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Finite Element Analyses of Laterally Loaded Pile Groups in Um Qaser Port

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Abstract—The finite element method, along with an elastoplastic constitutive model, is used to investigate the response of laterally loaded single pile and pile groups in sand. Also, a real practical problem of an on-shore container yard in Um Qaser Port-Basra province is solved. The pile and surrounding soil are modeled by three-dimensional brick elements. The pile is modeled as a deformable body with linear elastic material properties, while the soil is modeled as an elasto-plastic Mohr-Columb continuum material. The effect of pile-soil-pile interaction (group action) is investigated by studying the effect of pile spacing on the behavior of two group configurations; namely (3×1) row and (2×2) square groups. The lateral pressure distributions and the p-y curves are obtained and the p-multipliers are calculated for all piles. For the (3×1) configuration, it is found that the p-multipliers of the leading piles are greater than their counterparts of the trailing and middle piles. Their values are around one, for the leading piles for all spacing values, and nearly equal for the other two. For the (2×2) square configuration, p-multipliers are greater for the leading piles than the trailing piles up to a spacing of, approximately, five times pile diameter. They approach unity at a spacing of six times pile diameter. The group efficiency is increased with pile spacing and approaches (100%) at a spacing of seven times pile diameter for the two group configurations.

Index Terms—: Finite element, Laterally loaded pile groups, P-multipliers, p-y curves

1.INTRODUCTION

The behavior of piles subjected to lateral loads is governed by the interaction between the pile and the soil. Pile properties (including pile stiffness and geometry), soil stress-strain behavior (including stiffness, shear strength, and volume change characteristics), and pile/soil interface properties play important roles in the response of piles. In addition to that, the response may also be affected by the interaction between individual piles. Individual piles in group may behave as isolated units if pile spacing is large enough or may interact with each other significantly if pile spacing is small. Apparently, as closely spaced pile groups move laterally, the failure zone for individual piles overlap as shown in Figure (1). The tendency of a pile in a trailing row is to exhibit less lateral resistance because of the pile in front of it is commonly referred to as "shadowing".

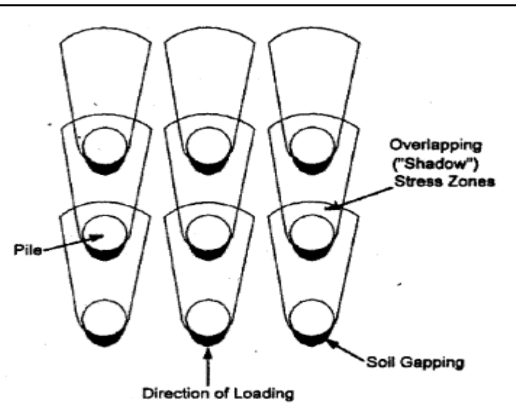

Fig. 1. Schematic drawing illustrating reduction in load capacity in pile groupdue to overlapping of failure zone and gap formation behind piles [2].

This shadowing effect becomes less significant as the spacing between piles increase and is relatively unimportant for spacing greater than about six pile diameter center-to-center based on model tests [2].

In this study, the finite element method is utilized to analyze the behavior of single piles and pile groups, embedded into sandy deposits, and subjected to static lateral loads. The objectives of this study are to investigate the following:

1- The effects of pile spacing (2D,3D,4D,5D,6D,7D), for different group configurations [(1×3) and (2×2)], on the p-multiplier values of the piles in the group and group efficiencies.
2- The interface between soil and pile.
3- The nonlinear soil behavior, adopting Mohr-Coulomb yield criterion.

2. ADOPTED STRATEGY

A three-dimensional finite element mesh is used to discretize the soil domain around the pile diameter segment. The pile is modeled as a deformable body with linear elastic material properties, while the soil is modeled as an elasto-plasticMohr-Coulomb continuum material [7]. Due to the geometric symmetry, all analyses are performed on one-half of the model to reduce the time of computations. Theplane of symmetry is assumed to be supported by rollers which moves in the vertical plane.This plane is parallel to the direction of the applied horizontal load.Restrainingeffects are considered in the direction perpendicular to the symmetric plane and for the sides and base of the soil mass. In order to reduce the effects of boundaries on the results, soil boundaries should be taken at a distance range of (6-18) times pile diameter from outer pile edge [8]. In this work, the width or diameter of the soil mass is taken as (30D) for the single pile, in which, (D) is the pile diameter; and equals [17D + (n-1)S] for the pile groups,in which, (S) is pile spacing (center to center) and, (n) is the number of piles in that direction. The thickness of soil mass is (L+7.5D), in which, (L) is the pile length. A relatively fine mesh is used near the pile-soil interface, becomes coarser farther from the

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pile.The 20-node quadratic brick element, with reduced integrationis used to discretize both the pile and soil medium.

