Numerical Simulation Research on Energy Dissipation Characteristics of Fish Scale Weir

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Abstract: In order to make the design of hydro buildings no longer limited to traditional models, Zhejiang Province has built various forms of novel art dams. Based on the numerical simulation method, the numerical simulation distribution of pressure and the influencing factors of the energy dissipation rate of the fish scale weir are studied. The results show that with the increase of the head h on the weir, the negative pressure area on the fish scale weir increases, but the negative pressure value remains unchanged or decreases; the h value ($0.120m \le h \le 0.140m$) is inversely proportional to the energy dissipation rate of the fish scale weir, and the θ value ($135° \le \theta \le 180°$) is proportional to the energy dissipation rate of the fish scale weir.

1 Introduction

In order to promote the ecological construction of beautiful rivers and lakes, enhance the hydrophilicity of wading buildings, and maintain the original ecological beauty of rivers and lakes, under the promotion of the Beautiful Rivers and Lakes Construction Action, multiple river training projects in Zhejiang Province have renovated the existing overflow slopes, and various innovative forms of artistic dams have been built. On the basis of effectively raising the water level of the river, a curved drop and waterfall landscape effect has been created, increasing the hydrophilicity of the water body [1].The weir studied in this article has a unique appearance, resembling a fish scale shape, and the length of the overflow front edges at all levels is the same. Due to its curved step edges on the plane, each level is connected by multiple arc lines, and each step has the same arc size. The downstream slope is in a step shape, with a beautiful shape, so this article calls it a fish scale weir. Figure 1 is a schematic diagram of the structure of the fish scale weir on a plane, where the length of the discharge front of each level of the plane is the same, θ is the arc angle.

The fish scale weir has a beautiful shape and a novel structure. The curved crest axis of the weir not only allows for vertical flow, but also horizontal flow. The water tongue intersects and collides, forming a three-dimensional flow area. In appearance, it can be called an "artistic weir". It can not only meet the functions of water storage, regulating upstream water level, flood control and drainage, farmland irrigation, etc, but also integrate with nature to improve water quality, forming a clever combination of artificial architecture and nature, adding beautiful scenery to the beautiful rivers and lakes has strong functional and ornamental value.

Compared to traditional linear weirs, fish scale weirs are a very novel weir type. Although fish scale weirs can effectively raise the water level of rivers [2], improve the hydrophilicity and observability of weirs, compared to the long history of traditional linear weirs for hundreds of years, fish scale weirs only have advantages in shape, and there is very little research on this type of fish scale weir at home and abroad. Chen Qun et al[3] used turbulent numerical simulation methods to study some of the main factors that affect the energy dissipation rate of multi-stage weirs and dams, such as unit width flow rate, dam slope, and step height; Run Shuxun et al[4] also found through experiments that the appearance of aerated water flow is one of the reasons for the high energy dissipation rate; Munish Kumar et al[5] conducted a series of experimental studies and simulations on the flow coefficients of trapezoidal and rectangular keyed weirs. M. Leite Ribeiro et al. Domestic scholar Li Shanshan [6] studied the impact of the main geometric parameters of the Qinjian weir, such as inlet and outlet width, weir height, upstream and downstream suspension ratio, on its discharge capacity. In recent years, due to the construction of beautiful rivers and lakes, some internet famous dams have emerged, attracting many tourists to come and check in for travel. Therefore, the fish scale weir has left a deep impression on people. However, the energy dissipation effect and geometric parameter determination of the fish scale weir have not yet

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developed. Therefore, it is necessary to conduct in-depth analysis of the energy dissipation characteristics of the fish scale weir. Currently, there is no mature theory to support engineering design and promotion, therefore, this article takes the fish scale weir as the research object, using numerical simulation methods, study the pressure distribution on the weir surface, and compare the water head h and arc angle on the weir surface θ analyze the impact of the value on the energy dissipation effect of the fish scale weir. The research results have important scientific significance and technical support for the construction of overflow weirs that meet water landscape standards and meet energy dissipation safety.

