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Study on the lateral bearing characteristics of well composite pile

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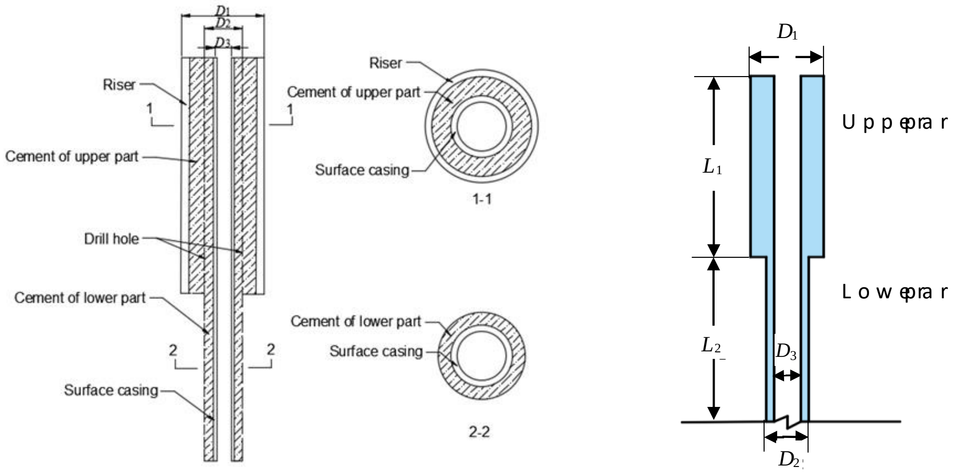
Abstract: The well composite pile, used as a wellhead structure to support offshore oil platform, can effectively reduce the construction cost of the platform. The riser composite pile, with its variable cross-section foundation, has different lateral characteristics compared to ordinary pile foundations. In this paper, numerical analysis methods are used to analyze the lateral bearing capacity and the distribution of bending moments along the composite pile under lateral load. The results indicate that the upper part of the composite pile bears most of the load, with the bending moment concentrated towards the upper section. For the same pile top displacement, as the penetration depth of the riser decreases, its lateral bearing capacity weakens, and the lateral load is gradually borne by the surface casing, causing the location of the inflection point of the composite pile to be closer to the mudline.

1. Introduction

To address the high construction costs associated with marginal oilfield platforms, the well composite pile has been proposed to support platform loads, either replacing or partially substituting the traditional steel pipe pile foundation[1]. The well composite pile mainly consists of a conductor, surface casing, and the intermediate cementing grout, as illustrated in Figure 1 (LIU 2021)[2]. The unique variable cross-section of these piles differentiates their bearing mechanism from that of ordinary single piles. LIANG et.al (2021)[3]through field tests and numerical calculations, have demonstrated that the presence of a variable cross-section significantly alters the vertical bearing capacity and have proposed a revised calculation method. However, there are currently no systematic research findings available on the deformation characteristics and pile response of well composite piles under lateral loads. Relevant studies can refer to other research on tapered piles, such as wedge-shaped piles.



(a)well structure (b)well composite pile

Figure 1: Schematic diagram of the well composite pile.(LIU 2021)[3]

Ismael (2006)[4] conducted comprehensive field tests on step-tapered and fully tapered piles in various soil conditions, demonstrating that tapered piles can withstand significantly higher lateral loads than uniform diameter piles. Shafaghat (2015)[5], utilized 3D finite element models to demonstrate that tapered piles provide enhanced lateral resistance compared to cylindrical piles. Xiong and Chen (2021)[6]further validated these findings through a combination of field tests and numerical simulations, confirming that the presence of a tapered section significantly improves lateral load distribution and reduces pile deflection.Comparative studies have consistently shown that tapered piles outperform cylindrical piles in terms of lateral bearing capacity. Lee et al. (2020) compared the buckling behavior of tapered and cylindrical friction piles in inhomogeneous soils, concluding that the tapered design mitigates the risk of buckling and improves overall stability under lateral loads. Similarly, Nasrollahzadeh and Hataf (2022)[7]conducted experimental and numerical studies on the lateral efficiency of tapered pile groups, highlighting that tapered piles not only increase lateral resistance but also enhance the group effect, making them ideal for applications involving high lateral load demands.

This paper uses numerical analysis as the primary research method to analyze the lateral bearing characteristics of well composite piles. Firstly, the parameters and applicability of the numerical analysis model are studied. Then, the numerical model is used to analyze the lateral bearing capacity and stress distribution of the well composite pile, revealing the impact of pile diameter, pile length, and variable cross-section on its lateral bearing characteristics.

