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ORIGINAL

Estimation of The Maximum Bending Moment on Pile Group Under One-Way Cyclic Loading in Sandy Soil

Estimación del momento de flexión máximo en el grupo de pilotes bajo carga cíclica unidireccional en suelo arenoso

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ABSTRACT

In fact, most civil engineering projects are subjected to cyclic loads. The sources of this load are usually seismic, wind, sea waves, and others. Model tests in sandy soil were performed to determine the maximum bending moment at which a pile group (2x2) would respond under one-way lateral cyclic loading. The group pile was made of aluminum piles that were installed in sandy soil with a 70 % relative density and three-pile spacing of (3D, 5D, and 7D). The cyclic loads ratio (CLR) used are (0,6, 0,0,8, and 1,0) that is a result from average lateral static load. It can be concluded that an increase in group pile spacing can reduce the maximum bending moment by up to 92 %. In addition, As the distance increases, the bending moment decreases, the front pile group provides a greater maximum bending moment than the back rows, as the maximum value in comparison reached 53 %.

Keywords: Sandy Soil; Cyclic Load; Static Load; Pile Group; Maximum Bending Moment.

RESUMEN

De hecho, la mayoría de los proyectos de ingeniería civil están sometidos a cargas cíclicas. Las fuentes de esta carga suelen ser sísmicas, eólicas, olas del mar y otras. Se realizaron ensayos con modelos en suelo arenoso para determinar el momento flector máximo al que respondería un grupo de pilotes (2x2) bajo una carga cíclica lateral unidireccional. El grupo de pilotes estaba formado por pilotes de aluminio que se instalaron en suelo arenoso con una densidad relativa del 70 % y una separación de tres pilotes (3D, 5D y 7D). La relación de cargas cíclicas (CLR) utilizadas son (0,6, 0,0,8, y 1,0) que es un resultado de la carga estática lateral media. Se puede concluir que un aumento de la distancia entre pilotes en grupo puede reducir el momento flector máximo hasta en un 92 %. Además, a medida que aumenta la distancia, disminuye el momento flector, el grupo de pilotes delantero proporciona un momento flector máximo mayor que las filas traseras, ya que el valor máximo en comparación alcanzó el 53 %.

Palabras clave: Suelo Arenoso; Carga Cíclica; Carga Estática; Grupo de Pilotes; Momento Flector Máximo.

INTRODUCTION

High buildings, high-rise bridges, offshore wind turbine foundations, and deepwater offshore platforms are all supported by pile foundations. Ships impact, wave, wind action, or other sources frequently cause significant lateral cyclic loads on the above structures. The distance between these piles, the source of loading, the soil condition, and other factors influence the group pile's ability to resist horizontal loads.[1] One-way lateral cyclic load also has greater effects on soil stiffness and strength at the front of the piles than at the back of them.[2] Previous studies have revealed that various parameters regulate the behavior of cohesionless soil under recurrent loading such as the level of stress, the relative density, the number of cycles, the confining of pressure, and the spacing of the pile.[3] Investigational studies have also been conducted on groups of piles implanted in various types of clay soil; these groups were exposed to one-way cyclic loading. It has been discovered that as the number of loading cycles increases, the maximum bending moment increases.[4]

Niemann et al.[5] investigate the group pile behavior in silica sand exposed to lateral one-way cyclic load and indicate that the pile group is affected by pile spacing and amplitude of cyclic load. In addition, the pile group's lateral displacement accumulation increased as the piles were closer together, and the cycle load amplitude increased. Furthermore, the bending moment decreases when the spacing between piles in a group increase. Such lateral cyclic loads on piles induced the reversal of stresses in the nearby soils, resulting in progressive degradation in strength and stiffness, which in turn caused a reduce in pile capacity with considerable irreversible deformation, resulting in failure in major situations.[6] Another study which is carried out by Mahmoud and Abbas [7], states that the group piles were exposed to cyclic and vertical loading to illustrate the effect of the cyclically load ratio (CLR) on the behavior of piles. The findings showed that the lateral movement of the pile's head varied with the cyclically loaded ratio (CLR), before settling in a more consistent pattern, as the number of cycles increased. Moreover, the existence of vertical loads on the pile group cap corresponded to the permissible vertical load capacity. Basack [8] concluded that, under cyclic load, the soil around the piles disturbed especially in the top soil layer, and this is mainly the reason to lateral pile performance under lateral load. In addition, Park [9] shows that a lateral force on a pile refers to a pile foundation that is subjected to horizontal load would create a maximum bending moment.

