Research on structure optimization of overflow orifices in Hydropower Station

Yang Xue *, Jianrong Xu, Yu Peng, Weidi Zhang
Powerchina Huadong Engineering Corporation Limited, Hangzhou, China

*Corresponding author e-mail: xue_y3@hdec.com

Abstract. With the characteristics of large flood discharge and high water head, the flood discharge and energy dissipation structures of the dam body of A Hydropower Station are composed of overflow orifice, deep orifices, pond behind the dam and the second dam. In order to reduce the impact of the flood tongue on the cushion pond behind the dam, the method of stratified flow and air collision are adopted in the design of overflow orifice and deep orifice. The hydraulic model test is carried out to analyze body structure parameters such as diversion pier of overflow orifice, trajectory angle of outlet and so on, finally put forward the recommended structure design of overflow orifice. The model test showed that The setting of the diversion pier reduces the collision effect, therefore, it is not advisable to set the diversion pier. The structure of great differential drop and tongue without diversion pier are put forward, which can achieve the effect of layering the water tongue into the water, and colliding water tongue fully. The recommended structure can control the peak pressure of the cushion pond behind the dam within the allowable range.

1. Introduction
Due to the characteristics of large flood discharge and high water head, the overflow orifice, middle orifice, deep orifice are set up as flood discharge facilities. According to the characteristics of its dam body discharge, valley width and water depth downstream, different orifice drainage methods are adopted to disperse the water tongue in the air, and reduce the energy of the cushion pond after falling into the downstream dam. Some hydropower Stations [1-3] adopt the orifice discharge method of "stratified outflow, air collision", some hydropower Stations [4] adopt the orifice discharge method of "stratified flow, no collision in the air". For this kind of dam body orifice layered flow, the design of the orifice structure is particularly critical. Currently for the overflow orifices, mostly adopt the large-differential outflow arrangement pattern of the launch angle or depression angle, and tongue-shaped nose pier, diversion pier, wide tail pier, etc.

2. Original design structure and test results
The maximum dam height of the concrete arch dam of the hydropower station is 289m, the total discharge is 42348m³/s. The flood discharge structure is composed of 6 overflow orifices, 7 deep orifices and 3 spillway tunnels on the left bank of the arch dam body, the flood discharge orifice of the dam body undertakes about 70% of the flood discharge task, the maximum total discharge of the dam body is 30098m³/s, the drop is nearly 200m. In order to reduce the concentration of water flow, the type of
overflow orifice and deep-orifice water tongue layered outflow and air collision energy dissipation is adopted. A water cushion pond and a second dam are set as energy dissipation structures downstream of the arch dam. The 6 overflow orifices are open spillway, orifice size is 14.0m×15.0m, weir crest elevation is 810.00m. The orifice is arranged radially in the center of the arch dam. The 7 deep orifices are pressure orifices, arranged in the pier of the overflow orifices, arc-shaped working gate is set at the end of the runner, orifice size is 5.5m×8.0m, weir crest elevation is 724.00m.

The structure and hydraulic characteristics of the overflow orifice are studied on the overall hydraulic model of the 1:50 scale hub. In addition to the hydraulic characteristics when it is discharged separately, the hydraulic characteristics of overflow orifice participating in joint flood discharge are also an important factor in evaluating the structure of overflow orifices. The results showed that:

1) The water flow at the inlet of the overflow orifice is smooth, and there is no bad hydraulic phenomenon. By the adopted type of large differential and combined with the outlet tongue pier and the shunt tooth pier, in addition to the overlap between the edges of the orifices, the water tongues of overflow orifice also collide with multiple deep orifice water tongues in the air. After the collision, the water tongues split severely and the air is strongly aerated.

2) When the overflow orifice discharges flood separately, the drop point of the water tongue is between about 85m~150m downstream of the orifice, and the water inlet width is about 125m. When the overflow orifice and deep orifice are combined for flood discharge, the overflow orifice and the deep orifice water tongue collide in the air and are pressed down by the water tongue of the overflow orifice. Compared with the deep orifice alone, the front edge of the water tongue after the collision recedes and the water tongue falls. The point is located between about 89m~196m downstream of the orifice, and the water inlet width is about 130m. The drop point of the water tongue is basically located at the bottom of the cushion pond.

3) Judging from the results of the pressure test of the cushion pond behind the dam, the maximum dynamic water shock pressure is 20.1×9.81kPa during deep orifice joint flood discharge when it is check condition, it is 16.4×9.81kPa when the 6 overflow orifices are discharged separately, both of them exceed 15×9.81kPa, the other conditions are relatively small. The maximum dynamic water shock pressure is 15.7×9.81kPa during combined flood discharge of overflow orifice and deep orifice joint flood discharge when it is check condition, it is 12.6×9.81kPa when the 6 overflow orifices are discharged separately, both of them exceed 10×9.81kPa. On the whole, the pressure distribution of the cushion pond floor after the water tongue enters the water is basically the same as the fluctuating pressure distribution, but the dynamic pressure and fluctuating pressure root mean square values are higher in some working conditions.

