TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Khảo sát tham số ảnh hưởng đến nội lực đài cọc bằng phương pháp phần tử hữu hạn

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TÓM TẮT

Móng cọc ngày càng được áp dụng rộng rãi, đặc biệt là cho nhà cao tầng. Theo một số quan điểm thiết kế móng cọc hiện nay, người ta xem đài móng là tuyệt đối cứng và chưa xem xét đến sự làm việc của đất nền dưới đáy đài nên chưa phản ánh đúng thực tế. Bài báo này phân tích ảnh hưởng của cách bố trí cọc, chiều dài cọc và đất nền dưới đáy đài đối với các thông số áp lực xuống cọc và độ lún của nền đất dưới mũi cọc bằng phần mềm sử dụng phương pháp phần tử hữu hạn Plaxis 3D Foundation.

Từ khóa: *Móng cọc, phân tích phần tử hữu hạn, cách bố trí cọc, chiều dài cọc.*

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Investigating parameters affecting pile cap internal forces using the finite element method

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ABSTRACT

Nowadays pile foundation is more and more widely applied, especially for high-rise buildings. According to some current perspectives on pile foundation design, pile caps are often considered to be rigid, and the behavior of the soil beneath the pile cap is not fully taken into account, leading to an incomplete reflection of reality. This paper analyzes the influence of pile arrangement, pile length and the geology at the bottom of the pile foundation on the pressure on the pile and foundation settlement under the pile tip using Plaxis 3D software.

Keywords: *Pile foundation, finite element analysis, pile arrangement, pile length.*

1. INTRODUCTION

The utilization of pile foundations is increasingly pervasive, notably in the construction of high- rise structures. However, prevailing viewpoints in pile foundation design often depict pile caps as rigid entities, overlooking the dynamic interactions with the underlying soil, hence presenting an incomplete portrayal of real-world conditions.[1] This study utilizes Plaxis 3D software to investigate the effects of pile arrangement, pile length, and subsurface geology on pile load distribution and foundation settlement beneath the pile tip. The numerical results reveal that pile arrangement significantly influences internal forces within the pile group and settlement, with a square pile configuration emerging as the optimal choice over triangular arrangements. Moreover, the findings indicate that the subsoil beneath the raft contributes to bearing the load alongside the piles.

2. THEORETICAL FORMULATION

2.1. Calculation of low-cap pile foundations

The meaning of the issue of low-cap pile foundations is that the pile foundation is constructed with the pile cap located in the soil at a lower depth, which must satisfy the following working conditions:[1,2]

- The horizontal load must be balanced with the passive pressure of the soil so that the pile is not affected by horizontal force and only works in compression.

- The external moment is balanced by the reaction forces at the pile head with the coordinates (xi, yi) of the pile.

- Particularly for foundations with only one pile placed at the center, it is necessary to consider that the pile can withstand moment and horizontal load. Therefore, the low-cap pile foundation must have more than 2 piles

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to resist the moment, and the depth of the foundation must be lower than the depth of undisturbed soil to resist horizontal forces. The reaction force on the pile head has coordinates (xi, yi) as:

$$P_i = \frac{N}{n} \pm \frac{M_y}{\sum x_i^2} \times x_i \pm \frac{M_x}{\sum y_i^2} \times y_i \qquad (1)$$

in which:

My: moment in the y-axis direction

Mx: moment in the x axis direction

xi: x coordinate of ith pile compared to load position

yi: y coordinate of ith pile compared to load position

Conditions that need to be checked to satisfy the maximum compression (x_{max}) are:

$$P_{max} \leq Q_a^{tk} \qquad (2)$$

Allowable load capacity of piles:

$$Q_a^{tk} = \frac{\gamma_0}{\gamma_n} \times \frac{R_{c,k}}{\gamma_k} \qquad (3)$$

with

γ_0 is the working condition coefficient, taken as 1 for single piles and 1.15 in multi-pile foundations

γ_n is the reliability coefficient on the importance of the project, equal to 1.2; 1.15; 1.1 corresponds to the importance of level I, II and III buildings (TCVN 10304:2014: Pile foundations - Design standards)

γ_k is the reliability coefficient according to soil (TCVN 10304:2014: Pile foundations - Design standards).

