Application of One-Dimensional and Two-Dimensional Coupled Overtopping Embankment Flood Model in Wuyi River

Teng Hui\(^1\,\)^2, Wang Lirong\(^1\,\)^2, Li Hanze\(^1\,\)^2, Zheng Hongri\(^1\,\)^2 and Li Qian\(^1\,\)^2

\(^1\)Zhejiang Institute of Hydraulics & Estuary, Hangzhou 310020, Zhejiang Province, China

\(^2\)Zhejiang Provincial Key Laboratory of Hydraulic Disaster Prevention and Mitigation, Hangzhou 310020, Zhejiang Province, China

E-mail: forzath@qq.com

Abstract: Numerical simulation is an effective method to study the law of flood evolution. Adopting a one-dimensional two-dimensional coupling approach, the river flood evolution uses a one-dimensional model and the flood protection areas on both sides of the river adopt a two-dimensional model. The two-dimensional model is laterally connected to the one-dimensional model, which can simulate the flood evolution process in the two-dimensional flood protection area after the flood of one-dimensional river overtopping the dam. A one-dimensional and two-dimensional coupled overtopping dam flood model in Wuyij River basin is established. The model calculation accuracy is relatively high and the results are overall reasonable.

1. Introduction

In order to resist flood attack and reduce flood damage, it is of great importance to study flood evolution law for the sake of flood control work. Based on the hydrodynamic theory, numerical simulation of flood evolution is an effective method to study the law of flood evolution.

The one-dimensional hydrodynamic model can quickly simulate the evolution process of flood such as in long river sections, complex river networks and has relatively high calculation efficiency. The two-dimensional hydrodynamic model can better simulate the evolution process of flood after flowing out of the river and provide detailed information such as the extent of flood inundation. The flood evolution processes of one-dimensional river channels and two-dimensional flood protection areas affect each other. Coupling the one-dimensional model with the two–dimensional model can simulate the flood evolution process in the two-dimensional flood protection area after flood overtopping the embankment of the one-dimensional river channel. Compared with the separate one-dimensional model and two-dimensional model, it has higher simulation accuracy and faster calculation speed.

This paper adopts a one-dimensional and two-dimensional coupling approach to establish the flood model in Wuyi River basin in Wuyi County, Zhejiang Province and analyses the law of flood evolution.
2. Model theory

2.1 One-dimensional model of the river channel

The equation of the one-dimensional model is the one-dimensional open channel non-constant flow equation. The difference format uses a sin-point central implicit difference format and uses the “catch-up method”.

continuity equation:

\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \]  \hspace{1cm} (1)

motion equation:

\[ \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + gA \frac{\partial z}{\partial x} + gA \frac{Q^2}{K^2} = 0 \]  \hspace{1cm} (2)

where: \( x \) and \( t \) are respectively spatial and temporal coordinates; \( A \) is the area of the river cross section; \( Q \) is the discharge of the cross section; \( q \) is lateral inflow; \( z \) is water level; \( K \) is discharge modulus and \( g \) is gravitational acceleration.

2.2 Two-dimensional model

The two-dimensional model uses a two-dimensional non-constant flow equations describing the motion of the plane water flow, including three equations: the flow continuity equation, the momentum equation in the \( x \) direction and the momentum equation in the \( y \) direction. The form is as follows:

flow continuity equation:

\[ \frac{\partial z}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = s \]  \hspace{1cm} (3)

momentum in the \( x \) direction:

\[ \frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) + gh \frac{\partial z}{\partial x} + g \frac{\sqrt{p^2 + q^2}}{h c^2} - \Omega q - E \left( \frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 q}{\partial y^2} \right) = s_{ix} \]  \hspace{1cm} (4)

momentum in the \( y \) direction:

\[ \frac{\partial q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{q^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) + gh \frac{\partial z}{\partial y} + g \frac{\sqrt{p^2 + q^2}}{h c^2} - \Omega p - E \left( \frac{\partial^2 q}{\partial x^2} + \frac{\partial^2 q}{\partial y^2} \right) = s_{iy} \]  \hspace{1cm} (5)

where: \( z \) is water level; \( p \) and \( q \) are respectively unit discharges in the \( x \) and \( y \) direction; \( h \) is water depth; \( s \) is the source sink term; \( s_{ix} \) and \( s_{iy} \) are the components of the source sink term in the \( x \) direction and \( y \) direction; \( c \) is Chézy resistance coefficient; \( \Omega \) is Coriolis force and \( E \) is turbulent diffusion coefficient.

According to the above equations, the finite volume method can be used to obtain the water level and water depth at \((x, y)\) and velocity in the \( x \) and \( y \) directions at each moment.

