Effects of the Asphalt Permeable Pavement on Highway Runoff

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ABSTRACT: Asphalt permeable pavement (APP) is a passive structural low impact development material and green infrastructure for rainfall-runoff control. Multifunctional engineered APP can fulfill requirements as a load-transmitting surface while serving as a more environmentally conscious infrastructure material that functions to restore the in situ hydrology, reduce runoff, filter, and treat infiltrating runoff, reduce thermal pollution and temperature, also provide the load-carrying capacity of conventional pavement. Determining the main value indices of runoff pollutants, the efficient control of runoff pollutants has been studied from materials and structures of permeable pavement in this paper. The results indicate the rational permeable pavement structure has great removal effect on chemistry oxygen demand (COD) and suspended solid (SS). The porous structure of permeable pavement acts as a filter of the storm water and pollutants can be filtered out as the water flows through the pores with the function of filtration, absorption and block. Fibers can be used in the subbed course to filtrate the suspended solids to purify the groundwater effectively. The water quality improvements suggest that the permeable pavement is an effective best management practice for treating highway storm-water runoff, as the SS removal is more than 50 % and the COD removal is more than 60 %. The significant advantage of APP is that storm-water treatment is incorporated into the pavement structure itself and does not require additional right-of-way to site a structural best management practices (BMP).

KEY WORDS: Asphalt permeable pavement, runoff pollutant, porosity, chemistry oxygen demand, suspended solid.

1 INTRODUCTION

In most built environs, the degree of imperviousness can be greater than 60 %, Deleterious impacts on the hydrologic, physical, chemical, and thermal rainfall runoff relationships in the built environs are significantly related to the constructed impervious surfaces (Kuang et al. 2007). Conventional pavements are the most common examples of impervious surfaces in the urban environment and in part cause a significant modification of the local hydrologic cycle. Expansive impervious areas have a significant impact on reductions in groundwater recharge, the depletion of soil moisture, and the corresponding increase in runoff, also reduction evaporation and evapotranspiration, known as heat island effects (Sansalone and Zheng 2004). With respect to the problems caused by impervious pavements, asphalt permeable pavement functions as a passive unit operation and process for storm water quality and quantity control through infiltration, evaporation, filtration, absorption and reaction mechanisms. Permeable pavement reduces runoff, flooding, and treatment requirements; act as a sorbent filter that reduces the pollutant loads of phosphorus and nutrients to the environment; and reduces pavement and water temperatures. It also increases infiltration back to the soil to provide groundwater recharge to enhance future water supplies (Sansalone et al. 2008). But there is little study on runoff pollutant control by asphalt permeable pavement, especially in China. So this study focuses on the efficient control of runoff pollutants by materials and structures of asphalt permeable pavement which is very significant to purify underground water and make full use of rainfall.

2 TEST METHODS

2.1 Indices of Runoff Pollutants

Studies indicated that runoff pollutants included suspended solid (SS), chemical oxygen demand (COD), phosphorus and nutrients, and the levels of Zn, Cu, Cd, Pb, Cr, Ni and so on (Park and Tia 2004, Sabbir et al. 2005). SS and COD are the main pollutants, which mainly come from tire abrasive granules, pavement material abrasive granules, leak of transportation goods and other granules relative to transportation. So in this study, COD and SS are determined as the main runoff pollutant indices.

Chemical Oxygen Demand: In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. The removal rate of COD indicates the degree of removing organic pollutants in the water. The greater the removal rate of COD, the better the ability of removing organic pollutants in the water.

Suspended Solid: Suspended solids refer to small solid particles which remain in suspension in water as a colloid or due to the motion of the water. It is used as one indicator of water quality.Suspended solids are important as pollutants and pathogens are carried on the surface of particles. The smaller the particle size, the greater the surface area per unit mass of particle, and so the greater the pollutant load that is likely to be carried.

