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Review Article

The Causes of Floods and Control Measures during the Rainstorm Period in Cities with Flat Terrain

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Abstract: In the process of rapid urban expansion, flooding has become a common problem in cities with flat terrain. This is due to the high volume and intensity of rainstorms, which has exceeded the drainage capacity of the existing municipal rainwater channels. Proposal has been made to divide large-area drainage into small-area drainage, disperse the discharge and add a self-controlled drainage pump to solve the problem of internal defects of the old city. At the same time, the new urban area will establish different rainstorm return periods according to the level of the road, build large underground storage tanks and rainwater pumping stations, and combine the newly proposed sponge city construction theory and deep water storage technology to retain and use part of the rainwater. At the same time, the siltation of dredged rivers and lakes will be increased and regional flood scientific dispatch during heavy rains will be implemented to improve the city's ability to resist heavy rains.

Keywords: *Urban flooding, rainwater pipes, rainwater pumping stations, sponge cities, deep water storage.*

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1 The grim situation of urban flood

In recent years, with the rapid expansion of cities in the world, many large cities, especially large cities with flat terrain, will suffer from varying degrees of flood during heavy rains in summer and autumn, leading to a "sea view" mode in cities, Figure 1.

Figure 1. The "sea view" mode during the rainy season

Flooding causes serious natural disasters such as traffic congestion in urban areas, stalling of vehicles, flooding in shops, basement parking lot and garages, subway stations, and construction sites as well as road collapses (Figure 2), posing a huge threat to the safe operation of the entire city, causing significant economic losses and social impacts, severely hampering the development of every aspects in the city and the daily life of the citizens, as well as the safety of life and property.

Figure 2. Flooding in basement parking lot

Judging from the development momentum of the current urban flood, if the problem of urban flood is not resolved effectively, it will directly threaten the underground railways, underground air raid shelters, underground shopping malls, underground tunnels, underground garages, underground pipe corridors that many large cities are building. The safety issues will become more severe and obvious with the never-ending city expansion. Therefore, in-depth discussion of the causes of urban flooding and effective control and preventive measures have become an insurmountable major technical problem and major livelihood issue in urban infrastructure construction.

2 The causes of urban flooding

Over the years, the author has been engaged in the design of water supply and drainage pipe network in municipal and residential areas. Author has the privilege to access the materials pertaining to municipal water supply and drainage design of some large and medium-sized cities such as Shenzhen, Guangzhou, Xuzhou, Wuhan, Zhengzhou and Sanmenxia, and to perform field survey, data collection and consolidation in these regions. In addition to heavy rain caused by extreme weather and high intensity and volume of rainfalls, there is a direct correlation between the following innate shortcomings of the construction of rainwater drainage systems in these cities.

2.1 The section of the rainwater pipe is too small

In the design, many urban districts, especially the old urban rainwater canals are too small. The experience shows that the rainwater dry tubes on both sides of the road have exceeded the diameter of the municipal rainwater main tube, which cannot accept the rain water accumulated on the both sides of the road and rain water received from the upstream. This huge amount of water cannot be easily eliminated in time if the city is affected by heavy rainstorms.

2.2 The gradient of the rainwater pipe is too small

In order to reduce daily operation and management costs, many cities have designed rainwater pipelines based on the principle of gravity drainage (self-flowing) to get rid of water into downstream rivers and canals. Due to the water level limitation of downstream discharge channels and main canals, the depth and drainage gradient of the pipes are reduced. The slope of the rainwater pipe design is basically determined along the road surface. The gradient of many pipe sections is very much lower than the minimum drainage gradient (0.002~0.003) as required by the regulations. As a result, the gaps of the upstream and downstream pipes become too small, leading to sluggish drainage and low water passing capacity. The underground rainwater pipe is essentially an underground storage pipe, causing the deposition of dirt on dry days. Slops emerge from the rainwater inspection wells and gutter strainer due to upstream water pressure and water being pushed from downstream on rainy days, as shown in Figure 3. Thus, water cannot be removed easily during rainstorms.

Figure 3. Slops emerging out of rainwater inspection well and gutter strainer due to upstream water pressure and water being pushed from downstream

2.3 The section shape of the rainwater pipe is unreasonable

At present, the rainwater pipes buried beneath the municipal roads in many cities, especially the old cities, adopt flat-bottomed drain pipe with rectangular cross-section and very small slope. Thus, the flow rate of water in the rainy or dry season is very slow, and the self-cleansing velocity of the pipeline is not reached (≥0.6 to 0.75m/s). This not only causes the pipe channel to be blocked and reduces the flow area of the pipe and the channel, but also floods the road with the rainwater during the rainstorm, which brings the filth and smell of the street after the rainstorm. The correct approach is to use a circular pipe or a pipe with a circular flow channel at the bottom to

increase the drainage flow rate during the dry season and prevent the deposition of dirt.