Brown et al.[10] reported that the performance of the leading row ingroup was comparable to that of an isolated pile under horizontal cyclic loads.one-way cyclic loads would have resulted in more soil resistance degradation and less densification. Furthermore, with the same lateral loads, the piles in the front row exhibited remarkably comparable bending moments to the lonely single piles. Due to the front row received a bigger share of the overall load distribution applied to the group pile head; it had the greatest bending moment for the given load. In addition, Kahribt and Abbas [11] conducted cyclic loading tests to estimate the maximum bending moments of the piles at 100 cycles. The depth, that corresponds to the maximum bending moment acted on the pile (L/D = 25), is deeper than it was at the first cycle. However, for piles subjected to combined loads in dense soil, a slight increase in the depth equivalent to the maximum bending moment is observed. Therefore, the limited investigations on the one-way cyclic load with static load for these ranges, this study included a model in which a group of piles submerged in sand soil was subjected to a lateral one-way cyclic load with different spacing and cyclic load ratios to determine the maximum bending moment on the pile group.

METHODOLOGY

Pile and Pile Caps

Aluminum closed-end pipes are utilized to represent individual piles with round cross-section Inside a group. These pipes have a total length of 690 mm in length, with an outside diameter of 16mm, and the embedding length is 640mm. In addition, the slenderness ratio (L/D) equals 40, the pile caps are made of durable composite material as shown in figure 1. The pile caps are topped with a flat with 6mm thick. In the caps, there are four holes, each of 16 mm in diameter and circular cross-section were drilled to accommodate the four piles. The rivets in the holes attached to the piles were flattened to prevent the steel sheets from bending while inspected.

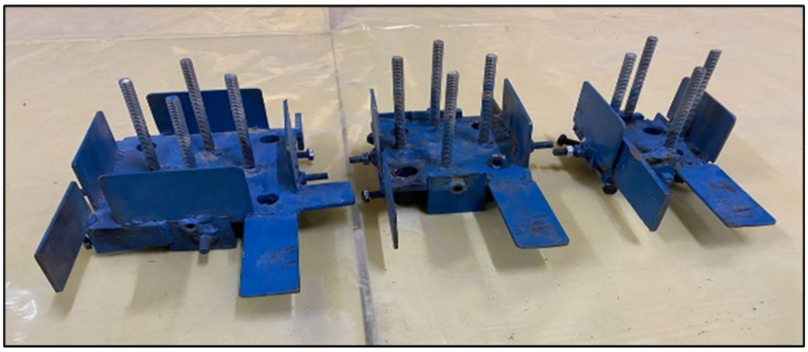

Figure 1. Pile caps

Properties of Soil Used

The sandy soil is collected from Karbala in the south of Iraq. All relevant tests were carried out at the University of Diyala's soil laboratory/College of Engineering. The results were shown in table 1.

Table 1. Properties of Sandy Soil

Property	Value	Standard
Analysis of grain size		
The effective size D10, in (mm)	0,18	ASTM D 422 and ASTM D 2487 (2006)
D30, in (mm)	0,32	ASTM D 422 and ASTM D 2487 (2006)
The mean size D, 50 in (mm)	0,38	ASTM D 422 and ASTM D 2487 (2006)
D 60 in (mm)	0,49	ASTM D 422 and ASTM D 2487 (2006)
Uniformity coefficient (Cu)	2,72	ASTM D 422 and ASTM D 2487 (2006)
Coefficient curvature (Cc)	1,16	ASTM D 422 and ASTM D 2487 (2006)
The classification (USCS)	SP	ASTM D 422 and ASTM D 2487 (2006)
Specific gravity (GS)	2,65	ASTM D 854 (2006)
Internal friction angle (Ø)	35,2	ASTM D3040-04(2006)
Cohesion (c) in (kN / m2)	0	ASTM D3040-04(2006)

Installing Piles

Before beginning the raining process, piles are set within the container with the use of guides, as they are shown in figure 2a. The steel container has dimensions of (1x1x1m). The stress bulb is considered effective to a depth of (3-4)B and the distribution of stress with depth is followed by the universal law which is 2:1 (vertical: horizontal) . According to that the dimensions of the container are satisfied as shown in figure 2c. The top rainy container's holes may be adjusted to control the height at which sand is released, to achieve relative density of Dr= 70 % . The pile caps are settled after the rain technique is completed. Pile group under cyclic loading with wave loading represents one-way cyclic lateral loading is illustrated in figure 2b.

