Design method of large-diameter rock-socketed pile with steel casing

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Abstract: There is a lack of the design and calculation method of large-diameter rock-socketed pile with steel casing. Combined with the “twelfth five-year plan” of the National Science & Technology Pillar Program of China about “Key technologies on the ports and wharfs constructions of the mountain canalization channels”, this paper put forward the structured design requirements of concrete, steel bar distribution and steel casing, and a checking calculation method of the bearing capacity of the normal section of the pile and the maximum crack width at the bottom of the steel casing. The design method will have some degree of guiding significance for the design of large-diameter rock-socketed pile with steel casing.

1. Introduction
Large-diameter rock-socketed pile with steel casing is deep foundation which often used in deepwater wharf and cross-river bridge construction. Set up steel platform on the water before the construction of pile foundation. Next, install the construction machinery on the steel platform. Then hit the steel casing and making it form cofferdam. Finally, bore a hole in the steel casing. Rock-socketed pile with steel casing consist of two parts: one part is steel casing which buried into the formation; another part is reinforced concrete which embedded in the steel casing. The steel casing is one of the construction measures. Reinforced concrete is the major structure which is used to bear load. The steel casing will not be dismantled after construction. Large-diameter rock-socketed pile with steel casing has been widely used in cross-river bridge construction and deepwater wharf. But the research of design and calculation method of large-diameter rock-socketed pile with steel casing is quite scarce and there isn’t complete method. The designs of large-diameter rock-socketed pile with steel casing refer to rock-socketed pile in the actual engineering. Therefore, it is necessary to research the design and calculation method of large-diameter rock-socketed pile with steel casing.

2. Structure design requirements
2.1 Structure design requirements of concrete
There are some requirements should be satisfied for the concrete of the large-diameter rock-socketed pile with steel casing in the structural design. The concrete strength should not be lower than C30 to meet pile strength under the large-tonnage load. The concrete cover thickness of the main steel should not be less than 50mm.
2.2 Structure design requirements of steel bar
There are some requirements should be satisfied for steel bar of the large-diameter rock-socketed pile with steel casing in the structural design. The main steel should be deformed steel, whose diameter should not less than 14mm. The cross-sectional area should be determined by calculation. The reinforcement ratio should not less than 0.4%. The number should not less than 12. The steel bar should evenly spaced along the circumference of the long layout, the distance should not less than 80mm. Stirrup should be I1 steel, whose diameter not less than 6mm and distance should be 200-300mm. The distance should be less than 60mm in the range of 1000mm below and over the rock surface. Spiral or ring welded stirrup should be used. And strengthen stirrup should be welded every 2m, whose diameter should more than 16mm. Longitudinal steel bar at the rock surface and the underside of the steel casing should be increased 20% without over reinforcement. The distance should more than 1.5 times pile diameter where is from the rock surface to the top of the steel bar and from bottom of the steel casing to the bottom of the steel bar. The steel bar should be increased within steel casing, which should be smooth or ribbed steel. The diameter is not less than 6.0mm. The steel spacing is not more than 20.0cm.

2.3 Structure design requirements of steel casing
There are some requirements should be satisfied for steel casing of the large-diameter rock-socketed pile with steel casing in the structural design. The distance of steel casing embedded in rock should not less than 0.5 times the pile diameter. The center distance of the pile should not less than 2 times the diameter. Steel casing connection, stiffened rib welding, vertical and horizontal bracing and steel casing welding should in accordance with Code for Design of Steel Structures in Port and Waterway Engineering (in Chinese) and other relevant specifications for design.

3. Checking calculation method
For the large-diameter rock-socketed pile with steel casing, the most critical sections should be focused on checking the bending capacity and crack width to meet the design requirements. According to the existing related experimental research, due to the variable cross-section of the bottom surface of the steel casing, the steel casing and the reinforced concrete pile bear the load above of the variable cross-section together, the load under the variable cross-section borne by the reinforced concrete pile alone, the stress in the variable section suddenly becomes large, cause the phenomenon of the stress concentration, so the damage of large-diameter rock-socketed pile with steel casing occurs in here. Therefore, the ultimate flexural capacity and crack width of the pile normal section at the bottom of the steel casing shell be checked in the design. The load and its effect combination act on the pile refer to current standard in China: Load Code for Harbor Engineering(in Chinese), Design and Construction Technical Standard for Cast in-Situ Pile of Harbor Engineering (in Chinese), Code for Pile Foundation of Harbor Engineering(in Chinese) and Design and Construction Code for Open Type Wharf on Piles (in Chinese).

