Research on the Selection and Optimization of Horizontal Swirling Energy Dissipation Flood Discharge Tunnel

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Abstract. Through the study of the diameter control of the horizontal swirling efficiency shaft and the swirling tunnel and the cross-section of the aeration sill, a flood discharge tunnel with a scale of about 100 meters and a discharge volume of more than a thousand is obtained. The horizontal swirling energy dissipation type is combined with the diversion tunnel. At the time, the diameter of the shaft can be controlled and determined according to the average velocity of 15-20m/s; the diameter of the swirling hole can be calculated according to the empirical formula \(D=(Q^2/g)^{0.2}\). In order to reduce the impact of water flow pulsation on the concrete lining and surrounding rock of the shaft, the flood discharge tunnel inlet should adopt a submerged flow pattern. Its discharge capacity will be controlled by the cross section \(A\) of the aeration sill in the shaft and the inlet section \(\omega\) of the swirl chamber. When the slope of the aeration sill is 1:2.5 to 1:3.0, \(\omega/A\) should be controlled at 1.05. The research results can provide a reliable basis for the design of horizontal swirling energy dissipation.

1. Introduction
In the construction of high dams, combined with the unique high mountains, valleys, large flow, high water head and complex natural conditions, the construction usually requires several large-sized diversion tunnels[1]. These diversion tunnels were mostly temporary buildings in the early days, after completing the diversion task, the tunnel is basically abandoned, which wastes engineering resources. In response to this situation, the use of diversion tunnels to transform into permanent drainage structures has become the focus of research. The diversion tunnels were mostly used to rebuild the flood discharge tunnels of the dragon head type, inclined well type or deep hole type[2]. This method not only shortens the construction period, but also saves investment. However, due to the high dam height, the flow rate of the downstream discharge is relatively high[3]. There are also certain safety issues.

The common problems are: (1) Improper energy dissipation methods, severe erosion of downstream river beds and bank slopes, seriously threatening the stability of the rock mass on the bank; (2) Water cavitation causes cavitation damage to buildings, and hydrodynamic pressure fluctuations cause structures vibration, and even cause serious accidents[4]; (3) The water depth changes due to aeration or exhaust, which destroys the stability of the water flow and causes the transition of the open and full flow in the water channel; (4) Water loss stably produces shock waves, rolling waves and other phenomena, which deteriorate the connection conditions of upstream and downstream water flow of the.
discharge structure, and adversely affect the normal operation of the building and downstream flow patterns[5]; (5) High-speed water flow with high sand content causes severe abrasion of buildings[6]. In order to solve the above problems, high dams and large flow discharge structures need to adopt necessary efficiency methods.

2. Comparison and selection of energy dissipation tunnels

Since the rotating water flow forms a hollow gas core in the vortex chamber and the shaft, which takes up a part of the space, the average flow velocity of the section cannot be used to determine the diameter of the shaft. The diameter of the shaft is affected by the exit section of the diversion channel. If the diameter of the shaft is too small, the diversion channel will choke water, affecting the discharge rate and the flow pattern of the diversion channel. If the shaft is larger, negative pressure may occur. Therefore, the diameter of the shaft is affected by the flow velocity of the water channel, the required discharge and the acceleration of gravity. Based on the previous research experience, the following formula can be used to estimate:

$$D = K(Q^2/g)^{0.2}$$  \hspace{1cm} (1)

Where $D$ is the diameter of the shaft (m), $Q$ is the required discharge flow (m$^3$/s), $g$ is the acceleration of gravity ($m/s^2$), and $K$ is the coefficient (when Fr $< 1$, slow flow $K=1$; When Fr$>1$, it is rapid $K>1$).

The flow calculation formula is as follows:

$$Q = \mu be(2gH)^{0.5}$$  \hspace{1cm} (2)

Where $Q$ is the discharge flow rate (m$^3$/s), $\mu$ is the discharge coefficient; $H$ is the head above the top plate of the gate hole (m), $e$ is the gate hole opening (m), $b$ is the gate hole width (m), and $g$ is Acceleration due to gravity. The relationship between water head and discharge flow is shown in Figure 1.

2.1 The layout and size of the spillway tunnel

2.1.1. Layout of horizontal swirling energy dissipation and spillway tunnel

The horizontal swirling energy dissipation flood discharge tunnel is composed of a single-hole overflow weir inlet, a vertical well, a swirling tunnel, a cushion pond and a receding tunnel. The inlet of the overflow weir is designed according to free flow.

