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Brief analysis on rainwater regulation and storage for pressure alleviation of municipal drainage system

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Abstract: Rainwater plays an important role in the improvement of the drainage performance while leaving the drainage network structure and capacity unchanged. Based on the comparison of rainwater storage performance in projected rainwater drainage systems, it shows that the rainwater storage facilities based on the current rainfall intensity computing formulation can improve the drainage system. The results show that the decentralized rainwater drainage network in municipal drainage helps to reduce the designed rainfall intensity capacity in the drainage network. Thus, the effect can be equal to increasing the rainfall duration in the rainwater drainage network design. Therefore, the rainwater storage facilities in decentralized networks optimize the rainwater drainage network in community rainwater drainage design. It also reduces the capacity of the drainage network and improves the safety of the municipal rainwater drainage system in residential areas.

Key words: urban waterlogging; rainwater regulation and storage; rainstorm intensity; rainstorm return period

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Rainwater runoff is the main rainwater source of the storm-water drains for most built up residential districts. Rainwater drainage is an important infrastructure in the urban construction, and it is one of the major infrastructures to be constructed in the early stage of urban development construction and it will become permanent underground construction after project completion[1]. Therefore, it is impossible to immediately improve urban storm sewers when the urban waterlogging becomes severe. The effective measure to relieve the pressure of the urban storm sewer is to reduce the water displacement from the residential district and postpone the rainwater entering time to the urban storm sewer.

Various measures have been taken by related municipal management authorities in many cities to install unequal-sized rainwater storage pools around different locations and drainage paths. The purpose is to regulate rainwater through the Peak shifting discharge method of stormwater runoff, and finally realize alleviation on pressure of urban drainage and waterlogging. Yet, after visiting these municipal management authorities, we have discovered that the construction of related facilities not matching the local rainfall intensity leads to an unsatisfactory function of the storage facilities.

Based on professional view on water supply and drainage, combining prevailing specifications, this study puts forward that rainwater regulation and storage plays an important role in alleviating municipal drainage pressure in the neighborhoods construction, and this study also summarizes the construction standard of rainwater storage facilities for the reference of design engineers in the fields.

1 Analysis on Reasons Causing Urban Waterlogging

The reason for urban waterlogging varies according to different conditions and we can summarize it as follows:

1) Failure of surface water being guided to be underground;

2) Failure of underground water to be drained off in a timely fashion.

In our opinions, urban waterlogging is generally caused by improper operation during one or more of the three-phases design, construction and management, in which design is the most important. Urban storm sewers applied very low design standards since the establishment of the People's Republic of China[2], i.e., a low standard and low flow calculation method is used in designing the recurrence intervals of rainstorms, and a low value is applied to safety coefficients in the computing method of flow calculation.

2 Function of Rainwater Regulation and Storage in Computational Formula of Prevailing Regulation

2.1 Water flow computational formula in prevailing regulation

Krakow, the expert of the former Soviet Union, first brought forward the calculation concept of rainwater drainage in which the pipeline volume is used to regulate and store rainwater. The theoretical basis is that the runoff of different design sections inside the storm sewer does not reach their maximum flow volume at the same time. As for pipelines designed according to the maximum volume of runoff, its cross-section of the passage-

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way will produce void volume inside the ditch. The calculation concept of using pipeline volume to regulate and store rainwater can help to reduce the designed flow. Krakow[3] took the storm formula as the basis and supposed that the probability of raining from heavy to light and from light to heavy is a half-and-half balance. Then he took a calculation method based on full pipeline filling time to reduce the design flow and gave the following formula:

$$Q = \frac{A}{t^n} F\Psi = \frac{AF\Psi}{(t_1 + mt_2)^n} \tag{1}$$

where Q is the designed discharge capacity of rainwater, L/s; F is the catchment area, hm^2; Ψ is the flow runoff coefficient; t_1 is the ground (roof) catchment time, min, and it varies on length, topographic slope and ground surface condition. Normally, the catchment time is from 5 to 10 min for outdoor ground, and 5 min for building roof. When the roof slope is larger and short time ponding will cause hazardous events, the value of actual catchment time should be used. When the calculation condition cannot be met, correction factor should be used for simplification; m is the coefficient of delay, normally $m = 2$; t_2 is the rainwater flow time in pipe and ditch; A and n are the local rainfall parameters[1].