3.1 The checking calculation of the flexural capacity of the normal cross section of the pile body at the bottom of the steel casing
The calculation of flexural capacity of the normal cross section of the pile body at the bottom of the steel casing is referenced to Design Code for Concrete Structures of port and waterway Engineering (in Chinese), the method of calculating the flexural capacity of normal section is as follows

\[ M_u = \frac{2}{3} f'c Ar \frac{\sin^2 \pi \alpha}{\pi} + f'_y A_s r_s \frac{\sin \pi \alpha + \sin \pi \alpha_t}{\pi} \]  

(1)

\[ \alpha_t = 1.25 - 2\alpha \]  

(2)

\( A \) is the cross-section area of pile core concrete; \( A_s \) is the total section area of the longitudinal common steel bar; \( r \) is the radius of the pile core; \( \alpha \) is the ratio of the circular angle (rad) to 2\( \pi \) in the
area of the concrete section of the compression zone; $\alpha_t$ is the ratio of the section area of the longitudinal tensile bars to the total area of the longitudinal common steel bar, when $\alpha$ is more than 0.625, $\alpha_t$ is 0; $M_o$ is the bending moment design value in the bottom of the steel casing it is composed of design load, positive bending moment generated by the design bending moment of the bottom surface of the steel casing and negative bending moment which is at bottom of the steel casing generated by horizontal resistance of pile side soil and bedrock above of steel casing, the formula is as follows:

$$M_o = M_F + M' - M_r$$

(3)

$$M_F = F_k l'$$

(4)

$M_F$ is the bending moment of pile top load on the bottom surface of steel casing; $M'$ is the design value of pile top moment; $M_r$ is the bending moment which is at bottom of the steel casing generated by the horizontal resistance of pile side soil and bedrock above of steel casing; $F_k$ is the design value of pile top horizontal load; $l'$ is the distance between the horizontal load of pile top and the bottom surface of steel casing.

### 3.2 The calculation of the maximum crack width at the bottom of the steel casing

According to the normal use of the request, the maximum crack width should less than 0.2mm. The calculation method of maximum crack width of the steel casing refers to Design and Construction Technical Standard for Cast in-Pile of Harbour Engineering (in Chinese). According to the differences and the similarities between the large diameter steel casing rock-socketed piles and ordinary cast-in-situ piles, factors in the formula should be adjusted appropriately to make it applicable to design checking calculation of large diameter steel liners of rock-socketed pile. The formula is as follows:

$$W_{\text{max}} = k_i \frac{\sigma_{sl}}{E_s} \left( \frac{30 + d_s}{0.817 + 6.67 \rho} \right)$$

(5)

$$\rho = \frac{A_s}{\pi r^2}$$

(6)

$$\sigma_{sl} = \frac{130 \alpha_{Es} [(r/ r) + \cos \phi]}{27.3 \phi + 203.6 (r/ r)^2 \alpha_{Es} \rho} \cdot \frac{M_u}{r^3} \cdot 10^3$$

(7)

$$\phi = \frac{48.2 + 614 \alpha_{Es} \rho}{50 + 390 \alpha_{Es} \rho} \cdot 10^3$$

(8)

$W_{\text{max}}$ is the maximum crack width(mm); $k_i$ is the influence coefficient of surface shape of steel bar, smooth steel to take 1.4 and deformed steel to take 1.0; $\sigma_{sl}$ is the longitudinal steel bar stress on the edge of the pile(MPa); $E_s$ is the elastic modulus of reinforcement(MPa); $d_s$ is the diameter of reinforcement(mm); $\rho$ is the reinforcement ratio of pile core section, when it is less than 0.6%, takes 0.6%; $A_s$ is the area of reinforcement section(mm$^2$); $\alpha_{Es}$ is the ratio of elastic modulus of steel bar to elastic modulus of concrete; $r_s$ is the radius of the circumference of the longitudinal steel bar; $\phi$ is the half of the central angle of the concrete section area of the compression zone.

### 4. Conclusion

For designing calculation of large-diameter rock-socketed pile with steel casing, this paper comes up with structure design requirements, it mainly includes how to select concrete strength grade, distributes main steel bar, stirrup, the longitudinal steel bar near rock surface and bottom of the steel casing, smooth or ridded steel bar within steel casing, arrange steel casing. And this paper discusses a checking calculation method of the bearing capacity of the normal section of the pile and the
maximum crack width at the most critical sections that is bottom of the steel casing. This research result will have some degree of guiding significance for the design of large-diameter rock-socketed pile with steel casing.

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