



The Behavior of Pile Group Under Inclined Static Load With Different Angle of Inclination in Sandy Soil

Reyah D. Khurshed*, Jasim M. Abbas

Department of Civil Engineering, College of Engineering, University of Diyala, 32001 Diyala, Iraq

ARTICLE INFO

Article history:

Received 9 March 2021

Accepted 5 May 2021

Keywords:

Inclined loading; Pile foundation; Bearing capacity; Sandy soil

ABSTRACT

Pile is the form of deep foundation some time may be applying as a condition of inclined loading. There are limited experimental studies in existence on the performance of vertical piles exposed to inclined loads. In this paper, a static inclined load with four angles applied load varying (i.e., 0, 15, 30, and 45 degrees) from the horizontal axis of the pile are used to the comparison of behavior for pile group as a three configurations 2x2, 2x3, and 3x2 in sandy soil. The experimental works include a soil tank and several of tools used to achieve the objective of this study. It can be seen that the pile group is influenced by the angle of inclination of applying load, furthermore the results displays that the increase in spacing between pile cause decrease lateral movement under the similar angle of inclination of load applied. The performing of each models better-quality using $S/D=7$, this is attributable to reduce the interface of pile-soil-pile for the group. Groups 2x3 showing resistance and have bearing capacity to the lateral displacement from other groups about 40% for group 2x2 and about 50% for group 3x2.

1. Introduction

Pile's foundations designed for retaining walls, bridges and marine constructions are generally expose to combined action of vertical and horizontal loads. With the absence of reliable practicable methods, in existing applications the pile condition under vertical load is often investigated individually from the pile condition exposed to horizontal load. Nevertheless, for a reasonable design of the piles, the existence of inclined loads should be taken into account in the computations, such as subjected to the loads applied by moving vehicles, ship impacts, and waves. Testing piles under inclined load is significantly more difficult than that under a single load. There are very few

experimental investigations accessible on the performance of piles under inclined loading with the angle of pile take into consideration the combined effect of vertical and horizontal load components in the design of inclined loading [1].

Several of studies have been carried out to understand the performance of piles group under inclined static loading in cohesionless soil under different conditions. An experimental investigation to study the horizontal displacements of single flexible instrumented model piles jacked into homogeneous sand and clay and exposed to inclined loads was studied and observed that the load inclination has an applied ultimate load was the important effect on the effective depth ratios and noticed that the

* Corresponding author.

E-mail address: eng_grad_civil032@uodiyala.edu.iq

DOI: 10.24237/djes.2021.14205

bending moment change with depth in a flexible pile exposed to an inclined load [2]. In 1993 (Meyerhof) studied the performance of a single free-head model flexible vertical and batter pile exposed to inclined loads inside two-layered soil. He suggested that the inclination factors that connect the vertical component of the ultimate inclined loads with the vertical component of the axial load have larger values for the piles with a negative batter than those with positive batter for the similar angle between the load direction and pile axis [3]. And (Meyerhof) also added another investigation in 1994 about the lateral soil stresses, bending moments, pile displacements at the ground surface, and bearing capacity of device vertical single flexible pattern piles in layered sands containing loose sand covering compressed sand under vertical eccentric and central inclined loads [4]. Furthermore, another researcher used the theoretical study to investigate the behavior of piles under different conditions of loading compression and tension forces and for different pile installation vertical and inclined piles. The researcher find the bearing capacity of the piles increase through increasing of load inclination up to the inclination angle (37.5°) which signifies the maximum bearing capacity and then the bearing capacity decreased by increasing load inclination additionally Positive batter pile has a smaller uplift capacity as evaluating with the negative batter pile under the similar state of the pull[5]. Some researcher used model piles to examine the lateral and inclined tension capability of piles and tested each pile in three changed values of angle of inclined tension loads and he was observed that, as the inclination of the load with the horizontal was increasing, the pull-out capability of the pile was discovered increasing [6]. Other researchers were studied the Inclined compressive load [7]. An additional study to the Ultimate Capability of the vertical short pile and Load inclination is various from vertical to the horizontal direction, and he

showed that an inclination of load could decrease the ultimate vertical bearing capability of the short pile as well as lateral capability of a vertical pile [8]. The other researchers have studied the effect of a cross-section of the pile on the lateral behavior with combined loading and found the lateral capacity of the square section was more than that of the circular section [9, 10]. Another analysis approach has been made to study the behavior of a single pile exposed to changing inclined load until failure and he shows the bearing capacity of the vertical pile is a function of the applied load inclination angle [11]. The ABAQUS finite element software is used to show the numerical simulation model to investigate the influence of horizontal component of inclined load on pile group and noticed Inclined load, embedded depth of pile cap, and eccentricity of the column are commonly influenced to improve the force of pile group [12]. Another researcher studied the influence of vertical loads on the pile group to lateral displacement [13].

