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Pile Group in Consolidating Clay Pile Group in Consolidating Clay

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ABSTRACT

Due to rapid development in the country and shortage in suitable land, construction of high-rise building was carried out in backfill swamp land. Piles are used because its ability to carry large loads, easy in construction and its ability to transport the loads to underlying strong soil layers. In case of using pile foundations in consolidating soil the soil may settle more than piles which produces (NSF) and imposed loads on piles which may discard in the design and might cause structural failures. In the present study 4-pile group and 9-pile group wished in consolidating clay were analyzed by three dimensional finite element model using (ABAQAUS, 6.14). In this model, clay was simulated using Cam Clay model (CCM) while the friction at pile-soil interface and sand was represented by Mohr-Coulomb model (MCM). The piles and cap were described by a 3D linear elastic model. An appreciable percentage of peak drag-load ($P.P_{DL}$) and down-drag (W) are mobilized at early stage of consolidation (U) equal 40% in case of 2x2 pile group. While in case of 3x3 pile group 70% to 90% of down-drag (W) occurred at (U) equal to 40% depending upon surcharge load (q) and (PHL). The rate of developing the peak drag-load imposed on a pile depends upon the location of the pile within the group.

Keywords: *Drag-load, Down-drag, consolidating clay, Slip condition, Axial load.*

1.Introduction:

The behavior of pile group attracts many research work such as [1], [2], [3], [4], [5],[6] and [7]. Piles in consolidating clay are subjected to drag-load (P_{DL}) and down-drag (W), the first affects the structure deficiency of the piles while the later affects their serviceability. Jeong,[8] proposed a design procedure for calculating the drag-load of pile group at spacing 5 D and 2.5 D. The most crucial factor affecting on the serviceability of the structure is the differential down-drag rather the drag-load, [9]. Lee,[10] pointed out that the longer the piles in the group are the greater shielding effect on down-drag. The development and magnitude of drag-load (P_{DL}) on pile group is dependent on the adopted numerical model of pile-soil interface and the method of analysis. It is noteworthy that the pile-soil interface was modeled using; slip analysis, no-slip analysis, and continuum element. Slip at the pile-soil interface takes place by implementing either limiting shear displacement (ε_γ) and interface friction coefficient (μ), [11] and [12] or limiting friction stress (τ_{lim}) at pile-soil interface, [13], additionally to a hyperbolic interface model,[14]. The elasto-plastic slip analysis coupled with consolidation of clay is limited to[4] ; [15] [16]; [12]; and [17]. Notably that, the performance of pile group in consolidating clay was achieved by different methods; analytical method,[18], [19] and [20], simplified linear elastic analysis, [21] and [22] and no-slip linear elastic finite element analysis,[9] and [23].

2. Verification and modelling:

2.1. Geometry and model discretization:

A soil domain with pile group inclusion of cylindrical shape having a diameter of 60m, which is equal to 50 times the pile diameter, and having a height of 1.52 times the pile length, was discretized. Due to symmetry only one-quarter of the pile group and soil domain was modeled. The clay and sand domain were simulated using C3D4P (a 4-node linear tetrahedral, coupled displacement-pore water pressure elements), while the pile was simulated using (a 4-node linear tetrahedral elements). More than 151876 elements were used to discretize the 4-pile group and soil domain resulted 31320 nodes while 160855 elements with 35034 nodes for 9-pile group and soil domain were obtained. The mesh was staged refinement by using elements most refined adjacent pile-soil interface and the size of elements gradually increased as the distance increased radially from the pile group center line.

2.2. Boundary condition:

The vertical boundary of soil domain is located far away from the pile by a distance equal to 25 times the pile diameter (30m), while the bottom boundary at depth equal to about 1.5 times pile length. The vertical and radial displacements of soil elements at bottom boundary were restrained by the means of pinned supports. The soil elements along the vertical boundaries of soil medium were restrained against radial displacements; only vertical displacement is allowed using roller supports on the side boundary of the soil domain. Top boundary of soil domain is free to move at vertical and radial directions. At the top and bottom of clay layer, the excess pore water pressures were set equal to zero at any time.

2.3. Interface modeling:

The interface between the pile group and the soil was modeled using surface to surface algorithm in (ABAQUS, 6.14). Surfaces are in contact where the relative displacement (Δ) between master node (Pile) and slave node (Soil) is less than 5mm. If shear displacement becomes more than 5mm, the slip between surfaces (soil and pile) will occur. The interface elements which are of zero thickness transfer shearing force across the interface between pile and soil. Friction between the pile-soil interfaces before slippage was simulated by Mohr-Coulomb Model (MCM) with friction interface angle (δ). In the present study (μ) was set equal to 0.3 at pile-soil interface for clay and sand.

