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Studying the effects of negative skin friction on driven pile groups in Basrah governorate

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ABSTRACT

The finite element method is used to simulating the behavior of deep foundations subjected to negative skin friction in Basrah soil. Pile groups are analyzed under dragforces using 3D Plaxis software. Linear elastic and Mohr–Coulomb constitutive relations are adopted for the pile and soil materials. Three sites are selected to perform the study, where the negative skin friction is developed due to fill loads. The dragforces on driven piles, within (3 x 3) square groups with spacing of (3B), are evaluated and compared to their counterparts of single piles. The dragforces are decreased on piles constituting the group, and the reduction depends on pile location within the group. Centeral piles exhibit maximum reductions of (50%). To study the effect of pile spacing, a range of [(3B) to (6B)] was adopted. Apart from pile location, it is concluded that, the dragforce is proportional to pile spacing.

1. Introduction

Negative skin friction is developed on a pile shaft due to the relative vertical displacement between the pile and the surrounding soil, where settlement of soil more than settlement of pile. The negative skin friction developed along upper part of piles and will add to the external loads, A common case where loads are applied on ground surface at the vicinity of a pile or pile group after construction of piles met in practice, is the construction of a bridge approach embankment, which follow the construction of a bridge foundation (Fig. 1) (Kouretzis 2018). Drag load defined as the load transferred to a deep foundation unit from negative skin friction, and can be calculated from negative skin friction time surface area of imbedded pile to the neutral point.

The magnitude of negative skin friction that could be transferred to pile depends on pile material; pile installation method; soil nature; and rate and amount of relative movement between pile and soil (Geotechnical Engineering Office, 2006).

Usually, ground settlement relative to the pile may be attributed to the following reasons (Tomlinson, 2004):

(1) Weight of superimposed fill.

(2) Groundwater lowering.

(3) Disturbance of clay caused by pile driving and reconsolidation of the disturbed clay under its own weight.

Several methods have been developed to reduce the expected negative skin friction on deep foundations (Samtani and Nowatzki, 2006). These include: using piles with shafts of small cross-section area compared with the points; driving piles inside a casing with the space between pile and casing filled with a viscous material and the casing withdrawn; and coating the piles with bituminous or asphalt materials.

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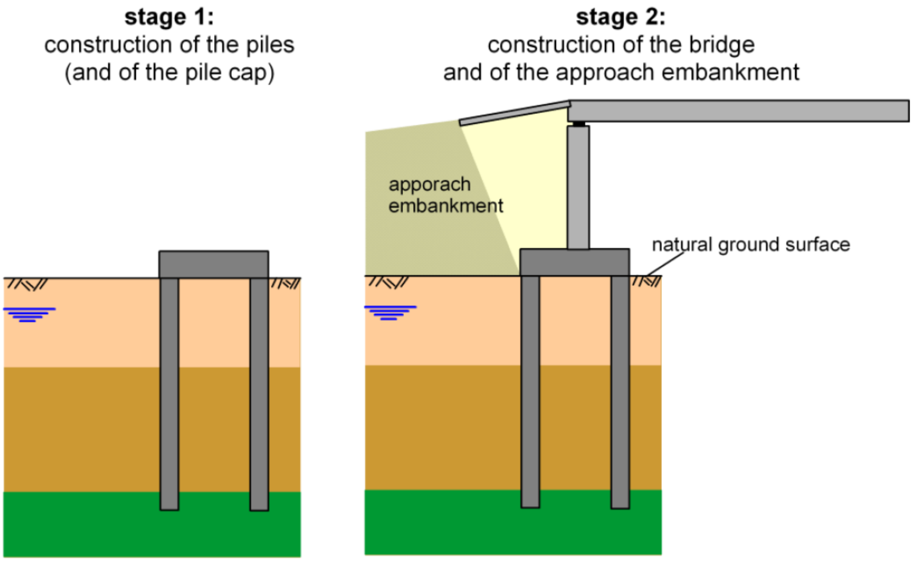

Fig.1 Negative skin friction development on abutment piles of a bridge foundation construction (Kouretzis, 2018).

