In this study a series of experimental tests on a single pile and piles groups is carried out to show the induced down darg forces with time along the tested model piles. The effect of drainage condition that can not be thoroughly investigated is done to shed the light on the induced srag forces. The results were also verified and supported using finite element analysis to apply the research findings in large scale pile.

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully, and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work. As far as possible, keep the introduction comprehensible to scientists outside your particular field of research.

Testing Equipment Shed A light

To study the behaviour of a pile group subjected to down drag force about twenty laboratory experiments are conducted on steel circular piles of diameter (D) equals to 30mm and length of 400mm. The model piles have smooth surface. To facilitate the pile loading the pile head is attached to a circular steel plate of diameter 200mm. The pile was used as a single pile in some experiments, and in some other experiments two, and four of the same pile were gathered to act as a pile group, the piles were held together with steel pile cap of thickness 25mm, designed to give a pile spacing of 2D, 3D, and 4D from center to center. Two dial gauges of accuracy 0.01mm were used to measure the pile/pile group vertical displacement. The top plate also facilitates the measurements of the pile movements. The general layout of the equipment used in the present study is illustrated in Fig. (1). The soil bin is a steel cuboid tank of side dimension 600 mm, that satisfy the scale effect (Nazir and Azzam, 2011and Azzam and Elwakil , 2016).

Experimental Procedure

The geomaterial formed in the soil bin consists of two main strata, sand stratum, and a man-made clay stratum. The sand is silicious of medium size, has a maximum dry unit weight 18kN/m3, and a minimum dry unit weight 14kN/m3. Its effective diameter is equal to 0.17, and uniformity coefficient is 2.32. To form the clay stratum a designed volume of water is added to a designed weight of dry powdered clay. This mix was manually pasted to form a homogeneous clay soil of water contents 50%, 60%, and 65% to gain cohesion of 30 kN/m2, 20 kN/m2, and 10 kN/m2 respectively. The clay has consolidation index, Cc of 0.35, 45 and 0.70 for cohesion of (30, 20 and 10kPa) respectively. Also, Liquid limit, LL of 120%, Plastic limit, PL equal to 30%, Plasticity index, PI = 90%, and liquidity index, LI = 0.3. The clay then is formed into the soil bin into layers till the designed level. It is worth mentioning that no air voids are allowed in the formed clay layers. Clay was then covered with plastic sheets and wet piece of cloth then left for 24 hours before completing the experiments. After 24 hours plastic sheets and wet cloth are removed and the experiment is formed (Nazir and Azzam, 2011).

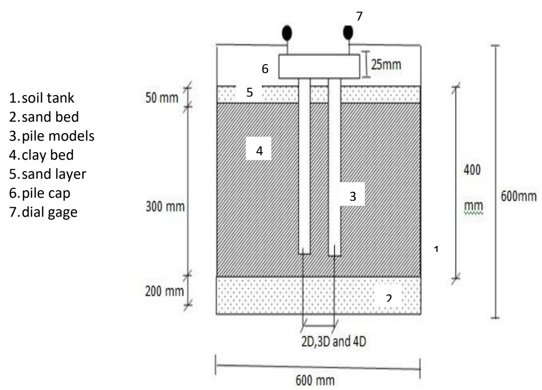

Figure 1 physical model of equipment

Three main groups of tests are performed; the first group consists of two strata, a saturated compacted sand stratum of thickness 200mm, acting as a soil bed under the pile/piles tip, with relative density of 85%, and angle of shear strength (ϕ) of 30º, and a clay stratum of thickness 300mm, and cohesion (Cu) of 30 kN/m2. The second group consists of 200mm saturated compacted sand of relative density (Dr) 85%, and angle of shear strength (ϕ) of 30º underneath 350mm of clay stratum with cohesion (Cu) of 20 kN/m2. The third group consists of the same sand bed underlying a clay stratum of thickness 350mm and cohesion (Cu) of 10 kN/m2.

Once the pile/piles is/are embedded vertically into the designed place into the soil bin, overlying the sand bed according to the testing program. The mixture was then left to set. It is worth mentioning that the pile was vertically installed into the soil bin using a water level instrument of an accuracy of 0.5 degrees and before performing the experiment the verticality of the pile was rechecked, and also ensuring that no gap occurred between the pile and the soil. Twelve loading tests are conducted for the three different soil alignments. The testing program is shown in Table 1. Surcharge is applied over an impermeable layer on the clay stratum; the surcharge is a sand bed of 50mm thickness giving a uniform load of 0.85 kN/m2. The vertical displacements of the pile/piles are measured within an accuracy of 0.01 mm using two dial gauges every 24 hours until the vertical displacement remains constant. It is worth mentioning that the impermeable stratum makes the clay layer single drainage, that's to say water is allowed to come out from the clay stratum from one direction only. The three groups are repeated in the same previous sequence but this time, the impermeable stratum between the clay layer and the surcharge is removed, that's to say the clay layer in the second three groups is double drainage in each experiment.

