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Evaluation of the Pile Group Response for Machine Foundation under Lateral Cyclic Load in Sandy Soil

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Keywords:
Pile group; Machine foundation; Cyclic load; Lateral displacement.

Highlights:

- *Behavior of pile group under periodic load.*
- *Performance of machine foundation subjected to cyclic load.*
- *Estimation of pile group foundation under machine capacity subjected to cyclic load.*

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Abstract: In this paper, two types of loads have been applied at the same time, the first was one-way cyclic, and the second was dynamic load from the machine in sandy soil with a relative density of 70%. These loads were applied in a group of piles of (2×2) with a spacing of S/D= 3, 5, and 7. Close to practical situations, the loads were applied simultaneously at frequency rates of (15, 20, and 25 Hz) for dynamic load and different rates of cyclic loading of (0.6, 0.8, and 1.0) obtained from critical load rate CLR. It can be concluded that, the lateral displacement decreased when increasing the machine frequency. In addition, the increase of CLR usually influenced pile group performance, and the displacement increased to 75% for closed-spaced piles.

تقييم استجابة مجموعة الركائز لأسس الماكينات تحت التحميل الدوري الجانبي في التربة الرملية

سيف سمير عبدالحافظ، جاسم محمد عباس
قسم الهندسة المدنية/ كلية الهندسة/ جامعة ديالى/ بعقوبة، العراق.

الخلاصة

في هذا البحث تم تطبيق نوعين من الأحمال في نفس الوقت، الأول كان تحميل دوري في اتجاه واحد، والثاني هو الحمل الديناميكي من الآلة في التربة الرملية كثافتها النسبية ٧٠٪. يتم تطبيق هذه الأحمال في مجموعة من الركائز مقاسها (٢×٢) بمسافة (S/D =٣،٥،٧.) وفي الحالات العملية، يتم تطبيق الأحمال في وقت واحد بمعدلات ترددية (١٥، ٢٠، ٢٥ هرتز) الحمل الديناميكي ومعدلات مختلفة للتحميل الدوري (٠,٦، ٠,٨، و١,٠) تم الحصول عليها من معدل الحمل الحرج CLR. يمكن الاستنتاج أن الإزاحة الجانبية تقل عند زيادة تردد الآلة. فضلاً عن إن زيادة CLR عادة ما تؤثر على أداء مجموعة الركائز، وترتفع نسبة الإزاحة إلى ٧٥٪ للأكوام ذات المسافات المغلقة.

الكلمات الدالة: مجموعة الركائز، أسس الماكينة، الحمل الدوري، الإزاحة الجانبية.