In calculating the amount of negative skin friction, it is necessary to locate the neutral plane position, the level where pile settlement equal settlement of the surrounding ground. For end bearing piles, the neutral plane would be located close to the compressible stratum base (Kouretzis, 2018, Guo, 2013). For friction piles, many methods of estimating the neutral point position.Guo (2013), stated that, the ratio of depth of neutral point to pile embedment depth may be taken as (0.8 to 0.9) (Guo, 2013). Where the strength of soil increased with depth, George Kouretzis found the location of neutral point at mid-point of pile (Kouretzis, 2018).

Kong et al. described a semi-empirical model to calculate the pile group effect coefficient. The unit negative skin friction and pile length subjected to the phenomenon were proportional to the degree of consolidation. The neutral plane position was also influenced by the stiffness of the end bearing soil (Kong et al., 2013).

Abhijit Saha studied influence of negative skin friction on pile and pile group & structures settlement, he found that negative skin friction is dependent on the degree of consolidation and the time factor, there for can be negligible when complete soil consolidated. Using of concrete piles combined with slab and beams was employed to treat the negative skin friction on piles in soft soil (Abhijit Saha 2015).

2. Finite element analysis

The basic idea in the finite element methods is to get the solution of a complicated problem by replacing it by a simpler one. Accordingly, an approximate solution rather than an exact one is gained. The existing mathematical tool would not be sufficient to get exact solutions of most of practical problems. Thus, in absence of any other convenient methods to get even approximate solutions of given problems, the finite element method has favored (Rao, 2011).

In this analysis, the 3D PLAXIS finite element method software has been used for analysis. PLAXIS is a commercial finite element software designed for solving geotechnical engineering problems such as groundwater flow, stability and deformation. It utilizes advanced constitutive laws to express the complicated behavior of soils (Brinkgreve, 2002). PLAXIS-3D automatically imposes the boundary conditions on the model geometry. The pile material was defined as an isotropic linear elastic material and Mohr-Coulomb's model was utilized to represent soil materials. Higher order triangular element is chosen for pile and soil clusters (15 node), with model dimension is (10 m *10 m).

3. Equations

Three sites in Basrah province (Umm Qasr Port, Khor Al-Zubair, and Shatt Al-Arab Hotel) are selected to perform the study. The adopted soil properties are listed in Tables 1, 2, and 3. Pile properties are listed in Table 4.

Table 1 - Soil properties at Umm Qasr Port (Fugro Middle East, 2017).

Material	Fill	Medium stiff 1	Medium stiff 2	Dense/very dense sand
Depth of layer (m)	3 – 0	0 – -7.5	-7.5 – -14.5	-14.5 – -20
Drainage type	Drained	Drained	Drained	Drained
Unit weight, γ, γ_{sat} (kN/m^3)	18, 20.3	16, 18	16, 18	18.6, 20.4
Initial void ratio, e_{init}	0.5	0.85	0.85	0.4
Stiffness modulus, E (MPa)	48	3.5	2.5	57.6
Effective cohesion, c'(kPa)	1	3	3	1
Effective friction angle, $\phi'(^0)$	36	27	31	40
Dilatancy angle, $\psi(^0)$	6	0	1	10
Permeability, k (m/day)	4.32	0.00086	0.00086	4.32
Poissons ratio, v	0.27	0.4	0.4	0.3

Table 2 - Soil properties at Khor Al-Zubair site (Petrolinvest, 2015)