Table 1 Testing Program and parameters

Group	Piles spacing S/D	Water Content Wc,%	Cu kPa	Draingae conditions
G-1	Single pile	50	30	Single and double drainage
	2			Single drainage
	3			
	4			
G-2	Single pile	60	20	Single and double drainage
	2			Single drainage
	3			
	4			
G-3	Single pile	65	10	Single and double drainage
	2			Single drainage
	3			
	4			

Experimental Results

The behaviour of single and pile group installed in soft clay with different cohesion are discussed with details to shed the light on the obtained produced downdarg response. For single pile the settlement increased with increasing the loading time, and then it became almost constant after three days. In addition, to increasing the cohesion of the soil decreasing the pile settlement due to cohesion between soil granules, this may be reduce sliding of soil around the pile and increasing the cohesion between the pile and the soil mass. The pile settlement/daondarg decreased from 0.2 mm at Cu = 20 kN/m2 to 0.14 mm at Cu = 10 kN/m2 after three dayes. Also changing the drainage system from single to double drainage increasing the settlement as shown in Fig. 2 and Fig. 3, that present the time settlement behaviour of singe pile for both single and double drainage to shed the light on the settlement response of pile. The settlement of the pile was 0.1 mm in single drainage case then it increased to be 0.13 mm in double drainage at Cu = 30 kN/m2 , it also increased from 0.15 mm to 0.21 mm at Cu = 20 mm this indicates that the settlement or downdarg increase with decreasing the cohesion due to increasing the sliding of soil particles resulted in negative force around the pile.

While, in piles in a group it has been concluded that less settlement occurs due to pile-soil-pile interaction. Using of pile group with small distance between piles resulted in less settlement, this is because increasing the cohesion of the soil between the piles and this reducing the expected settlement due to soil pile inter action. Also using the pile group resulted in distributing the loads on a number of pile instead of one pile in case of single pile so the settlement in pile group is less than the single one.

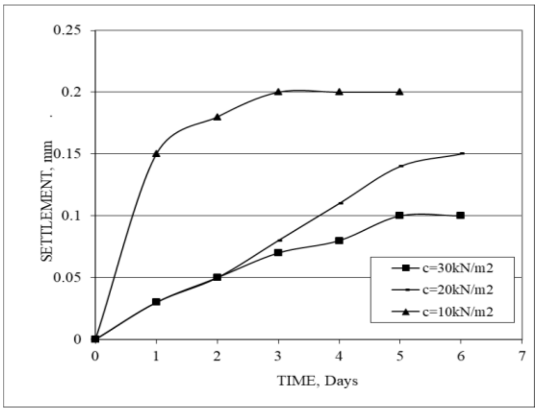

Figure 2 Time – settlement curve for single pile for different C – single drainage

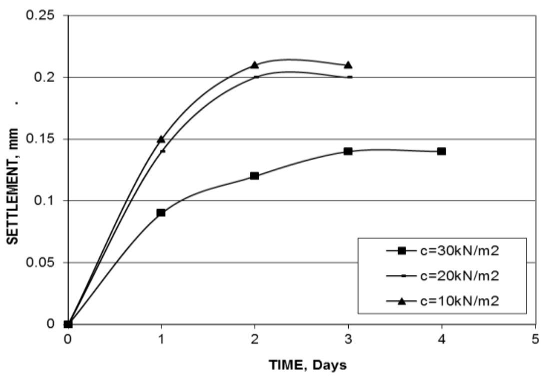

Figure 3 Time – settlement curve for single pile for different C – double drainage

The results show that for the first pile group with Cu = 30 kN/m2 as shown in Fig.4 the settlement was 0.16 mm to 0.18 mm at S/D = 4 and 2 respectively this indicate the role of decreasing the spacing between pile in decreasing the expected settlement. Also the settlement decreased from 0.21 mm in case of single pile to 0.18 mm at S/D = 2, this confirm that using the pile group resulted in less settlement. For the second pile group with Cu = 20 kN/m2 the settlement was almost constant and equal to the settlement of single pile 0.2 mm this may be because of decreasing the cohesion between soil particles, resulted in the soil around the piles will move down more than the pile, so the settlement is nearly constant as shown in Fig. 5. For third pile group the cohesion of the soil decreased to 10 kN/m2 this resulted in increasing the soil sliding down around the pile so the negative force around the piles increased consequently the settlement increased as illustrated in Fig. 6.