Therefore, this study includes an experimental program for the case of inclined loading applied on different pile group configurations in sandy soil.

2. Materials used and experimental program

Soil: The soil is sand used collected from Karbala Governorate, in Iraq. The properties of used sand were tabulated in Table 1.

Table1: Sand physical properties

Property	Value
Specific Gravity, G_s	2.67
Angle of Internal Friction(ϕ)	35.5
Cohesion (c) (kN/m^2)	0
Maximum, γ_d (max.) (kN /m^3)	17
Minimum, γ_d (min.) (kN /m^3)	15.3
Initial dry unit weight, γ_d (kN/m^3)	16.5
Relative density D_r	70%

Pile and pile cap: Aluminum hollow piles as a circular cross-section at 16 mm diameter in groups 2x2, 2x3 and 3x2 models as shown in Figure 1. The L/D is equal to 40 in a group where's the space in the direction of loading is

different (i.e., $s/d=3, 5,$ and 7). The thickness of pile cap 6 mm and at the top of piles leaving 50 mm over the ground surface as a freestanding length for the group.

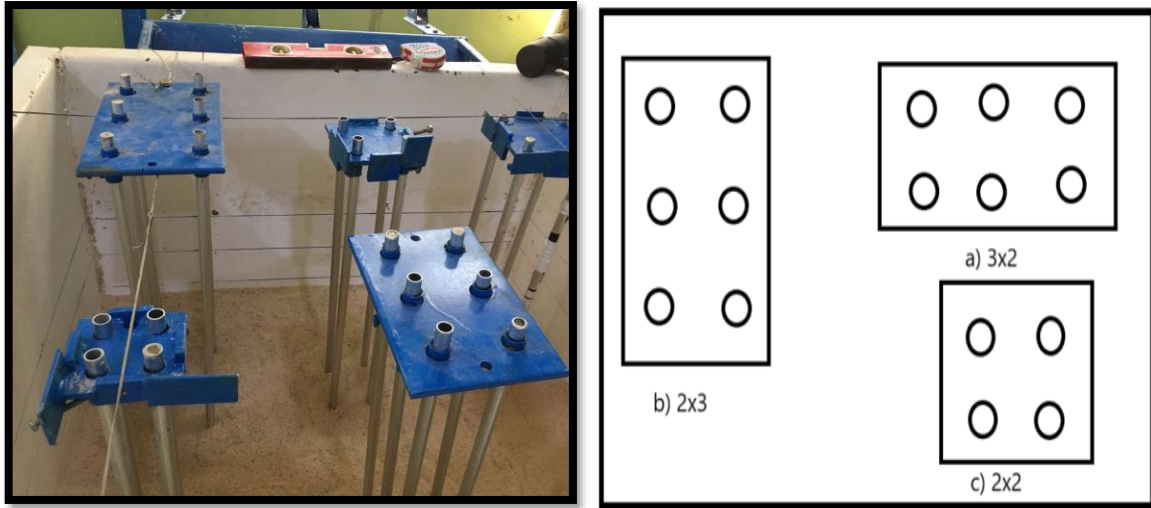


Figure 1. Pile group configuration

Test Setup: The laboratory tests system is used for applying inclined static lateral loading at angles 0, 15, 30 and 45 degrees on pile groups is shown in Fig. 2. In this case, the inclined lateral static loading experiments on model piles group embedded in dry sand in steel testing container of dimensions (1x1x1) m. The piles were installed inside the container, then sandy soil is prepared as layers by insert a plate for the

raining technique machine is designed to achieve a uniform soil layer and the required relative density D_r of 70%, The relative density equal 70% can be gotten by making the height of the fall for sand particle from the raining technique is 1140 mm. The capacity of the static lateral load is taking as the load equivalent to the deflection of 3.2mm (20% diameter of the pile) as recommended by Broom's theory [14].