Material	Fill	Loose silty sand	Medium stiff clay	Very stiff clay	Very dense sand
Depth of layer (m)	3 – 0	0 – -1	-1 – -10	-10 – -17	-17 – -25
Drainage type	Drained	Drained	Drained	Drained	Drained
Unit weight, γ- γ_{sat} (kN/m^3)	18-20.3	16.5-20	15.6-19.4	15.6-19.4	19.4-21.5
Initial void ratio, e_{init}	0.5		0.61	0.61	
Stiffness modulus, E (MPa)	48	11.7	30	62.7	60
Effective cohesion, c'(kPa)	1	1	5	14.7	1
Effective friction angle, $\phi'(^0)$	36	31.8	23	20	40
Dilatancy angle, $\psi(^0)$	6	2	0	0	10
Permeability, k (m/day)	4.32	1	0.001	0.001	4.32
Poissons ratio, v	0.27	0.20	0.30	0.24	0.30

Table 3 - Soil properties at Shatt Al-Arab Hotel (The University of Basrah, Engineering Consulting Bureau, 2012).

Material	Fill	Very stiff slit	Medium stiff slit	M. stiff slit	D. / V.D sand
Thickness (m)	3 – 0	0 – -1.5	-1.5 – -22	-22 – -25	-25 – -30
Drainage type	Drained	Drained	Drained	Drained	Drained
Unit weight, γ, γ_{sat} (kN/m^3)	18, 20.3	15.9, 18.9	14.7, 19.3	15.7,19	19.9, 22.7
Initial void ratio, e_{init}			0.89		
Stiffness modulus, E (MPa)	48	12.8	4.4	6.8	60
Effective cohesion, c'(kPa)	1	12	2.8	5	1
Effective friction angle, $\phi'(^0)$	36	24.5	26	24	40
Dilatancy angle, $\psi(^0)$	6	0	0	0	10
Permeability, k (m/day)	4.32	0.002	0.002	0.002	4.32
Poissons ratio, v	0.27	0.3	0.34	0.34	0.27

Table 4 - Pile properties.

Site	Section dimensions (m)	Tip penetration below ground surface (m)	E (MPa)	ν
Umm-Qasr Port	0.285 x 0.285	16	29700	0.2
Khor Al-Zubair	0.285 x 0.285	11.5	29700	0.2
Shatt Al-Arab Hotel	0.285 x 0.285	26.5	29700	0.2

Table 5 - Interface strength (R_{inter}) and water table level

Site	Interface strength, R_{inter}					Water table level
Umm-Qasr Port	Fill	Medium stiff 1	Medium stiff 2	Dense/very dense sand		3.2 m
	0.7	0.7	0.7	0.7		
Khor Al-Zubair	Fill	Loose silty sand	Medium stiff clay	Very stiff clay	Very dense sand	3.5 m
	0.64	0.65	0.81	0.85	0.66	
Shatt Al-Arab Hotel	Fill	Very stiff slit	Medium stiff slit	M. stiff slit	D. / V.D sand	3.0 m
	0.64	0.82	0.67	0.82	0.66	

4. Analysis and results

A (3 x 3) square group with a pile spacing of (3B) in both directions is adopted. The group configurations are illustrated in Fig. 2.

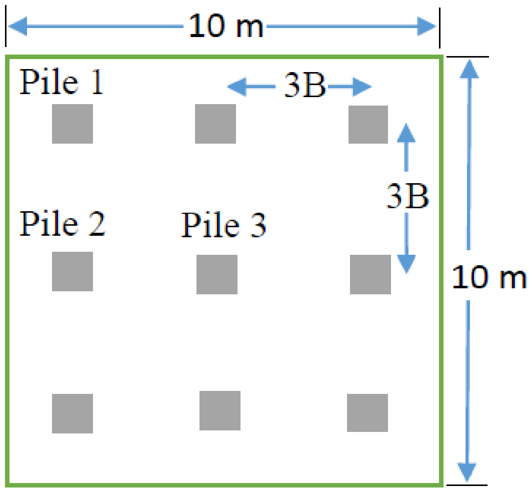

Fig. 2 The adopted pile group configurations.

4.1. Group Effect

The variations of dragload with depth for single (0.285 m x 0.285 m) driven pile are compared to pile individuals' within the group at the different sites, as shown in Fig. 3, 4, and 5.

