

Development of Block pavement system with water-retention and pollution control

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ABSTRACT: Heat transfer from paved road surfaces within the city contributes to create "urban heat islands", leading to increased energy cost, discomfort environment for human beings, and increased smog formation. Therefore, this study focused on the development of a block pavement system with water-retention and pollution control to improve the heat and water cycle in urban area.

The block pavement system was designed to store water in a storage space for further evaporation and infiltration. Additional water was supplied to the block using capillary phenomenon. A wood filter layer was applied to remove pollutants in road runoff. The permeability, absorptiveness, and the efficiency of temperature reduction of the block pavement system was investigated and compared with existing block system. Experimental results indicated that absorptiveness ability was about twice and the continuous efficiency of temperature decline was excellent than those of existing block system.

Keywords: Rainwater, Block, Pollution control, Heat island, Permeability

NOMENCLATURE

MFBP : Multi-Functional Block Pavement
FFM : Fiber Filter Mat
UHI : Urban heat islands

1. INTRODUCTION

Human activity in urban environments has changed not only the water cycle and ecosystems but also climate in local scale. The most clear local indicator of climate changes due to urbanization is a well-known urban/rural convective circulation known as urban heat islands (UHI), which is defined as a dome of high temperatures observed over urban centers as compared to the relatively low temperatures of the rural surroundings [1]. Some of the factors causing the formation of a heat island are the intensive use of asphalt and diverse construction materials, mainly concrete [2].

Recently, porous pavements have drawn attention as a novel solution to the problem of UHI [3]. Porous pavements are made up of a matrix of concrete blocks with voids [4]. These voids allow water to be captured inside the pavement, which in turn can play a significant role in reducing the temperature of the pavement. In addition, porous pavements are also effective to alleviate damages caused by stormwater runoff.

Nevertheless, porous pavements have several disadvantages such as weak strength and fouling. In addition, water from porous pavements may be contaminated by heavy

metals and toxic organics, leading to contamination of ground water by infiltration. Moreover, the effect of temperature reduction by porous pavements is limited because a continuous supply of external water is required for evaporative cooling.

In this study, a new pavement system combining water-retentive block, water storage space, and wood filter was developed for better control of road temperature and contaminants. The capability of temperature reduction and pollutant removal for our pavement system was compared with existing pavements in laboratory-scale runs and field tests.

2. MATERIALS AND METHODS

2.1 Design of multi-functional block pavement

2.1.1 Multi-functional block pavement (MFBP)

The structure of the multi-functional block pavement (MFBP) system was shown in Figure 1. The pavement system consists of two sections including i) a storage part and ii) an infiltration part. The top of the pavement system is covered by water-retentive blocks.

The storage part keeps water in rainy time and let it absorbed by the water-retentive blocks through capillary effect in sunny time. This allows an additional decrease in road temperature by evaporation. The extra rainwater flows into the infiltration part in heavy rainfall. Prior to infiltration, the rainwater passes through a wood filter layer (fiber filter mat: FFM) to control contaminants such as suspended solids and heavy metals. Since the pavement system is designed to be easily disassembled, the fiber filter mat can be replaced after its life time.

2.1.2 Water-retentive block

The water-retentive block was made of silica. The width, length, and depth of the

block were 10 cm, 20 cm, and 4 cm, respectively. The permeability constant was 1.3×10^{-2} cm/sec, indicating a high permeability of water. The block has small pores, allowing the absorption of water at the bottom side through capillary effect.

To estimate the maximum water absorption capability, the block sample was immersed into water for 24 hours at 20 °C. The experimental result indicated that one block can absorb 182 mL of water. Thus, the maximum water absorption capacity was calculated as 0.15 g/cm³.