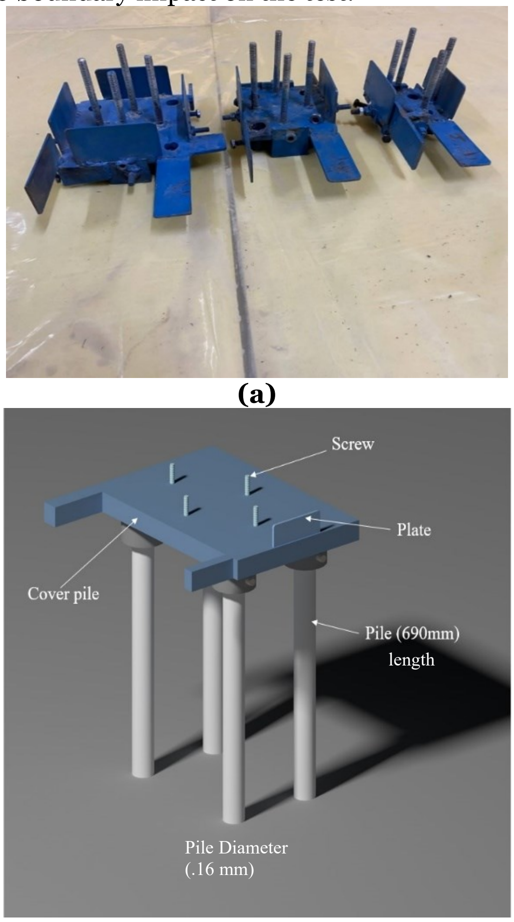
1.INTRODUCTION

Pile foundations are commonly employed to support significant structures, including bridges, piers, docks, dolphin constructions, offshore platforms, and jetties. Based on practical situations, piles support vertical, lateral, and combined vertical and lateral loads, and other sources, such as cyclic and dynamic loads. In the case of cyclic load, the loads exerted by wave and wind should be considered in pile group design. In addition, the pile foundation may carry the dynamic load from machine work. Based on previous reports and when examining the lateral response of piles, it is common practice to assess the piles' vertical or lateral reactions independently while considering the potential interplay between them [1]. As a result of the reversal of stresses induced by the cyclic load on piles, the strength and stiffness of the nearby soil gradually change, resulting in a decrease in pile capacity and irreversible deformation [2]. Pile groups often respond differently when resisting cyclic lateral loads due to the interaction between neighboring piles, typically reducing pile group capacity. Loads on the front piles, i.e., on the free load side, of a group are always greater than those on the back piles, i.e., on the load side, even though the same amount deflects both piles. A row of piles' lateral resistance behind the failure surface is reduced due to interference (shadowing) from the row ahead [3]. The number of cycles, frequency, and amplitude of cyclic loading significantly impacted pile capacities and displacements [4]. In addition, One-way lateral cyclic load also significantly impacts the soil's stiffness and strength towards the front of the piles rather than the rear [5]. Many studies consider these parameters. For example, the pile's lateral movement varies with the critical load ratio (CLR). In addition, the distance between piles, the design and size of the group, the characteristics of the loading, the kind of soil, the relative stiffness, the length of the embedment, and the state of the pile head fixity have been tested for pile groups behavior [6]. The pile spacing significantly impacts the pile group load distribution. Therefore, the pile loads decrease with increasing pile spacing [7]. Another study investigated group piles' load-deflection and bending behavior in soft clay subjected to cyclic lateral loading. The study examined the impact of various factors, including the number of loading cycles, cyclic load level, spacing, and group size [8]. In the laboratory test conducted, Khursheed and Abbas [9] performed four values of CLR at a frequency of 0.2 Hz. The test results indicated a reduction in the lateral resistance for all groups and distances examined. Displacing pile groups increased with the number of cycles [9]. The complex nature of foundation design under dynamic loads necessitates involving various fields, including geotechnical engineering, structural and mechanical engineering, and vibration sources. When utilizing a deep foundation system, it is imperative to comprehensively comprehend the dynamic interplay between the piles and the soil, commonly called pile-soil interaction, and the interplay between adjacent piles [10]. Novak and El-Sharnouby [11] conducted dynamic experiments in the field on many small, closely spaced piles. They concluded that the dynamic analytic methods may accurately forecast the key characteristics. Al-Mosawe et al. [12] experimentally investigated machine foundations subjected to harmonic load on dry and wet sandy soil. It was found that increasing the relative density, degree of saturation, depth of embedding, and area foundation decreases the amplitude of foundation displacement. In contrast, the amplitude of dynamic force and operation frequency increased the amplitude of foundation displacement [12]. The impact of a footing form lying on dry sand when subjected to machine dynamic loads at various frequencies, including 0.5, 1, and 2 Hz. Sand with medium and dense relative densities, i.e., R.D. = 50% and 80%, was used. The amplitude displacement decreased as the operation frequency and area of the footing increased [13]. Fattah and Hamood [14] used ANSYS.11, a finite element software, as an instrument for the dynamic analysis of machine foundations. They determined the effect of the pile geometry beneath the foundation, the dynamic load amplitude, the damping ratio, and the load frequency. It is concluded that the frequency ratio decreased as the distance between piles increased due to natural frequency increase, except in the case of 3 m spacing. Therefore, this paper used a laboratory model to estimate the lateral response of a pile group under combined loading, i.e., machine and one-way lateral cyclic loadings, with various spaces in sandy soil.

2.MATERIALS AND TEST SPECIFICS

2.1.Piles Model and Piles Cap

Aluminum hollow pipes with circular cross-sections and a diameter of 16 mm (closed-ended pile) were employed. The length of the pipes was 690 mm, the embedded depth was 640mm, and the ratio of the embedded length to its diameter (L/D) was 40. The modulus of elasticity was estimated through the conduction of tensile tests in accordance with the ASTM-A370 standard of 2005, yielding a value of E=68.75 MPa. The cap contained four screws to place the dynamic load on it, as shown in Fig. 1. The pile cap dimensions were (96×96, 128×128, and 160×160 mm) depending on the distances between the piles, i.e., 3D, 5D, and 7D, respectively. Because the sandy soil top surface was squared meter, the pile was installed with no boundary impact on the test.



(a)

(b)

Fig. 1 Pile and Pile Caps, a) Pile Caps and b) Pile Group.

2.2.Preparation of Sand and Pile Installation

Before beginning the raining process, piles were set within the container using guides. The sand was emptied when fixed model piles, and specialized raining apparatus was developed and constructed to provide a uniform deposit of the desired density. The device comprised a steel framework, an openable container (1000-200-200 mm), two opening strips, and motorized gates. The drop height and sand discharge rate significantly affect the targeted unit weight of the sand deposit in the raining method. The two movable shafts allow for the free-fall height of the sand to be modified concerning the sand tank. The top rainy container's holes may be adjusted to control the sand's release pace. A relative density reached Dr= 70%, as shown in Fig. 2. The pile caps were then fixed while the raining technique was completed. The density achieved with 70% was 1140 mm, corresponding to the fall's height, as illustrated in Fig. 2 (c). The sand was put into the container by moving it back and forth while specifying the proper height by sprinkling sand within the rain mechanism. Then, until reaching a total height of 1000 mm from the base of the container, construct ten layers of sand, each with the same height of 100 mm.