It should be mentioned that, the group of driven piles with a spacing of (3B) at Khor Al-Zubair was numerically failed and a pile group with a spacing of (4B) is analyzed for the comparison purposes.

The depths of neutral points increase in pile groups (all pile) compared to single piles' because interface between piles in group. The following prcentage increase are predicted (15%) at Umm Qasr Port; (35%) at Khor Al-Zubair; (16%) at Shatt Al-Arab Hotel. The results are summarized in Table 6.

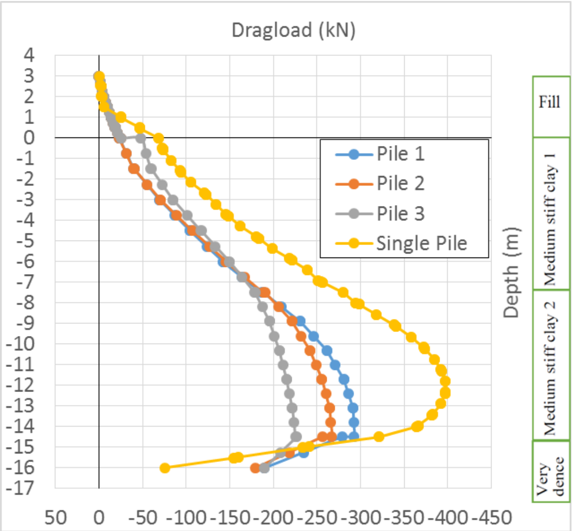

Fig. 3 Dragload vs. depth for single pile and piles within the group at Umm Qasr Port

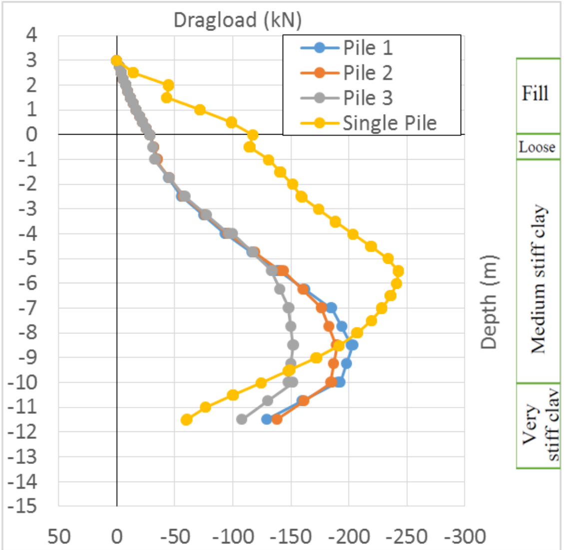

Fig. 4 Dragload vs. depth for single pile and piles within a group at (4B) spacing at Khor Al-Zubair.

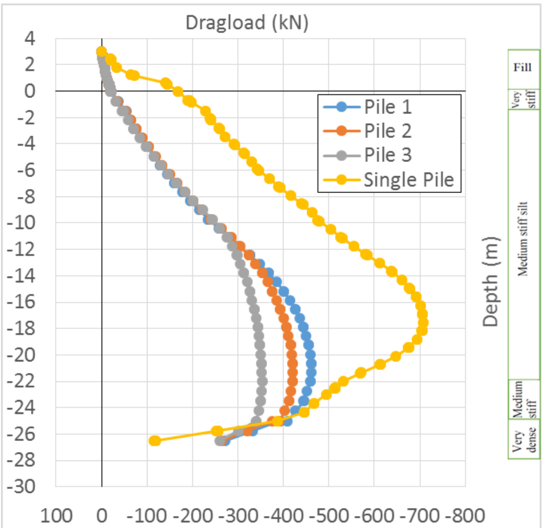

Fig. 5 Dragload vs. depth for single pile and piles within the group at Shatt Al-Arab Hotel.

Table 6 - Comparison of dragloads between single piles and pileswithin the group.

