The Effectiveness of the Rainwater Garden under Different Rainfall and Different Soil Conditions in Hangzhou, Zhejiang

H Q Zhang\textsuperscript{1, 2*}, M Q Shi\textsuperscript{3}, S P Qiu\textsuperscript{1, 2}, Z M Wang\textsuperscript{1, 2}

\textsuperscript{1}Zhejiang Institute of Hydraulics & Estuary, Hangzhou 310020, China
\textsuperscript{2}Zhejiang Institute of Marine Planning and Design, Hangzhou 310020, China
\textsuperscript{3}College of Harbor, Coastal and Offshore Engineering, Hohai University, Nanjing 210098, China

E-mail: zhanghangqing8@126.com

Abstract. At present, there are still problems in applicability and lack of basic research in the construction of sponge cities in Zhejiang Province. In this paper, a generalized model of the rainwater garden box is established. The planting soil, park soil and soil mixed with fine sand and coarse sand in Hangzhou area are selected as the rainwater garden medium layer. The artificial rainfall test method is used to simulate seepage and storage efficiency of rain garden under the once every two years rainfall and once every five years rainfall of Hangzhou city. The test results show that under the same soil conditions, the maximum infiltration flow rate under the once every two years rainfall is 0.2 cm\(^3\)/s more than that under the once every five years, and the maximum infiltration rate of planting soil has exceeded the maximum infiltration rate under the once every five years. Under the once every two years rainfall, the maximum infiltration flow of the planting soil, planting soil and fine sand are each composed of half, and planting soil and coarse sand are each composed of half are 2.1, 4.8 and 5.6 cm\(^3\)/s, respectively; the maximum infiltration flow of the the park soil, park soil and fine sand are each composed of half, and the park soil and coarse sand are each composed of half, are 0.7, 7.7 and 9.2 cm\(^3\)/s, respectively. At the same time, after adding fine sand, the infiltration amount increases by about 1/4 compared to before mixing; after adding coarse sand, the infiltration amount increases by about 1/3 compared to before mixing. It can be seen that the infiltration capacity of the park soil is much better than that of the planting soil after the sand-grain mixing ratio.

The results of this research can provide theoretical basis and technical reference for the construction of Hangzhou sponge city.

1. Introduction

In recent years, as the urbanization process continues to accelerate, the hydrological conditions of the original runoff confluence have been largely changed, and the general trend is to show increased confluence and frequent flooding. Sponge City proved to be able to effectively achieve multiple runoff rainwater control, reconstruct the city’s ecological structure, enrich the city’s functionality, and reduce the adverse effects of city development [1-4]. As a new type of ecological rainwater flood control and utilization facility, rainwater garden has the advantages of reducing urban rainwater runoff, purifying rainwater quality and recharging groundwater [5-9]. This form was first applied in Prince George County, Maryland, USA in the early 1990s. Later, this design concept was recognized by countries all over the world [10-12]. The measure was gradually implemented and further developed [13,14].
Since 2016, Zhejiang Province has required various new districts, parks, and development zones to fully implement the construction of sponge cities to solve the problems of urban water logging, rainwater collection and utilization, and black and odorous water treatment. As of the end of 2020, more than 25% of the urban built-up areas in Hangzhou have reached the sponge city construction target requirements. However, judging from the existing research results, the construction of the sponge city in Hangzhou still has the following problems: First, the design of the existing sponge city construction mainly refers to foreign experience, and there is insufficient analysis of the suitability of local construction, such as rainwater characteristics, physical properties of soil, etc. Second, Hangzhou is stepping up its pace to build a sponge city and does not pay much attention to basic research. How to determine the composition of the soil and how to design suitable LID facilities is a problem. Third, the selection of the parameters of the sponge city mathematical model usually relies on empirical values, and the lack of analysis of the model parameters of specific projects results in uncertainty in the simulation results. Therefore, this article takes the rain garden as the research object, and a generalized model of the rainwater garden box is established. The planting soil, park soil and soil mixed with fine sand and coarse sand in Hangzhou area are selected as the rainwater garden medium layer. The artificial rainfall test method is used to simulate seepage and storage efficiency of rain garden under the once every two years rainfall and once every five years rainfall of Hangzhou city.

