Strategies of Flood Control and Water Logging in the Forbidden City and Enlightenments on the Treatment of the Modern Cities’ Water logging

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Abstract: With the climate change and acceleration of urbanization, there has been a growing tendency in the frequency, the scope as well as the losses caused by city water logging, which undoubtedly challenge city’s safety. With a history of more than 600 years, the drainage system in the Forbidden City successfully resisted the 2012 Beijing 100-year extreme rainstorm and there was no water logging in the whole city, which offers certain reference for the flood control and water logging of modern cities. This article analyzes the causes of the modern city water logging and explores the engineering and non-engineering measures of the drainage system in Beijing (including the operational mechanism, the overall project layout strategy, as well as the maintenance and management model) and the systems of point-line-plane, the surface and underground three-dimensional drainage and water storage project. Finally, based on the enlightenment of the drainage system in the Forbidden City and theories of urban water circulation, the article, from the perspective of city security, proposes a three-dimensional system responding to climate changes and a water logging construction model of low impact health cities. The possible development of city water logging in the future is also predicted.

1. Introduction

The climate change and human activities have changed the natural process of water cycle, affected the patterns of rainfall and runoff generation and confluence, and presented new requirements for the city flood protection and water logging drainage. Urbanization is a typical activity for mankind to change the natural environment. The enhancement of anthropogenic heat caused by air conditioners and automobile exhaust as well as the rise of temperature in the context of climate change leads to increasing thickness of the thermal current in the sky, precipitation surge, prominence of the rain inland effect [1-3], increase of storm frequency and intensity, which is in turn changing the features of urban water logging. Meanwhile, in the past city water logging was concentrated in the south, but now it gradually tends to happen in the north.

In recent years, many cities in China have suffered from water logging disasters to varying degrees. The research of 351 cities in the 32 provinces indicates that 213 cities experienced different levels of water logging between 2008 and 2010, which account for 62% of all the cities being investigated [1]. Among all the disasters, the most serious one was the Beijing July 21 rainstorm in 2012. The average precipitation was 170mm. The affected population of the city was 1,192,800, among whom 77 died. The direct economic losses caused by this flood reached 11,835,000,000 yuan. Under the dual influences of climate change and aggravation of human activities, the frequencies of city water
logging have been increasing and the damages caused by extreme climate will become worse. City water logging has been considered as the first natural disaster in the world, the other being agricultural drought. It is quite urgent to improve the prevention and responding models of the current water logging.

The construction of the Forbidden City started in the fourth year of Yongle (1406) and finished in the 18th year of Yongle (1420). With a total area of 724,250 square meters, it survived the 2012 Beijing 100-year extreme rainstorm. Since it was built, there has been no large ponding area. The drainage idea of the Forbidden City made full use of the original conditions and terrain characteristics, designed a complete layout and comprehensive plan containing the upper (the overground), the middle (surface) and the lower (underground) parts, and then gradually finished the construction from underground to overground. A thorough analysis of the water logging treatment strategies of the Forbidden City can provide modern cities with some references of water logging manipulation.

This article explores the Forbidden City’s design theories and water logging system, studies the engineering and non-engineering measures of the drainage system in the Forbidden City, which include the operational mechanisms, the flood-prevention strategies and the management and maintenance models. In view of case studies of the drainage system and the theory of healthy cities water circulation, the article puts forward a flood control and water logging technology system which can cope with the climate changes in the healthy cities, proposes some security measures and management idea in relation to flood prevention, discusses the directions and outlets of city flood control in the period, all of which will promote the harmonious relationship between human and nature.

