Applicability analysis of squeezed branch pile with different embedded depth of Boulder

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Abstract. Based on Zhongshan-Tan zhou express 65 # pier boulder geological engineering landscape avenue viaduct, using PLAXIS3D to study in the different boulder embedment depth of squeezed branch piles expansion and common pile ultimate bearing capacity and the applicability of the squeezed branch piles expansion, the calculation results show that the squeezed branch piles expansion of P-S curve is slowly, the ultimate bearing capacity of pile is equal to the load value corresponding to the pile tip diameter when the pile settlement is 1/20, and the ultimate bearing capacity of pile foundation does not always increase (the peak point appears) with the increase of pile length, but the ultimate bearing capacity of ordinary pile is less than the ultimate bearing capacity of extruded and expanded bracing pile. Under certain geological conditions, the pile length can be shortened and the bearing capacity of pile can be improved effectively. On the basis of the load of the upper bridge which satisfies the geological condition of boulder, the use of extruded and expanded bracing pile instead of ordinary pile can effectively avoid the boulder, avoid the pile passing through the boulder layer, which can greatly save the construction period and reduce the difficulty of construction.

1. Introduction

Boulder geology is a geological form often encountered in coastal areas, which has the characteristics of hard quality and irregular shape. In order to meet the requirements of pile foundation bearing capacity, the pile often needs to pass through the boulder layer to complete the construction. In the construction process, due to the complex situation in the hole, it is difficult to pass through the boulder layer, which will lead to drilling tool damage, borehole collapse, slow construction efficiency, high cost and low cost A series of problems such as poor economic benefits.

Static load test method, static and dynamic pile test method, dynamic test technology and self balance test method are the four main methods of pile bearing capacity test [1], and the most effective and intuitive method is static load test method [2]. Its core is to obtain the settlement of pile under different loads by continuously loading on the pile top, and determine the bearing capacity of pile foundation according to the change of P-S compression curve. Peng Wei [3] took kalupar bridge as an example, discussed the static load test of pile foundation, and put forward some modification suggestions for the design and construction specifications of pile foundation; Chen guike [4] elaborated its influence on P-S from the aspects of pile type, geotechnical physical and mechanical properties, construction process, etc. The research of Zhang Ying [5] shows that under the same load, the simulated P-S curve is consistent with the measured P-S curve. In addition, increasing the bearing capacity of pile can avoid boulders in the limited range of pile length, and generally improve the
bearing capacity of pile by increasing the length and diameter of pile; Li Zhizhong \(^6\) obtained the determination formula of ultimate bearing capacity related to pressure and pile length by analyzing the data obtained from static load test of jacked pile, and when the length diameter ratio of pile exceeds a certain critical value, the ultimate bearing capacity of jacked pile is increased. The load reaches the peak value and then tends to be stable. A large number of research results and engineering practice show that \(^7\)-\(^11\), the branch structure and plate structure can play its unique excellent performance in different soil layers, that is the branch plate pile has high bearing capacity and small deformation; its compaction hardness can make the surrounding soil more dense, improve the soil bearing performance, and then reduce the pile length and diameter, save the cost and raw materials. Under the same conditions, within a certain range of pile length, the squeezed branch pile has good economic benefits.

In this paper, the three-dimensional finite element software is used to simulate the static load test of extruded and expanded supported disc pile and common pile with different pile lengths, to analyse the boulder geological conditions, extrusion expansion of ultimate bearing capacity of squeezed branch pile and common pile, P-S curve and the maximum axial force features, thus for the squeezed branch piles expansion in boulder engineering geological conditions of the use and promotion to provide the reference.

2. Calculation Content
The site CT survey of pier 65# of viaduct of landscape road of Tan zhou express line project in Zhongshan city reveals that there are 6~8m boulder in pile foundation 1~3 of pier 65, and 2~4m fully weathered and strongly weathered rock strata under the boulder. Considering the limit of the construction period, if the pile passes through the boulder layer, it is not only difficult to construct, but also possible to collapse holes, inclined holes, drill damage and other situations. Moreover, the construction period is long, which increases the construction time. The difference of the pile is that the lateral resistance of the pile foundation can be effectively converted into end resistance by setting up the support plate, which can effectively shorten the pile length and improve the bearing capacity. After various researches, squeezed branch pile is adopted as the pile foundation at the bottom of the 65# pier.
In order to make the results comparable, the following conditions are considered in the calculation model:

1. The length of squeezed branch pile is $L = 20m$, $L = 30m$, $L = 40m$, $L = 60m$, and the diameter of pile is $d = 1.6m$;

2. The squeezed branch and disk pile adopts the structure form of branch and disk combination. The first row and the last row adopt the eight star branch structure, and the middle adopts the disk structure. The ring width of branch and disk is 0.75m. The distance between branch and disk, disk and disk can refer to the technical code for squeezed branch and disk pile engineering of highway bridges and culverts (DB33 / T 750-2009)\(^{[12]}\), set a 6m disk ring width, and the structure of branch disk pile in the model includes: 2 branches and 1 disk ($L_1 = 20m$), 2 branches and 2 disks ($L_2 = 30m$), 2 branches and 3 disks ($L_3 = 40m$) and 2 branches and 6 disks ($L_4 = 60m$).