2.2. Mohr - Coulomb model in Plaxis

The model is based on the idea of the law of elastic-plastic equilibrium with a fixed threshold not affected by plastic deformation and in the stress state of a point located in the purely elastic threshold surface (Figure 1).[3] Re-strengthening or softening rules are not required with the Mohr - Coulomb model. This model is relatively simple and easy to use, often used to approximate the behavior in the early stages of soil with 5 basic parameters.

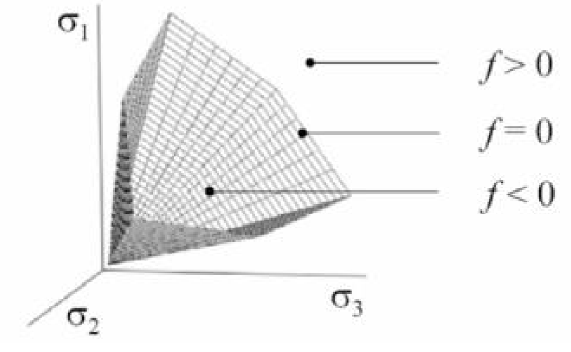

Figure 1. Mohr-Coulomb failure envelope in stress space.

3. NUMERICAL EXAMPLES

3.1. Problem

Input parameters: bored reinforced concrete piles, pile diameter D=0.5 m, pile length 17m; concrete grade B25 with Ep=27.10[6] kPa, the subsoil consists of medium coarse sand with the following parameters: Unit weight γ_{unsat}, saturated unit weight γ_{sat}, elastic Modulus E, internal friction angle φ, Specific gravity Gs,… (Table 1).

Table 1. Subsoil parameters.

Model	Type	Thickness (m)	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	E(kN/m^2)	φ(^{0})	G_s	Groundwater level (m)
M-C	Drained	30	16.8	18.99	22.000	36^{0}03	2.66	-2.8

The 4-pile foundation model in the Plaxis 3D Foundation software (Figure 2) with a mesh size is 0.1 m

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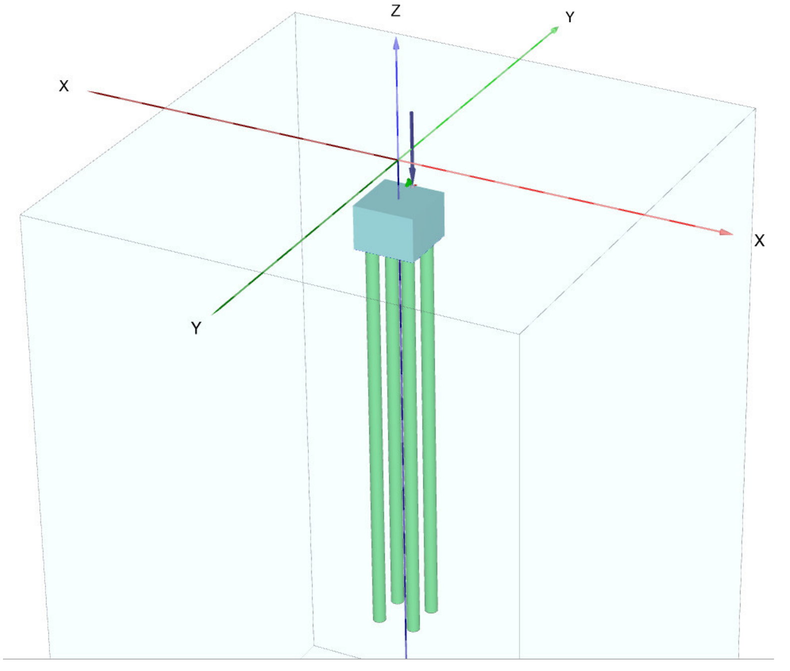

Figure 2. Model of pile foundation using Plaxis 3D Foundation V.22.

Using Plaxis 3D Foundation to analyze a foundation with group of 4 piles with the same length and varying pile spacing to calculate the group efficiency factor. The results are compared with the empirical formula of Converse-Labarre, TCN 272-05 (22TCN 272 – 05: Bridge design standards), and the experimental results of Professor Al-Mhaidib, A.I,[4] as shown in Figure 3.

