Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Inclination Effect of Cyclic Load Synchronous with Lateral Static Load on Pile Group in Sandy Soil

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ARTICLE INFO

Article history:
Received May 5, 2022
Revised October 8, 2022
Accepted October 11, 2022
Available online September 1, 2023

Keywords:
lateral static loads
cyclic response
pile group
pile spacing

ABSTRACT

In general Pile foundations are often subject to more than one load in nature. Two loadings, when simultaneous, cause serious problems in the bearing capacity. Therefore, the major objective of this study is to assessment the performance of piles under inclined cyclic loads simultaneous with static lateral loads in sandy soil with a relative density of 70%. The experimental works were conducted to determine the effect of several factors on pile group performance 2×2, including: the ratio of spaces between piles (i.e. 3D, 5D, 7D), effect of cyclic loading inclination angles (i.e. 0°, 10°, 20°, 30°) and the effect of the presence of a static lateral load on the cyclic load. In light of the findings, the presence of the static load with the inclined lateral cyclic load has a positive effect on the deep foundations where the lateral deflection was reduced by an average of 54% for the three spaces. Also the lateral deflection at combined lateral loading decreases with increasing pile spacing, the percentages of decreases in the lateral deflection were (16%, 73%, 75%) for spacing (3D, 5D, 7D) respectively.

1. Introduction

In practice, it is clear that the piles foundations are inevitable wherever strong soil is positioned below weak soil to transfer the weights from the main structure to the strong soil. These piles are frequently under the control of two loads [1]. The lateral loads that affect the engineering structures have different sources depending on the location of the building, its height and other factors [2, 3]. Static loads accumulate very little dynamically, even to the point of negligence while cyclic load produces compressibility's of the piling soil, which grows exponentially with increasing number of cyclic loads [4]. Earthquakes, Traffic, currents, operations of plant, tide, seasons, waves, wind, blasting activities or rotating machinery could all be the cyclic loadings' source [5]. Piles that loaded laterally may subject to failure, as: Failure material of piles after it reach to yielding, Failure soil around the pile, when the lateral deflection overrides the permissible level of the design, the piles will be unstable, and this is a failure [6]. The upper piece of piles lateral Loaded are the critical piece because it hold up biggest of loads proportion [7]. The spacing between piles, the source of loading, , condition of the soil and other factors all effect on the piles groups' capacity in resistance the horizontal loads [8]. Cyclical load's influence on performance of lateral pile foundation has been tested in a number of the prior studies by using laboratory models and (FEM) [9]. Investigational study has been done on piles group were placed in vary kinds of clay soil with

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DOI: 10.24237/djes.2023.16307

two values of the relative densities are: (10 and 90) %, the groups subjected to cyclic-loading in one direction. It is found that when number of cycles increases, the deflections increase [10]. Another work tested a single pile's behavior under static inclined-loads till the failure [11]. In case the piles subjected to the combined loads: lateral and vertical loads, the influence of an increase in the number of cycles regarding piles' horizontal deflection under combined loads is lesser than its influence in state the piles are subjected to cyclic-lateral load only [12]. Lateral deflection diminishes as the pile spacing increases, the pile group's lateral resistance will diminishes through the initial cycles, as number of the cycle's increases, and the group's deflection will be nearly constant because of the soil's densification [13]. A piled raft loaded with pure cyclic load once and combined loads again was tested to determine how the clay soil saturation degrees affected the model's performance [14]. A static lateral force and a cyclic lateral load were applied to groups of piles, respectively, and the behavior of these piles under each load was examined independently. The results of the investigation demonstrated that the kind and degree of deformation are significantly influenced by the intensity and magnitude of the load. Additionally, how the groups are arranged and the form of the piles affect how the foundation functions [15]. The applied force would be split into two components, horizontal and vertical, when pile foundations are subjected to inclined cyclic loads. The horizontal component functions as the horizontal load on the pile groups, while the vertical component acts as a vertical load on the pile groups, increasing the stiffness of the pile. [16]. So, this project covers an experimental program to investigate of inclined cyclically loading combined with static laterally loading applied on three spacing of pile group in sandy soil.

2. Materials and methods

2.1 Pile group model

Hollow aluminum piles with a circular cross-section of 16 mm in diameter were used as in Figure 1. A length of the piles of 690 mm. moreover, (L/D=40).

