Analysis of Optimal Internal Water Pressure During The Operation Period of Ultra-long Water Tunnel

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Abstract. At present, the per capita shortage and imbalance of water resources are the basic national conditions of China, water-conveyance tunnel can solve some some these problems. Because the tunnel project is a covert project, people cannot accurately know the operation of the project in advance, and can only basically know the operation state of the tunnel through the existing test means, thus bringing certain blindness to the tunnel operation management. This paper takes the Qiandao Lake Water Distribution Project as an example, the stability of surrounding rock under different internal water pressure is analyzed and studied by using numerical simulation, and an optimal internal water pressure is obtained, which provides some guidance and suggestions for tunnel operation management and ensures the security of operation.[1][2][3][4][5]

1. Project introduction
The Qiandao Lake is Hangzhou's second water source, Qiandao Lake Water Distribution Project take water from Chun'an County, and water will be diverted to Xianlin Reservoir in Yuhang District Hangzhou City through water-conveyance tunnel, to provide high quality Qiandao Lake water for the downstream raw water conveyance, at the same time, water supply will be provided to Jiande City, Tonglu County and some areas of Fuyang District on the way of water transmission line. This project is first-class class projec, the main buildings of Qiandao Lake, such as water intake, water transport tunnel, water diversion and outlet flow control building are Grade 1 building. The water conveying line from Qiandao Lake to Xianlin Reservoir is 113.23Km long, of which the concrete lining section and buried pipe section of the water conveying tunnel are about 102.30Km in total.
2. Numerical calculation model

According to the actual situation of the project, the simplified numerical calculation model is established as shown in Figure 2 below. The tunnel length is 10m, the tunnel bottom to the top of the model is 180m, the tunnel bottom to the bottom of the model is 60m, and the model width is 200m.

3. Calculation parameters

In this paper, the selection of calculation parameters is based on the engineering experimental results and some research data of tunnel at home and abroad, and the Morel-Coulomb elastoplastic constitutive model is adopted. The calculation parameters are shown in the following table.

| Material          | Modulus of elasticity (GPa) | Poisson's ratio | Bulk modulus (GPa) | Shear modulus (GPa) | Volume weight (kN/m³) |
|-------------------|-----------------------------|-----------------|--------------------|---------------------|-----------------------|
| IV class rock     | 3.0                         | 0.35            | 3.3                | 1.1                 | 23                    |
| C30 concrete lining | 30                          | 0.167           | 15                 | 12.9                | 24.5                  |

4. Simulated reliability analysis

In this numerical simulation, the conditions were selected from section K8+160.3m of Hongqiutang main cave. The convergence monitoring layout of this section is shown in Fig. 3(a). The corresponding point displacements are selected from the numerical calculation results for comparative analysis, as shown in Fig. 3(b). Table 2 shows the comparison between monitoring data and numerical calculation results.
It can be seen from the table that the error values between the simulation calculation results and the actual monitoring results of each measuring point are all within 0.6mm, with the maximum proportion of 28.95%. The comparison between the monitoring results and the numerical calculation results shows that the numerical calculation results are reasonable.

Table 2 Comparison of monitoring data and numerical results (mm)

| Monitoring project | The displacement of monitor | Simulation results | Error | ratio |
|-------------------|------------------------------|-------------------|-------|-------|
| X1-X4             | 2.44                         | 2.36              | 0.08  | 3.11% |
| X1-X5             | 3.01                         | 2.48              | 0.53  | 17.73%|
| X2-X4             | 0.63                         | 0.51              | 0.12  | 19.05%|
| X2-X5             | 1.17                         | 1.24              | -0.07 | 5.90% |
| X3-X5             | 1.30                         | 1.68              | -0.38 | 28.95%|
| X4-X5             | 0.91                         | 0.74              | 0.17  | 18.68%|

5. The result of the calculation

According to the operation of the project, the stability of surrounding rock of tunnel is analyzed under the conditions of no water pressure, 0.05MPa (5m water pressure), 0.01MPa (10m water pressure), 0.15MPa (15m water pressure), 0.2MPa (20m water pressure), 0.25MPa (25m water pressure), 0.3MPa (30m water pressure), 0.4MPa (40m water pressure), 0.5MPa (50m water pressure) and 6MPa (60m water pressure) respectively.

5.1. Displacement analysis

Fig. 4 shows the variation curve of surrounding rock displacement with internal water pressure, and Fig. 5~Fig.11 shows the displacement nephogram under different water pressures.

It can be seen from the chart that the displacement of all parts of the tunnel decreases with the increase of water pressure, among which the arch foot position changes the most, followed by the waist and the foot. In the maximum displacement, the maximum position of the vault is 1.97mm, the maximum position of the arch waist is 0.99mm, and the maximum position of the arch foot is 2.06mm, all of which occur under the condition of no water pressure inside.

