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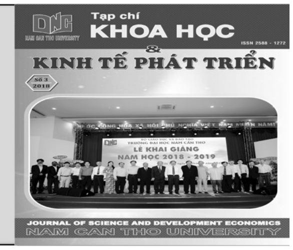

Investigation of the pile group effect subjected to lateral load based on finite element analysis

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Từ khoá: *cọc chịu tải trọng ngang, hiệu ứng nhóm cọc; Plaxis 3D, tính toán phần tử hữu hạn*

ABSTRACT

This study aimed to investigate the pile group effect subjected to lateral load. To achieve this scope, the finite element analysis program Plaxis 3D was used to model a single pile and a pile group with a depth of 18 m. The 2x2 pile groups spaced at 3D and 5D, where D is the pile diameter, were evaluated. The pile diameter D of the piles in the group was 0.4 m and 0.6 m. The pile groups were installed in the soil which located in Southern Vietnam. It comprised of gravel, clayey, and was underlain by stiff clay. Based on the results, it was concluded that the pile group effect is significantly dependent on the pile spacing and the pile diameter. When the pile spacing increased, the pile group effect increased. Similarly, as the pile diameter increased, the pile group effect increased. In the future, further investigation should be performed in order to study the pile group effect, including soil property, pile spacing, pile diameter, and pile length, with practical experiments to gain a better understanding of the pile group effect.

TÓM TẮT

Mục tiêu của bài báo khảo sát hiệu ứng nhóm cọc dưới tác dụng của tải trọng ngang. Phần mềm tính toán phần tử hữu hạn Plaxis 3D đã được sử dụng để mô phỏng cọc đơn và nhóm cọc có chiều dài là 18 m. Nhóm cọc mô phỏng có cấu tạo 2x2 với khoảng cách các cọc là 3D và 5D, với D là đường kính cọc. Đường kính cọc trong nhóm cọc lần lượt là 0,4 m và 0,6 m. Nhóm cọc được mô phỏng trong tầng đất ở miền Nam Việt Nam. Tầng đất được *cấu tạo gồm sỏi sạn, sét và sét cứng. Dựa vào kết quả, nghiên cứu kết luận rằng hiệu ứng nhóm cọc phụ thuộc đáng kể vào khoảng cách cọc và đường kính cọc trong nhóm. Khi khoảng cách cọc tăng, thì hiệu ứng nhóm cọc tăng. Tương tự, khi đường kính cọc tăng, thì hiệu ứng nhóm cọc tăng. Các nghiên cứu tiếp theo về hiệu ứng nhóm cọc cần được thực hiện chú ý đến đặc trưng cơ lý của đất, khoảng cách cọc, đường kính cọc, chiều dài cọc bằng phương pháp thí nghiệm thực nghiệm để hiểu rõ hơn về hiệu ứng nhóm cọc.*

1. INTRODUCTION

Many structures such as offshore constructions, bridge constructions, and earth retaining walls are subjected to a large magnitude of lateral loads, mostly due to wind, wave, traffic movement, and water pressure [1]. For these constructions, the pile foundations are commonly employed to support not only for the vertical loads, but also for the lateral loads. As reported in previous studies, the behavior of a single pile subjected to lateral load is different from that of a pile group [2],[3]. It has been explained in literature for a pile group subjected to lateral load, the individual piles against the soil behind that, themselves, creating shear areas in the soil which enlarge and overlap each other in the pile group [4]. This effect, known as the pile group effect, is dependent on many aspects including the pile spacing, pile diameter, pile arrangement, and soil properties [5],[6]. Several studies have dealt with the pile group effects in considering the lateral load, and these methods can be classified under five solutions: empirical stiffness distribution method [7], hybrid model [8], characteristic load method [9], continuum method [10], and finite element method [11].

