The Analysis of the Vertical Uplift Bearing Capacity of Single CEP Pile

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Abstract: By analyzing the existing calculating model of uplift bearing capacity of the CEP pile, the article put forward the deficiencies of the traditional calculating model for the uplift bearing capacity of the CEP pile, and according to the failure characteristics of soil and forced mechanism of pile of the CEP pile under vertical tension, it is put forward that the final calculation model of the uplift bearing capacity of the CEP pile, which provides reliable theoretical basis for the design and application about the type of pile.

Keywords: Calculating model, the concrete expanded-plates pile (the CEP pile), uplift bearing capacity.

1. INTRODUCTION

The CEP pile is also called concrete Multi-Expanded pile or radical Multi-Section-Expanded pile. It is a new type of pile developed on the basis of the traditional pile poured. According to the different bearing capacity of the pile and characteristics of subsoil, bearing plates are set in different locations of pile and which will improve the compression bearing capacity and uplift bearing capacity of the pile [1]. Pile foundation mainly bears three kinds of loads such as pressure stress, horizontal stress and tensile stress. A lot of research on the analysis of bearing capacity and deformation of pile under compression stress have been done, while the research on the uplift bearing capacity of pile is much less [2, 3]. In practical engineering, the CEP pile used as uplift pile is more and more widely, while it is unreasonable that the traditional empirical formula, which is used to calculate the uplift bearing capacity of the CEP pile and it can not meet the actual needs of the project. Therefore, from the view of theory and practical, further research on the uplift bearing capacity of the CEP pile is necessary.

2. THE EXISTING CALCULATING MODEL OF UPLIFT BEARING CAPACITY OF THE CEP PILE

It currently has no mature mode about the calculating methods of the standard values of uplift bearing capacity of the CEP pile, the basis of the formulas are conclusions obtained from the uplift tests about some common piles with same-diameter section, so it is generally determined by the static load test, and it is determined by combining empirical parameter method with other estimation methods [4].

2.1. The Calculating of Uplift Bearing Capacity of the Ordinary Pile

The uplift bearing capacity of ordinary pile mainly relies on the side-friction of pile, in the practical engineering, the side-friction of pile is usually estimated by the calculating formula of compressed pile under static load, and then the uplift bearing capacity of pile is obtained by multiplying the reduction factor [5].

In accordance with the specification of the literature [6], the standard values of ultimate uplift bearing capacity of pile can be calculated as follows:

$$T_{uk} = \sum \lambda_i q_{ski} u_i l_i$$

T_{uk} ---the standard values of ultimate uplift bearing capacity of pile, the unit is KN,

u_i ---the circumference of the pile, the unit is m, for equivalent-diameter pile, $u_i = \pi d$,

q_{ski} --- the standard values of compression ultimate side-friction of the ith layer soil surrounding the pile, the unit is KPa,

λ_i --- the uplift factor of the ith-layer soil, due to l/d>20, so λ is gotten a greater magnitude, it is 0.8.

However, due to the calculating result is smaller than the measured value, although this is partial to safe in engineering, it can be easily lead the results that the under utilization of the bearing capacity of pile and wasting material[7].

2.2. The Limitations of the Existing Theoretical Analysis of Uplift Bearing Capacity of the CEP Pile

Because of the research of the CEP pile is still in the primary stage of exploration, there are still some limitations of the awareness of uplift bearing capacity of the CEP pile.

1. Due to the lack of depth research of theoretical basis in the design, there are still no clear rules of the calculating of uplift bearing capacity of the CEP pile in norms, and most results can only be defined based on static load test in the field. During the tests of engineering piles, loads are not allowed up to failure loads, so it is difficult to get the values of ultimate load, and we can only make an estimate through simulation, calculation and other methods; the calculating formula of the uplift bearing capacity of

single the CEP Pile in rules is also an immature empirical formula. Due to the lack of theoretical research of the CEP pile as uplift pile, it has brought a certain constraints to the application of design and construction [8].