3. The soil is simplified into two layers, which are respectively viscous soil (upper layer) and sandy soil (lower layer). The interface between clay and sandy soil is at the middle position of the first row branch structure and the first disk structure, and the water level is 5m below the surface;

4. When modelling, the isolated stone is simplified as a cuboid structure of $5.5m \times 5.5m \times 8.3m$, and its top surface is in contact with the bottom surface of the pile.

### Table 1. Calculate the soil parameter table.

| Soil layer   | Constitutive model | $kN/m^3$ | Cohesion kPa | Friction angle $^\circ$ | Compression modulus MPa | Poisson's ratio | Rinter |
|--------------|--------------------|----------|--------------|--------------------------|--------------------------|----------------|--------|
| Cohesive soil| HS                 | 20.3     | 25.7         | 16.9                     | 14.49                    | 0.2            | 0.67   |
| Sand         | HS                 | 18.5     | 0            | 30                       | 38                       | 0.2            | 0.67   |
| Lone rock    | HS                 | 26.9     | 200          | 36                       | 1000                     | 0.2            | 0.67   |
(5) The pile material is C30 concrete.

| Material | Bulk density kN/m³ | Deformation modulus GPa | Poisson's ratio |
|----------|--------------------|--------------------------|----------------|
| Concrete | 25                 | 30                       | 0.2            |

The pile-soil interaction is simulated by interface element. The interface element consists of 6 pairs of nodes, which are compatible with the 6-node triangular edge of soil. The virtual thickness of interface is set to simulate and calculate the stiffness attributes of interface. The stiffness matrix of interface element is obtained by Gauss integration of six integration points according to the attributes defined in the material data group. The positions of these integration points (or stress points) make the numerical integration a linear stress distribution. The two nodes of the interface element at the end of the interface are reduced to a single node. Moreover, when the structural elements are connected vertically, the double nodes of the interface elements will be reduced to a single node to avoid the separation between the structural elements.

Based on the above assumptions, the calculation model is shown in figure 3.

3. Confirmation method of pile bearing capacity
In this paper, the pile diameter D=1600mm (greater than 800mm). Referring to the confirmation method of vertical bearing capacity of pile foundation in Technical Code for Testing Building Pile Foundations (JGJ106-2014) [13], it can be seen that: when P-S curve is a steep drop, the ultimate bearing capacity of pile is the inflection point value; on the contrary, the ultimate bearing capacity of pile is the corresponding load value when settlement value is 80mm.

Figure 3. Calculation model
4. Study on the change law of pile P-S curve
The P-S comparison curves of extruded and expanded branched and disc piles with different pile lengths and ordinary piles are shown in figure 4-7.

![Figure 4. P-S comparison curve of two piles (L=20m)](image)

![Figure 5. P-S comparison curve of two piles (L=30m)](image)

![Figure 6. P-S comparison curve of two piles (L=40m)](image)

![Figure 7. P-S comparison curve of two piles (L=60m)](image)

It can be seen from figure 4-7 that when \( L = 20 \text{m} \), the settlement of branch pile and ordinary pile is basically coincident when the vertical pressure \( P < 5000 \text{kpa} \), and they start to separate when \( P > 5000 \text{kpa} \), and the decline rate of ordinary pile is faster; When the vertical pressure is \( 0 < P < 6000 \text{kpa} \) and \( L = 30 \text{m} \), the settlement of ordinary pile and branch and disk pile is approximately linear with the change of load; when \( L = 40 \text{m} \) and \( 60 \text{m} \) and the vertical pressure is \( 0 < P < 9000 \text{kpa} \), the settlement of ordinary pile and branch and disk pile is basically the same under the same load. When the external load exceeds the interval, the settlement of ordinary pile is greater than that of branch pile no matter \( L = 20 \text{m} \), \( 30 \text{m} \), \( 40 \text{m} \) or \( 60 \text{m} \). In addition, the P-S curves of ordinary pile and branch and disk pile are of slow change type. According to the above pile bearing capacity confirmation method, the ultimate bearing capacity of the pile is the corresponding load value when the settlement value is 80mm, and the specific value is shown in table 3.

| Pile length /m | Type of pile foundation | Ultimate bearing capacity (kPa) |
|----------------|-------------------------|---------------------------------|
| 20             | Squeezed branch pile    | 13500                           |
|                | Ordinary pile           | 11500                           |
| 30             | Squeezed branch pile    | 18000                           |
|                | Ordinary pile           | 14000                           |
| 40             | Squeezed branch pile    | 21000                           |
|                | Ordinary pile           | 16200                           |
| 60             | Squeezed branch pile    | 21000                           |
|                | Ordinary pile           | 18620                           |
The curve of bearing capacity of squeezed branch pile and ordinary pile with pile length is shown in figure 8.

