Analysis of Design Rainfall Depth in Sponge City Construction — a Case Study of Hefei, China

Xinwei Song¹*, Youxiao Tu¹ and Luxiu Chai¹

¹College of Architecture and Civil Engineering, West Anhui University, Luan, Anhui, 237012, China
*Corresponding author’s e-mail: 36650804@qq.com

Abstract. The design rainfall depth is an important parameter in the construction of sponge cities. Based on the analysis of 39 year daily precipitation data in Hefei city, this paper concludes that the inter-annual and intra-annual distribution of precipitation in Hefei is uneven. Based on the comparison and analysis of volume capture ratio of annual rainfall calculation method and rainfall percentage control calculation method for design rainfall depth, it is proposed that the designed rainfall in Hefei should not be too high, and it provides suggestions for the construction of the sponge city in Hefei.

1. Introduction

A sponge city is a city that can, like a sponge, absorb, store, seep, and purify water when it rains, and can release or use the stored water when needed[1]. The designed rainfall depth refers to the rainfall control value used to determine the design scale of low-impact development facilities in order to achieve a certain control target of sponge city construction. The designed rainfall depth is an important index in the construction of sponge city, which directly affects and determines the annual runoff amount and other goals of sponge city construction, and indirectly affects the runoff pollution control goals and rainwater resource utilization goals. Therefore, it is of great significance to determine a reasonable design rainfall depth. Based on the data of daily precipitation in Hefei city, this paper analyzes the characteristics of rainfall, calculates the designed rainfall depth, and discusses the influence of extreme weather such as heavy rain on the total runoff control.

2. Rainfall analysis

2.1 Annual rainfall analysis

The annual precipitation of Hefei City is obtained from the daily data collection of climate data at the China International Ground Exchange Station[2]. The specific data are shown in Table 1 and Figure 1. It can be seen from the figure that the interannual rainfall distribution in Hefei is uneven. In the past 39 years, the largest rainfall in Hefei was 1502.0 mm in 2016, the smallest was 584.1 mm in 1995, and the average annual rainfall was 1034.5 mm. Maximum annual precipitation is 2.57 times the minimum annual precipitation. The interannual precipitation in Hefei has changed greatly, and the annual precipitation has an increasing trend.
Table 1. Annual rainfall of Hefei from 1980 to 2018

| Year | Annual rainfall / mm | Year | Annual rainfall / mm | Year | Annual rainfall / mm |
|------|----------------------|------|----------------------|------|----------------------|
| 1980 | 1103.8               | 1993 | 1081.7               | 2006 | 992.8                |
| 1981 | 870.7                | 1994 | 790.9                | 2007 | 929.7                |
| 1982 | 1013.9               | 1995 | 584.1                | 2008 | 910.2                |
| 1983 | 1102.7               | 1996 | 1157.8               | 2009 | 951.9                |
| 1984 | 997.1                | 1997 | 697.2                | 2010 | 1316.8               |
| 1985 | 995.1                | 1998 | 1123.0               | 2011 | 1000.5               |
| 1986 | 775.2                | 1999 | 986.0                | 2012 | 939.4                |
| 1987 | 1322.8               | 2000 | 901.9                | 2013 | 893.2                |
| 1988 | 800.5                | 2001 | 792.4                | 2014 | 1180.2               |
| 1989 | 1380.1               | 2002 | 1085.3               | 2015 | 1258.2               |
| 1990 | 796.5                | 2003 | 1404.6               | 2016 | 1502.0               |
| 1991 | 1470.4               | 2004 | 908.3                | 2017 | 951.9                |
| 1992 | 791.2                | 2005 | 1091.3               | 2018 | 1495.6               |

Figure 1. Annual precipitation changes in Hefei from 1980 to 2018

2.2 Monthly rainfall analysis

Hefei is located in a mid-latitude zone and belongs to a subtropical monsoon humid climate. The monsoon is obvious, the four seasons are clear, the climate is mild, and the rainfall is moderate, but the average monthly rainfall is unevenly distributed. The rainfall is mainly concentrated in spring and summer (April-August), of which the most concentrated from June to August, the precipitation accounted for 45.6% of the annual precipitation, the most precipitation in July was 185.8mm; December-February, the precipitation was less, only 12% of the whole year, The least amount of precipitation is 30.2mm. The monthly average precipitation in Hefei is shown in Table 2 and Figure 2.