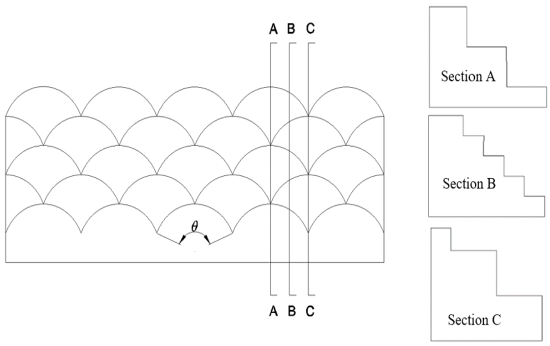


Fig. 1. Schematic diagram of fish scale weir structure

2 Numerical simulations

Compared to other fluid dynamics simulation software, Flow-3D powerful tracking free surface method (VOF) can accurately track the shape and changes of the free surface, and provide accurate feedback information. Favor technology can accurately describe the shape of the rendered structure and clearly define the geometric structure [7], accurately simulating different situations that are difficult to measure in real experiments. This article uses RNG in Flow-3D software k-ε turbulence model, RNG k-ε turbulence models can accurately calculate turbulent water flows with high intensity.

2.1 Model setting and meshing

This section uses fish scale weirs with different radians as models, using arc angles θ as a variable, for θ=135°; θ=150°; θ= 180° fish scale weir (as shown in figure 2) was simulated and calculated using Flow-3D software. The physical experimental model and numerical model size were controlled to be 1:1, the pressure and energy dissipation rate were calculated and analyzed under steady flow conditions.

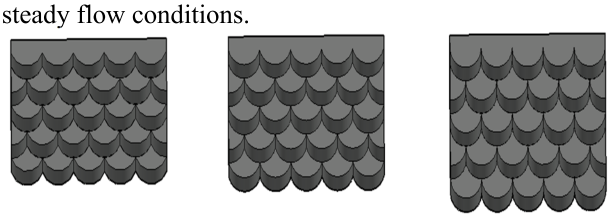


Fig. 2. Model diagram of fish scale weirs with different body types

This model includes the upstream area, fish scale weir body, and downstream scouring area, which are divided into three grids as shown in figure 3. The size of the grid determines the accuracy of the simulation data. In order to more accurately track the flow state on the weir surface and obtain accurate hydraulic data, the grid size of grid 2 is set to 0.003m, and the sizes of grid 1 and grid 3 are set to 0.007m, resulting in a total of 482490 grids.

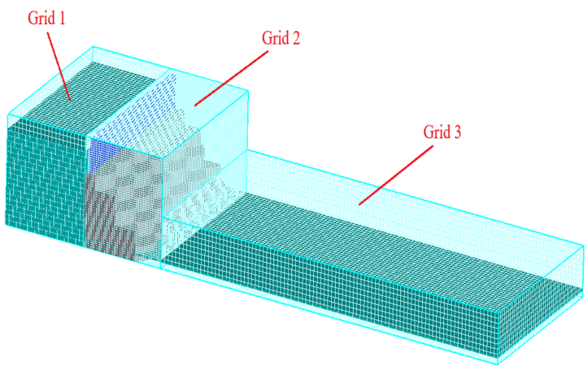


Fig. 3. Grid division diagram

2.2 Parameter settings

2.2.1 Boundary conditions

The specified pressure is set at the upstream inlet grid 1Ymin. The fluid elevations used are 0.120m, 0.125m, 0.130m, 0.135m, and 0.140m, respectively. The downstream outlet grid 3 Ymax is set with the specified pressure, the water flow height fluid elevation is set to 0.01m, and the Ymin and Ymax of the other grids are set to the default values of symmetry. The left, right, and bottom Xmin, Xmax, Zmin sets the wall, and Zmax at the top of the grid sets the air (fluid fraction=0).