2. Lateral Bearing Characteristics Analysis

2.1. Numerical Model Establishment

Numerical analysis of the lateral load-bearing characteristics of composite piles was conducted using ABAQUS finite element software. Based on the lateralloading characteristics of pile foundations, a half-model was selected to improve computational efficiency, as shown in Figure 2. Based on the lateralloading characteristics of pile foundations, a half-model was adopted to improve computational efficiency. The soil follows the Mohr-Coulomb yield criterion, and both the pile and soil mesh properties are selected as C3D8R. Normal contact between the pile and soil surfaces is defined as hard contact, while tangential contact uses the penalty friction formulation with a friction coefficient of 0.4. The radial mesh size of the model ranges from $0.1D_1$ to $3D_1$, and the axial grid size is D_1. As shown in Figure 1(b), D_1 and L_1 represent the upper part diameter and length of the composite pile, while D_2 and L_2 represent the lower part diameter and length of the composite pile.

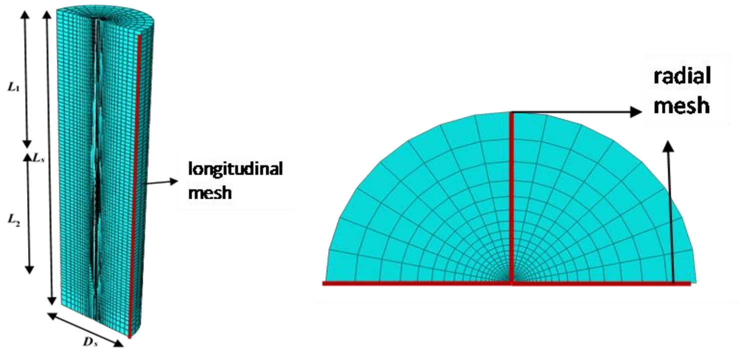


Figure 2: Numerical Model.

In the calculations, the pile top surface is coupled with the reference point, and a lateral displacement is applied to the reference point to analyze the lateral bearing characteristics of the well composite pile. The soil parameters are shown in Table 1, and homogeneous clay is used as the foundation for this analysis. Considering the undrained conditions, the internal friction angle is set to 0.

Table 1: Soil parameters.

effective unit weight, γ'(kN/m3)	Poisson's ratio, ν	Undrained shear strength, S_u(kPa)
6	0.49	50

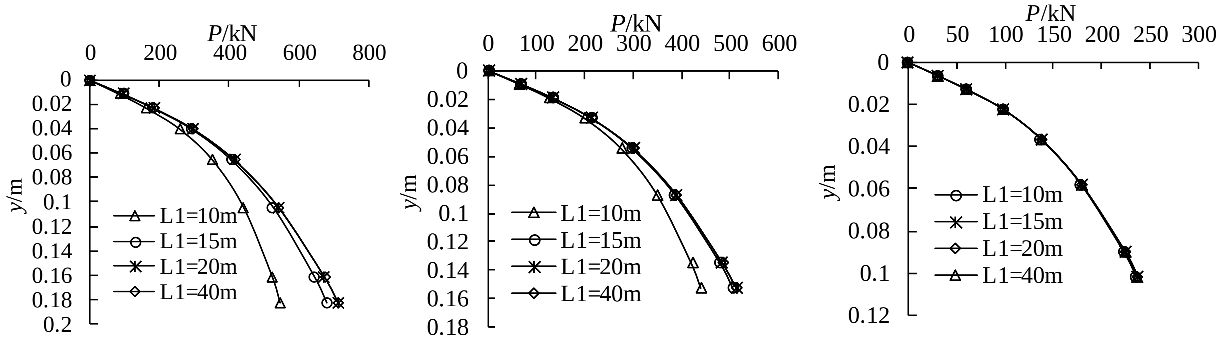
2.2. Lateral bearing capacity analysis

To compare the load-bearing characteristics between composite variable-section piles and commonly used constant-section piles, comparative calculations were conducted for the constant-section piles under the conditions listed in Table 2. The calculations included applying a lateral displacement of $0.2D_1$ at the pile top.

Table 2: Pile parameters.

NO.	D_1(m)	D_2(m)	L_1(m)	L_1+L_2(m)	S_u(kPa)
1	0.914	0.444	10,15,20	80	50
2	0.762	0.444	10,15,20	80	
3	0.508	0.444	10,15,20	80	

The load-displacement curves were extracted for different conditions, as shown in Figure 3.