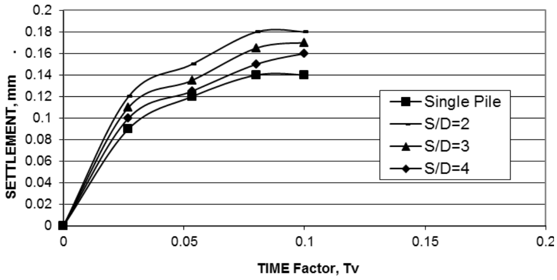

Figure 4 Time factor- relationship for group (1), Cu = 30 kN/m^2

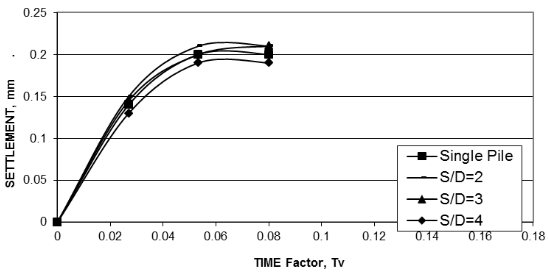

Figure 5 Time factor- relationship for group (1), Cu = 20 kN/m^2

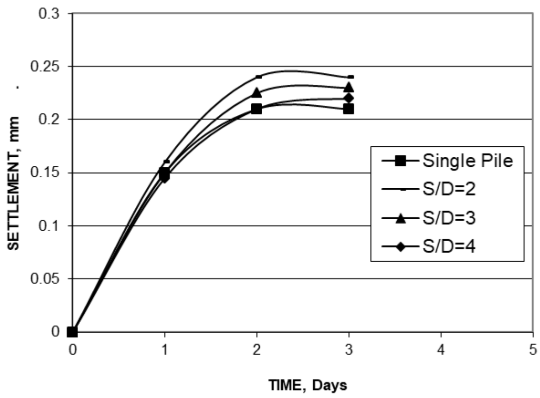

Figure 6 Time factor- relationship for group (3), Cu = 10 kN/m^2

Numerical Modelling

Numerical modeling is a widespread approach to study the effect of negative skin friction NSF on piles (Jeongetal.1997, 2004; Leea and Ng 2004; Lametal. 2009). Modeling of the soil-pile interface is decisive to the problem. In common, the interface is modelled by a linear-elastic perfectly plastic Coulomb type friction allow. In the study, steel cap/raft and piles are modeled as elastic materials. The piles are simulated by rode element. The nonlinear behavior of soil is modeled with elastic ideally plastic constitutive model. These has been done using Pl axis 3d to simulate such problem as clearly shown in the flowing analysis.

The soft clay layer and sandbed are modeled as an elasto plastic material with a non-associated flow rule and using the hardening soil model (Indraratna et al., 1992).

Soil mass is described by an eight-node brick, tri-linear displacement and tri-linear pore pressure element. A vertical pressure of o.85kPa is imposed on the top clay layer, as a distributed load. The sand and clay layers are modeled by elasto-plastic with non-associated Mohr Coulomb model. In the "no-slip continuum" model, interface elements are used to connect the pile to the adjacent soil. The interface elements evaluated shear force from normal stress by a Coulomb's friction law, with a friction coefficient μ, (μ = tanδ) of 0.2 - 0.5, δ was the interface friction angle. Duplicated nodes are used to form an interface of zero thickness to allow soil slip at the pile/soil interface. In a brief, Pl axis 3d was used to perform numerical analysis for this analysis. The hardening soil–Coulomb model was used for the soft clay 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.

Program validation and verification example

The model example adopted in this research was also validated by a field case study. As stated and discussed by Indrartna et al. (1992), it has been studied a long-term large-scale results and investigated numerical study of negative skin friction that took place on two piles with pile length (L) = 26m, with diameter (d) of 1m results from a 2m thickness embankment inside 265 days. The studied pile with coated surface with and without bitumen to show the negative skin phenomenon.. First, Fig.7 shows the field observation and the arrangements of the studied problem in the field.. It noticed that The numerical analysis of the dragload transmitted to the uncoated pile after 265 days (Indrartna et al. (1992))

While Fig. 8 presents the finite element mesh/ elements of the simulated and modelled the filed test the 3D finite element results. Table 3 and 4 provided the all input material data used for verification example and present study of model test in the laboratory Moreover, it has been found that, there is a superior conformity between the filed, pl axis 3d output as Cleary mention in Fig. 9.

The instant settlement throughout the first 3 days can be predicted accurately using untrained soil properties. Other than a better assessment for the settlement after 265 days was recorded by means of drained soil technique. The long-term measured and extracted adown drag load was recorded for uncoated pile after 9 months. Also, The position of neutral plans was also mentioned for comparison in Fig. (9). From presents curve, the neutral point was located at depth of 20m corresponding to the maximum load of 300 kN roughly. On the other hand, the neutral point of a illustrated curve at maximum load of 283 kN is located at 17.3m depth. This finding agree with data obtained by Altahrany and Elshehahwy (2022)

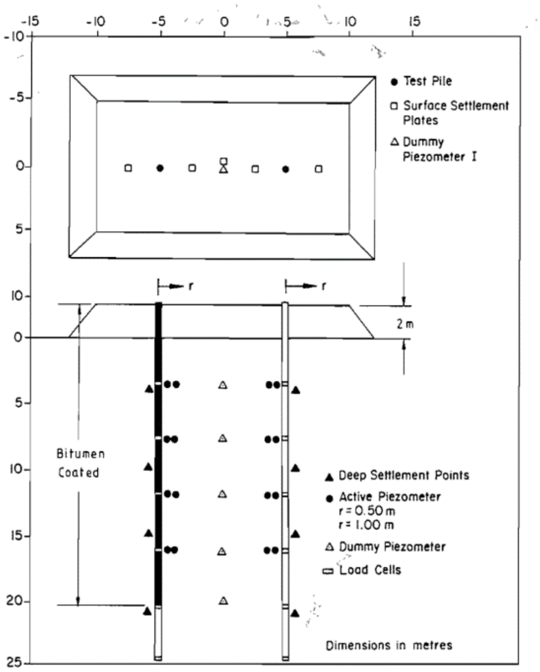

Figure 7 Filed tested element of surcharge, pile and Ground monitoring systems, (After Indraratna et al., 1992)

