Bearing mechanism and bearing capacity analysis of bidirectional crimping uplift pile

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Abstract. Through the analysis of the design, mechanism of action and mechanics principle of bidirectional crimping uplift pile, the scientificness and feasibility of method are further expounded. The basic concept, basic principle and method of the secondary structure function design are given, Emphasis is placed on the research and application of structural functions in the later stages of deformation to optimize structural design and the potential for structural play. The research shows that the compressive and pull-up bearing capacity of the bidirectional crimping uplift pile is not lower than that of the multi-plate-pile. Compared with the same volume of concrete square pile, the uplift capacity is increased by 170%; the construction process is more reasonable and extensive. Applicability, in the context of industrial building products, has significant economic benefits.

1. Introduction

The internal force effects in structural members are usually tensile, compression, bending, shearing and twisting. Under various loads, the design of tension, compression, bending, shearing and torsion of structural members can be carried out directly. For structural members with different mechanical properties, the process of reaching the limit state is generally different after the load is applied. Due to the mechanical properties of the structural members themselves, or due to human intervention in this process, the phenomenon of reducing or increasing their resistance may occur. The so-called concomitant effect is the effect of the non-direct action target in the process of load action. For example, under the action of load, the lateral deformation of concrete in steel tube is restrained, so that the internal concrete is in the state of three-dimensional compression, and the mechanical properties of concrete materials are changed[1]. The second-order effect is the transfer of dangerous section when the column is under eccentric load. The former shows the improvement of carrying capacity while the latter decreases the carrying capacity.

In both cases, the mechanical behavior opposite to the structural functional objectives of the design occurs during the increasing load effect. Confining the concrete to improve the bearing capacity is completely achieved by design. The idea of this design is to take advantage of the changes in the mechanical properties of the constrained concrete.

This paper studies "bidirectional crimping uplift pile design method" [ZL201310007835.5] [2], aiming at effectively improving the pile's uplift bearing capacity, which is characterized by a set of two piles, which rotate in opposite directions. The pile-forming method of the pile driving is realized and consolidated at the pile cap. When there is an external load, the opposing twists and turns are mutually constrained, and the generated torque is balanced as an internal force at the cap. Thereby, the pressure resistance and the pull-out bearing capacity are improved, and the pull-out bearing capacity is...
prominently improved. Its main technical advantages are reflected in the load, and the way to change the bearing mechanism is designed. The outstanding features of this method are reliable pull-out bearing capacity, extremely convenient construction and low cost.

2. Secondary structure function design method based on Concomitant effect

2.1. basic concepts
The so-called secondary structural function accompanying the effect of action means that under the action of the load (or external environment), the internal action of the structure will have an effect, and the original bearing mechanism is changed or partially changed due to the material of the structure and the internal structural structure. In accordance with the new bearing mechanism, the structural function is significantly improved within a certain range, and the effect of improving the structural function is improved. We are concerned with the part that enhances the structural function, that is, the advantageous secondary structure function. Has the following characteristics:

- Don’t change the external mode of action.
- The effect is increasing.
- The secondary function of the designed structure is continuously strengthened in a certain range during the process of increasing the effect. Some of the enhanced structural functions are accompanied by effects.

The design method can be realized through two channels: one is the impact on the structural function reduction caused by the additional bending moment, we have enough safety by improving the safety reserve of the structure; the second is to change the mechanical environment of the material. Improve its mechanical properties or change its structural bearing mechanism.

2.2. Design of bidirectional crimping uplift pile
This section applies the design theory of secondary structure function to design the two-way compression-resistant uplift pile.

Bidirectional crimping uplift pile is a kind of pull-out pile designed by the author in the long-term research and practice according to the idea that the bearing capacity of the pile increases continuously with the effect of load action[2]. The shape of the pile is formed on the basis of a square pile (as shown in Fig. 1a), which is surrounded by a spiral surface formed by rotation. As shown in the figure: Since the friction angle of most soils is between 60° and 70°, the angle of the cutting angle is 60°, and when the rotation is 90°, the height is tan60°=1.732b, square. The length of the side. Rotate 360° to the height of a pitch: There are four spirals, and the equation is:

\[
x = r \cos \theta, \quad y = r \sin \theta, \quad z = \frac{6.928b}{2\pi} \theta
\]

Among them, \( \theta \) is the helix radial rotation angle and rotation radius. When \( \theta < 0 \), the spiral equation for counterclockwise rotation is obtained. The pile tip is a square pyramid that is rotated and is divided into two directions. The pile body is prefabricated with high-strength concrete. Since the modulus of concrete is much larger than the modulus of soft soil, piling into the soil is completely feasible. When the pile is piled, the pile load is continuously applied. When the effect is greater than the bearing capacity of the soil in contact with the curved surface, the spiral surface is rotated by the passive earth pressure. The piles that rotate in both directions are combined into one group, and are fixed by the cap after piling. The piling equipment adopts a static press machine, and a plane ball joint is installed on the top of the pile cap to facilitate the free rotation of the pile body when it is rotated downward.