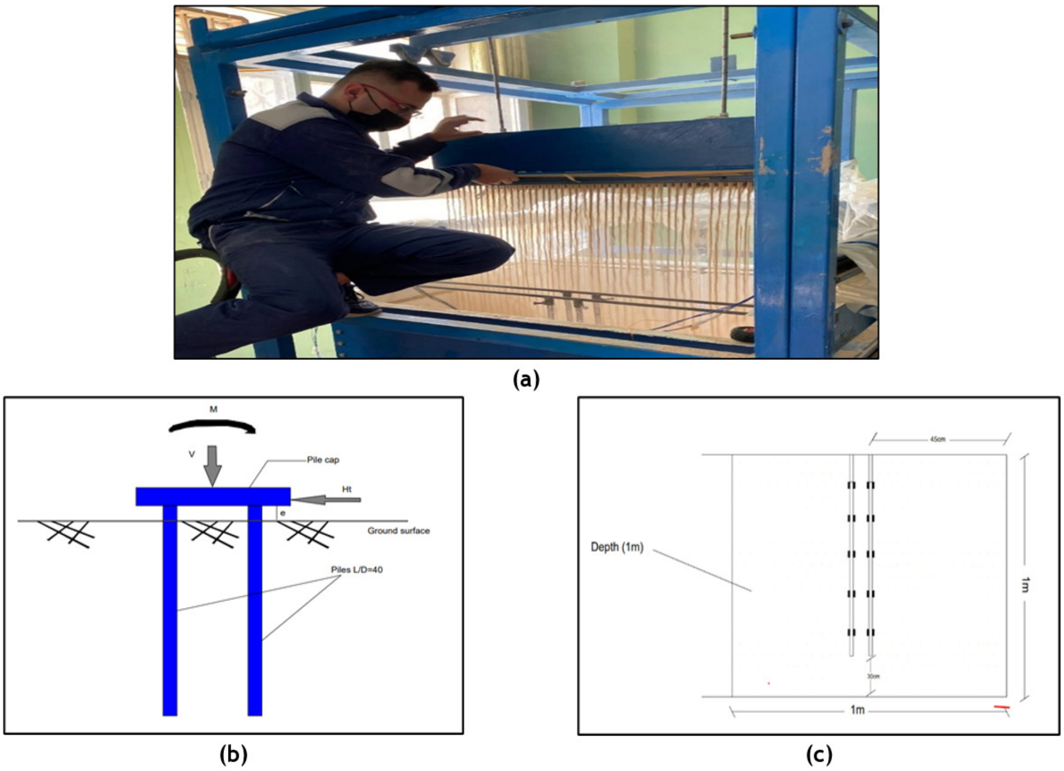

Figure 2. (a) piles installation and raining technique (b) schematic view one-way loading on group piles (c) Sketch of steel container dimensions

Test Setup

For a cyclic load, an actuator driven by a gear system applies it to the pile cap laterally in one direction, as it

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is illustrated in figure 3. Then, the ultimate bending moment head is measured using a strain gauge Connected to the strain indicator device along the pile at different depths . Three distances are used for the pile groups, namely 3D, 5D, and 7D. In addition, three values for the cyclic loading rates are used in these laboratory tests, which are 60 %, 80 %, and 100 % at 100 cycles. The cyclic loading values are calculated from the determination of the average rate of the static loading test, which is 200 N.

