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Simulation of dam-break flood evolution in Jiangkou Reservoir

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ABSTRACT: Dam-break floods are extremely sudden and destructive. Calculation of reservoir dam-break floods and analysis of flood evolution are the basis for scientific response to sudden safety accidents in reservoir dams. Taking Jiangxi Jiangkou Reservoir as an example, this paper uses HEC-RAS to establish a two-dimensional dam-break flood evolution model, analyzes the characteristics of dam-break floods in the evolution process and its impact on downstream coastal buildings and facilities, and the calculation results show that the flooding depth reaches the maximum at the initial moment of dam break, with a maximum depth of 15m, and the flow velocity at the breach is the largest, reaching about 12m/s. The research results can provide a theoretical basis for the flood control and rescue command and emergency plan preparation of Jiangkou Reservoir.
KEYWORDS: dam break; flood evolution; numerical simulation; reservoir

I. INTRODUCTION

The formation and occurrence of dam-break floods are both difficult to predict and abnormal events. Dam-break floods are far more destructive than floods caused by general snowmelt or heavy rain, and the disasters they cause are often devastating. Once a serious dam-break event occurs, it will not only cause huge damage to the transportation and social economy of the downstream area, but also cause great harm to people's lives and property [1-4], and at the same time cause extremely serious impacts on the downstream environment and ecology [5,6]. Among the many dam emergencies, dam break has the greatest harm and the most serious consequences, and floods are one of the most important causes of dam failure. In order to prevent disasters before they happen, it is necessary to study dam-break floods, estimate their impacts in advance, make reasonable response measures, establish more complete reservoir dam safety management methods [7] and risk identification and analysis methods [8], establish a dam-break flood risk assessment system, formulate dam-break flood emergency plans, improve the ability to predict dam break, and reduce the loss of life and property.

At present, many scholars at home and abroad have conducted research on dam-break floods, and numerical simulation is the mainstream research method in these studies. Cai Xinming [9] and others introduced the advantages and disadvantages of HEC software, and how HEC can be well combined with GIS for terrain pre-processing and visualization post-processing; Wang Xiaohang [10] conducted numerical simulation of dam breach, analyzed the calculation results using the spatial analysis function of GIS, and used GIS to visualize the calculation results; Ding Can [11] and others used HEC-RAS software to establish a dam-break flood model, and took the Dadu River Zhentou Dam Hydropower Station as an example, used Arc-GIS to visualize the calculated results, and obtained the flood inundation range; Sun Ruijiao [12] and others used HEC-RAS to calculate the flow process line at the dam breach and the evolution process of the dam-break flood in the downstream based on the geographic data extracted by Arc-GIS, and then combined with ArcGIS to obtain the inundation range of the dam-break flood. In this paper, HEC-RAS is used to calculate the dam break flood of Jiangkou Reservoir on the Ganjiang River tributary in Jiangxi Province. The results of flood inundation range, water depth, flood evolution characteristics under dam break conditions are obtained, providing a theoretical basis for reservoir flood season scheduling and emergency rescue.

II. HEC-RAS2D HYDRODYNAMIC MODEL

Model Introduction

The HEC-RAS model is a hydraulic calculation model developed by the U.S. Army Corps of Engineers (USACE). The software includes modules such as basin hydrological

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calculation, river hydraulic calculation and analysis model, reservoir system analysis, one-dimensional sediment transport model, hydrological simulation model and ecosystem simulation evaluation. It also provides three-dimensional visualization of simulation results (depth, water surface, speed, etc.) and terrain data.

Governing equations

The principle of the HEC-RAS two-dimensional hydrodynamic model is a two-dimensional simplified form of the Navier-Stokes equation, the shallow water equation [13]. It assumes that the water depth scale is much smaller than the other two plane scales, and the calculation formula is as follows:

Continuity equation:

$$\frac{\partial H}{\partial t} + \nabla \cdot hV + q = 0$$

Momentum equation:

$$\frac{\partial V}{\partial t} + V \cdot \nabla V = -g\nabla H + v_t \nabla^2 V - c_f V + fk \times V$$

The momentum equation in the diffusion wave format, when combined with the continuity equation, is faster than the complete shallow water equation and has a smaller cumulative error. It is suitable for rivers with large riverbed slopes [14]. The calculation formula is as follows:

$$V = \frac{-(R(H))^{\frac{2}{3}}}{n} \frac{\nabla H}{|\nabla H|^{\frac{1}{2}}}$$

Where: H is the water surface elevation (m); h is the water depth (m); V is the flow velocity (m/s); R is the hydraulic radius (m); q is the lateral inflow (m^2/s); g is the gravitational acceleration (m/s^2); vt is the horizontal kinematic viscosity (m^2/s); cf is the roughness of the riverbed; f is the Coriolis coefficient; k is the unit vector in the vertical direction; n is the roughness; k is the unit vector in the vertical direction. The numerical calculation of the HEC-RAS two-dimensional hydrodynamic model is a mixture of the finite volume method and the finite difference method. The computational grid uses an unstructured grid, the non-boundary grid is a square, and the boundary grid is an irregular polygon. The edge of each grid is similar to the river section, and the terrain can be extracted. Therefore, at a lower grid density, sufficient terrain details can still be extracted to ensure the accuracy of the model.