Solid in the water can be divided into soluble solid and suspended solid, ab. SS (mg/L). The quality and quantity of soluble and suspended solid are quite different in all kinds of water. In the highway runoff, pavement granules are the suspended solid. The removal rate of SS indicates the degree of removing solid particles in the water. The greater the removal rate of SS, the better the ability of removing solid particles in the water.

2.2 Water Sample

Water samples were prepared by two kinds of methods, one was collected from the drainage along the edge of pavement; the other was prepared in the lab according to the components and quantities of runoff pollutants (Li et al. 2005).

2.3 Compaction

Samples made in the laboratory should have a good affinity with reflecting real road conditions. Studies made in Sweden and other countries have proven that the traditional Marshall method is not suitable in this regard (Ozen et al.2008). A study in China revealed that the compaction effect of the Marshall method and vibrating compaction was equivalent to suspended-dense asphalt mixture and was quite different to framework-void asphalt mixture when the content of coarse aggregate was more than 60 % (Xie et al. 2001). The vibrating compaction method can enhance the degree of compaction and generate better distribution of particle orientation angles, exhibiting better mechanical properties. Thus, in this study, specimens are compacted by vibratingr compaction equipment. The vibrating force, frequency, and amplitude can be adjusted (Xie et al. 2001). The optimum vibrating compaction parameters are determined as following: vibration frequency (30 Hz), low amplitude (0.957 mm), vibration force (7 kN), vibration time (2.5 minutes). Specimen dimension: 150 mm×100 mm. For cement permeable pavement materials, the vibrating time influences the uniformity of specimen directly. The optimum vibrating time is determined as 1 minute to keep the specimens uniformity.

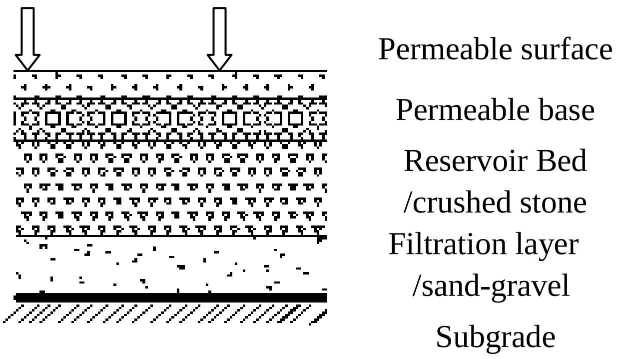

Figure1: Structure of permeable pavement

3 STRUCTURE OF PERMEABLE PAVEMENT

Permeable pavements have been more and more widely applied in the United States, Europe, Australia and Japan in the last two decades (Mangani et al. 2005). Especially in Japan, infiltration facilities including permeable pavements were introduced and progressively implemented during the 1980s. When rainfall infiltration was first implemented, its primary objective was to reduce runoff volume. With the enhanced recognition of water quality benefits, as well as the Japanese desire to maintain closeness with nature in an urban setting, however, permeable pavement philosophy has shifted more towards groundwater cultivation than runoff reduction since the 1990s. Until now typical permeable pavements have been formed in Japan. Permeable pavement has seldom been studied in China for its durability. But from the view of alleviating heat island effects, supplying groundwater, reducing runoff and so on, permeable pavements have more advantage. This kind of permeable pavement should be designed at the roads of squares, resident sections, parking lots and some places in which load bearing and traffic volume are lower. The structure of permeable pavement in this paper is shown in Figure1.

4 TESTS AND RESULTS DISCUSSION

4.1 Materials Composition

In order to distinguish the degree of removal rate of pollutants in different asphalt mixtures, continuous gradation and gap gradation of asphalt permeable mixture are adopted in the permeable pavement surface. Cement stabilized aggregate is adopted in the permeable base. Single seize as 13.2 mm is applied to aggregate layer and 4.75 mm is applied to sand-gravel bed course. The gradations are as follow Table1.