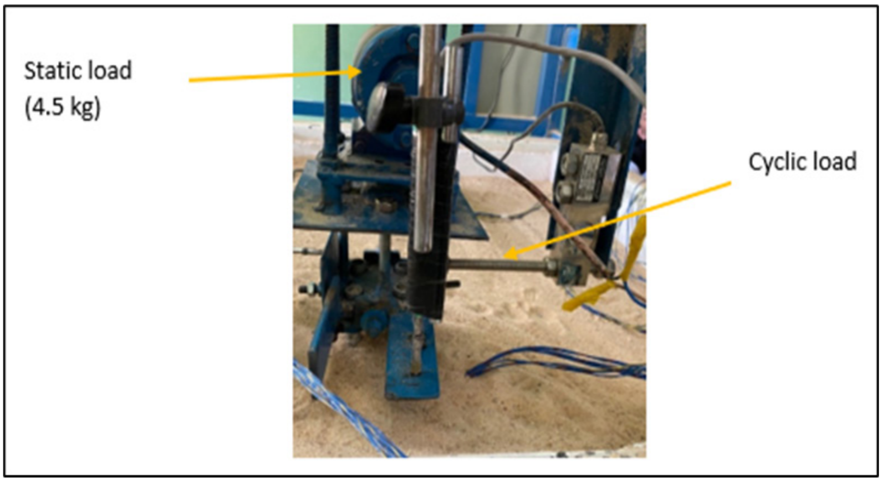

Figure 3. The tools used in this work

Technique Strain Gage

One method for measuring the bending moment of a pile group involves placing strain gages at specific locations along the pile shift. The following is a description of the steps involved in this method in detail:

The General Explanation

Five pairs of 5 mm-long strain gauges of the FLA-5-23 type are pre-installed in the pile models of the pile group's first and second rows. The pile is inserted lengthwise with an appropriate adhesive, the strain gauged instilled in two piles only, the front and rear piles in the direction of load. Table 2 illustrated the specifications of strain gauge.

Table 2. Properties of the strain gauge

Parameters	The value
Type	FLA-5-23
Gauge length	5mm
Gauge resistance	120 ∓ 0,3Ω
Gauge factor	2,16 ± 1 %
Adhesive	CN

Figures 4 and 5 demonstrate the setup of a water-resistant adhesive substance (SB TAPE) which are used to shield the strain gauges from the friction of sand and the impact of water.

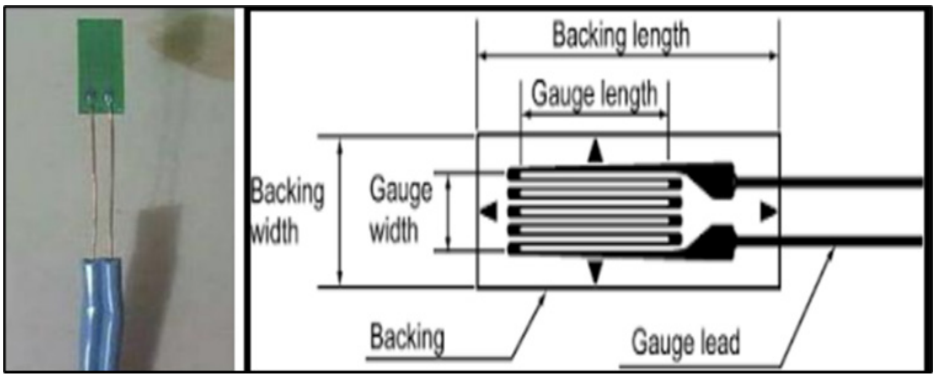

Figure 4. The strain gauges

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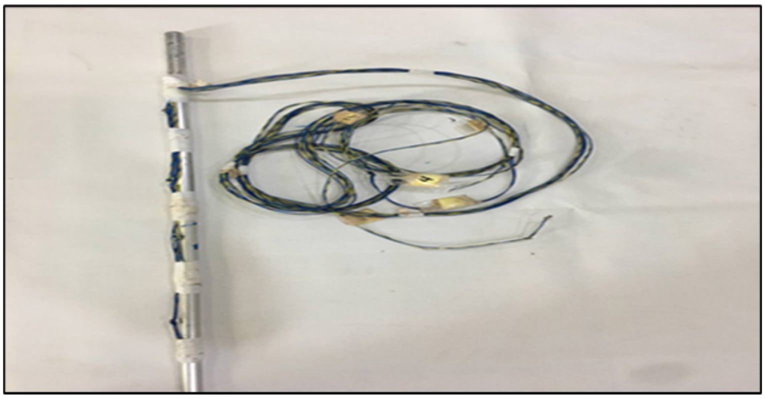

Figure 5. A Pile with Strain Gauges

RESULTS AND DISCUSSION

To determine the bending moment, the following equation can be used along the piles shift in group based on strain gauges data.

