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Lateral and Axial Displacement of 2×2 Pile Group Under One-way Lateral Cyclic Loading in Sandy Soil

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ABSTRACT

This paper presents the lateral static and cyclic response of a group of piles. The experimental program included this on a small scale using hollow piles of aluminium, and the sand rain method was employed to prepare the sandy soil with a 70% relative density. The case study is a laboratory model of a pile group 2x2 with spacing (i.e., 3D,5D, and 7D), and the proportion of embedded length to circular pile diameter (L/D) = 43. Different lateral cyclic loading ratios CLR of 60%, 80%, and 100% from pile group capacity are used. According to the experiments' results, the vertical and lateral piles' capacity and displacement are greatly impacted by the cyclic-loading variables, which include the number of cycles and the cyclic-load ratio. It can be concluded that when increases in CLR usually influence on pile group performance, and the lateral displacement increasing up to 66% for closely spaced piles. The pile group spacing affects the uplift displacement; the highest reach value (4.7mm) upward is 7D.

1. Introduction

Pile foundations are frequently exposed to horizontal loads generated by various sources, including seismic activity, wind, wave action, landslides, ice flows, ship collisions, etc. Most case studies and experimental investigations about pile foundations for lateral load testing have been conducted utilizing circular piles. [1]. Continuously exposed piles were subjected to lateral cyclic loads caused by wind, earthquake, and wave, particularly when used in offshore structures, therefore it is essential to understand pile behavior in such situations [2]. The engineering structures are subject to several sources of lateral loads, which vary based on the building's location, height, and other pertinent factors [3]. The lateral load capacity of a pile group is affected by the loading method, pile spacing, and soil type [4]. The cycles number, amplitude of cyclic and frequency, and loading also significantly influenced the pile capacities and displacements [5]. Poulos and Davis [6] have proposed two phenomena that could increase the displacement of laterally loaded, increasing there are number of cycles. These include cyclic soil degradation, which reduces the soil's hardness and strength. There are number of studies have been taken into account the influence of cyclic load on the pile group response. In this case, Chandrasekaran [7] investigated using a laboratory model, it analyzes the load-deflection and bending behavior of pile groups embedded in soft clay under cyclic lateral loads. The study investigates the effect of several parameters such as the

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number of loading cycles, cyclic load level, spacing, and group size. Niemann and Loughlin [8] Investigated pile groups in silica sand using a centrifuge model with lateral one-way cyclic loads. Pile spacing, Cyclic load amplitude inside the pile group, and cycle number affect the pile group response. As the number of cycles increases, cyclic loading transfers the load from the leading to the resulting piles. The lateral displacement accumulation of the pile group increased as the piles were closer spaced, and the cycle load amplitude increased. Other study included pile groups subjected to cyclic lateral loads to determine which these loads interact and impact pile group performance. One-way cyclic lateral loads led to permanent pile group displacements [9].

In addition, Abass [10], investigated the influence of cyclic load ratio (CLR) on the deflection of a group head in layered soil. This study showed that as the number of cycles increased within the range of CLR 20% to 40%, a deflection of the group head exhibited an upward deflection. Khurshed and Abbas [11] employed a sandy soil pile group model in the laboratory. The group was exposed to cyclic loading in two different directions. In this Research has found that the piles with smaller spacing, denoted as S=3D, exhibit greater deflection than piles with wider spacing. As the spatial separation between the (5D) and (7D) increases, the impact of the pile’s interaction becomes increasingly negligible. As pile spacing increases, the decrease in shadowing results in a reduced level of disparity. Ahmed and Abass [12]2) investigated to estimate capacity lateral load conditions under inclined pile groups (1x2) and (2x1). In this study, utilized were slope degrees (5°,10°,15°) to confirm the lateral behavior of the pile group under static lateral loads. The sandy soil used contains a relative density of 65%. The results of this study show that the (1x2) model is more resistant to lateral movement while placing the lateral static load than the (2x1) model at all angles of inclination (5°, 10°, and 15°) Because its resistance to lateral displacement is greater.

Therefore, due to limit studies regarding the one-way cyclic load with static load for these ranges, this paper investigates the influence pure lateral loading which one-way cyclic lateral loadings to estimate the lateral and axial response with different spacing using a laboratory model in sandy soil.