Table1: Gradations of different layers

Gradation	Air void /%	seize/mm cumulative passing percentage / %											
		26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Continuous Gradation of HMA	26.2	100	72	60.2	48.5	34.7	15.6	9.1	7.7	5.8	3.6	1.6	0
Gap Gradation of HMA	20.2	100	100	100	50	50	25	25	13	13	5	5	5
Cement Stabilized Aggregate	21.8	100	89.7	80.8	61.7	29.3	0	0	0	0	0	0	0

The optimum asphalt contents of permeable asphalt mixture are determined following Marshall design method. The optimum asphalt content for continuous gradation is 2.8 %, while 3.0 % for gap gradation. The coarse skeleton of cement stabilized aggregates is showed as Table1, which air voids is filled by 15 % of cement mortar, composed by w/c (0.36) and water reducer (0.6 %). Above materials are compacted by vibrating techniques (seen as compaction).

4.2 Efficiency in Removal Pollutants of Structure Layers

The values of COD and SS are measured for original water samples and the structures' samples accordingly. The removal rates of COD and SS are calculated, the detail results are as follow Table 2 and Figure 2-4.

Table 2: The removal rate of pollutant through different layers

Structure layer	Material	Compaction method	Air voids/%	Removal rate / %	
				COD	SS
Permeable surface	Continuous gradation	vibrating	26.2	21.74	62.82
	Gap gradation	vibrating	20.2	53.62	64.77
Permeable base	Cement stabilized aggregate	vibrating	21.8	47.83	62.04
Reservoir bed	Single size aggregate (13.2mm)	loose	42.1	42.03	-40.43
Filtration layer	Sand-gravel /4.75mm	loose	40.8	36.78	-95.06