2.4. Constitutive model and material parameters:

The subsoil soft clay is simulated by Cam Clay Model, (CCM). Three parameters are implemented in the model λ, k and m. λ and k parameters are related to normally consolidated clay properties, while the parameter m is the slope of critical state line in $q - P'$ space.The pile is simulated as a 3D linear elastic material. Sand layer is simulated by Mohr- Coulomb Model (MCM). The model is configured for flow of water to complete dissipation of excess pore water pressure. The flow of water is kept on during the analysis, and the excess pore water distributions within the clay layer were computed at time intervals. In the analysis, the flow of water is kept on, while the properties of clay λ, k and m are kept constant independent of the effective stress variation. The drained-coupled analysis is simultaneous action of pore water fluid for with the volumetric change of clay soil; therefore pore water flow is simultaneous actions with the drag load, and down drag of the pile. The inelastic behavior of material is accompanied by volume change. Dilation angle ψ of 0.1^0 is set for clay and 10° for sand. The analysis was carried out up to a degree of consolidation of clay equal to 90%, to save computation time.

2.5. Loading and solution steps:

In the numerical analysis, the effect of pile installation on soil properties is discarded. Simultaneous loading of pile head (PHL) and surcharge load (q) is considered. The first step of the analysis is the geostatic deformations of soil domain. At the end calculation of first step, numerical analysis indicated negligible deformations. During the geostatic step the interaction between pile and soil is allowed, as well as all boundary conditions are implemented. In case of simultaneous loading, where the pile head load (PHL) and surcharge load on ground surface (q) were applied simultaneously. Pile head load (PHL) is applied as uniformly distributed load over the pile cap while the surcharge load (q) is applied on unlimited area on ground surface. The average pile head load (PHL) and surcharge load (q) are kept constant. The consolidation process continues up to a predefined time corresponding to a specified degree of consolidation (U). On reaching specified time the output results are harvested. Different elapsed time intervals corresponding to different degree of consolidation (U) are considered. Each time interval is started from initial conditions.

2.6. Verification of FE model:

Jeong [25], carried out three dimensional analysis on 5*5 pile group wished in place through 20m soft layer followed by 5.0m sand layer, piles configuration shown in figure (1). The soil properties are presented in table (1). The pile diameter was 0.50m and water level at ground surface. The piles were not connected with the pile cap. The pile group was analyzed using the developed model with a flexible cap of thickness 0.50m above ground surface. Surcharge load of 25kPa was applied on ground surface. Numerical analysis continues up to reached 90% degree of consolidation. The mobilized skin friction (τ_m) obtained from numerical analysis was normalized to shear strength near pile tip (τ_f), [25]. The comparison was presented in figures (2) through (4). The figures indicate reasonable matching of NSF mobilized along center pile while there are some discrepancies in case of side and corner piles. This may be due to that the authors implemented drained analysis instead of coupled analysis with consolidation process. Also the group effect was compared for the present study and Jeong [25] in table (2). The difference in the values affected by the analysis method and the flexible cap implemented in the present study.

Table 1: Constitutive model parameters of pile group verification.

Properties	Clay	Sand	Pile
Unite weight γ (kN/m^3)	18	20	25
Modulus of elasticity E (kN/m^2)	5000	50000	1.25 E 7
Poisson's ratio (ϑ)	0.3	0.3	0.3
void ratio (e_0)	0.9	0.4	0.2
Frictional angle at critical state ($\emptyset'$)	20°	35°	-
Angle of dilation (ψ')	0.1^0	10°	-
Coefficient of earth pressure at rest K_0	0.65	0.50	-
Permeability $K_s(m/s)$	1e -5	1e -4	1e -10
(mm)$\gamma_{critical}$	5.0	5.0	-

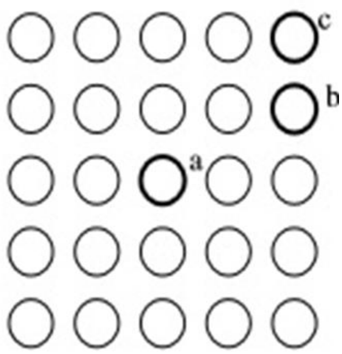

Fig. 1 Pile group configuration Jeong [25].

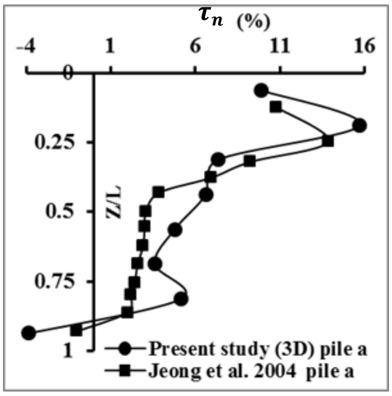

Fig. 2 Normalized skin friction versus Z/L for center pile.

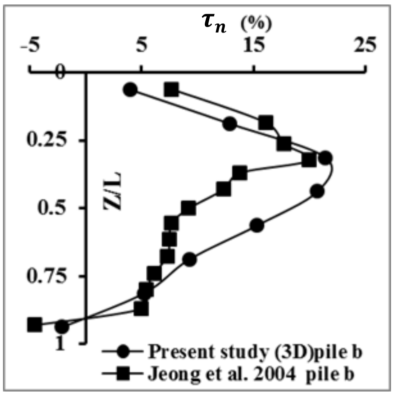

Fig. 3 Normalized skin friction versus Z/L for side pile.

