

# Urban permeable pavement system design based on “sponge city” concept

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**Abstract.** Based on the "sponge city" concept, to implement the goal of building a city within the city to solve the sponge waterlogging, rational utilization of water resources, reduce water pollution this paper, combined with the city planning level in China, establishes the design system of city road flooding from the macro, medium and micro level, explore the design method of city water permeable pavement system, and has a practical significance the lower flood risk water ecological problems. On the macro level, we established an urban pavement sponge system under the regional ecological pattern by “spot permeable open space – low impact developing rain water road system – catchment area and catchment wetland”. On a medium level, this paper proposed the permeable suitability of pavement and the planning control indicators when combined with urban functional districts to conduct permeable pavement roads plans and controls. On micro level, the paper studied sponge technology design of permeable pavement from road structure, surface material, and other aspects aimed at the pavement permeability requirements.

## 1. Introduction

The urbanization accelerated in recent years while the speed of the municipal facility construction in many cities is much further behind, causing many urban diseases. The waterlogging problem have especially become normal after heavy rain, seriously constraining urban development.

According to the 2010 research of Chinese 351 cities for three years during 2008-2010, 62% of the city incurred waterlogging events [1] and a series of problems, such as loss of rainwater resources, runoff pollution, flood risk, and so on. The city's hard impervious surface is one of the primary reasons causing waterlogging. Now the average area of impervious is 50% in our country, while in the megacities Beijing and Shanghai, the average impervious area reaches 71.3% [2], pavement waterproof, blocking the rain adding to groundwater, rainwater exclude poor aggravate the automobile exhaust pollution, rainwater drainage, evaporation increased dust pollution in the city, and hard surface absorbs heat to increase urban heat island effect.

Searching for a new method for storm water management is the fundamental approach to solving these problems [3]. In the 1990s, America proposed low impact development model (LID) based on urban ecology environment to realize the comprehensive management of storm water runoff control and rainwater exploitation. Based on this, China proposed the “Sponge city” theory in 2009, and the Ministry of Housing and Urban-Rural Development issued “Sponge City Guide-Low Impact Development System Construction” and ruled sponge city construction, which indicated permeable pavement being an important method. The permeable pavement refers to the use of good permeability materials on ground pavement, enhancing ground air and water permeability, and the natural rainwater

