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Numerical Simulation Model with an Irregular Unstructured Cell Structure for Flood Inundation Computation in JingJiang Region of Yangtze River Basin

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1. Introduction

A horizontally 2-dimensional numerical model is presently a typical approach for flood inundation computation, in which regular rectangle cells are employed to build grid cell structure. To adopt such structure, barriers such as levee and river channels have to be modified into linear structure along cells or even ignored in view of the cell size.

In actual cases, especially in analyzing flood inundation of large floodplain, river break or overflow is usually the main reason to cause flood inundation, and barriers of high elevation have an important effect on the movement of flood flows. In addition, compared with large flat floodplain, their scale is quite small. If the size of cell is small enough to evaluate the influence produced by them, the number of cell becomes extremely large and makes work load increase greatly. In this paper, an improved model is presented to meet these requirements, in which irregular unstructured cells are used, thus not only rivers and barriers but also topographical features can be represented flexibly by regulating the shape, size and density of cells.

2. Numerical Simulation Model

To discretise 2-dimensional shallow water equations, two assumptions are given:①Discharge per unit width on each link is assumed as the flow flux in the normal direction of the link;②Discharge per unit width on each link is decided by the water depths and discharges of contiguous cells. Therefore, continuity equation can be transformed into the following scheme:

in which, K is the link number for one cell, l_k is the length of the kth link, $q_k^{t+\Delta t}$ is the discharge per unit width on the kth link at $t+\Delta t$ time. A is the area of cell. Δt is the time step.

$$z^{t+2\Delta t} = z^{t} - \left(2\Delta t \sum_{k=1}^{K} q_k^{t+\Delta t} l_k\right) \Big/ A \tag{1}$$

Considering the mild slope of flooding plain, all convection terms of momentum equations are ignored in discretization. In addition, according to initial topographical status, the type of cell is divided into river and farmland types; the type of link is divided into river, farmland and barrier types. Furthermore, the resistance term is also omitted in the scheme of farmland type. To the link of barrier type, its discharge per unit width on the link can be approximated by discharge formula as shown in eq. (4). However, the types of river and farmland are decided according to the water depth on link.

1. River type
$$q_j^{t+\Delta t} = q_j^{t-\Delta t} - 2gh_j\Delta t\left(z_1^t - z_2^t\right)\Big/dl_j - 2g\Delta t n^2\, q_j^{t-\Delta t}\left|q_j^{t-\Delta t}\right|\Big/h_j^{7/3} \tag{2}$$

2. Farmland type
$$q_j^{t+\Delta t} = sign\left(z_1^t - z_2^t\right)h_j^{5/3}\left(\left|z_1^t - z_2^t\right|\Big/dl_j\right)^{1/2}\Big/n \tag{3}$$

3. Barrier type
$$q_j^{t+\Delta t} = \sigma m\sqrt{2gh_j}\,h_j^{\frac{7}{3}} \tag{4}$$

in which, q_j and h_j are discharge per unit width of jth link and the water depth on the jth link, respectively. dl_j is the distance between two center points of contiguous cells. σ and m are discharge coefficients. n is Manning's coefficient. z_1^t and z_2^t are the water levels of contiguous cells. Staggered schemes are used in solving water level and flow flux, and water level is defined on the center of cell and discharge per unit width on the link.

3. Application in JingJiang Region

As shown in Fig.1, JingJiang region with a total area about 5000km^2 is located in Yangtze River basin, which includes JingJiang river reach with a length about 380km and JingJiang, YuanShi, RenMin and HongHu retarding basins with respective area 921, 96, 255 and 2783km^2. In past flood disasters occurred frequently in this area. One reason for flood disasters is that the discharge capacity of JingJiang river reach is not enough. The other is flood prevention standard of JingJiang river levee as current main prevention measures is low, and average elevation of JingJiang channel bed is about 10 meters higher than that of outside of JingJiang river reach. Once extraordinary floods occur, severe loss due to flooding would be caused. Based on these situations, Yangtze River Committee formulated a flood control project against a

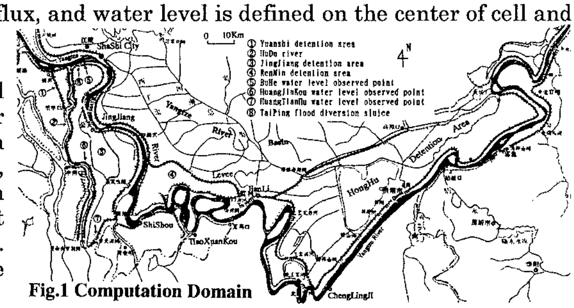

Fig.1 Computation Domain

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100-year designed flood, in which when and how to use retarding basins for flood diversion is stipulated. The efficacy of the project is verified by using the model introduced above.