According to $D = (Q^2/g)^{0.2}$, the diameter of the swirl hole is determined to be 10.5m. The inlet of the swirling chamber is the connecting section of the shaft and the swirling hole. In order to facilitate the generation of swirling flow, one side of the bottom of the shaft is connected to the swirling hole by an elliptic curve ($x^2/15^2+y^2/8^2=1$). After the side gradually shrinks, it intersects with the spin hole eccentrically, the inlet size of the spin chamber is 5.49×9=49.41m$^2$, and the shrinkage ratio is 0.777. The layout of the horizontal swirling energy dissipation flood discharge tunnel is shown in Figure 2.

2.1.2. Layout of vertical shaft swirling energy dissipation and spillway tunnel

The shaft swirling energy dissipation and spillway tunnel is composed of a single-hole pressure inlet, a diversion channel, a vortex chamber, a shaft, a stilling well and a retreat tunnel. The water inlet adopts a pressurized short water inlet and a pressure less water channel, and the pressure less water channel is directly connected to the arc vortex chamber tangent.

The connection between the shaft and the exit tunnel adopts a combination of a shallow stilling well and a low weir at the entrance of the exit tunnel, that is, the depth of the shaft stilling well is 3m, and a curved weir is set behind the stilling well, the end of the shaft is connected to the drainage tunnel with a 3 hole 3m×6m orifice, as shown in Figure 3.
2.2 Scheme comparison

Horizontal swirling energy dissipating spillway tunnels and vertical shaft swirling energy dissipating spillway tunnels have carried out 1:60 and 1:50 atmospheric hydraulic model tests respectively. The comparison of hydraulic conditions is shown in Table 1.

![Figure 1. The relationship between water head and discharge flow](image1)

![Figure 2. The layout of the horizontal swirling energy dissipation flood discharge tunnel](image2)

![Figure 3. Layout of the vertical shaft swirling flow energy dissipation and flood discharge tunnel](image3)

| Table 1. Comparison of hydraulic conditions |
|---------------------------------------------|
| Form | Horizontal swirling energy dissipation tunnel | Shaft swirling flow energy dissipation flood discharge tunnel |
| Flow(m³/s) | 1130 | 1052 |
| Flow pattern | The swirl hole is a smooth cavity swirling flow. The water flow in the plunge pool is turbulent, with circulation and secondary flows in clusters, with sufficient diffusion and aeration. The water flow in the receding hole gradually becomes an open flow state. | The water flow falls on the water cushion before the swirling flow is completely formed, and the wall of the shaft has a strong sense of vibration. The water flow in the receding hole is an open flow state. |
| Total energy dissipation rate | 86.5% | 85% |
| Root mean square (Pulsating pressure) (m) | 5.23 | 8.06 |
| Main frequency (Hz) | 1.28 | 0.01~1 |
The energy dissipation area of the horizontal swirling energy dissipation scheme is located in the lower flat section of the spillway tunnel. The swirling velocity is less affected by the upstream water level change. It can form a swirling flow under various working conditions, and the gravity of the horizontal swirling flow will not increase the swirling flow. The velocity along the longitudinal axis can form a longer path in the energy dissipating section of the same length than the shaft swirling flow, and the energy dissipation rate is higher. The horizontal length of the diversion tunnel section to be modified is fully utilized to reduce the shaft diameter, and the energy dissipation area of the shaft swirling energy dissipation flood discharge tunnel is the shaft section. Because the shaft is short, the circular swirling flow in the shaft is unstable and basically unable to form a swirling flow. The water flows directly into the stilling well to dissipate energy. It is mainly completed by the stilling pool water cushion at the bottom of the shaft, so the shaft vibration is strong.

3. Type selection of aerator type selection

In order to increase the aeration concentration at the edge of the lifting sill of the swirling chamber, the following two methods are mainly adopted to solve the problem, that is, setting a blind hole in the upstream of the swirling chamber and setting an annular aeration sill in the shaft.