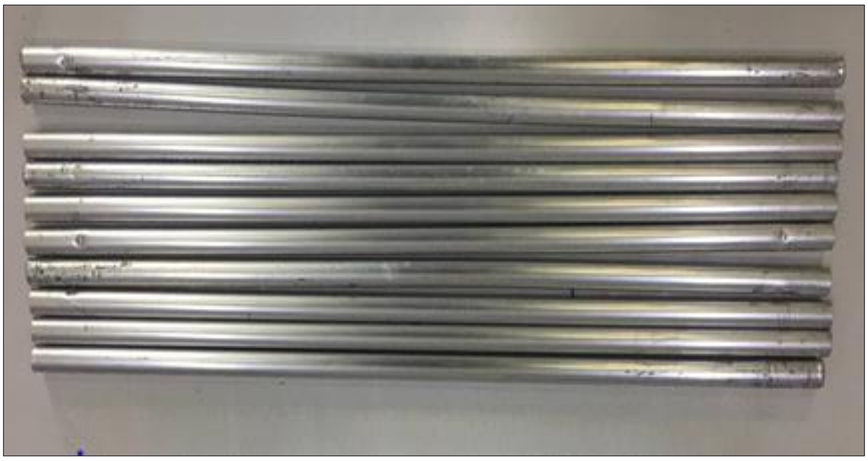


Figure 1. Piles models

The pile caps were made from a sturdy plate with a flat surface and a thickness of 6mm. A moveable joint has been fitted on both sides of pile group, with the objective of controlling the angularity of cyclic-lateral load inclination using two bolts on both sides of the plate, in addition a kickstand is also placed on the tip of the cap to apply the static loads through it, as illustrated in Figure 2.

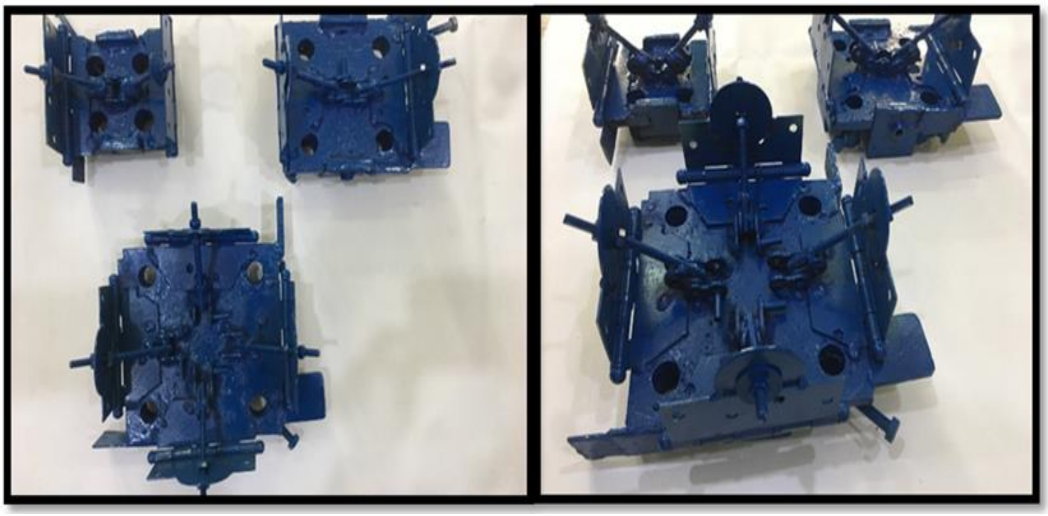


Figure 2. Caps of Pile group (S/D=3, 5 and 7)

2.2 Characteristics of soil

Sandy soil was provided from the city of Karbala, southwestern Iraq. All necessary examinations were done in the soil laboratories with in College of Engineering / University of Diyala, Table 1 shows the properties.

Table 1. Sand physical properties

Property	value
Specific gravity, Gs	2.61
Angle of internal friction, φ°	35.6
Cohesion, c (kPa)	0
Maximum dry unit weight, γ_{dmax} (kN/m^3)	17.5
Minimum dry unit weight, γ_{dmin} (kN/m^3)	15.1
Dry unit weight, γ_d (kN/m^3)	16.3
Relative density, Dr (%)	70

2.3 Soil tank

The container which used in this study is square, and it is formed of a massive steel plat with a thickness of (4 millimeters) to keep it from expanding when it's full for sand. The inside dimensions were (1000 x 1000 x 1000) mm width, length, and depth.

2.4 Loading device

2.4.1 Loading device of lateral static loads

A simple tool was used for the purpose of applying the static lateral load. It is a relatively small tool and movable that contains a lever to move the cable that connects the pile group to the weight-bearing disc. A high-tension cable connects the group of pile to the disc of loading. This tool ensures that the cable does not rub against the container as shown in Figure 3.