When the internal water pressure is 0~35m, the arch foot displacement is the largest, the vault displacement is the second, and the waist displacement is the least. When the internal water pressure is 35~60m, the arch displacement is the largest, the arch foot displacement is the second, and the waist displacement is the least. The displacement of the arch bottom is greater than that of the lining structure.
Fig. 4 Displacement of surrounding rock as a function of internal water pressure

Table 3: Maximum displacement of tunnel under different water pressures

| Water pressure (m) | Maximum displacement (mm) | Lining structure | vault | waist | foot | bottom of the arch |
|--------------------|---------------------------|-----------------|-------|-------|------|-------------------|
| 0                  | 1.97                      | 1.01            | 2.06  | 4.22  |      |                   |
| 5                  | 1.96                      | 0.98            | 2.03  | 4.14  |      |                   |
| 10                 | 1.94                      | 0.95            | 2.01  | 4.04  |      |                   |
| 15                 | 1.93                      | 0.93            | 1.98  | 3.98  |      |                   |
| 20                 | 1.92                      | 0.90            | 1.95  | 3.9   |      |                   |
| 25                 | 1.91                      | 0.87            | 1.93  | 3.83  |      |                   |
| 30                 | 1.89                      | 0.85            | 1.90  | 3.76  |      |                   |
| 35                 | 1.88                      | 0.83            | 1.88  | 3.69  |      |                   |
| 40                 | 1.86                      | 0.81            | 1.85  | 3.65  |      |                   |
| 45                 | 1.85                      | 0.79            | 1.82  | 3.58  |      |                   |
| 50                 | 1.84                      | 0.78            | 1.80  | 3.54  |      |                   |
| 55                 | 1.82                      | 0.76            | 1.78  | 3.49  |      |                   |
| 60                 | 1.81                      | 0.75            | 1.76  | 3.44  |      |                   |

Fig. 5 Displacement of surrounding rock without water pressure
Fig. 6 Displacement of surrounding rock under 10 m water pressure

Fig. 7 Displacement of surrounding rock under 20 m water pressure

Fig. 8 Displacement of surrounding rock under 30 m water pressure

Fig. 9 Displacement of surrounding rock under 40 m water pressure
5.2. Stress analysis

Table 4 shows the table of the maximum principal stress of surrounding rock under different water pressures; Figure 12 shows the variation of the maximum principal stress of surrounding rock with internal water pressure; Figure 13~Figure 19 shows the nephogram of the maximum principal stress under different water pressures.

It can be seen from the chart that the stress at all parts of the tunnel under different working conditions is compressive stress. The maximum principal stress in each part of the tunnel increased with the increase of water pressure, among which the position of the waist of the arch changed the most, followed by the foot of the arch and the top of the arch. Among the maximum principal stresses, the maximum compressive stress at the vault position is 1.75MPa, the maximum compressive stress at the arch waist position is 1.99MPa, and the maximum compressive stress at the arch foot position is 1.67MPa, which occurs when the internal water pressure is 60m.

Under different operating conditions, the maximum principal stress of each part of the tunnel varies smoothly with the water pressure. The maximum principal stress of the waist of the arch is the largest, followed by that of the vault, and the maximum principal stress of the arch foot is the smallest. When the internal water pressure is 0~50m, the compressive stress at the bottom of the arch is greater than that at the foot of the arch and less than that at the vault. When the internal water pressure is 50~60m, the compressive stress at the arch bottom is less than that at the arch foot.

According to the results of displacement and stress analysis of surrounding rock during the operation period, the project should be operated under the condition of water pressure as far as possible, avoiding the operation under the condition of no water, so as to ensure the long-term stability and safety of the project.
Table 4: Maximum principal stress of tunnel under different water pressures

| Water pressure (m) | Maximum principal stress (MPa) | Lining structure | vault | waist | foot | bottom of the arch |
|-------------------|--------------------------------|----------------|-------|-------|------|-------------------|
| 0                 | -1.65                          | -1.82          | -1.41 | -1.50 |
| 5                 | -1.66                          | -1.83          | -1.43 | -1.51 |
| 10                | -1.67                          | -1.85          | -1.46 | -1.52 |
| 15                | -1.68                          | -1.86          | -1.48 | -1.54 |
| 20                | -1.69                          | -1.87          | -1.5  | -1.56 |
| 25                | -1.69                          | -1.89          | -1.53 | -1.57 |
| 30                | -1.70                          | -1.90          | -1.55 | -1.58 |
| 35                | -1.71                          | -1.91          | -1.57 | -1.60 |
| 40                | -1.72                          | -1.93          | -1.59 | -1.61 |
| 45                | -1.73                          | -1.94          | -1.61 | -1.62 |
| 50                | -1.73                          | -1.96          | -1.63 | -1.63 |
| 55                | -1.74                          | -1.98          | -1.65 | -1.64 |
| 60                | -1.75                          | -1.99          | -1.67 | -1.64 |

Fig. 12. Variation of the maximum principal stress of surrounding rock with internal water pressure

Fig. 13. Stress of surrounding rock without water pressure
Fig. 14 Stress of surrounding rock under 10m water pressure

Fig. 15 Stress of surrounding rock under 20m water pressure

Fig. 16 Stress of surrounding rock under 30m water pressure

Fig. 17 Stress of surrounding rock under 40m water pressure
6. Conclusion

Based on the water distribution project of Qiandao Lake, this paper uses numerical simulation to analyze the stability of surrounding rock of water transport tunnel under different internal water pressure conditions, and draws the following conclusions:

(1) The displacement of each part of the tunnel decreases with the increase of water pressure, among which the position of the arch foot changes the most, followed by the arch waist and the arch foot.

(2) The stress of each part is compressive stress. The maximum principal stress in each part of the tunnel increased with the increase of water pressure, among which the position of the waist of the arch changed the most, followed by the foot of the arch and the top of the arch. The maximum principal stress in each part of the tunnel varies smoothly with the water pressure.

(3) According to the results of displacement and stress analysis of surrounding rock during the operation period, the project should be operated under water pressure as far as possible, to avoid the operation under the condition of no water, so as to ensure the long-term stability and safety of the project.

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