3. THE INTERFACE MODEL

For the pile-soil interaction, a contact algorithm is used to simulate the physics of the penetration, when the pile touches and displaces the soil, to allow for contact stresses to be transmitted across the soil and pile surfaces during the interaction. The soil and pile contact each through an interface model. The interface between the pile and the soil was simulated by using penalty-type interface. This type of interface uses a stiffness (penalty) method that permits some relative motion of the surfaces (an" elastic slip") when they should be sticking. While the surfaces are sticking, the magnitude of sliding is limited to this elastic slip. This type of interface is capable of describing the frictional interface (Coulomb type) between the pile surface and the soil in contact.Master/slave formulation is used to form the contact surfaces. The soil elements at the soil-pile interface were modeled at the slave surface, while pile elements at the pile-soil interface were modeled as the master surface with the condition that the slave surface must not penetrate each master surface.

3.1 CONTACT MODEL

The contact problem between pile and soil is highly nonlinear [5]. The elastic Coulomb friction model was adopted as the contact constructive model where friction coefficient (μ) and ultimate friction resistance (τ_{max})were used to reflect the friction activity between the two surfaces. The relationship between the shear stress, slip displacement and normal stress in the contact surface is shown in the Figure (2). The relationship between them is

$$\begin{cases} \tau = k\omega & \omega \leq \omega_s \\ \tau = \mu P_n & \omega \geq \omega_s \end{cases}$$

Where (μ) is the friction coefficient between contact surface, (τ) is the shear stress, (τ_{max}) is the user defined ultimate friction resistance, (P_n) is the normal stress, (k) is the shear stiffness, (ω_s) is the elastic ultimate slip displacement and (ω) is the slip displacement in the contact surface.

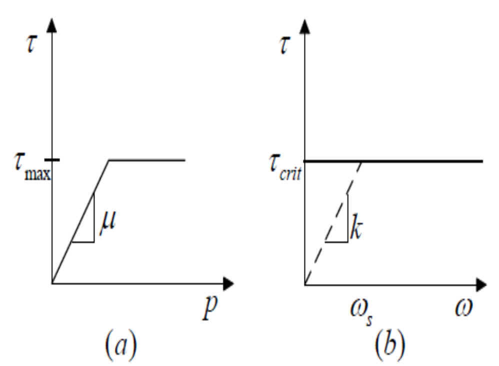

Fig. 2. Elastic Coulomb friction model

The solid line in the Figure (2b) represent the ideal friction activity, where shear motion keeps zero until the drag force in the contact surface reaches the critical shear stress (τ_{crit}=min(μP_n, τ_{max}). When slip displacement is less than (ω_s) this small-amount motion is allowed. The pile-soil shear stress is relevant to the friction coefficient, normal stress and the user defined ultimate friction resistance.

3.2 FRICTIONAL PARAMETERS

Surface contact requires the input of various parameters that govern the behavior of the two bodies in contact. Interaction tangential to the surface is governed by the value of coefficient(μ). Determining an appropriate value of (μ) for the interaction of pile and soil is more difficult because the different materials of piles and soil types and method of construction. Table (1) can be used as a guide.

TABLE (1)
Values of the angle of pile to soil friction for various interface conditions [9]

Pile/soil interface Condition	Angle of pile/soil friction,δ
Smooth (coated) steel/sand	$0.5\bar{\varphi}$ to $0.7\bar{\varphi}$
Rough (corrugated) steel/sand	$0.7\bar{\varphi}$ to $0.9\bar{\varphi}$
Precast concrete/sand	$0.8\bar{\varphi}$ to $1.0\bar{\varphi}$
Cast-in-place concrete/sand	$1.0\bar{\varphi}$
Timber/sand	$0.8\bar{\varphi}$ to $0.9\bar{\varphi}$

4. CASE STUDIES

The case studies are selected from a project at Um Qaser port, south of Basra province. A container yard is to be extended by utilizing steel pipe piles. The properties of piles and in-situ soil profile are listed in Tables (2) and (3), respectively [6]. It should be mentioned that, the values of elastic parameters are assigned by the researchers based on soil consistency and depending on selected references [3,4].

