Modelling and Application of Urban Drainage Based on Mike Urban Model

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Abstract. To alleviate the drainage pressure of urban pipeline network and reduce flood disaster, for the problem of non-convergence of design standards caused by inconsistency of design rainstorm duration between urban construction and water conservancy departments, this paper takes a residential district in Wenzhou City of Zhejiang Province as an example, and analyzes the relationship of recurrence periods between pipeline network drainage and waterlogging drainage under the regulation and storage capacity of rivers. Mike Urban was used to establish the drainage model of pipeline network to simulate the drainage situation when facing different river water levels at the outlet. The results are as follows: (1) when the recurrence period of pipeline design is 1 year, 3 years and 5 years respectively, the corresponding design rainstorm recurrence period of waterlogging drainage is about 5 years, 15-20 years, 20-30 years; (2) when meeting the high water level at the outlet, the once a year rainfall of pipeline network encountering is equivalent to that of the pipeline network encountering the once in three years rainfall when the water level of the outlet is constant; (3) when the water level at the outlet is high, the once in three years rainfall of the pipeline network encountering is equivalent to that of the pipeline network encountering the once in five years rainfall when the water level of the outlet is constant. Relevant research can provide reference for the design standard of pipeline network.

1. Introduction

Affected by climate change and human activities, the frequency of extreme weather events and the probability of disasters have increased accordingly.[1][2] Especially in urban areas, the “heat island effect”[3] caused by urbanization has had a significant impact on the construction of urban drainage and drainage facilities.[4] In addition, the drainage standards in cities around China are generally low, and the design standards are inconsistent, [5][6] aggravating the potential risks drainage. [7] These problems have become hot issues that need to be urgently addressed.

Aiming at the planning management and analysis of urban drainage pipe networks, scholars currently conduct research mainly through models.[8] For example, the commonly used models are the STORM model [9] developed by the American Institute of Engineers, the SWMM model [10][11] launched by the US Environmental Protection Agency (EPA), and the Info Works model [12] developed by Wallingford Software in the UK. In general, these models have high requirements for basic data, and the calibration of parameters and other operations are more complicated. [13][14] The Mike Urban model is a model simulation tool based on discrete solutions to hydrodynamic equations. It has the advantages of high degree of simulation, high simulation accuracy and powerful functions. It
is widely used in Europe, Australia, Hong Kong and Taiwan [4]. Li et al.[15] applied the Mike Urban model to a Chengdu urban drainage pipe network under pressure and operating conditions under different rainfall intensities and pipe point overflow conditions, and achieved good simulation results. In response to the urban waterlogging problem, Ma H. T. et al. [16] put forward a method for formulating emergency drainage measures based on the Mike Urban model, which provided a basis for emergency plans for urban waterlogging. In the past, the pipe network drainage simulation based on Mike Urban had a vague understanding of the flood control design standards of urban construction and water conservancy departments, and lacked overall consideration of the relationship between the height of the pipeline outlet and the water level of the water outlet when designing the network. [17]

Wenzhou City is located in the lower reaches of rivers in the plain area, where the river network is well developed and the river flows slowly. [18] Therefore, when the flood (or high tide level) comes at the same time as large-scale rainfall, if the drainage capacity of the river network is insufficient, the city will suffer severe flooding disasters, [21] causing inestimable losses. [22] Therefore, this paper builds a pipe network drainage model based on Mike urban. The main research objectives include the following content: (1) calculating the correspondence between the drainage period of the river and the drainage period of the river after considering the storage capacity of the river; [23] (2) The water level of the river under the design standard of the pipe network; (3) Simulation of the drainage situation of the pipe network when the water level of the river and the normal water level of the river. The research in this paper can provide reference for pipe network design standards.

2. Calculation of return periods considering river regulation capacity

There is a difference in the regulation and storage capacity of rivers and pipelines. [24][25] If the drainage pipelines do not exceed the standard, and the drainage capacity of the rivers is insufficient, the drainage of the pipelines will be impeded. This situation will seriously affect the design standards of the pipelines and lead to low design standards. In order to find the river water level corresponding to the design standard of pipe network drainage, this section first calculates the connection method of the recurrence period considering the difference between the capacity of the river and the pipeline. [26]

The design standards for the recurrence period of the pipe network planning of urban construction departments are usually one in one year, one in three years, and one in five years. The calculation procedure is as follows:[27]

- The selected design period of the pipeline is Δh (Δh = 1h, 2h, 3h), and the Δh design rainfall X1 for a specific recurrence period (1-year recurrence period, 3-year recurrence period, and 5-year recurrence period) is calculated.
- Count the rainfall process of all the n-year measured data according to multiple sample methods each year, and count the 24-hour rainfall X 24 of each time (a total of kn times, k is the number of samples selected annually);
- Select the nx rainfall process where the 1-hour rainfall is less than X1 in all the n-year measured data, and count the 24-hour maximum rainfall X 24 m during the nx rainfall process;
- Arrange X24 in order of size, determine its serial number M (X24M), and calculate the corresponding frequency;
- Use p (secondary frequency) to measure the design rainfall (X24p) for each period on the frequency curve of multiple sample periods in the year;
- Calculate T24p (corresponding recurrence period) on the time-frequency curve of the annual maximum method with the same design value.