To study about the pile group effect of a pile group subjected to lateral load, the maximum displacement and the bending moment of the pile are discussed. These are the important information for the design criteria of pile foundations that are subjected to the lateral loads [1]. To date, a number of researches have been conducted for the pile group effect due to the lateral loads by using finite element analysis methods. Liu et al. (2023) observed the pile group effect considered in soil-pile relative stiffness and pile spacing [12]. In their study, they employed the OpenSee program, an open-source finite element analysis to obtain pile behavior. The number of piles in the group was fifteen. Piles are arranged in five rows, three piles for each row. The results showed that the pile group effect happened to be larger with the larger in soil–pile relative stiffness and the amount of piles in the group. Additionally, the pile group effect increased with the decrease in pile spacing. The pile group effect was significantly affected by pile group arrangement. In another study by Khaled (2022), single piles and pile groups with 2 x 1 and 2 x 3 were investigated [13]. They used the finite element analysis program Plaxis 3D to model the single piles and pile groups with a pile spacing S = 3D (D being the diameter of the pile). They concluded that the pile group effect for the lateral load was strongly dependent on the pile arrangement in the group; the lateral capacity of a single pile was always larger than that of an individual pile in a group. In the past, Kim and Brungraber (1976) performed full-scale lateral load tests of pile groups in the cohesive soil [14]. Three 2 x 3 pile groups spaced at 3.6D and 4.8D were manufactured and tested. They concluded that when the pile spacing increased, the resistance of the pile group increased, and the load-carrying capacity for the individual pile in the group was lower than that for a single pile at the same displacement. In 1973, Singh and Verma (1973) observed the lateral behavior of a single pile and pile group embedded in sand with the large-scale model tests. The results indicated that the load-deflection curves of the pile under lateral loads were non-linear. The behavior of the single pile and the pile groups was different due to the pile group effect [15]. It can be seen that, when subjected to lateral loads, the pile group effect had a significant effect on the behavior of the individual pile. To investigate the pile group effect, the experiment method and the finite element analysis have been commonly employed. There have been a large number of concerns related to the pile group effect, including the effect of pile diameter, pile arrangement, pile numbers, and soil properties...

The aim of this study was to figure out the impact of pile diameter and pile spacing in a group on the pile group effect. To achieve this scope, the finite element analysis was used. A single pile and a pile group with a pile cap of size 4.2 m x 4.2 m were modeled. The pile group configuration of 2x2 pile groups spaced at 3D and 6D, where D is the pile diameter, was evaluated. The pile diameter of the piles in the group was 0.4 m and 0.6 m. The study focused on the effect of pile diameter and pile spacing on the pile group effect. Therefore, a consistent lateral load value of 100 kN was applied. The single pile and pile group were installed in the soil located in Southern Vietnam.

2. MATERIALS AND METHODS

2.1 Finite element analysis program Plaxis 3D

The pile group effect in this study was evaluated using finite element analysis program Plaxis 3D, a software designed for advanced analysis of geotechnical problems. The pile foundations were modeled with a three-dimensional geometry according to the work-plan. It is noted that the model should be large enough to ensure that the boundary conditions will not affect to the analysis results. The three-dimensional network model used in this study was presented in Figure 1.

