Study on the Application of the Drainage Pipe Network and River Channel Coupling Model in Urban Flood Control and Drainage

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Abstract. Based on the one-dimensional channel conservancy model, this paper considers the factor of urban pipe network drainage, and couples the pipe network model with the one-dimensional channel conservancy model to fully analyse the interaction between the channel water level and the drainage pipe network displacement. Taking a coastal city as an example, the model simulation results show that when the water level of the river is high, it will cause the drainage of the pipe network; the lower part of the terrain will become waterlogged because of the aging of the urban pipe and rainstorm. It is impossible to effectively solve the problem of flood control and drainage by widening the river channel. It is necessary to adopt the coordinated improvement of the pipe network and the river channel to achieve effective targets.

1. Introduction
In recent years, with the acceleration of urbanization, the urban population has grown rapidly, and the scale of cities has expanded rapidly. All cities in the country are facing different levels of flooding problems. The main problems are as follows. First, the city has developed rapidly this year. The construction of high-density cities has led to dense urban housing, increased urban hardening rate, reduced urban permeable area for rainwater infiltration, and reduced urban rainwater storage capacity. Second, the construction of urban drainage pipe network was substandard in China. The urban waterlogging is affected by old pipe network, disordered system and rain pollution.

In the study of urban flood control and drainage, the mathematical model of the river channel has been widely used. In this type of one-dimensional river water conservancy model, the flood inflow of each catchment zone is selected as the upper boundary of the model, and the flood process is generally carried out by designing a rainstorm process. Hydrological analysis is recommended. However, traditional hydrological analysis is difficult to accurately simulate the urban drainage process and can only be simply generalized by controlling the maximum value of the drainage flow of the pipe network. Therefore, the accuracy of the input boundary of river hydrodynamic model can be improved by combining the operation process of urban pipe network with the mathematical simulation of river channel. It can be used to guide the planning and design of urban flood control and drainage better.

2. Construction of coupling model of drainage pipe network and river channel

2.1. One-dimensional river hydrodynamic
The one-dimensional river hydrodynamic model is based on the mass and momentum conservation equations of the vertical integral, that is, the one-dimensional unsteady flow Saint-Venant equations:
\[
\begin{align*}
\frac{\partial Z}{\partial t} + \frac{\partial Q}{\partial s} &= q(t) \\
\frac{1}{g} \frac{\partial v}{\partial t} + \frac{\partial}{\partial s} \left( \frac{v^2}{2g} \right) + \frac{Q}{A} [K] &= 0
\end{align*}
\]

Where: \(x, t\) are the coordinates of the calculation point space and time, \(A\) is the cross-sectional area of the water, \(Q\) is the flow of the over-current, \(h\) is the water level, \(q\) is the flow of the side inflow, \(C\) is the coefficient of Xie, and \(R\) is the hydraulic radius. \(\alpha\) is the momentum correction coefficient, and \(g\) is the gravity acceleration.

The equations are solved by using the Abbott-Ionescu six-point implicit finite difference scheme, as shown in Figure 1. This format alternately calculates the water level or flow rate in order of each grid point, which is called \(h\) point and \(Q\) point, respectively. The Abbott-Ionescu format features high stability and high computational accuracy.

![Transfer Abbott format water level, flow point alternate layout](image)

2.2. Drainage network hydrodynamic model

The urban pipe network hydrodynamic model is mainly used to calculate the unsteady flow in the pipe network. The calculation is based on the Saint-Venant equations (mass conservation) and the momentum equation (momentum conservation - Newton's second law):

\[
\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0
\]

\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + gA \frac{\partial y}{\partial x} - gAI_0 = gAI_0
\]

The model uses the Abbott-Ionescu six-point implicit format finite difference numerical solution. This calculation method can automatically adjust the time step and provide an effective and accurate solution for the branch or ring network. And the calculation method is suitable for the pressurized flow of the sewage pipe and the vertical uniform flow of the free water surface. Both critical and supercritical flows are processed using the same numerical solution. Water flow phenomena such as backflow and overflow can be accurately simulated.

The complete non-linear flow equation can be solved based on user-supplied or automatically provided boundary conditions. In addition to the complete dynamic description, the model also provides simplified water flow simulation.

2.3. Couple of drainage pipe network and river hydrodynamic model

The main difficulty in coupling the drainage network to the hydrodynamic model of the river is the connection between the two models. The model used in this analysis uses three methods to express the connection of the drainage network and the river.

1. The drainage system discharges water to the river through the sewage outlet.
2. Sewage discharges water to the river through the pump.
3. The drainage system drains water through the raft.
By setting the connection port to a certain mileage of a river channel in the hydrodynamic model of the river, the model will automatically introduce the outflow result of the drainage pipe network model. Using this result as the upper boundary of the river hydrodynamic model calculation, the impact of the drainage network on the hydrodynamics of the river can be reflected accurately.

3. Case study

3.1. Overview of the study area
The study area is in the coastal area of Fujian Province. The east, west and north sides of the city are surrounded by mountains and it faces the sea in the south. The old city is in the north of the Nanzhuang Plain. The planned new city is located on the Nanzhuang Plain. The source of mountain rivers is short-lived, and every flood period, mountain floods quickly flow into urban rivers. The slope of the plain river is smooth, and it is affected by the tidal level of the outer sea and the water blocking of some of the control gates, which hinders the flood discharge and the water level of the river is high. The high-water level of the river channel affects the drainage of the water, which leads to the flooding of urban areas.