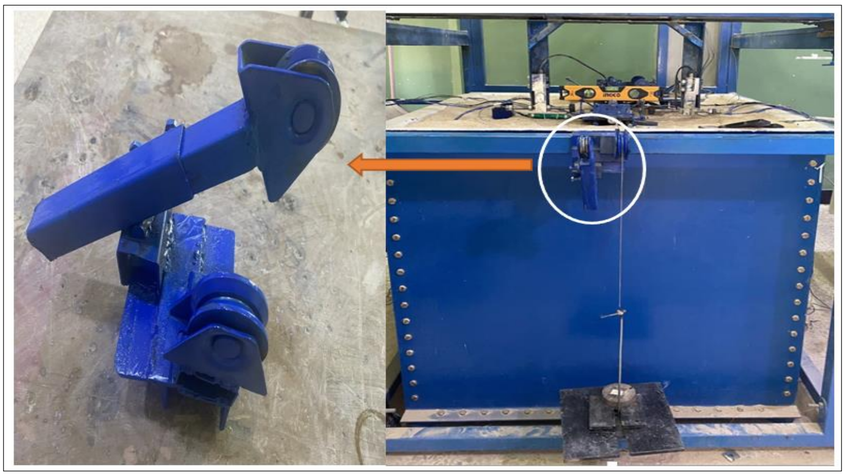
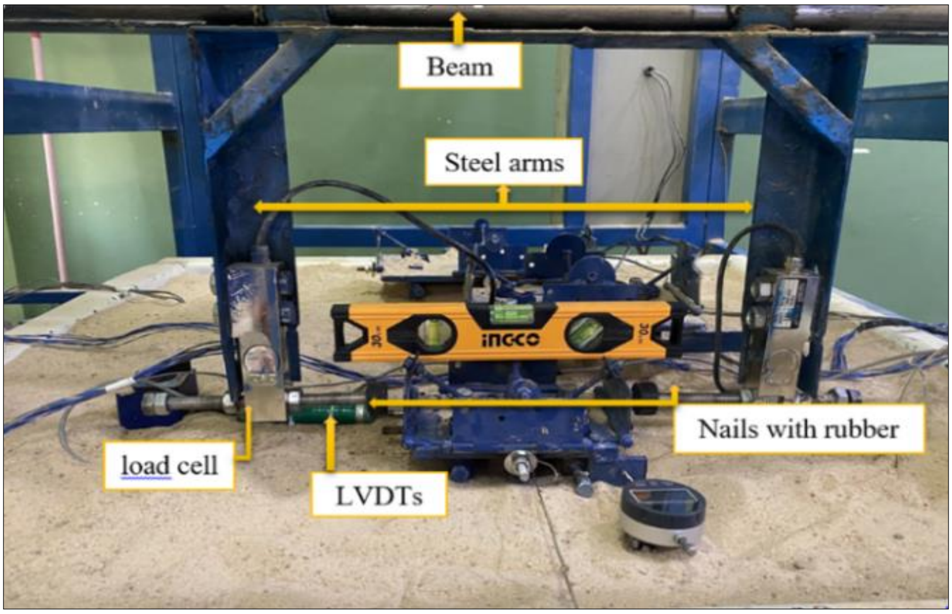


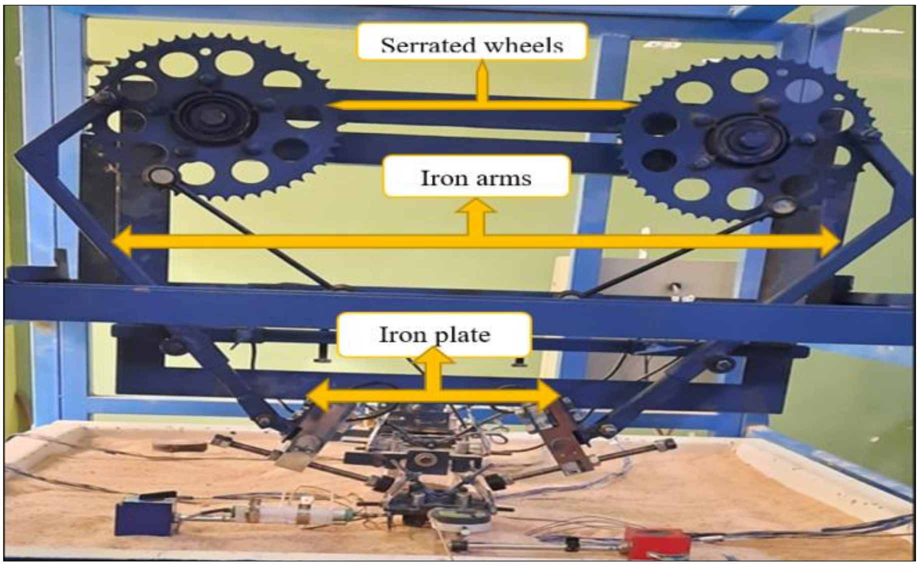
Figure 3. System of static loading

2.4.2 Loading device of cyclic loads

In the event that the lateral cyclic loads is shed horizontally, the device has been designed in a way to achieve a two-way cyclic loading system that is shed at an angle =0, using two steel arms, one parallel to the other, connected to each other by a horizontal beam extending along both sides of the device as in Figure 4a. In case the pile groups are loaded with inclined lateral cyclic loads, the horizontal cyclically loading device is replaced with a bidirectional inclined cyclic-loading device with tilt angles of 10°, 20°, and 30°. The mechanism is made up of two serrated wheels joined by iron arms that transfer movement. The angle of inclination of the applied load can be controlled by means of a movable plate to which the load cell is fixed, which, in turn, transfers the loads to the piles by means of nails with rubberized ends. The displacement is gauged with an LVDT positioned on the piles' side, as clear in Figure 4b.