Table 2. monthly average precipitation of Hefei from 1980 to 2018

| Month | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Precipitation /mm | 42.2 | 52.9 | 73.6 | 81.7 | 94.0 | 148.8 | 185.8 | 136.4 | 70.6 | 60.3 | 58.0 | 30.2 |
### 2.3 Daily rainfall analysis

When the daily precipitation is less than 2mm/d, the rainfall is small, and the rainfall does not produce runoff due to vegetation interception, soil infiltration, and depression water storage. Combined with the precipitation intensity classification standard issued by the China National Meteorological Administration, the daily precipitation is divided into six grades, as shown in Table 3.

| Grade | downpour | torrential rain | heavy rain | moderate rain | light rain | less than 2mm |
|-------|----------|-----------------|------------|---------------|------------|---------------|
| 24Hourly precipitation (mm) | ≥100 | 50-99.9 | 25-49.9 | 10-24.9 | 2.1-9.9 | ≤2 |
| Cumulative days (d) | 13 | 101 | 303 | 813 | 1515 | 1722 |
| Annual average days (d) | 0.33 | 2.59 | 7.77 | 20.85 | 38.85 | 44.15 |

During the 39 years of statistics, the total precipitation days were 4467d, with 13 times of downpour, which were concentrated in May - September, among which the maximum daily rainfall was 238.4mm in 1984. There were 101 torrential rains and 35 in July; downpours and torrential rains only accounted for 2.6% of the total number of days of rainfall, while precipitation was 20.7% of the total rainfall. The proportions of various precipitation levels in the total precipitation of the year are shown in Figure 3. The frequency of heavy rain is shown in Figure 4.
3. Design rainfall depth calculation method

3.1 Calculation method based on the annual runoff total control rate

The total annual runoff control rate index refers to the proportion of the total annual controlled (not discharged) annual rainfall in the site through the natural and artificial enhanced infiltration, accumulation, utilization, evaporation, transpiration, and other methods. The “Technical Guide for Sponge City Construction” proposes a calculation method based on the design rainfall depth corresponding to the total annual runoff control rate. That is, according to the daily rainfall data of not less than 30 years, the precipitation of rainfall events less than or equal to 2 mm is deducted, the daily rainfall value is sorted according to the amount of rainfall from small to large, and the proportion of the total rainfall amount less than a certain rainfall depth in the total rainfall is calculated. If the rainfall is less than the depth, the total rainfall is calculated according to the actual rainfall. If it is
greater than the rainfall depth, just calculate the depth. The corresponding rainfall (daily value) of this ratio (annual total runoff control rate) is the designed rainfall depth[^3]. The design rainfall depth corresponding to different annual runoff control rates serves as an important basis for determining and decomposing the planning goals of sponge cities. The corresponding relationship between design rainfall depth and runoff control rate calculated based on daily rainfall data of Hefei in the past 39 years is shown in figure 5.

![Figure 5. Total runoff control rate design rainfall curve of Hefei City](image)

3.2 Calculation method based on the control rate of rainfall frequency

U.S. Energy Independence and Security Act (EISA) of section 438 put forward that stormwater management measures are implemented to the maximum extent technically feasible (METF) to maintain or restore the pre-development hydrology[^4]. It is proposed that Retain the 95th Percentile Rainfall Event in Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. The calculation method is to sort the daily precipitation data after removing data for small rainfall events that are 0.1 inch or less and snowfall events, and then calculate the percentage of rainfall events that are less than each ranked event[^5,6]. In order to be consistent with the data of runoff control rate, rainfall less than or equal to 2mm was deducted from the calculation of the control rate based on the number of fields in Hefei, as shown in figure 6.

![Figure 6. Total runoff control rate design rainfall curve of Hefei City](image)
4. Discussion on the calculation method of designed rainfall depth

The comparison between calculation methods of runoff control rate and field control rate is shown in figure 7 and table 4. Under the same control rate, the design rainfall depth calculated by rainfall frequency method is less than that controlled by the total runoff.