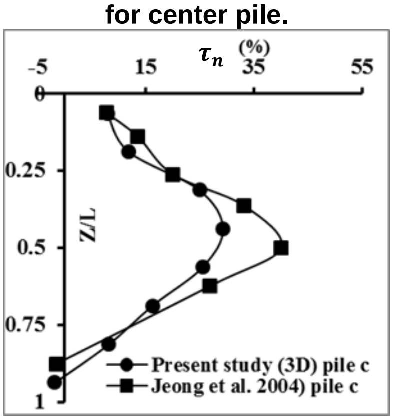

Fig. 4 Normalized skin friction versus Z/L for corner pile.

Table 2: Group effect of 5x5 pile group

Group effect = $\frac{P_{single}-P_{(center,side\ and\ corner)}}{P_{single}}$ %				
Surcharge	**Case**	**Center(a)**	**Side (b)**	**Corner (c)**
25kPa	Present	86%	76%	70%
	Jeong [25]	70.77%	66.92%	40%

3. Discussion of results:

Pile group comprising four piles and nine piles were analyzed. The piles have a diameter of 1.20m and pile length of 23.0m. The piles are arranged in square pattern at space S/D equal to 2.50 times the pile diameter. Piles were wished-in-place into 18.0m of clay underlying 5.0m of sand as shown in figures (5) and (6). The pile groups and the consolidating clay were analyzed under surcharge load of 30kPa and 40kPa and imposed average pile head load of 2MN per pile. The surcharge load and the piles heads load were applied simultaneously. The pile head load was applied uniformly distributed on the pile cap. The pile group is connected to rigid pile cap of thickness 0.90m free standing above ground surface by 0.30m. For comparison free-head load piles group were analyzed. The constitutive model parameters of the numerical model are shown in table (3).

The peak drag-loads ($P.P_{DL}$) of free-head load pile group and pile loaded with different head load up to 2MN were calculated and normalized as expressed in equation (1).Then drawn against the degree of consolidation (U), figure (7).

$$(P.P_{DL})_N = \frac{P.P_{DL}}{\pi * D * H^2 * \gamma_{eff}} \quad \textbf{(1)}$$

Where;
D Pile diameter,
H Thickness of clay layer,
γ_{eff} Effective unite weight which expressed as ($\gamma_{wet} - \gamma_{water}$).

3.1 Four-pile group:

Figures (5) and (6) show the arrangement of four pile group. The soil displacements at ground surface were obtained at points A to D at pile-soil interface.

3.1.1 Peak drag-load and down-drag:

Figure (7) shows that, the peak drag-load ($P.P_{DL}$) imposed on a pile in the 4-pile group increased with the increase of the degree of consolidation. This can be attributed to that the increase of the soil displacement relative to the pile displacement. While, the peak drag-load ($P.P_{DL}$) decreased with the increase of pile head load due to the increase of pile displacement. Also the peak drag-load ($P.P_{DL}$) increased with the increase of surcharge load (q). The peak drag-load imposed on pile increased with the increase of consolidation (U), surcharge load (q) and decreased with the increase of pile head load. The figure shows that the developed peak drag-load ($P.P_{DL}$) at degree of consolidation U equal to 40% was 63% of that developed at degree of consolidation U 90% in case of pile head load (PHL) of 2MN/pile and surcharge load q 30kPa. This percentage was 86% in case of free-head-loaded pile group and surcharge load q 40kPa. Therefore an appreciable percentage of peak drag-load ($P.P_{DL}$) was mobilized on the pile at early stage of consolidation.

The down-drag (W) of free-head-load and load-head 4-pile group is presented in figure (8). The figure indicates that the down-drag (W) of the pile group subjected to pile-head load is bigger than that of free-head-load pile group due to a decrease on NSF. The down-drag (W) also increased with the increase of the degree of consolidation and with the increase of surcharge load (q) and pile head load (PHL). The down-drag (W) of the pile group at U equal to 40% is 95% of that at U equal to 90% in case of surcharge load q equal to 40kPa where this percentage is reduced to 85% in case of surcharge load q 30kPa for both free-head-load and load-head pile group.

Table 3: Constitutive model parameters of numerical analysis model.