III. CALCULATION OF DAM BREACH FLOW

There are many methods to calculate the instantaneous flow at the breach of earth-rock dam, and the calculation results of different methods are slightly different. This paper adopts instantaneous breach as the breach mode, and uses the following series of formulas to calculate the maximum dam breach flow of instantaneous breach:

$$Q_{max} = \frac{8}{27}\sqrt{g}\left(\frac{B}{b_m}\right)^{1/4} b_m H_0^{3/2}$$

Where:QmaxThe maximum flow rate of the dam breach (m^3/s);g is the acceleration due to gravity (m/s^2) ;B for dam chief(m);bm is the final breach width (m); H0 is the breach depth (m).

The flood flow process adopts the following formula:

$$Q = Q_{max}\left(\frac{Q_{max}}{5W}t - 1\right)^4$$

Where: W is the reservoir capacity (m^3); t is the flood drainage duration (s).

IV. EXAMPLE ANALYSIS

Overview of Jiangkou Reservoir

Jiangkou Hydropower Station is located in the middle reaches of Yuanhe River, a tributary of Ganjiang River, 18km downstream from Xinyu City. Yuanhe River is a first-level tributary of Ganjiang River and belongs to Ganjiang River system. The basin area is 6262km^2, the average length of the basin is 145km, the average width is 44km, the basin shape coefficient is 0.308, the total length of the river is 273km, the river drop is 1129m, and the average gradient of the river channel in the basin is 1.1‰. Jiangkou Water Conservancy Project is located on Wulangtan, Yingqian Village, Yuankou, Xinyu City, in the middle reaches of Yuanhe River, a tributary of Ganjiang River. The reservoir basin is located in the west of central Jiangxi Province, between 113°50′~115°45′ east longitude and 27°30′~28°10′ north latitude. The reservoir dam site controls a basin area of 3900 km^2 above the dam site, with a total storage capacity of 890 million m3, accounting for 61% of the total basin area of Yuanhe River. The reservoir has 8 auxiliary dams and 1 main dam. The main dam has a crest elevation of 78.36m, a wave wall crest elevation of 78.70m, a maximum dam height of 33.36m, a crest length of 467m, a crest width of 10.5m, and a homogeneous earth dam. The Jiangkou Hydropower Station Dam is a large (2) type reservoir, with a project grade of II, and a flood standard of 100-year flood design and 2000-year

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flood verification. The geographical location of the Jiangkou Reservoir Project is shown in Figure 1.

Figure 1 Geographical location of Jiangkou Reservoir Project

Model input data processing and generation

The most important data for the dam-break flood evolution model are terrain and flow process data. For the sake of simplicity and convenience in calculation, this paper only studies one working condition: assuming that the Jiangkou Reservoir is completely breached instantly due to an earthquake when the normal water level is 72.0m, the breach width is 467m of the dam length, and the reservoir capacity is 524 million m3. According to the calculation, the maximum flow of the breach is 21152.7m^3/s, and the flow process line is shown in Figure 2. As can be seen from Figure 2, the dam-break flow process is the largest at the initial moment, and gradually decreases with time, and the flow change gradient is large. The dam-break process lasts for a short time, about 123861s (34h) and the reservoir capacity is basically discharged.