3.TEST SETUP

These tests include combined loading, i.e., one-way cyclic and dynamic loading. Inside the container, a damper was implemented to avoid wave reflection. The dimensions of this container were (1 × 1 × 1) m. The lateral static load-bearing capacity was determined by considering the loads corresponding to a 3.2 mm deflection based on [1], i.e., equivalent to 20% of the diameter of the pile [15]. The critical Load Ratio (CLR) was determined as a percentage of the cyclic load level to the ultimate static lateral capacity of the pile [16]. In this case, the cyclic load was (0.6, 0.8, and 1) from CLR with a frequency of 0.2 Hz. This test continued for 100 cycles. At the same time, these loads were tested with three frequencies resulting from the machine foundation, i.e., 15, 20, and 25 Hz. Based on whether the maximum and minimum loads were in the same or opposite directions, the nature of the cyclic lateral loading can be classified as one-way or two-way. Cyclic loads that induce compression or tension on the upper section of piles or a group of piles in any direction are referred to as one-way loads, Fig. 3 (c). The machine foundation, consisting of a base, was installed on a group of piles. Above this base, a machine that oscillates worked in a rotating disc, where this oscillator consisted of a disc rotor made of steel with a diameter of 60 mm and a thickness of 13 mm. A mass was connected to a disk rotating at an eccentricity of (25mm) from the rotation of the central axis. The Digital

Tachometer was employed to check the frequency of the machine foundation. A DC motor was used to drive the oscillator at different frequencies, i.e., 900, 1200, and 1500, that can be divided into 60 minutes to fix the required frequencies (rpm) to identify the impact of the dynamic load on the group pile response during the combined loading with the lateral cyclic load, as shown in Fig. 3.

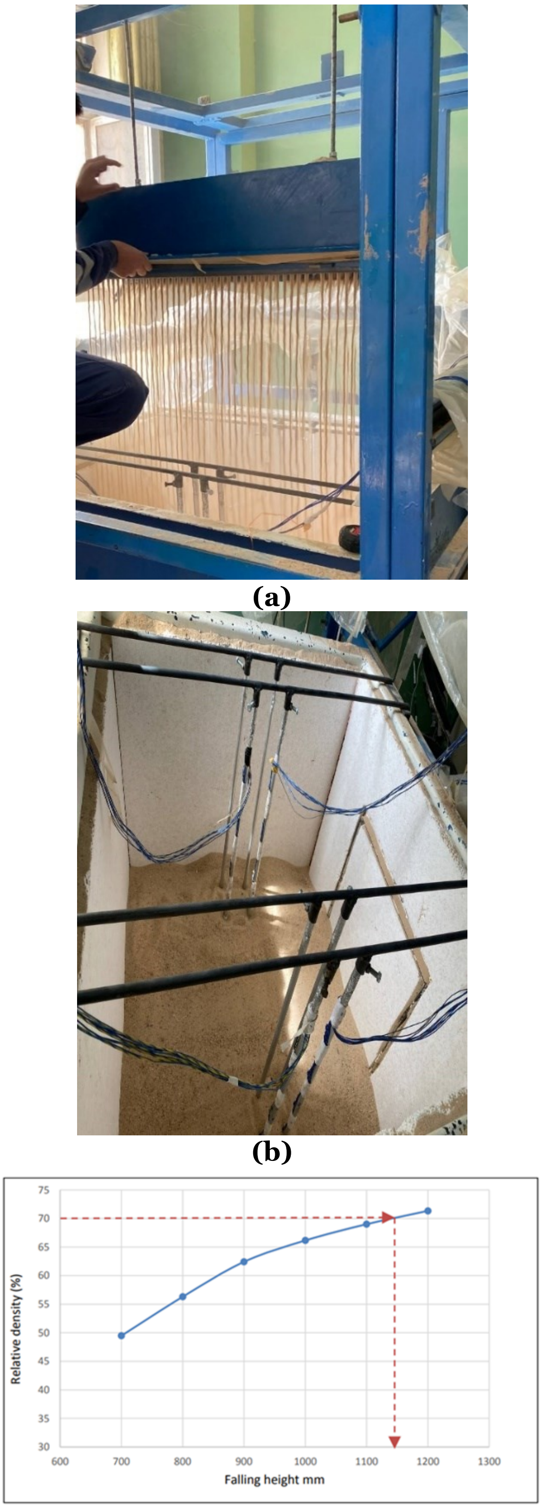


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Fig. 2 Preparation of Sand (a) Rain Technique, (b) Piles Installation, and (c) Calibration of Sand Density.