The Converse-Labarre formula for calculating the group efficiency factor is:

$$\eta = 1 - 2.\frac{Arctg(D/S)}{\pi}.\left(2 - \frac{1}{m} - \frac{1}{n}\right) \quad (4)$$

where m and n are the number of piles in a row and the number of rows of piles, respectively; S is the spacing between piles; D is the diameter of the piles.

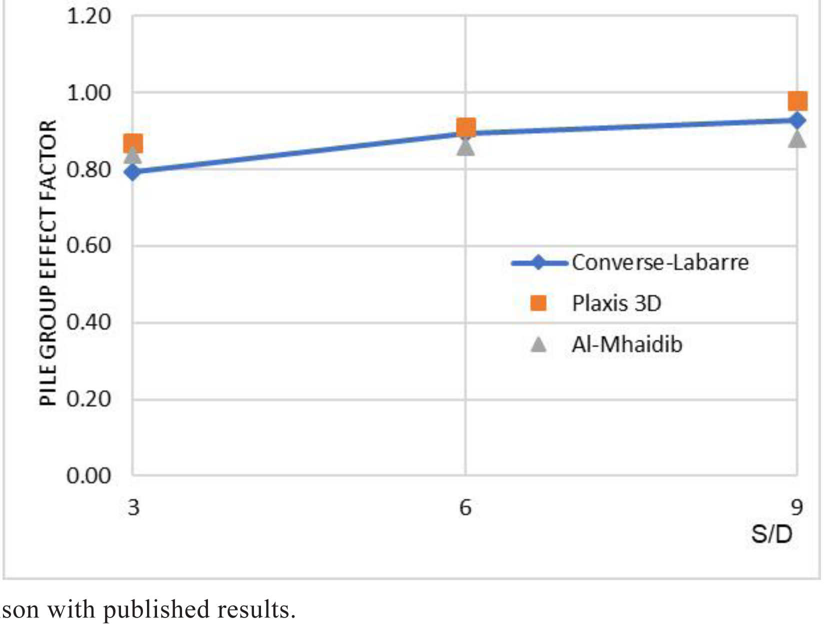

Figure 3. Comparison with published results.

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Comments: Finite element analysis using Plaxis 3D Foundation provides results that closely match the empirical formula, TCN 272-05, and experimental results, demonstrating the reliability of the calculation method. Based on this, Plaxis 3D analysis is continued to investigate the following cases:

The authors sequentially varied the pile arrangements, as shown in Figure 4, to analyze the pile head reaction (Pi) and the settlement of the foundation (S). The pile cap height h=1.8 m. The calculated data is as follows: N=2040.36 kN, Q_x=128.85 kN, Q_y=16.76 kN, M_x=35.07 kN.m, M_y=339.21 kN.m.

The authors continued to alter the subsurface geology beneath the pile cap with layers of clay and silty clay to analyze the pile head reaction (Figure 5). Then, we investigated scenarios involving changes in pile lengths. In this case, the pile cap height h=1.8 m, the foundation is only affected by the vertical force P, with P changing the following times: 2000 kN, 4000 kN, 8000 kN, 12000 kN, 16000 kN.

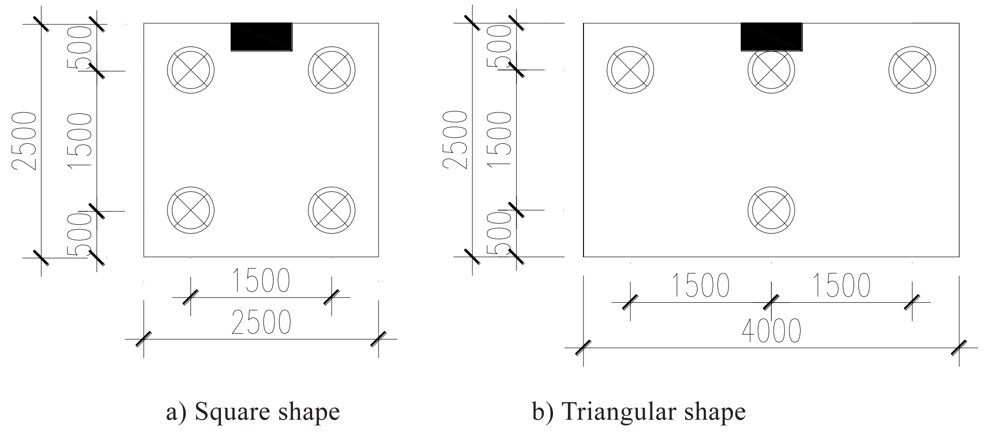


Figure 4. Pile arrangement.

