Creative Application of Steel Cylinder Structure in Anchorage of Ultra-long Suspension Bridge

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Abstract. The damage of anchorage itself and the instability of surrounding rock around the anchorage are difficult to construct. It is very difficult to analyse and summarize the possible failure modes of the anchorage from the perspective of engineering examples because of the safety of the existing suspension bridge tunnel anchorage. The steel cylinder anchorage structure is innovatively put forward in this paper.

1. Background
The common anchorage structure of the suspension bridge includes gravity anchorage, gravitational rock-socketed anchorage, tunnel-type anchorage and rock-socketed anchorage. At the feasibility design and preliminary design stage, there are several anchor foundation schemes, such as continuous concrete wall foundation and placed caisson foundation. An innovation method using the large steel cylinder as anchor foundation is proposed for the suspension bridge. In this paper, numerical calculation is carried out to analyse the feasibility of large-steel-cylinder anchorage to provide guidance for design and construction [1-7].

2. Engineering condition
The suspension bridge to be built is located in the south of China and the mainspan is about 1620m. The average water depth of the anchorage is 4-5m. According to the geological exploration there is obvious fluctuation for the bedrock surface. The elevation difference is as large as 10m within 100m range. The buried depth is small and the elevation of top surface of the strong weathered granite is about -36m.

2.1. Design scheme
A group of six steel cylinders with 30m diameter is adopted for the foundation of the anchorage, as shown in Figure 1. For the two anchorages located at both east and west direction, there are two working surface for the construction of cylinder installation, soil excavation, dewatering and concrete pouring. Firstly the surrounding soil around the steel cylinder is reinforced by deep cement mixing method. Then the steel cylinder and its vice cell are vibro-driving installed by floating crane and...
medium coarse sand is refilled into the steel cylinder and its vice cell. The high-pressure jet grouting pile is further used to reinforce the surrounding soil around the cylinder to satisfy the impermeable condition and the driven cast-in-place pile inside each steel cylinder is constructed simultaneously. The soil inside the steel cylinder is excavated by layers. The circumferential stiffening ribs are installed step by step along the height until the bottom of the steel cylinder. The concrete is constructed from the bottom plate to the wall sequentially. After all the wall inside the cylinder has been completed, the concrete on the top surface is built through delaminating and blocking method.

Figure 1 Plan sketch of steel-cylinder anchorage

2.2. 3D model
The calculation model is shown in Figure 2. In order to display all the structures in the model some part of the soil is hidden and the compositions of the steel cylinder anchorage are shown in Figure 2-4. As can be seen, the calculation model includes the anchorage, concrete top surface, anchorage foundation, concrete inside the cylinder, chemical churning cement soil, DCM and rock-socketed filling pile from up to down. The embedded depth of the filling pile is 7m in the medium-weathered rock.

Figure 2 Three-dimensional imaginary model
3. Construction procedures
The calculation procedure is shown in Figure 3, including geo-stress equilibration, steel cylinder installation, filling pile construction, concrete pouring inside the cylinder, pile cap and anchorage installation. In order to consider the anchorage deformation under the action of the pulling force of the suspension bridge, the displacement of the anchorage is reset before the action of the pulling force.

4. Calculation result and analysis
Figure 4 shows the horizontal displacement of steel cylinder foundation and rock embedding cast-in-place pile foundation. It can be seen that there is a tendency of rotation deformation as a whole of six steel cylinders. With the bottom of the steel cylinder as the rotation centre, the horizontal displacement gradually increases from the bottom to the top and the maximum horizontal displacement is about 3.97cm. Similarly, the maximum horizontal displacement of rock embedding cast-in-place pile is about 1.67cm, which is located at the top of pile.

In addition, in order to understand the deformation of the soil inside the foundation in detail, the model section is taken for analysis, and the corresponding deformation contour is shown in Figure 5. It can be seen from the figure that due to the reinforcement of the high-pressure rotary spraying and DCM around the cylinder, part of the horizontal force of the anchorage is transmitted to the soil layer through the steel cylinder and the horizontal displacement range in the soil layer becomes larger. The vertical deformation is consistent with the deformation of pile cap under horizontal load.
(1) Horizontal displacement of steel cylinder (maximum 3.97cm)

(2) Horizontal displacement of rock embedding cast-in-place pile foundation (maximum 1.67cm)

Figure 4 Horizontal displacement of steel cylinder and cast-in-place pile

(1) Horizontal (maximum 6.6cm)  (2) vertical (up 2.3cm, down 2.1cm)

Figure 5 Section contour of ground deformation

5. Conclusions
As an alternative to the underground continuous wall anchorage structure, the steel cylinder anchorage structure is innovatively put forward. In this paper, the construction procedure of the steel cylinder is introduced in detail and the deformation of the cast-in-place pile inside the cylinder and the steel cylinder are also calculated. The conclusions are as follows:
(1) Six steel cylinders show a trend of rotational deformation with the bottom of the steel cylinder as the rotation centre. The horizontal displacement gradually increases from the bottom to the top and the maximum horizontal displacement is about 3.97 cm. Similarly, the maximum horizontal displacement of rock embedding cast-in-place pile is about 1.67 cm, which is located at the top of pile.

(2) There is great application of the steel-cylinder structure in different field as both bearing structure and watertight structure.

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References
[1] Xu J. Zhou A.Z. Jiang P.M. (2019) Mechanical and deformation characteristics of deep and large circular anchor pit with inclined rock surface. Journal of Jiangsu University of Science and Technology (Natural Science Edition), 33(4):116-122.
[2] Wang Y. (2018) Numerical Simulation Study on Prestressed Anchorage System for Bridge Anchorage. Transportation Science & Technology, 6: 25-27.
[3] Huang W. and Xu Z.W. (2019) Research Status of Tunnel Anchorage in Suspension Bridge. Sichuan Building Materials, 45(2): 152-154.
[4] Sun Y.F. and Xue C.G. (2019) Scheme innovation research on the underwater anchorage foundation of huge suspension bridge. China Harbour Engineering, 39(1): 15-18.
[5] Zhou L. and Yin Y. (2019) Non-uniform Layered Construction Technology of the Gravity Anchorage Bottom Plate. Journal of Civil Engineering and Management, 36(2): 132-137.
[6] Wu L.Z. You B. and He C. (2018) Application of underwater three-dimensional sonar in anchor caisson construction. China Harbour Engineering, 38(11): 65-67.
[7] Qi X. and Zhang D. (2018). Experimental study on tunnel anchorage model and bearing mechanism of jinsha river bridge of the tiger leaping gorge, Construction Technology, 47(13): 127-131.