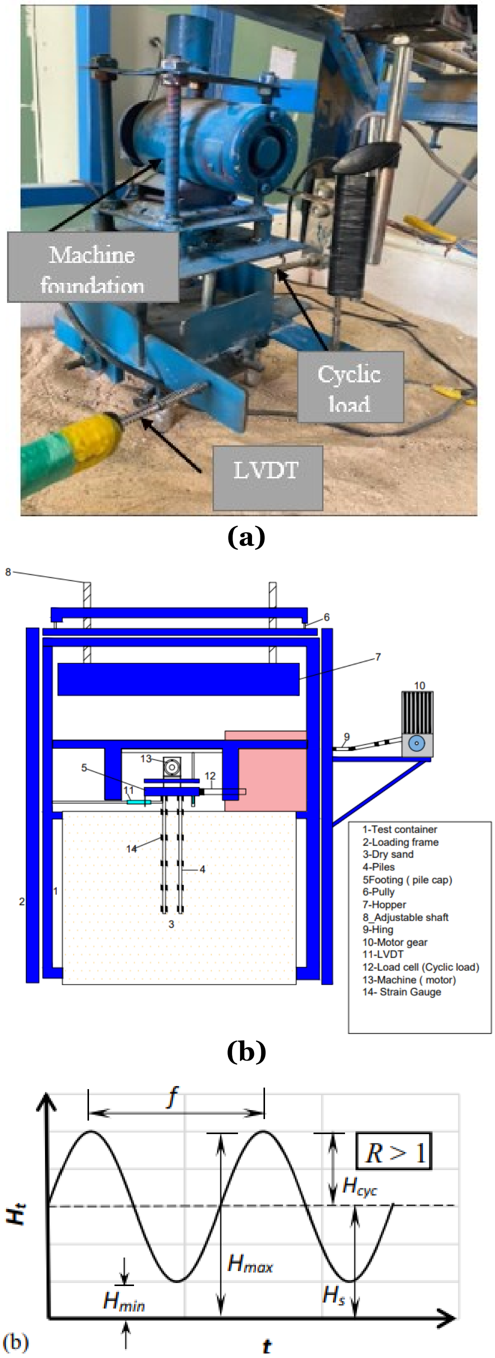

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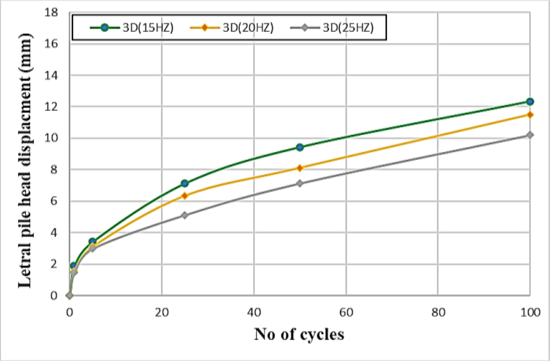
Fig. 3 The Device Used in Work, (a) Machine Device, (b) System Details, and (c) One-Way Cyclic Loading [4].

4.RESULTS AND DISCUSSION

4.1.Lateral Pile Head Displacement in Different Critical Load Ratio (CLR)

Figures 4-6 show the simultaneously combined cyclic and dynamic loading cases. The group of piles was investigated with a spacing of (S/D= 3, 5, and 7), as the results are associated with the impact of the number of cycles on the lateral displacement of the piles group. In the pile group, the head deflection was controlled using a type of inductively Linear Variable Displacement Transducers (LVDTs). The transducer bolted with a data logger read with eight Channels. These cycles were selected as (1, 5, 25, 50, and 100). The results explained the increase in lateral displacement with the load ratio and cycle number. When the number of cycles increased, the soil's resistance decreased due to the gap that had developed between the piles and the soil due to the accumulated pressures, also indicated by Chandrasekaran [8]. For a group with 3D, compared to the 60% CLR with 15Hz, when the cyclic loading rate was increased to 80%, the lateral displacement increased by 15.5% and increased by 45.7% when the cyclic loading rate was increased to 100%. In the case of 20Hz, when increasing the percentage of cyclic loading to (80% and 100%), the displacement increased by (15.4% and 36.7%), respectively. While at 25Hz, the displacement increased successively at (13.1% and 33.6%) rates when increasing the cyclic loading percentage to (80% and 100%). This reduction in lateral displacement possibly occurred due to soil densification during the increase in dynamic load. In addition, when increasing pile spacing to 5D with 15 Hz, the lateral displacement increased to 12.1% and 50.5% by increasing the CLR from 60 to 80 and 100%, respectively. Conversely, for 20 Hz, the lateral displacement increased by 26.4% and 49.5%. While in the case of 25 Hz, these values were 23.6% and 47.1%. Finally, for 7D, this lateral displacement increased from 60 to 100 CLR with increasing the machine frequencies from 15 to 25 Hz of (18.4, 75.3%) and (18.8%, 58.4%) and (23.1%, and 52.8%), respectively.