TABLE 2
Steel pipe pile parameters

Properties	Values
Total pile length, m	18
Outer diameter, m	0.9144
Wall thickness, m	0.0127
Modulus of elasticity (Ep), kN/m²	2.1×108
Poisson's ratio (υ)	0.3
Unit mass (ρ), kg/m³	7800

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TABLE 3
Soil properties for Um Qaser Port [6]

Depth (m)	Type of Sandy Soil	N_{corr}	γ (kN/m^3)	φ* (degree)	ψ (degree)	υ	Es (Mpa)
0.0 – 3.0	Medium dense (above W.T)	34	20.1	33	20	0.30	40
3.0 – 4.5	Loose (above W.T)	7	18.3	28	20	0.25	15
4.5 – 6.0	Loose (below W.T)	10	8.5	31	20	0.25	20
6.0 – 8.68	Dense (below W.T)	50	9.61	37	25	0.33	80
8.68 – 11.36	Medium dense (below W.T)	26	10.2	32	20	0.30	35
11.36 – 14.0	Dense (below W.T)	50	9.61	35	25	0.33	80
14.0 – 23.5	Medium dense (below W.T)	15	10.2	33	20	0.30	30
23.5 – 26	Dense (below W.T)	50	9.61	35	25	0.33	80

* $\delta = 0.6\,\varphi$

4.1 Laterally Loaded Single Piles

Single piles are analyzed with different head conditions; namely free-head (without cap) and fixed-head (with cap). The cap dimensions are (5m×5m×1m) and is located above ground to eliminate the action of pile-raft system. The properties of cap concrete are (E=2.5×104MPa, υ = 0.16, γ = 24 kN/m3). The finite element meshes for the two cases are shown in Figures (3) and (4).

It is observed from the load-deflection responses of Figure (5) that, the load required to produce a specified lateral displacement is larger for a fixed-head condition than its counterpart for a free-head condition; [(128 kN) and (201 kN)] compared to [(102 kN) and (144 kN)] for a pile head displacement of (6.35 mm) and (12.7 mm), respectively.

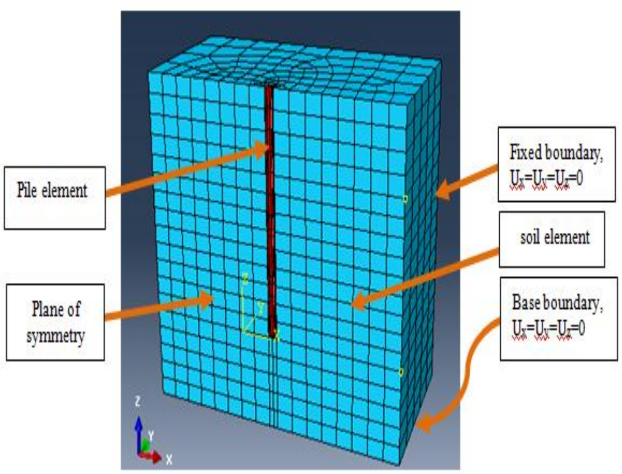

Fig. 3. Three dimensional finite element mesh for a single pile without cap.

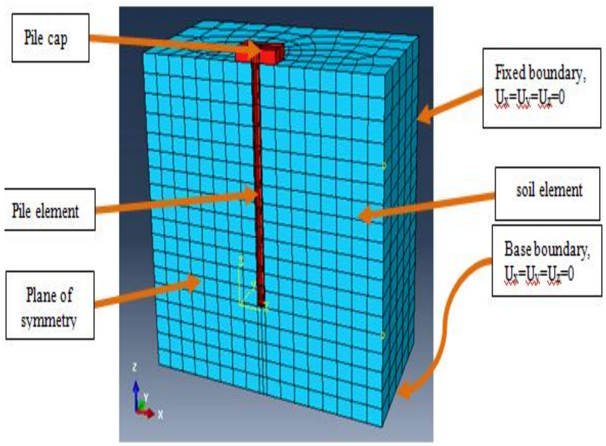

Fig. 4. Three dimensional finite element mesh for a single pile with cap.