Site	Dragload (kN)			
	Single pile	Corner	Edge	Central
Umm Qasr Port	397	292	267	226
Khor Al-Zubair	243	203	189	152
Shatt Al-Arab Hotel	708	461	421	353

The dragload on pile individuals within the group is less than that on the single pile. The reduction depends on the pile location within the group. Since the central pile is affected by the overlapping stress zones from four directions, it is subjected to the minimum dragload. The corner pile is subjected to the maximum dragload because it is affected by only two interacted adjacent stress zones.

4.2. Effect of Pile Spacing

The effects of varying pile spacing on dragloads regarding corner, edge, and central piles are demonstrated in Fig. 6 to 14.

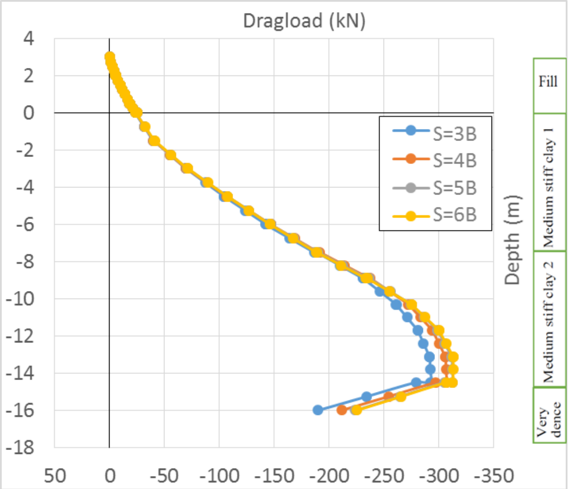

Fig. 6 The effect of spacing on the corner driven pile dragload at Umm Qasr Port.

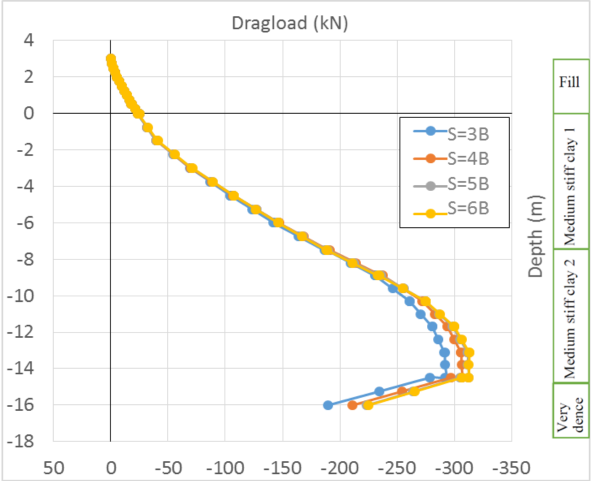

Fig. 7 The effect of spacing on the edge driven pile dragload at Umm Qasr Port.

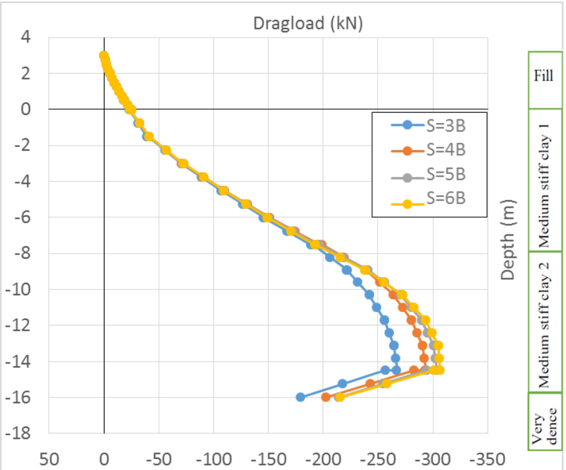

Fig. 8 The effect of spacing on the central driven pile dragload at Umm Qasr Port.