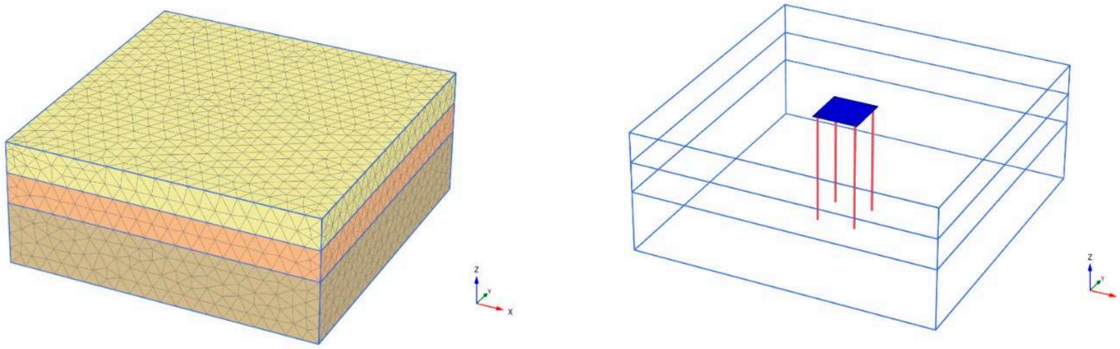

Figure 1. The pile group in the finite element analysis program Plaxis 3D

A single pile and a 2x2 pile group of concrete piles with a depth of 18 m and diameters of 0.4 and 0.6 m were analyzed. The groups with pile spacing three times (3D) and five times (5D) the pile diameter were driven into a soil profile composing of gravel, clayey sand underlain by stiff clay. The pile group subjected to a static lateral load through a concrete pile cap. The square pile cap had a size of 4.2 m x 4.2 m and a thickness of 2.0 m. Figure 2 showed the pile group configuration in the current study.

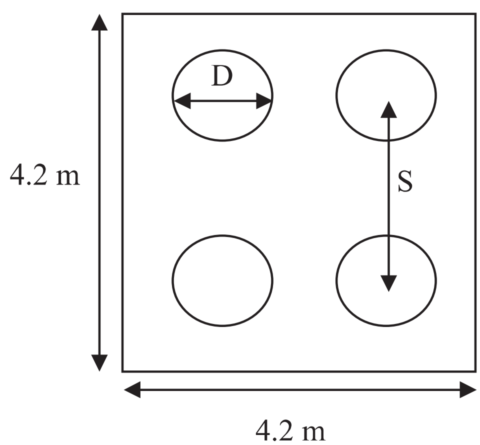

Figure 2. The pile group configuration in the study

2.2 Material parameters

For the single pile, the unit weight of concrete for the pile was chosen as 25 kN/m^3, and the Young's modulus of concrete (E) was taken as 30 x 10^6 kN/m^2, with the assumption for the Poisson's ratio of concrete (μc) being 0.2. For modelling the single pile and the piles in group, the embedded beam element was used, and for the modelling the pile cap, the plate element was used. The embedded beam element and plate element were considered as linear elastic and their behavior was defined using elastic stiffness properties. The interface value for providing the interaction between the beam and the surrounding soil was used as 1. The pile and pile cap parameters were displayed in Tables 1 and 2, respectively.

Table 1. Pile parameters in the finite element analysis program Plaxis 3D

Identification	Unit	Value
Material type		Embedded beam
Color		■ (red)
γ	kN/m³	25.00
E	kN/m²	30.00E6

Table 2. Pile cap parameters in the finite element analysis program Plaxis 3D

Identification	Unit	Value
Material type		Plate
Color		■ (blue)
γ_{unsat}	kN/m³	25.00
γ_{sat}	kN/m³	25.00
E	kN/m²	18.00E6
ν (nu)		0.2000
G	kN/m²	7.500E6
Eoed	kN/m²	20.00E6
Rinter		1.000

For the soil, the finite element analysis program Plaxis 3D has four different models: the Mohr–Coulomb model (MC), the Hardening Soil model (HS), the Soft-Soil model (SS), and the Soft–Soil–Creep model (SSC) to describe the different behaviors of soil. In the present study, the soil analysis was carried out using the Mohr–Coulomb model, an elastic-perfectly plastic model. This model is simple and works based on parameters in most practical situations. The soil profile used for this present analysis had three layers. The soil parameters were calculated based on the manual of Plaxis 3D. Table 3 showed the soils parameters used for this study.