M = ε EI/r (1)
where:
M = represents the bending moment. ($N.\ mm$).
ε = a measured Strain (mm/mm).
E = the elasticity modulus of aluminum pipes (N/mm^2).
I = the pile section's moment of inertia (mm^4).
r = the aluminum pipes outside radius (mm).

One of the basic principles of safe foundation design determines the maximum bending moments along the pile, as well as understanding its performance under horizontal cyclic loading, as a result, in this section of the research, the maximum moment of piles is calculated for cyclic and static loads (4,5 kg).

Estimate the Maximum Bending Moments for Different CLR

A comparison of the front and back row piles provides to comprehend the impact of shadowing. After a significant number of cyclic loadings can be made, each row is shown independently, and the difference in moments at 100 cycles is compared.

The value of the maximum bending moments increases with increasing cyclic loading ratios (CLR) from 60 to 100 % as shown in Figure 6. In the case of the front rows of the pile group, for a group with 3D, the comparison between load CLR of 60 % and other magnitudes of 80 % and 100 % increased the maximum bending moment by 29 % and 60 %, respectively. In addition, when increasing pile spacing to 5D, the maximum bending moment increased to 56 % and 95 %, respectively. Finally, for 7D, the maximum moment increases to 34 % and 82 %, respectively. As for the back rows of the pile group, where the maximum bending moment appeared at the surface, for the 3D pile group, the amount of bending moment increased when the CLR ratio increased from 60 to 80 by 8 %, and when it increased from 60 to 100, the percentage was 29 %. In addition to that, the group for 5D piles, the percentages increased by 15 % and 46 % when the CLR ratio increased from 60 to 100 %, respectively. Finally, at 7D, the value of the maximum bending moments increased by 56 % and 68 %, respectively.

When comparing the front rows and the back rows, the maximum moments are higher in the front rows because they face the soil directly. For a group with 3D the comparison between load CLR of 60 %, the maximum moment of the front rows is greater than the bending moment of the back rows increased by 24 %. When the CLR ratio increased to 80 % and in comparison, the maximum moment ratio of the front rows was greater than the back rows by 48 %. Finally, at 100 %, the ratio increased by 52 %. In addition, when increasing pile spacing to 5D, the maximum bending moment at CLR equal to 60 % is 3 % higher, while it is 40 % higher when the CLR ratio increases to 80 %, and finally when the CLR ratio increases to 100 %, the percentage is 18 %. Finally, for 7D, the maximum bending moment increases to 41 %, 21 %, and 53 %, respectively.

Based on that, the front rows of the piles are subjected to greater soil resistance than the back rows. The bending moments of these rows are greater and more dangerous even when they are presented at the maximum applied cyclic loading ratio. Maximum bending moment of piles occurs at the soil surface in back piles due to closed to load sources. This indicates that the front row piles have a larger load carry. This is due to the cyclic action reduced the soil reaction between the rows of piles. In other hand, the shadowing effect caused the leading piles to disrupt the soil between the rows this also recommended by [7].

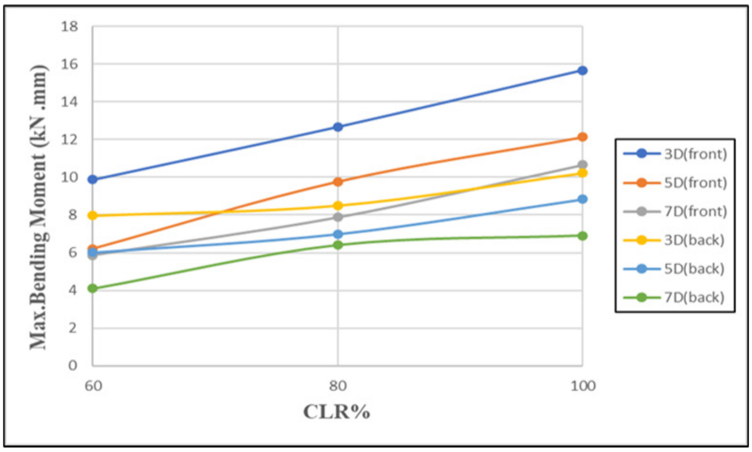

Figure 6. The Maximum bending moment of the front and back pile groups with different CLR