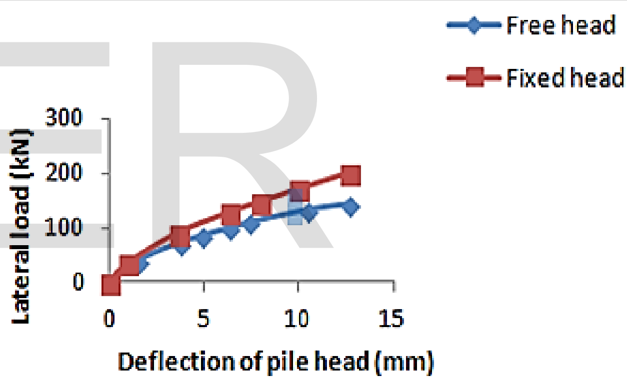

Fig. 5. Load versus deflection of pile head for single piles.

4.2 Pile Groups

The behavior of each pile within the group is compared to the fixed-head single pile response. In order to determine the p-multipliers, the ratio of pile resistance are computed for (6.35 mm, 12.7 mm) pile head displacements at three depths (1.5 m, 3.0 m, 4.5 m) from ground surface. The values of group efficiency are calculated based on the ultimate loads defined by the points of intersections of initial and final tangents to the load-displacement curves. Therefore:

$$Ge = \frac{(H_{ult})_g}{n \times (H_{ult})_s}$$

Where:
Ge: group lateral efficiency
$(H_{ult})_g$: ultimate lateral capacity of the pile group
$(H_{ult})_s$: ultimate lateral capacity of the single pile
n : number of piles in the group

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4.2.1 LATERALLY LOADED (3×1) PILE GROUPS

A row of three piles is analyzed repeatedly for different values of spacing, range from (2D) to (7D). A typical section of the pile group is shown in Figure (6).

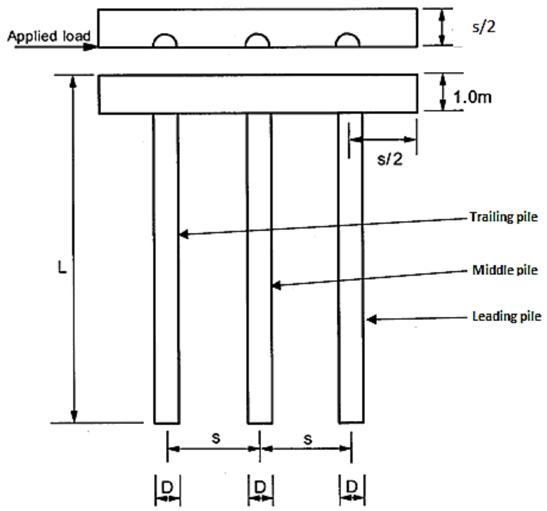

Fig. 6. Typical section for the (3×1) pile group

For the pile spacing (S=2D), Figures (7) and (8), show the horizontal soil pressure along pile length for all piles at maximum deflections of (6.35 mm and 12.7 mm), respectively. The soil pressure against the leading pile and the single pile are almost the same, which means that, the p-multiplier is approximately (1.0). The soil pressures in front of the trailing and middle piles are less than their counterpart for a single pile due to the overlapping shear zones. Therefore the p-multipliers are less than unity.

Figures (9), (10) and (11) show the p-y curves at different depths. The soil resistance against the leading pile is greater than its counterparts for the trailing and middle piles, which are approximately the same.

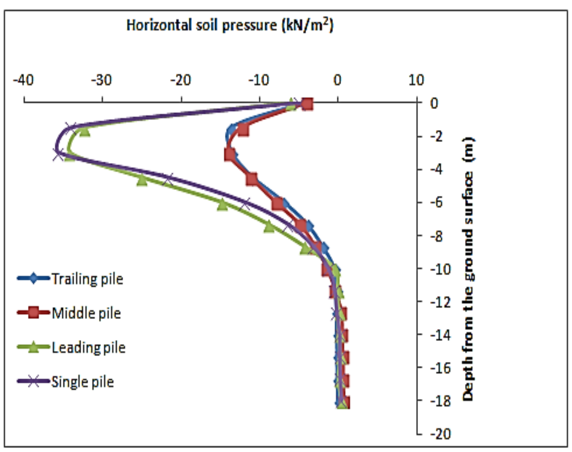

Fig. 7. Horizontal soil pressure [(3×1) group,S=2D, max. displacement = 6.35 mm]