Based on the above two approaches, six plans have been drawn up for experimental research: Scheme 1 is to set up a 5.0m long blind hole on the upstream side of the whirling chamber; The height of the bottom of the aerated sill of scheme 2 is 960.04m, the sill thickness is 0.88m, the slope of the sill is 1:4.5, an aeration trough is set under the sill, and the slot length is 2m; Scheme 3 aerated sill bottom elevation is 1962.88m, sill thickness 0.88m, sill slope 1:2.5, under the sill a circular air passage and 8 ventilation holes, the length of the enlarged section under the sill is 5m; Scheme 4 the sill thickness is 0.88m, the slope of the sill is 1:2.5, and a vent pipe is set under the sill; the thickness of the sill is 0.88m, and the slope of the sill is 1:2.5. There are annular air passages and 8 vent holes; plan 6 sill thickness 0.88m, sill slope 1:2.5, four vents below the sill trachea. And the results are shown in Table 2.

| Scheme | Flow (m³/s) | Aeration concentration (%) | Ventilation (m³/s) |
|--------|-------------|---------------------------|-------------------|
| 2      | 1074.4      | 2.6                       | 0.0               |
| 3      | 1028        | 3.0                       | 54.0              |
| 4      | 1028        | 3.6                       | 51.5              |
| 5      | 1028        | 4.0                       | 54.0              |
| 6      | 1028        | 4.0                       | 73.2              |

The water flow in the fifth and sixth schemes is stable, the cavity is longer, and the vertical shaft under the sixth sill is not enlarged, the structure is simple, and the construction is convenient. Therefore, scheme 6 is adopted. However, its discharge volume still cannot fully meet the design requirements, and further research is needed.

Under the condition of pressure pipe flow, the discharge volume is mainly controlled by the local loss of the flow channel, but in the case of a free jet under the venting sill and an aerated cavity, the flow should be mainly controlled by the slope of the annular sill and the contraction section. Therefore, experiments are carried out to expand the entrance section of the swirling chamber and modify the size of the ventilation sill. The test results are summarized in Table 3.

| Serial number | Entrance area of spinning chamber (m²) | Circular vent | Flow area A (m²) | Flow coefficient | Annular ridge ventilation (m³/s) | Ventilation of the swirling chamber (m³/s) |
|---------------|----------------------------------------|---------------|-----------------|-----------------|-------------------------------|---------------------------------|
| 1             | 4.58×9.0                               | 0             | 63.62           | 0.65            | 0                             | 459.1/316.5                     |
| 2             | 4.58×9.0                               | 1: 4.5        | 41.17           | 1.0             | /                             | 0                               |
| 3             | 4.58×9.0                               | 1: 2.5        | 41.17           | 1.0             | 0.826                         | 27.0                            |
| 4             | 4.70×9.6                               | 1: 2.5        | 41.17           | 1.1             | 0.832                         | 50.1                            |
| 5             | 4.70×9.6                               | 1: 2.8        | 43.47           | 1.04            | 0.836                         | /                               |
According to the test results: (1) The flow rate is significantly reduced after setting the ventilation sill (compare the results of 1 and 2); (2) the slope of the ventilating sill becomes slower and the flow becomes larger (comparing the results of 2 and 3); (3) Ventilation When the slope of the sill remains unchanged, the aeration volume of the annular sill increases with the increase in the entrance area of the kick-off chamber (compare the results of 3, 4 and 6, 7); (4) When the slope of the sill is 1:2.5 to 1:3.0, if \( \omega/A \) is greater than (or equal to) 1.0, a cavity can be formed under the ring, which is normal ventilation (see the results of 3 to 7); if \( \omega/A \) is greater than 1.1, the ventilation volume of the ventilation hole is too large, and the ventilation volume of the whirl chamber is large Decrease (see the results of 4 and 7); \( \omega/A \) is less than 1.0, the aeration volume of the annular sill is very small, and cannot play a role in aeration (see the results of 8).

4. Conclusions

(1) When the horizontal swirling energy dissipation type is combined with the diversion tunnel for a spillway tunnel with a water head of about a hundred meters and a discharge volume of over a thousand, the diameter of the shaft can be determined according to the average velocity of 15-20m/s, and the diameter of the swirling tunnel can be determined according to Empirical formula calculation of \( D = (Q^2/g)^{0.2} \).

(2) The annular ventilation sill in the shaft can aerate the water flow in the lower part of the shaft and increase the aeration concentration at the ascending sill of the cyclone chamber.

(3) In order to ensure that the annular ventilation sill can play a role in aeration, the flow should be controlled by the annular ventilation sill, and the inlet area of the swirling chamber must match the flow area of the annular ventilation sill. After test comparison, when the slope of the venting sill is 1:2.5-1:3.0, \( \omega/A \) should be controlled at about 1.05.

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