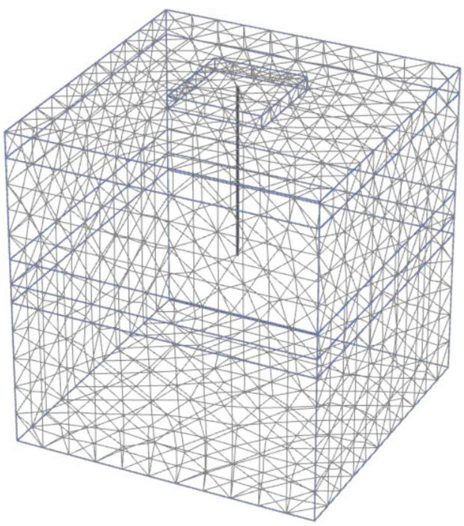

Figure 8 Finite element mesh used in the validation of Indraratna et al., 1992

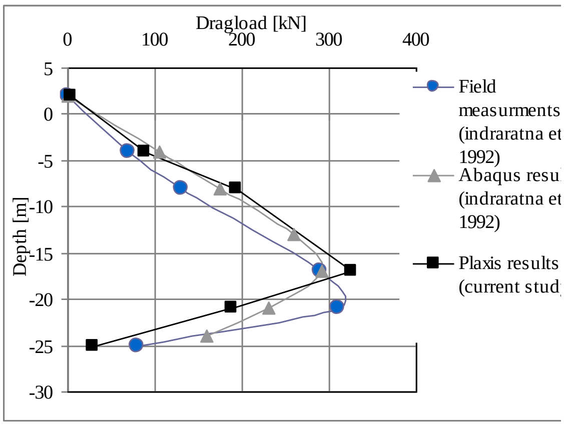

Figure 9 Measured and numerical results of drag load along uncoated pile.

Table 2 Input data for Soil properties (After Indrartna et al., 1992)

Hardening Soil		Fill	Weathered Crust	Soft Clay	Medium Clay	Stiff Clay	Sand
Type	Unit	Un-drained	Drained	Un-drained	Un-drained	Un-drained	Drained
γ	(kN/m3)	17.00	17.00	15.50	19.00	19.50	20.00
Kx	(m/day)	1.00	0.008	0.008	0.004	0.004	1.00
Ky	(m/day)	1.00	0.008	0.008	0.004	0.004	1.00
Kz	(m/day)	1.00	0.008	0.008	0.004	0.004	1.00
E	(kN/m2)	50000.00	6500.00	7000.00	8750.00	20000.00	55000.00
power (m)	(-)	0.50	1.00	1.00	1.00	0.80	0.50
C	(kN/m2)	0.00	0.00	5.00	10.00	60.00	0.00
Φ	(o)	30.00	25.00	13.00	16.00	30.00	35.00
υ	(-)	0.200	0.200	0.200	0.200	0.200	0.200
Rinter	(-)	1.00	0.65	1.00	0.85	0.70	1.00

Table 3 Input material Properties used in numerical study for model test (present study)

Properties	Clay	Clay	Clay	Sand	Steel/pile
Unit weight (kN/m3)	17.44	17	16.25	18.00	65
Young's modulus (E) (kPa)	1400	1325	1250	45000	28x 106
Poisson's ratio (?)	0.4	0.47	0.5	0.3	0.20
Permeability K (m/day)	0.006	0.007	0.008	1	-
Void ratio (e)	0.763	0.802	0.889	0.55	-
Friction angle (?)	0	0	0	35	-
Dilation angle	0	0	0	5	-
Cohesion (Cu) (kPa)	30	20	10	0.069	-
Abs plastic strain	0	0	0	0	-

Based on the above observation of validation and calibration, the FEM using plaxis 3d vesrion 2013 is proficient of predicting the performance of the tested problem of negative skin friction along the pile length. Therefore the current program can be valid for predicting the induced down drag load corresponding to dawn drag movement that can not be measured in the laboratory. Therefore a series of numerical model a has been done at different studied parameters mentioned before in Table 1. This analysis I aimed to shed the light on the indiced drage load corresponding to pile settlement.

Numerical results and discussions

In order to study the performance of pile group for each group a reference model was performed on a single pile on the same soil conditions. The dragload and -downdarg relationships for each studied model with different spacing and soft clay cohesion were shown for each series as given in Fig. (10 to 15). These figures present the performance of single pile and pile group with different spacing that installed in soft clay with different cohesion.

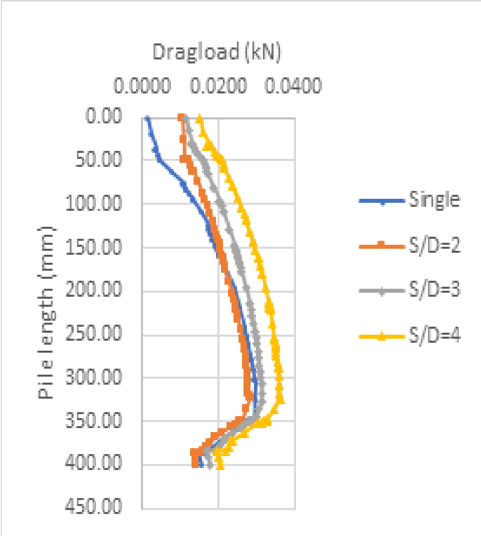

Figure 10 The induced dragload along piles in group (G1) Cu =30kPa.