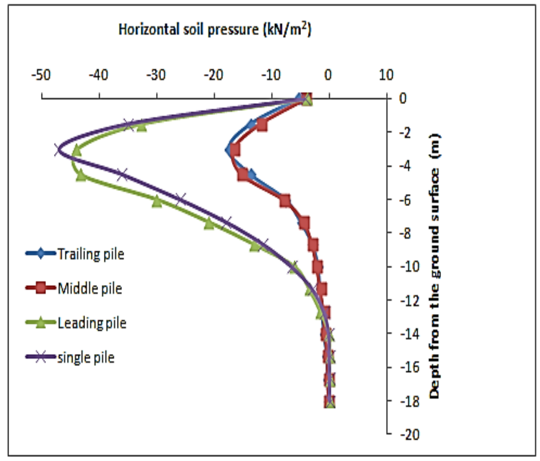

Fig. 8. Horizontal soil pressure [(3×1) group,S=2D, max. displacement = 12.7mm]

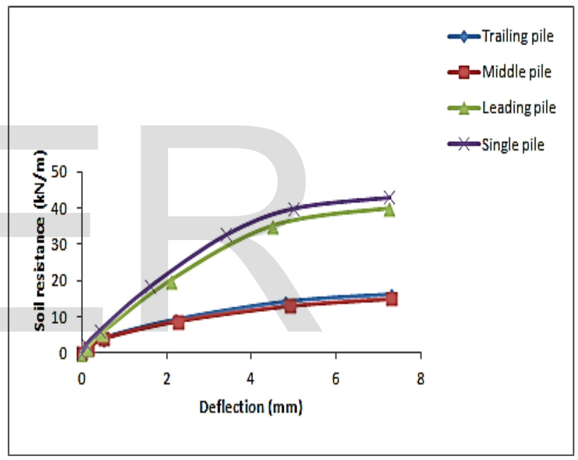

Fig. 9. p-y curves [(3×1) group, S=2D,depth=1.5 m]

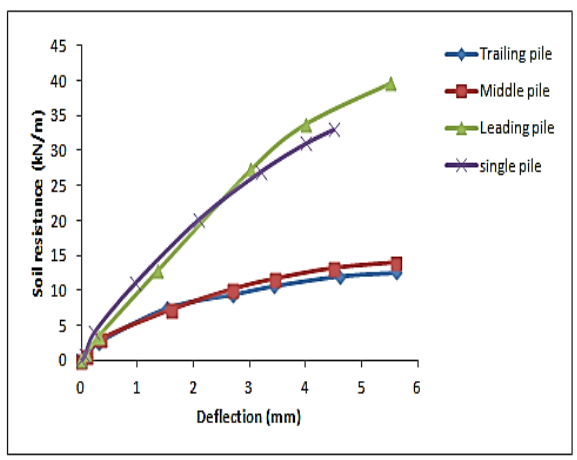

Fig. 10. p-y curves [(3×1) group, S=2D,depth=3 m]

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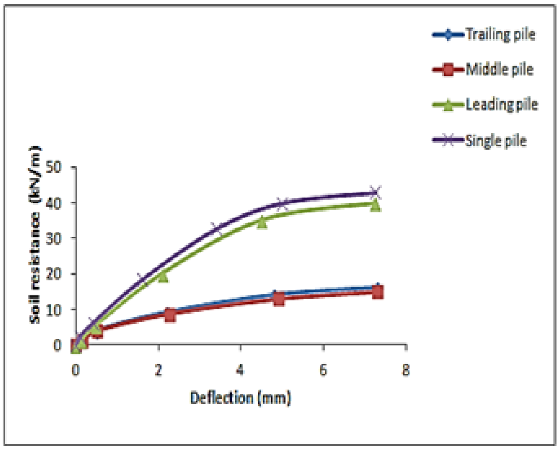

Fig. 11. p-y curves [(3×1) group,S =2D, depth=4.5 m]

Table (4), lists the p-multiplier average values at different pile head displacements. It can be realized that, the average values for trailing and middle piles are decreased with the increase in pile head deflection due to extension of the overlapping zones.