The correspondence between the drainage of each pipeline and the recurrence period of river drainage (Table 1) was obtained. In summary, when the design rainstorm recurrence periods of the pipeline are 1 year, 3 years, and 5 years, the corresponding rainstorm recurrence periods of the river drainage design are around 5 years, 15-25 years, and 20-30 years.
Table 1. Relationship between rainfall and return period

| Rainfall duration (h) | 1     | 2     | 3     |
|-----------------------|-------|-------|-------|
| Return period of pipe drainage (a) | 1 | 3 | 5 |
| Return period of river drainage (a) | 2.38 | 15.38 | 16.67 | 2.86 | 18.46 | 20.00 | 5.81 | 19.61 | 21.3 |

3. Simulation and Application of Pipe Network Drainage Based on Mike Urban

3.1 Study area

The research area is located in Lijing Street, Ouhai District, Wenzhou (Figure 1). The main river channel in the project site is Litangyu. The length of the river channel is about 1500m, and the width of the river channel is 9.8~33.0m, and the elevation of the river bottom is 0.58~1.98m. The river channel flows from the upstream mountain stream, and the downstream is connected to the Wenruitang River. The nearest rainfall station in the river basin is the Fanyou station. The elevation of the station is 10 meters, and the series of measured storm data for one day and three days is from 1985 to 2010, which can basically represent the long series of rainfall in the region.

3.2 Introduction of Mike Urban

Mike urban is one of the Mike series software developed by the Danish Hydraulic Institute (DHI)[28], which has a high application rate and recognition in the industry. This series of software mainly includes MIKE11, Mike 21, [29] Mike flood, Mike urban,[30] Mike basin, Mike she, etc., which are widely used in many fields such as urban waterlogging and water pollution simulation. Mike urban has the characteristics of simple modeling and accurate calculation, which is often used in urban waterlogging simulation.

Mike urban includes a complete urban pipe network model and GIS environment, including water supply system and drainage system. Its drainage network simulation module includes rainfall runoff module, pipe flow module, control module, pollutant transmission module and so on. When Mike urban is used for waterlogging simulation, the first step is to carry out runoff and confluence calculation first. In the runoff calculation module, the fixed runoff coefficient method is generally used, and in the confluence calculation part, the time interval unit line method and the equal flow time line method are used. The second step is to simulate the pipe network. The flow in the pipe network is unsteady. The principle is to use Abbott Ionescu six-point implicit finite difference scheme to solve the Saint Venant equations of one-dimensional free water surface.[31]
3.3 Construction of the model

According to the collected data of the existing pipe network, the current pipe network model is established. The model generalizes 112 rainwater nodes (including 1 water outlet), 112 rainwater pipelines and 123 sub catchments. The top elevation and bottom elevation of nodes in the model, the top elevation and bottom elevation of pipe section, and the diameter, length, shape and layout of pipe section are directly read from the pipe network design drawing. The percentage of impervious area is 75% based on experience. According to the standard that each area contains a water collection well and rainwater flows into the nearest water collection well, the water collection area is divided. The established pipe network model is shown as Figure 2.

![Figure 2: Diagram of drainage pipe network model](image)

3.4 Calculation of boundary conditions

3.4.1 Design flood level. In this calculation, the unsteady flow program of river network is used to calculate the flood evolution within the research scope, and the flood discharge and maximum water level corresponding to each flood frequency of each characteristic section of the main river in the project area are calculated. The model generalizes 1120 sections, including 249 river branches, 103 sluice branches, 177 generalized lakes and 39 concentrated inflow. The upper boundary of the river network is the discharge boundary, while the lower boundary of the river network is the water level boundary, which is mainly the flood tide process under the sluice. The calculation results are shown in Table 2:

| return period (a) | 5    | 10   | 20   | 50   | 100  |
|-------------------|------|------|------|------|------|
| water level (m)   | 3.92 | 4.1  | 4.25 | 4.4  | 4.5  |

3.4.2 Procedure of design flood. In Chicago rain pattern, the rainfall in any duration is equal to the design rainfall,[32] and the rainfall process is easy to determine. It calculates the design rainfall process based on the rainstorm intensity formula. Based on the analysis of the rainfall situation and the position of the rainfall peak in the study area, the comprehensive parameters of the rainstorm are obtained. The coefficient of the position of the rainfall peak is \( r = 0.5 \). There is a rainstorm formula in Wenzhou:

\[
i = \frac{13.274 + 0.573 \ln P}{(t + 12.641)^{0.863}}
\]  

(1)
where $i$ is the rainfall intensity (mm/min), $P$ is the return period of design storm (a), and $t$ is the rainfall duration (min).

