The Three-dimensional Simulation of Granular Mixtures Weir

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Abstract. In recent years, with the development of ecological water conservancy engineering, many new weir designs have also emerged. This paper has put forward a new kind of granular mixtures weir based on the systematic carding weir researches, combined with investigation. The numerical simulation of granular weir is carried out by using Flow-3D, and the results are compared with the physical model experiment results. The numerical simulation results of the flow velocity, flow distribution and the failure of the weir are in good agreement with the experimental results, which indicates that the 3-D mathematical model can be combined with physical model experiments to simulate the granular mixtures weir in all directions. Using this method to analysis the characteristics and hydraulic parameters can provide technical support for the follow-up research of ecological weir.

1. Research background

Weir is a kind of backwater building built on river to store water. Its main function is to intercept the flow of water to raise the water level of the river, and to adjust the quantity of water to meet the needs of human beings. In addition, water diversion can be used to irrigate farmland, generate electricity and adjust the slope of the whole river to consolidate sediment [1-2]. On the other hand, as a water blocking structure, the dam will change the flow state, thus forming the siltation of the upstream and the erosion of the downstream of the dam, and changing the original form of the river bed.

In recent years, with the continuous development of water conservancy projects in Zhejiang Province, comprehensive river treatment project has gradually become an important part of water conservancy projects. The comprehensive treatment of river course is often accompanied by the development and construction of regional humanities, ecological environment and social economy, among which the construction of Weir can effectively form water landscapes, which has become an indispensable part of the river course treatment project.

2. Granular mixtures Weir

At present, the research on Weir is mainly focused on the characteristics of water flow [3-5], Changes in erosion and siltation [6-8], Fish Road Design [9-10]. In other aspects, the research and exploration of the new Weir is mainly focused on the type, and more appearance types are designed on the basis of the original concrete Weir.

Through field investigation, it is found that there is a low Weir formed by the accumulation of loose particles and stones in the natural mountainous river course. It also has the natural and beautiful characteristics of the river, and does not affect the life of aquatic organisms. Therefore, this paper puts
forward a new type of granular mixtures Weir as a new type, which can meet the needs of partial river water lifting and meet the concept of river ecology, as shown in figure 1.

Natural Granular Weir in Miaoyuan River

3. The 3-D Numerical Simulation
Because the flow environment around the weir is complicated, most scholars use numerical simulation to study the flow field environment[11-13]. The commonly used three-dimensional numerical simulation techniques are mainly Fluent, Mike3, Delft3D and Flow-3D. Compared with other software, the Flow-3D has the characteristics of free mesh partition and strong adaptive ability of solid boundary. The damage of granular mixtures Weir can be accurately simulated. In this paper, Flow-3D software is used for numerical simulation.

3.1. Simulation Programme
The height of the dam is 2 m, the width of the dam top is 1 m, and three groups of schemes with different slope are selected for numerical simulation. Each group of schemes simulates two working conditions, the depth of the dam top is 1 m and 1.6 m respectively, and there are 6 calculation schemes.

(1) Project1: Weir type 1, upstream discharge 266 m³/s, The top water depth is 1.6 m, the downstream free outflow.
(2) Project 2: Weir type 1, upstream discharge 157 m$^3$/s, The top water depth is 1.0 m, the downstream free outflow.

(3) Project 3: Weir type 2, upstream discharge 266 m$^3$/s, The top water depth is 1.6 m, the downstream free outflow.

(4) Project 4: Weir type 2, upstream discharge 157 m$^3$/s, The top water depth is 1.0 m, the downstream free outflow.

(5) Project 5: Weir type 3, upstream discharge 266 m$^3$/s, The top water depth is 1.6 m, the downstream free outflow.

(6) Project 6: Weir type 3, upstream discharge 157 m$^3$/s, The top water depth is 1.0 m, the downstream free outflow.

