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Study on Hydrological Characteristics of Large Permeable Parking lot in Sponge City

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Abstract. Pervious pavement of large parking lot in sponge city is a new structural form, which is conducive to solving the problem of deterioration of urban ecological environment. The hydrological characteristics of large permeable parking lot are studied. The results show that the effect of large permeable parking lot on flow delay is obvious. No runoff occurs in the structure of large permeable parking lot when the maximum rainfall intensity reaches 0.968 mm/min. When the recurrence period increases from one year to 100 years, the percentage of total runoff reduction are 100%, 66%, 56%, 48%, 44%, and the peak flow reduction rate are 100%, 58%, 50%, 46%, 41%, respectively. With the extension of rainfall recurrence period, the total amount of runoff reduction in large permeable parking lots increased, and the reduction rate showed a downward trend. The research results can provide reference for the construction of large permeable parking lot in sponge city.

1. Introduction

According to the Ministry of Public Security Traffic Management Bureau data, China had 322 million motor vehicles until September 2018, 235 million of which were owned by vehicles and 184 million by private vehicles[1]. According to the international experience standard, the parking space of motor vehicles and parking spaces is 1:1.2-1.5, and the standard equivalent parking space is about 10m²[2]. As a result, the parking lot covers an area of more than 3,000 square kilometers. Due to the unreasonable urban planning and the blind pursuit of scale in urban construction, many urban ecological environment problems, such as urban pollution and deterioration of urban environment, have emerged at the same time. The most representative problems are heat island effect, urban waterlogging, poor air quality and serious noise pollution. These problems will directly reduce people's quality of life, and even cause harm to people's physical and mental health. In order to meet the load requirements, cement concrete and asphalt mixture are widely used in urban parking lots. These impervious materials blocked the pore of soil, and the material and energy flow between natural soil and atmosphere was cut off, resulting in huge differences between the ecological environment and the natural ecological environment of the city, causing difficulties in draining water in rainy days, leading to urban waterlogging, aggravating urban water environmental pollution, and deteriorating the urban living environment. The large permeable parking lot in sponge city can effectively solve these problems caused by the use of impervious pavement. It has the advantages of high load-bearing, high greening rate and high durability, which are lacking in the permeable pavement of ordinary small parking lot. At present, the study on the hydrological characteristics of permeable pavement has attracted the attention of scholars at home and abroad, and some progress has been made.



Hunt et al. tracked the North Carolina test site in the United States from 1999 to 2001. The results show that the runoff coefficient of the permeable pavement in the test site is 0.2-0.5[3]. Watanabe S. has done a lot of hydrological experiments on runoff control of permeable pavement in Yokohama, Japan. The results show that permeable pavement can reduce peak flow by 15-20%[4]. Fassman et al. monitored the permeable pavement of interlocking bricks in New Zealand in real time. The reachability of LID target applied in the test site was studied. Compared with the common impervious pavement, the average time lag of runoff generation on the surface of the permeable pavement was 2.4 hours, the peak flow of 18 rainfalls by 83% on average, and the peak flow of once-in-10-year rainfalls by 70%[5].

Zhao Fei, Zhang Shuhan and others used artificial rainfall simulation experiments to study the effect of permeable pavement area proportion on the overall structure of rainwater regulation ability. The results show that the porous structure of permeable pavement has good permeability and adsorption capacity for rainwater. The permeable pavement can reduce the total runoff by 30-80% and the peak flow by 7-70%[6]. Zhang Yuyu put forward a new type of permeable pavement technology, permeable concrete pavement with seepage guide pipe. The results show that the maximum reduction of peak flow of permeable concrete road with seepage guide pipe can reach 70%, and the reduction effect of peak flow is worse with the increase of recurrence period, and the reduction rate can still reach 56% at worst[7]. Wang Yao, Wan Yuqiu and others have proposed that pervious pavement structure can reduce surface runoff, increase pollutant reduction, improve urban water environment, beautify urban landscape, and optimize local microclimate of parking lot[8].

Generally speaking, although some studies on the hydrological characteristics of permeable pavement have been carried out at home and abroad, most of the current studies focus on the study of drainage pavement, involving less permeable parking lots, especially large parking lots which can withstand high-strength loads. Large-scale permeable parking lot plays an important role in solving urban ecological environment problems. The study of large-scale permeable parking lot will provide a positive reference for urban flood control.