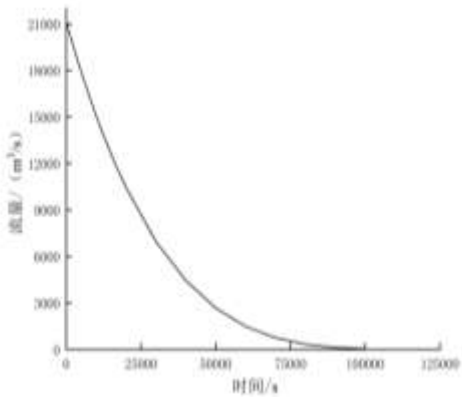

Figure 2 Breach flow process line

Construction of dam-break flood evolution model

The key point of establishing the HEC-RAS model lies in the accuracy of the terrain model and the determination of hydrological data. The two-dimensional model of dam-break flood mainly includes several modules, including engineering files, terrain model, geometric data (grid generation), unsteady flow data (boundary conditions and initial conditions setting), operation analysis, and result viewing. The terrain data for geographic modeling comes from the 30m resolution DEM of the Yuanhe River Basin. The terrain accuracy is set to a moderate 1/128. The spatial step size of a single grid within the calculation range is 100m*100m. There are 115,377 grids in total, of which the largest grid area is 19102m^2, the smallest grid area is 8685m^2, and the average grid area is 10038m^2. Related studies have shown that the size of the grid set in the two-dimensional model of dam-break flood evolution should be controlled within 0.05km^2, and the grid set in this model meets the requirements. The boundary condition of the upstream section is set as the breach time-flow process line, and the boundary condition of the downstream outlet is set to normal water depth, that is, the average gradient of the river channel is 0.0011, and the initial water level of the two-dimensional model is set. The calculation is performed by using the Courant number and custom time step to control the time step at the same time. The custom setting calculation time interval is 1 minute, and the total simulation time is 24 hours.

Simulation results and analysis

According to the output flow rate information, the flow pattern diagrams at 10 minutes, 20 minutes, and 30 minutes after the reservoir burst are obtained. As shown in Figure 3:

No. 10min

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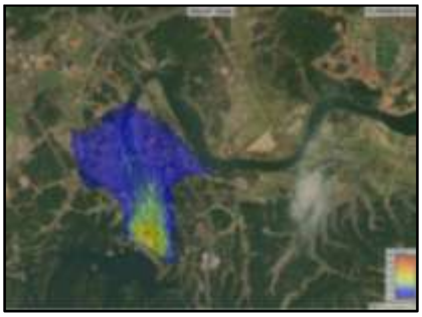
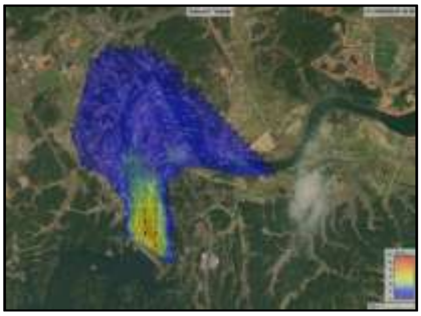


No. 20min



No. 30min

According to the velocity diagrams at each time, the distribution of the flow field fits the terrain, the flow direction conforms to the natural law of water flowing to the lower downstream, the velocity does not change suddenly, and the overall regularity is strong. The velocity distribution also reflects the feasibility of numerical simulation.

The evolution and inundation range of floods in the study area at different time periods after the Jiangkou Reservoir dam breach is shown in Figure 4. As can be seen from the figure, with the extension of time after the dam breach and the change of upstream flow, the inundation range of the flood also changes from small to large. At the initial moment of the dam breach, the inundation depth reaches the maximum, with a maximum depth of 15m. At the 2nd hour, the inundation depth is about 7-13m. At the 10th hour, the inundation depth varies between 3-6m. At the 20th hour, the inundation depth in most areas is about 3m. At the 24th hour, the inundation depth is between 1-2m. The longer the flood evolution time, the gradually reduced inundation depth from upstream to downstream, which conforms to the law of change in the flood evolution process.

Dam failure 2 h

Dam failure 10 h

Dam failure 20 h

Dam failure 24 h

Figure 4 Dam breach flood inundation area

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The velocity distribution of the dam breach flood is shown in Figure 5. As can be seen from the figure, the flood velocity is the highest around the deep line of the main river channel, and the velocity is relatively low in the open areas of villages and towns on both sides. The velocity is the highest at the breach, reaching about 12m/s, and the velocity in the plain areas of villages and towns is mostly about 1-2m/s.

Figure 5 Maximum flow velocity distribution

V. CONCLUSION

Taking the Jiangkou Reservoir in Jiangxi Province as an example, a two-dimensional model of reservoir dam breach flood evolution was constructed, and the rationality of the dam breach flow pattern analysis proved that the model was reasonable and feasible. The simulation results show that: (1) If the main dam of the Jiangkou Reservoir is instantly breached due to an earthquake when the normal water level is 72.0m, the maximum flow of the breach is 21152.7m3/s, and the reservoir capacity is basically emptied in about 34h. (2) At the initial moment of the dam breach, the flooding depth reaches the maximum, with a maximum depth of 15m. As the flood evolution time becomes longer, the flooding depth gradually decreases from upstream to downstream. (3) The flow velocity is the largest at the breach, reaching about 12m/s, and the flow velocity in the village and town plain area is mostly about 1-2m/s. There are still some shortcomings in this study. For example, for the sake of simplicity in calculation, the instantaneous breach assumption was adopted without considering the development characteristics of the breach, and the water blocking effect of the building was ignored. In addition, the 30m DEM data used in the study was not accurate enough, resulting in certain errors in the simulation results. Therefore, further improvement is needed in future research.

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