Properties	Clay	Sand	Pile
Unite weight γ (kN/m^3)	16.3	19.4	27
Modulus of elasticity E (kN/m^2)	λ = 0.14 k = 0.012 m = 0.98	1.2 E 5	2.4 E 7
Poisson's ratio (ϑ)	0.45	0.35	0.15
void ratio (e_0)	1.6	0.4	0.2
Frictional angle at critical state ($\emptyset'$)	25^0	35°	-
Angle of dilation (ψ')	0	10°	-
Coefficient of earth pressure at rest K_0	0.58	0.5	-
Permeability $K_s(m/s)$	1e -9	1e -5	1e -13
(mm)$\gamma_{critical}$	5.0	5.0	-

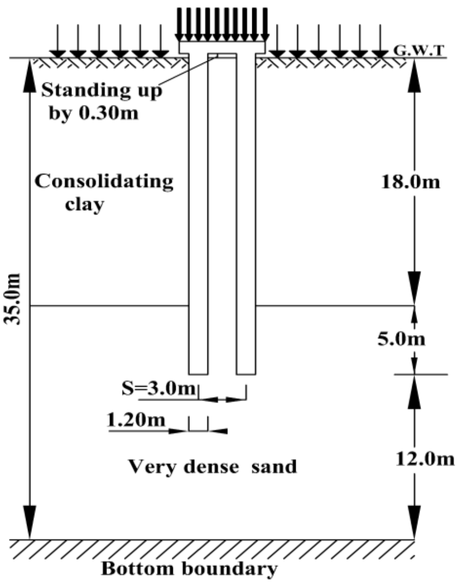

Fig. 5 Soil profile for 4-pile group.

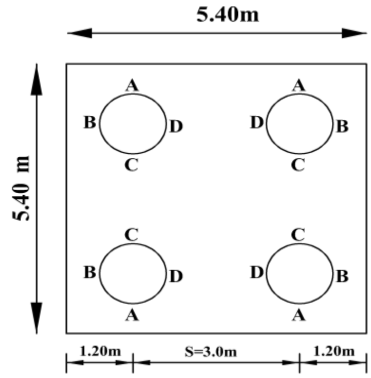

Fig. 6 Piles Configuration for 4-pile group.

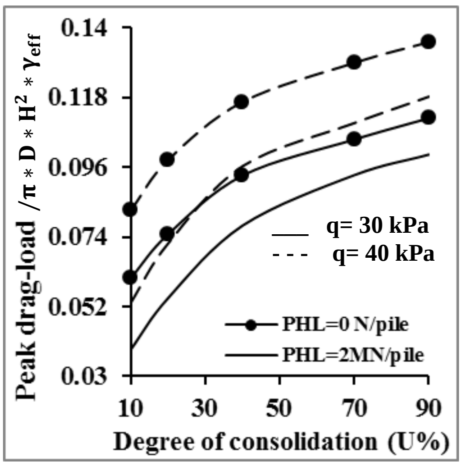

Fig. 7 Normalized peak drag-load versus degree of consolidation.

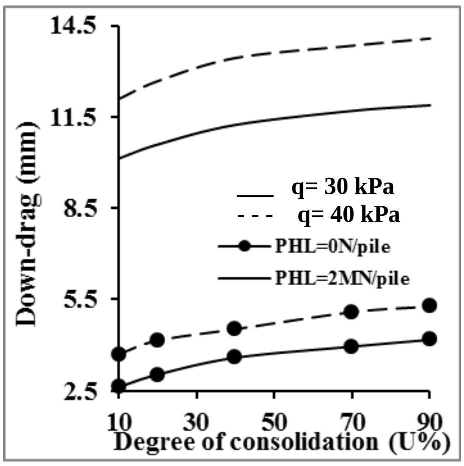

Fig. 8 Down-drag versus degree of consolidation for 4-pile group.

3.1.2 Soil surface settlement:

The surface soil displacements at points C and D are less than that exhibited at points A and B, figure (6). The surcharge load (q) had appreciable effect on soil surface displacement as shown in figures (9) and (10). The soil surface displacement (S) increases with increase of the degree of consolidation U and with the increase of surcharge load (q), and not appreciable affected by the increase of pile head load (PHL).

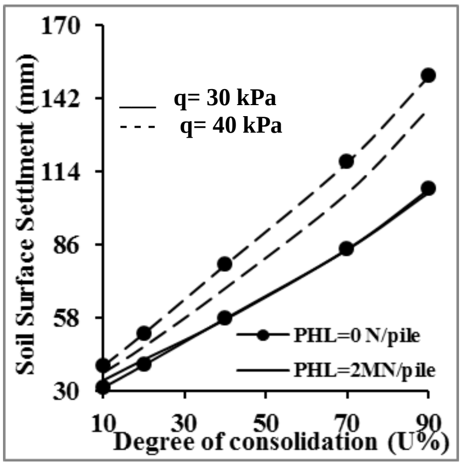

Fig. 9 Soil surface settlement versus degree of consolidation outside the group (Points A&B).

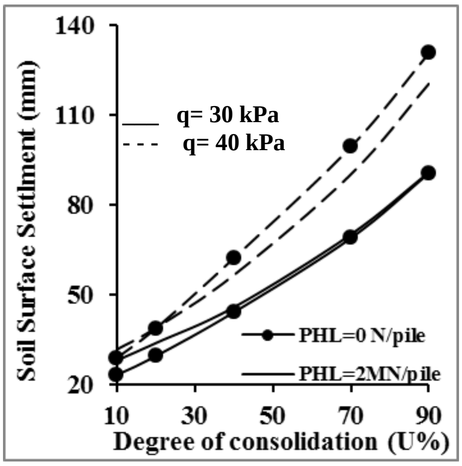

Fig. 10 Soil surface settlement versus degree of consolidation inside the group (Points C&D).