2. The current research of ultimate bearing capacity of the CEP pile mostly limited to the analysis of load transfer characteristics of the pile, but it lacks of in-depth research of the interaction of pile and soil and the failure behavior of the soil between the upper and lower plates. They mostly ignored the damage state changes of soil surrounding the pile after setting bearing plates, and the existing calculating formula of uplift bearing capacity of pile was derived from the calculating formula of compressive pile in norms. It just calculated the uplift bearing capacity of the end of bearing expanded-plate of each length of pile (calculated on the basis of compression and shear failure of soil) and side-friction of pile (according to the full length of the pile) conventionally, and then adding the results and pile weight simply. This did not consider the influence of the sliding failure of the soil surrounding the pile on the bearing capacity after the extreme compression, so the existing calculating formula of the uplift bearing capacity is not perfect enough.

3. For the factors of bearing expanded-plate, such as diameter, spacing, position, ratio of diameter to height, number and other factors, affecting the bearing capacity of single pile, there is also no reliable theoretical basis to support now. We just put forward aspects of influence should be considered, but did not make further research on the above-mentioned factors. Since the calculating formula of ultimate uplift bearing capacity of CEP pile did not reflect the influence of the above factors, design value has certain error, and this bring certain limits to the actual engineering.

2.3. The Empirical Calculating Model of the Uplift Bearing Capacity of the CEP Pile

The existing formula of calculating standard values of the ultimate uplift bearing capacity of the single CEP pile is as follows:

$$U_{mk} = \sum \lambda_i q_{sik} F_m + \sum q_{pk} A_m + \sum R_{pk} A_b \cos\theta + \sum f_{sik} F_b + G$$

When calculating the standard values of ultimate uplift bearing capacity of single pile, based on the geological conditions and construction experience of engineering and other factors [8], it should be multiplied by the construction process coefficient φ_c, $\varphi_c = 0.9 \sim 1.1$.

As can be seen from the formula, the full length of pile is taken into account in calculating the side-friction of pile, and the resistance of the end of plate is identified by compression of soil and shear failure. In the current formula calculating the uplift bearing capacity of the CEP pile, due to neither the changes of the side-friction of pile caused by the influence of expanded-plate on soil is considered, nor the complexity of changes of soil surrounding the pile. Therefore, in practical applications, it is often found that the result from using existing formula about uplift bearing capacity to calculate the bearing capacity of the CEP pile is greater than the value measured, which is partial to unsafe in the engineering design.

3. THE STRESS CHARACTERISTIC OF THE CEP PILE AND THE FAILURE MECHANISM OF SOIL UNDER VERTICAL TENSION

From the structure itself and mechanism formed of the CEP pile, it can be understood that the uplift bearing capacity of the CEP pile is consists of the side-friction of pile, end-resistance of bearing plate, (or addition of side-friction of soil between bearing plates when the plate spacing is smaller) and the weight of the pile. But the number of the bearing plates, the distance between the plates, the technology of forming pile, the size of pile and other factors, etc., all of them have a direct impact on the uplift bearing capacity of the CEP pile.