Eq. (1) was used in Code for Design of Outdoors Wastewater Engineering in 1963 and it is now still in use[2]. According to the calculation formula of *Building Water Supply and Drainage Design Manual*[4],

$$Q = \frac{167kA(1 + c\lg P)F\Psi}{(t_1 + mt_2 + b)^n}$$

where k is the correction factor, normally $k = 1$. When the roof slope is so steep that short time ponding will cause hazardous events (for instance, roof gutter overflow entering indoor space), the factor will be 1.5. P is the designed recurrence interval. A, b, c and n are the local rainfall parameters[2,5].

2.2 Rainwater regulation and storage

The rainwater runoff calculation formula in the existing rules uses the ditch volume flood regulation method which reduces the design flow by increasing the calculation time of pipe flow (change t_2 to mt_2)[4]; and, therefore, for the secondary development district, it can effectively increase the calculation time of pipe flow and reduce the design flow of municipal storm sewers by setting up rainwater regulation and storage facilities before connecting the rainwater pipelines with municipal storm sewers within this district.

Tab. 1 reveals that in secondary development zones of 1 ha and according to storm formulae for different districts, rainwater regulation and storage facilities can be set before connecting the rainwater pipelines to municipal storm sewers within this district, and then the flow entering the municipal storm sewers can be calculated. The following conclusions can be drawn through Tab. 1:

1) The designed flow of municipal rainwater drainage pipes can be effectively reduced by setting rainwater regulation and storage facilities before connecting the rainwater drainage pipelines to municipal stormwater sewers within the secondary development district.

2) For the same district, the higher standard of rainwater regulation and storage facilities, the better it works in alleviating the municipal drainage pressure.

3) For the same rainwater storage, the smaller the intensity of storm, the better it works in alleviating the municipal drainage pressure.

In most cases, the rainwater drainage design standard for the secondary development zone and the planning design standard for the municipal rainwater pipe network are two independent systems. The rainwater drainage design standard of two-year or three-year recurrence interval will often be applied to the drainage design of the secondary development zones located in planned drainage standard of a one-year recurrence interval zone. Therefore, rainwater regulation and storage facilities shall be constructed in addition to improving the safety coefficients of rainwater drainage for projects inside the rainwater planned district of low design standard[6]. Taking Beijing as an example, the municipal storm sewer network with a one-year recurrence interval can accommodate drainage storm runoff for constructed project with a three-year recurrence interval and 20 mm rainfall capacity, and it can accommodate drainage storm runoff for the project with a five-year recurrence interval and 50 mm rainfall capacity. The municipal storm sewer network with a three-year recurrence interval can accommodate drainage storm runoff for a constructed project with a five-year recurrence interval and 20 mm rainfall capacity, and it can accommodate drainage storm runoff for a constructed project with a twenty-year recurrence interval and 50 mm rainfall capacity. The municipal storm sewer network with a ten-year recurrence interval can accommodate drainage storm runoff for a constructed project with a twenty-year recurrence interval and 20 mm rainfall capacity, and it can accommodate drainage storm runoff for a constructed project with a hundred-year recurrence interval and 50 mm rainfall capacity.

We have applied the above-mentioned method to optimize the drainage system in hot spring area of Beichuan new county district, Mianyang city, Sichuan province of China. The scale of construction of the rainwater discharge system has been reduced by 1/3, and its systemic function meets the requirements and design expectations in all major heavy rain ever since 2010; the function featuring rainwater regulation and storage facilities alleviating the drainage pressure has been proved in this case.

Moreover, rainwater regulation and storage facilities have now been introduced to many cities to address the grim situation of urban waterlogging[7-11].