3.1. 3 Normalized Mobilization length (NL_m):

The soil displacement outside the pile group is bigger than that inside the group. Therefore the mobilized length (L_m) along a pile within the group does not extend to the same depth. The mobilized length (L_m) goes further down along the outsides of a pile compared by the insides. Table (4) shows the mobilization length normalized to the clay length (18m) inside and outside the group. The mobilized length (L_m) outside the pile group develops with increasing depth along the pile as (U) increased and attained the full mobilization length at degree of consolidation U equal to 40%. The mobilized length (L_m) along outside faces of piles was remaining constant beyond (U) equal to 40% while mobilization length (L_m) along inside pile-soil interface increased with the increase of (U) up to (U) approaching equal to 70%.

Table: 4 Mobilization length to clay length (18m) of 2x2 pile group.

(P_{HL}) (kN)	(q) (kPa)	Outside points (A&B)			Inside points (C&D)		
		U= 10%	U= 40%	U= 90%	U= 10%	U= 40%	U= 90%
0.0	30	0.30	0.85	0.81	0.07	0.42	0.63
	40	0.96	0.94	0.94	0.09	0.63	0.69
2000	30	0.10	0.71	0.76	0.04	0.25	0.60
	40	0.13	0.79	0.78	0.06	0.45	0.63

3.2 Nine pile group:

The configuration of 3x3 pile group is shown in figures (11) and (12). The spacing between piles in the group S/D is 2.50.

3.2.1 Peak drag-load and down-drag:

The peak drag-load versus the degree of consolidation (U) is presented in figures (13) through (15) for different (P_{HL}). The effect of surcharge load (q) and pile head load are inquired. The figures indicated that as the surcharge load (q) increased the drag-load (P_{DL}) and the peak drag-load ($P.P_{DL}$) increased. At U equal to 40% the increase of surcharge load from 30kPa to 40kPa in case of free head load 9-pile group, the peak drag-load increased by 53.14%, 27.5% and 40.75% for center pile, corner pile and side pile, respectively. As the pile head load increased the pile-soil relative displacement decreased and the drag-load and the peak drag-load decreased. The increase of (PHL) from 0kN to 2MN, caused a decrease in drag-load and peak drag-load, but the decrease is not appreciable. Consequently the NSF does not affected appreciable by the increasing of pile head loads. By comparing figures (13) through (15) the peak drag load ($P.P_{DL}$) imposed on center pile is less than that imposed on corner pile, the side pile exhibit peak drag-load with values in between that values imposed on center and corner piles. This is attributed to the hang-up effect during consolidating of clay that produces shielding around the center pile. The shielding effect depends upon the location of the pile within the group. For center pile and side pile the peak drag-load ($P.P_{DL}$) continue in mobilization up to degree of consolidation (u) equal to 90% where the corner pile attained most of its value at (U) equal to 40%.

The piles heads load are normalized to the average axial load per pile, 2MN, table (5). The table indicates that, as anticipated, the corner pile shared the biggest percentage of the overlying load, while side and center piles shared smaller percentage. This distribution of loads amongst piles within 3x3 pile group is well documented in literature, [18]. Based on the assumption that there is no enhancement of clay properties during consolidation process, the distribution of external vertical load among the piles in the group is not appreciably affect by surface loading (q) and degree of consolidation (U). The table shows that tension forces are developed near pile head that depends on the location of pile within the group, degree of consolidation (U) and surcharge load (q). Lee, [26] reported that tension forces developed in outer piles of 5x5 pile group were 3.8% of maximum drag-loads in the piles. Tension forces developed near the pile heads of outer piles were reported by [27] ; [19]; [28]; [26] and [15].

The variation of down drag (W) of pile group with the degree of consolidation (U) at different applied load on the group and surcharge load on ground surface is presented in figure (16). The down drag of the group increases as the degree of consolidation increased due to the increase of drag load, and as the applied load decreased and as surcharge load increased. The increase in down-drag (W) due to applied pile head load is due to decreasing the NSF which contacts the soil surface displacement due to surcharge load (q).

3.2.2 Soil surface settlement:

The hang up of soil affect the soil surface settlement at any point within clay layer, either the point inside the pile group or outside. Figure (17) present soil surface soil settlement (S) around the center pile at different applied load (PHL) and different surcharge load (q). The soil surface settlements (S) around the center pile increased with the increase of surcharge load and with the increase of the applied load (PHL) but not appreciably. Figures (18) and (19) present the soil surface settlement (S) around the corner pile. The soil surface soil displacement outside the corner pile in the average of 90 mm and 125mm in case of surcharge load (q) 30kPa and 40kPa at U equal to 90%. The corresponding soil surface settlements (S) inside the group beside the corner pile are the same. These displacements are 1.9 and 1.76 times the displacement around center pile. The side pile exhibit soil surface displacement inside the pile group on the average of 47mm and 70mm at U equal to 90 % and surcharge load q of 30kPa and 40kPa, respectively. The corresponding values outside the pile group are 75 mm and 107 mm, respectively figures (20) and (21). The soil is hang-up on piles in the group. The hang up produces shielding around center pile. The shielding reduces the vertical effective stress inside the pile group compared by the far field effective stress.