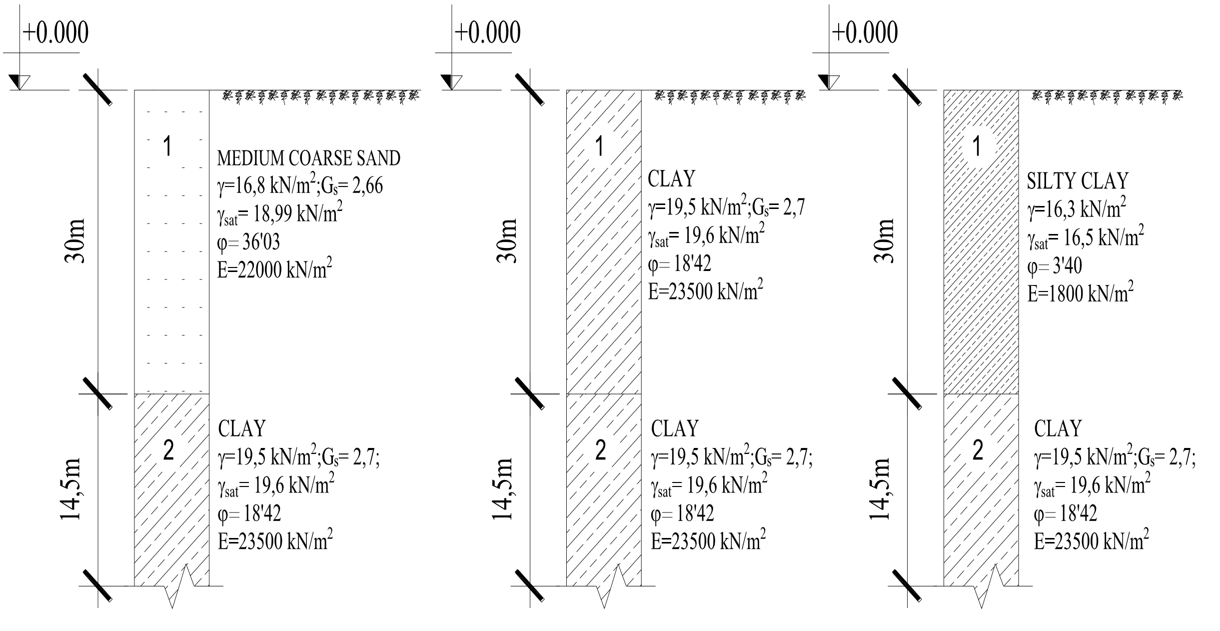


Figure 5. Geological parameters when changing the soil at the bottom of the pile cap.

This paper examined 3 different cases for a group of 4 piles:

a) All piles have the same length L=17 m

b) 2 boundary piles are 17 m long, while the remaining 2 piles are 19 m long

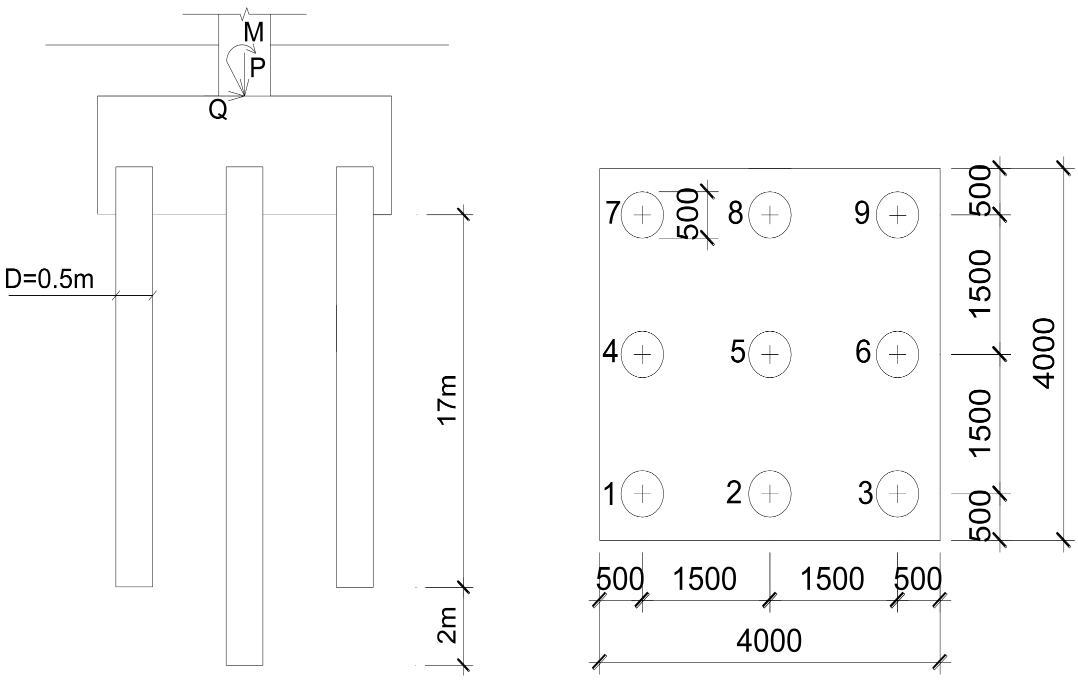
c) All piles have the same length L=19 m

This paper examined 3 different cases for a group of 9 piles:

a) All piles have the same length L=17 m

b) Middle pile is 17 m long, while boundary piles are 19 m long

c) All piles have the same length L=19 m



a) side view

b) top view

Figure 6. Layout of 3x3 pile group.

3.2. Calculation results

Table 2. Calculation results for settlement and pile head reaction when varying pile arrangements.

Pile arrangement	Square shape	Triangular shape
Settlement (cm)	1.106	0.940
P1 (kN)	407.85	267.56
P2 (kN)	152.72	632.97
P3 (kN)	739.85	518.48
P4 (kN)	856.00	634.87
$\sum P_i$ (kN)	2.156.42	2.053.88

Table 3. Calculation results for settlement and pile head reaction when varying subsurface geology beneath the pile cap.

Geology under the pile cap	Sandy soil	Clay soil	Silty clay soil
Settlement (cm)	1.106	1.105	1.120
P1 (kN)	407.85	407.53	407.86
P2 (kN)	152.72	160.09	155.49
P3 (kN)	739.85	746.04	749.13
P4 (kN)	856.00	852.40	856.87
$\sum P_i$ (kN)	2.156.42	2.166.07	2.169.34

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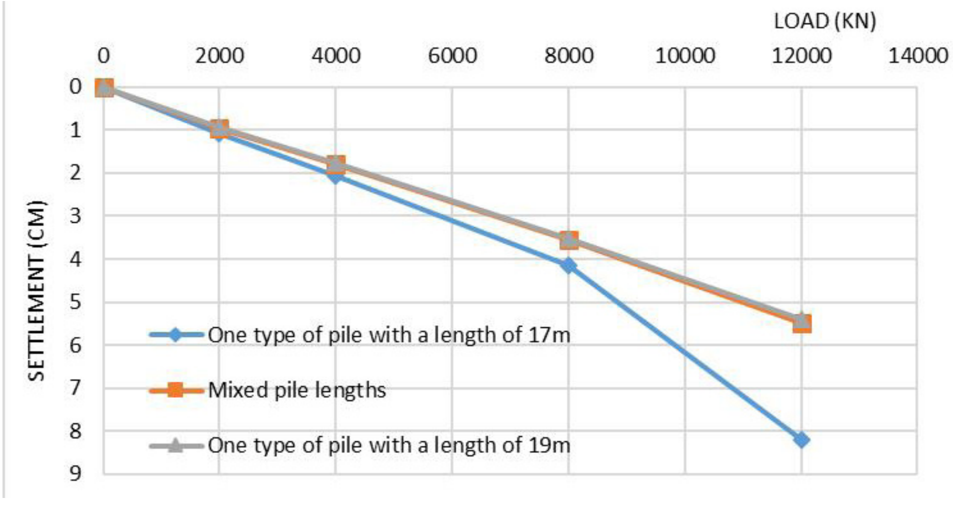

Figure 7. Load-settlement relationship for the 4-pile foundation option.