![Curve of ultimate bearing capacity of two kinds of piles changing with pile length](image)

Figure 8. Curve of ultimate bearing capacity of two kinds of piles changing with pile length

Table 3 and figure 8 show that under the same conditions, with the same pile length L, the ultimate bearing capacity of extrudated and expanded bracing pile foundation is greater than that of ordinary pile foundation. Under this geological condition, when the buried depth of pile is more than 40 meters, the ultimate bearing capacity of the expanded supported pile will remain at a stable level, and its peak load will remain around 21,000 kPa. However, the ultimate bearing capacity of ordinary pile will also show an increasing trend with the increase of pile length, but its increasing rate is significantly reduced.

5. Stress analysis of pile

The variation of maximum axial force of squeezed branch pile and ordinary pile with external load under different pile lengths is shown in figure 9-12.

![Maximum axial force contrast curve](image)

Figure 9. Maximum axial force contrast curve  
(L=20m)

![Maximum axial force contrast curve](image)

Figure 10. Maximum axial force contrast curve  
(L=30m)

![Maximum axial force contrast curve](image)

Figure 11. Maximum axial force contrast curve  
(L=40m)

![Maximum axial force contrast curve](image)

Figure 12. Maximum axial force contrast curve  
(L=60m)
It can be seen from figure 9 to figure 12 that under different pile lengths, there is little difference in the maximum axial force between ordinary pile and squeezed branch pile. Under the action of ultimate bearing capacity, the axial force nephogram of squeezed branch pile and ordinary pile under different pile lengths is shown in figure 13 to figure 16.

**Figure 13.** L = 20m axial force nephogram (×30e6 kN/m).

**Figure 14.** L = 30m axial force nephogram (×30e6 kN/m).

**Figure 15.** L = 40m axial force nephogram (×30e6 kN/m).

**Figure 16.** L = 60m axial force nephogram (×30e6 kN/m).
As can be seen from figure 13-16, the axial force of pile decreases gradually with the increase of buried depth and length of pile, and its attenuation rate decreases from large to small. The axial force of ordinary piles decreases linearly and attenuates uniformly due to the influence of pile lateral resistance. However, the axial force of the supporting and disc pile shows a decreasing trend of undulating (mountain shape), which is because the load bearing plate is added to the pile body, so that the force transfer path is changed. When vertical load is applied on the top of branch and disk pile, the load will be transmitted downward, and a large relative displacement occurs at the pile-soil contact, which makes the lateral friction of pile play a bearing characteristic. As the load increases and transfers downward along the pile to the position of the support and plate structure, the soil under the pile will be squeezed, and the load will spread to the soil around the plate.

6. Conclusion
In this paper, plaxis3D numerical calculation and comparative analysis are used to study the bearing mechanism, ultimate bearing capacity and end side resistance sharing of squeezed branch pile and ordinary pile under different embedded depth of boulder.

(1) Based on data investigation and relevant specifications, combined with pile length, pile diameter and P-S curve, the ultimate bearing capacity of pile foundation is the external load corresponding to the settlement of 80mm. At the initial stage of the pile, the settlement s of the two kinds of piles presents an approximate linear relationship with the change of the vertical load P. When the external load exceeds this range, the settlement of the ordinary pile is greater than that of the branch pile. In addition, the ultimate bearing capacity of the pile has a great relationship with the geology. When the pile length increases to a certain extent, the bearing capacity of the pile foundation will not increase or increase slowly.

(2) Under the condition of different pile length, the axial force of pile body gradually decreases with the increase of depth, and the attenuation of ordinary pile is more uniform. The axial force of pile body increases abruptly and decreases greatly due to the compression of the soil at the bottom of the pile.

(3) Within the allowable range of pile length under suitable geological conditions, the bearing capacity of pile body can be effectively improved and the pile length can be shortened by using squeezed branch and disk pile. On the basis of meeting the upper bridge load of boulder geological conditions, the use of squeezed branch and disk pile instead of ordinary pile can avoid boulder and avoid the pile passing through the boulder layer, which can greatly save the construction period and reduce the construction difficulty.

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