a) Horizontal loading



d) Inclined loading
Figure 4. Loading device of cyclic loads

3. Results and discussion

3.1 Assessment of lateral pile group deflection

It is clear from Figure 5 that the bearing capacity of the pile group increases with the increase in the inclination angles of cyclic loading in both cases: pure loading and combined loading. Where the values of lateral displacements decrease as the inclination angles increase. To analyze this response and explanation of this behavior that happened for pile groups under the inclined loading, the inclined loading would be split into two components namely the axial and the horizontal components. The vertical load is being applied by the axial component of the inclined load on the pile groups, lead to an increase of the pile's stiffness and a decrease the lateral deflection in the soil and this would be more with increasing of the load inclination angles, recommended by (Enrico Conte et al., 2016).

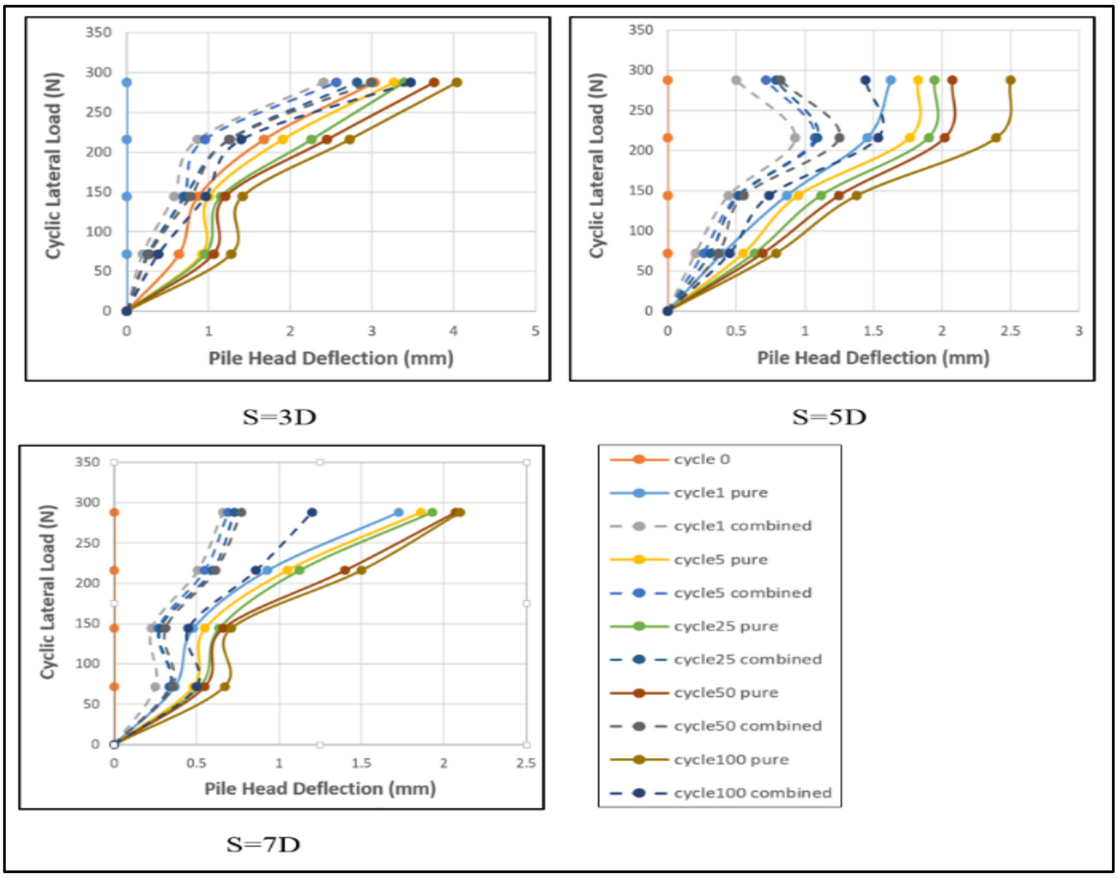
The presence of static lateral load reduces the lateral deflection of the pile head caused by cyclic loading. It can be concluded that the critical angle in this study is zero because it caused the highest value of lateral deflection.

3.2 Influence of pile spacing on load-displacement performance

It is clear from Figure 6 that largest deflection magnitude occurred at spacing of 3D. The lateral displacement begins to noticeably decrease as the pile spacing expands to 5D and 7D, this behavior is attributed to overlapping stresses zone of passive and active wedges.

