Numerical Analysis of Steel Cylinder Anchorage Deformation for Suspension Bridge

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Abstract. In this paper, the deformation of the new structure under the tension of the suspension bridge is calculated and analysed in detail using the finite element software. The maximum horizontal displacement is about 6.65cm, which is located at the top of the anchor structure. The downward vertical deformation occurs at the side of the anchorage structure, with the maximum value of about 2.7cm. The upward vertical deformation occurs at the rear of the bearing surface, with the maximum value of about 3.0cm. The deformation of the anchorage in this scheme satisfies the specification requirements.

1. Background

Suspension bridge is recognized as the most important structural form of long-span bridge, with the largest span capacity. Because the suspender spacing of suspension bridge is not large, its beam height does not increase with the increase of span. In China, there are many high mountains and canyons and the modern suspension bridge starts late, but its scale and development speed are unprecedented. The main components of the superstructure of suspension bridge are tower, main cable and stiffening beam, followed by sling, cable clip. The anchor solid at both ends of the main cable is considered as the substructure, but it is an important part of the ground anchored suspension bridge. The load is transmitted from the sling to the main cable, and then to the anchorage. The transmission way is simple and clear [1-5].

The anchorage system of suspension bridge can be divided into two types: steel anchorage system and prestressed anchorage system. The steel anchorage system of the anchorage frame is composed of section steel, with large amount of steel, high requirements for fabrication, installation and construction accuracy. Because of the large quantity, the use of prestressed anchorage system in large suspension bridges tends to decrease gradually obviously. The main components of anchorage prestressed anchorage system are: cable strand connection system and anchorage prestressed system. The cable strand is connected with the prestressed reinforcement through the connector and transmits the tension to the anchor block. Because the system uses less steel and the layout is relatively flexible, and the fabrication and installation requirements of supporting steel frame are low the construction is convenient.
2. Calculation model
The calculation model is shown in Figure 1. 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.

Table 1 Soil parameters used in calculation

| NO.  | Density $\rho$(g/cm$^3$) | Water Content $\omega$(%) | Void ratio | Cohesive $C_u$(kPa) | Frictional angle ($\phi_{uu}$) (°) | Cohesive $C_u$ (kPa) | Frictional angle ($\phi_{uu}$) (°) | $E_{1-2}$ (MPa) | $K$ (cm/s) |
|------|--------------------------|---------------------------|------------|---------------------|-----------------------------------|---------------------|-----------------------------------|----------------|-----------|
| ②_2Silt | 1.6 | 60.9 | 1.77/2 | 1.96 | 8.59 | 3.79 | 12.81 | 2.4 | 8.0e-7 |
| ②_2Clay Silt | 1.83 | 31.8 | 0.95/9 | | | | | 4.1 | 3.1e-7 |
| ②_3Mud silt | 1.71 | 47.1 | 1.36/1 | 7.2 | 10.3 | 7.43 | 14.32 | 3 | 4.0e-7 |

The calculation procedure includes 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.

3. Construction analysis
Figure 2 demonstrates the deformation scheme of the model. As can be seen, under the action of the pulling force of the suspension bridge the anchorage deforms towards the force direction and the maximum deformation is around 6.7cm.

The distribution of horizontal displacement is shown in Figure 3. In order to observe the displacement of each structure some parts of the soil layers are hidden. It can be seen that the maximum horizontal displacement is about 6.65cm, located at the top of the anchorage. The model
takes the rock-socketed cast-in-place pile as the turning centre and the horizontal displacement of the steel cylinder increases gradually from bottom to top.

Similarly, the vertical displacement of the model is shown in Figure 4. As can be seen, there is obvious subsidence in the front and uplift in the rear, which is similar to the deformation of pile cap with multi-pile. The maximum subsidence and uplift are 2.7cm and 3.0cm respectively. According to the term 8.4.3 of Specifications for design of highway suspension bridge (JTG/T D65-05-2015), during the operation stage the allowable horizontal displacement of the anchor is recommended to be smaller than 0.0001 times of the main span and the allowable vertical displacement is recommended to be smaller than 0.0002 times of the main span. If the main span is 1600m, the horizontal and vertical displacement of the anchor are recommended to be smaller than 16cm and 32cm respectively. Therefore, the deformation of the anchor satisfies the requirement of the specification.
4. Conclusions
As an alternative to the underground continuous wall anchorage structure, the steel cylinder anchorage structure is innovatively put forward. In this paper, the deformation of the new structure under the tension of the suspension bridge is calculated and analysed in detail using the finite element software. The main conclusions are as follows:

(1) As a whole, the anchor structure takes the rock embedding cast-in-place pile as the rotation centre and the horizontal displacement gradually increases from the bottom of the steel cylinder to the top. The maximum horizontal displacement is about 6.65cm, which is located at the top of the anchor structure;

(2) Similar to the deformation of multi-pile platform foundation under horizontal load, the downward vertical deformation occurs at the side of the anchorage structure, with the maximum value of about 2.7cm. The upward vertical deformation occurs at the rear of the bearing surface, with the maximum value of about 3.0cm.

(3) 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 3.97cm. Similarly, the maximum horizontal displacement of rock embedding cast-in-place pile is about 1.67cm, which is located at the top of pile.

(4) According to term 8.4.3 of specifications for design of highway suspension bridge (JTG/T D65-05-2015), the horizontal displacement of the anchorage should not exceed 16cm and the vertical displacement should not exceed 32cm. The deformation of the anchorage in this scheme satisfies the specification requirements.

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