![Figure 1. Discharge flow pattern of 6 overflow orifices](image1)
![Figure 2. Discharge flow pattern when the overflow orifice and deep orifice are combined](image2)
Table 1. The pressure distribution of the cushion pond floor

| Flood discharge conditions | Flood discharge (m³/s) | Maximum hydrodynamic shock pressure (9.81kPa) | Root Mean Square of Maximum Pulsating Pressure (9.81kPa) | Appearance position |
|----------------------------|------------------------|--------------------------------------------|-------------------------------------------------|---------------------|
| 1  Check condition         | 30102                  | 20.1                                       | 15.7                                            | Right 24           |
| 2  Design condition        | 24378                  | 12.1                                       | 11.3                                            | Right 24           |
| 3  Energy dissipation condition | 21103                | 11.6                                       | 8.1                                             | Right 24           |
| 4  6 overflow orifices     | 9446                   | 16.4                                       | 12.6                                            | Left 29–35         |
| 5  1#, 4# overflow orifices | 3149                  | 17.9                                       | 14.5                                            | Left 29            |
| 6  2#, 5# overflow orifices | 3149                  | 4.1                                        | 3.3                                             | Left 57            |
| 7  3#, 6# overflow orifices | 3149                  | 3.1                                        | 3.4                                             | Right 24           |

3. Research on structure optimization of overflow orifices

The ultimate goal of the optimization of the overflow orifice diversion pier is to disperse the water tongue concentration and reduce the pressure of the cushion pond behind the dam. Therefore, considering the aspects of increasing the pier radius, increasing the width of the pier, adjusting the pick angle of the pier, or canceling the pier, three optimization plans have been formulated.

Table 2. Optimal solution for diversion pier

| number | radius R (m) | angle α (°) | Arc angle β (°) | length L1(m) |
|--------|--------------|-------------|-----------------|--------------|
| 1      | 7            | 20          | 55              | 6.42         |
| 2      | 7            | 15          | 50              | 6.96         |
| 3      | canceling the pier |          |                 |              |

Figure 3 and figure 4 is a comparison chart of the maximum dynamic water impulse pressure and fluctuating pressure in the cushion pond between the original scheme and the three optimized plans. As can be seen from the figure, it can be seen that optimization plan 1 and optimization plan 2 under the conditions of 1# and 4# surface flood discharge or 6 surface flood discharge conditions, the maximum impact pressure of the bottom of the cushion pond is significantly reduced. It has little effect under flood conditions.

Combining the observation of the water tongue of several optimization plans, the overflow orifice water tongue without the diversion pier can also achieve the effect of layered dispersion, and the collision relationship of the overflow orifice and deep orifice water tongue is relatively simple, and there is no need to consider setting the diversion pier which may causes cavitation problems, so the structure of overflow orifice should adopt a plan without diversion pier.
4. Research on structure optimization of overflow orifices

In this paper, through physical model test research, the 1# and 4# overflow orifices are provided with shunt piers and the depression angle of 6# overflow orifices and other structure design plans are verified and experimentally optimized, and suitable overflow orifice structure design parameters are proposed.

Under the condition that the structure of the surface hole is basically determined, the project has improved the dispersion and collision effect of the overflow orifice and deep orifice water tongue through further optimization of the deep orifice water tongue. The maximum dynamic water impulse pressure of the water cushion pond for the flood discharge of the arch dam body is controlled at 11.6×9.81kPa (appearing in the design condition), and the root mean square of the maximum fluctuating pressure is controlled at 9.6×9.81kPa (appearing in the check conditions), the peak pressure is controlled within the same level of similar projects and within the allowable range.

Table 3. Structure parameter of overflow orifices in arch dam

| overflow orifices | crest elevation (m) | crest width (m) | Exit elevation (m) | Exit width (m) | Exit pick/depression angle | Plane spread angle left/right |
|------------------|-------------------|----------------|-------------------|----------------|--------------------------|-----------------------------|
| 1#               | 810.00            | 14.00          | 788.38            | 17.26          | -35°                     | 0°/6°                       |
| 2#               | 810.00            | 14.00          | 799.37–799.63     | 18.34          | 5°                       | 4°/4°                       |
| 3#               | 810.00            | 14.00          | 800.62            | 18.34          | -15°                     | 6°/2°                       |
| 4#               | 810.00            | 14.00          | 788.38            | 18.34          | -35°                     | 2°/6°                       |
| 5#               | 810.00            | 14.00          | 799.37–799.63     | 18.34          | 5°                       | 4°/4°                       |
| 6#               | 810.00            | 14.00          | 793.12–794.52     | 17.26          | -25°                     | 6°/0°                       |

5. Conclusion

(1) Setting the diversion pier is a common way to disperse the water tongue in the flood discharge surface of the arch dam, but for the overflow and deep orifice collision energy dissipation project, the distribution and trajectory control of the water tongue of each orifice should be considered comprehensively to achieve the comprehensive optimal effect. The structure of great differential drop and tongue without diversion pier are put forward, which can achieve the effect of layering the water tongue into the water, and colliding water tongue fully. The recommended structure can control the peak pressure of the cushion pond behind the dam within the allowable range.

(2) Although the optimization adjustment of the depression angle of 6# overflow orifice has no obvious advantage compared with the original plan in terms of the peak pressure of the cushion pond behind the dam, it has a significant effect on adjusting the layered morphology of the overflow orifice water tongue. Considering the delamination effect of overflow orifice water tongue and the collision relationship between overflow orifice and deep orifice, the plan with better layering effect should be recommended.

(3) When high arch dams use overflow and middle orifices (or deep orifices) and other layered joint flood discharge facilities, the structure design of flood discharge orifice needs to consider the dispersion of the water tongues at different elevations and drop points.

References

[1] Shuangke Sun. The latest progress in research on high dam flood discharge and energy dissipation in my country. Journal of China Institute of Water Resources and Hydropower Research, 2009, 7(2): 89-95.
[2] Hongqi Ma. Summary of key technologies for the Xiaowan Hydropower Project. Hydropower, 2004, 30(10): 13-16.
[3] Jing Yang, Yaqin Chen. Selection and practice of body structure parameters of the energy dissipater behind the super-power dam of Xiluodu Hydropower Station. Hydropower Station Design, 2015, 31(3): 10-12.
[4] Jimin Wang, Hong Yang. Research on key technologies for flood discharge and energy dissipation in Jinping I Hydropower Station. People's Yangtze River, 2017, 48(13): 85-90.