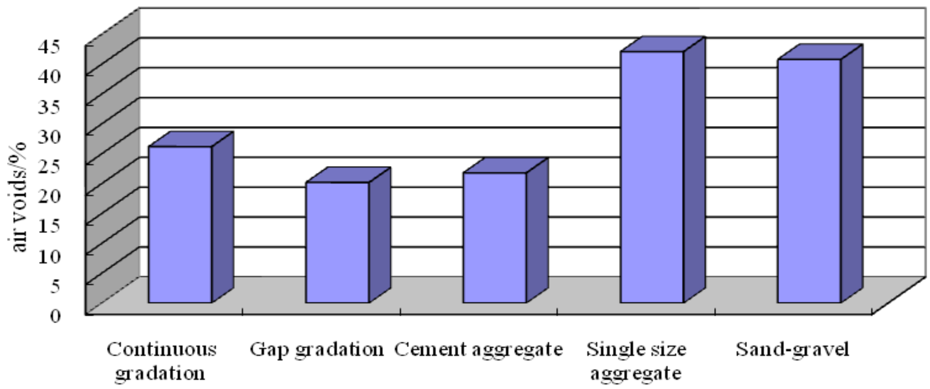

Figure 2: Materials and air voids

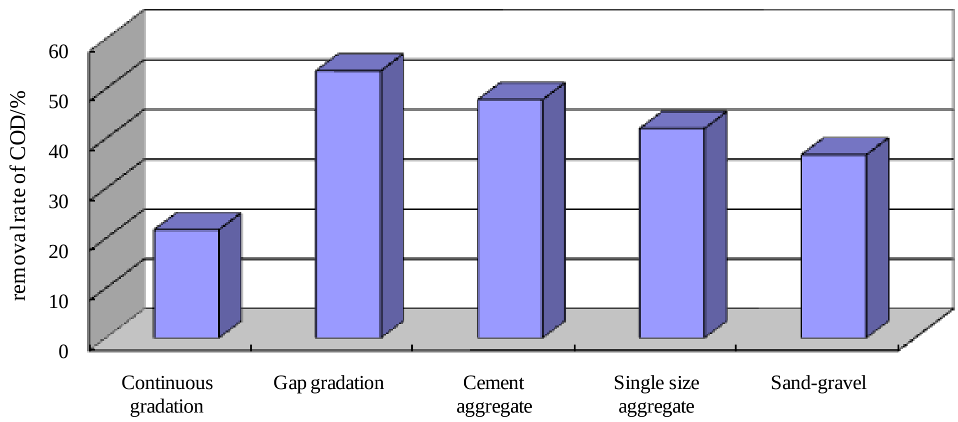

Figure 3: Materials and removal rate of COD

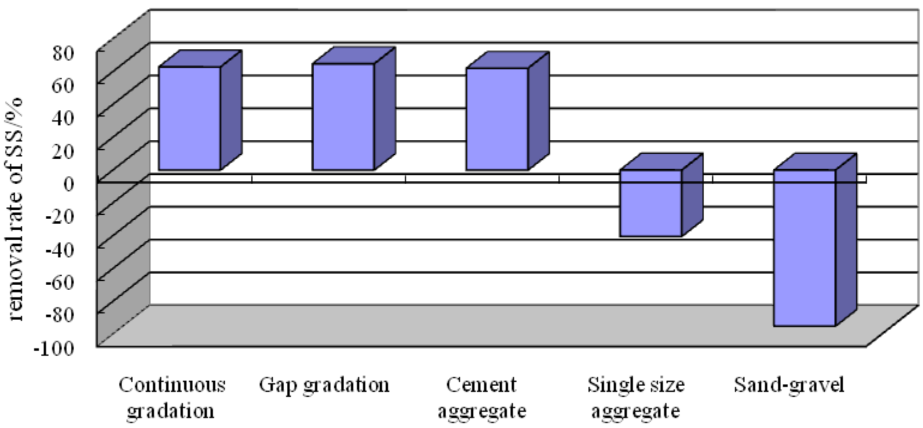

Figure 4: Materials and removal rate of SS

Some conclusion could be derived from Table 2 and Figure 2 to 4:

- For permeable surface and base, the removal rates of COD increase from 21.74 % to 47.83 % with the decrease of air voids from 26.2 % to 21.8 %, while the removal rates of SS are equivalent (62.82 % — 62.04 %）. The removal of the COD depends on the filtration and absorption of porosity, which is greatly influenced by the pore characteristics, while less influenced by the component materials. Thus, the pore characteristics of asphalt mixtures are the key to design the permeable pavement.
- For loose reservoir bed and filtration layer, the air voids of crushed stone and sand-gravel are similar. The removal rates of COD are equivalent, ranging from 36 % — 42 %. The value of SS is increasing evidently compared with fixed water sample, that is, the removal rate of SS is negative. The reason is the materials of loose reservoir bed and filtration layer are dirty, including sand, mud and so on. When the water samples pass through the structure layers, companying with small particles of sand and mud, the suspended solids in the water sample are increased. The values of SS become greater, the removal rates of SS are respectively -40.43 % and -95.06 %。

- Although the air voids of continuous and gap gradation are similar, the removal rates of COD are quite different. With the decrease of air voids, the removal rates of COD could improve to 2.47 times, from 21.74 % to 53.62 %, while the removal rates of SS are equivalent (62.82 % — 64.77 %). The removal rate of COD is intimately relative to pore characteristics. Although continuous gradation can form larger porosity, aggregates interfere each other and do not form space network structure, while gap gradation could form the whole space network structure according to the filling theory. The air voids between large aggregates being filled by small aggregates, and the air voids between small aggregates being filled by smaller ones. The removal rates of COD mainly depend on the absorption and block of pore micro structure. The network structure of asphalt pavement will benefit for absorbing and blocking smaller granules, while COD is commonly adhere to the small granules or structure surface. When the content of SS is decreased, the content of COD is decreased too correspondingly.
- Structure layers in the permeable pavement have certain removal effect on COD, which degree is relied on material design. Mixtures of permeable surface and base have been wrapped by binder, so the clean degree of aggregates has little influence on the removal rate of SS. For materials of loose reservoir bed and filtration layer，the clean degree of aggregates has great influence on the removal rate of SS. So, for these two layers, materials should be washed in advance in order to reduce minor crumbs and sands or using fiber cloth as subbed course to block suspended solid in order to ensure the removal rate of SS.