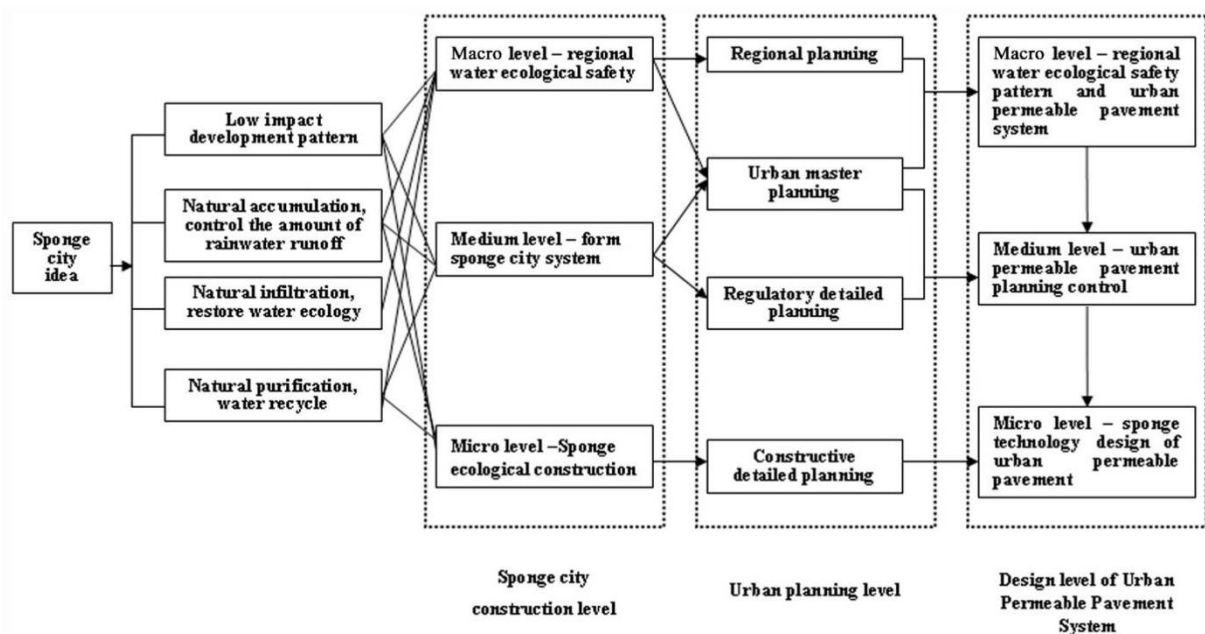


infiltration and purification. It has various functions to reduce surface runoff, relieve urban waterlogging, purify rainwater runoff pollution, improve river water quality, effectively supply groundwater, cooling, humidification, reduce noise, improve urban environment, restore soil ecological environment, promote biodiversity and more [2]; the permeable pavement is very significant for solving the urban waterlogging problem, improving urban environments, and promoting urbanization. At present, our country's primary study of permeable pavement focused on design, construction and other technical aspects [4-8]. It has less relation with urban planning, which led to the lack of systematic theoretical guidance and operational methods for permeable pavement construction. This paper is based on "Sponge city" theory combined with urban planning, and established urban permeable pavement design system. It has crucial realistic significance to implement the sponge city constructing target and solve waterlogging and ecological problems.

## 2. Sponge city concept

"Sponge city" theory was proposed based on low impact development rainwater exploitation model and water sensitive city planning theory; its essence is to realize the urban development coordinates and resources. By controlling rainwater runoff, natural accumulation, and peak regulation, the sponge city proposes low impact development to play regulation function to promote rainwater's natural infiltration, repair water circulation system, restore water ecology, and purify water quality by nature to solve water storage problem [9]. By infiltration, storage, purification and reuse, water circulation ecological balance between ecology and human is achieved.

Water ecological problems relate to basin problems, so sponge city should not only focus on inner city's water system regulation, rainwater processing, and site measures, but should also focus on basin and region issues and combine urban planning's scale and stage to study cross regional, scale urban planning, and construction based on water ecology (figure 1).



**Figure 1.** Sponge city concept combined with urban planning work.

On the macro level, sponge city mainly refers to the urban water system. The construction key is to study regional water ecological safety, establish safe patterns for the water ecological system by analyzing important locations and relationships of the system, implementing it into regional and urban planning, and gradually realize water ecology by controlling the space administration of region and urban construction. The system provides control objectives for urban annual runoff, gives clear low

impact development strategies and construction processes, and brings relative requirements into municipal projects planning.

On a medium level, sponge city primarily refers to urban areas where the construction key is effectively used in regional water systems. The urban master and regulatory planning is combined with urban pavement patterns to set watershed and catchment areas, form the sponge city system with spots, lines, and surface combinations, and satisfy functions like regional rainwater storage and regulations, purify the water quality, and protect water ecological wetlands.

On the micro level, sponge city primarily refers to the construction of some water catchment units like urban road, square, parking, and garden sites. The key problem of construction is the technical implementation of water ecological infrastructure, including the urban rainwater administration green sponge technique, human wetland water purification technique, water ecological restoration technique, permeable pavement design, construction technology, and so on [10]. By the construction of detailed planning and design and the use of modern technology, maximum develop the water ecological system's function to realize construction aims of sponge city.

Permeable pavement is used as the sponge city's measure of construction, which should integrate the concept into the entire urban planning and each step throughout the construction. It should follow the guidance of "regional systematic technology" and combine the permeable pavement design with urban planning working steps to establish an urban permeable pavement design system, and clear every steps' content of urban permeable pavement: on the macro level, systematic planning is based on regional water ecological patterns. On the medium level, planning control is combined with urban functional districts. On the micro level of permeable pavement, the sponge technology is designed.

### 3. Urban permeable pavement systematic composition

Urban pavement consists of road, square, parking lot, and urban site pavements. Each type has different water requirements due to different traffic quantities, and road loads directly impact the permeable pavement design (table 1). The quality of runoff road rainfall water has a relationship with geographical environment, nature of surrounding land, road grade, rainfall intensity, and rainfall duration [4], and the permeable requirements are also based on runoff water quality. According to China's current urban road classification standards and road characteristics, expressway, trunk road, logistics, and warehouse and car traffic, the industrial sites have a large amount of traffic volume, and rainwater quality is poor with serious pollution, therefore the permeable requirement is low. Secondary roads and parking lots have a large traffic volume, and the rainwater quality is general, so the road permeable requirement is high. Garden and green land have good rainwater quality, so the permeable requirement is high.