2. Research method

2.1. Brief description of test model
The test model is divided into two parts, which is shown in Figure 1: rain machine and rain garden box model. The rainfall machine is composed of a water tank, an adjustable water pump, a simulated rainfall device, and a rainfall device bracket; the rainwater garden box model is composed of a box body, an aquifer, a cover layer, a growth medium layer, a filter layer, a water collector and a base. Among them, the cover layer, namely the vegetation layer, selects ophiopogon japonicus; the growth medium layer selects Hangzhou local soil, which is planting soil and park soil, respectively, and is matched with coarse sand and fine sand to obtain six different soil types, with a thickness of 50cm; 30cm block gravel pavement is used for the filtering water storage layer. The box model is designed in accordance with the standard requirements of the rain garden, and the aquifer above the covering layer is reserved for a height of 10cm. According to the rainfall intensity and rain pattern of this test, the maximum accumulated rainfall of the aquifer is about 7.2cm, the overflow of the aquifer cannot reach the outflow condition, and all the downstream seepage flows out through the drainage pipe under the box. The elevation of the drainage pipe is consistent with the elevation of the bottom of the filter layer.
2.2. Test group

2.2.1. Rain frequency test group. This study includes rain frequency test and soil proportion test. The rain frequency experiment group was tested by changing the rain return period. At this time, the growth medium layer in the box was planting soil. The rainfall process of this rain frequency experiment is as follows.

According to the notice issued by the Zhejiang Provincial Department of Construction on the rainstorm intensity formulas of various cities in Zhejiang Province, the Hangzhou rainstorm intensity formula uses the annual maximum method to select samples, the specific form is as follows:

\[
i = \frac{57.694 + 53.476 \log P}{(t + 31.546)^{1.008}}
\]

In the formula, \(i\) is design storm intensity, \(t\) is rainfall duration, \(P\) is design return period. Based on the formula of rainstorm intensity, the rainfall of Hangzhou City is calculated to be 56mm in the return period of once every two years and 72mm in the recurrence period of once every five years. This article uses the short-term measured rainfall on July 21, 2015 as a typical rain pattern, and distributes the rainfall under the recurrence period of once every two years and once every five years. The recurring period of short-duration rainstorm in Hangzhou area once every two years and once every five years is shown in Figure 2.
Figure 2. The recurring period of short-duration rainstorm in Hangzhou area once every two years and once every five years.

2.2.2. soil proportion test group. The soil proportioning group was tested by the soil and sand mixing proportion. At this time, the rainfall process was rainfall once every two years. This soil proportioning test includes single soil group and mixed soil group, as shown in Table 1. Among them, the single soil group includes the planting soil group and the park soil group, which totals two groups. In the mixed soil group, half of the soil in a single soil group is replaced with fine sand or coarse sand, for a total of four groups.

| Test number | Rain return period | Growth medium (Ratio)          |
|-------------|--------------------|--------------------------------|
| A1          | Once every two years| Planting soil                  |
| A2          |                     | Park soil                      |
| A3          |                     | Planting soil and Fine sand (1:1) |
| A4          |                     | Park soil and Fine sand (1:1)   |
| A5          |                     | Planting soil and coarse sand (1:1) |
| A6          |                     | Park soil and coarse sand (1:1) |

2.3. Text steps
This test consists of 8 steps, which are as follows: (1) Fill the bottom of the box with 30cm pebbles as a filter layer; (2) Cover with geotextile above the filter layer;(3) Continue to fill in 50cm test soil as the growth medium layer; (4) Plant the test plants on the growth medium layer as a cover layer, and the plants will be cultivated for one week after being transplanted in situ;(5) Use an artificial rainfall machine to fully rain the box until the accumulation of water is at a certain height, and leave it overnight; (6) Carry out a rainfall test, using the artificial rainfall period to give the return period rainfall;(7) Use a water storage tank with a length of 50cm, a width of 15cm, and a height of 25cm to store water, and use a water level meter to read the water level;(8) Record the water level data and calculate the infiltration flow rate.