2.4 The rainwater pipes are not buried deep enough

The burial depth of municipal rainwater and sewage pipes must meet the prerequisites for the smooth discharge of rainwater and sewage from the municipal roads into the municipal drainage system. According to the data of some urban rainwater networks, the burial depth of municipal rainwater pipes does not meet this prerequisite of burial depth, but only the requirement to discharge rainwater on the municipal road surface is met. As a result, there will be no outlet for the rainwater in the communities on both sides of the road. The rainwater in the community will be discharged to the lower-lying urban roads, which will bring great pressure to the drainage of urban roads. In addition, the burial depth of the pipes is too small, and the ability of upstream and downstream water level adjustment is limited. It is easy to see the phenomenon as shown in Figure 4, that excessive rainwater emerging from the inspection well and gutter strainer in the middle and lower reaches.

Figure 4. Rainwater from the middle and lower reaches emerges from the inspection wells and rainwater rafters

2.5 There is a problem with water discharge

Whether it is urban or rural region, rainwater is generally discharged into the rivers, ditches, canals, ponds, moorings, and shoals in the surroundings, and the city mainly relies on rivers for purpose of water discharge. The rivers on the plains usually have artificially stacked river banks on both sides. The flow rate of rivers is slow, and the flow and water level are highly variable depending on the seasons. The water level is very low during dry days, and thus, water can be discharged using gravity drainage (self-flowing) even at the beginning of rainfall. During the rainstorm, the river water level rises sharply, and sometimes rises above the ground surface on both sides of urban area. Not only does it not function as a rainwater discharge in the urban area, but it also forms a backflow in the urban area through the rainwater pipe network. Since the river water does not retreat and water accumulation is difficult to get rid of through self-flowing, the occurrence of floods is inevitable[1].

2.6 Improper discharge measures

Many urban rainwater drainage pipe network systems adopt the concepts of gravity drainage (self-flowing discharge), reduced daily operation and lower maintenance costs. This is more suitable when the city is small, and it is not suitable when the city is rapidly expanding. The reason is that the runoff of rainwater will increase rapidly with the expansion of the city scale and the coverage of buildings, roads, plazas, etc. The ditches, canals, ponds and rafts that were used to store rainwater are filled and leveled up, built upon which are the buildings, roads and infrastructure in the process of urban expansion. As a result, the condition for rainwater adjustment is lost, causing a large amount of rainwater being discharged into nearby rivers in a short time. With this, the water level of rivers rises rapidly. It is far from the water level change and flood return period reflected by the hydrological data observed many years ago. Therefore, the use of large-scale rainwater gravity discharge systems in the plain areas when the city scales up will cause urban flood inevitably.

In view of the above drawbacks and problems, it is difficult to solve the innate problems in the old cities. This old urban rainwater discharge design standard and construction concept is still being used in the construction of some emerging cities (such as Shenzhen) and new urban districts. It will definitely endanger the construction and development of large- and medium-sized cities in the long run. Therefore, in the construction of municipal rainwater pipe network systems in emerging cities and new urban districts, we must take a long-term plan to overcome the above-mentioned technical inaccuracies caused by short-term behavior and non-scientific judgment and decision-making[2].

3 The preventive measures of urban flood

3.1 Reconstruction of the rainwater system in old cities

To increase the return period of heavy rain in the old city areas, it is necessary to increase the amount of rainwater discharge, increase the rainwater pipe diameter and increase the drainage gradient, but the problem is that many urban rainwater pipes are laid in the middle of each road. Large-scale reconstruction will cause immeasurable destructions not only measurable for traffics, but also for the operation of the entire city. Therefore, the main preventive measure or urban flood in old cities is to divide the rainwater gravity drainage system in a large area into a drainage system combining the rainwater self-flow and mechanical lifting in a small area[3]. The method is to divide the large regional pipe network into small regional pipe networks according to the existing rainwater pipe network system organization structure, so that the rainwater load in each region is not too large, and does not exceed the existing rainwater pipe channels. The flow capacity is used to solve the stubborn problems such as the existing rainwater pipe channel which has small cross section, slow drainage gradient, slow flow rate, and insufficient flow capacity.

The construction of the sub-division outlets on the bank of the nearest river should be disperse, so that rainwater can be discharged through the drainage outlet during the initial stage of rainfall, while water discharge can also be increased with the aid of drainage pump during the rainstorm. This would resolve a situation where the original self-flow discharge caused the failure to discharge or reverse flood during rainstorms. When the water level of the river water falls back below the warning level, the drain valve is automatically opened for self-flow discharge, and the drain pump is shut down.