2. Flood control and drainage strategies of the Forbidden City

2.1 Overview of the drainage system in the Forbidden City
The floor planning of the Forbidden City makes full use of the terrain conditions which are lower in the south and higher in the north. The three defensive lines, which are set up outside the Forbidden City based on the natural slope and the planning gradient, constitute the comprehensive drainage system. The first defensive line consists of the Ming Moat, the Daming River and the Taiping Lake. The second one includes the Taiye Pool in the west garden and Houhai. And the Outer Jinshui River and Tongzi River (the Forbidden City Moat) are the third defensive line. These rivers and lakes are always used in urban water supply, but they also can be used for drainage in the flood seasons, ensuring that large amount of rainwater and torrential flood won’t flow into the city. Composed of the surface and underground drainage systems on a micro level, the courtyards of the Forbidden City divide the city into different catchment units, ensuring the drop slopes of the flows. The north-south passes in the center of the yards, whose sections resemble the “backs of bears” (that is, the north-south road sections in the yards are normally higher in the middle but lower in the two sides), form the divides of courtyards. In the rain seasons, part of the rainwater firstly flows into the open drains which surround the houses, and the east-west tributaries are collected in the dry ditches. After flowing into the Inland Jinshui River, they feed into the Forbidden City Moat and finally flow into Houhai. Meanwhile, another part of the rainwater infiltrates the soil and the underground culverts through the pervious surface and trapezoidal bricks, which take full advantage of the flood. The overall layout of the drainage system in the Forbidden City is shown in Fig. 1.
2.2 Strategies of surface drainage

(1) To follow the geomorphological characteristics of regions

Beijing is located north to the Yanshan Mountain and east to the Bohai Sea. The terrain features are high in the northwest and low in the southeast, and the rivers flow from east to south. The architectural patterns inside and outside the Forbidden City and the flood control and drainage system follow the geomorphological characteristics. The ground elevation of the Shenwu Gate to the north and the Meridian Gate to the south is 46.05 meters and 44.28 meters respectively, with a difference about 2 meters. The east-west rainwater runs into the dry ditches in the north and the south and then flows into the Inland Jinshui River.

(2) To divide the Forbidden City into different catchment units

The walls inside the Forbidden City divide the Imperial Palace into more than 90 courtyards. Inside the yards, the north-south passes become the divides of catchment units. In the process of precipitation, the Imperial Palace is divided into different catchment units via the buildings and the divides, which achieves the function of breaking the whole into parts.

(3) To combine the urban and regional water circle and keep the integrity of water system

After the rain falls, via the drainage ditches and the underground storage system and by making use of the terrain (higher in the north but lower in the south), it flows into the culverts and finally goes to the Inland Jinshui River. The underground channels in the Forbidden City are highly developed. The full length of channels and drainage pipes is 8km and 5km respectively. The Inland Jinshui River is the inland river of the Forbidden City, with a length of 2.1km. The water from the Inland Jinshui River flows out from the sluice in the south of the Donghua Gate and joins the water from the Outer Jinshui River. The rainwater eventually flows to the Inland Jinshui River through the tributary channels, which achieves the function of gathering parts into a whole. In the process of construction and development, the Forbidden City kept its original water system, which strengthens the regulation and storage capacity of floods without occupying the water surface area.

(4) Surface drainage system

On the east and west sides of the ground in every courtyard, there are many small holes carved out of ashlars. Since they resemble the copper coins in the Ming and Qing dynasties (which are carved into five holes, round in the outside and square in the center) and can let the water in, they are called “money eyes”. These money eyes are the entrances via which the rainwater flows from the surface to the underground channels (see Fig.2).
The "three big halls" of Supreme Harmony, Complete Harmony and Preserving Harmony are the most important buildings in the Forbidden City, with an area of 25,000 square meters. Surrounding the halls, there are openings for running off the water in the bottom of each white marble handrail. Under each baluster there is also an elegantly carved stone "dragon head", with a round hole in its mouth, which is also used for drainage (shown in Fig. 3). When it rains, the water is discharged from the 1142 "dragon heads". It flows successively into the yard and then is drained to the Jinshui River.

(5) Lay water pervious materials to enhance the infiltration capability of surface water

As is shown in Fig.4, the materials used for laying the ground mostly are inverted trapezoidal grey bricks. The grey bricks are water pervious sand there are grooves at the bottom to carry water into the sewer, which are used for drainage. The laying of water pervious materials leads to an increase of water infiltration volume; therefore, the capacity that soil regulates and stores the water resources fortifies. There are two kinds of grey bricks. One kind of bricks have compact layer on the surface and are laid in the northwest of the city. Another kind is smaller, with a lot of holes in it, and absorbs water easily. They are laid in the south of the city, which reduces the ground evaporation.