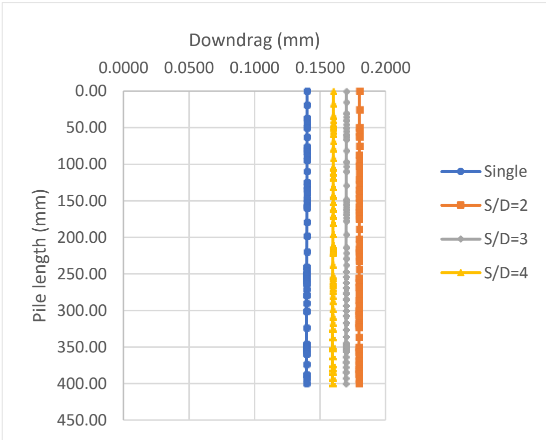

Figure 11 The disparity of downdrag along piles in group (G1) Cu =30kPa

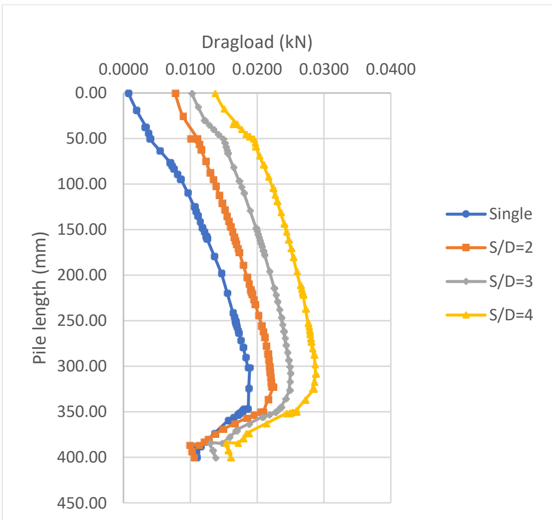

Figure 12 The values of dragload along piles in group (G2) Cu =20kPa

 DOI: 10.21608/jpme.2023.184917.1149

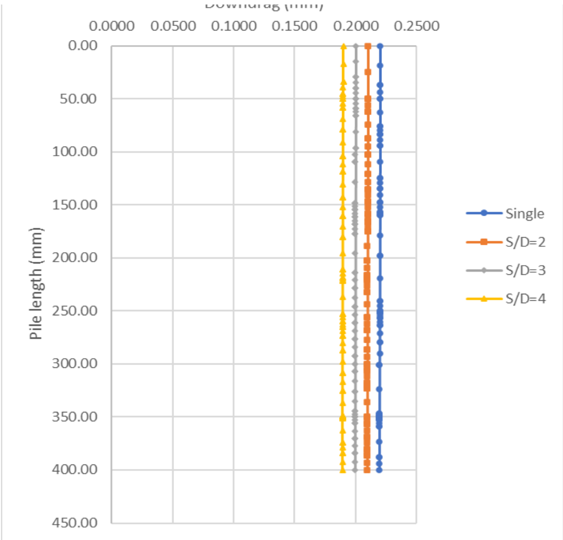

Figure 13 The variation of downdrag along piles in group (G2) Cu =20kPa

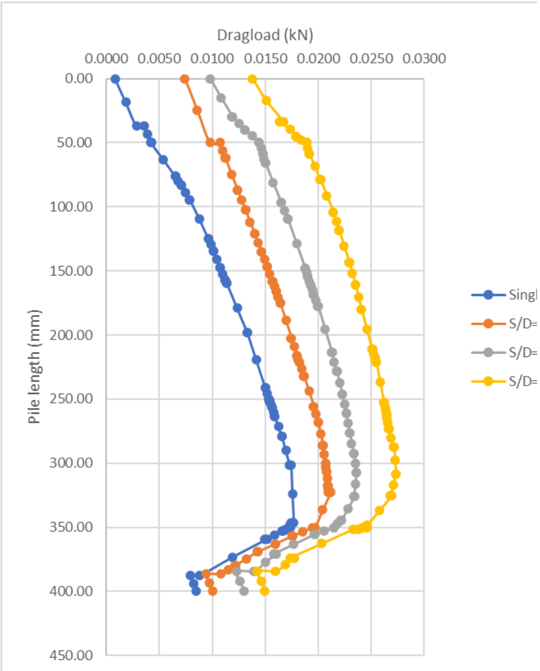

Figure 14 The variation of dragload along piles in group (G3) Cu =10kPa

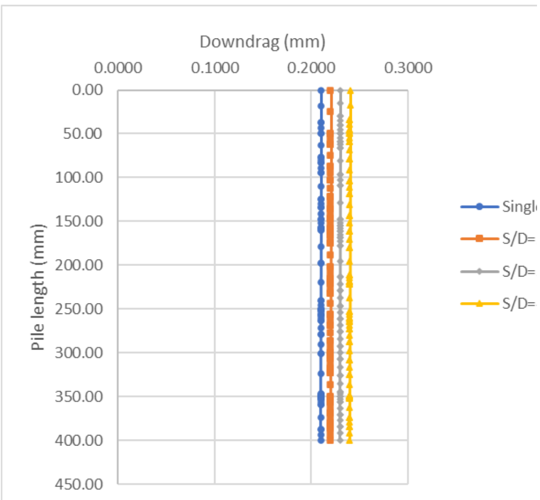

Figure 15 The variation of downdrag along piles in group (G3) Cu =10kPa

In general it can be seen that the single pile has a lesser dragload compared with those of pile group at different pile spacing. The drag load can significantly increase with the increase of pile spacing. On the other hand, the decrease in soft clay cohesion leads to gradual decrease in dargload. Also, it noticed that the higher cohesion has a higher dragload. It has been found that in G1 , Cu =30kPa, the dragload for pile group of spacing S =4D, 3D are 1.22, 1.05 time of single pile. While these values are found to be 1.54, 1.33 for spacing S of 4D and 3D respectively in case of Cu =10 kPa. whereas for corresponding downdarg movement the relevant figure clearly shown that as the pile spacing S/D increases the darg movmental maximum dragload is relatively reduced. The dawndrag displacement is highly depends on the soft clay cohesion. Where at the same pile group spacing, the decrease in soft clay cohesion is achieved obvious increase in dawndrag movement. It has been found that at S/D = 4 the variation of soft clay cohesion from 30 to 10 kPa significantly increase the drag movement by as much as 150% of its initial value corresponding to Cu =30kPa. In addition to these values of such increase is found to be 135% , 122% at S/D = 3 and 2 in that order. This can be confirm that the pile spacing and soft clay cohesion has important role in dawndrag movement as clearly tabulated in Table 4 and 5. These table are summarized the obtained maximum drag load and corresponding dawndrag movement of single of pile group with different both cohesion and spacing.