In such a combined design of piles, when there is external load, the pile will still rotate under passive earth pressure, whether it bears vertical pressure or uplift force. However, due to the locking effect of the cap, the rotating pile body will be fixed, and the reverse torsion produced by the two piles will be balanced at the cap (as shown in Fig. 1b and 1c). At this time, the bearing capacity of the pile has the same effect as that of the screw pile, and its bearing capacity can be continuously improved.
with the load.

![Section design drawing](image1)
(a) Section design drawing  
(b) Bidirectional crimping uplift pile position  
(c) Pile body after pile caps are fixed

Fig.1. Cross section design and simulation effect diagram of bidirectional crimping uplift pile

The shape of the pile based on the parametric design is shown in Figure 2.

![Model diagram](image2)
Fig.2. Model diagram of bidirectional crimping uplift pile wire frame

### 3. Study on bearing capacity of Bidirectional crimping uplift pile

#### 3.1 Single-pile lateral resistance of Bidirectional crimping uplift pile

The lateral resistance of a conventional linear cast-in-situ pile is:

$$Q_{sk1} = u \sum q_{sk} l_i = 4h \sum q_{sk} l_i$$  \hspace{1cm} (2)

Where: $q_{sk}$ is the standard value of the ultimate side friction of the $i$-th layer of the pile side; $u$ is the circumference of the pile; $r$ is the diameter of the pile; $l_i$ is the diameter of the pile; $d$ is the thickness of the pile through the soil of the $i$-th layer.

For the two-way compression-resistant uplift pile with a real length of $L$, the pile side area increases by $0.134bL$. The lateral resistance of the two-way compression-resistant pile is:

$$Q_{sk2} = u \sum q_{sk} L_i = 4h \sum q_{sk} L_i = 4.536b \sum q_{sk} l_i$$  \hspace{1cm} (3)

Comparing formula (2) with formula (3), the lateral resistance of the two-way compression-resistant pile with a real length of $L$ is 1.134 times that of the ordinary square pile.

#### 3.2 Bearing capacity of single pile in Bidirectional crimping uplift pile

For the production of the two-way compression-resistant pile, the vertical height of a pile unit is $H = 1.732b$, and within a length of $H$, the spatial oblique surface of the pile unit body can be horizontally projected into a disk. Therefore, in the pile unit of the $H$ length, it is considered that there is a disc, and the bearing capacity is estimated by the method of analogizing the multi-plate-pile.

According to the force mechanism of the multi-disc cast-in-place pile, the pile end, the pile bearing plate and the side resistance bear the load together. According to the Technical Specification for Building Pile Foundation, the formula [3], [4]:

$$Q_{uk} = Q_{sk} + Q_{pk} = u \sum q_{sk} l_i + \sum \eta_{pi} q_{pk} A_{pi} + \psi \eta_p q_{pk} A_p$$  \hspace{1cm} (4)

Among them: $Q_{uk}$ is the standard value of vertical ultimate bearing capacity of single pile. $Q_{sk}$ is the standard value of total limit side resistance of single pile. $Q_{pk}$ is the standard value of total end resistance of single pile. $q_{sk}$ is the limit side resistance standard of pile section in $i$th layer soil Value. $q_{pk}$ is the standard value of the limit end resistance of the $j$th branch or disk. $q_{sk}$ is the standard value of...
the ultimate end resistance of the chassis. It can be calculated according to local experience. If there is no local experience, the "Technical Specifications for Building Pile Foundation" can be checked. \( u \) is the circumference of the pile body. \( l_i \) is the thickness of the pile body in the \( i \)-layer soil (this thickness is the value after removing the section or the thickness of the disc). \( A_p \) and \( A_p \) respectively are the \( j \)-th branch or disc except the pile body area \( A_p \) and chassis area. the manufacturing principle and upper sectional view of the two-way compression-resistant pile can be obtained: \( A_p = 0.333bL = 0.577b^2 \), \( \eta_p \), \( \eta_p \) is the correction coefficient of the limit value of the limit end resistance of the disk, see the value Table 1, \( \psi_p \) is the chassis size effect coefficient.

| Type of soil | Hard clay | Hard plastic clay | Plastic clay | Silty soil | Silty sand | Fine sand | Coarse sand |
|--------------|-----------|------------------|--------------|-----------|-----------|-----------|------------|
| Correction factor | 0.5~0.7   | 0.8~1.0          | 1.0~1.4      | 1.4~1.6   | 0.8~1.0   | 0.6~0.7   | 0.4~0.5    |

According to the formula (4), the bidirectional crimping uplift pile can be simplified into multi-disc pile perfusion for general analysis and calculation. The section obtained by the cross-section projection is a plane, and the thickness of the support disc is negligible. Zhu Qingdong [5] and others have carried out the calculation and comparison of actual engineering. The comparison results show that the bearing capacity of the circular piles with piles is 1.14 times higher than that of ordinary round piles.