3.2. 3 Normalized Mobilization length (NL_m):

The normalized mobilization length along the corner pile is nearly equal all around the periphery of the pile and attained its maximum limiting value at (U) equal to 40%, table (6). The normalized mobilization length of corner pile is equal to 0.82 of clay depth in case of (q) 30kPa and 0.93 in case of (q) 40kPa. These values decreased to 0.78 and 0.85 in case of load-head pile group. Normalized mobilization length (NL_m) along outside and inside side pile exhibited increasing in depth up to 90%-degree of consolidation of clay, therefore the pile can also receive drag-load up to (U) equal to 90% . Normalized mobilization length (NL_m) of center pile ranged from 0.24 to 0.27 of clay depth in case of surcharge load (q) equal to 30kPa and 90% degree of consolidation (U) while increased to 0.48 to 0.50 in case of 40kPa surcharge load (q) depending upon the pile head load (PHL).

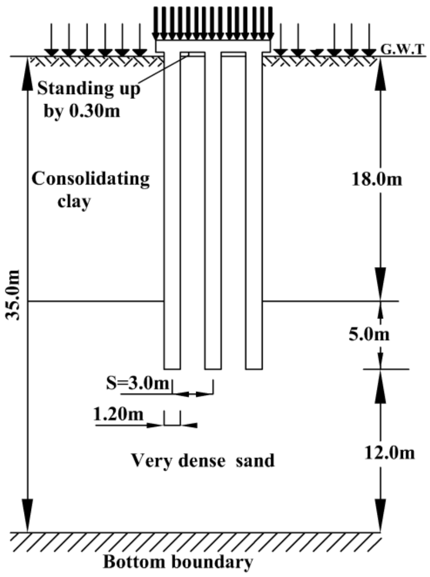

Fig. 11 Soil Profile of 9-pile group.

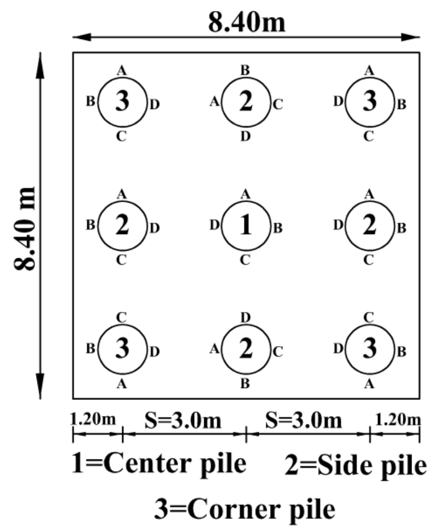

Fig. 12 Pile configuration for 9-pile group.

Table:5 Normalized pile head load of 3x3 pile group.

(U%)	(q) (kPa)	Center		Corner		Side	
		Free-headed load $(P/P.P_{DL})$	2000kN (P/P_{HL})	Free-headed load $(P/P.P_{DL})$	2000kN (P/P_{HL})	Free-headed load $(P/P.P_{DL})$	2000kN (P/P_{HL})
40	**30**	0.69	0.66	- 0.07	1.23	0.03	0.85
	40	0.40	0.70	- 0.02	1.24	- 0.02	0.83
90	**30**	0.06	0.64	0.03	1.27	- 0.05	0.82
	40	- 0.06	0.61	0.06	1.29	- 0.06	0.81

Table:6 Mobilization length to clay length (18m) of 3x3 pile group.

a- Center pile						
(P_{HL}) (kN)	Surcharge load=30kPa (A,B,C&D)			Surcharge load=40kPa (A,B,C&D)		
	U=10%	U=40%	U=90%	U=10%	U=40%	U=90%
0.0	0.04	0.10	0.27	0.06	0.13	0.50
2000	0.04	0.10	0.24	0.06	0.12	0.48

b- Corner pile							
(P_{HL}) (kN)	Surcharge load	Outside points (A&B)			Inside points (C&D)		
		U=10%	U=40%	U=90%	U=10%	U=40%	U=90%
0.0	**30**	0.23	0.84	0.81	0.37	0.86	0.84

	40	0.93	0.96	0.93	0.97	0.98	0.94
2000	**30**	0.11	0.72	0.78	0.12	0.72	0.78
	40	0.17	0.89	0.86	0.18	0.90	0.88
c- Side pile							
(P_{HL})	**(q)**	**Inside points (A,C&D)**			**outside point (B)**		
0	**30**	0.06	0.12	0.43	0.08	0.39	0.64
	40	0.07	0.18	0.56	0.11	0.64	0.71
2000	**30**	0.04	0.11	0.36	0.07	0.28	0.62
	40	0.07	0.17	0.53	0.09	0.58	0.68