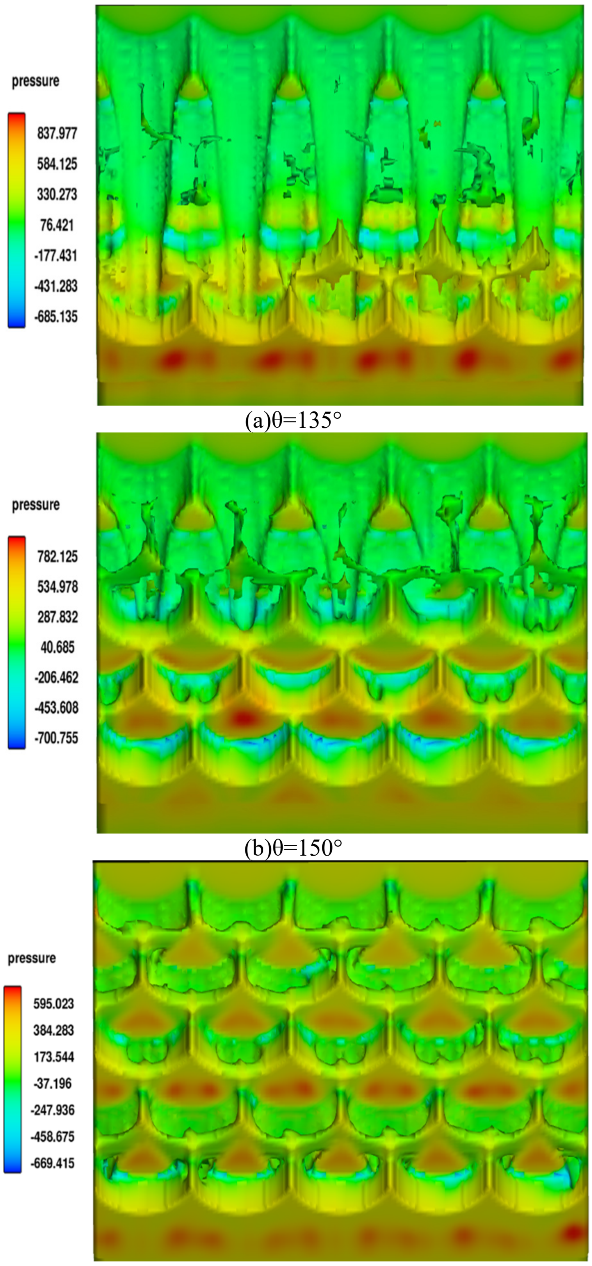
2.2.2 Model and initial conditions

Flow-3D simulation analysis selects the gravity and non-internal reference frame and RNG turbulence model, with a given Z-direction of -9.81m/s^2 and initial conditions of five upstream water levels h (0.120m, 0.125m, 0.130m, 0.135m, 0.140m), and a downstream water depth of 0.01m.

3 Pressure distributions

Figure 4 shows the difference θ in water head on the weir when h=0.14m, the 3D rear view of the pressure distribution at the bottom of the fish scale weir shows that under the condition of high flow rate at h=0.14m. As the θ value (135°~180°) increases, the positive pressure on the fish scale weir decreases gradually, and the negative pressure area increases with θ the value increases until the negative pressure covers five steps. At h=0.140m, the negative pressure value on the fish scale weir varies with θ increase in value remains basically unchanged.

Equivalent methods differ when h=0.120m according to the analysis of the pressure distribution at the bottom of the fish scale weir, it can be concluded that at h=0.120m, under low flow conditions θ as the value increases, the positive pressure on the fish scale weir shows a pattern of first decreasing and then increasing, and the negative pressure area increases accordingly until negative pressure values appear on the vertical surface of each arc; along with θ as the value increases, although the negative pressure range increases, the negative pressure value generated gradually decreases.



(a)θ=135°
(b)θ=150°
(c)θ=180°

Fig. 4. 3D rear view cloud map of pressure distribution on the bottom surface of three types of fish scale weirs

4 Energy dissipation rate analyses

This section will study the influencing factors the effect of the θ value and water head h on the energy dissipation rate of the fish scale weir is simulated and calculated using the energy dissipation rate formulas [8-9] (1), (2), and (3) to obtain three different types of energy dissipation rates θ the energy dissipation rates of the fish scale weir under five types of weir head h under a total of 15 working conditions are recorded in table 1, with the calculated values and energy dissipation rates of various variables. In flow-3D, the cross-section Y=-0.01m is taken as the E_1 calculation cross-section, and the cross-section Y=0.32m is taken as the E_2 calculation cross-section. The height Z_1 of the upstream reservoir bottom relative to the downstream bottom is taken as 0m.

$$\eta = \Delta E / E_1 \times 100\% = (E_1 - E_2) / E_1 \times 100\% \quad (1)$$

$$E_1 = Z_1 + h_1 + \alpha_1 v_1^2 / 2g \quad (2)$$

$$E_2 = h_2 + \alpha_2 v_2^2 / 2g \quad (3)$$

Table 1. Energy dissipation rate of fish scale weir under different working conditions