TABLE 4
Average values of p-multipliers for [(3×1) group, maximum deflection =6.35 mm, 12.7mm]

Spacing (S)	P-multiplier (average value)					
	Trailing pile		Middle pile		Leading pile	
	Maximum deflection =6.35mm	Maximum deflection =12.7mm	Maximum deflection =6.35mm	Maximum deflection =12.7mm	Maximum deflection =6.35mm	Maximum deflection =12.7mm
S=2D	0.43	0.38	0.42	0.37	1.02	1.02
S=3D	0.68	0.67	0.68	0.67	1.04	1.01
S=4D	0.74	0.7	0.74	0.71	1.02	1.01
S=5D	0.84	0.82	0.83	0.80	1.05	1.05
S=6D	0.89	0.88	0.92	0.91	1.05	1.01
S=7D	0.98	1.01	0.99	0.97	1.06	1.03

Figure (12) illustrates the prediction method of ultimate load of the fixed head single pile, from the point of intersection of the two tangents to be (632kN). Table (5) lists the ultimate lateral loads and efficiencies of the pile groups at different spacings.

TABLE 5
Theoretical efficiency of the (3x1) pile group at different spacings

Pile Spacing	Ultimate Lateral Load (kN)	Theoretical Efficiency (%)
S=2D	880	46
S=3D	1040	55
S=4D	1290	68
S=5D	1480	78
S=6D	1620	85
S=7D	1860	98

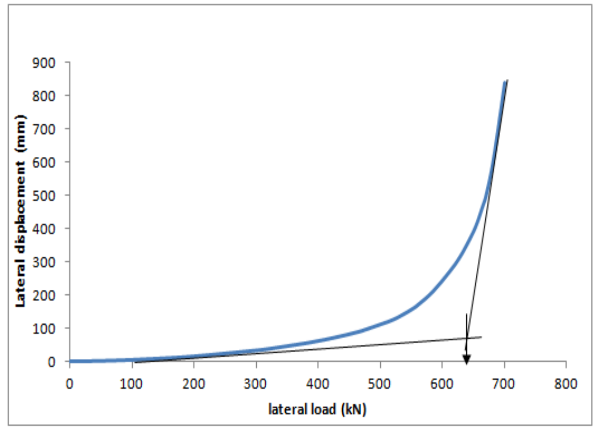

Fig. 12. Load versus deflection for fixed head single pile

4.2.2 Laterally Loaded (2×2) Pile Groups

A square group of four piles is analyzed repeatedly for different values of spacing. A typical section of the pile group is shown in Figure (13).For the pile spacing (S=7D),Figures (14) and (15) show the horizontal soil pressure along pile length for all piles at maximum deflections of (6.35 mm and 12.7 mm), respectively.
Figures (16), (17) and (18), show the p-y curves at various depths. It is noted that the soil resistance for a single pile is greater than the soil resistance for the piles in the group. Table (6) lists the p-multiplier values. Small values of the average p-multiplier are reported due to the shadowing effect.
Table (7) lists the ultimate lateral loads and efficiencies of the pile groups at different spacings.

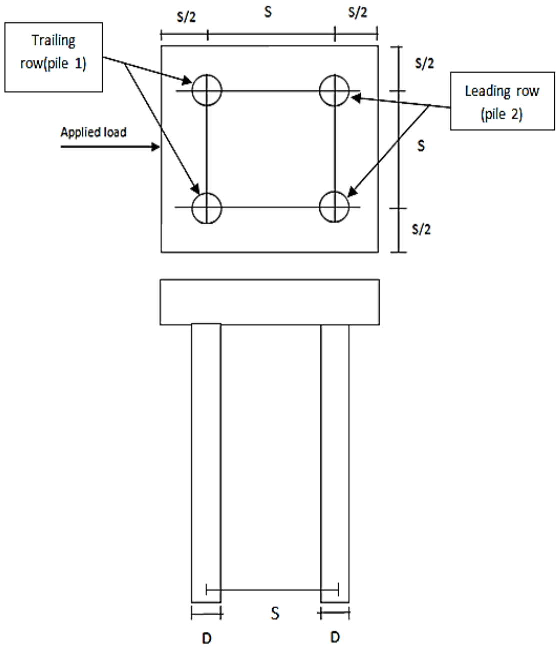

Figure (13) Typical section for the (2×2) pile group

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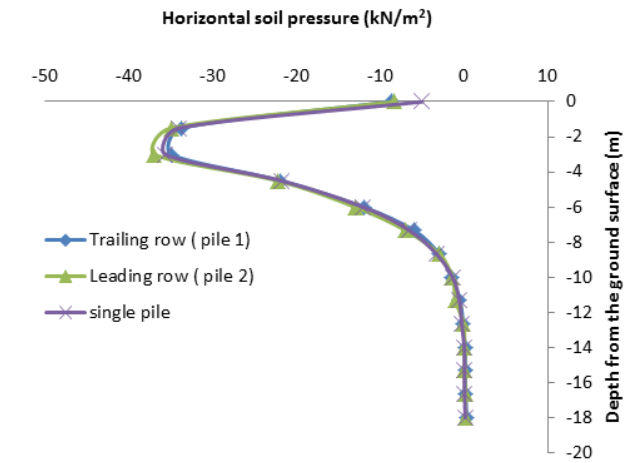

