Numerical computation of multi-level intake of diversion project

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Abstract: Multi-level intake of diversion project has the advantage of selective intake. To further understanding of the hydraulic characteristics of this intake, a numerical simulation was carried out by RNG $k-\varepsilon$ turbulent model. The parameters of flow pattern and velocity distribution, water head loss, water source stratification are analyzed. Researches show that the local flow shape is complicated. The water head loss coefficient at inlet is in a range of 0.31 to 0.62. The effect of multi-level intake structure is fairly good. The results provide reference for the design and operation of similar engineering.

1. Introduction
The temperature and water quality of the reservoir water are obviously stratified along the depth, often showing obvious seasonal changes [1-5]. In recent years, with the attention of people's ecological protection and the improvement of living standards, stratified water intake is gradually being used, in order to selectively take water of different elevations.

In stratified water intake, the flow condition of the intake is more complex than that of the conventional deep water intake. The research methods for its hydraulic characteristics are mainly physical model test and numerical simulation. Zhang et al. [6] combined with the arrangement of stratified intake of stoplog gate in Jinping I Hydropower Station, through the hydraulic model test. The hydraulic characteristics of the intake of the power station were systematically studied. Wang et al. [7] combined with the stratified intake of Lianghekou Hydropower Station, studied the flow pattern, vortex, head loss and velocity through model test. By analyzing the design and model test results of several domestic pumped storage power stations, Yang et al. [8] summed up the model design of water inlet and outlet, velocity distribution and flow distribution, trash rack simulation and head loss law of pumped storage power stations. Taking Tingzikou hydropower station as an example, Yang et al. [9] studied the hydraulic characteristics of velocity distribution and head loss by using mathematical model. Lei et al. [10] used turbulence model to carry out three-dimensional numerical simulation of stratified intake of a large hydropower station, and compared with the model test results. Li [11] used numerical simulation method to study the hydraulic characteristics of conventional deep, double-layer and multi-layer inlets. Gao [12] taken the stratified intake scheme of stoplog gate of Nuozhadu Hydropower Station as an example, and studies the flow law of stratified intake of stoplog gate by...
numerical simulation method. Duan et al. \cite{13-14} systematically described the hydraulic characteristics of the stratified intake inlet of the stoplog gate, such as the flow pattern, the minimum operating water depth at the top of the gate, and the head loss, by model test and numerical simulation. Both Tong and Yang \cite{15-16} take a large hydropower station as an example to study the hydraulic characteristics of stratified intake with model test and numerical simulation.

How to ensure the smooth flow of stratified intake and reduce the head loss is the key purpose of intake design. Most of the researches are focused on the intake of power station. In this paper, the stratified intake of a diversion project is taken as the research object, and the numerical simulation technology is used to discuss the hydraulic characteristics of stratified intake, so as to provide the basis for its operation.

2. Research method

Model range: CFD software is used to simulate typical flood conditions. RNG $k-\varepsilon$ turbulence model and VOF method were used. The model includes reservoir, intake channel, sluice chamber section and tunnel section. The intake adopts bank tower type layered water intake with two layered water intake service gates. The gate size is $6.5m \times 6m$, and the elevation of diversion channel and gate sill is $26.5m$. In order to ensure that the inflow conditions are as uniform as possible and reduce the interference on the flow field behind, the section $140m$ away from the inlet of the water inlet in the reservoir is taken as the inflow boundary in the calculation model, and the section $100m$ downstream of the transition section of the diversion tunnel is taken as the outflow boundary. The structural layout of the water inlet is shown in Figure 1.

Model mesh: the geometric shape of the calculation model adopts three-dimensional model, and the grid division adopts Cartesian orthogonal structure grid. The whole calculation area is $380m$ long, $160m$ wide and $39.5m$ deep, which is composed of $480000$ hexahedral grids. At the same time, key areas such as lock chamber section and transition section are encrypted. The geometry of the model is shown in Figure 2.

Boundary conditions: the inlet boundary of the calculation area is set as the pressure inlet, and the corresponding water level is set. The outlet boundary is set as the average velocity, and a certain velocity and flow direction are set. The pressure on the outlet boundary is set as the von Neumann boundary condition. The bottom plate is set as the non-sliding wall condition, which is determined by the wall function method. The top surface in contact with the air is set as the symmetry surface. The initial water body range is set for the reservoir, and the initial water level is set, and the pressure is hydrostatic pressure. The calculation conditions are shown in Table 1. The of elevation is in m, and the rest is in cm.
3. Results and discussion

3.1. Flow regime and velocity

The flow pattern and velocity distribution of water diversion project is an important index to evaluate the effect of stratified water intake. The typical conditions (1 and 5) are analyzed. Detailed locations of the chosen points and measurements are illustrated in Figure 3. Figure 4 and 5 show the flow pattern and velocity distributions.