Table 4 The values of maximum dragload on piles

Case	Dragloadmax, G1 (kN)	Dragloadmax, G2 (kN)	Dragloadmax, G3 (kN)
Single	0.0298	0.0189	0.0177
S/D=2	0.0287	0.0224	0.0212
S/D=3	0.0316	0.0249	0.0236
S/D=4	0.0364	0.0288	0.0274

Table 5 The values of maximum downdrag on piles

Case	downdragmax, G1 (mm)	downdragmax, G2 (mm)	downdragmax, G3 (mm)
Single	0.14	0.22	0.24
S/D=2	0.18	0.21	0.22
S/D=3	0.17	0.2	0.23
S/D=4	0.16	0.19	0.24

Note: G1 at C=30kPa, G2 at C=20kPa, and G3 at C=10kPa

Other wise, the study investigated the power of confident examined parameters such as pile spacing, and clay cohesion on the induced reduction in dragload (Pr), and the corresponding reduction in downdrag (Wr) in pile groups.

According to Leung, et al., (2004), explain that the relative reduction in dawndeag load (Pr) and the corresponding diminution in downdrag (Wr) due to group effect as follows:

Pr = (Pmax,s – Pmax,g)/ Pmax,s and Wr = (Ws – Wg) / Ws

These terms can be defined as; W: downdrag, P: maximum dragload, at the same time as "s" and "g" mention to a single pile and for pile in a group correspondingly.

Table 6 The obtained values of reduction in dragload on piles

Case	Pr, G1 (%)	Pr, G2 (%)	Pr, G3 (%)
S/D=2	4	-19	-20
S/D=3	-6	-32	-33
S/D=4	-22	-52	-55

Note: G1 at C=30kPa, G2 at C=20kPa, and G3 at C=10kPa

Table 7 The values of relative reduction in downdrag on piles

Case	Wr, G1 (%)	Wr, G2 (%)	Wr, G3 (%)
S/D=2	-29	5	-5
S/D=3	-21	9	-10
S/D=4	-14	14	-14

Note: G1 at C=30kPa, G2 at C=20kPa, and G3 at C=10kPa

Based on the above equation the relative reduction in Pr and Wr at different spacing and soft clay cohesion is obtained and plotted in Fig. 16 and 17. moreover the extracted values of such parameter is plotted in Table 6 and 7 to provide more understand the effect of group action on the drag load.

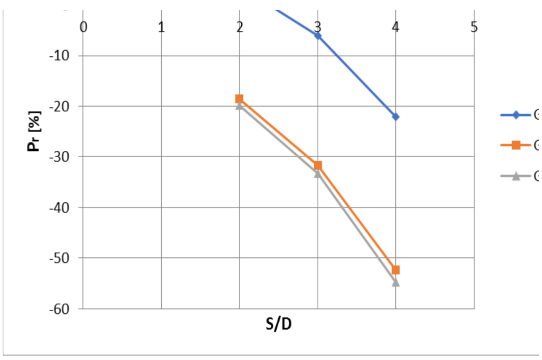

Figure 16 The Pr versus S/D.