Figure 2. Inclined static loading device system

After the tank was filled with sand, the pile cap was applied to the inclined lateral load by a flexible wire was connected between the pile cap and load plate as shown in Figure 2. The applied vertical load was transferred to lateral load by using a frictionless pulley. Piles head deflection in-group is measured by using dial gage was fastened to the pile cap to obtain the lateral displacement. And can easily change the angle of inclined load by using two screws in the arm of the device operated for this purpose.

3. Results and discussion

This section discusses the results obtained from the experimental study. The effect of inclination of the angel, the effect of spacing on lateral resistance, and effect of the configuration of piles are discussed in the next subsections.

3.1. Effect of inclination angle

Figures 3 to 5 represent a group of piles 2×2, 2×3, and 3×2 respectively under inclined load at three values of S/D (i.e., 3, 5, and 7) and four angles of inclination (i.e., 0, 15, 30, and 45) to investigate the influence of these angles on the performance of pile groups. The displacement-

load curves recorded for several values of angle show that, the angle 30° has approximately the same behaviour with angle 45° and also it is clear from these figures that the angle 0° represent the critical state. Additionally, the groups 2×3 showing resistance and have bearing capacity against the lateral displacement from other groups about 40% for group 2×2 and about 50% for group 3×2.

This is attributed to the increase in number of lead piles (i.e., the pile lay in the first row) in front of the soil that give the groups more stiffness than others. Furthermore, the stiffness and bearing capacity of the pile groups generally increase with increasing of the angle of inclination (i.e., from 0° to 45°). To analyze this behavior and highlight some distinct aspects of the pile groups response to the inclined loading, the inclined load would be divided into two components, axial and horizontal component. The axial component of inclination load is working as the vertical load on the pile groups, and causing the increase of the stiffness of the pile and decreasing the lateral deflection in the soil in front of the pile and this would be seen when the angel closes to the vertical axis (i.e., 45° degree).