2. Testing device and method

The large permeable parking lot in sponge city improves the water accumulation problem caused by the large area of rigid parking lot through the reinforced concrete permeable structure. While increasing the carrying capacity and prolonging the service life, it also improves the permeability of parking lot, and enlarges the green area of parking lot, which conforms to the concept of sponge city construction. Fifteen kinds of rainfall intensity were designed according to the formula of urban rainstorm intensity in Kunshan. The difference of hydrological characteristics between large-scale pervious parking lot structure and ordinary impervious structure was studied through self-designed artificial rainfall simulation device.

2.1. Artificial rainfall simulator

As shown in Fig. 1, the artificial rainfall simulator for the test consists of a water supply system and a rainwater generating system, which consists of a submersible pump and a water tank. The water supply system consists of 16 rainwater generators which can adjust direction and rainfall. Different types of sprinklers are combined to form different rainfall intensities. The sprinklers above the corresponding parking lot structure can provide uniform and stable rainfall covering the parking lot structure. The effective coverage of actual rainfall is 1m². In the artificial simulated rainfall test, the submersible pump in the water supply system absorbs water from the water tank, and the water flow is conveyed to the rainwater generator through the water supply pipe. The raindrops are generated by the small holes on the top of the rainwater generator and form artificial rainfall. After raindrops fall into the pervious parking lot structure model, they gradually infiltrate until seepage occurs. Finally, rainwater collectors are used to collect raindrops and carry out relevant experiments.



Fig 1. Artificial rainfall simulator

2.2. Structural simulation device for large permeable parking lot

The simulation device of large permeable parking lot is shown in Figure 2. The size is 630 mm *630 mm *600 mm and the thickness is 2 mm. The steel formwork is laid in accordance with the structural layer of the permeable parking lot. Among them, the bottom layer is 300 mm graded gravel base, the middle layer is 30 mm coarse sand leveling layer, and the top layer is 150 mm permeable surface layer. The bottom of each structural layer is provided with a water outlet on the side for experimental water intake. In order to ensure the permeability of the test device, uniform perforation was made at the bottom of the steel mould with a diameter of 15 mm. The bottom of the steel mould is paved with permeable cloth to prevent the base material from falling from the hole in the permeable parking lot.



Fig 2. Structure simulation device of permeable parking lot

2.3. Test method

The hydrological characteristics and laws of large permeable parking lot are mainly studied by comparing the structure of large-scale pervious parking lot with ordinary impervious parking lot. The advantages of the structure in hydrological characteristics are analyzed, and the characteristics of the large-scale pervious parking lot in runoff control are found and put forward. The control effects of the large-scale pervious parking lot in delaying runoff generation, reducing runoff and reducing peak flow are obtained. Through the analysis of the relationship between infiltration effect and rainfall intensity, the effect of reducing rainwater runoff in large permeable parking lot is determined.

The rainfall intensity was designed by using the formula of storm intensity of Kunshan(formula 1). The recurrence period of rainfall was 1 year, 10 years, 20 years, 50 years and 100 years, and the duration of rainfall was 30 minutes, 60 minutes and 120 minutes. The results of rainfall intensity calculation are shown in Table 1.

$$i = \frac{9.5336(1+0.5917\lg p)}{(t+5.9828)^{0.6383}} \quad (1)$$

Table 1. Rainfall intensity under different rainfall recurrence periods and duration (mm/min)

Rainfall duration /min	Recurrence period /a				
	1	10	20	50	100
30	0.968	1.541	1.714	1.942	2.114
60	0.658	1.047	1.164	1.319	1.436
120	0.435	0.693	0.770	0.873	0.950

3. Test results and analysis

3.1. Analysis of runoff time

Artificial rainfall simulator and large permeable parking lot structure simulator were used to simulate the runoff generation and confluence process of large permeable parking lot and common impervious structure under different rainfall conditions. The runoff generation time was recorded. Five different recurrence periods and three different rainfall duration were designed to fully simulate the actual situation of rainfall. The relationship between runoff generation time of large permeable parking lot and common impermeable structure with the recurrence period and rainfall duration was shown in the following figures.