As can be seen from the Fig. (**1**) as follow, when the bearing expanded-plate spacing is larger, the upper and lower plates have little effect on the failure behavior of the soil. When the spacing is smaller, it will have a greater affection. If the bearing expanded-plate spacing is smaller, the top bearing expanded-plate plays a role, then the soil between the upper and lower plates is compacted and sheared, while the lower bearing expanded-plate did not fully play the role, and t he ultimate bearing capacity values will be controlled by the shearing failure of the soil column between the bearing expanded-plates [8].
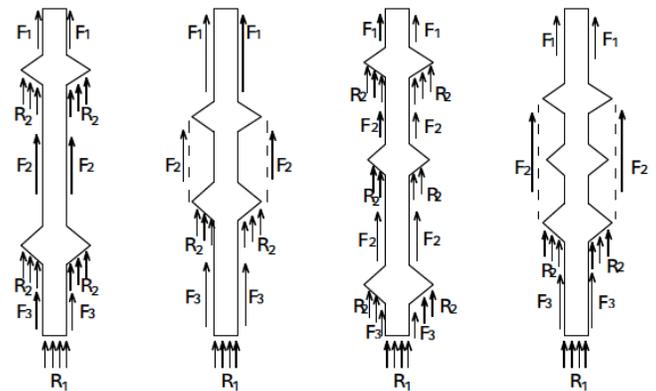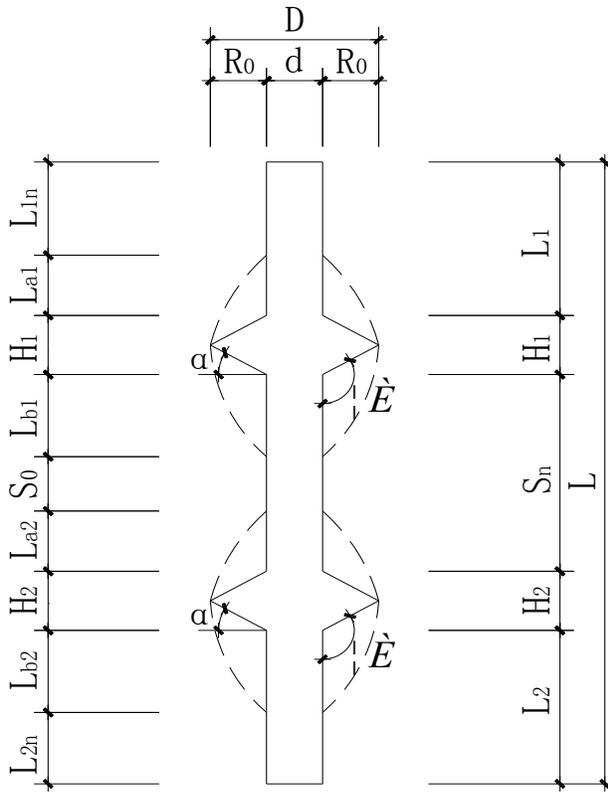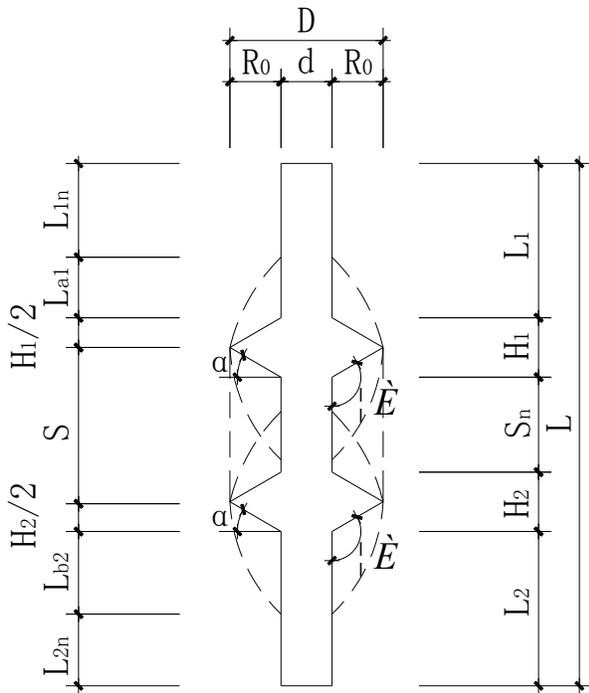

Fig. (1). Diagram about the stress states of the CEP pile under uplift load.

The expanded-plate bear load is mainly by through the following two ways. First, it the external load can be directly shared. Second, the stress distribution of the surrounding soils is changed. Under the uplift load, during the initiation of loading, the expanded-plate drives the surrounding soils to extrude the upper soil adjacent, thereby increasing the shear stress of the upper part of the soil and the mechanical properties of it get improved. While continuing loading, a certain range of soil upper the plate will develop sliding, and finally reach the behavior of sliding failure of soil (as seen in Fig. (**2**) and Fig. (**3**). Usually, the part of side-friction of pile of the bearing capacity of the pile is gradually increasing with the increase of the uplifting load, but when the relative displacement of pile and soil reaches a certain level, the value of the side-friction of pile reaches a peak and begins to decline. But the uplifting resistance of expanded-plate can continue to grow, until the uplifting displacement of pile reaches quite large, and then the overall failure of soil develops and contributes to the loss of stability.
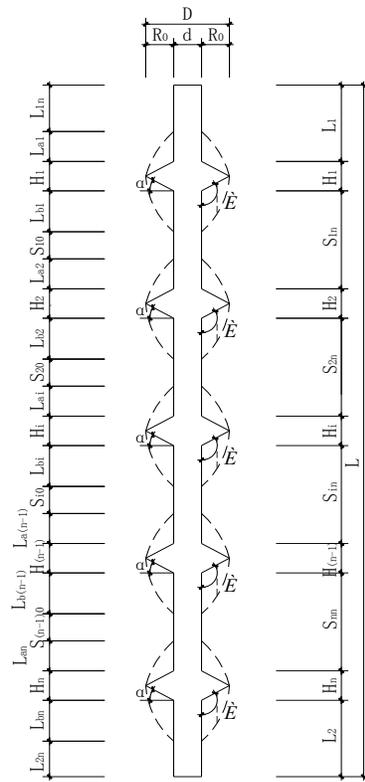
The distance of the expended-plates is larger