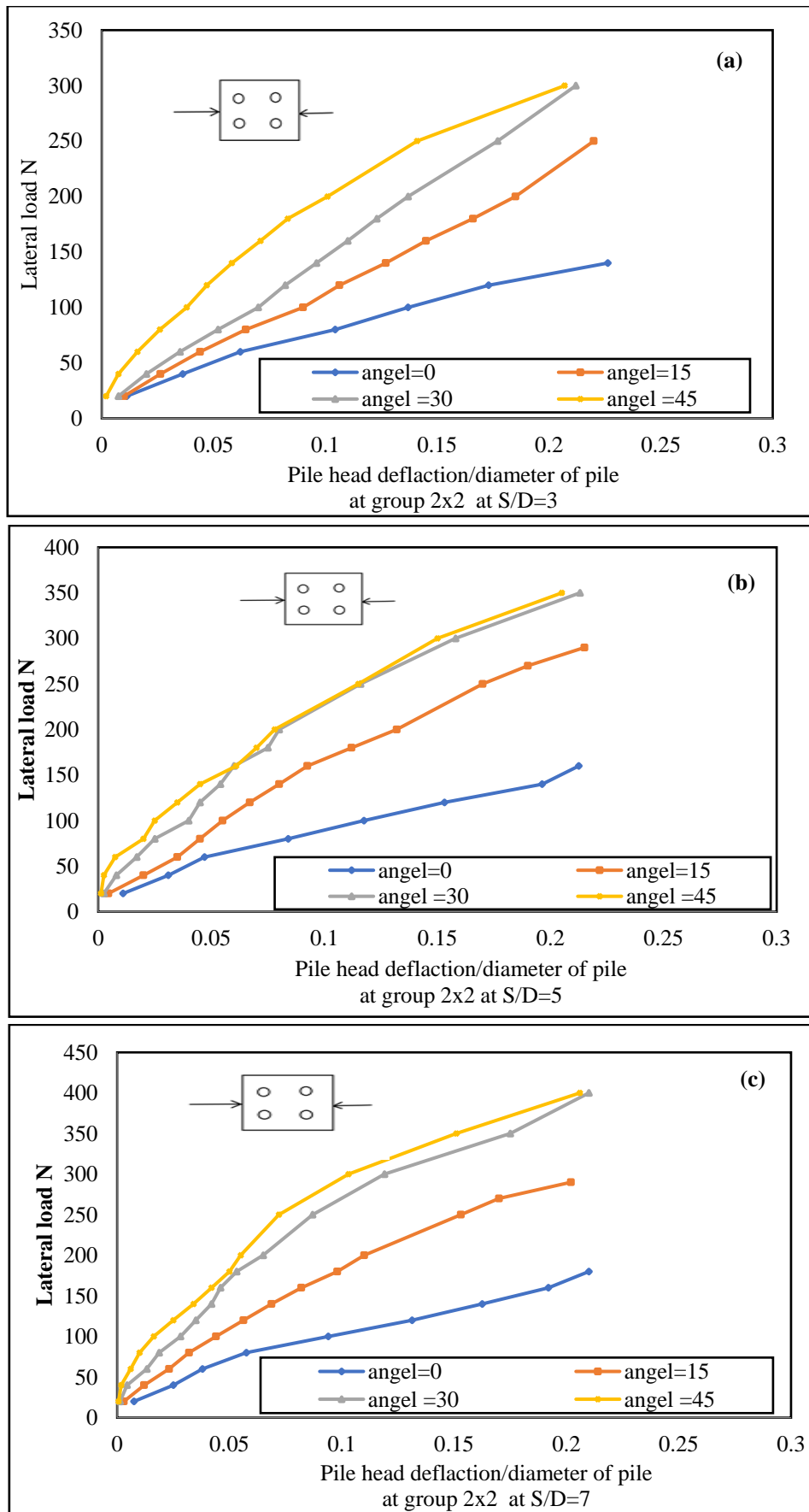


Figure 3. The load-displacement relationship of piled groups model 2x2 under inclined static load with S/D (3,5 and 7), a) S/D =3, b) S/D = 5 and c) S/D=7 with different angle of inclination