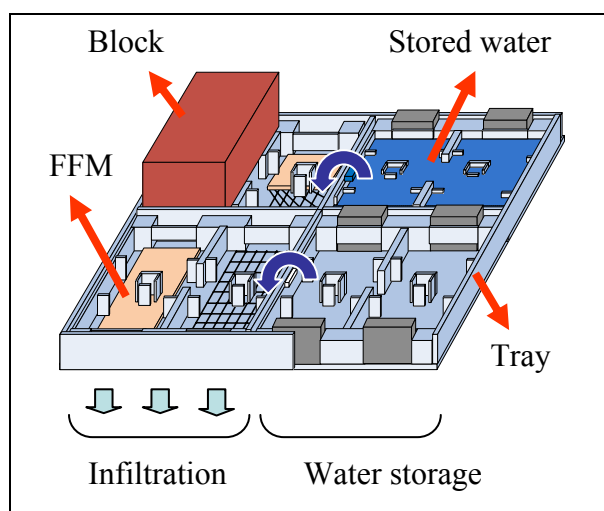


Figure 1. Structure of multi-functional block pavement system

2.1.3 Fiber filter mat

Three different types of fiber filter mat were prepared and compared in terms of the treatment efficiency of particles (turbidity) and heavy metals, which are known as major contaminants in road runoff. The fiber filter mat were originally manufactured by USDA forest product laboratory and fiber sheet was pretreated using the protocols shown in Table 1. The fiber sheet was inserted inside the permeable pavement so that the infiltrated water can pass through the fiber sheet.

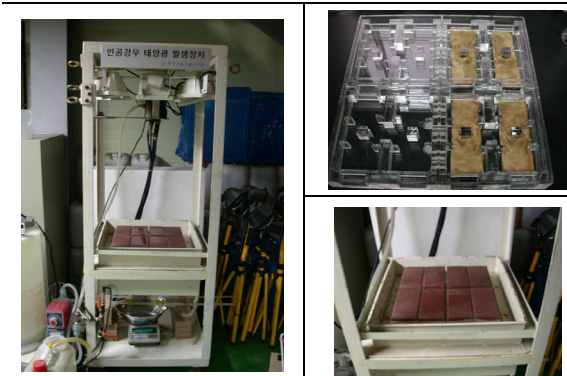
Table 1 : Protocols for the pretreatments of fiber filter mat

1 st Step	2 nd Step	3 rd Step
Bleaching with 1N NaOH solution	- Washing - Heat treatment at 120 °C, 2.5 atm for 30 min	- Soaking in 0.65 M FeCl ₃ - Contacting with conc. HCl for 2 min - Washing/drying

2.2 Experimental procedure

2.2.1 Laboratory-scale experiments

Experiments were performed using a laboratory scale experimental setup that simulates rainfall at different intensities. The area and height of block pavement system were 40×40 cm and 8 cm, respectively. The rates of surface runoff and infiltration were recorded with 5-second interval using an electronic balance connected to a data logger. The temperature of pavement surface was measured using an IR thermometer mounted on top of the pavement system. Rainwater runoff samples collected from the surface of real roads were used as the feed solution

**Figure 2** : Laboratory-scale equipment

2.2.2 Field test and monitoring

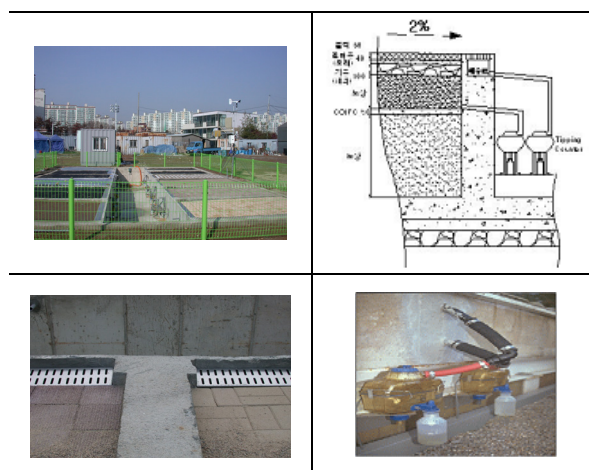
In addition to the laboratory-scale experiments, field tests were also carried out using outdoor pavement facility. The outdoor pavement facility had 12 sample pavement regions with different characteristics. The area of each sample pavement was 6 m² (2W×3L). The outdoor

facility allowed the comparison of various pavement materials and systems, including natural ground, asphalt, and block pavements under same environmental conditions.

Tipping counters were equipped to measure flow rates of overflowed and infiltrated rainwater. A pyrheliometer and a k-type thermocouple were applied to monitor the thermal properties of pavements continuously.

2.2.3 Analytical methods

Spectrophotometric methods of Hach using DR-4000 spectrophotometer were adapted to measure the heavy metals.