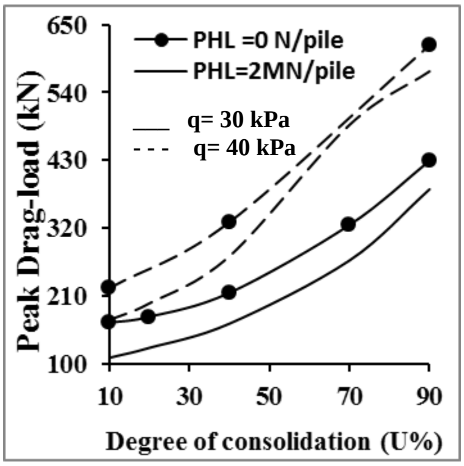

Fig. 13 Peak drag-load versus degree of consolidation for center pile.

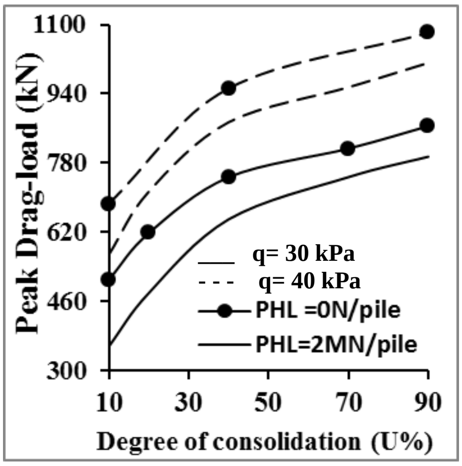

Fig. 14 Peak drag-load versus degree of consolidation for corner pile.

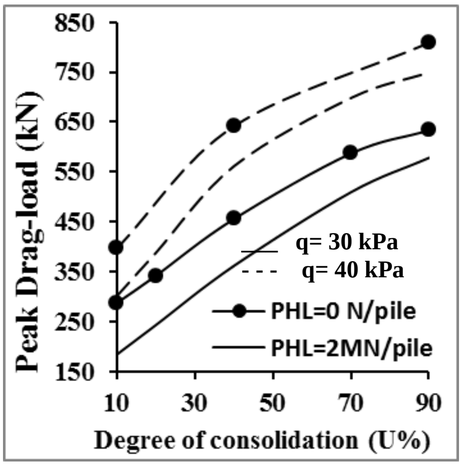

Fig. 15 Peak drag-load versus degree of consolidation for side pile.

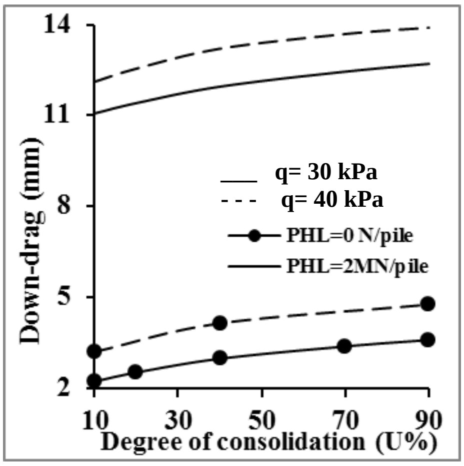

Fig. 16 Down-drag verses degree of consolidation at 9-pile group.

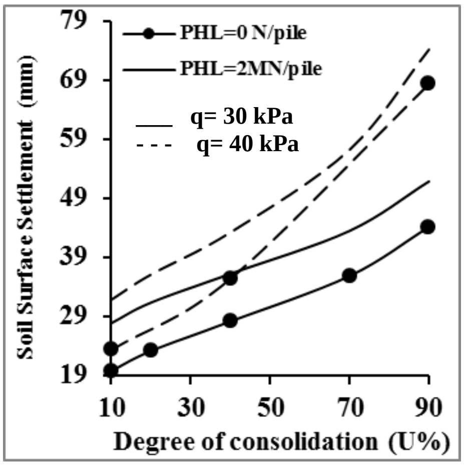

Fig. 17 Soil surface settlement versus degree of consolidation around center pile.

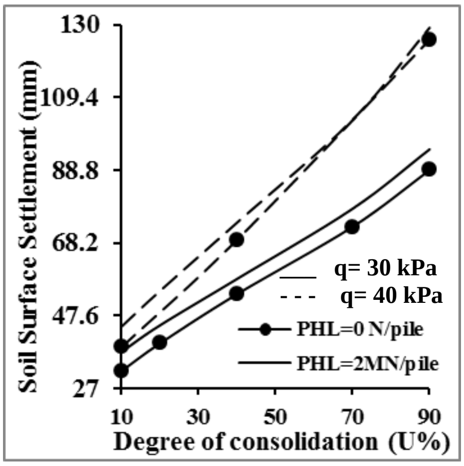

Fig. 18 Soil surface settlement versus degree of consolidation outside corner pile points (A&B).