Effect of Pile Spacings on Bending Moment along the Pile's Depth

The results show that the influence of tight spacing (3D) causes a significant increase in the magnitude of the maximum moment. Due to stresses, zones overlap in the direction of cyclic loading.[12,13] This case must be considered when developing pile groups under lateral cyclic loading for all group pile models.

For comparison of the spacing between piles for the front rows, the value of 3D gives a maximum bending moment greater than 5D and 7D, as shown in figure 7. For the group with 3D, with 60 % CLR, it gives a maximum moment greater than 5D by 58 % and 68 % greater than 7D. When the cyclic loading was increased to 80 % CLR, the maximum moment of 3D was greater than that of 5D and 7D by 30 % and 61 %, respectively. While for 100 % CLR, the value of 3D gave a maximum moment greater than 5D and 7D by 29 % and 48 %, respectively.

On the other hand, the effect of the spacing between the piles in the back rows, as shown in Figure 8, for a group with 3D, compared to the 60 % CLR, can increase the maximum bending moment greater than 5D by 32 % and 92 % greater than 7D. When the cyclic loading was increased to 80 % CLR, the maximum moment of 3D was greater than that of 5D and 7D by 23 % and 32 %, respectively. While for 100 %, the value of 3D gave a maximum bending moment greater than 5D and 7D by 16 % and 48 %, respectively.

