Calculation and Analysis of the Stability of Steel Lining Structure of the Flat Tunnel Manhole in a High-head Power Station

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Abstract: This article is based on finite element calculation software for finite element model establishment and meshing. Through the stability calculation of the steel lining structure at the connection part of the flat tunnel manhole and main pipe in the diversion water of a high-head hydropower station, it is concluded that the structural design meets the requirements. The calculation result can be a reference for similar projects.

1. Introduction
In order to facilitate the normal maintenance, it is usually necessary to set the maintenance access manhole in the concrete plugging body of the branch tunnel construction of the diversion tunnel. For the high-head hydropower station, the internal water pressure of this part is relatively high, and the part structure is a special-shaped structure. The conditions are more complicated. If structural instability occurs, it will bring huge losses to the operation of the power station. Therefore, it is necessary to calculate and analyze the structural stability of the connecting part of the manhole and the main pipe to ensure the stability and safety of the part. Due to the complicated force conditions of the steel lining manhole, it is necessary to use the three-dimensional finite element method to analyze the force of the steel lining and to study the force at the opening of the steel lining to provide a basis for the reinforcement design of the steel lining. Regarding the calculation and analysis of steel pipes, predecessors have made many research results: Wang Jiawei et al. [1] studied the ultimate bearing capacity calculation formula of the penstocks of hydropower stations with local thinning; Zhang Yi [2] studied the penstocks of the South Russia Five Hydropower Station Design analysis and bifurcated pipe; Guan Peiwen [3] carried out structural calculation and design optimization of buried stiffening penstocks in hydropower stations; Guo Hanggang [4] studied the stress classification method for the strength design of exposed steel pipes in hydropower stations; Zhang Jing [5] conducted research on hydropower penstock risk analysis and calculation; Jiang Huaping [6] calculated and measured and controlled the parameters of the penstock of the Xiaowan Hydropower Station; Jiang Tao [7] carried out calculations on the penstock elbow of a hydropower station in Xinjiang. These research results provide a reference basis for the design and analysis of penstocks.

In order to facilitate the calculation, this article needs to make the following explanations and assumptions when using the three-dimensional finite element method to calculate: (1) This calculation presupposes that the weld strength has met the requirements of the specification; (2) The gap between the main pipe, the inlet pipe and the reinforcing plate welded parts are treated as common nodes; (3) The effect of surrounding rock and outer concrete on the steel tube is simulated by nonlinear springs.
2. Finite element model establishment and meshing
This calculation uses a three-dimensional finite element linear analysis method \cite{8} to simulate its deformation and stress state under the action of external water pressure and dead weight. In this calculation, in order to obtain a complete and accurate stress field in the reinforcement area of the pipe, it should be used to use 8-node three-dimensional solid elements to simulate its physical structure to carry out corresponding analysis and evaluation. The welded parts between the main pipe, the connecting pipe and the reinforcing plate are all handled as common nodes. The unwelded part between the main pipe and the reinforcing plate is provided with rigid frictionless contact. The steel lining is divided by solid elements \cite{9}, and the mesh division is shown in Figure 1 to Figure 2.

3. Load and correlation coefficient selection
The calculation and design structure mainly includes the main pipe, stiffening plate, stiffening ring, welding seam, and connection pipe. In total, two working conditions of internal pressure and external pressure need to be calculated. Under internal pressure conditions, the maximum hydrostatic pressure during calculation is 373.93m, the water hammer pressure is 154m, and the water hammer pressure coefficient is 1.1. The comprehensive internal water pressure is 5.33MPa; under external pressure conditions, the external water pressure is 0.78MPa.

4. Analysis of calculation results
In the model, the two ends of the main pipe are far away from the reinforcing hole, so the two ends of the main pipe are restrained by a fixed end. The internal water pressure is exerted on the inner surface of the main pipe and the connecting pipe. Non-linear springs are applied to the steel pipe joints to simulate the action of the surrounding rock. The spring stiffness is converted from the elastic resistance coefficient of the surrounding rock, and the gap between the steel pipe and the concrete is considered. The gap value is 1.175mm.