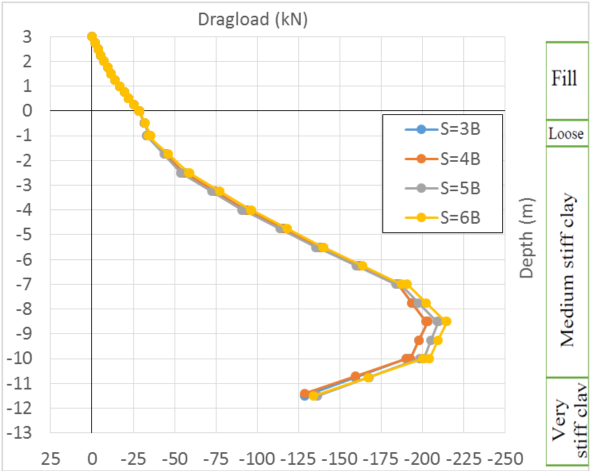

Fig. 9 The effect of spacing on the corner driven pile dragload at Khor Al-Zubair site.

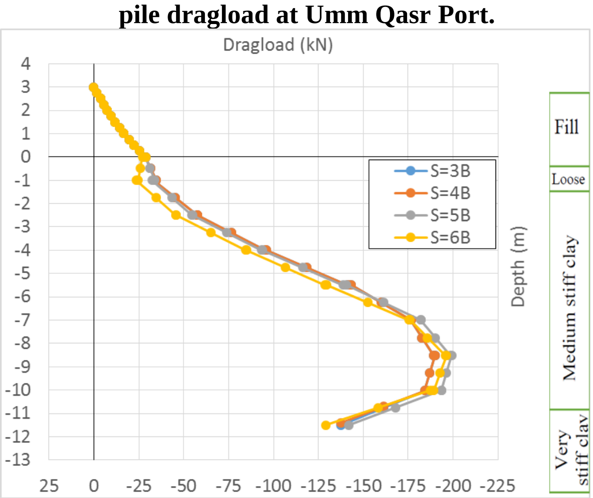

Fig. 10 The effect of spacing on the edge driven pile dragload at Khor Al-Zubair site

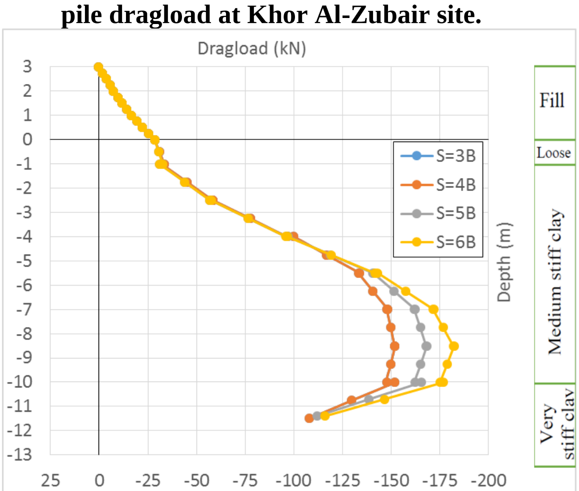

Fig. 11 The effect of spacing on the central driven pile dragload at Khor Al-Zubair site.

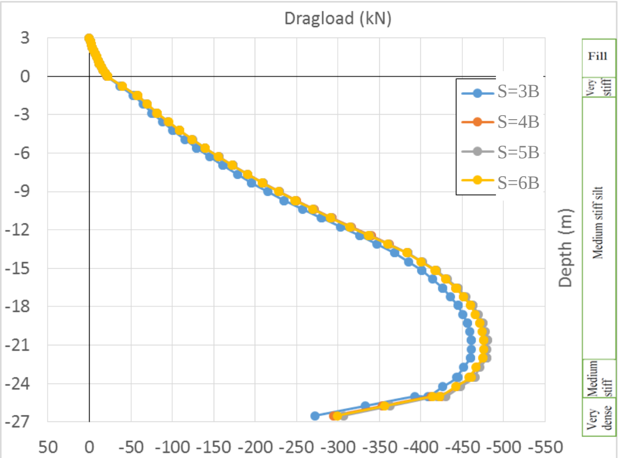

Fig. 12 The effect of spacing on the corner driven pile dragload at Shatt Al-Arab Hotel.