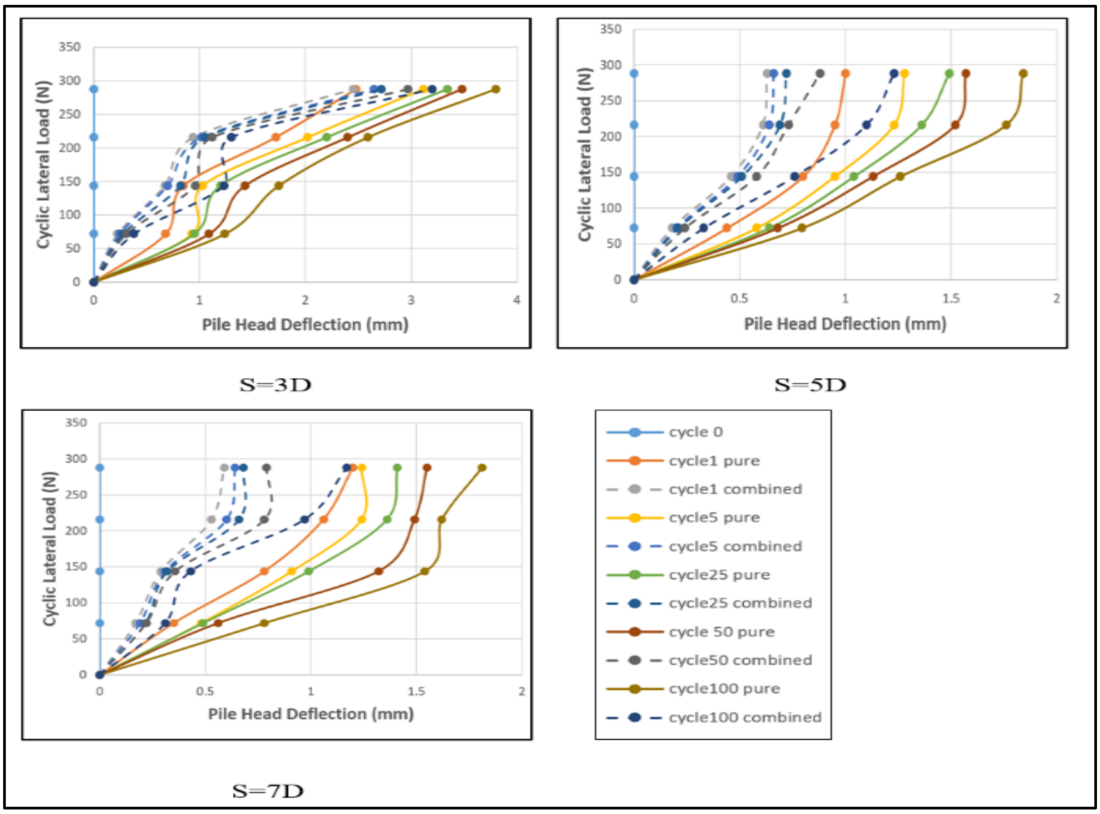
When Comparison the lateral displacement of the pile group for the three spacing at combined loading, that it decreases at S = (5D and 7D) than it is at S = 3D where the decrease equal (140%, 189%) at inclined cyclic loading with angle 0, (160%, 173%) at angle 10°, (77%, 75%) at angle 20° and (67%, 154%) at angle 30°.

That because of the group's shadow influence (the contact between the soil and the pile). The farther the piles are, the less stress areas overlap, resulting in the pile group's better lateral capacity. As well, a gap is formed ahead of the piles at the pile-soil line. This phenomenon is diminished whenever the pile spacing exceeds S =5D because the stress overlap be minimal [17].