The aim of the research is to study the effect of the cyclic load ratio (i.e., 60,80,100 CLR) on the behavior of a group pile embedded into sandy soil. the group of pile consist on different spacing (3D,5D, and 7D).

2. Experimental work

2.1 Laboratory container

The container of soil is made of square steel with dimensions of 1000 mm for each side. The sidewalls of the tank are built of 4 mm thick steel plate. These measurements were taken to ensure that the soil tank's walls did not interfere with the failure zone surrounding the piles.

2.2 Properties of soil used

From southern Iraq, Karbala, sandy soil is collected. All required tests were conducted at the soil laboratory of the University of Diyala/ College of Engineering. Table 1 illustrated the results.

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 (∅)	35.2	ASTM D3040-04(2006)
Cohesion (c) in (kN / m^2)	0	ASTM D3040-04(2006)
	Dry unit weight	
γd (max.)(kN /m^3)	17.7	ASTM D 4253 - (2006)
γd (min.) (kN /m^3)	14.7	ASTM D 4254 - (2006)
Maximum void ratio, e_{max}	0.79	…………………………………
Minimum void ratio, e_{min}	0.53	…………………………………
Field dry unit weight, γd (kN/m^3)	16.23	…………………………………
Relative density D_r.	70%	…………………………………

2.3 Pile and pile caps

The piles are hollow pipes with 16 mm in diameter and circular cross-sections made from aluminum. The total pile length is 690 mm, while the embedded depth is 640 mm; therefore, the ratio of the length to the diameter (L/D) of 43. By performing tensile tests by the 2005 ASTM-A370 standard, the modulus of elasticity was calculated, yielding the value E=68.75 MPa. The cap pile contains a plate in order to perform one-way cyclic loading with four screws are fixes on the cap to stabilizes the static axial load, as shown in Figure 1.

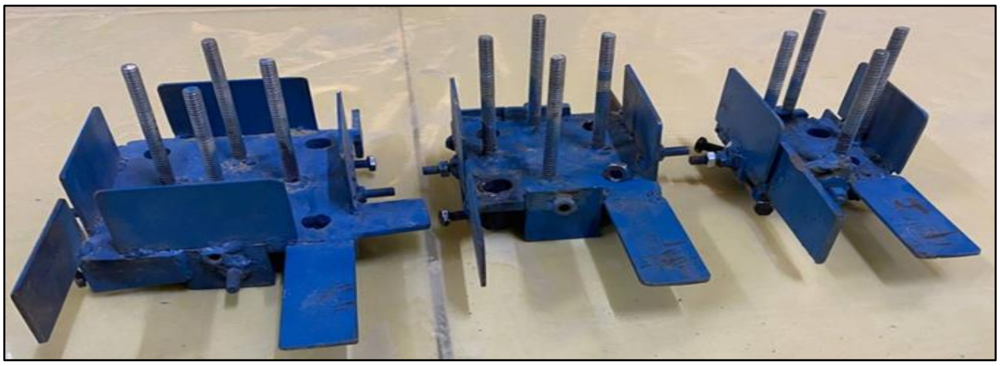


Figure 1. Pile caps with different spacing

2.4 Preparation of sand

Specialized raining apparatus is devised and built when fixed model piles are used to provide a uniform deposit of the specified density as illustrated in Figure 2. A steel framework, an openable container (1000-200-200 mm), two opening strips, and motorized gates compose the device. In the rainy method, the drop height and sand discharge rate have a major impact on the targeted unit weight of the sand deposit. The two moveable shafts allow the sand's free-fall height to be adjusted in relation to the sand tank. The openings in the top rainfall container can be changed to control the rate at which sand is released. Dr= 70% relative density was attained.

Figure 2. Preparation of Sand (a) rain technique - (b) piles installation

2.5 Testing procedure

1. During the static loading phase, and separately, the group is exposed to lateral loading depending on the Broms criteria for failure that the final lateral capacitance should be equivalent to the load equivalent to a 20% deviation from the pile diameter [13].

2. The second stage included the lateral cyclic load that applied in one direction in different ratios of the cyclic load ratio (i.e., 0.6, 0.8. and 1.0), as illustrated in Figure 3. The CLR is defined as the ratio between the maximum cyclic lateral load and the ultimate static lateral capacity of the pile [14]. Where the examination is based on the number of cycles, where takes place in 100 cycles in the natural frequency of (0.2HZ), where the duration of one cycle is 5 seconds.