**Figure 3** : Outdoor test facility for various pavement materials and systems

3. RESULT AND DISCUSSION

3.1 Estimation of infiltration and absorption capacity

As shown in Figure 4, infiltration tests with artificial rainfall was carried out for the MFBP systems using the laboratory-scale equipment. The simulated rainfall intensity was 30 mm/hr and the duration time was 90 min. There was no surface runoff from the pavement during the test period, indicating that the infiltration and water absorption efficiency of the pavement system was high.

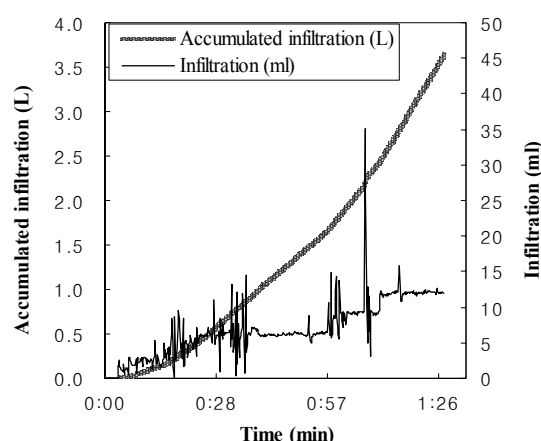


Figure 4 : Infiltration of rainwater through the multi-functional block pavement system

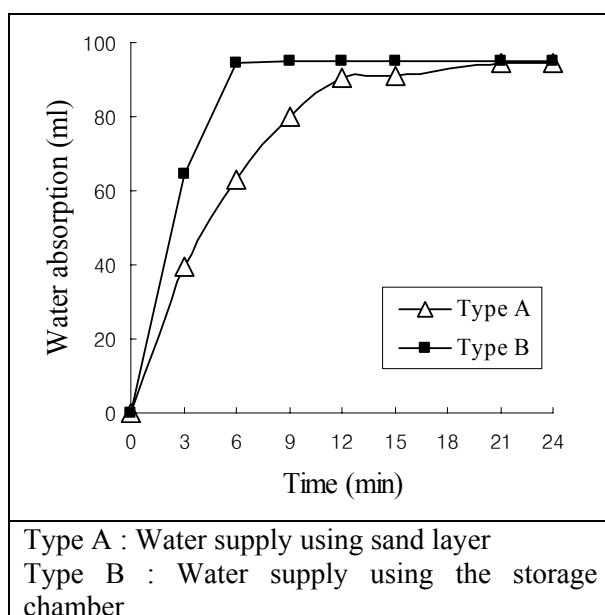


Figure 5 : Comparison of different materials to supply additional water in the multi-functional pavement systems

The rate of water absorption by water retentive block can be affected by the means to supply water. In the MFBP system, a specially designed structure and permeable material was used to supply water from the bottom side of the water-retentive block. Here, the water absorption rate of MFBP system was compared with that of water-retentive block on the wet sand layer. When the sand was used for water supply (Type A), it took 20 min to reach its maximum absorption capacity. On the other hand, it

only took 6 min to reach maximum capacity in the MFBP system. This result indicates that the structure of MFBP system is efficient for water transport from bottom side to the water-retentive block. Considering the fact that the water absorption rate is closely related to the evaporation rate and cooling effect, it is expected that the MFBP system can efficiently decrease surface temperature

3.2 Control of pollutant by multi-functional pavement system

To examine the pollution control of the MFBP system, experiments were carried out using the real rainwater runoff from road surface in the laboratory-scale equipment. The infiltrated water quality was compared without and with fiber filter mat.

Table 2: Comparison of water quality for road runoff and infiltrated water from the pavement system

Parameters	Feed water	Sample A	Sample B
Turbidity (NTU)	305	122	67
Cu (mg/L)	0.4	0.22	0.09
Fe (mg/L)	0.99	0.43	0.19
Zn (mg/L)	0.226	0.156	0.085

Feed water : Road runoff
Sample A: Infiltrated water from block
Sample B: Infiltrated water from block with fiber filter mat

As shown in Table 2, turbidity was reduced after passing through the block pavements. The turbidity removal was much higher in the presence of fiber filter mat (78%) than without fiber filter mat (60%). This implies that the fiber filter mat is effective to remove particles and colloidal matters in rainwater runoff.