![Figure 7. Table Comparison of design rainfall depth between the total annual runoff control rate and frequency control rate in Hefei](image)

| Control rate | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A            | 6.9 | 8.1 | 9.6 | 11.3| 13.2| 15.5| 18.2| 21.6| 25.9| 31.8| 40.9| 56.8|
| B            | 6.5 | 7.6 | 8.7 | 9.8 | 11.1| 12.9| 15.0| 17.4| 20.6| 25.1| 32.0| 45.6|

Line A is the design rainfall depth (mm) corresponding to the annual runoff control rate; line B is the design rainfall depth (mm) corresponding to the frequency control rate.

The difference in the design rainfall depth is mainly due to the difference in daily rainfall levels. In the calculation model of total runoff control, it is possible to control the rainfall with a small rainfall level and the initial rainfall. The frequency of small rainfall is high, but the impact on the total runoff is small. The rainfall frequency from heavy rain to downpour is low, but it has great influence on the total runoff control rate. Under the calculation model of rainfall frequency control, the rain is fully controlled. Therefore, the control based on rainfall frequency is mainly affected by the number of medium and small rainfall frequency. The more the number of small-scale rainfall, the lower the designed rainfall depth.

According to the technical guide for sponge city construction, the mainland of China is roughly divided into five regions, and the lowest and highest limit values of total annual runoff control rate $\alpha$ in each region are given, i.e. region I ($85%<\alpha\leq90%$), region II ($80%<\alpha\leq85%$), region III ($75%<\alpha\leq85%$), Region IV ($70%<\alpha\leq85%$), region V ($60%<\alpha\leq85%$). Hefei belongs to region III of total annual runoff control rate. The total annual runoff control rate is $75%\leq\alpha\leq85%$. The notice of the General Office of the People's Government of Anhui Province on accelerating the construction of the sponge city proposed that $70%$ of the rainfall will be absorbed and utilized on the spot.

The green soil of Hefei city is mainly yellow brown soil and paddy soil, accounting for about $85%$; its structural characteristics are thick soil layer, compact and rigid structure, and water is difficult to penetrate downward, the soil infiltration rate is generally much lower than $1.27\text{cm/h}$. The test results of surface soil infiltration ability of green land in Hefei showed that the stable infiltration rate accounted for $21.1\%$ of the fast and faster grades, and $78.9\%$ of the medium and slow grades. Therefore, the total annual runoff control rate should not be too high on the basis of meeting relevant requirements.
In the process of construction and operation of sponge City, the two calculation models of design rainfall depth control the small-scale and initial rainfall, and the runoff control of large-scale rainfall is limited, in the case of heavy rainfall, the runoff coefficient of rainfall is much higher than the design value, and The rainfall in Hefei is mainly concentrated in summer (April - August), and heavy rainfall are also concentrated in this period. Therefore, in the design of rainwater pipes and channels, the parameters such as runoff coefficient should not be reduced even in the construction of sponge city.

Acknowledgments
Key Research Project of West Anhui University (WXZR201720)

Reference
[1] Ministry of Housing and Urban-Rural Construction of the People’s Republic of China. (2014) Sponge city construction technology guide: low impact development of rainwater system construction (trial version). China Architecture and Building Press, Beijing.

[2] China Meteorological data network. (2019) Daily data set of climate data of China surface international exchange station (V3.0). http://data.cma.cn/data/cdcdetail/dataCode/SURF_CLI_CHN_MUL_DAY_CES_V3.0.html

[3] Zhao J, Shen Z. (2017) Discussion on two rainfall control modes of sponge City. Journal of water conservancy, 48(12): 1490-1498.

[4] U S Environmental Protection Agency. (2009) Technical guidance for implementing the stormwater runoff requirements for federal projects under section 438 of the energy independence and security act of 2007. U S Environmental Protection Agency, Washington D.C.

[5] Shrestha, S., Fang, X., & Zech, W. C. (2013). What should be the 95th percentile rainfall event depths?. Journal of Irrigation and Drainage Engineering, 140(1), 1-5.

[6] Li Junqi. (2017) Technical guidance for stormwater runoff control in United States and its significance. Water resources protection, 33(2), 10-16+66.