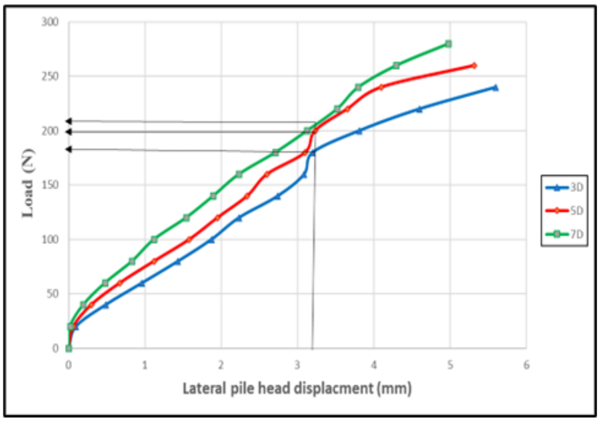


Figure 3. The tool used in this study

3. Results and discussion

3.1 lateral pile group exposed to a static load

Estimating the lateral displacement under static loading of a pile group (2x2) in various spacing (3D, 5D, and 7D). That is, the lateral load is applied to the head of the pile groups to estimate the ultimate bearing capacity for all the spacing groups in the model. Then the average is taken to calculate the loading ratio of cyclic load through the average ultimate loading values of the lateral static loads of these circular piles. Figure 3 shows the results of static loads for a group of piles. It can seem that the maximum lateral displacement reaches to 3.2mm at the failure zone to estimate the load capacity as illustrated in Figure 4.

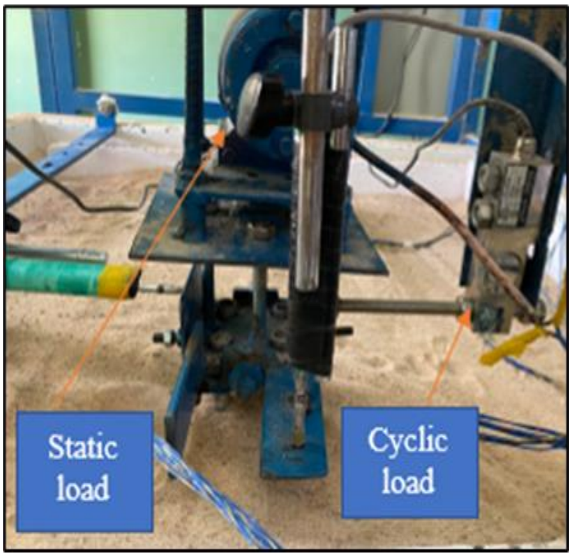
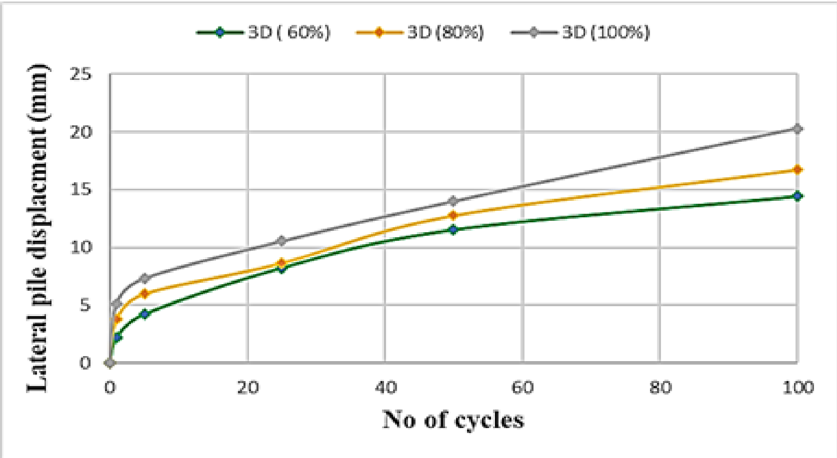