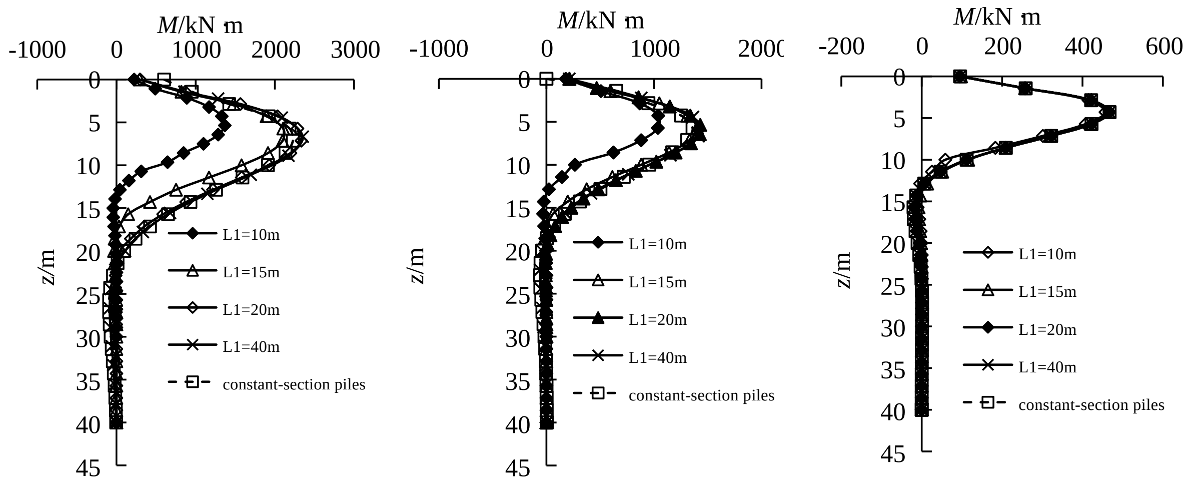


(a) D_1=0.914m (b)D_1=0.762m (c)D_1=0508m

Figure 3: Load-displacement curve.

From the pile head load-displacement curves in Figure3, it can be observed that as the depth of the riser (upper part) into the mud decreases, the lateral bearing capacity of the pile decreases under the same pile head displacement. This is because some of the lateral load is borne by the surface casing with smaller diameter at the lower part of the composite pile. As the diameter of the riser decreases, the difference in the bearing capacity of the composite pile due to the shallower depth of penetration gradually decreases. The results from the figure also indicate that there is overlap in the pile head load-displacement curves for different depths of riser penetration into the mud. After reaching a certain depth, L_1, the lateral bearing capacity of the composite pile does not change with variations in L_1.

Figure 4 presents the bending moment distribution along the composite piles with different depths of water-sealing casing penetration into the mud, where D_1 = 0.914m, when the pile head displacement reaches $0.2D_1$.



(b) D_1=0.914m (b)D_1=0.762m (c)D_1=0508m

Figure 4: Bending moment distribution.

From the bending moment distribution chart, it can be observed that under the same displacement conditions, different depths of riser penetration into the mud have a significant impact on the bending moment distribution along the composite piles. Figures 4(a) and 4(b) show that for constant-section piles, the neutral bending point depths are 21.6m and 18.6m respectively. When L1 of the composite pile is greater than the depth of the neutral bending point of the constant-section pile, the bending moment distribution is similar to that of the constant-section pile, indicating that the variable section does not affect the lateral load-bearing mode of the composite pile. However, when L_1 of the composite pile is less than the depth of the neutral bending point of the constant-section pile, the position of the neutral bending point changes significantly. For a composite pile with a diameter of D_1 = 0.914m and penetration depths of 10m, 15m, and 20m, the corresponding depths of the neutral bending point are 13.5m, 18.0m, and 21.8m respectively. For a composite pile with a diameter of 0.761m and penetration depths of 10m, 15m, and 20m, the corresponding depths of the neutral bending point are 13.0m, 17.5m, and 20.1m respectively.

In Figures 4(c), due to smaller variations in diameter, the influence of the variable section on the bending moment distribution of the composite pile is smaller. For a constant-section pile with a diameter of 0.508m, the neutral bending point is located 13m below the mud surface. For the condition where L_1 = 10m, the depth of the neutral bending point is 11.5m.

From the above analysis, it is clear that when the penetration depth of the variable section into the mud is less than the depth of the neutral bending point of the constant-section pile, the variable section participates in the lateral load-bearing of the composite pile, influencing the bending moment distribution along the pile, and causing the neutral bending point of the composite pile to be closer to the mud surface.

3. Conclusions

This paper employs numerical calculations to analyze the lateral load-bearing characteristics of variable-section well composite piles. The specific conclusions are as follows:

- The upper part of the well composite pile primarily bears lateral loads, and as the length of the upper part increases, its load-bearing capacity gradually improves.
- When the variable section of the composite pile is located above the neutral bending point, it affects the lateral load-bearing mode of the composite pile.
- As the penetration depth of the water-sealing casing into the mud decreases, its lateralload-bearing capacity weakens. Lateralloads are progressively borne by the surface casing, causing the inflection point of the composite pile to move closer to the mudline.

Acknowledgements

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