The distance of the expended-plates is larger

The distance of the expended-plates is smaller

Fig. (2). Diagram about the effective length of side-friction pile and soil damage with two expended-plates.

The distance of the expended-plates is smaller

Fig. (3). Diagram about the effective length of side-friction pile and soil damage with multi-expended-plates.

The analysis of the stress characteristic of the CEP pile shows that the uplift bearing capacity characteristic of the CEP pile are better than the common pile. With the load increasing on the top of the pile, the ratio of load shared by side-friction of pile will gradually decrease, while the ratio shared by bearing plate will gradually increase. The resistance of bearing plate will be gradually over the side-friction of pile. Uplift load on the top of the pile is mainly bore by the uplift resistance of the bearing plate.

By analyzing the failure mechanism of soil surrounding the pile, it is shown that, due to the setting of the bearing expanded-plate, under the action of vertical tension, the soil upper the plate is not a simple compression failure, while the soil upper the plate has a greater compression stress in the early, then the soil will slide. These changes make the calculating length of the side-friction of pile to be greatly reduced. Therefore, it can't be considered by the whole pile length when calculating the side-friction of pile. The bearing capacity of the end of expanded-plate can't be simply gotten though multiplying the resistance of subsoil per unit area by the expanded-plate area. At the same time, the tensile stress develops at the soil surrounding the pile under the plate within a certain range, and the friction between the pile and soil will be disappeared. Therefore, the bearing capacity of the end of plate should be determined by the slip-line theory, and based on it to determine the effective length of calculating the side-friction of pile. Due to the traditional formula about calculating bearing capacity of single pile is unreasonable and design theory of pile foundation is imperfect, the failure mechanism of the soil surrounding the pile should be analyzed carefully. After full consideration of various factors, the calculating model of the uplift bearing capacity of the single pile will be determined, and which can ensure the rationality and reliability of the design of this type of pile.

4. CONCLUSION AND OUTLOOK

They can be obtained that the following conclusions according to the analysis above:

Due to the existence of the bearing expanded-plate, the failure mechanism of the soil surrounding the CEP pile is changed. The traditional formula about calculating bearing capacity of the single pile is without considering the tensile stress caused by the soil under the plate and the influence of soil slippage on the side-friction of pile, and the influence of the sliding failure of the soil on the bearing capacity of the end of bearing plate. Therefore, the traditional calculation method is unreasonable, which will make a difference between the actual situation and the design, therefore, that is unsafe.

According to the failure mechanism of soil surrounding the pile, the calculating mode of uplift bearing capacity of single pile should be determined by the slip-line theory. The tensile stress area of the soil under the bearing expanded-plate and slip range of the soil upper the plate should be fully considered. The effective calculating length of calculating side-friction of the pile should be determined, and the bearing capacity of the end of soil upper the plate should be determined according to the sliding failure. So as to modify the irrational part of the traditional formula and put forward a new calculating mode of the uplift bearing capacity of the single CEP pile.

For the research on the uplift bearing capacity of the CEP pile, it still be required that a large number of in-depth theoretical analysis and experimental research. The main research directions are currently the accumulation of more basic data and making the design more reasonable and reliable. Therefore, the relative factors of uplift bearing capacity of single pile should be further studied, in order to improve the new calculating mode of uplift bearing capacity and provide reliable theoretical basis for the application of the CEP pile, which will contribute to large-scale popularization and application about this technology.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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