Table 3: The removal rate of pollutant through different layers combination

Structure layer	Material	COD		SS	
		Value (mg/L)	Removal rate /%	Value (mg/L)	Removal rate /%
Permeable surface+ permeable base	Continuous gradation of HMA+ Cement stabilized aggregate	101.7	43.48	2567.6	35.81
	Gap gradation of asphalt mixture+ Cement stabilized aggregate	79.9	55.62	2418.8	39.53
Reservoir bed+ Filtration layer	Single size aggregate(13.2mm) +sand-gravel+fiber	96.8	46.20	8328.4	-108.21
Reservoir bed+ Filtration layer	Single size aggregate(13.2mm) +sand-gravel+fiber	63.5	64.72	1980.2	50.49
Water sample	——	180	——	4000	——

4.3 Efficiency in Removal Pollutants of Structure Combinations

There are two kinds of combination of structure layers, one is Permeable surface+ permeable base, and the other is Reservoir bed + Filtration layer. The values of COD and SS are measured for original water sample and through the structures' respectively. The removal rates of COD and SS are calculated as follow Table 3 and Figure 5 and 6.

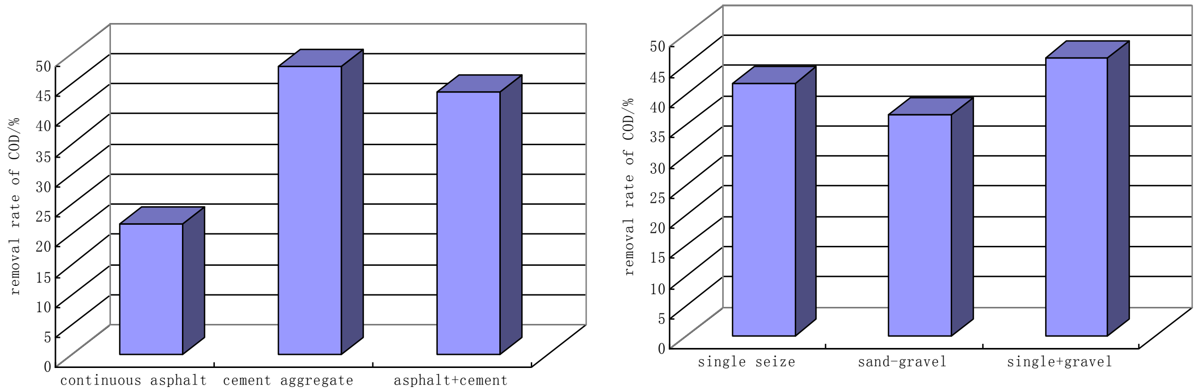

Figure 5: the removal rates of COD of structure compositions

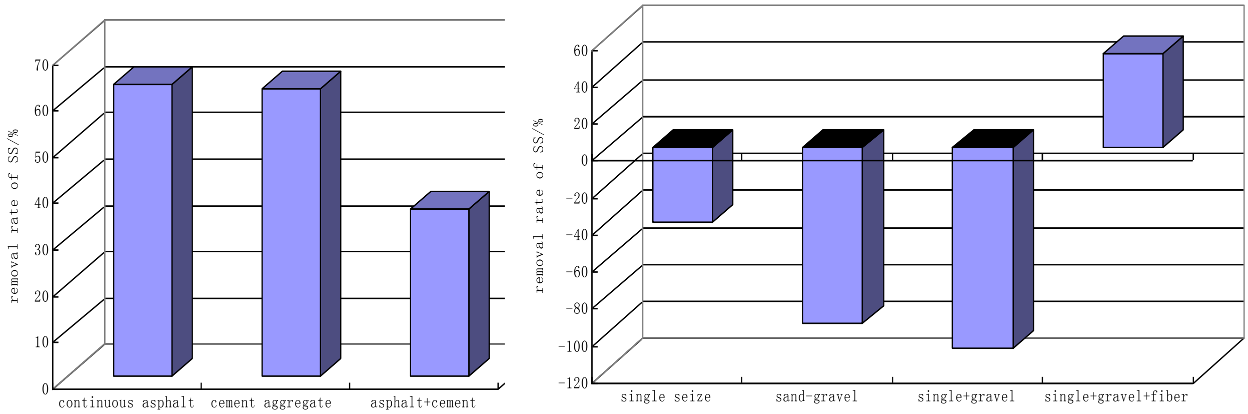

Figure 6: The removal rates of SS of structure compositions

Several conclusions could be derived from Table 3 and Figure 5 and 6:

- From Figure 5, the removal rate of COD of the structure combination is not accumulated by the removal rate of individual structure layers. The removal effect of structure combination is determined by the removal effect of individual structure and structure combining mode. The removal effect of COD mainly depends on the filtration, block and absorption of pore structure. The different layers may have similar pore characteristics, so the removal rates have similar values. The removal rate of COD through the structure combination is equivalent to the structure layer having higher removal rate of COD.
- Materials of different structure layers should be designed according to the functions of individual layers. That is, if the removal effect of COD is supposed on surface layer, the relationship between pore characteristics and the removal rate of asphalt mixtures should be studied further. The materials of permeable asphalt mixtures should be designed

according to pore structures. While the removal effect of COD can be weaken in the design of base materials, which just meet the performance demand of the infiltration and bearing loads.

- From Figure 6，the removal rate of SS of the structure combination is lower than the removal rate of individual structure layers. The reason is that the small particles increase with the increase in the thickness of structure. The small particles will flow with water sample leading to increase the value of SS and decrease the removal rate of SS. It is further evident that the degree of removal rate is relative to the clean degree of materials in loose reservoir bed and filtration layer. In order to improve the water quality, fibers can be used under the filtration layer to retain the suspended solids effectively.

