Research on Calculating Method for the Design Rainfall of Urban Flooding Prevention Engineering

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Abstract: For the moment, on the one hand, the rainstorm intensity formula that applied in urban flooding prevention mostly comes from urban development department's derived formula, which the longest duration is only 2 hour, it has been unable to meet the requirement of design rainfall, so a long duration rainstorm intensity formula is needed. On the other hand, for the prevention of urban flooding disaster more from the total amount of water and the flow hydrograph, so the rainfall duration distribution that can reflect the real situation of the Basin Rainfall is also needed. In view of the above problems, at first, the study integrated and normalize the original rainfall data that offered from meteorological data of a City, a total of 52 years rainfall data of the center city, and selected P- III frequency distribution curve to fit the sample data, then prioritized a group of parameters that the error from six classical methods is smallest, thus the long duration rainstorm intensity formula was obtained, chose a typical rainfall process from original rainfall, then adopted the typical duration amplification method, combined with the storm intensity formula to derive the rainfall duration distribution under the corresponding return period and lay a theoretical foundation for the design and planning for the urban rain water drainage system.

1 Introduction

Design rainstorm intensity formula and design rainfall type is the foundation of the urban flooding prevention engineering. Presently, for most Chinese cities, short duration rainstorm intensity formula derived based on multiple sample method is used in the design of municipal stormwater network design, but long duration rainstorm intensity formula derived based on annual maximum value method is applied in the design of urban waterlogging system. When used for planning and construction of urban flooding prevention engineering system (Liu et al.2016), the above two formulas have certain defects, firstly, due to the longest duration is 120 min (Du et al.2012) in the rainstorm intensity formula of municipal drainage engineering, it can't meet the requirement of design rainfall duration of urban flooding prevention engineering (generally from 2 hours to 24 hours). Secondly, the sampling time interval of rainstorm intensity formula of water drainage engineering is generally longer, usually for an hour, it can't meet the needs of design of municipal drainage engineering, generally for 5 minutes (Pizarro et al. 2012). But in fact they are taken from the same rainfall data, only different in statistical methods, therefore, a long duration (24 hours) design storm intensity formula that combined with the above two formulas is feasible.

The prevention and control of urban flooding disaster not only from the perspective of instantaneous peak flow, but more from the aspect of total amount of water and flow hydrograph, therefore, rainfall duration distribution should be considered.\cite{1-3} At present, the general methods include typical historical rainfall scaling method, IDF cure method, Dimensionless standard curve
method and so on (Veneziano.1999; Seong.2014). According to the relevant experience of urban flood control engineering, the design rainfall type should be able to reflect the real basin long duration rainfall statistics law.

Based on the above understanding, this paper studied a design rainfall type that suit for the planning and construction of urban flooding prevention engineering and a new calculation method of design rainstorm, then can achieve the standard of cohesion and unity of meaning of municipal drainage engineering, urban flooding prevention engineering and water drainage project on real significance.

2 Methodology

This paper mainly studied the calculation mention of the long duration (24 hours) rainstorm intensity formula and design rainfall duration distribution, the technical route is shown in Figure 1 and Figure 2:

Figure 1 Technology for rain intensity formula

Figure 2 Technology for Design rainfall pattern

2.1 Research on the Rainstorm Intensity Formula

2.1.1 Data collection

Based on the original rainfall data, data consolidation and data integration are carried out.

2.1.2 Data processing

Through computer programming and database technology, the format of the original data can meet the requirements of sampling.

2.1.3 Sample selection

Considering the effective connection of design rainfall between municipal drainage facilities, flood control and drainage facilities, the rainfall duration was selected in this study is 5min, 10min, 15min, 20min, 30min, 45min, 60min, 90min, 120min, 150min, 180min, 240min, 360min, 720min, 1440min, a total of 15 and the return period range corresponding used in this system is 2 ~ 100 years.
2.1.4 Frequency analysis

Through the analysis of the probability distribution of the sample, we can determine what kind of frequency analysis method is applicable to the sample data. Then, match the empirical frequency curve and the empirical frequency curve using curve fitting method, which can be used to determine the appropriate statistical parameters \(^4\). In this study, due to the convergence of the municipal drainage, water drainage and urban flooding prevention engineering, we consider more of the curve between the return period 2 to 100 years under the premise of meeting the basic requirements of the curve fitting method, based on the principle of optimal line method (Huang, 2006), we should adjust \(C_v\), \(C_s\) value that corresponding to each duration, until the theoretical frequency curve and the sample group fit, and then record the final \(C_s\) as well as the corresponding \(C_v/C_s\) value. At last, table of the relationship between the return period \((P)\), the rainstorm intensity \((i)\), and the rainfall duration \((t)\) table will be given in the light of the corresponding parameters under the corresponding frequency distribution.