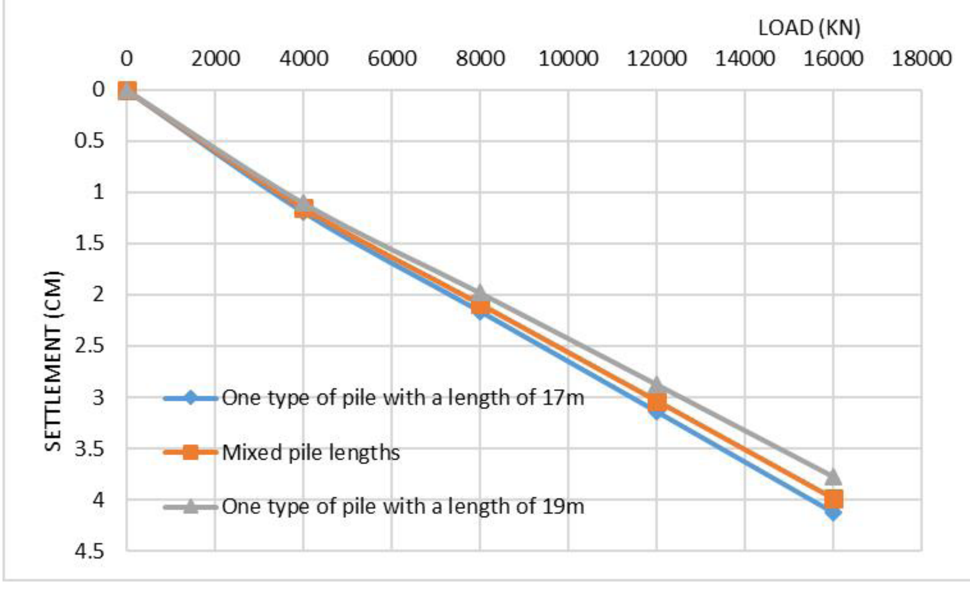

Figure 8. Load-settlement relationship for the 9-pile foundation option.

The analysis results obtained from the Plaxis 3D Foundation software show that when the arrangement of piles varies, the settlement and the value of the reaction force at the pile head in triangular configuration are slightly lower (about 5%) compared to the square configuration (Table 2).

The analysis results of pile head reactions using Plaxis 3D Foundation software show that, with the same applied load, the pile head reaction is affected when the subsoil beneath the raft changes. Among the cases where the subsoil beneath the raft changes, the case with the subsoil being clay yields the highest total pile head reaction value (2169.34 kN), whereas the case with the subsoil being sandy clay results in the smallest calculated value (2156.42 kN) (Table 3).

From the results presented in Figure 7 and Figure 8, we can see that the stiffness of the two boundary piles (4-pile foundation) and the three middle piles (9-pile foundation) is significantly higher than that of the remaining piles due to the increased length of these piles. However, the 9-pile foundation, with a higher number of piles, exhibits weaker performance compared to a similar arrangement in the 4-pile foundation case. The analysis results indicate that the effectiveness of a mixed foundation scenario with varying pile lengths lies between the other two cases. This suggests the feasibility of utilizing this type of foundation. However, merely increasing the length of two piles does not significantly enhance the overall load-bearing capacity as in the case of a 3-pile foundation.

4. CONCLUSION

The arrangement of piles affects the internal forces within the pile group and settlement. When changing the pile arrangement to a triangular layout, the internal forces within the pile group decrease. However, a larger pile cap width also leads to material waste. Therefore, to ensure material efficiency while maintaining load-bearing capacity, a square pile arrangement may be chosen.

The pile head reaction is influenced by the subsoil beneath the raft; when the subsoil is good, it yields a smaller total pile head reaction, whereas weak subsoil results in a larger pile head reaction. This calculation result indicates that the subsoil beneath the raft contributes to bearing the load along with the piles.

The research results enable the analysis of the performance of pile foundations in cases where the piles have different lengths. This aids engineers in practical applications, especially during the construction process, where situations may arise where soil compression leads to some piles not achieving their intended lengths as per the design.

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