3.2. Establishment of the coupled model

3.2.1. One-dimensional river hydrodynamic model. Through the generalization of the river network, a one-dimensional river hydrodynamic model was established to simulate the convergence process of the rivers in the study area. The generalization of the one-dimensional river water conservancy calculation model is shown in Figure 2.

3.2.2. Drainage network hydrodynamic model. Through the analysis of the pipe network data and the established drainage pipe network model, the urban rainfall process and the pipe network water drainage process in the study area were simulated. The generalization of the regional pipe network model is shown in Figure 3.

3.2.3. Drainage-channel hydrodynamic coupling model. The organic coupling between the models is achieved by organically connecting the drainage network and the river model, and the organic coupling between the models is achieved. The coupling model is generalized as shown in Fig. 4.

3.3. Model determination
In this study, the coupled model was determined using a measured data of water level and flow from a typhoon. The typhoon occurred in October 2013. The average process rainfall in the whole region was 301mm, the maximum 1h rainfall was 50.7mm, the maximum 3h was 144.1mm, the maximum 6h was 200.3mm, and the maximum 24h was 262.8mm.
Through the model calculation, taking two sections as example (Figure 5~6), the comparison of the measured water level process and the simulated water level process is as follows. According to the simulation results, the results are in line with the requirements, and the trend of rising water and water withdrawal is well fitted. The simulated water level results of each measuring point and the measured water level scatter errors are following relevant specifications and rules.

3.4. Analysis of model results
The main water system in the area consists of “three vertical and four horizontals”, namely three longitudinal river channels and four horizontal river channels. Three of the longitudinal river channels are the main flood drainage channels, which have functions of communicating water system, urban landscape and ecological restoration. In order to consider the effect of the widening of the longitudinal channel on the flood control and drainage of the area, it is analysed that the three longitudinal river channels are respectively widened by 10m and 20m.

According to the calculation results, in the case of working conditions and working conditions, when the three rivers are widened, the P=2% flood level of the river channel drops significantly, indicating that the widening of the river channel is an effective measure to reduce the flood level of the river, but the water level in the old city is low. There is no significant improvement over the current situation;

In view of the above situation, starting from the output of the drainage pipe network model, through the analysis of the output of the drainage pipe network, in the above two working conditions, due to insufficient drainage capacity of some drainage networks in the old city, some drainage openings have appeared in the flow, in the area Internal sputum is formed, and floods in some areas cannot be discharged into the river. The problem of urban drainage is not solved. Therefore, based on working conditions 1 and 2, the working conditions of the old city pipe network transformation are increased. The results of the model calculation are available. After the old city pipe network is changed, the water level of the longitudinal river channel increases, and the water level in the old city area increases. Significantly reduced, due to the accelerated drainage process, the water level of the river was slowed down by the downstream tide level, and the water level of the river also decreased significantly.

The calculation results of water level in each working condition are shown in Table 1.

| Table 1. Working conditions 1 ~ 4 rivers flood level and flood point level table. |
|---------------------------------------------------------------|
| Current water level | Longitudinal channel 1 | Longitudinal channel 2 | Longitudinal channel 3 | Flood point |
|---------------------|------------------------|------------------------|------------------------|-------------|
| Working condition 1 | 3.77~4.07              | 3.82~4.04              | 3.77~4.09              | 3.29        |
| Working condition 2 | 3.77~4.05              | 3.82~4.01              | 3.77~4.03              | 3.29        |
| Working condition 3 | 3.78~4.15              | 3.83~4.20              | 3.77~4.21              | 3.1         |
| Working condition 4 | 3.69~3.98              | 3.78~3.87              | 3.68~4.00              | 2.98        |
4. Conclusions and recommendations
As the main flood drainage channel of the city, the river channel has always been the main research object of urban flood control and drainage. However, with the acceleration of the urbanization process, the situation of urban underlying surface has changed drastically, and the urban population has increased rapidly. The traditional hydrological calculation method has been difficult to meet the requirements of urban river water conservancy model establishment. Therefore, by coupling the urban pipe network model with the river channel model, the convergence results of the urban underlying surface can be effectively reflected into the river hydrodynamic model, and a more reasonable and effective flood control and drainage plan and measures can be obtained.

In the research and formulation of flood control and drainage schemes, through the trial calculation of the coupled model, it is not only possible to pass river channel measures, such as widening river channels, setting up flood detention areas, expanding the water area of hydraulic structures. The urban pipe network transformation is also should be considered. Reconstruction, renovation of old urban areas and other measures will expand flood control and drainage from pure river channel engineering to an organic whole combining urban planning and water conservancy planning and form a more effective flood control and drainage system.

References
[1] Quan R, Liu M, Lu M, Zhang L. (2010) Assessment of waterlogging hazard in central urban area of Shanghai based on simplified urban waterlogging model. People’s Yangtze River,41(2):32-37.
[2] Yuan Y, Shi P. (2001) Effect of land use on the rainfall-runoff relationship in a basin—SCS model applied in Shenzhen city. Journal of Beijing Normal University (Natural Science),37(1):131-137.
[3] Lu L, Zhao D, Chen X, Shen Z, Luo R, Zhang T. (2014) Simulation study on coupling of urban drainage pipe network and internal river channel. Water Supply and Sewerage,40(10):103-107.
[4] Keifer C J, Chu H H .(1957) Synthetic storm pattern for drainage design. Journal of the hydraulics division,83(4):1-25
[5] Chen Q. (2011) Study on countermeasures against heavy rainfall in North China Plain. Transformation and Reconstruction - Proceedings of the 2011 China Urban Planning Annual Conference. Nanjing,98-102.