### Table 1 Numerical simulation programme table

| Type of Weir | Mathematical model | Section type | Weir Size | Depth of weir top (m) |
|--------------|--------------------|--------------|-----------|----------------------|
| 1            | Top width 1 m, Riverside slope 1:1, Backwater Slope 1:3 | 1            | 1         |
| 2            | Top width 1 m, Riverside slope 1:2, Backwater slope 1:3 | 1            | 1.6       |
| 3            | Top width 1 m, Riverside slope 1:1, Backwater Slope 1:5 | 1            | 1.6       |

### 3.2. Simulation results

#### 3.2.1. Flow characteristics

Compared with the experimental results of physical model, the maximum error is 3.92% and the minimum error is 0.32%. The error between the calculated velocity and the experimental value is less than ±5%, which meets the reasonable error range. The detailed comparison results are shown in Table 2.

### Table 2 Comparison of Weir Top Flow Rates

| Working conditions | The water depth above the top of the weir |
|--------------------|----------------------------------------|
|                    | Weir Type 1 | Weir Type 2 | Weir Type 3 |
|                    | 1 m | 1.6 m | 1 m | 1.6 m | 1 m | 1.6 m |
| Numerical results(m/s) | 2.96 | 3.28 | 3.12 | 3.15 | 3.08 | 3.45 |
| Physical experimental results(m/s) | 2.98 | 3.20 | 3.14 | 3.14 | 3.14 | 3.32 |
| Compare | -0.56% | 2.61% | -0.64% | 0.32% | -1.91% | 3.92% |
Fig. 2 shows that the top velocity of Weir tends to stabilize after 20 s, and the top velocity of Weir increases with the increase of the water depth above the top. Different weir types have different effects on the velocity under different water depth. The velocity of top is the least affected by the depth of weir top in type 2, and the velocity of top is the most affected by the depth of weir top in type 3.

![Figure 2 Numerical Calculate Top Velocity of Weir](image)

3.2.2. Distribution of flow state along course

The calculation results of figure 3 show that the flow state is relatively smooth, the flow state before weir remains stable, and the flow velocity shows the situation that top of Weir > behind Weir > before Weir, the overall flow velocity changes tend to ease, and there is no obvious circulation structure. It is close to the flow state obtained by experiment. Hence, from the flow state and velocity distribution, the numerical simulation results are in good agreement with the experimental results, Flow3D can well simulate the 3D flow structure.
3.2.3. Damages of Weir

Fig. 4 shows that there are some degree of damage in the six kinds of weir, but there are some differences in the damage factors of the water depth, position, slope and so on, which are as follows:

In terms of damage degree, the damage degree of six groups is not serious, the surface damage is just beginning to form, and the top velocity of weir is in the critical starting velocity of granular mixtures weir.

In terms of the water depth above the top of the weir, the damage degree of the water depth of 1.6 m is greater than that of the water depth of 1.0 m, with the increase of the weir top water depth, the top velocity of the weir also increases, which increases the damage degree of the weir.

In the aspect of position influence, the damage of backwater slope is more obvious than that of riverside slope, which indicates that the impact force of water flow on backwater slope is greater, and the damage of granular mixtures weir often begins with backwater slope.

In the aspect of slope influence, the damage of 1:5 backwater slope is lighter than that of 1:3 slope, which indicates that the slower slope has the stronger ability to resist damage.
4. Peroration

According to the existing natural granular weir in mountainous river, this paper puts forward several kinds of weir types of different sizes, and carries on the 3D numerical simulation to the flow environment and the destruction situation around the weir. The simulation results are in good agreement with the physical model experimental data. It shows that Flow-3D can simulate the three-dimensional flow environment around the weir. According to the simulation results, the characteristics of the granular mixtures weir can be obtained as follows:

(1) The construction of granular mixtures weir can be based on local materials, which save transportation and raw material cost, and be more economical and environmentally friendly.

(2) The granular mixtures weir has a certain backwater effect, and its stability is related to the flow velocity of the river. During the dry season, a certain amount of upstream water can be accumulated, and when the flow rate exceeds the critical flow rate during the flood season, it will be washed away, thus not affecting the flood flow of the river.

(3) The damage of granular mixtures weir often starts from the backwater slope. The damage of the backwater slope is more obvious than that of the riverside slope, and the slower slope has the stronger ability to resist damage.

(4) The top velocity of weir is the key index of the damage of the granular mixtures weir. With the increase of the top velocity, the failure strength increases gradually, and the critical impact velocity can be calculated by Flow-3D simulation as the design standard of the granular mixtures Weir.

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