3. Analysis of test results

3.1. Soil grading test result
Before the test, the gradation test was carried out on the soils of the above six kinds of ratios. With more than 2mm, 0.075~0.5mm, 0.005~0.075mm and less than 0.005mm as the critical value of particle size, it is defined as four types of soil, namely gravel, sand, powder and clay, the results of six groups of soil grading tests are shown in Table 2. It can be seen from Table 2 that the proportion of clay and powder particles in the planting soil reached 53.4%, of which the powder content reached 41% and the sand content reached 37.3%. It can be seen that the planting soil belongs to the soil...
between fine grains and smaller coarse grains; compared with planting soil, the proportion of powder in the park soil has increased to 88%, while the proportion of sand has decreased to 4.7%. It can be seen that the park soil belongs to fine-grained soil; when half of the volume of a single soil body is replaced by fine sand, the proportion of sand in the planting soil and in the park soil increases, accounting for 67.3% and 53.9%, respectively. The particle size is mainly concentrated in 0.075–0.25mm, accounting for 53.6% and 52.2% respectively. It can be seen that the particle size of the fine sand to be replaced is mainly concentrated in the range of 0.075–0.25mm. Compared with the replacement of fine sand, after the replacement of coarse sand, the proportion of sand in the planting soil and park soil increased by 6.7% and 9.2%, respectively. The particle size is mainly concentrated in 0.25–0.5mm, accounting for 46.5% and 44.8% respectively. It can be seen that the particle size of the coarse sand to be replaced is mainly concentrated in 0.25–0.5mm.

Table 2. Particle analysis results of soil samples of various proportions.

| Sample number          | gravel  | sand    | Powder  | Clay    |
|------------------------|---------|---------|---------|---------|
|                        | 10~2mm  | 2~0.5mm | 0.5~0.25mm | 0.25~0.075mm | 0.075~0.005mm | <0.005 mm |
| Planting soil          | 9.3     | 8.9     | 10.9    | 17.5    | 41.4    | 12.0      |
| Park soil              | 0.2     | 0.1     | 0.5     | 4.1     | 88.0    | 7.1       |
| Planting soil and Fine sand | 5.9     | 6.2     | 7.5     | 53.6    | 19.7    | 7.1       |
| Planting soil and coarse sand | 3.4     | 10.6    | 46.5    | 16.9    | 15.5    | 7.1       |
| Park soil and Fine sand | 0.6     | 0.2     | 1.5     | 52.2    | 41.7    | 3.8       |
| Park soil and coarse sand | 2.3     | 7.3     | 44.8    | 11.0    | 30.8    | 3.8       |

3.2. Rain frequency test result

Process line of infiltration flow of rainwater garden box test in different rainfall recurrence periods is shown in Figure 3. It can be seen from Figure 3 that the infiltration flow curves under two rainfalls are basically in the same direction, divided into four stages. First, within 20 minutes to 60 minutes from the start of the experiment, the infiltration flow increased rapidly from 0 cm³/s to above 2 cm³/s. Second, during the period of 1 hour to 5 hours, the infiltration flow slowly decreased from the maximum value to about 1.5 cm³/s. Third, in the next 5 to 10 minutes, it quickly decreased to 0.3 cm³/s. Finally, slowly reduce to 0cm³/s. However, in the second and third stages mentioned above, there is a difference between the rain once every five years and the rain once every two years. In the second stage, the maximum infiltration flow rate of once every five years was 2.3 cm³/s, which was an increase of about 10% compared with the rainfall once every two years, but at this time the rainfall increased by more than 25%. It can be seen that the maximum infiltration capacity of the planting soil has been reached under once every five years rainfall; in the third stage, compared with once in two years rainfall, the infiltration process is extended by 30 minutes under once in five years rainfall. It can be seen that when the rainfall reaches the maximum infiltration rate, the aquifer has accumulated water and the soil infiltration has been saturated. As the rainfall decreases, the stagnant water also gradually decreases, and the amount of soil infiltration is finally the same as that under once in two years rainfall.
3.3. Soil proportion test result

Process flow line of seepage flow in rainwater garden box test with different proportions of soil samples is shown in Figure 4. It can be seen from Figure 4 that the maximum infiltration flow of planting soil and park soil under rainfall conditions of two years is 2.1 cm³/s and 0.7 cm³/s, respectively. The maximum infiltration flow after planting soil and park soil mixed with fine sand are 4.8 cm³/s and 7.7 cm³/s respectively. The maximum infiltration flow after planting soil and park soil mixed with coarse sand were 5.6 cm³/s and 9.2 cm³/s respectively. At the same time, in the single soil scheme, after the infiltration flow reaches the maximum value, there is a gentle process line, in which the planting soil is gentle for 3.5 hours, and the park soil is as long as 10 hours. The main reason is that the park soil is fine-grained soil, and the planting soil contains a lot of sand, so the planting soil has a greater infiltration capacity. When the planting soil and the park soil are mixed with fine sand or coarse sand, the original smooth infiltration process curve becomes a sudden change curve, that is, when the infiltration flow reaches the maximum, the infiltration flow decreases to 1 cm³/s or less after 0.5 to 1 hour. Compared with fine sand, the abrupt curve of coarse sand is thinner and taller, that is, it drops below 1 cm³/s in a shorter time. It can be seen that after adding fine sand or coarse sand, the planting soil accounts for a larger amount of clay particles, and the infiltration capacity of the planting soil is smaller than the sandy soil of the park soil at this time. By calculating the area enclosed by the infiltration flow process line and the time axis, it can be obtained: after adding fine sand, the infiltration amount increases by about 1/4 compared to before mixing; after adding coarse sand, the infiltration amount increases by about 1/3 compared to before mixing. It can be seen that when the same kind of soil is mixed into sand, the infiltration capacity of the coarse sand is greater than that of the fine sand.
Figure 4. Process flow line of seepage flow in rainwater garden box test with different proportions of soil samples.