Table 3. Soil parameters

Identification	Unit	Layer 1	Layer 2	Layer 3
Drainage type		Drain	Drain	Drain
Color				
γ_{unsat}	kN/m³	19.7	19.7	20
γ_{sat}	kN/m³	20	20	20.5
E’	kN/m²	16000	6300	11200
E_{oed}^{ref}	kN/m²	19200	7560	4480
Power m		0.5	0.5	0.5

3. RESULTS AND DISCUSSION

In this study, the pile group effect was evaluated by measuring the displacement of the single pile and the pile group in response to the lateral load. The results of the analysis model and the displacement of the piles were shown in Figure 3.

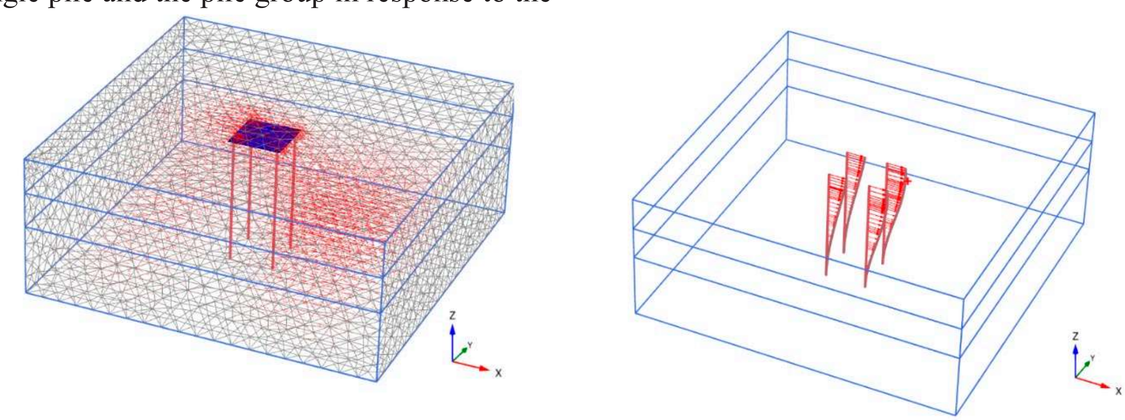

Figure 3. Pile group model and pile displacements after analysis

3.1 Effect of pile spacing on the pile group effect

The effect of pile spacing on the pile group effect was evaluated. Figures 4 and 5 presented the pile depth-lateral displacement curves for single piles and pile groups with different pile spacings of 0.4 m and 0.6 m diameter, respectively. Generally, it can be seen that the behavior of the single pile and the pile group were different. This is because the deformation and failure characteristics of the single pile were obviously different from those of the pile group. Furthermore, the total bearing capacity of the pile group was not equal to the summation of the bearing capacities of each single pile in the group [16]. In a group, between two interactions appeared piles due to pile spacing, causing the pile group effect [17].