**Table 1.** Urban permeable pavement construction analysis.

Permeable pavement construction		Characteristics	Quality of rainwater analysis	Permeable requirement
Urban road surface	Express way	Large amount of traffic volume, high demands on road load	SS <sup>a</sup> : >1000 mg/L COD: >800 mg/L	Relatively low
	Main road	Large amount of traffic volume, high demands on road load	SS>1000 mg/L COD>800 mg/L	Low
	Secondary road	Large amount of traffic volume, high demands on road load	SS: 500-1000 mg/L COD <sup>b</sup> : 400-800 mg/L	General
	Branches	Small amount of traffic volume, low demands on road load	SS: 100-400 mg/L COD: 100-400 mg/L	Relatively high
Urban square,	Urban square	Pedestrian traffic, low demands on road load	SS: 100-200 mg/L COD: 100-200 mg/L	High

parking lot surface	Parking lot	Car traffic, high demands on road load	SS: 100-400 mg/L COD: 100-400 mg/L	General
Urban site surface	Urban garden, green space	Pedestrian traffic, low demands on road load	SS: <100 mg/L COD: <100 mg/L	High
	Other sites	Pedestrian and car traffic, general demands on road load (high demands on logistics warehouse, industry site)	SS: 100-200 mg/L COD: 100-200 mg/L	Relatively high (low demands on logistics warehouse, industry site)

<sup>a</sup>SS (Suspended Solids) refers to the content of suspended solids in water, including insoluble in water, inorganic matter, organic matter and mud sand, clay, microorganisms, etc., is one of the indicators to measure the degree of water pollution.

<sup>b</sup>Under certain conditions, COD (Chemical Oxygen Demand) refers to the chemical oxygen demand to take a certain strong oxidant treatment of water samples consumed by the amount of oxidation, often used as a measure of the amount of organic matter in water indicators. The bigger the COD, the more serious the pollution of organic matter.

#### 4. Multi scale urban permeable pavement system design on sponge city theory

##### 4.1. Macro level – regional water ecological safety pattern and urban permeable pavement system

On the aspect of regional and urban master planning, we analyzed some key water ecological safety issues using the ecological safety pattern method to regulate flood storage, water quality and safety, water environment protection, and to establish comprehensive water ecological safety pattern surrounding ecosystem services.

The water ecological safety pattern uses low impact development rainwater exploited mode to plan urban road system, and to enhance roads and surrounding green land construction. The permeable pavement method is used for road green space and rainwater tree pools to improve road capacity of absorbing water and reducing road rainwater runoff quantity. The continuous and open space system is formed with high permeable requirements of urban square, garden, and green lands, combined with rainwater runoff pipe system and exceeding rainwater runoff discharge system to enhance the rainwater absorbing and discharging capability of urban square, green land, and garden, for the support of the urban water system. By using nature, traffic volume, geological conditions, and climate conditions, urban sites determine the comprehensive permeable pavement catchments. The urban pavement sponge system is finally formed by “spot permeable open space – low impact developing rain water road system – catchment area and catchment wetland” (figure 2). It proposed the requirements and goals of all constitutes under the low impact development, then translated them into special planning design requirements. Urban green space planning should combine spot permeable space to reasonably reserve space, help square, garden, green land, and their surrounding hardening areas’ rainwater runoff infiltrate and regulate, purify, and should connect the rainwater drainage system. Combined with road and green water retention facilities, traffic planning should coordinate the land and space use and vertical design inside and outside of the road boundaries to achieve low impact road development targets.

##### 4.2. Medium level – urban permeable pavement planning control

Urban regulatory detailed planning stage decomposes and refines the low impact development aims and requirements, which is proposed by urban master planning on the aspects of spot infiltrate open

space, low impact development rainwater road system, catchment area, and wetland in urban permeable pavement system, and brings land planning points into focus, converts specific lot control indicators, overall coordinates, and is systematically designed and constructed.