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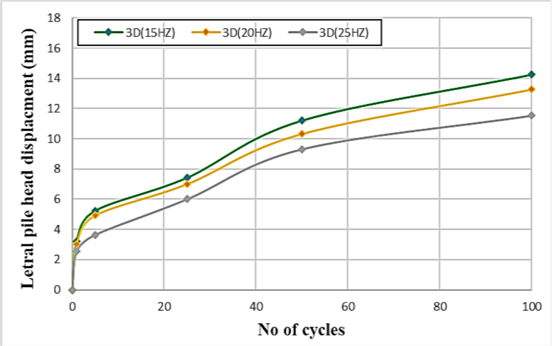

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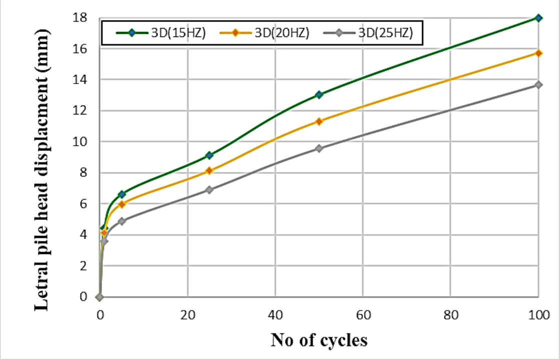

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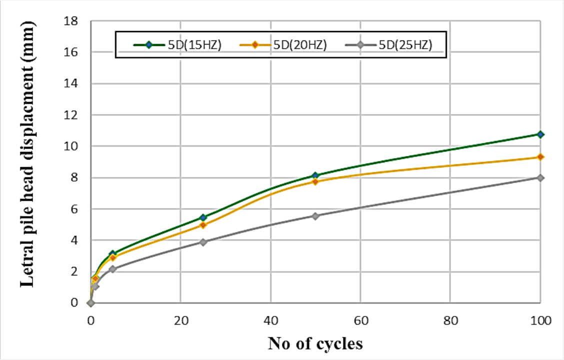
Fig. 4 Pile Head Lateral Displacement for 3D (a) CLR 0.6 with (15, 20, and 25) Hz, (b) CLR 0.8 with (15, 20, and 25) Hz, and (c) CLR 1.0 with (15, 20, and 25) Hz.



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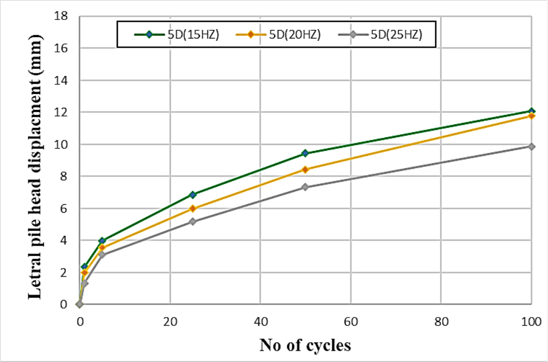

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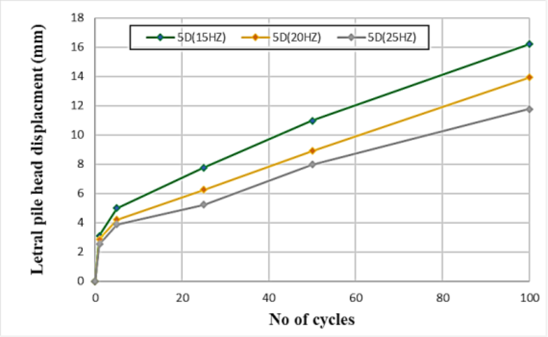
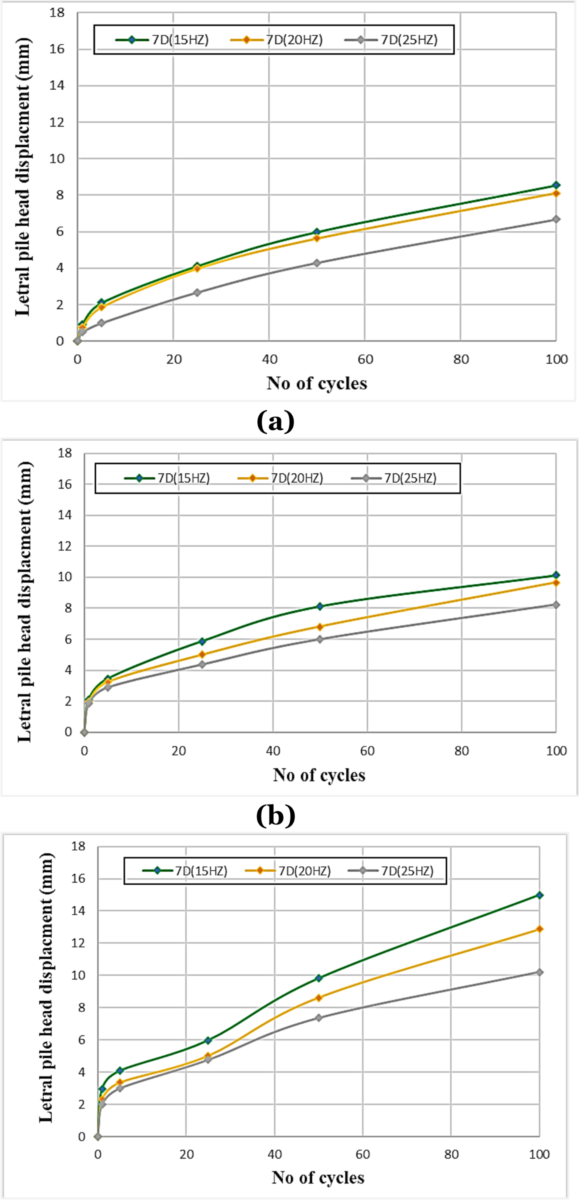