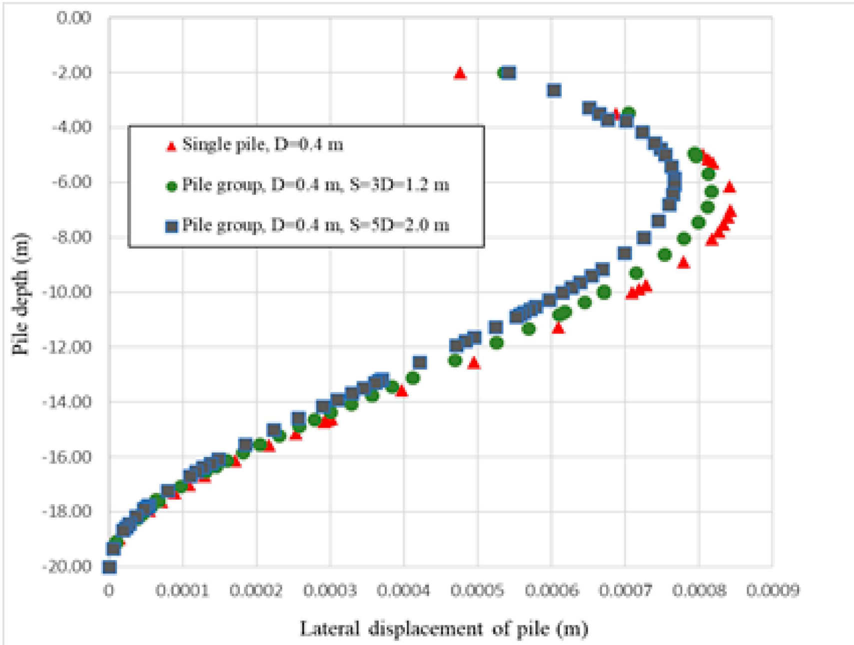

Figure 4. The effect of pile spacing on the pile group effect for 0.4 m pile diameter

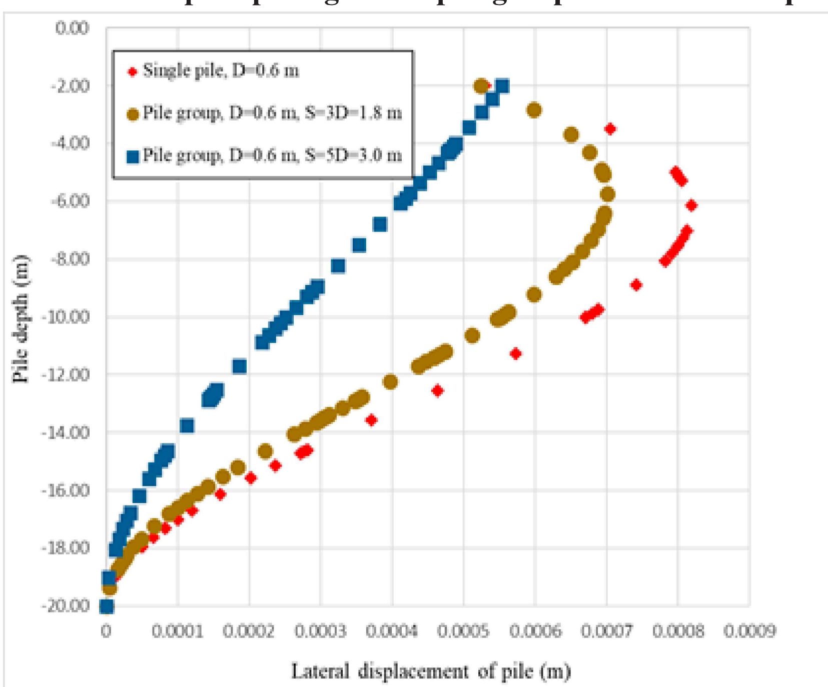

Figure 5. The effect of pile spacing on the pile group effect for 0.6 m pile diameter

As shown in the Figures above, the pile group with 5D spacing produced the lowest lateral displacement among the three analysis cases. While the single pile resulted the highest lateral displacement. It was inferred that the pile group effect tends to be larger as the pile spacing increases. This behavior was consistent with the previous studies [16],[18],[19]. Nevertheless, some studies have reported that the pile group effect had a reverse trend to the pile spacing

[20],[21]. There might be some remarkable concerns to be addressed regarding the effect of pile spacing on the pile group effect.

3.2 Effect of pile diameter on the pile group effect

This study also examined the effect of pile diameter on the pile group effect. In the finite element analysis, two different pile diameters were analyzed. The first one was 0.4 m and the second one was 0.6 m. The lateral displacement of piles according to their pile depth was presented in Figures 6 and 7.