Fig. 14. Horizontal soil pressure [(2×2) group, S=7D, max. displacement = 6.35 mm]

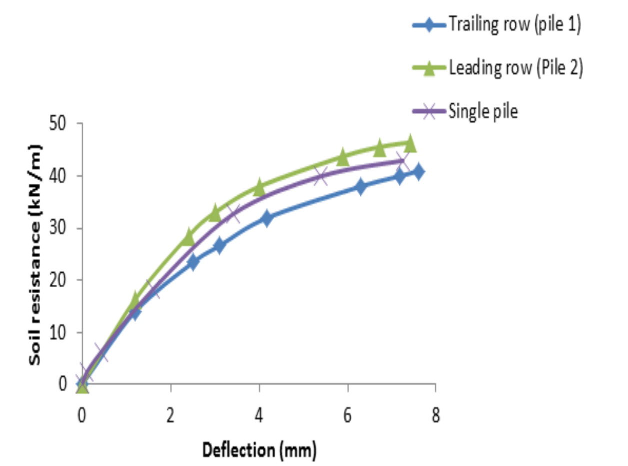

Fig. 17. p-y curves [(2×2) group, S=7D, depth=3.0 m]

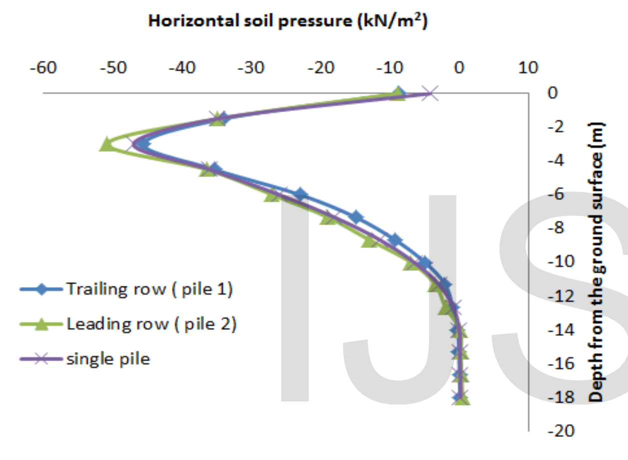

Fig. 15. Horizontal soil pressure [(2×2) group, S=7D, max. displacement = 12.7 mm]

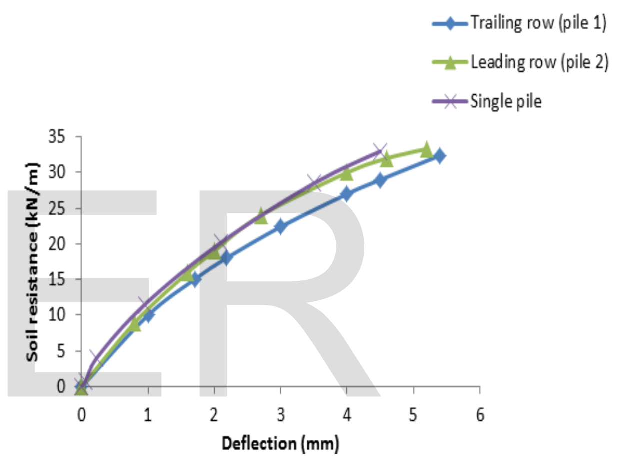

Fig. 18. p-y curves [(2×2) group, S=7D, depth=4.5 m]