Figure 4. lateral static displacement of pile group

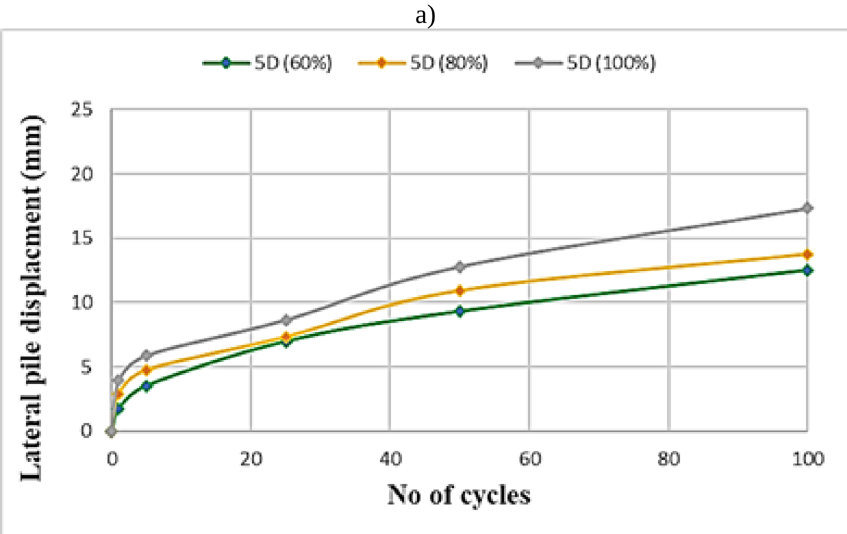
3.2 lateral pile head displacement in different critical load ratio

Figures 5 shows the cases of pure cyclic in pile groups with the influence of the number of cycles and critical load ratio (CLR) on the lateral displacement of the piles group. These cycles in this investigation were selected (1, 5, 25, 50, 100). This figure illustrates reducing pile spacing from 7D to 3D greatly increased lateral displacement, this is because stress zones that develop at close pile spacing are superimposed with the group's shadow impact (the contact between the soil and the pile). This reduced the resistance of the soil inside the pile group to further loading cycles. The soil column inside the group is remolded and softened by repeated cycles of lateral pressure, leading to massive deflections, when the pile is composed of closely spaced groups that exhibit failure behavior, this is according to research (Chandrasekaran). In most cases, it can be seem that the rapid rise in lateral displacement is due to the formation of gaps around the piles, which decreases the soil's resistance to passive pressure [15].

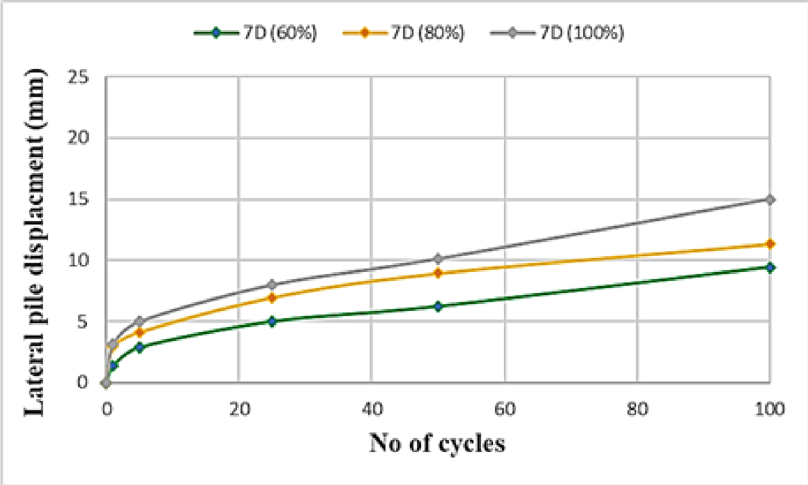
For a group with 3D, the comparison between load CLR of 60%, with other magnitudes of 80% and 100%, the lateral displacement increased by 14% and 42%, respectively. In addition, when increasing pile spacing to 5D, the lateral displacement increased to 8% and 42%, respectively. Finally, for 7D, the lateral displacement increases to 22%, 66%, respectively.



a)



b)



c)

Figures 5. lateral pile displacement with various spacings (a) 3D (b) 5D (c) 7D

3.3 Effect of pile spacing in the lateral pile head displacement

Figure 6 shows load-displacement curves computed with varied pile spacing at 100 cycles. The results show that increased in pile group spacing leads to decreased lateral displacement. In this case, 3D has a greater lateral displacement than 5D and 7D because the overlap of stress zones decreases, resulting in an increase in the lateral capacity of the pile group and a decrease in pile-soil interaction, commonly referred to as the "shadow effect." This phenomenon is recommended by many researchers (e.g. [16 and 17]). For a group with 3D, compared to the 60% CLR, can be obtain lateral displacement greater than 5D by 15% and 52% greater than 7D. When the cyclic loading was increased to 80% CLR, the displacement of 3D was greater than that of 5D and 7D by (21.5% and 47.7%), respectively. While for 100%, the value of 3D gave a displacement greater than 5D and 7D by (17.2%, 35%), respectively.