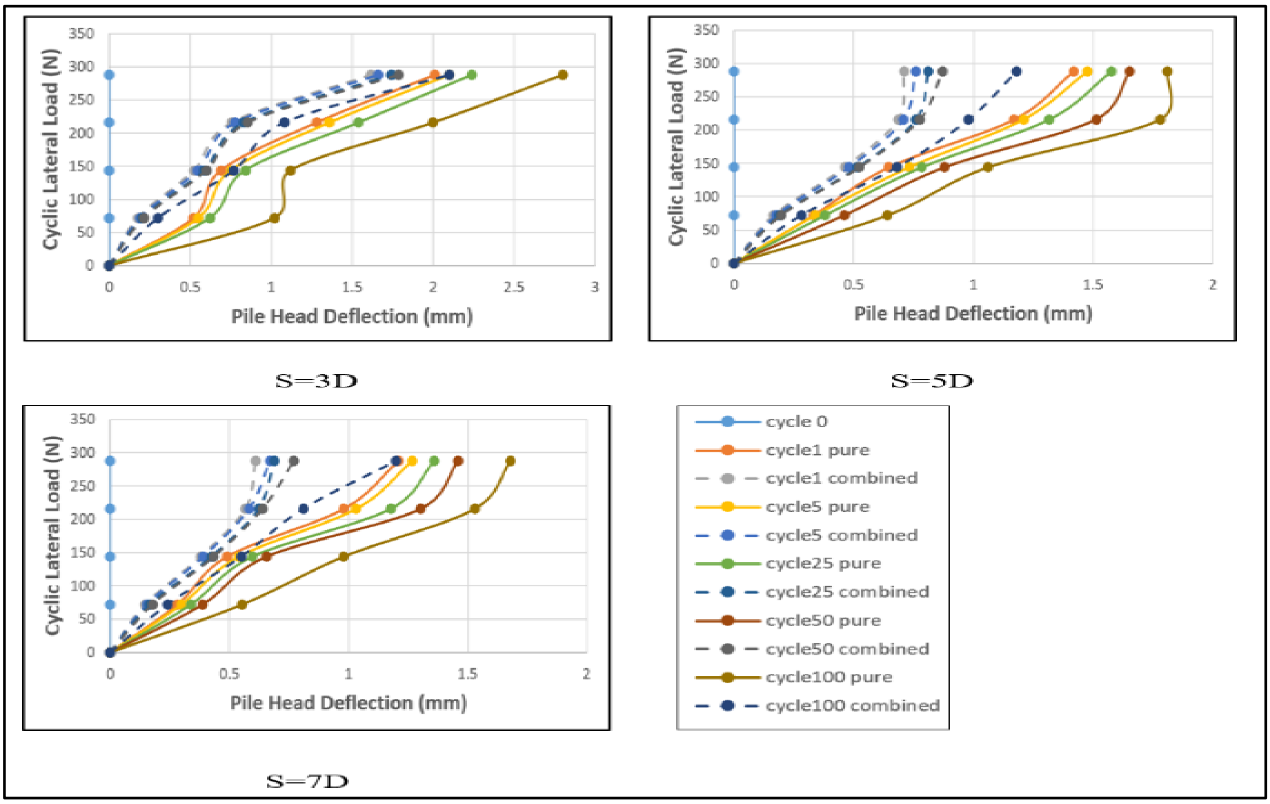
Cyclic Lateral Load (N)
Pile Head Deflection (mm)
S=3D
S=5D
S=7D
cycle 0
cycle1 pure
cycle1 combined
cycle5 pure
cycle5 combined
cycle25 pure
cycle25 combined
cycle50 pure
cycle50 combined
cycle100 pure
cycle100 combined

a)