According to the above formula, the design rainstorm process with 1-year return period, 3-year return period and 5-year return period in Wenzhou City is obtained, as shown in Figure 2.

![Figure 3. Rainfall time distribution](image)

Figure 3. Rainfall time distribution

Among them, the cumulative rainfall of 5-year return period is 59.19mm, that of 3-year return period is 53.4mm and that of 1-year return period is 22.22mm.

### 3.5 Analysis of pipe network load based on Mike Urban

#### 3.5.1 Working condition

The simulation results of different schemes are affected by the rainfall process and the water level at the outlet of the pipe network. According to the calculation results of 1, when the design rainstorm of the pipeline drainage system is 1-year return period, the corresponding design rainstorm of the river channel is 5-year return period, and the corresponding flood is 5-year return period, with the high-water level of 3.92m. When the design rainstorm of pipe network is 3-year return period, the corresponding design rainstorm of river channel is 20-year return period, and the corresponding flood is 20-year return period flood, with the high-water level of 4.25m. The normal water level of the river is taken as 3.8m according to the hydrological monitoring data. In order to discuss the pipe network load under different river water levels, the following five working conditions are simulated with the established drainage model of Li’ao Street pipe network in Wenzhou, taking into account the rainfall process and the return period of river water level. See Table 3 for classification and boundary conditions of working conditions.

| Working condition | Rainfall duration (h) | Return period (a) | Water level                  |
|-------------------|----------------------|-------------------|------------------------------|
| A                 | 1                    | 1                 | Normal water level (3.8m)    |
| B                 | 1                    | 3                 | High water level (3.92m)     |
| C                 | 1                    | 5                 | Normal water level (3.8m)    |
| D                 | 1                    | 3                 | Normal water level (4.25m)   |
| E                 | 1                    | 5                 | Normal water level (3.8m)    |
3.5.2 Analysis of overflow nodes. The model in this paper is mainly based on the overflow of nodes as the main basis of the load capacity of urban pipe network. In the operation diagram of the model, the value of the node is the difference between the highest water level of the node and the ground elevation, so when the display value of the node is negative, it means that the ground elevation is higher than the high water level of the node, and no overflow occurs; otherwise, if the display value of the node is positive, it means that the node overflows. See Table 4 for node overflow of pipe network.

Table 4. Overflow nodes

| Return period | Normal water level | Normal water level |
|---------------|--------------------|--------------------|
|               | number | percentage | number | percentage |
| 1h1a          | 0      | 0%         | 12     | 11%        |
| 1h3a          | 25     | 22%        | 31     | 28%        |
| 1h5a          | 36     | 32%        | -      | -          |

It can be seen from Table 7 that when the water level of the outlet channel is high, and the pipe network encounters one-year rainfall, which is equivalent to that when the water level of the outlet is constant, and the pipe network encounters one-to-three-year rainfall of the same duration. When the water level of the outlet channel is high, and the pipe network encounters three-year rainfall, which is similar to that when the water level of the outlet is constant, and the pipe network encounters three-to-five-year rainfall of the same duration. Therefore, in the design of the pipe network, the water level at the outlet should be considered as high-water level to increase the drainage capacity of the pipe network.

4. Conclusion
This paper analyzes the relationship between pipe network drainage and river drainage recurrence period considering the river storage capacity. Using Mike Urban to establish a pipe network drainage model to simulate pipe network drainage at different water outlet river levels, the following conclusions are obtained:(1) When considering the storage capacity of the river channel, the relationship of the recurrence period between the pipeline and the river is as follows: When the recurrence period of the design storm of the pipeline is 1 year, the recurrence period of the corresponding drainage design storm of the river is about 5 years; when the corresponding pipeline design When the rainstorm recurrence period reaches 3 years, the design rainwater recurrence period corresponding to river drainage design is 15 to 25 years; when the corresponding pipeline design rainstorm recurrence period reaches 5 years, the corresponding river drainage design rainstorm recurrence period is 20 to 30 year. With the same design storm, the pipeline design return period is much lower than the river drainage design.(2) The relationship between the water level of different outlets and the drainage standard of the pipe network: When the river water level is high, the pipe network encounters rainfall once a year, which is equivalent to the same period of time that the pipe network encounters when the water level of the outlet is constant. Rainfall encountered when the water level of the water outlet channel is high, the pipe network encounters rainfall once every 3 years, which is equivalent to the same rain that occurs once every 3 to 5 years when the water level at the outlet is normal. In the design of the pipe network, the supporting effect of the river water level on the pipe network should be considered, and the design standards of the pipe network can be appropriately raised to reduce the flood disaster.

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