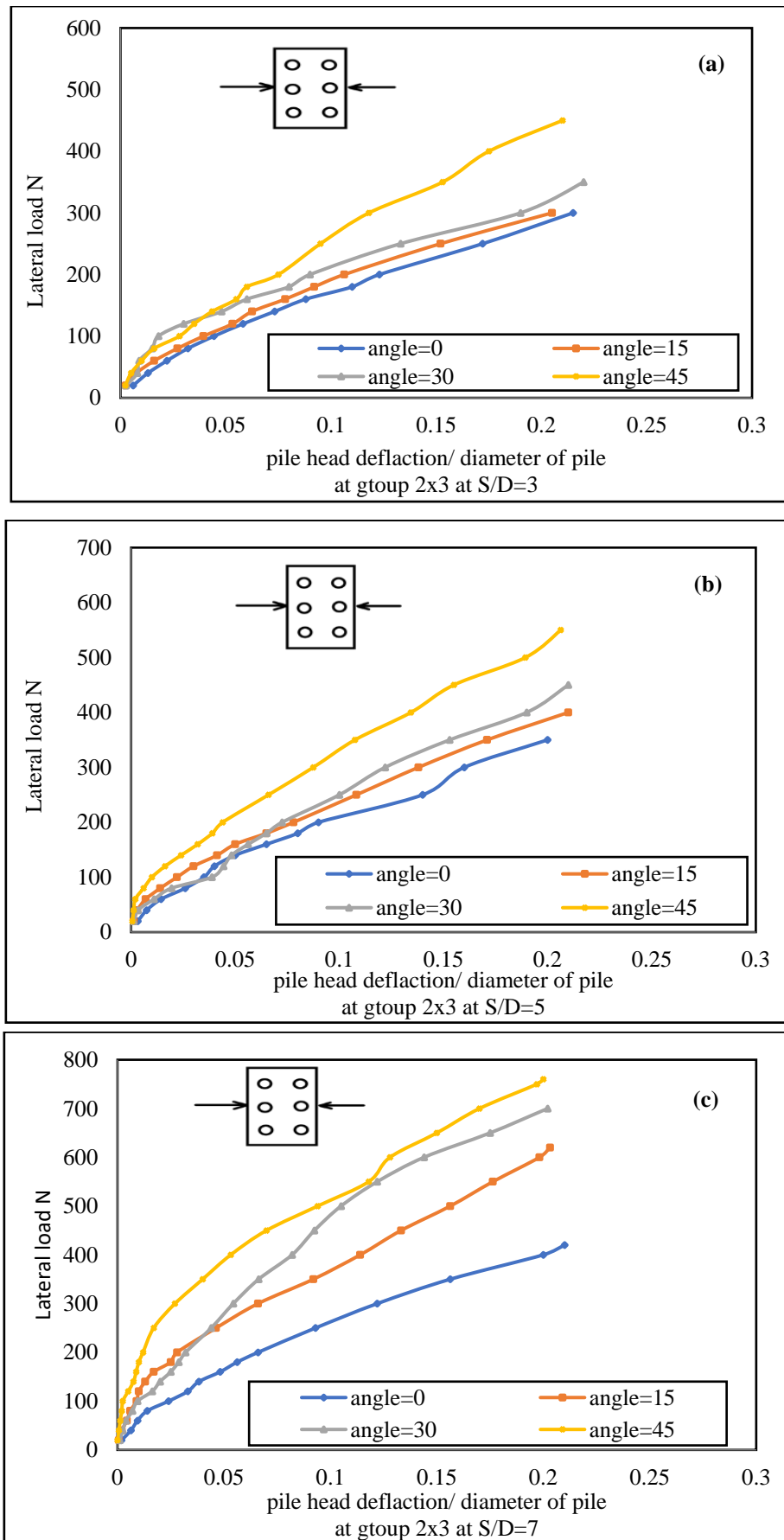


Figure 4. The load-displacement relationship of piled groups model 2x3 under inclined static load with S/D (3,5 and 7), a) S/D =3, b) S/D = 5 and c) S/D=7 with different angle of inclination