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In order to facilitate the calculation, we quote the geological conditions in the actual engineering case studied by Ju Yuwen [6] and others. In the actual project, multi-disc piles are used for construction. The experiment shows that the bearing capacity is obviously improved compared with the ordinary pile foundation. However, the construction of the support pile is complicated and the economy is relatively poor. Therefore, we use the two-way compression-resistant pile as the pile foundation in the same geological conditions, and carry out the calculation of the compressive and pull-out bearing capacity, and the same volume. The square piles and the pile body are square branch piles for bearing capacity comparison.

The distribution of the soil layer and the test pile size are shown in Fig.3 below. In the figure, the distance between the support plates of bidirectional crimping uplift pile is the distance of one unit. The support disc distance of the multi-disc cast-in-place pile is the same as the original text.

In order to facilitate the calculation and comparison, we can take the common square pile length of 700mm and the pile length to be 24m. According to the "Technical Specifications for Building Pile Foundation", the formula can be used to calculate.

\[
Q_{sk} = Q_{sk} + Q_{pk} = u \sum q_{s1}l_i + q_{pk}A_p
\]  \hspace{1cm} (5)

The length of the two-way compression-resistant pile is also 700mm, and the pile length is 24m. According to the principle of pile formation, the pile plate projected by each unit is a square circumcircle, so the diameter is 790mm, and the formula (4)is used. Calculation, calculation results are shown in Table 2.
Table 2. Comparison table between the uplift bearing capacity of bidirectional crimping uplift pile and the uplift bearing capacity of ordinary square piles

| Side length (h/mm) | length (m) | Branch diameter (mm) | Branch height (mm) | Frictional resistance /kN | End bearing force /kN | Bearing capacity of Branch/kN | Bearing capacity calculation/kN | percentage |
|-------------------|-----------|----------------------|--------------------|--------------------------|----------------------|-----------------------------|-------------------------------|------------|
| Ordinary square pile | 700 24 | — | — | 3684 | — | 3684 | 100 |
| muti-plate-pile | 700 24 1800 1650 2840 | — | 4285 | 7125 193% |
| Bidirectional crimping uplift pile | 700 24 790 | — | 4178 | 5824 | 10002 270% |

The comparison results show that the uplift capacity is 170% higher than that of the ordinary square pile. The piles are increased by 77%; the multiples of different geological conditions may fluctuate. In general, the resistance to pull-out of two-way compression-resistant piles is significantly improved. Compared with the muti-plate-pile, it can not only make up for the difficulties of construction of the muti-plate-pile, but also has better bearing capacity improvement than the muti-plate-pile, which has a very broad prospect.

4. Conclusion
(1) The secondary structure function design method of the bidirectional crimping uplift pile proposed in this paper is realized by changing the bearing mechanism of the structure. During the structural load-bearing process, the mechanical properties under the direct action effect are changed.

(2) Through the theoretical analysis and comparative study of the bidirectional crimping uplift pile, it is concluded that compared with the ordinary straight-type cast-in-place pile, the single-pile is due to the large contact surface area between the bidirectional crimping uplift pile and the foundation soil. The pile side resistance is 1.134 times of the ordinary square pile.

(3) The bidirectional crimping uplift pile are simplified into multi-disc piles for ultimate bearing capacity calculation. The results show that the compressive bearing capacity of the bidirectional crimping uplift pile is 130% higher than that of ordinary square piles. 54% higher than that of the muti-plate-pile. the uplift bearing capacity is increased by 170% compared with ordinary square piles, and 77% higher than that of muti-plate-pile. Studies have shown that bidirectional crimping uplift pile have superior mechanical properties and wide applicability.

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References
[1] Li Y, Zhang L. (2005)The investigation and application of self-compacting expensive concrete filled steel tube. J. Journal of Beijing University of Technology. 31(5): 496-499.
[2] Wang H. (2013)A bidirectional crimping uplift pile design method: 201310007835.5.P.
[3] Wu Y, Zheng G, Yan P. (2000)A settlement prediction method for multi-under-reamed cast-in-situ pile foundation. J. Chinese Journal of Geotechnical Engineering. 22(5): 528 -531.
[4] Xu Z, Zhang X. (2002)Application of Extruding-expanding multi-brace-disk pile in Engineering. J. Building Structure. 32(7): 13-16.
[5] Zhu Q. (2004)On design method of cast-in-place concrete pile with supporting-disc. J. Yangtze River. 35(10): 29-32.
[6] Ju Y, Liang R, Bai X, Zhang S. (2003)Experimental study of bearing and deformation behavior of squeezed branch pile and its bearing capacity calculation.J. Engineering mechanics. 6: 34-38.