**Figure 2.** Urban pavement sponge system.

Combined with existing research and practice [11-15], and some related technology standards and requirements, such as “Outdoor Drainage Design Specifications” and “Green Building Evaluation Criteria”, the effective control indicators of urban permeable pavement mainly includes the permeable ground proportion, runoff coefficient, and low elevation green space ratio. The permeable ground proportion and runoff coefficient are important indicators to measure rainwater infiltration capability which directly affects pavement permeable effects. The low elevation green space is an effective measure to maximize the permeability of pervious pavement and rainwater storage and achieve water ecological system regulating balance. Because the permeable pavement is different from city lake water system the site aspects, land using characteristics, service objects, water quality, and landscape demand, its control indicators should be determined by urban functional distract and related requirements in order to provide future urban road surface technical designs.

Urban comprehensive functional distract generally includes green leisure area, residential area, public service area, logistics and warehouse area, and industrial area. Based on the analysis of traffic volume and road surface load, the green leisure area is primarily for walking as its air condition and rainwater quality is good and its landscape requirements are relatively high. The residential area has traffic volume, but its number and road load are small, and the air condition and rainwater are good. The public service area has a large traffic volume and road load, and a normal air condition and rainwater quality. The logistics warehouse area and industrial area have large traffic volume and road



load and its air condition and rainwater quality are poor, therefore the high permeability will cause pollutants to seep with rain, causing contamination to the soil and underground water. Based on the above analysis, this paper holds suitable classification on urban permeable pavement and proposes corresponding planning control indicators recommendations. (tables 2 and 3 and figure 3)

**Table 2.** Suitability partition of urban permeable pavement.

Urban functional district	Traffic volume and road load	Rainwater quality	Landscape demands	Water suitability grade	permeable
Green leisure area	Pedestrian traffic, low demands on road load	Good	high	I	
Residential area	Small volume of traffic, low demands on road load(refer to branches)	Relatively	Relatively high	II	
Public service area	Large volume of traffic, high demands on road load(refer to secondary road)	General	Relatively high	III	
Logistics and warehouse area, industry area	Large amount of traffic volume, high demands on road load(refer to main road and secondary road)	Bad	General	IV	

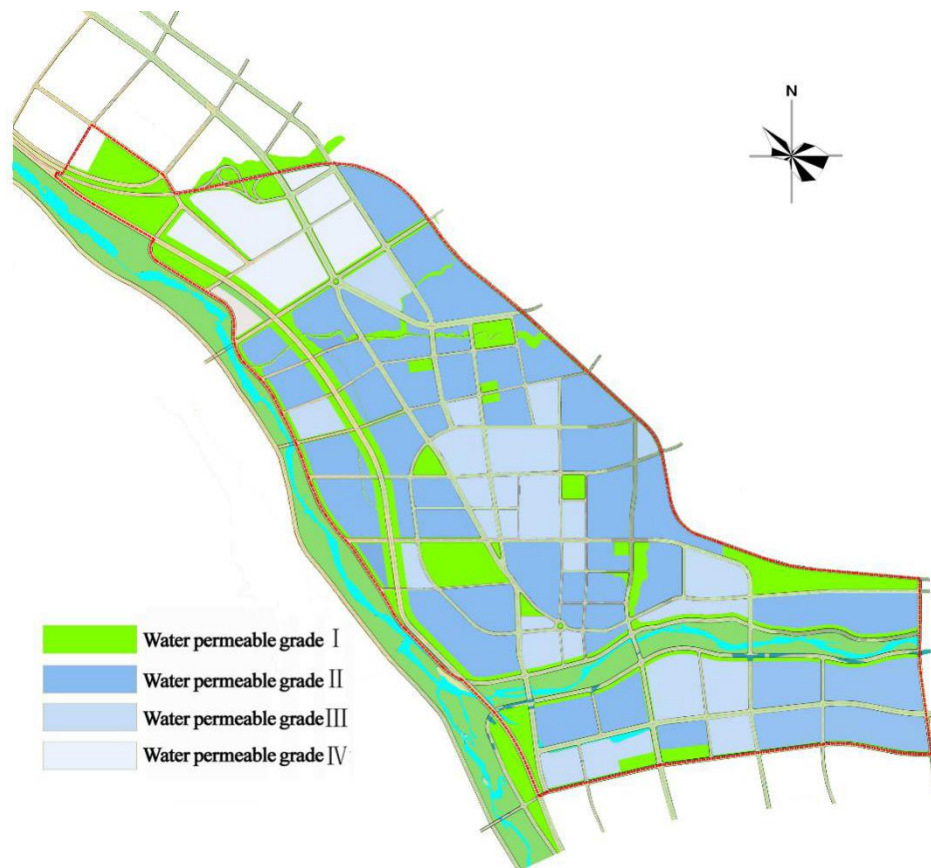
**Table 3.** Urban permeable pavement planning control.