The validity of the model to analyze flood inundation only in retarding basins is first verified through comparing the observed water levels with the calculated ones in three different points of JingJiang detention area as seen in Fig.2.

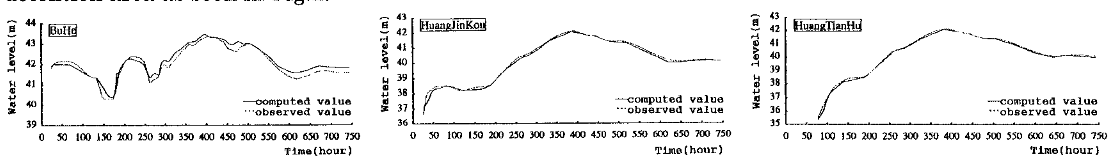

Fig.2 Comparison of Water Stage Hydrographs

The verified model is used to analyze flood inundation caused by a 100-year designed flood in JingJiang region. Fig.3 indicates the flood control project is feasible, but reasonable location and operation steps for dike breach need to be determined by numerical simulations. Moreover, corresponding refuge countermeasures for property and nearly 1.5×10^6 people living in these retarding basins need to be given based on flood analysis.

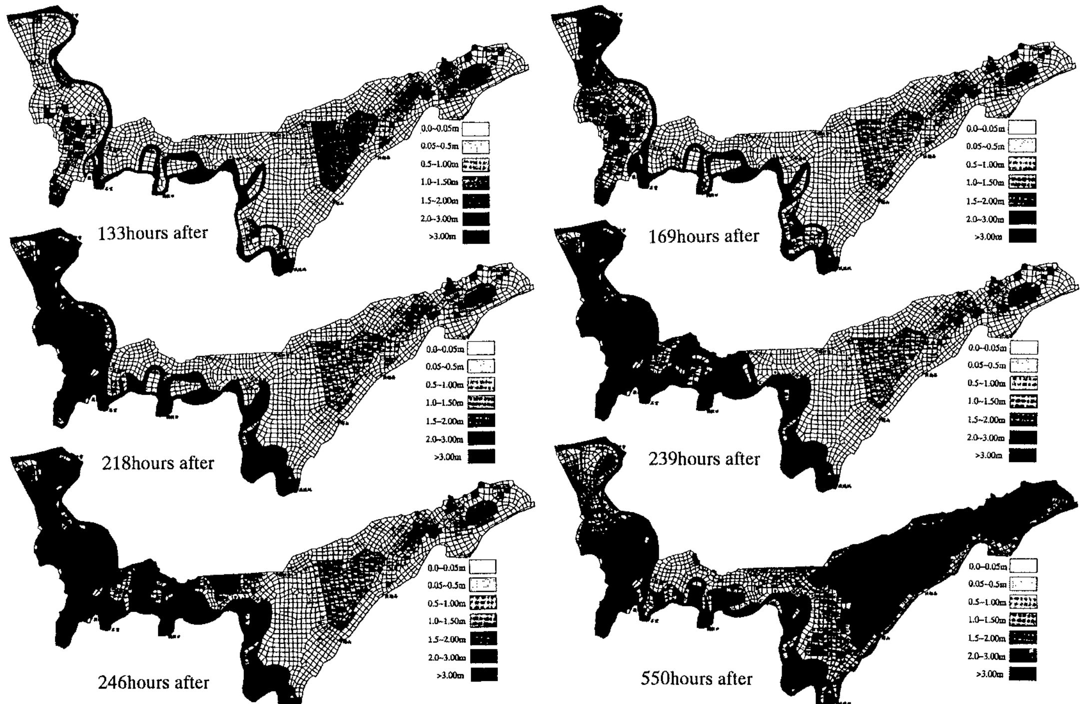

Fig.3 Water Depth Distribution at Different Times

4. Conclusions

Numerical method using irregular unstructured cell is applied to analyze 2-dimensional flood inundation in JingJiang region caused by a 100-year designed flood. Calculated results show this model is feasible and applicable.

Main features of this model can be concluded as follows: ①Using irregular unstructured cells to build grid cell structure, topography condition can be flexibly considered. ②According to the type of link, momentum equations are simplified into different schemes under improving computation speed and assuring computation precision. ③Calculation scheme has good stability. ④Using NDP-Fortran computer language to develop numerical procedure, the display of dynamic imagine of calculation result can be gotten. However, some important problems should be solved in future: ①Using irregular unstructured cells for data acquisition adds the workload of original data arrangement, thus, developing suitable software and utilizing digital map for data control is necessary. ②Comparative study of actual observed value and calculated result. ③How to include nonlinear terms of momentum equations. ④Further research on applying this model in urban area and how to develop it into comprehensive simulation model combined with other models such as typhoon, storm surge and refuge simulation models.⑤How to convert present numerical procedure from Dos into Windows environment.