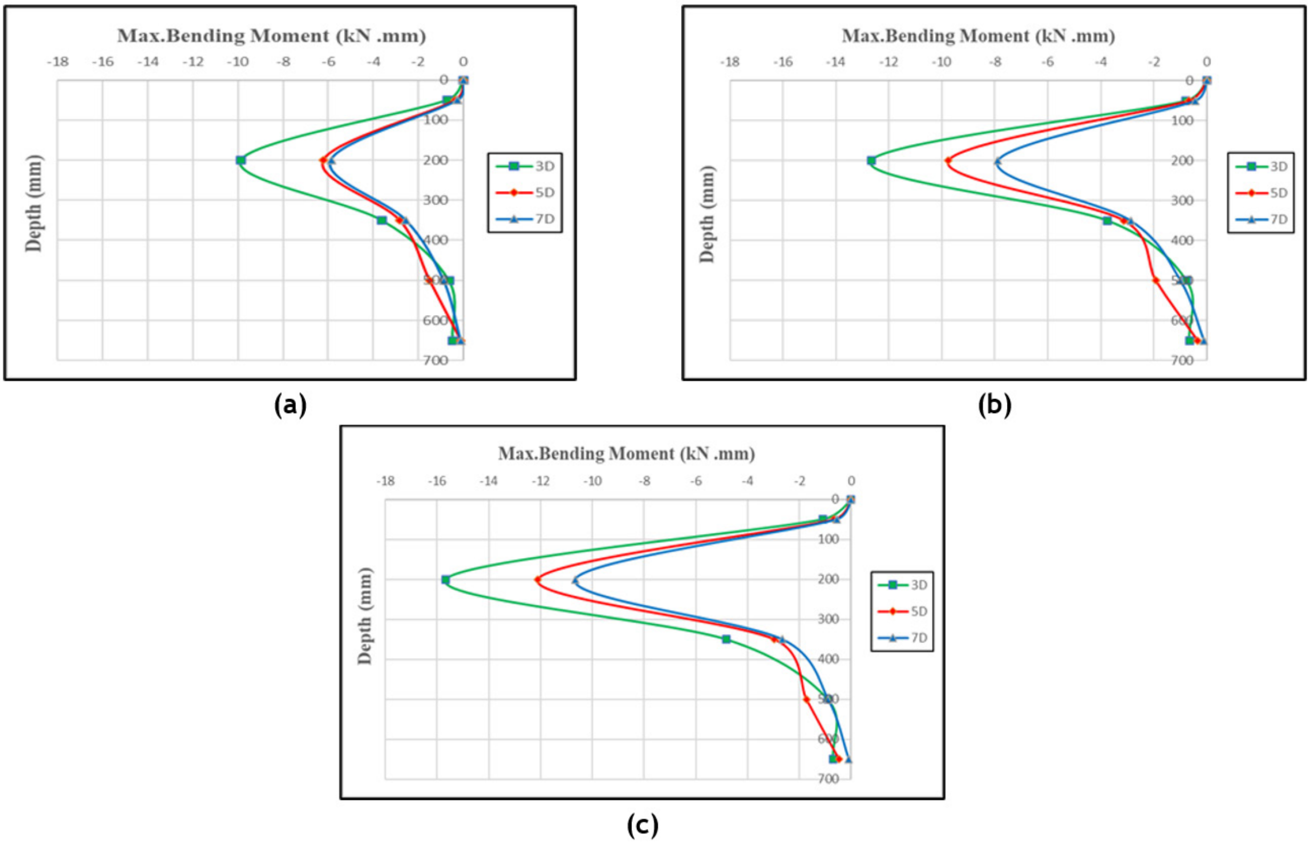

Figure 7. The impact of the spacing between piles on the maximum bending moments of the front pile group with different CLR (a) 60 % (b) 80 % (c) 100 %

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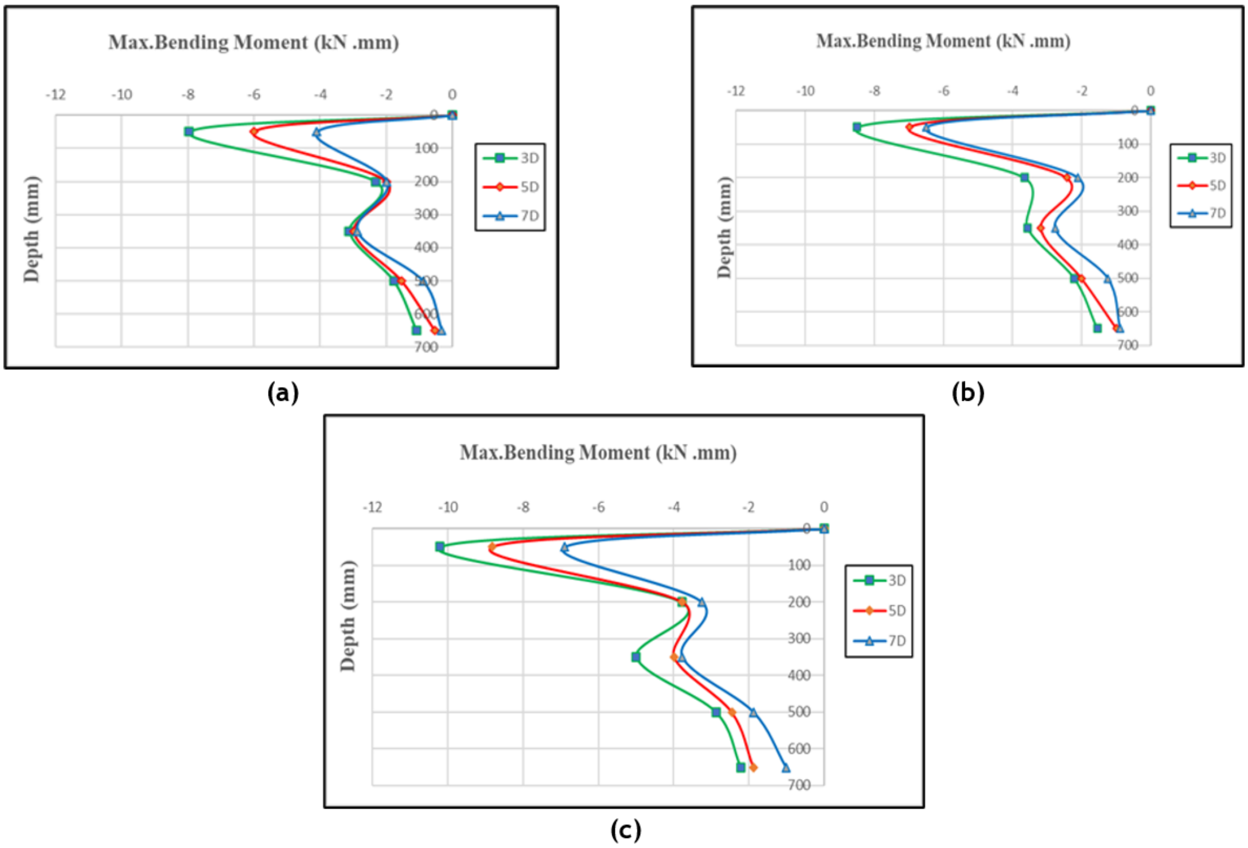