Urban permeable pavement grade	Indicator control demands
Water permeable grade I	Proportion of permeable pavement $\geq 70\%$ , runoff coefficient $\leq 0.15$ , proportion of low elevation green space $\geq 80\%$
Water permeable grade II	Proportion of permeable pavement $\geq 50\%$ , runoff coefficient $\leq 0.45$ , proportion of low elevation green space $\geq 70\%$
Water permeable grade III	Proportion of permeable pavement $\geq 50\%$ , runoff coefficient $\leq 0.45$ , proportion of low elevation green space $\geq 50\%$
Water permeable grade IV	Proportion of permeable pavement $\geq 40\%$ , runoff coefficient $\leq 0.6$ , proportion of low elevation green space $\geq 30\%$

The above indicators are combined with recommended values of practice experience and research. Because the differences between nature conditions, development status, and construction speed, as well as the problems between new and old cities, to take reference and adjustments, it is important to start from the actual situation during the specific construction and planning controls of urban permeable pavement. Old city area control indicators could be moderately reduced and large rainfall area of urban control indicators could be moderately improved.

#### 4.3. Micro level – sponge technology design of urban permeable pavement

Based on the LID technology, urban permeable pavement design must construct new types of permeable pavement (table 4). On the one hand, to enhance the capability of rainfall runoff to infiltrate into urban sponge system. On the other hand, permeable pavement should combine low elevation green space, rain garden, and ecological grass site to form the sponge system, collect the rainwater, then store, filter, and purify it.



**Figure 3.** Urban permeable pavement planning control classification.

**Table 4.** Urban permeable pavement technical design.

Permeable pavement type	Pavement structure	Surface material
Urban road	Expressway	Surface layer uses permeable materials, base layer and cushion layer use poor permeable and impermeable materials
	Main road	Sidewalk use permeable brick; roadway use permeable concrete, permeable asphalt mixture
	Secondary road	Surface layer uses permeable materials, base layer and cushion layer use poor permeable and impermeable materials
	Branches	Sidewalk use permeable brick; roadway use permeable concrete, permeable asphalt mixture
Urban square pavement	Surface layer and basement have good permeability, cushion layer has low permeability	Sidewalk use permeable brick; roadway use permeable concrete, permeable asphalt mixture
Parking lot	Surface layer and basement have good permeability, cushion layer has low permeability	Surface use permeable concrete, permeable asphalt mixture

	permeability				
Garden, green space	Surface layer, base layer, cushion layer have good permeability and water storage capability	Permeable concrete	brick,	color	permeable
Logistics warehouse, industrial pavement	and area Surface layer uses permeable materials, base layer and cushion layer use poor permeable and impermeable materials	Site road surface concrete, permeable materials; permeable concrete	use other brick or	permeable asphalt pavement color	permeable mixture use permeable
Other sites	Surface layer and base layer have good permeability, cushion has low permeability	Site road surface concrete, permeable materials; permeable concrete	use other brick or	permeable asphalt pavement color	permeable mixture use permeable

For the road types, permeable demands are different for each area, and permeable pavement has relative difference on road structure and surface materials. By the current practice, water permeable brick, pervious concrete, and permeable asphalt mixture are good permeable pavement materials.

High permeable required pavement: pavement surface layer, base layer, and cushion layer must have good water permeability and water storage capability. The surface layer usually uses larger pore permeable brick, pervious concrete, and pervious asphalt mixture. The cushion layer could use pervious sand cushion to enhance the pervious effect. It is mainly applicable to the road of urban square, garden and green space, and the pavement permeability could reach 70%.