Moreover, the fiber filter mat was effective to remove heavy metals from the runoff. With fiber filter mat, the removal of Cu was 78%, which is much higher than that

without fiber filter mat (45%). The removal efficiencies of Fe and Zn were also improved using the fiber filter mat. These results indicating that the fiber filter mat is effective to control not only particles but also soluble contaminants such as heavy metals.

3.3 Temperature reduction by multi-functional pavement system

The thermal property of pavement was examined using the laboratory-scale equipment with halogen lamps. The intensity of the lamps was controlled to reach up to 60 °C of pavement surface temperature without external water supply. Experiments were performed under ambient temperature of 25 ± 1 °C and humidity of 65%.

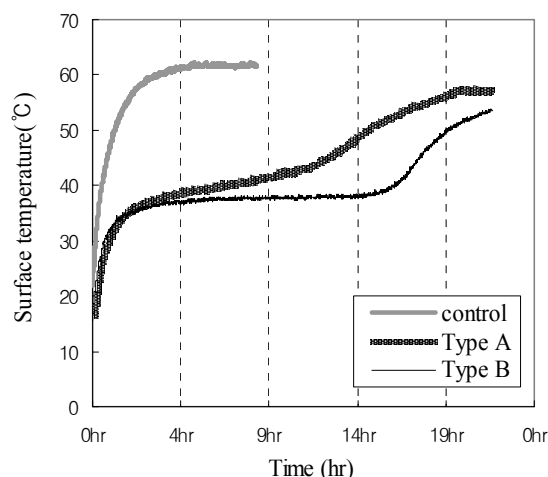


Figure 6 : Profiles of surface temperature for dry pavement block (control), pavement block with wet sand support (Type A), and multi-functional pavement system (Type B)

The MFBP system reduced the surface temperature compared to the case without water. For the first 15 hours, the surface temperature of the MFBP system was lower than 40 °C (Type B), which is even lower than the case with water supply by wet sand surface (Type A). After 15 hours, the surface temperature increased because all water stored in the MFBP system was used. Nevertheless, the surface temperature for the MFBP system maintained less than 52 °C,

which is 8 °C lower than that of dry pavement surface. Assuming that the time for high-intensity solar irradiation in summer days is 5 hours, the MFBP system may have cooling effect for about 3 days.

3.4 Monitoring of pavements under outdoor conditions

To confirm the efficiency of the pavement system under more realistic conditions, the field tests were carried out using the outdoor pavement facility. The pavement samples were monitored from 5/27/2008 to 6/4/2008.

Figure 7 shows the runoff and infiltration rates of pavements during the test period. On the first day, the pavements received total 33 mm of rain. In the asphalt pavement, which is impervious, surface runoff was observed from the beginning. At the peak time (rainfall intensity = 16 mm), the runoff rate of the asphalt surface was 22 L/min.

In the MFBP system, there was no surface runoff during the period of rainfall. Infiltration started after the end of rainfall event and lasted for 8 hours, indicating an excellent runoff control. On 6/3/2008, there was another rainfall with total amount of 18.4 mm. In this case, the surface runoff from the MFBP system was not observed while that from the asphalt was substantial. These results suggest that the MFBP system may be effective to control urban flood by reducing the surface runoff of storm water.

During the same period, the temperatures of pavements were monitored as shown in Figure 8. The surface temperatures of pavements increased in daytime and decreased in night time. Depending on the ambient temperature and sunlight intensity, the peak temperatures ranged from 38°C to 52°C for the asphalt pavement, which are 15 °C to 20 °C higher than those of ambient temperature.

The MFBP system showed temperature reduction effect compared to the asphalt pavement. After rainfall events, the difference in surface temperatures between