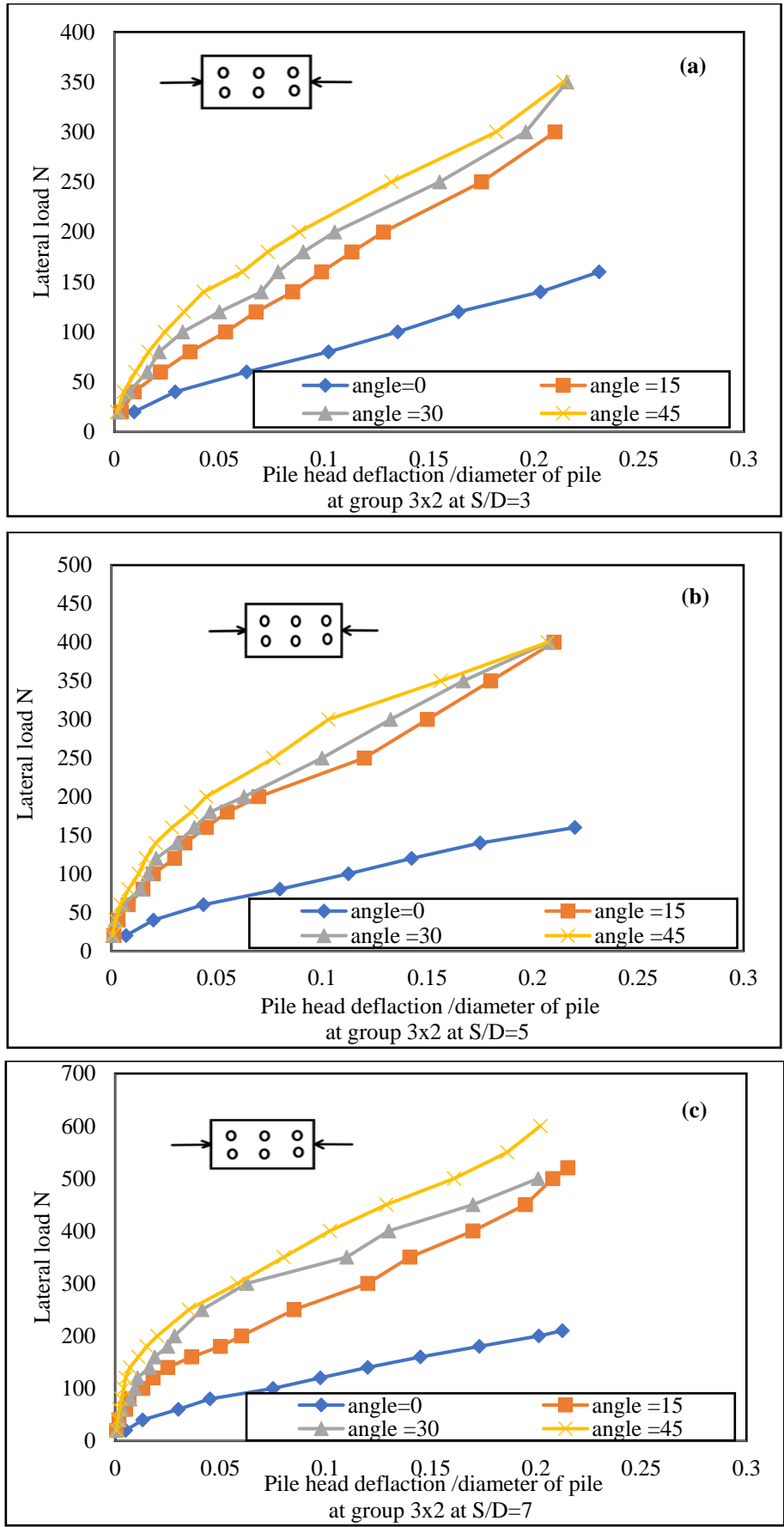


Figure 5. The load-displacement relationship of piled groups model 3x2 under inclined static load with S/D (3,5 and 7), a) S/D =3, b) S/D = 5 and c) S/D=7 with different angle of inclination

3.1.2 Effect of spacing on lateral resistance

Figure 6 to Figure 8 represent a group of piles 2x2, 2x3, and 3x2 respectively for S/D=3, 5 and 7 about the influence of Spacing on the lateral displacement for all angles. It has been observed from results showing that piles at close spacing (i.e., S/D = 3) deflect extra than the other spacing from other spacing 5,7. This behaviour is attributed to overlapping stresses zone of passive and active wedges. Group interaction consequences become less substantial as the spacing between 5 and 7.

The difference becomes less important with the increase in pile spacing due to the decrease of the interaction between piles [15]. Besides, the movement of the piles placed in the first row (leading) in the direction of the applied force is resisted by the soil in front of it. In contrast, the piles in the rows behind the first row (the piles in the trailing rows) pushed on the soil, which in turn pushed on the piles in the rows in front of them the lateral deflection usually is greater than in wide spacing, this is due to the short distance between the piles that causes overlap in stresses. This is attributing to the growth of the gap. at the soil–pile line wherever the stress attention happens [16, 17].

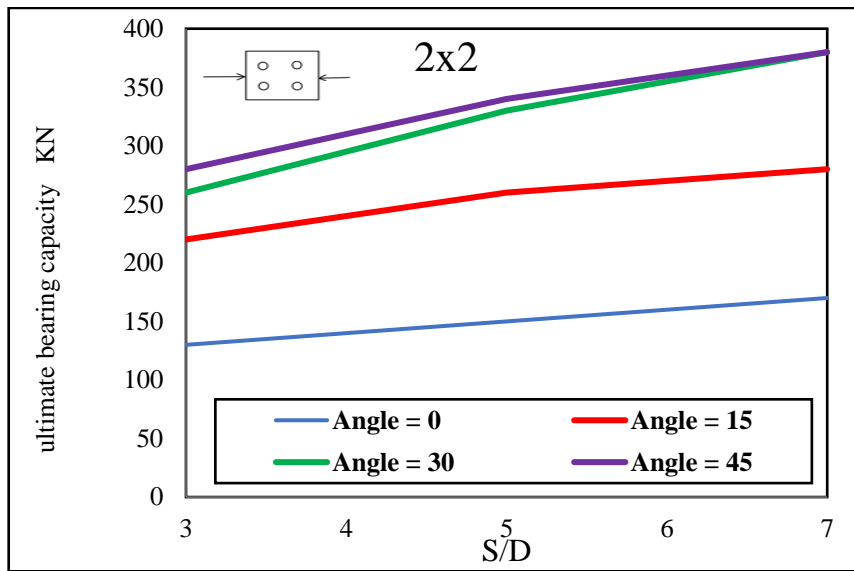


Figure 6. Effect of spacing on the ultimate bearing capacity of piled groups 2x2 model under inclined static load at S/D are 3,5 and 7, at angles 0°, 15°, 30°, and 45°