θ	h_1 (m)	h_2 (m)	v_1 (m/s)	v_2 (m/s)	E_1 (m)	E_2 (m)	η (%)
135°	0.120	0.842	0.065	0.619	0.120	0.028	76.7
	0.125	1.048	0.084	0.774	0.125	0.041	67.2
	0.130	1.310	0.095	0.896	0.130	0.054	58.5
	0.135	1.436	0.128	1.076	0.136	0.073	46.3
	0.140	1.160	0.158	1.092	0.141	0.077	45.4
150°	0.120	0.778	0.048	0.582	0.120	0.025	79.2
	0.125	0.950	0.068	0.693	0.125	0.034	72.8
	0.130	1.231	0.086	0.849	0.130	0.049	62.3
	0.135	1.380	0.113	1.028	0.136	0.068	50.0
	0.140	1.485	0.142	1.092	0.141	0.076	46.1
180°	0.120	0.708	0.047	0.518	0.120	0.021	82.5
	0.125	0.827	0.067	0.617	0.125	0.028	77.6
	0.130	0.982	0.084	0.757	0.130	0.039	70.0
	0.135	1.131	0.110	0.927	0.136	0.055	59.6
	0.140	1.397	0.139	1.014	0.141	0.066	53.2

From table 1, it can be seen that in different θ, as the water head h on the weir increases, the total water heads E_1 and E_2 of the upstream and downstream stable sections also increase, and are different θ the E_1 and E_2 values corresponding to the water head h on the weir are not significantly different [10]. As v_1 and v_2 values are the average flow velocity of the calculated cross-section, the surface flow velocity on the cross-section is relatively large, while the bottom flow velocity is relatively small. Therefore, the calculated average flow velocity is significantly reduced compared to the flow velocity in the surface layer of the water flow, resulting in smaller v_1 and v_2 values. As shown in figure 5, the energy dissipation rate of fish scale weirs under three different body types decreases roughly the same as the increase of water head h on the weir when the θ value is constant, 0.120m≤h≤0.140m, the energy dissipation rate of the fish scale weir decreases with the increase of the water head h on the weir [11]. When the water head h on the weir is constant, 135°≤θ≤180°, the θ value of is directly proportional to the energy dissipation rate of the fish scale weir, as the θ value as increases, the energy dissipation rate shows a decreasing trend.

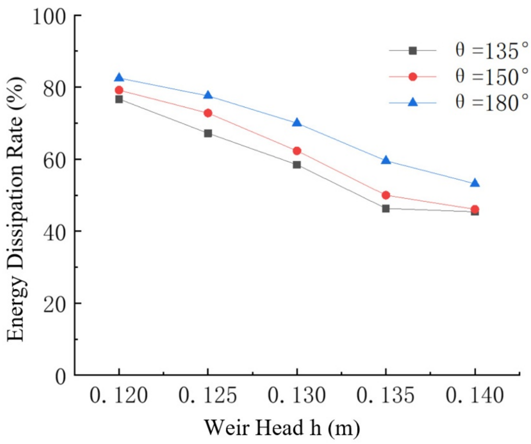


Fig. 5. Changes in energy dissipation rate of fish scale weir under different working conditions

From figure 5, it can also be seen that the energy dissipation rate of the fish scale weir studied in this article is at a water head h=0.120m above the weir θ= 180°, the highest energy dissipation rate reaches 82.5%, while the lowest energy dissipation rate is only 45.4%, indicating that the energy dissipation effect of this semi curved fish scale weir is θ=180°, the best state can be achieved when the water head h on the weir is low.

5 Conclusions

Considering the needs of river and lake landscapes and the construction of dam shapes, increasing the hydrophobicity of water bodies, and providing theoretical basis and technical support for the construction of artistic dams that meet water landscape standards and energy dissipation safety, this article proposes to use numerical simulation methods to study the pressure distribution and energy dissipation characteristics of fish scale dams. The main conclusions are as follows:

(1) At low flow rate (h=0.120m), with the θ value (135°~180°) as increases, the positive pressure on the fish scale weir shows a pattern of first decreasing and then increasing, and the negative pressure area follows a trend of the θ value increases, but the negative pressure value gradually decreases; At high flow rate (h=0.140m), with the θ value (135°~180°) as increases, the positive pressure on the fish scale weir decreases gradually, and the negative pressure area increases with the θ value increases until the negative pressure covers five steps, but the negative pressure value increases with the θ value increase in remains basically unchanged.

(2) Based on numerical analysis results, determine the arc angle of the fish scale weir θ value (135°≤ θ≤180°) is directly proportional to the energy dissipation rate and the water head h on the weir (0.120m ≤h≤0.140m) is inversely proportional to the energy dissipation rate. This provides technical support and theoretical basis for the construction of fish scale weirs in practical engineering, and the arc size of fish scale weirs θ value should be selected at 180°, and the energy dissipation effect of the dam is optimal at low water heads.

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