(c)

Fig. 5 Pile Head Lateral Displacement for 5D (a) CLR 0.6 with (15, 20, and 25) Hz, (b) CLR 0.8 with (15, 20, and 25) Hz, and (c) CLR 1.0 with (15, 20, and 25) Hz.



(c)

Fig. 6 Pile Head Lateral Displacement for 7D (a) CLR 0.6 with (15, 20, and 25) Hz, (b) CLR 0.8 with (15, 20, and 25) Hz, and (c) CLR 1.0 with (15, 20, and 25) Hz.

4.2.Effect of Pile Spacing

Load-displacement curves were obtained for a group of (2×2) piles with various pile spacing at 100 cycles, as shown in Figs.7 - 9. The results indicated that larger spacing was generally great for the lower lateral displacement. In this case, 3D showed a greater lateral displacement than 5D and 7D due to the overlap of stress zones reduction, resulting in enhancing the lateral capacity of the pile group and can be due to a decrease in pile-soil interaction, which is commonly referred to as the 'shadow effect.' This phenomenon is indicated by many researchers [17, 18]. For a group with 3D, compared to the 60% CLR with 15HZ, it caused lateral displacement greater than 5D by 12.7% and 30.7% greater than 7D. When the cyclic loading was increased to 80% CLR with 15Hz, the displacement of 3D was greater than that of 5D and 7D by (15.3% and 28.9%), respectively. For 100% CLR with 15HZ), the value of 3D gave a displacement greater than 5D and 7D by (9.3%, 16.2%), respectively. In addition, at the frequency of 20Hz, the 60% CLR of the pile's group of 3D gives lateral displacement greater than that of 5D and 7D (18.9%, 29.3%). Also, for 80%, the displacement increased to 11.2% and 27.2%; for 100%, CLR was 11.3% and 18.1%, respectively. Finally, for frequency of 25 HZ, the percentage for 60% CLR was 21.7% and 34.5%; for 80% and 100% were 14.5% and 28.8% and 13.8%and 25.2%, respectively.