2.3 One-dimensional model coupled with two-dimensional model

The two-dimensional model is laterally connected to the one-dimensional model to simulate the process of mutual exchange and common evolution of water between the one-dimensional river and the two-dimensional protection area. When the water level of the one-dimensional river is higher than the top of the embankment, the flood overflows the river and enters the two-dimensional area. The one-dimensional model provides the overtopped channel side water level and the two-dimensional model provides the water level behind the overtopped embankment. Then weir flow formula is used to calculate the water flow through the lateral connection.
\[ Q = \begin{cases} C_1 W (H_{US} - H_W) \frac{H_{US} - H_W}{H_{US} - H_W} & H_{DS} - H_W < 2/3 \sqrt{H_{US} - H_W} / H_{US} < 2/3 \\ C_2 W (H_{US} - H_W) \frac{H_{US} - H_W}{H_{US} - H_W} & H_{DS} - H_W \geq 2/3 \sqrt{H_{US} - H_W} / H_{US} \geq 2/3 \\ C_2 = 3\sqrt{3C_1}/2 & \end{cases} \]  

where: \( Q \) is the discharge overtopping the embankment, \( m^3/s \); \( C_1 \) and \( C_2 \) are weir flow coefficients; \( W \) is weir crest width, \( m \); \( H_{US} \) is upstream water level, \( m \); \( H_{DS} \) is downstream water level, \( m \); \( H_W \) is weir crest height, \( m \).

3. Model application

3.1 Model construction

3.1.1 One-dimensional model
Taking urban areas and important towns in Wuyi County as protection objects and considering potential flood threats, the main stream of Wuyi river and its tributary Shu river are selected to establish a one-dimensional generalized model. Wuyi river is about 38.8km and 66 sections are arranged. The tributary Shu river is about 10km and 19 sections are arranged. 45 water-related buildings are generalized including 9 weirs, 1 sluice and 35 water-blocking bridges in the model.

The upstream boundary of the model adopts the corresponding flood discharge hydrograph and the downstream one adopts the relationship between water level and discharge. The inflows of other small rivers in the basin are treated as lateral centralized inflows of the main channel.

3.1.2 Two-dimensional model
Both sides of the river channel are generalized and simulated using a two-dimensional model. According to the field investigation, the calculation extent should be appropriately expanded to ensure that the main towns and villages on both sides of the Wuyi river basin in Wuyi County are included in the scope of the two-dimensional model. There are 11 generalized protected areas with 128km². The model is generalized with an unstructured triangular grid to accommodate the complex terrain changes in Wuyi river basin. The grid length on the riverside is 20m and the grid length on the non-riverside is 60m. A total of 135273 grids are divided.

3.1.3 Model coupling
The lateral connection is used to couple the one-dimensional model and the two-dimensional model. The model is provided with 13 lateral connections and 2066 coupling units.

Figure 1. Sketch map of the model
3.2 Calibration and verification

In the hydrodynamic model, the parameter to be calibrated is mainly the roughness coefficient, and the roughness is a comprehensive coefficient that reflects the degree of resistance when the water flows. In this paper, the flood on 8.20, 2014 is used for calibration and the flood on 6.25, 2017 is used for verification. The roughness values are shown in table 1.

| Category         | Straight channel | Curved channel | River beach | Settlement place | Forest | Dry land | Paddy field | Clearing land |
|------------------|------------------|----------------|-------------|------------------|--------|----------|-------------|----------------|
| Roughness (n)    | 0.025-0.035      | 0.035-0.04     | 0.06        | 0.07-0.12        | 0.065  | 0.06     | 0.05        | 0.035          |

There is Wuyi hydrological station in the basin. The measured water level and discharge hydrograph are collected and compared with the calculated ones and the results are shown in table 2 and figure 2-3. It can be seen that the water level error is less than 0.1m and the discharge error is with 10%. The calculation accuracy is high and the water level and discharge at the flood peak are basically consistent with the measured ones.

The calculated inundation situation is compared with actual survey situation to analyze the rationality of the calculation of the two-dimensional model. According to the information of the local water conservancy bureau, the calculated flood and the actual one are basically consistent in terms of the location of the overtopped embankment and the inundation area. The inundation area is shown in figure 2. Therefore, the flood analysis model and its parameters are reasonable.

| Event                  | Maximum water level at Wuyi hydrological station (m³/s) | Maximum discharge at Wuyi hydrological station (m) | Error(m) |
|------------------------|--------------------------------------------------------|---------------------------------------------------|----------|
|                        | Observation | Calculation | Relative error(%) | Observation | Calculation |          |
| Flood on 8.20,2014     | 2030        | 2184        | 7.5               | 67.4        | 67.36       | -0.04    |
| Flood on 6.25,2017     | 1580        | 1608        | 1.7               | 66.55       | 66.49       | -0.06    |

Figure 2. Calibration of the flood on 8.20,2014
4. Conclusions and suggestions

(1) In this paper, a one-dimensional and two-dimensional coupled overtopping embankment flood model is established in Wuyi river basin. The one-dimensional river channel model uses the one-dimensional open channel non-constant flow equation and the two-dimensional model of the protection area uses the two-dimensional non-constant flow equation. The latter is laterally connected to the former and the former provides water level value and inflow discharge for the latter in real time.

(2) After calibration and verification, the errors between the calculation values and the observation values are small and the calculated water level and discharge hydrograph during the peak are basically consistent with the measured process. The calculated location of the overtopped embankment and inundation area are also basically consistent with the actual flood investigation. Thus, the model calculation accuracy is high, the results are generally reasonable and can provide a scientific basis for flood control in this region.

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