2.1.5 Rainstorm intensity formula derivation

According to the current water supply and drainage design manual, six classic calculation methods (Beijing method, Beijing simplified method, Nanjing method, the simplified method of least squares method, Tongji University method and Direct fitting method) are often used to calculate the rainstorm intensity formula parameters. The formula is as follows:

\[
i = \frac{A_1(1 + C \lg P)}{(t + b)^n}
\]

(1)

Where \(i\) is rainstorm intensity, unit is mm; \(t\) is rainfall duration, unit is min; \(P\) is return period, unit is year; \(n, A_1, b, C\) are regional parameter

We can get the parameters of the \(A_1, C, n, b\) generation into the formula, respectively, and then obtain rainfall intensity value by different methods, according to the rainfall intensity values above obtained and value got from p-i-t table, we can calculate the corresponding absolute and relative mean variance.

Finally, the parameters of the formula that the error is smallest are selected from the 6 methods.

2.2 Study on the rainfall distribution

2.2.1 Rainfall process division

When the continuous time of rainfall that less than 0.1mm (or stopped raining) is more than 12 hours, it is defined as two separate "rain processes." according to the definition, rainfall process is divided after raw data processed by data processing system.

2.2.2 Typical rainfall selection

Owing to rainfall intensity varies greatly with duration, it is necessary to analyze the rainfall process after finishing statistics of rainfall process, we should pick out the most typical rainfall process through comprehensive analysis, after that combined with the design rainfall to modify the rain type.

The principles of selecting the rainfall process are as follows:

1) The total rainfall is large, the quantity of rainfall peaks is much and the highest peak is in the rear as far as possible.

2) It can reflect the general characteristics of heavy rain in the region.

3) The selected rainfall process is close to the design conditions, and is disadvantage to the safety of project.

2.2.3 Design rainfall type selection

On the basis of the relevant experience of urban flooding prevention at home and abroad, the design rainfall pattern applied in urban flooding prevention engineering should satisfy the following
conditions:
(1) Urban flooding prevention engineering design must be a long duration rainfall type, on the basis of the area size and the concentration time, design rainfall type lasted for 24 hours can meet the needs of urban flooding engineering planning and design.
(2) The design rainfall distribution should be able to reflect the real long duration rainfall statistical law.
(3) The design rainfall duration distribution of urban flooding prevention engineering should also try to take into account the effective connection with municipal drainage facilities and water drainage facilities.

In China, it is generally analyze the typical rainfall from the actual rainfall process, and to control different rainfall duration and frequency design rainfall, then adopt the method of the same times ratio or the same frequency to design rain type.

In conclusion, this paper used typical duration amplification method to calculate the design rainfall type lasted for 24 hours.

2.2.4 Typical duration amplification method
The typical duration amplification method is a common method to study rainfall type, which is mainly used in the process of rainfall amplification.

For example, design 15min rainfall type using 5min as a statistical unit, the steps are as follows:
(1) Firstly, we should extract the maximum 15min rainfall from the rainfall each selected. Assuming the 6 years of the original rainfall process data are selected, so there are a total of 6 maximum 15min rainfall processes, each 15min rainfall process will be divided into 3 sections with 5min rainfall as statistical unit.
(2) Secondly, for the 3 part rainfall process obtained by the first step, we respectively statistics of each section (5min) in the proportion of each rainfall, and then takes the average of the proportion of the distribution of the position, to find out the location of the largest 5min.
(3) Thirdly, for the rest of the two part, recalculate the corresponding distribution ratio.
(4) Finally, we can get the rainfall distribution of 15min by inserting the design rainfall process of 5min and 15min.

And so on, the rainfall distribution of 45min, 60min, 90min, 120min, 150min, 180min, 240min, 360min, 720min, 1440min can be obtained.

3 Case Study
3.1 Research on the Rainstorm intensity formula
This study took a city of China as an example, based on the meteorological data of City, to research on the rainstorm intensity formula \(^5\). The original rainfall data were come from Meteorological Bureau, a total of 52 years rainfall data of the center city, all information would be changed into a unified lattice, namely every minute rainfall data electronic document by programming, and selected 5min, 10min, 15min, 20min, 30min, 45min, 60min, 90min, 120min, 150min, 180min, 240min, 360min, 720min, 1440min, a total of 15 rainfall duration data as sample for frequency analysis, through the study of probability distribution of samples, curve type of P- III distribution was chose. P- III distribution curves that fitting each sample were shown in Figure 3:
Figure 3 P-III distribution curve by fitting the sample of long duration

According to the corresponding parameters, we could get the relationship between and among return period (P), heavy rain intensity (I), rainfall duration (T), the relationship was shown in Table 1.