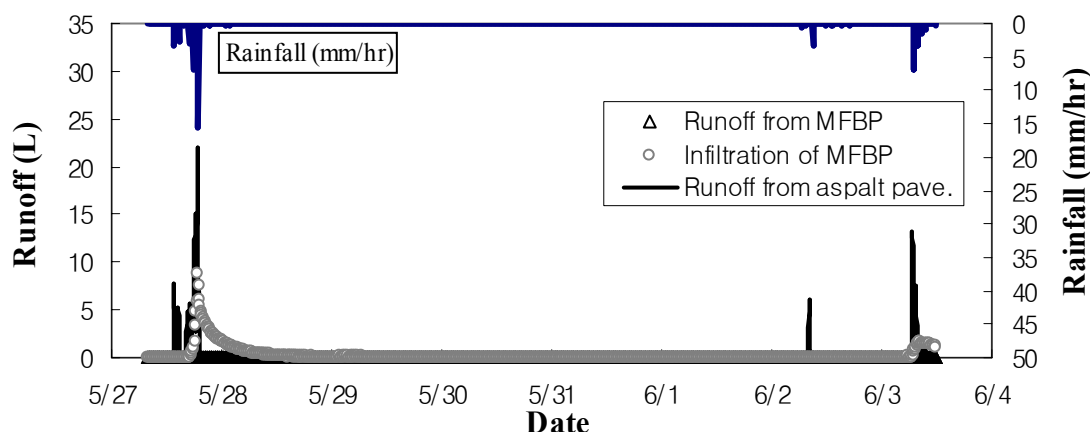


Figure 7 : Comparison of runoff and infiltration rates for various pavements in outdoor tests

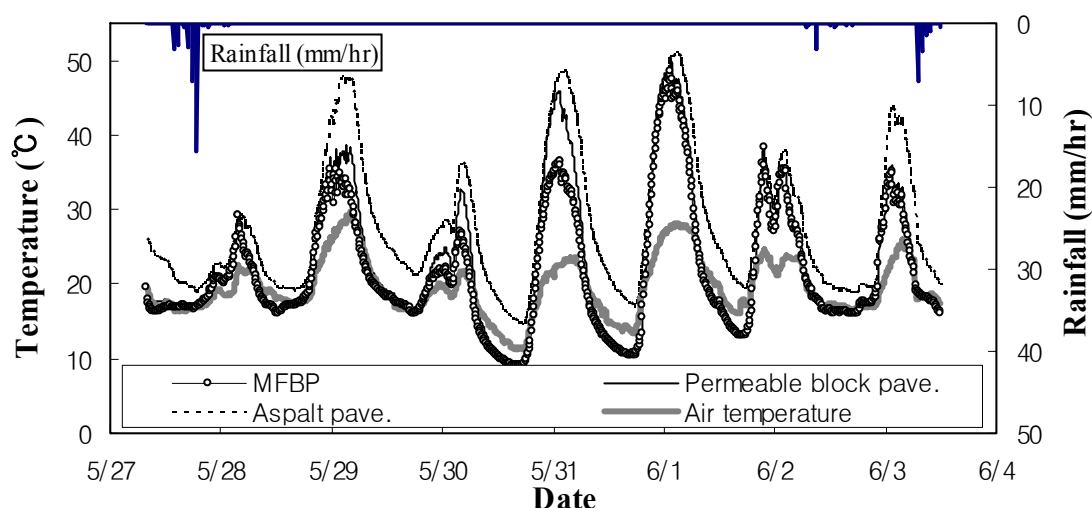


Figure 8 : Comparison of ambient and surface temperatures for various pavements in outdoor tests

the MFBP system and the asphalt were up to 15 °C. This is due to the evaporative cooling by stored rainwater inside the pavement system. After 4 days, the peak temperatures for the pavement system and asphalt became similar because all the water inside the pavement system was evaporated. With another rainfall event, however, the pavement system recovered its cooling effect.

The permeable block pavement, which lacks water storage chamber, also showed lower temperatures than those of the asphalt pavement. However, the temperature difference was smaller than the case of the MFBP system.

4. CONCLUSION

In this study, the MFBP system was developed for better control of pollutants in infiltrated water, stormwater runoff, and surface temperature. The following conclusions were withdrawn:

1. In the MFBP system, all water could be infiltrated at 30 mm/hr of rainfall for 90 min. The pavement system exhibited faster absorption of water from the bottom of water-retentive blocks.

2. In the presence of fiber filter mat, the water quality of infiltrated water from the MFBP system was better. The removals of turbidity and heavy metals (Zn, Cu, and Fe) were in the range of 70 % to 80 %.
3. In laboratory-scale test, the surface temperature of MFBP system was 20 °C lower than that of normal pavement. When the water inside the MFBP system was depleted, the surface temperature started to increase. It is likely that the cooling effect can maintain for 3 days.
4. The outdoor test also confirmed the efficiency of the MFBP system.

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