5 CONCLUSIONS

A series of objectives are examined with respect to design the permeable pavement, and the removal rates of pollutant for different structure layers are examined. There are a number of conclusions that can be drawn from the results.

1）Although the materials of different structure layers are quite different in the permeable pavement, they all have certain removal effect on COD. The test results indicate that the organic pollutants stay in the pore structure of the permeable pavement through filtration, absorption and block. The porous structure of permeable pavement acts as a filter of the storm water and pollutants can be filtered out as the water flows through the pores. The permeable pavement can improve the runoff quality.

2）Mixtures of permeable surface and base have been wrapped by binder and have better space network structure, which make suspended solid could stay in the inner pore structure, exhibiting the better removal rate of SS. There is no binder to connect the aggregates in the loose reservoir bed and filtration layer and some small particles (mud and dust) exist in these layers. The suspended solids increase when water sample flows through the structure layers, and the removal rate of SS is negative.

3）The removal rate of COD of the structure combination is not accumulated by the removal rate of individual structure layers, and is equivalent to the structure layer having higher removal rate of COD. The removal effect of structure combination is determined by the removal effect of individual structure and structure combining mode. The removal rate of SS of the structure combination is lower than the removal rate of individual structure layers.

4）Permeable pavement structures have better removal effect on organic pollutant in the runoff, while increasing the content of the suspended solid. The organic pollutants have greater influence on water quality than suspended solids, so it can be derived that permeable pavement has the efficiency on control runoff pollutants. Fibers can be used in the subbed course to filtrate the suspended solids to purify the groundwater further.

5）The water quality improvements observed to data suggest that the permeable pavement is an effective best management practice for treating highway storm-water runoff, as the SS removal (> 50 %) is comparable to that documented for many structural treatment practices. The significant advantage of APP is that storm-water treatment is incorporated into the pavement structure itself and does not require additional right-of-way to site a structural BMP.

6） It is just a beginning to study permeable pavement from control runoff pollutants, in order to apply the permeable pavement widely, the mechanism of pore structure controlling runoff pollutants should be researched deeply, which will benefit to carry out material and structure design definitely.

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