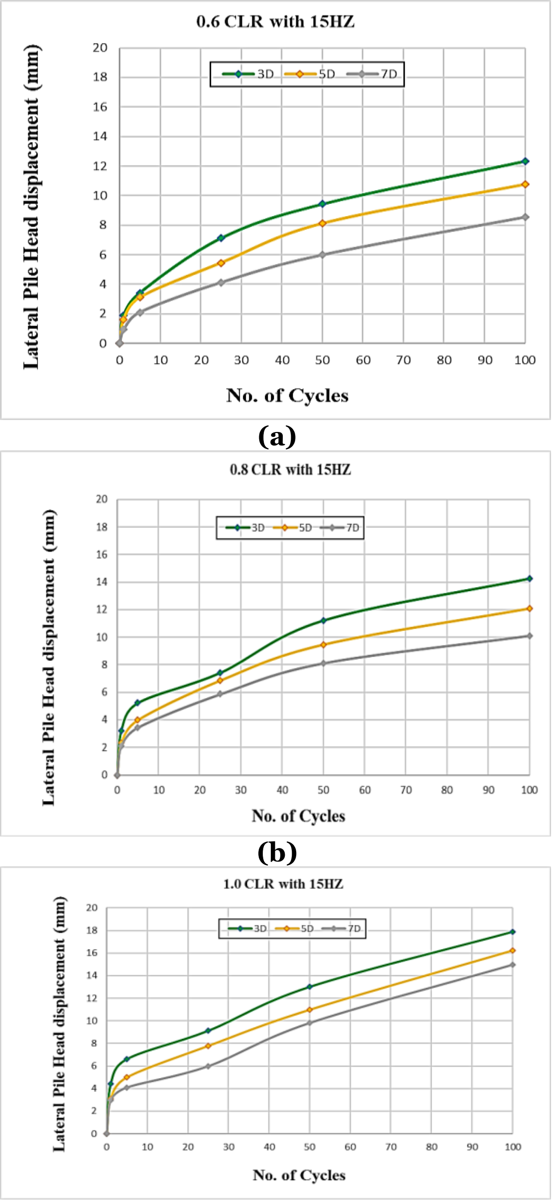


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Fig. 7 Lateral Pile Head Displacement with 15 Hz (a) 0.6 CLR, (b) 0.8CLR, and (c) 1.0 CLR.

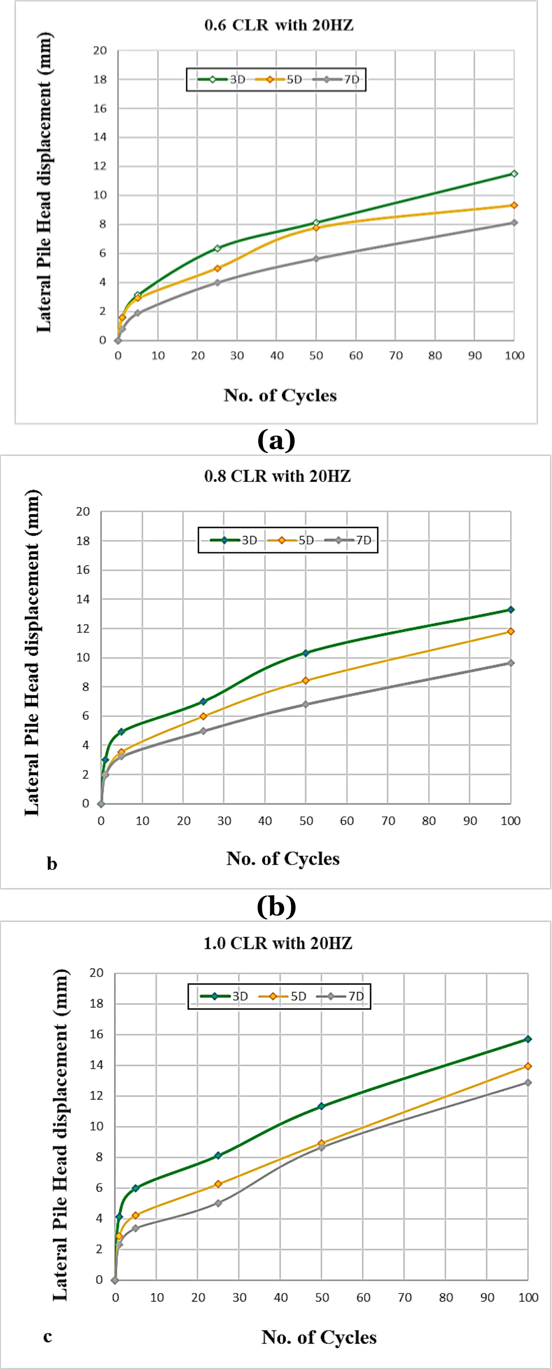

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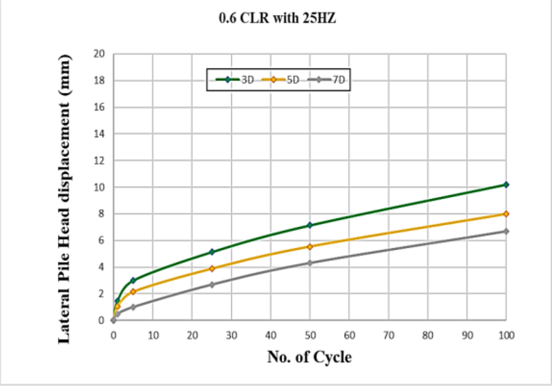
Fig. 8 Lateral Pile Head Displacement with 20 Hz (a) 0.6 CLR, (b) 0.8CLR, and (c) 1.0 CLR.