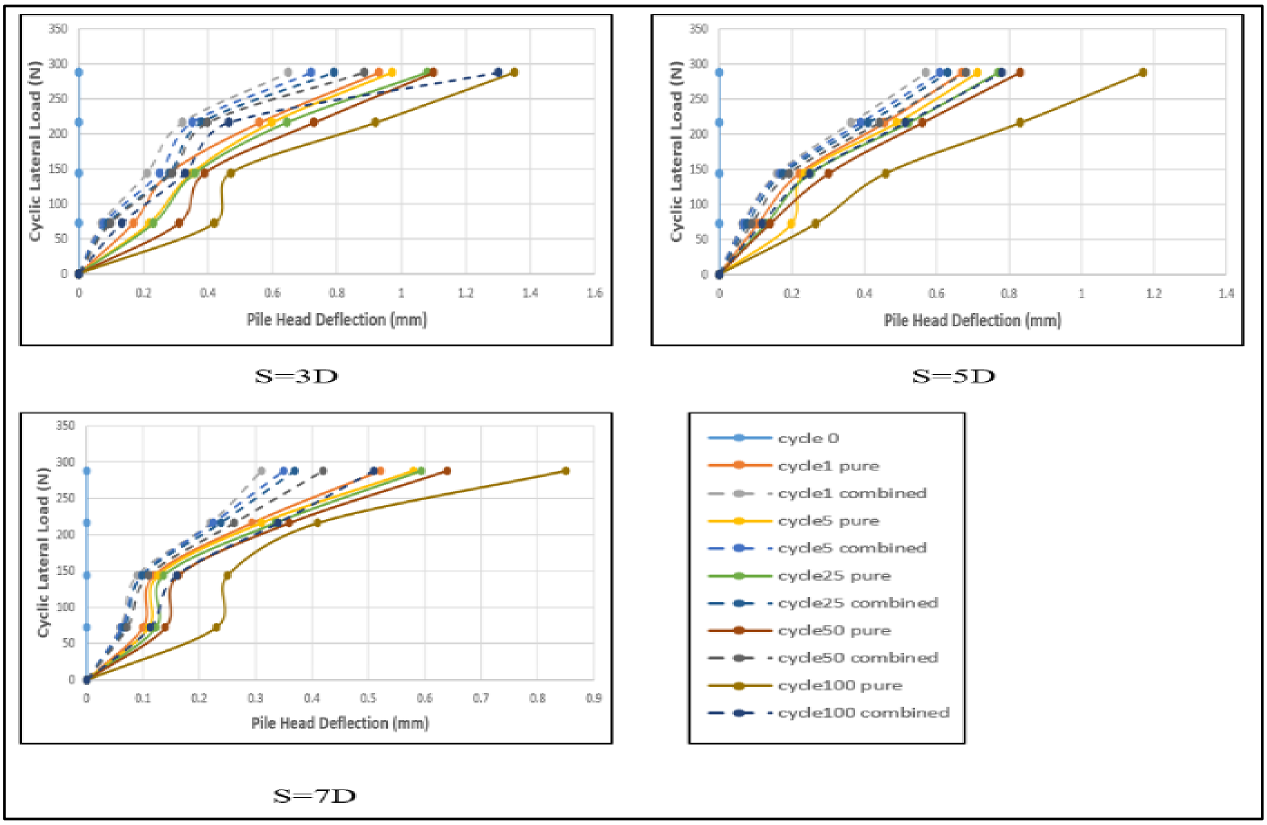


Cyclic Lateral Load (N)
Pile Head Deflection (mm)
S=3D
S=5D
S=7D
cycle 0
cycle1 pure
cycle1 combined
cycle5 pure
cycle5 combined
cycle25 pure
cycle25 combined
cycle 50 pure
cycle50 combined
cycle100 pure
cycle100 combined

b)

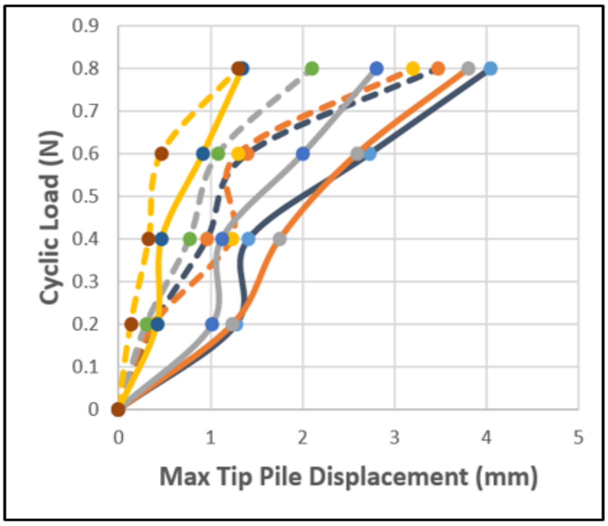


c)

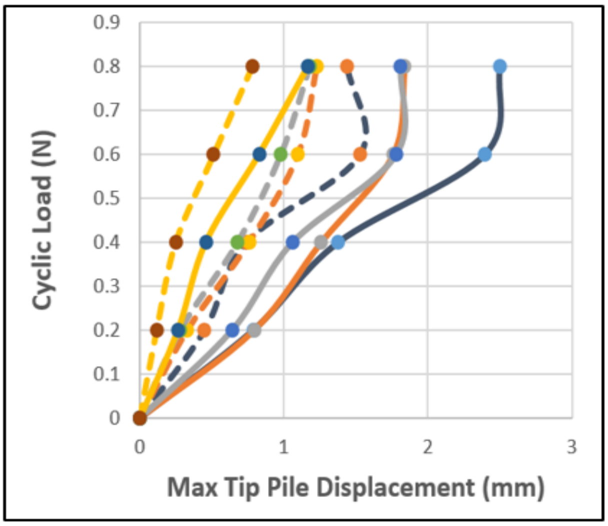


d)

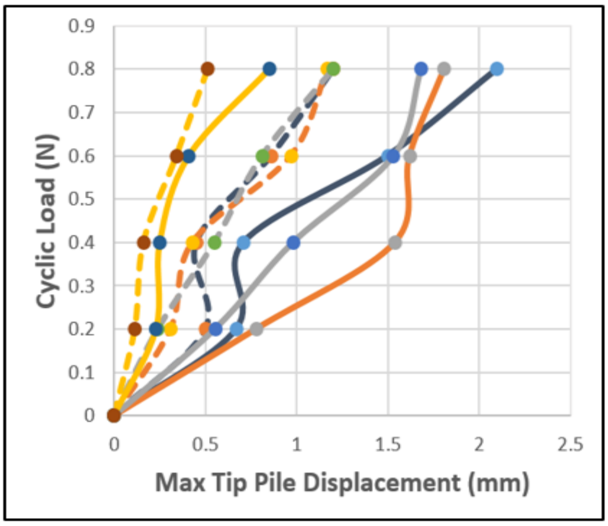
Figure 5. Load-deflection curve at the 100th cycle under pure and combined loads for three spacing at inclination Angles a) 0°, b) 10°, c) 20°, d) 30°