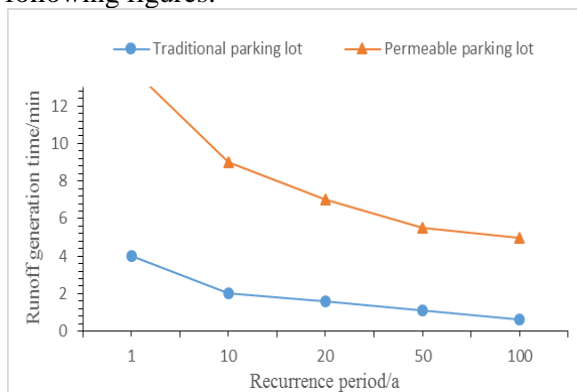


Fig 3. Characteristic chart of runoff yield of parking lot with rainfall time of 30 mins

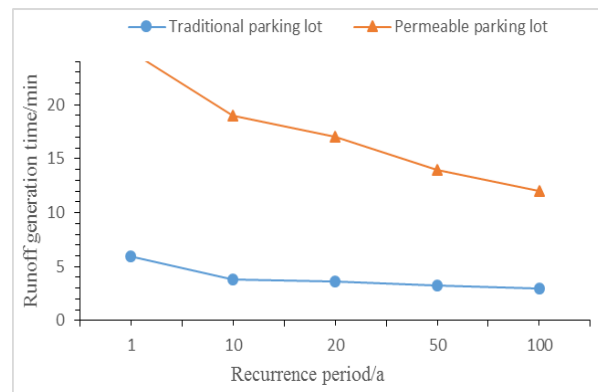


Fig 4. Characteristic chart of runoff yield of parking lot with rainfall time of 60 mins

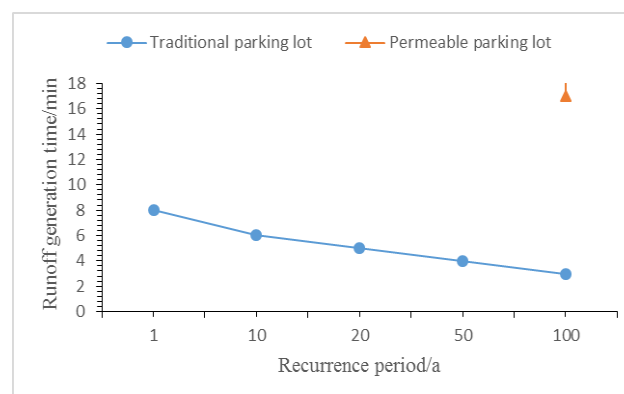


Fig 5. Characteristic chart of runoff yield of parking lot with rainfall time of 120 mins

According to the test results, large permeable parking lots have good runoff reduction effect. When the maximum rainfall intensity reaches 0.968 mm/min, the structure of permeable parking lot does not produce runoff. The runoff characteristics of permeable parking lot in 30 minutes and 60 minutes are the same. The runoff of parking lot structure only occurs in 120 minutes when the recurrence period is 100 years. Therefore, the experimental results of 30 minutes and 60 minutes of rainfall are selected for analysis. The test results show that the effect of delaying runoff yield of large permeable parking lot is

much better than that of ordinary impervious structure. Under the same recurrence period and rainfall duration, runoff occurs earlier in the ordinary impervious structure. Taking the 30-minute rainfall duration as an example, when the recurrence period is 1 year, no runoff will occur in large-scale permeable parking lots; when the recurrence period is 10 years, the formation of runoff in large-scale permeable parking lots will be delayed for 7 minutes compared with ordinary impervious structures; and when the recurrence period is 100 years, although the effect of runoff delay will decrease, it will still be delayed for 4.4 minutes. The main reasons are as follows:

When rainfall occurs, the parking lot surface quickly accumulates water and can not penetrate downward, because the surface layer of ordinary impervious structure does not have water permeability, so the runoff generation time appears earlier. The permeable structure layer of large-scale permeable parking lot has reserved permeable channels, and the planting materials with larger permeability coefficient are selected. Rainwater can penetrate downward through the gap between planting materials. The surface of large permeable parking lot is covered with plants, and the roots of plants have certain adsorption and water storage effects on rainwater.

3.2. Analysis of runoff reduction effect

The runoff reduction effect of the permeable parking lot is mainly evaluated by the total runoff reduction rate, peak flow reduction rate, peak-to-present time delay and other indicators. The variation of total runoff and runoff reduction rate with the recurrence period in large permeable parking lots is shown in figs. 6-9.