Medium permeable required pavement: surface layer and base layer must have good water permeability. The surface layer is usually use pervious brick, pervious concrete, and pervious asphalt mixture. The base layer could use good permeable grading gravel, and the cushion layer has low permeability and could use impervious materials, such as asphalt sand. Anti-infiltration earthwork cloth could be put on the ground to protect the subgrade. It is suitable for the urban parking lot road, sub roads, and branches, and the pavement permeability could reach 50%.

Low permeable required pavement: the pervious surface layer must use pervious materials, and the base and cushion layers must use impervious or poor permeability materials, such as asphalt. Rainwater passes through the surface layer, then flows directly out of the roadbed and protected roadbed. It is suitable for the urban expressway, main roads, logistics and warehouse area, industrial area, and so on, and its pavement permeability could reach 40%.

## 5. Conclusion

Urban permeable pavement is the most effective way to solve urban rainwater drainage, flood regulation, and water purification, but partial construction and spot repair could not achieve all of the demands. This paper established a system design fame combined with urban planning work stages. To ensure its operability, such aspects of study need to be continued to truly achieve the goal of sponge city construction:

On the technique research aspect, we should strengthen the research on permeable pavement of urban control, choosing suitable technology to take long-term monitor on permeable pavement, and collect continuous data to evaluate different road drainage and storage effect by different functional distracts. To make permeable pavement more adaptable, the permeable pavement design research of sponge technology should be enhanced, especially on the aspects of road surface layer pervious performance, material diversification, drainage mode, and its reasonable research.

The technique operation aspect should be based on and suit the regional condition. To reduce the safety hazard of groundwater pollution, it is unsuitable to use the high permeable road type in unfavorable geological conditions, unfavorable soil permeability, and highly polluted areas. The construction of legal system should be improved as soon as possible to make the legal protection on



permeable pavement construction. To simultaneously conduct the new and old area, the urban permeable pavement system steps should be reasonably created.

## References

- [1] Li X Z and Li N 2012 "Hard" pavement and permeable pavement *Enc. Knowl.* **16** 26-7
- [2] Shu P and Zhang F X 2016 Permeable pavement application of old quarter in North under the background of sponge City *Mod. Dec. (Theory)* **10** 202
- [3] Feng B 2016 Discussion on comprehensive utilization of low impact development rainwater model *Chin. High-tech. Ent.* **33** 109-10
- [4] Zhu M and Dang Q P 2014 Design and utilization of urban green road rainwater control *Sichuan Arch.* **34(1)** 213-5
- [5] Dong X and Shen Z 2010 Analysis on choice of engineering site and type in Chinese urban pervious pavement construction *J. Gansu Agric. Univ.* **6** 145-50
- [6] Li M L, Chen J, Wang Z H and Di S G 2015 Evaluation of ecological effect of permeable slow-traffic system based on low-carbon perspective *J. Highway Tran. Res. Dev.* **4** 40-4, 51
- [7] Xu D K and Lv W Y 2012 Low impact development model application-pervious pavement development review *N. Build. Mater.* **3** 31-4
- [8] Chu T, Han B and Xu Y J 2014 A discussion on city pedestrian pervious pavement and its pervious surface layer materials *Chin. Build Mater. Sci. Tech.* **4** 68-70
- [9] Qiu B X 2015 Connotation, approaches and prospect of LID *Constr. Sci. Tech.* **1** 1-6
- [10] Yu K J, Li D H, Yuan H, Fu W and Wang S S 2015 "Sponge city": Theory and practice *City Plan. Rev.* **39(6)** 26-35
- [11] Wang Q, Gu L R, Li W Y and Liu Z 2016 The sponge city practice of the Gui'an innovation park *City & House* **7** 9-14
- [12] Zheng D Y and Zhou X Y 2016 A study on technical guideline of sponge city regulatory planning *Planners* **32(5)** 17-22
- [13] Zhang L 2016 Path of sponge city construction in northwestern China: An empirical study on Xixian new area *City Plan. Rev.* **40(3)** 108-12
- [14] Li K 2014 Indicator analysis of integrated rain water management in low-carbon eco-city *Green Build.* **2** 17-20
- [15] Su Z Y and Guo T 2016 Study on runoff control zoning and LID measures quantification in sponge city planning: A case study of Kunming *Shanghai Urban Plan. Rev.* **4** 115-9