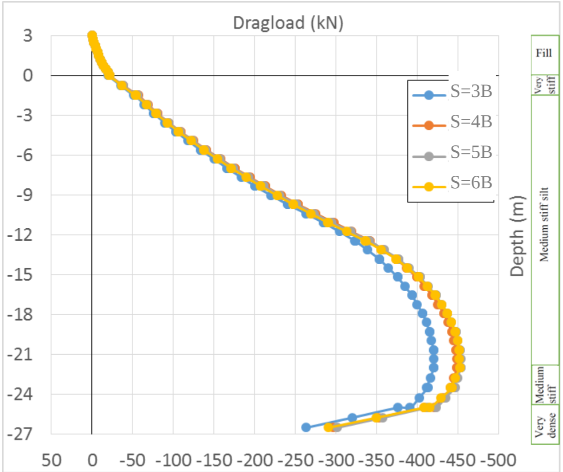

Fig. 13 The effect of spacing on the edge driven pile dragload at Shatt Al-Arab Hotel.

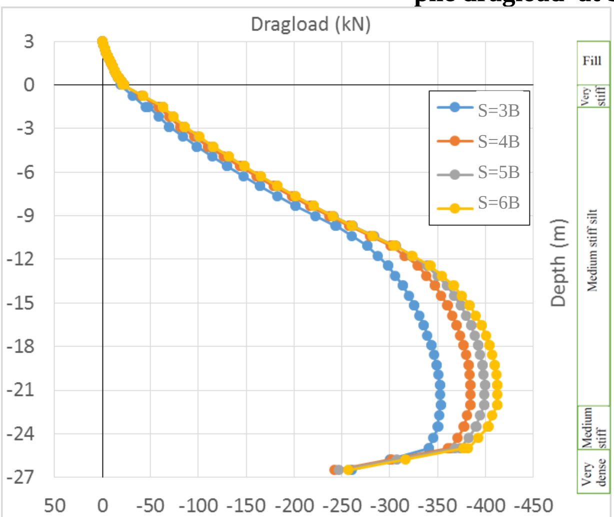

Fig. 14 The effect of spacing on the central driven pile dragload at Shatt Al-Arab Hotel.

The results are summarized in Table 7. Appart from pile location, it is realized that the maximum dragload is proportional to the spacing among.

Table 7 - The maximum dragload on piles within the group at different sites.

Site	Pile location	Maximum dragload (kN)							
		S=3B	Relative to single pile	S=4B	Relative to single pile	S=5B	Relative to single pile	S=6B	Relative to single pile
Umm Qasr Port	Corner pile	300	76%	306	77%	312	79%	313	79%
	Edge pile	292	74%	306	77%	312	79%	312	79%
	Central pile	267	67%	292	74%	305	77%	306	77%
Khor Al-Zubair	Corner pile	-	-	203	84%	209	86%	215	88%
	Edge pile	-	-	190	78%	199	82%	199	82%
	Central pile	-	-	152	63%	168	69%	183	75%

Shatt Al-Arab Hotel	Corner pile	461	65%	472	67%	480	68%	480	68%
	Edge pile	421	59%	449	63%	452	64%	452	64%
	Central pile	353	50%	384	54%	399	56%	412	58%

5. Conclusions

1. The dragloads on the individual piles within the group is less than their counterparts for single piles, due to the piles' stress zones interaction.
2. The depths of neutral points increase in pile groups (all pile) compared to single piles' because interface between piles in-group.
3. The reduction of dragloads depends on pile location within the group. A reduction of (50%) is realized for a driven centeral pile in some locations.
4. The dragload on the pile group is proportional to pile spacing.

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