4. Acknowledgment
This experiment was supported by the Dean's Fund of Zhejiang Institute of Hydraulics & Estuary. At the same time, it was supported and helped by Hao Xinyu and Wang Yong of Zhejiang Urban and Rural Planning Design Institute Co., Ltd. Thank you here.

5. Conclusions
Based on the preliminary study of rainfall and underlying surface in Hangzhou area, by constructing a rainwater garden geotechnical model, the effectiveness of the rainwater garden under different rainfall and different soil conditions is discussed. The results show that: Under the same rainfall, the maximum infiltration flow of the plant soil is greater than that of the park soil. Under the same soil condition, the maximum infiltration flow once every five years is greater than the maximum infiltration flow once every two years. When the two kinds of soil and sand are mixed in the same proportion, the maximum infiltration flow of the park soil is greater than that of the plant soil. The experimental results in this paper can provide a reference for the design of rainwater gardens in Hangzhou area and similar areas of hydrology and geology.

References
[1] Zhang L, Oyake Y, Morimoto Y, Niwa H and Shibata S 2019 Rainwater storage/infiltration function of rain gardens for management of urban storm runoff in japan Landscape and Ecological Engineering 15 421-35
[2] An K J, Lam Y F, Hao S, Morakinyo T E and Furumai H 2015 Multi-purpose rainwater harvesting for water resource recovery and the cooling effect Water Research 86 116-21
[3] Campisano A and Lupia F 2017 A dimensionless approach for the urban-scale evaluation of domestic rainwater harvesting systems for toilet flushing and garden irrigation Urban Water Journal 14 883-91
[4] Ghimire S and Johnston J 2017 A modified eco-efficiency framework and methodology for advancing the state of practice of sustainability analysis as applied to green infrastructure. Integrated Environmental Assessment and Management 13 821-31
[5] Gao Y, Fan R, Li H, Liu R, Lin X, Guo H and Gao Y 2016 Thermal performance improvement of a horizontal ground-coupled heat exchanger by rainwater harvest Energy & Buildings 110 302-313
[6] Basdeki A, Katsifarakis L and Katsifarakis K L 2016 Rain gardens as integral parts of urban sewage systems—a case study in Thessaloniki, Greece Procedia Engineering 162 426-32
[7] Slyš D and Stec A 2020 Centralized or decentralized rainwater harvesting systems: A case study Resources (Basel) 9 5
[8] Liuzzo L, Notaro V and Freni G 2016 A reliability analysis of a rainfall harvesting system in southern Italy Water (Basel) 8 18
[9] Boogaard F, Kluck J, Bosscher M and Schoof G 2017 Flood model Bergen Norway and the need for (sub-)surface INnovations for eXtreme climatic EventS (INXCES) Procedia Engineering 209 56-60
[10] Chubaka C E, Whiley H, Edwards J W and Ross K E 2018 A review of roof harvested rainwater in Australia Journal of Environmental and Public Health 2018 1-14
[11] Miao Z, Han M, and Hashemi S 2019 The effect of successive low-impact development rainwater systems on peak flow reduction in residential areas of Shizhuang, China Environmental Earth Sciences 78 1-12
[12] Kelly D 2018 Impact of paved front gardens on current and future urban flooding Journal of Flood Risk Management 11 S434-S443
[13] Angelakis A, Antoniou G, Voudouris K, Kazakis N, Dalezios N and Dercas N 2020 History of floods in Greece: Causes and measures for protection Natural Hazards 101 833-52
[14] Behzadian K, Behzadian K, Kapelan Z, Kapelan Z, Mousavi S J, Mousavi S J and Alani A 2018 Can smart rainwater harvesting schemes result in the improved performance of integrated urban water systems? Environmental Science and Pollution Research 25 19271-82