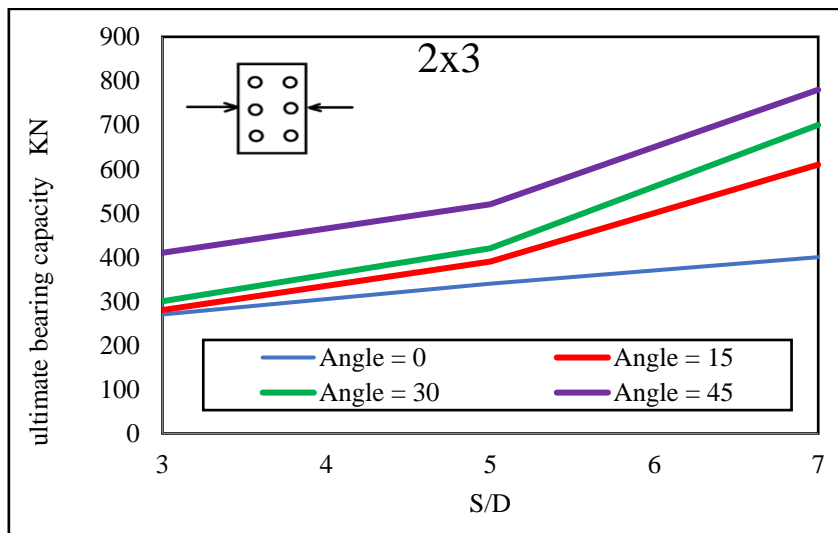


Figure 7. Effect of spacing on the ultimate bearing capacity of piled groups 2x3 model under inclined static load at S/D are 3,5 and 7, at angles 0°, 15°, 30°, and 45°.

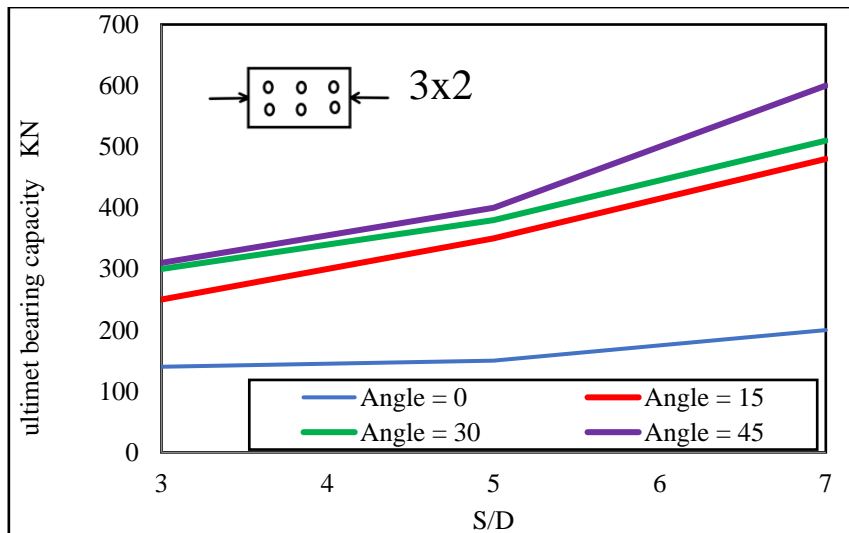


Figure 8. Effect of spacing on the ultimate bearing capacity of piled groups 3x2 model under inclined static load at S/D are 3,5 and 7, angles 0°, 15°, 30°, and 45°

3.1.3 Effect of the configuration of piles on lateral resistance

In Figures 6, 7 and 8, show how the lateral displacement of pile groups 2x2, 3x2, and 2x3 would influence by the configuration of piles. The results for all angle of inclination indicate that the bearing capacity of group 2x3 have more resistance from group 3x2 and 2x2. when comparing the pile group 2x2 with 2x3 would find a high increase in lateral resistance, the reason for this rises due to the increase in the number of the pile in a lead row (i.e.in front of soil that exposes the lateral deflection), this would cause an increase in lateral resistant and give the group more stiffeners. For another comparison, it can seem that the pile group 2x3 is safer against inclined loading compared with group 3x2, the decrease in lateral resisting of group 3x2, is attributable to the middle row exhibit less lateral resistance and leads to weakening the group [18].

4. Conclusion

1. The inclination angle for applied load influences on the responses of laterally displacement. The bearing capacity of pile group are increasing with increase the inclination angles and become near to the vertical axis and leads to less displacement of the pile head.