2.3 Strategies of water conservation

A large number of turfs, arbors, bushes and trees are planted in the imperial harem, which increase the water retention of soil. The vegetation changes the physical and chemical properties of soil, which reduces its bulk density, increases its porosity and enhances its permeability and its anti-scourability and anti-erosibility. Meanwhile, the consolidation of plant roots and plants’ resistance to water increase the resistance of water movement, retard the flow rate, boost the infiltration and weaken the flows’ erosion of the surface.

2.4 Underground strategies

(1) To lay underground culverts and wells for the water storage in rain seasons and supplements to underground water in dry seasons
The other important facilities underground are infiltration-drainage culverts and wells. Buried deeply, their walls and bottoms are built with the grey bricks. During droughts, the water stored in the culverts and wells seeps into the soil, enhancing the water content of soil; when it rains, the underground water permeates through the culverts and wells, which not only makes full use of the flood resource, but also benefits the interchange of the stored water and underground water in the culverts, which can improve the surface soil temperature and are helpful to vegetation growth (see Fig. 5).

(2) Well-developed underground drainage network
The underground drainage network is advanced. The drainage pipes are everywhere under the Imperial Palace, with a full length of about 8km. The sections are reasonably designed, fully ensuring the normal operation of the drainage system.

2.5 Operation-management-maintenance modes
The drainage trenches in the Forbidden City in Qing dynasty were governed by the Edile of the Imperial Household Department, excavated and dredged by the soldiers from the three banners, that is, the Plain Yellow, the Bordered Yellow and the Plain White. In Ming and Qing dynasties, it was stipulated that trenches in the palace should be dredged on time every spring in order to make them function in good condition.

Fig. 5 Diagram of culverts
When designing the Forbidden City, the designers not only considered the way of draining off water, but also made full use of the water resources and combined storage with drainage in order to keep the healthy development of the ecosystem. The drainage system is intricate and scientific. By combining point (money eye drainage, dragon head drainage and well drainage), lines (trench and culvert drainage) and planes (lake and pond drainage), blending surface drainage, underground drainage and storage facilities, and utilizing the terrain (higher in the north but lower in the south), the water is drained into the culverts and finally goes to the Inland Jinshui River. The intricate water cycle pattern and rigorous management-maintenance system assure that there has been no large area of waterlogging in the past 600 years.

3. Conclusions
The Forbidden City is the largest, most majestic and most complete imperial complex remaining in the world, which can be considered as natural cultural relics and its drainage system is a miracle in the history of hydraulic engineering in China. As a model of the urban drainage system and crucial guarantee of city safely, the Forbidden City is a mirror of the drainage system for many cities in China and even in all over the world.

Urban construction should be planned scientifically. We should respect and conform to nature,
realizing the harmony between man and water and scientific development. Ponds, rivers, lakes and wet lands are important carriers of urban water storage and drainage, and they cannot be occupied and buried at will. We should gradually change the ways of excessively hardening the city surface, improve the greenbelt, gravel, pervious and natural ground surface capability of absorbing the rainfall, and utilize the detention and storage function of the elements such as pervious ground surface, pervious bricks and green lands. Through retaining the natural “exhaling” function of soil evaporation, plant transpiration and water surface evaporation, and improving the “inhaling” function of water bodies such as soil and lakes, cities can breathe freely. Besides, regular dredging and maintenance of drainage pipes, channels and lakes can make sure the free flow of water bodies in the “blood vessels”, which keep the cities healthy. By decreasing the rainfall runoff and increasing accumulation infiltration volume as well as combining the small and separate rainwater storage facilities into systematic water cycling space, the ecological functions of the urban rainwater and water system can be brought into play comprehensively and the mutual transformation of urban “resource water-flood-environmental water” can be achieved, therefore, the urban water logging problem can be resolved from its origin.

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