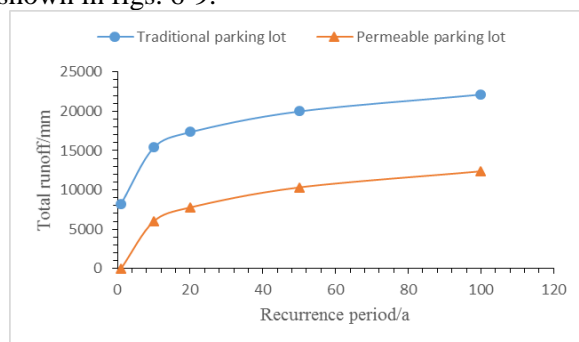


Fig 6. Parking lot runoff with rainfall duration of 30 minutes

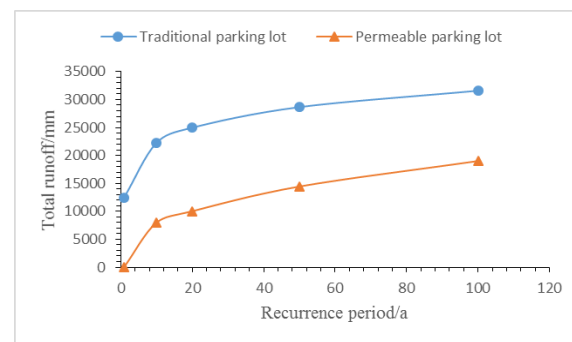


Fig 7. Parking lot runoff with rainfall duration of 60 minutes

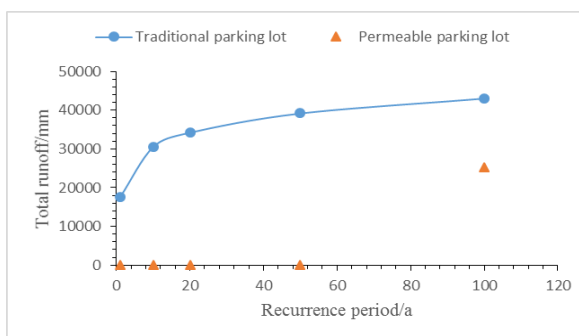


Fig 8. Parking lot runoff with rainfall duration of 120 minutes

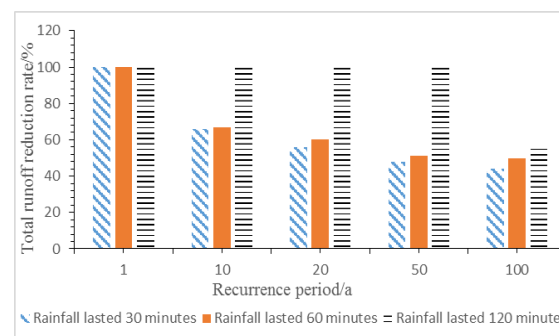


Fig 9. Reduction rate of runoff of permeable parking lot

From Table 2, it can be seen that the runoff reduction is infiltration in numerical value. With the increase of rainfall recurrence period, the infiltration of large permeable parking lots shows a rapid growth, and then gradually stable trend. The reason is that the retained rainwater in large permeable parking lots mainly depends on infiltration or material absorption to water. With the increase of rainfall intensity, the infiltration capacity of planting materials tends to saturate gradually. Therefore,

the steady infiltration of large permeable parking lots remains almost unchanged with the increase of rainfall intensity when the rainfall intensity is more than the 10-year recurrence period. The reduction rate of rainwater runoff in large permeable parking lots decreases with the increase of rainfall recurrence period. The relationship between seepage and runoff reduction rate and recurrence period of permeable parking structures is studied by selecting 30 minutes of rainfall duration, as shown in Fig. 10.

Table 2. The relationship between seepage, runoff reduction rate and recurrence period of permeable parking lot with 30 minutes rainfall

Recurrence period/a	Influent volume/mm	Infiltration rate/mm	Runoff/mm	Total runoff reduction rate/100%
1	12269	12269	0	100
10	19532	13533	5199	66
20	21725	13957	7368	56
50	24615	14312	10303	48
100	26795	14450	12345	44

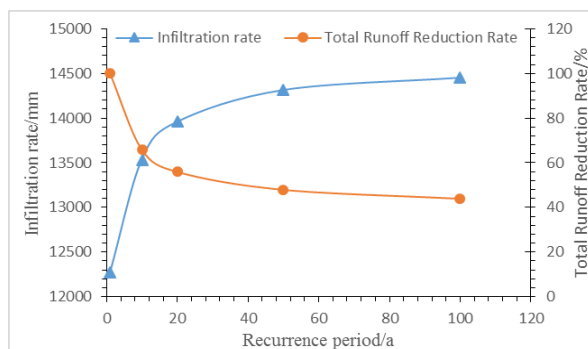


Fig 10. The relationship between seepage, runoff reduction rate and recurrence period in permeable parking lot