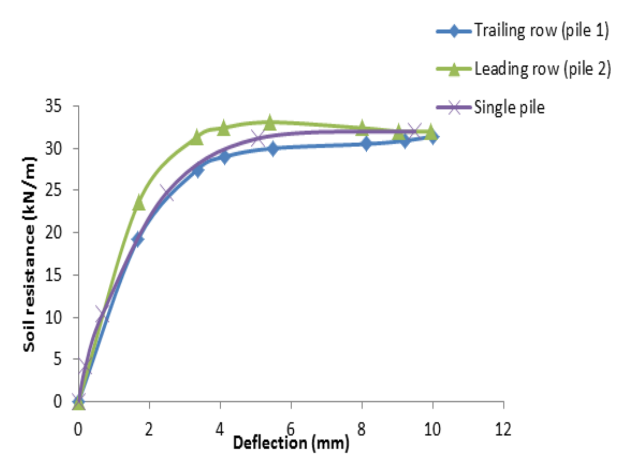

Fig. 16. p-y curves [(2×2) group, S=7D, depth=1.5 m]

TABLE 6

Average values of p-Multipliers for [(2×2) group, maximum deflection =6.35 mm, 12.7mm]

Spacing (S)	P-multiplier (average value)			
	Trailing row (pile 1)		Leading row (pile 2)	
	maximum deflection =6.35mm	maximum deflection =12.7mm	maximum deflection =6.35mm	maximum deflection =12.7mm
S=2D	0.36	0.37	0.81	0.79
S=3D	0.53	0.54	0.82	0.83
S=4D	0.64	0.64	0.86	0.85
S=5D	0.8	0.8	0.86	0.86
S=6D	0.93	0.92	1.01	0.99
S=7D	0.99	0.98	1.04	1.03

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Table (7) lists the ultimate lateral loads and efficiencies of the pile groups at different spacings.

TABLE 7

Theoretical efficiency of the (2x2) pile group at different spacings

Pile Spacing	Ultimate Lateral Load (kN)	Theoretical Efficiency (%)
S=2D	1140	45
S=3D	1440	57
S=4D	1650	65
S=5D	1860	74
S=6D	2100	83
S=7D	2460	97

5. CONCLUSIONS

For the studied soil profile and pile properties in question, the following conclusions can be drawn:

1. The fixed-head single pile exhibits greater lateral resistance than that of free-head.
2. For the (3×1) row pile group;
a- The p-multipliers for the leading piles are greater than their counterparts for the trailing and middle piles, for all spacing values. They are greater than one for the leading piles and nearly equal for the others.
b- The calculated values at a pile head displacement of (12.7 mm) are, in general, less than their counterparts at a displacement of (6.35 mm), for the trailing and middle piles.
3. For the (2×2) square pile group;
a- The p-multipliers for the leading piles are greater than their counterparts for the trailing piles, up to a spacing of, approximately, five times pile diameter. They approach unity at spacing of six times pile diameter.
b- The predicted values at the two head displacement are almost equal.
4. The group efficiency is increased proportionally with pile spacing and approached the full value (1.0) at a spacing of seven times pile diameter for the two pile group configurations.

Refrences

1. Abbas, S.A. (2013), "Finite Element Analysis of Pile Groups Subjected to Lateral Loads", Ph.D. Thesis, University of Basrah, Department of Civil Engineering.
2. Ahn, K. (2003), “Pile-Soil-Pile Interaction in Pile Groups Under Lateral Loading”, Ph.D. Thesis, Graduate College, Illinois Institute of Technology, Chicago, Illinois.
3. Bowles, J.E. (1996), “Foundation Analysis and Design” McGraw-Hill Book Company, Singapore, Fifth Edition.
4. Budhu, M. (2007), “Soil Mechanics and Foundations”, John Wiley & Sons Inc.
5. Can, H.B., Hao, C., Jing-Song, Z., Cong-Jun, W., Xin, Z. and Guo-Jian, W. (2010),“Nonlinear FEM Analysis of Bearing Capacity and Sedimentation of Single Pile in Multi-Layered Soils”, Nottingham University, International Conference, Civil and Building Engineering.
6. National Center for Construction Laboratories & Researches-Basrah ConstructionLaboratory (2009)," Subsoil Investigation for Two Berths at Um Qaser Port/ Al-Basrah", Report No. 2/1/39, Basrah.
7. Owen, D.R.J., and Hinton, E. (1980), “Finite Element in Plasticity; Theory and Practice”, Pineridge Press, Swansea,U.K.
8. Reese, L.C. and Van Impe, W.F. (2001), "Single Piles and Pile Groups Under Lateral Loading", A.A. Balkema Publishers, 463 pp.
9. Tomlinson, M.J. (1994), "Pile Design and Construction Practice", E & FN Spon, Fourth Edition, 411pp.