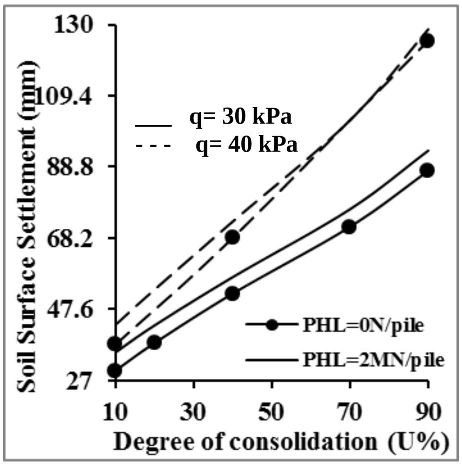

Fig. 19 Soil surface settlement versus degree of consolidation inside corner pile points (C&D).

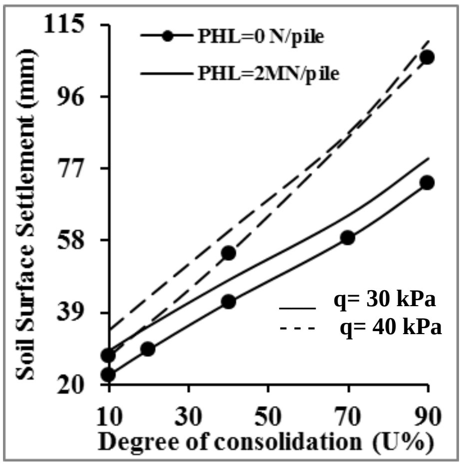

Fig. 20 Soil surface settlement versus degree of consolidation outside side pile point (B).

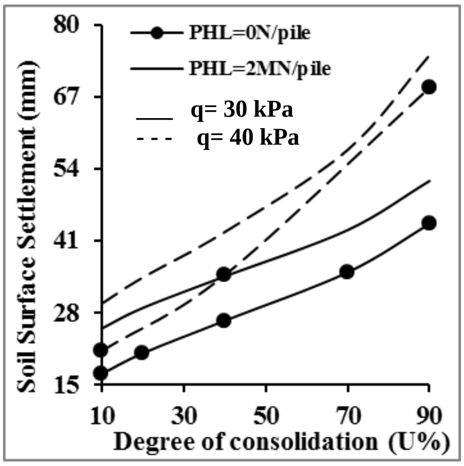

Fig. 21 Soil surface settlement versus degree of consolidation inside side pile points (A,C&D).

4. Summary and conclusions:

Four and nine pile groups arranged in square pattern wished in consolidating clay underlain by sand were analyzed. The course of investigated yield the following conclusion:

1- The peak drag-load ($P.P_{DL}$) increased with the increase of the degree of consolidation and surcharge load (q) while the peak drag-load ($P.P_{DL}$) decreased with the increase of pile head load.
2- For a pile within 4-pile group an appreciable percentage of peak drag-load ($P.P_{DL}$) was mobilized on the pile at early stage of consolidation, while in case of center and side piles the peak drag-load ($P.P_{DL}$) continue in mobilization up to degree of consolidation (u) equal to 90% but the corner pile attained most of its value at (U) equal to 40%.
3- The peak drag load ($P.P_{DL}$) imposed on center pile is less than that imposed on corner pile, the side pile exhibit peak drag-load with values in between that values imposed on center and corner piles.
4- Tension forces are developed near pile head of piles within free-head load 3x3 pile group. The tension force depends upon the location of pile within the group, degree of consolidation (U) and surcharge load (q).
5- The down-drag (W) increased with the increase of the degree of consolidation (U) and with the increase of surcharge load (q) and pile head load (PHL). The down-drag (W) of the pile group at U equal to 40% is 95% of that at U equal to 90% in case of surcharge load q equal to 40kPa, where this percentage is reduced to 85% in case of surcharge load q 30kPa for both free-head-load and load-head pile group.
6- The soil surface displacement (S) increases with the increase of the degree of consolidation (U) and with the increase of surcharge load (q).
7- For both 4-pile group and 9-pile group the inside soil surface settlement (S) is less than the outside the group due the hanging up effect and in case of 9-pile group the values are affected by the location of the pile within the group.
8- The mobilized length (L_m) along a pile within the group does not extend to the same depth due the difference of soil surface settlement inside and outside the group. The mobilized length (L_m) goes further down along the outsides of a pile compared by the insides.
9- For 4-pile group the mobilized length (L_m) along outside faces of piles was remaining nearly constant beyond (U) equal to 40% while mobilization length (L_m) along inside pile-soil interface increased with the increase of (U) up to (U) approaching 70%. The mobilization length (L_m) of a pile within 3x3 pile group depends upon the location of the pile within the group, degree of consolidation (U), surcharge load (q), pile head load (PHL) and the side of pile group either inside or outside the pile group.

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