Diversion channel section: the inflow is smooth and uniform, and the water flows into the gate chamber smoothly. Lock chamber section: under the interference of breast wall, the flow pattern in the lock chamber is disordered, and there is vortex area at the back of breast wall. Tunnel section: the flow enters the transition section of the tunnel from the gate chamber, and the main stream is located in the middle and lower part of the transition section. The vertical velocity distribution of the transition section is uneven. Velocity at top is small, and the streamline is still swings violently. After a distance adjustment of the flow in the tunnel, the velocity gradually tends to be uniform. The flow pattern is further analyzed as follows.

Condition 1: the maximum vertical velocity from position 1 to position 6 is 0.17, 0.20, 0.41, 0.50, 0.63 and 1.01 m/s respectively. Diversion channel section: the vertical velocity distribution tends to be uniform, and the maximum vertical velocity at positions 1 and 2 is 0.17 and 0.20 m/s. Gate chamber section: due to the barrier effect of breast wall, the flow velocity is not evenly distributed along the vertical direction, and the return flow velocity of upper flow is small, with a flow velocity of about 0.12 m/s. The closer the lower flow is to the tunnel, the greater the flow velocity, and the maximum change range of vertical flow velocity is 0.41-1.01 m/s. Tunnel section: the maximum flow velocity of the mainstream in the middle and lower part of the transition section of the tunnel can reach 1.07 m/s, and the top flow velocity is 0.31 m/s. The maximum flow velocity of the tunnel is 1.27 m/s.

Condition 5: the maximum vertical velocity from position 1 to position 6 is 0.05, 0.07, 0.18, 0.32, 0.64 and 1.24 m/s respectively. The large velocity is located in the elevation range from the bottom plate to the upper edge of the upper water inlet. The velocity distribution at the upper and lower sides of the inlet is significantly reduced, and the drainage range is mainly concentrated in the area near the inlet. When the water reaches the through bin section, it quickly converges at the bell mouth after...
passing a nearly 90° bend. The maximum flow rate is 1.25m/s, which is 2-3m from the bottom plate. Diversion channel section: the vertical velocity distribution tends to be uniform, and the maximum vertical velocity at positions 1 and 2 is 0.06 and 0.08m/s. Gate chamber section: due to the barrier effect of breast wall and lower gate, the flow velocity is distributed unevenly along the vertical direction. The maximum flow velocity of upper gate hole is 0.32m/s, and the maximum return flow velocity of back side of breast wall is 0.20m/s. The higher the flow velocity of lower layer is closer to the headrace tunnel, the greater the change range of maximum flow velocity is 0.32-1.25m/s. Tunnel section: the maximum flow velocity of the mainstream in the middle and lower part of the transition section of the tunnel can reach 1.27m/s, and the top return flow velocity is 0.13m/s. The maximum flow velocity of the tunnel is 1.27m/s.

Figure 3. Layout of velocity points

Figure 4. Velocity vector
3.2. Head loss

The head loss of the intake refers to the head loss between the section 60m upstream of the intake and the section 50m downstream of the transition section of the headrace tunnel. The calculated value of water head loss of intake is shown in Table 2. The local head loss is caused by the change of geometric boundary conditions. The local loss coefficient is the ratio of head loss and tunnel velocity head. The calculation formula of head loss and head loss coefficient is as follows:

\[
\Delta H_j = (z_i + \frac{p_i}{\rho g} + \frac{v_i^2}{2g}) - (z_j + \frac{p_j}{\rho g} + \frac{v_j^2}{2g})
\]

(1)

\[
\xi_j = \frac{\Delta H_j}{v_j^2 / 2g}
\]

(2)

Where: \(v_i\) is the average velocity of upstream section (m / s). \(v_j\) is the average velocity of downstream section (m / s). \(\xi_j\) is the head loss coefficient.

The head loss of water intake is mainly caused by breast wall, trumpet inlet, bulkhead gate slot, emergency gate slot and contraction transition section. The calculated head loss coefficients under different working conditions are 0.33, 0.31, 0.32, 0.62 and 0.62 respectively.

Condition 1: when taking water from the lower layer, the head loss is small, 0.02m, and the head loss coefficient is 0.33.
Condition 2 and 3: when the upper and lower layers take water at the same time, the larger the water supply flow, the greater the head loss. The head loss in condition 3 is 0.02m higher than that in condition 2, and the head loss coefficient is 0.01 higher.

Condition 4 and 5: when the upper layer takes water, the water flows through the top of the breast wall and enters the vertical channel of the intake chamber, which is similar to the weir flow. The flow direction changes from horizontal to vertical, and then the water flows through the intake chamber and enters the trumpet inlet, and the flow direction changes to horizontal. The flow direction changes sharply after two 90° turns, and its head loss is large. The head loss is about 0.04m and the coefficient of head loss is about 0.62.