Table 1 P-i-t table  unit: mm/min

<table>
<thead>
<tr>
<th>P</th>
<th>(t(min))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>4</td>
<td>2.8</td>
</tr>
<tr>
<td>5</td>
<td>2.9</td>
</tr>
<tr>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>3.0</td>
</tr>
<tr>
<td>8</td>
<td>3.1</td>
</tr>
<tr>
<td>9</td>
<td>3.1</td>
</tr>
<tr>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td>20</td>
<td>3.4</td>
</tr>
<tr>
<td>30</td>
<td>3.5</td>
</tr>
<tr>
<td>50</td>
<td>3.7</td>
</tr>
<tr>
<td>10</td>
<td>3.9</td>
</tr>
</tbody>
</table>

By using the above six methods, the parameter values of the rainstorm intensity formula were obtained, and the calculating errors of various methods were calculated. The results were shown in Table 2.
### Table 2 Results of storm intensity formula in center of City

<table>
<thead>
<tr>
<th>calculational methods</th>
<th>A1</th>
<th>b</th>
<th>n</th>
<th>C</th>
<th>absolute mean variance</th>
<th>relative mean variance %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing method</td>
<td>31.17</td>
<td>22.37</td>
<td>0.82</td>
<td>0.57</td>
<td>0.053</td>
<td>3.800</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beijing simplified method</td>
<td>16.53</td>
<td>10</td>
<td>0.72</td>
<td>0.57</td>
<td>0.16</td>
<td>11.588</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nanjing method</td>
<td>16.85</td>
<td>15.46</td>
<td>0.70</td>
<td>0.58</td>
<td>0.068</td>
<td>5.034</td>
</tr>
<tr>
<td>simplified method of least squares method</td>
<td>31.14</td>
<td>22.35</td>
<td>0.82</td>
<td>0.57</td>
<td>0.053</td>
<td>3.799</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tongji University method</td>
<td>21.11</td>
<td>18.32</td>
<td>0.75</td>
<td>0.61</td>
<td>0.066</td>
<td>4.835</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct fitting method</td>
<td>20.93</td>
<td>16.8</td>
<td>0.72</td>
<td>0.43</td>
<td>0.043</td>
<td>3.304</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the above table, the calculation result error of the direct fitting method was the smallest, so the formula obtained by the direct fitting method was as follows:

\[
t = \frac{20.934(1 + 0.431 \lg P)}{(t + 16.8)^{0.724}}
\]

(2)

### 3.2 Design of rainfall type

By dividing the process of rainfall in the City, and combined with the selected method of typical rainfall, we initially selected 10 rainfall processes from data of 52 years, they were September 4, 1964 to September 6th; September 3, 2010 to September 4th; August 21, 1999 to August 24th; June 16, 1983 to June 19th; May 6, 2010 to May 8th; September 25, 1993 to September 27th; May 16, 1989 to May 18th; June 25, 1989 to June 26th; May 26, 1975 to May 27th; May 14, 2010 to May 15th, in these rainfall processes, the September 4, 1964 rainfall process was pick up as the most typical rainfall process at last thought comprehensive consideration.[6]

The rainfall duration distribution under the corresponding return period could be derived by adopting the typical duration amplification method and combined with rainstorm intensity formula obtained above at the same time, the result was shown in Figure 4 (with a return period of 10 years as an example):

![Figure 4 Schematic lasted 1440 minutes of schedule distribution for 10-year period](image)

### 4 Conclusions

(1) This research described the necessity and feasibility of long duration rainstorm intensity formula research and design rainfall type. Based on the original rainfall data of 52 years in the central station of city, the study used the method of the maximum sampling frequency distribution and selected an appropriate theoretical frequency distribution, then the parameters value of
rainstorm intensity formula were obtained through six classical methods, and the corresponding error was acquired at same time, at last, choose a set of parameter values of the rainstorm intensity formula which is the error is smallest. In the meantime the flood control also needs to be considered from the point of the rainfall process curve, so long duration design rainfall type was discussed through the typical duration amplification method combined with design rainstorm intensity formula.

(2) Although the calculation error in calculation of rainstorm intensity formula was smallest, but the precision was not enough, it need further improvement. At present, for rainfall type selection, it need to be considered through long term rainfall data and combine with climatic conditions, in the study, from the point that could actually reflects the local long duration rainfall statistics law, we chose the typical duration amplification method to derive design rainfall type, but it could be used as the most appropriate local design type, need to be further studied in the late.

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References