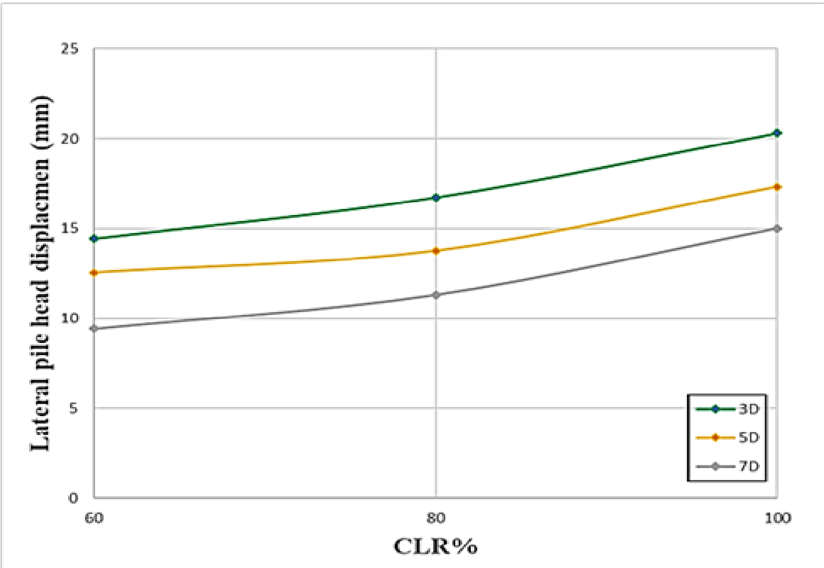
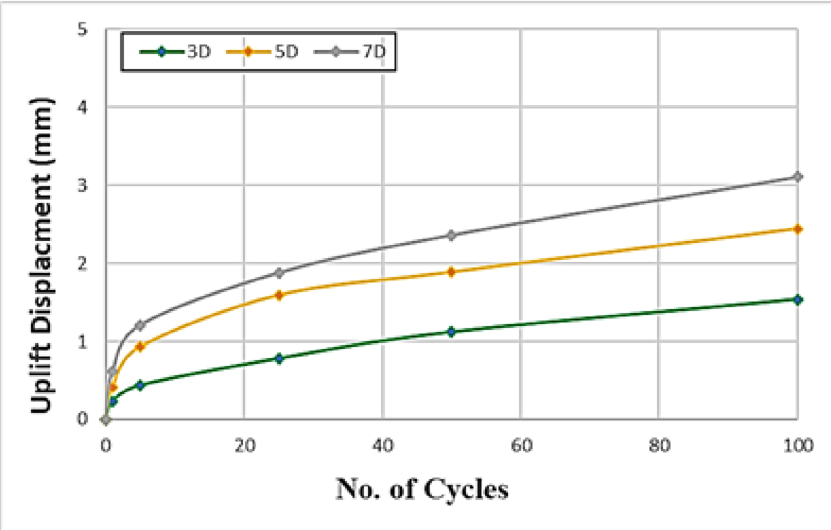


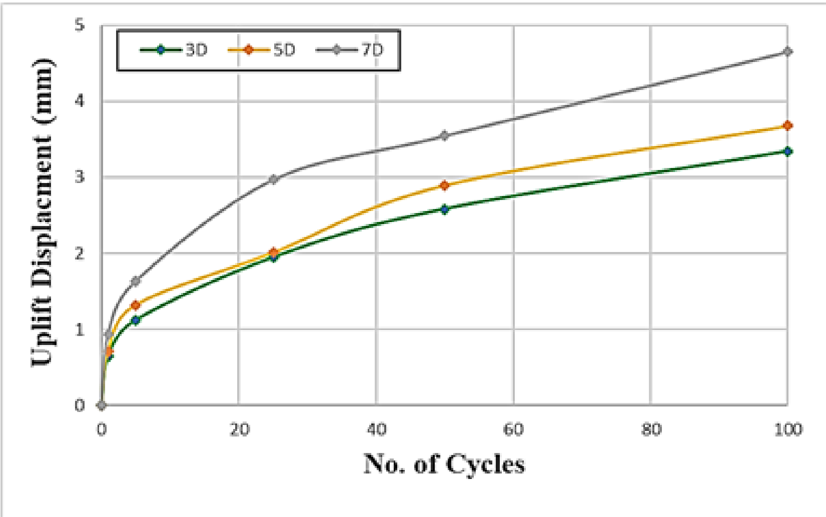
Figure 6. Effect of pile spacing in the lateral displacement with various of CLR