Table 2. Water head loss of intake

| Condition | Total head of upstream section (m) | Head loss (m) | Head loss coefficients |
|-----------|-----------------------------------|---------------|------------------------|
| 1         | 36.0                              | 0.02          | 0.33                   |
| 2         | 45.0                              | 0.02          | 0.31                   |
| 3         | 45.0                              | 0.04          | 0.32                   |
| 4         | 50.0                              | 0.04          | 0.62                   |
| 5         | 55.0                              | 0.04          | 0.62                   |

3.3. Stratification characteristics

From the perspective of inflow, the water source stratification of inlets in working conditions 1, 2, 4 and 5 is analyzed. The statistical table of inflow in each elevation range is shown in Table 3.

When the upper layer takes water, the water inlet elevation range is 38.2-44.7m. When the lower layer takes water, the water inlet elevation range is 26.5-33.0m. Under condition 4, 11.8m below the water surface is the water inlet elevation, that is, the difference between the water surface elevation and the bottom elevation of the upper sluice hole (50-38.2). Under condition 5, 16.8m below the water surface is the water inlet elevation, that is, the difference between the water surface elevation and the bottom elevation of the upper sluice hole (55-38.2).

Condition 1 adopts the lower layer water intake, Section 1 (i.e. the cross-section of sluice inlet, the same below), The inflow in the elevation range of the lower intake is 27.2m³/s, accounting for 70.1% of the total water intake. Section 2 (i.e. the cross-section 50m upstream of sluice inlet, the same below), The inflow in the elevation range of the lower intake is 30.9m³/s, accounting for 79.6% of the total water intake.

Under condition 2, the upper and lower layers of water intake are adopted, and the elevation range of water intake is 26.5-33.0m and 38.2-44.7m. In Section 1, the inflow of the upper intake elevation range is 14.6m³/s, accounting for 37.6% of the total water intake. The inflow of the lower intake elevation range is 14.2m³/s, accounting for 36.5% of the total water intake. In Section 2, the inflow of the upper intake elevation range is 15.7m³/s, accounting for 40.5% of the total water intake. The inflow of the lower intake elevation range is 11.2m³/s, accounting for 28.9% of the total water intake.

Condition 4 adopts upper water intake, and the elevation range of water intake is 38.2-44.7m. In Section 1, the inflow of the upper intake elevation range is 13.4m³/s, accounting for 34.5% of the total water intake. The inflow of 11.8m (50-38.2) below the water surface is 22.7m³/s, accounting for 58.4% of the total water intake. In Section 2, the inflow in the elevation range of the upper intake is 14.5m³/s, accounting for 37.4% of the total water intake. The inflow of 16.8m (55-38.2) below the water surface is 24.5m³/s, accounting for 63.1% of the total water intake.

Condition 5 adopts upper water intake, and the elevation range of water intake is 38.2-44.7m. In Section 1, the inflow within the elevation range of the upper intake is 12.2m³/s, accounting for 31.4% of the total water intake. The inflow of 16.8m (55-38.2) below the water surface is 23.7m³/s, accounting for 61.2% of the total water intake. In Section 2, the inflow in the elevation range of the upper intake is 13.2m³/s, accounting for 34.1% of the total water intake. The inflow below the water surface is 29.4m³/s, accounting for 75.7% of the total water intake.
The calculation results show that the location of the intake affects the flow in the diversion channel. Although some water will gradually enter the intake from the upper and lower layers of the diversion channel, the effect of water source stratification before the gate inlet is good. When the lower layer takes water or the upper and lower layers take water at the same time, the velocity before the inlet and the inlet flow are larger within the elevation range of the intake. Most of the water taken from the reservoir is within the elevation range of the intake. When taking water from the upper layer, most of the water taken is from the bottom elevation of the upper water inlet to the water surface.

| Condition | Section 1 (cross section of gate chamber inlet) | Section 2 (cross section 50m upstream of gate chamber inlet) | Remarks |
|-----------|-----------------------------------------------|---------------------------------------------------|---------|
|           | Upper intake | Lower intake | 38.2m elevation to water surface | Upper intake | Lower intake | 38.2m elevation to water surface |         |
| 1         | 27.2         | 30.9         | Lower gate fully open        |
| 2         | 14.6         | 15.7         | 11.2                         | Upper and lower gate fully open |
| 4         | 13.4         | 14.5         | 24.5                         | Upper gate fully open |
| 5         | 12.2         | 13.2         | 29.4                         | Upper gate fully open |

4. Conclusions
The multi-level intake of diversion project has the characteristics of selective water intake. Numerical simulation is used to analyze the hydraulic characteristics of this intake, which can provide reference for the design and operation management of related projects in the future.

(1) The water flow in the diversion channel section is smooth and even. The flow enters the gate chamber smoothly. Under the interference of the breast wall, the flow pattern in the gate chamber is complex, and there is a return area at the back of the breast wall.

(2) The head loss of the inlet section is closely related to the gate operation mode, water level and flow. When taking water from the lower layer, the head loss is relatively small. When taking water from the upper and lower layers, the larger the diversion flow, the greater the head loss. When the upper layer takes water, the head loss is the largest.

(3) By analyzing the vertical velocity distribution and inflow, the effect of water source stratification is good.

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