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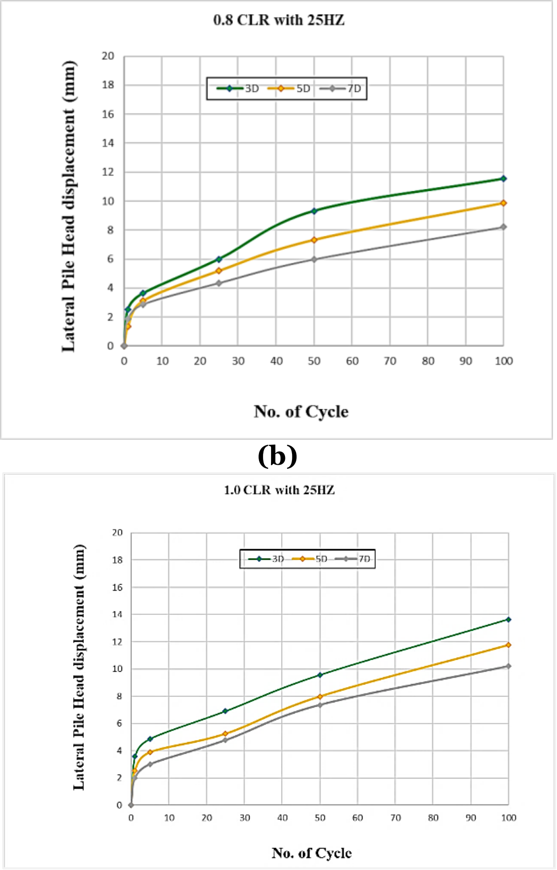


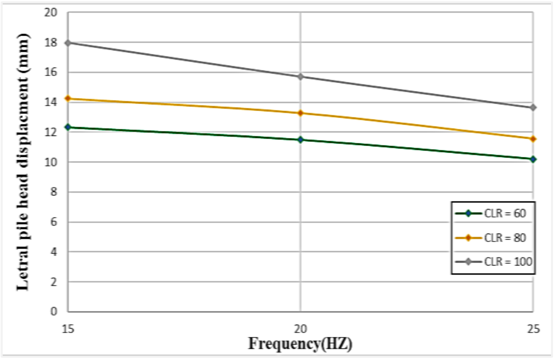
(b)

(c)

Fig. 9 Lateral Pile Head Displacement with 25 Hz (a) 0.6 CLR, (b) 0.8CLR, and (c) 1.0 CLR.

4.3.The Effect of Frequency and Lateral Pile Displacement

The lateral displacement on the pile group under different loading combinations is illustrated clearly in Fig. 10. When the frequency increased, the lateral displacement of the pile group decreased. It decreased with all the spacing in the distances (S/D= 3, 5, and 7) because the cyclic process was in one direction only for the lateral cycle load. While the dynamic load worked in horizontal and axial directions, decreasing the displacement due to soil densification. As the dynamic load increased, the frequency value increased, and the lateral displacement decreased significantly. For more comparison, the high frequency of 25 Hz generally decreased the lateral displacement.



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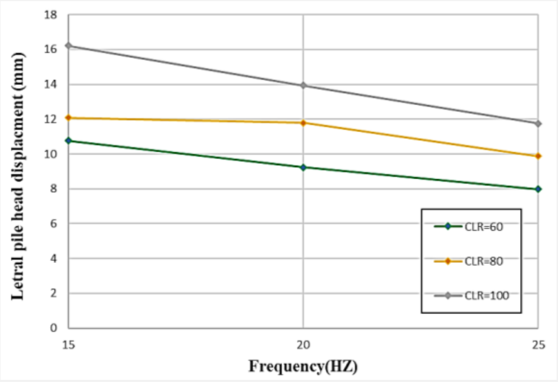

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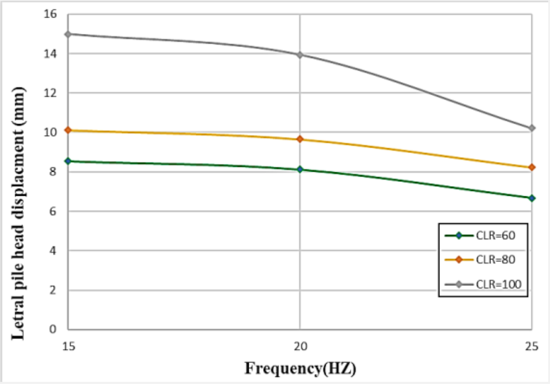

(c)

Fig. 10 Relationship between Frequency and Lateral Displacement with CLR (0.6, 0.8, and 1.0) with Frequency (15, 20, and 25) Hz (a) 3D, (b) 5D, and (c) 7D.

5.CONCLUSION

1- The lateral pile displacements were influenced by increasing the CLR with all machine frequencies, especially in the case of small spacing. The displacement usually increased to 75%.

2- The pile spacing largely affected the lateral pile group displacement. The maximum value reached 18% between 3D and 5D and 34% between 3D and 7D, i.e., 3D was considered the most dangerous case.

3- The lateral displacement generally decreased when applying the dynamic load, which means this type of loading positively affected the group performance for such cases. For further comparison, the lateral displacement of frequency 15 Hz was greater than that of 20 and 25Hz. The minimum displacement reached 7 mm at 25 Hz.

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