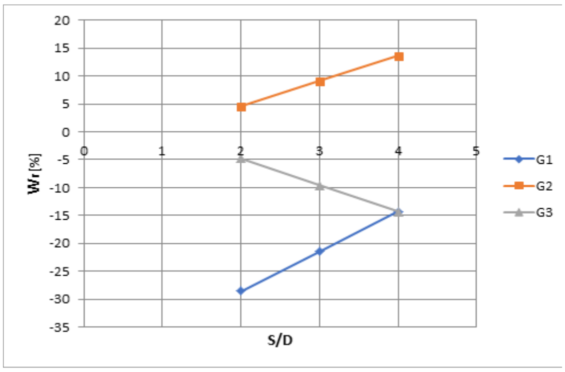

Figure 17 The Wr versus S/D.

Figure 16 and Figure 17 show that in pile groups, increasing the pile spacing provide a remarkable a reduction in values of relative reduction in dragload (Pr) with decreasing in soft clay cohesion. It can be seen that at S/D = 4, the values pf Pr is found to be 22, 55% for soft clay cohesion of 30 and 10kPa respectively. Nevertheless for (Wr), in the case of G1 and G2 is different form such values in G3 the values of Wr was positive in G2 while negative for other cases. It also confirm the grop of pile has lesser downdrag

It has been found that the relative reduction in dragload due to group effect (Pr) increases with increasing number of piles in a group and it can be also increase with reduction of pile spacing. It is found that In case of pile groups with 2D pile spacing, It has a variation from 29% and 5% in pile groups of S= 2D for Cu of 30 and 10 Kpa in that order. While it is found to be from 21% and 10% at S/D = 3.

Conclusion

In this research single and Piles group installed in consolidating soft clay are investigated experimentally to shed the light on the obtained drag movement due to negative skin friction with time factor for different pile spacing and soft clay cohesion. The effect of piles group on the measured dragload is investigated using the finite element program PLAXIS 3D. The following observations can be detected from the study:

1. The numerical results helped in better appreciate the response of single or pile group to assist the induced downdarg load and relative movement or settlemnt
2. the single pile has a lesser dragload compaerd with those of pile group at different pile spacing
3. The higher cohesion has a higher dragload. For case of Cu =30kPa, the dragload for pile group of spacing S =4D, 3D are 1.22, 1.05 time of single pile. While these values are found to be 1.54, 1.33 for spacing S of 4D and 3D respectively in case of Cu =10 kPa.
4. It has been found that for single drainage the settlement of pile in clay cohesion of 10 kPa is

higher than of other case of Cu= 20 and 30 which has a slit variation in settlement. At time over 3 days the settlement in cohesion Cu = 20 and 30 kPa is little. It seems to be in range of 3 to 12 % while in lower cohesion of Cu =10kPa the higher settlement is achieved compared with other cases due to single drainage. on contrary the double drainage is exhibited higher settlement due to larger drainage quantity of water through soil skeleton and acceleration of drainage in short term settlement. Also Change in voids ratio is time dependent, water must be squeezed length of time (t) is dependent on soil permeability

5. The dawndrag displcemnt is highly depends on the soft clay cohesion. Where at the same pile group spacing, the decreaes in soft clay cohesion is achived obvious increase in dawndrag movement.

6. The variation of soft clay cohesion from 30 to 10 kPa significantly increase the drag movement by as much as 150% of its initial value corresponding to Cu =30kPa , S/D = 4. These values of such increase is found to be 135% , 122% at S/D = 3 and 2 in that order

Conflicts of Interest

There are no conflicts to declare

References

[1] Altahrany, A., & Elshehahwy, E. (2022). Skin friction development on single pile and pile group embedded in soft clay. *Mansoura Engineering Journal (MEJ)*, *47*(3), 9 pages.

[2] Nazir, A. K., & Azzam, W. R. (2011). Improving the bearing capacity of footing in soft clay with sand pile with/without skirts. *Alexandria Engineering Journal*, *1*(49), 371–377.

[3] Azzam, W., & Elwakil, A. (2016). Model study on the performance of single-finned pile in sand under tension loads. *International Journal of Geomechanics*, 10.1061/(ASCE)GM.1943-5622.0000761, 04016072.

[4] Acar, Y. B., Avent, R., & Taha, M. R. (1994). Down drag on friction piles: A case history. *Vertical and Horizontal Deformation of Foundations and Embankment Settlement, ASCE GSP*, *40*, 986–999.

[5] Blanchet, R., Tavenas, F., & Garneau, R. (1980). Behavior of friction piles in soft sensitive clays. *Canadian Geotechnical Journal*, *17*, 203–224.

[6] Cao, W., Chen, Y., & Wolfe, W. (2014). New load transfer hyperbolic model for pile-soil interface and negative skin friction on single piles embedded in soft soils. *International Journal of Geomechanics*, 10.1061/(ASCE)GM.1943-5622.0000289, 92–100.

[7] Chen, R. P., Zhou, W. H., & Chen, Y. M. (2009). Influences of soil consolidation and pile load on the development of negative skin friction of a pile. *Computers and Geotechnics*, *36*(8), 1256–1271.