2. When spacing of pile increases, lateral deflection decreases in the similar load applied. Also, the difference caused by spacing of pile can be evidently noticed in all piles and rows, which is attributable to the influence of overlap among the pile-soil-pile in the group.
3. The configuration of pile group creates variations in ultimate resistance of soil for similar quantity of lateral load. The quantities of resisting load for the first trailing row considerably more than the quantities detected from the leading row. The group (2x3) showing more than (3x2) due to the increasing number of piles in the first trailing row.

References

- [1] Conte, Enrico, Antonello Troncone, and Mirko Vena. "On the pile response to inclined loads." *Procedia Engineering* 158 (2016): 206-211.
- [2] Sastry, V. V. R. N., and G. G. Meyerhof. "Behaviour of flexible piles under inclined loads." *Canadian Geotechnical Journal* 27, no. 1 (1990): 19-28.
- [3] Meyerhof, G. G., and A. S. Yalcin. "Behaviour of flexible batter piles under inclined loads in layered soil." *Canadian Geotechnical Journal* 30, no. 2 (1993): 247-256.
- [4] Sastry, V. V. R. N., and G. G. Meyerhof. "Behaviour of flexible piles in layered sands under eccentric and inclined loads." *Canadian Geotechnical Journal* 31, no. 4 (1994): 513-520.
- [5] Bhardwaj, S., and S. K. Singh. "Pile capacity under oblique loads—evaluation from load—

- displacement curves." *International Journal of Geotechnical Engineering* 9, no. 4 (2015): 341-347.
- [6] Borzooei, S., Reddy, E., Reddy, G., Improvement of lateral and oblique pull-out capacity of piles in sand-An experimental study. *National Congress on Soil Mechanics and Foundation Engineering*, 2014: p. 1-8.
- [7] Issac, S., Thomas, S., A Model Study on Pile Behavior under Inclined Compressive Loads in Cohesionless Soil. *International Journal of Engineering Research & Technology (IJERT)*, 2015. 4(11): p. 166-172S.
- [8] Goswami, A., Roy, S., Ultimate Capacity of Vertical Short Pile under Inclined Compressive Load, in *Indian Geotechnical Conference*. 2017.
- [9] Abbas, J., Hussain, Q., The Effect of Pile Cross Section on the Lateral behavior of Piles Under Combined.
- [10] Kahribt, Muqdad Abdallah, and Jasim M. Abbas. "Lateral response of a single pile under combined axial and lateral cyclic loading in sandy soil." *Civil Engineering Journal* 4, no. 9 (2018): 1996-2010.
- [11] Goswami, A., Roy, S., Ultimate Capacity of Vertical Pile Subjected to Combination of Vertical and Lateral Load. *International Journal of Innovative Technology and Exploring Engineering*, 2019. 8(9S2): p. 647-652.
- [12] Dong, Bin, Liang Wang, Wenting Liu, Aiguo Han, Yang Tang, and Lei Yuan. "Study on the optimization of pile group foundation under oblique load." In *Journal of Physics: Conference Series*, vol. 1732, no. 1, p. 012132. IOP Publishing, 2021.
- [13] Mahmood, A.K. and J.M. Abbas, The Effect of Vertical Loads and the Pile Shape on Pile Group Response under Lateral Two-Way Cyclic Loading. *Civil Engineering Journal*, 2019. 5(11): p. 2377-2391.
- [14] Broms, B.B., Lateral resistance of piles in cohesionless soils. *Journal of the Soil Mechanics and Foundations Division*, 1964. 90(3): p. 123-156.
- [15] Saleh, Wafaa A. "Effect of Spacing and Cross-Sectional Shape on Piled Raft System Subjected to Lateral Cyclic Loading." *Diyala Journal of Engineering Sciences* 13, no. 3 (2020): 114-122.
- [16] Memar, M., Vakili, A., Ali Zomorodian, S., Effect of pile cross-section shape on pile group behaviour under lateral loading in sand. *International Journal of Physical Modelling in Geotechnics*, 2019: p. 1-12.
- [17] Jose, S., Prakash, Paul, H., a model study on lateral behaviour of micropile under inclined compressive loads in sand. *International Research Journal of Engineering and Technology (IRJET)*, 2018. 5(4): p. 2946-2950.
- [18] Franza, Andrea, and Brian Sheil. "Pile groups under vertical and inclined eccentric loads: Elastoplastic modelling for performance-based design." *Computers and Geotechnics* 135 (2021): 104092.