4.1 Internal pressure conditions
Under the action of internal water pressure of 5.33MPa, the maximum Mises stress of the main pipe is 249MPa, which appears at the waistline position where the main pipe is in contact with the reinforcing plate, and the maximum Mises stress of the reinforcing plate is 237MPa, which appears at the waistline position where the main pipe is in contact with the pipe. The maximum Mises stress is 227MPa, which appears at the waistline where the pipe is in contact with the main pipe. The maximum Mises stress of the stiffening ring is 158MPa, which appears at both ends of the contact with the stiffening plate. The corresponding stress distribution is shown in the attached picture (Figure 3-figure 8). The maximum deformation of the main pipe is 2.34mm, the maximum deformation of the reinforcing plate is 2.34mm, the maximum deformation of the pipe is 3.27mm, and the maximum deformation of the stiffening ring is 1.60mm. See Figure 9-12 for details.
Figure 3 Main pipe Mises stress (outer side) (kPa)

Figure 4 Main pipe Mises stress (inside) (kPa)

Figure 5 Mises stress of reinforcing plate (the side away from the main pipe) (kPa)

Figure 6 Mises stress of reinforcing plate (the side close to the main pipe) (kPa)

Figure 7 Connecting pipe Mises stress (kPa)

Figure 8 Mises stress of the stiffening ring at the opening (kPa)
Stress concentration occurs at the connecting part of the connecting pipe and the main pipe. At the same time, the connecting part of the main pipe and the reinforcing plate has a large tensile stress at the two ends perpendicular to the direction of water flow. The peak Mises stress of the main pipe is 249MPa, the reinforcing plate is 237MPa, and the connecting pipe is 227MPa, and the stiffening ring is 158MPa, which does not exceed the corresponding resistance limit and yield strength.

4.2 External pressure conditions
Under the action of the external water pressure of 0.78MPa, the maximum Mises stress of the main pipe is 190MPa, appearing at the top and bottom positions where the main pipe is in contact with the reinforcing plate, and the maximum Mises stress of the reinforcing plate is 151MPa, appearing at the waistline position in contact with the connecting pipe. The maximum Mises stress is 122 MPa, which
appears at the waistline position where the pipe is in contact with the main pipe. The maximum Mises stress of the stiffening ring is 99 MPa, which appears on the outer part of the contact with the stiffening plate. The corresponding stress distribution is shown in the following figures (Figure 13-18). The maximum deformation of the main pipe is 3.99mm, the maximum deformation of the reinforcing plate is 2.97mm, the maximum deformation of the pipe is 3.55mm, and the maximum deformation of the stiffening ring is 3.64mm. See Figure 19-22 for details.

![Figure 13 Mises stress of the main pipe (outer side) (kPa)](image1)

![Figure 14 Mises stress of the main pipe (inside) (kPa)](image2)

![Figure 15 Mises stress of reinforcing plate (the side away from the main pipe side) (kPa)](image3)

![Figure 16 Mises stress of reinforcing plate (the side close to the main pipe) (kPa)](image4)
Figure 17 The main pipe Mises stress (kPa)

Figure 18 Mises stress of the stiffening ring at the opening (kPa)

Figure 19 Deformation of the main pipe (mm)

Figure 20 Deformation of reinforcing plate (mm)

Figure 21 Deformation of the main pipe (mm)

Figure 22 Deformation of the stiffening ring at the opening (mm)
Table 2 Summary of calculation results

| Working condition | Program       | Main pipe | Reinforcing plate | Connecting pipe | Stiffening ring |
|-------------------|---------------|-----------|-------------------|-----------------|-----------------|
| 0.78MPa external water pressure | Maximum Mises stress(MPa) | 190       | 151               | 122             | 99              |
|                   | Resistance limit(MPa) | 345.5     | 345.5             | 345.5           | 268.2           |
|                   | Yield Strengthσy(MPa) | 490       | 490               | 490             | 335             |

The peak Mises stress of the main pipe is 190MPa, the reinforcing plate is 151MPa, the pipe is 122MPa, and the stiffening ring is 99MPa, all of which do not exceed the corresponding resistance limit and yield strength.

5. Conclusion

Through the calculation of the stability of the steel lining structure at the connection between the flat tunnel manhole and the main pipe of a high-head hydropower station, it can be seen that the stress peaks of the main pipe, stiffening plate, connecting pipe and stiffening ring are all less than the resistance limit and yield strength of the corresponding steel, and the structural design meets the requirements under internal pressure conditions and external pressure conditions.

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