3.4 The uplift displacement of pile group

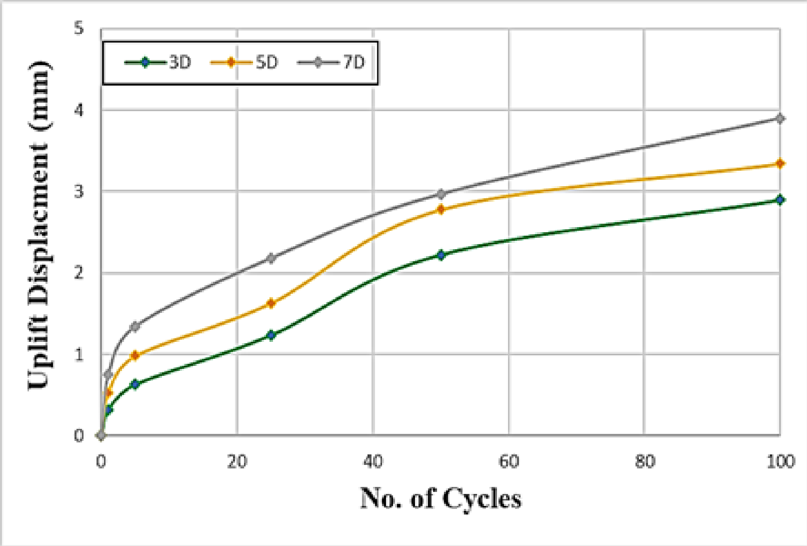
Figure 7 shows the uplift displacement with different spacing due to cyclic load. As the CLR ratio increases, the uplift displacement increases. Where the group of piles uplift to the top when testing the lateral cyclic loading with static load (4.5) Kg from the first cycle to the cycle 100 and the uplift displacement of the pile group increases as the CLR (i.e., 60,80, and 100%) ratio increases, as the group of piles gradually uplift with the increase in the number of cycles. This is because, as the number of cycles increases, the friction between the pile and the soil changes from positive to negative owed to the interplay of stresses and the radial movement of the soil around the pile. Furthermore, when subjected to repeated cyclic loading, the compact sandy soil a reduction in stiffness and developed voids between the particles that became filled with air. This resulted in an increase in the overall volume of the soil, consequently leading to the uplift of the group pile. Hussien et al. [18] conducted a study. from lab experiments it has been noted that the higher no of cycles the higher uplift displacement After 50 cycles the uplift of foundation is almost levelled off in other words the uplift is almost negligible. The value of 7D gives an upward displacement greater than 5D and 3D. For the group with 7D, with 60% CLR, it gives uplift displacement greater than 5D by 27% and 102% greater than 3D. When the cyclic loading was increased to 80% CLR, the uplift displacement of 7D was greater than that of 5D and 3D by (16% and 34%), respectively. While for 100% CLR, the value of 7D gave a displacement greater than 5D and 3D by (27%, 28.7%), respectively.



a)



b)



c)

Figure 7. Uplift pile displacement with various CLR (a) 60% (b) 80% (c) 100%

4. Conclusions

1. The increase in CLR often has an impact on the lateral pile displacements, especially when the spacing is smallest. The displacement between the smallest and largest spacings reaches 66%.
2. The lateral pile group displacement are typically influenced by the pile spacing and the maximum value reach (20 mm) for 3D
3. The pile group spacing affects the uplift displacement; the highest value (102%) is achieved between the smallest and largest spacings.
4. The laboratory results obtained had showed that the best performance that can be relayed on was at spacing of 5D. The maximum lateral displacement reached 17.3mm and the maximum uplift reached 3.6mm.

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