Figure 8. The impact of the spacing between piles on the maximum bending moments of the back pile group with various CLR (a) 60 % (b) 80 % (c) 100 %

CONCLUSION

1. The maximum bending moment was observed in the initial part of the pile shaft beginning at the soil face.
2. In general, the maximum moments of the pile group increases when the cyclic load ratio (CLR) increases, especially at 5D spacing, where the increase rate reached 95 % as compared to the smallest and largest value of the cyclic load ratios.
3. The spacing between piles affects the maximum bending moments of the pile groups, As the distance increases, the bending moment decreases, as the maximum ratio between the smallest and largest distances reached 92 %.
4. The front piles exhibited a greater bending moment than the back piles, as the highest percentage reached 53 % at the largest spacings (7D).

REFERENCES

1. S. Karthigeyan and, K. Rajagopal. Lateral response of 2× 2 pile group under combined axial and lateral loading. In Proceedings of Indian geotechnical conference (pp. 666-668). (2009)

2. S. Basack, M. Karami, and M. Karakouzian . Pile-soil interaction under cyclic lateral load in loose sand: Experimental and numerical evaluations. Soil Dynamics and Earthquake Engineering ,162, p.107439. (2022)

3. S. Agerby. Deformation Characteristics of Sandy Soil under Low-Frequency Cyclic. (2015)

4. A. Goswami, and S. Roy. Ultimate capacity of vertical short pile under inclined compressive load. In Indian Geotechnical Conference. (2017)

5. C. Niemann, C. O'Loughlin, M. Tian, Y., Cassidy, and O. Reul. Response of pile groups in sand due to lateral cyclic loading. International Journal of Physical Modelling in Geotechnics , 19(6), pp.318-330. (2019)

6. N. Allotey and M.H. El Naggar. A numerical study into lateral cyclic nonlinear soil-pile response. Canadian Geotechnical Journal , 45(9), pp.1268-1281. (2008)

https://doi.org/10.56294/sctconf2024841

7. A.K. Mahmood 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 , 5(11), pp.2377-2391. (2019)

8. S. Basack, and A.K. Bhattacharya. Influence of lateral cyclic load on pile foundation with emphasis on disturbance at ground surface. J]. Electronic Journal of Geotechnical Engineering , 14, pp.1-11. (2009)

9. Park. Nonlinear 3-Dimensional Analysis of Dynamic Py Curve in Sand. (2018)

10. D.A. Brown, C. Morrison, and L.C. Reese. Lateral load behavior of pile group in sand. Journal of Geotechnical Engineering , 114(11), pp.1261-1276. (1988)

11. M.A. Kahribt and J.M. Abbas. Lateral response of a single pile under combined axial and lateral cyclic loading in sandy soil. Civil Engineering Journal , 4(9), pp.1996-2010. (2018)

12. .S. Chandrasekaran, A. Boominathan, and G.R. Dodagoudar. Experimental investigations on the behaviour of pile groups in clay under lateral cyclic loading. Geotechnical and Geological Engineering, 28, pp.603-617. (2010)

13. L. Hazzar, M.N. Hussien, and M. Karray. On the behaviour of pile groups under combined lateral and vertical loading. Ocean Engineering , 131, pp.174-185. (2017)

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Research: Saif Samir Abdulhafiz, Jasim M Abbas.
Writing - original draft: Saif Samir Abdulhafiz, Jasim M Abbas.
Writing - revision and editing: Saif Samir Abdulhafiz, Jasim M Abbas.