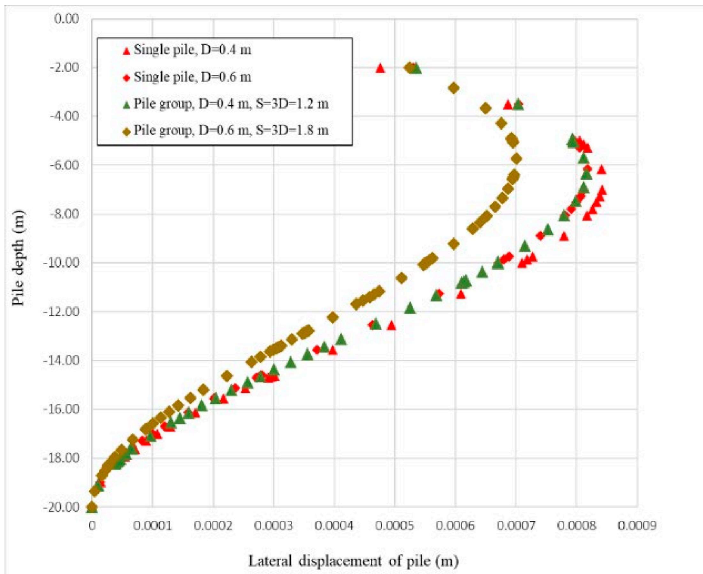

Figure 6. The effect of pile diameter on the pile group effect for 3D pile spacing

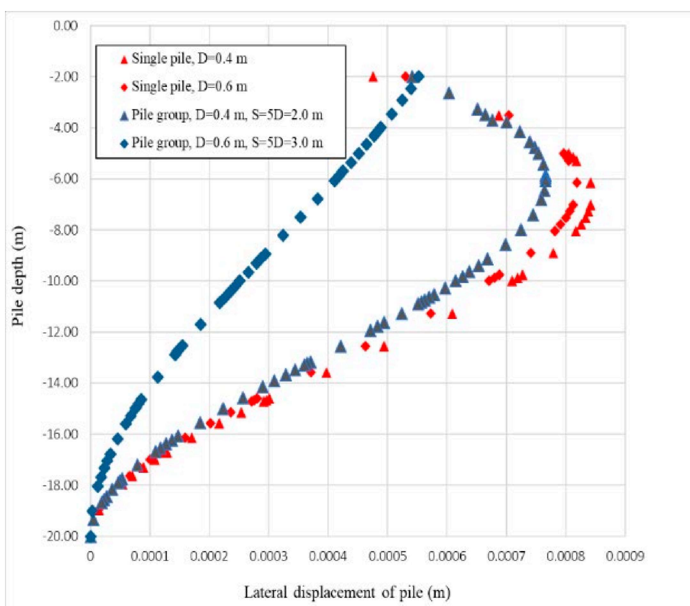

Figure 7. The effect of pile diameter on the pile group effect for 5D pile spacing

From Figures 6 and 7, it can be seen that as the pile diameter increased, the pile group displacement decreased. This result was similar to that reported in previous studies [3],[4],[22]. This can be explained by the fact that when the pile diameter increased, a larger soil wedge behind the appeared pile, resulting in a higher resistance to the soil pressure, thus the pile group displacement decreases [23]. The pile group effect was significantly affected by the pile diameter, as mentioned in the studies [23],[24]. Moreover, Figures 6 and 7 showed that a single pile and pile group with a diameter of 0.4 m produced similar displacement results, whereas those with a diameter of 0.6 m produced different displacement results. This, indicated that as the pile diameter increased, the pile group effect increased. The pile diameter had a significant effect on the pile group effect, as concluded in other studies as well [22],[25].

4. CONCLUSION

This study observed the impact of pile spacing and diameter in a group on the pile group effect subjected to the lateral load. The finite element analysis Plaxis 3D program was employed to extract the pile group effect through a 2x2 pile group of concrete piles, each 18 m in length. The results showed that as the pile spacing increased, the pile group effect increased. The pile group with 5D spacing produced the lowest lateral displacement among the three analysis cases. In addition, this study figured that as the pile diameter increased, the pile group displacement decreased and the pile group effect increased. This result was similar to that reported in previous studies. The conclusion of this study was based on theoretical analysis. Further investigation should be performed in order to study the pile group effect, including soil property, pile spacing, pile diameter, and pile length, with practical experiments to gain a better understanding of the pile group effect.

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