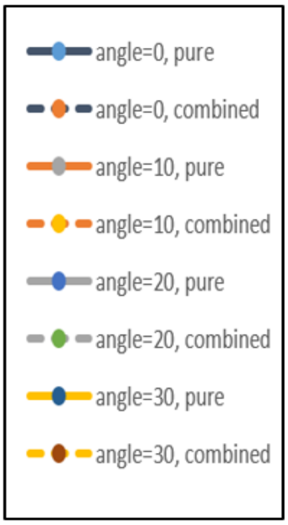


(a)



(b)





(c)

Figure 6. Load-displacement curve at 100 cycles loading under pure and combined loading for four inclination angles: (0^o, 10^o, 20^o and 30^o), a) S=3D, b) S=5D, c) S=7D

4. Conclusions

1. The combination of the static horizontal load with the inclined lateral cyclic load is considered to have a positive effect on the deep foundations where the lateral deflection was reduced by an average of 54% for the three spaces.

2. It is possible to assert that lateral deflection at combined lateral loading decreases with increasing pile distance Where the lateral deflection was decreased to (16%, 73%, 75%) for spacing (3D, 5D, 7 D) respective.

3. Clearly, the increase in the inclination of the cyclic load at combined lateral loading reduces the lateral deflection, where the average of decrease in the deflection of the pile tip is (14%, 32%, 140%) for the angles (10^o, 20^o, 30^o) respectively for three distances (3D, 5D, 7D).

References

[1] O. Azeez, R. Hummadi, and A. Hasan, “Effect of Embedded Length on Laterally Loaded Capacity of Pile Foundation,” American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS), Vol. 56, n. 1, pp. 182-192, 2019.

[2] W. G. K. Fleming, A. J. Weltman, M. F. Randolph, and W.K. Elson, “Piling Engineering”, Blackie and Son Ltd, 1992.

[3] J. C. Reese, and W. F. Van Impe, “Single piles and pile groups under lateral loadings”, Appl. Mech. Rev., Vol. 55, n. 1, B9-B10, 2002.

[4] M. P. Reilly, and S. F. Brown, “Cyclic Loading of Soils from theory to design”, Blackie and Son Ltd, London,1991.

[5] A. Puech, “Design for cyclic loading Piles and other foundation,” Proceedings of TC 209 Workshop 18th ICSMGE, Paris, 2013.

[6] B. B. Broms, “Lateral resistance of piles in cohesionless soils,” Journal of the Soil Mechanics and Foundations Division, vol. 90, n. 3, pp. 123-158, 1964.

[7] H. Poulos and E. Davis, “Pile Foundation Analysis and Design,” Wiley, New York, 1980.

[8] 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.

[9] K. B. Ladhane, and V. A. Sawant, “Effect of pile group configurations on nonlinear dynamic response,” International Journal of Geomechanics, Vol. 16, n. 1, pp. 1-14, 2016.

[10] W. Raongjant, and M. Jing, “Cyclic lateral response of model pile groups for wind turbines in clay soil,” International Journal of GEOMATE, Vol. 12, n. 32, pp. 76-81, 2017.

[11] A. Goswami, and S. Roy, “Ultimate Capacity of Vertical Short Pile under Inclined Compressive Load,” Indian Geotechnical Conference GeoN Est, Vol. 14, n. 16, pp. 1-4, 2017.

[12] 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, Vol. 4, n. 9, pp. 1996-2010, 2018.

[13] W. A. Saleh, and J. M. Abbas, “Effect of Spacing and Cross-Sectional Shape on Piled Raft System Subjected to Lateral Cyclic Loading,” Diyala Journal of Engineering Sciences, Vol. 13, n. 3, pp. 114-122, 2020.

[14] W. A. Saleh, and J. M. Abbas, “Influence of lateral cyclic loading on the piled-raft foundation embedded in layered soil,” IOP Conf. Ser.: Mater. Sci. Eng, pp. 1-12, 2021.

[15] J. M. Abbas, “Experimental Investigation of Pile Foundation Subjected to Lateral Static and Cyclic Loadings,” International Review of Civil Engineering (IRECE), Vol. 11, n. 3, pp. 127-134, 2020.

[16] R. D. Khurshed and J. M. Abbas, “An Experimental Investigation the Response of Pile Groups to Inclined Cyclic Loading in Sandy Soil,” Geotechnical Engineering and Sustainable Construction. Springer, Singapore, pp 435-446, 2022.

[17] S. Basack and A. K. Bhattacharya, “Influence of lateral cyclic load on pile foundation with emphasis on disturbance at ground surface,” Electronic Journal of Geotechnical Engineering, Vol. 14, 09120, 2009.