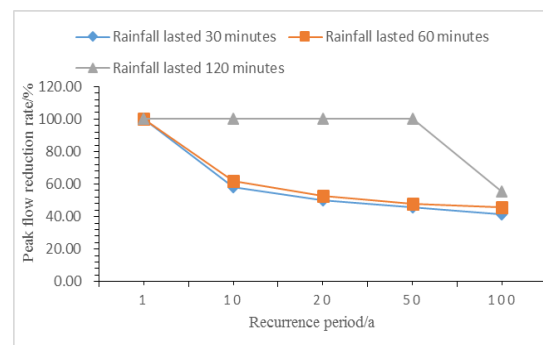


Fig 11. Peak flow reduction rate of pervious parking lot

In the process of increasing the recurrence period of rainfall from one year to 100 years, the percentage of total runoff reduction are 100%, 66%, 56%, 48% and 44%. This shows that with the increase of rainfall intensity, the amount of runoff reduction increases, the rainwater in large permeable parking lots is saturated, and more and more rainwater is discharged through surface overflow instead of infiltration.

As shown in Figure 11, the peak flow reduction rates of large permeable parking lots are 100%, 58%, 50%, 46% and 41%. Under the same rainfall duration, the peak flow reduction rates of large permeable parking lots gradually decrease with the increase of recurrence period. The reason is that with the increase of rainfall intensity, the seepage capacity of planting soil in the permeable area of large permeable parking lot is rapidly saturated, which ultimately leads to the decrease of flood peak reduction effect of large permeable parking lot structure.

Based on the peak-to-present time of common impervious parking lot structure, the peak-to-present delay effect of large pervious parking lot is studied. The test results are as follows.

Table 3 Analysis of peak-to-peak time delay in large permeable parking lots

Table 5 Analysis of peak-to-peak time delay in large permeable parking lots				
Recurrence period /a	Rainfall duration /min	Peak-to-peak time delay /min		
		30	60	120
1		/	/	/
10		6	15.8	/
20		4.3	13.9	/
50		3.2	11.8	/
100		3	10.4	16.3

In the experiments with repetition periods of 1a, 10a, 20a, 50A and 100a, the regularity of the delayed effect of large permeable parking lots on peak-to-peak time is consistent. Taking rainfall duration of 30 minutes as an example, the peak-to-peak time delays of large permeable parking lot structure are: no runoff, 6 minutes, 4.3 minutes, 3.2 minutes and 3 minutes, respectively. The structure of large permeable parking lot has a good effect on peak-to-present delay. With the increase of the recurrence period, the decrease of peak-to-present delay time gradually decreases.

4. Conclusions

This paper studies the hydrological characteristics of large-scale permeable parking lots, especially the impact on runoff delay and runoff reduction. The main contents include:

According to the formula of rainstorm intensity in Kunshan, fifteen kinds of rainfall conditions of artificial simulated rainfall test are designed. According to the hydrological test results, the delayed effect of runoff is positive in large permeable parking lots. When the maximum rainfall intensity reaches 0.968mm/min, the structure of large permeable parking lots is unproductive. Taking rainfall duration of 30 minutes as an example, when the recurrence period is 1 year, no runoff will occur in large permeable parking lots; when the recurrence period is 10 years, the formation of runoff in large permeable parking lots will be delayed by 7 minutes compared with that in ordinary impervious structures; and when the recurrence period is 100 years, although the effect of runoff delay will decrease, it will still be delayed by 4.4 minutes.

The steady infiltration of large permeable parking lots remains almost unchanged with the increase of rainfall intensity when the rainfall intensity is more than the 10-year recurrence period. The percentage of total runoff reduction are 100%, 66%, 56%, 48% and 44%. The total amount of rainfall runoff reduction of large permeable parking lot increases, and the reduction rate decreases with the increase of the recurrence period of rainfall.

The peak flow reduction rates of large permeable parking lot structure are 100%, 58%, 50%, 46% and 41%. Under the same rainfall duration, the peak flow reduction rate of large permeable parking lot decreases gradually with the increase of recurrence period.

Rainfall recurrence period is from 1 year to 100 years. Peak-to-peak time delay of large permeable parking lot structure is: no runoff, 6 minutes, 4.3 minutes, 3.2 minutes and 3 minutes, respectively. With the increase of rainfall recurrence period, the decrease of peak-to-peak delay of large permeable parking lot structure decreases gradually.

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