[8] Chow, Y. K., Lim, C. H., & Karunaratne, G. P. (1996). Numerical modelling of negative skin friction on pile groups. *Computers and Geotechnics*, *18*(3), 201–224.

[9] Fellenius, B. H. (2006). Results from long-term measurements in piles of drag load and down drag. *Canadian Geotechnical Journal*, *43*(4), 409–430.

[10] Fellenius, B. H. (1999). *Basics of foundation design* (2nd expanded ed.). BiTech Publishers Ltd.

[11] Fellenius, B. H. (1972). Down drag on piles due to negative skin friction. *Canadian Geotechnical Journal*, *9*(4), 323–337.

[12] Hanna, A. M., & Sharif, A. (2006). Drag force on single piles in clay subjected to surcharge loading. *International Journal of Geomechanics*, *6*(2), 89–96.

[13] Indraratna, B., Balasubramaniam, A. S., Phamvan, P., & Wong, Y. K. (1992). Development of negative skin friction on driven piles in soft Bangkok clay. *Canadian Geotechnical Journal*, *29*(3), 393–404.

[14] Jeong, S., Lee, J., & Lee, C. J. (2004). Slip effect at the pile-soil interface on dragload. *Computers and Geotechnics*, *31*(2), 115–126.

[15] Johannessen, I. J., & Bjerrum, L. (1965). Measurement of the compression of a steel pile to rock due to settlement of the surrounding clay. *Proceedings of 6th International Soil Mechanics and Foundation Engineering*, vol. 2, Montreal, Canada, 261–264.

[16] Kong, G., Zhou, H., Liu, H., Ding, X., & Liang, R. (2014). A simplified approach for negative skin friction calculation of special-shaped pile considering pile-soil interaction under surcharge. *Journal of Central South University*, 10.1007/s11771-014-2347-z, 3648–3655.

[17] Lam, S. Y., Ng, C. W. W., & Chan, S. H. (2009). Centrifuge and numerical modelling of axial load effects on piles in consolidating ground. *Canadian Geotechnical Journal*, *46*(1), 10–24.

[18] Lee, C. J., Bolton, M. D., & Al-Tabbaa, A. (2001). Recent findings on negative skin friction in piles and pile groups in consolidating ground. *5th International Conference on Deep Foundation Practice*, Singapore, 273–280.

[19] Lee, C. J., & Chen, C. Z. (2002). Negative skin friction on grouped piles. *Proceedings of International Conference on Physical Modelling in Geotechnics*, 679–684.

[20] Lee, C. J., & Ng, C. W. W. (2004). Development of downdrag on piles and pile groups in consolidating soil. *Journal of Geotechnical and Geoenvironmental Engineering*, *130*(9), 905–914.

[21] Li, K. S., & Lam, J. (2001). Design of driven pile foundations subjected to NSF: A case study. *5th International Conference on Deep Foundation Practice*, Singapore, 281–288.

[22] Leung, C. F., Liao, B. K., Chow, Y. K., Shen, R. F., & Kog, Y. C. (2004). Behavior of pile subject to negative skin friction and axial load. *Soils and Foundations*, *44*(6), 17–26.

[23] Little, J. A., & Ibrahim, K. I. (1993). Predictions associated with the pile downdrag study at the SERC soft clay site at Bothkennar, Scotland. *Predictive Soil Mechanics*, Thomas Telford, London, 796–818.

[24] Mahfouz, A. H. (2011). New technique of ground improvement: Driven cast-in-situ thin wall concrete pipe piles (PCC). *Geomechanics and Geoengineering International Journal*, *6*(2), 119–129.

[25] Mahfouz, A. H., Sallam, H. E. M., Wazir, A., & Kharezi, H. H. (2016). Geotechnical investigation of soil foundation for ramps of Dawar El-Tawheed Bridge in Jizan City - Kingdom of Saudi Arabia. *18th International Conference on Civil and Construction Engineering*, Jeddah, Saudi Arabia, *10*(1), 3230–3240.

[26] Morsy, M., Fakharian, K., Meskar, M., & Mohammadlou, A. (2014). Effect of surcharge pressure on pile static axial load test results. *International Journal of Geomechanics*, 10.1061/(ASCE)GM.1943-5622.0000310, 04014024.

[27] Knudsen, B. S., Østergaard, M. U., & Clausen, J. (2013). Implementation of a Stress-dependent Strength Material Model in PLAXIS 3D

[28] Ng, C. W. W., Poulos, H. G., Chan, V. S. H., Lam, S. S. Y., & Chan, G. C. Y. (2008). Effects of tip location and shielding on piles in consolidating ground. *Journal of Geotechnical and Geoenvironmental Engineering*, *134*(9), 1245–1260.

[29] Sun, T., Yan, W., & Su, D. (2013). Fully coupled consolidation analysis of shear strength mobilization and drag load of a pile subject to negative skin friction. *International Journal of Geomechanics*, 10.1061/(ASCE)GM.1943-5622.0000381, 04014057.

[30] El-Mossallamy, Y. M., Hefny, A. M., & Demerdash, M. A. (2013). Numerical analysis of negative skin friction on piles in soft clay. *HBRC Journal*, *9*, 68–76.