Some key areas where water discharge is unachievable, water accumulation is frequent and are affected by serious losses and serious consequences of water accumulation can use large underground rainwater storage tanks, large-scale storage and deep culverts in squares, parks and roadside green spaces, and directly use mechanical drainage measures, and correspondingly increase the drainage rate and the return period of heavy rain.

3.2 Construction of the rainwater system in the new cities

The impact of heavy rain on the city is far from being a flood of a street, blocking traffic for a while, and losing a few shops. It has become the second largest natural disaster except earthquakes. Therefore, the premise and key to building a modern big city should be addressed first. For the construction of the new district, the ability of cities to resist heavy rain disasters is necessary to replace the old construction concept, i.e. building a large city with a big investment concept for the construction of municipal infrastructure. Thus, the small-scale, short-term behaviors and practices should be abandoned to avoid "the history is indebted to today, while today is indebted to tomorrow" (a Chinese proverb)[4].

For the mega-cities such as Beijing, Guangzhou, Xuzhou, Zhengzhou, and Shenzhen, it is necessary to establish different levels of rainstorm return periods, make principal roads and neighborhoods more resistant to heavy rain and rainstorms and build large rainwater pipe culverts and rainwater automatic lifting pumping stations under principal roads according to the level of urban roads and their impact on urban security. At the same time, the rainwater system and the sewage system should adopt the construction mode of the discharge system combining regional self-flow and mechanical lifting. Appropriate increase of investment and an increase in operation and maintenance costs in exchange during the construction period are necessary for the city's security during the rainstorm, in order to effectively prevent the occurrence of urban flood in successive years.

In addition, combined with urban development and construction, the concept of sponge city construction which has been promoted in recent years is adopted, and some technical measures for rainwater storage are adopted to reduce urban rainwater runoff, increase urban underground water storage capacity, and reduce rainwater discharge, as shown in Figure 5.

3.3 Treatment and dispatch of rainwater discharge water

Reinforcements and dredging measures are necessary to prevent flooding and dyke accidents from happening in view of the increase of urban rainwater discharge that should be reviewed in combination with the rainfall data observed in recent years, especially the hydrological observations on the rivers for discharging purpose, and the flow capacity of existing rivers. The concept of regional governance on rivers and lakes should be taken seriously. It is necessary to firmly establish the concept of "Yu Gong Yi Shan" to increase the intensity and

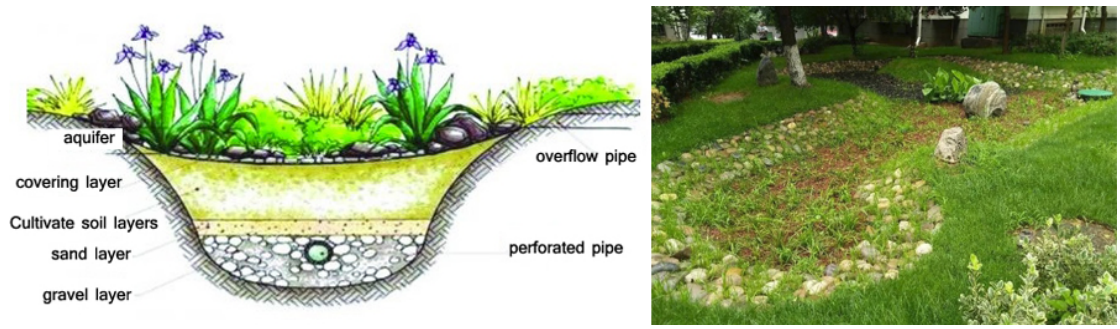

Figure 4. Rainwater from the middle and lower reaches emerges from the inspection wells and rainwater rafters

durability of rivers and lakes. It is necessary to raise this project to the national and urban strategic level and to treat it as a special area of environmental protection. We will also increase investment in science and technology, strengthen monitoring of rainstorms, establish early warning mechanisms and formulate emergency plans, set up special management agencies and teams, conduct integrated operation management and maintenance of rivers and lakes and urban drainage facilities, and strengthen river and lake dredging projects. During the rainstorm season, scientific regulation of regional flood control and flood diversion will be carried out in order to avoid frequent occurrences of heavy rain and flooding.

4 The conclusion

In recent years, the intensification of urban flood has attracted the attention of governments at all levels but with that embarrassments are inevitable in the face of this historical legacy. Some leaders with short-term behavior try to avoid this thorny problem. The key point is that they don't know much about the causes of urban flooding. Thus, they are unable to figure out scientific and rational governance programs and worried that such control measures do not achieve the expected results after corresponding labor and monetary expenditures. This article analyzes the causes of urban flooding from the perspective of water supply and drainage professionals, and devises urban internal control programs, for the reference of the city administrators, engineering and technical personnel at the decision-making level.

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