Tab. 1 Relationship between rainwater regulation & storage facilities and their role of improving drainage capacity in different cities

Storm formula	$P=10$			$P=20$			$P=100$		
	$V=0$	$V=200$	$V=500$	$V=0$	$V=200$	$V=500$	$V=0$	$V=200$	$V=500$
Beijing $2\,001(1+0.811\lg P)/(t+8)^{0.711}$	339.0	273.7	216.6	384.7	317.6	256.0	490.9	420.6	350.4
Shanghai $2\,969(1+0.823\lg P)/(t+10.472)^{0.796}$	356.6	288.2	226.7	405.1	334.9	268.7	517.6	444.4	369.3
Guangzhou $2\,424.17(1+0.533\lg P)/(t+11)^{0.688}$	350.0	291.1	236.5	386.6	326.6	268.9	471.7	409.5	345.8
Chengdu $3\,360(1+0.663\lg P)/(t+18.768)^{0.784}$	317.6	263.2	211.8	355.7	300.2	245.6	444.2	386.7	326.0
Wuhan $983(1+0.65\lg P)/(t+4)^{0.56}$	273.6	217.4	172.9	306.0	248.2	200.2	381.4	320.5	265.4
Taiyuan $1\,446.22(1+0.867\lg P)/(t+5)^{0.796}$	208.3	140.5	97.3	237.4	166.5	118.1	305.0	228.5	169.4
Changchun $1\,600(1+0.8\lg P)/(t+5)^{0.76}$	249.4	180.1	130.9	282.8	210.9	156.5	360.3	283.6	219.0
Storm formula	$P=1$			$P=3$			$P=5$		
	$V=0$	$V=200$	$V=500$	$V=0$	$V=200$	$V=500$	$V=0$	$V=200$	$V=500$
Beijing $2\,001(1+0.811\lg P)/(t+8)^{0.711}$	187.2	131.9	95.2	259.6	198.5	150.9	293.3	230.2	178.3
Shanghai $2\,969(1+0.823\lg P)/(t+10.472)^{0.796}$	195.6	137.4	97.5	272.4	208.2	156.7	308.2	242.0	185.9
Guangzhou $2\,424.17(1+0.533\lg P)/(t+11)^{0.688}$	228.3	175.1	133.7	286.4	230.0	181.6	313.4	255.8	204.6
Chengdu $3\,360(1+0.663\lg P)/(t+18.768)^{0.784}$	191.0	142.7	105.7	251.4	199.6	154.9	279.5	226.5	178.7
Wuhan $983(1+0.65\lg P)/(t+4)^{0.56}$	165.8	117.9	88.1	217.2	164.7	127.3	241.2	186.9	146.3
Taiyuan $1\,446.22(1+0.867\lg P)/(t+5)^{0.796}$	111.6	59.7	37.1	157.7	96.8	63.9	179.2	115.1	77.6
Changchun $1\,600(1+0.8\lg P)/(t+5)^{0.76}$	138.6	83.0	54.6	191.5	128.1	89.0	216.1	149.9	106.3

Note: V is the effective volume of storage facilities, m^3; $F=10\,000\ m^2$; $\psi=1$; $t_1=10$ min; $t_2=10$ min.

3 Conclusion

Rainwater regulation and storage ponds in the secondary construction projects play a positive role in alleviating municipal storm sewer drainage pressure. It is also applicable to rainwater storage ponds which are built between upstream and downstream rainwater pipelines inside secondary constructed projects and it can reduce the scale of downstream rainwater drainage pipelines. The way has been effectively proved in the construction of the hot spring area of Beichuan new county district, Mianyang city, Sichuan province of China. It has not only reduced the construction scale of pipelines but also improved the safety coefficient of municipal pipelines. It is effective in controlling rainwater.

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结合规范浅析建筑小区内雨水调蓄对缓解市政排水压力的作用

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摘要: 为了在不改变排水管网路径和不加大排水管网规模的同时优化雨水排水系统的性能,提升排水系统能力,在排水管网路径中设置雨水调蓄设施. 通过梳理、比对雨水调蓄在实际工程中对雨水排水系统的优化应用,并通过列表对比在不同城市中雨水调蓄在现行的暴雨强度计算公式中对优化排水系统的改善作用. 结果表明:分散地在排水路径上设置雨水调蓄设施可以降低排水管网设计的暴雨强度,其效果等同于延长雨水排水管网设计中的降雨历时. 因此在建筑小区雨水排水管网设计时采用分散地在排水路径上设置雨水调蓄设施是优化系统的有效措施. 该做法既可降低建筑小区排水管网规模又可提高市政雨水排水的安全.

关键词: 城市内涝;雨水调蓄;暴雨强度;暴雨重现期

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