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Development of Treatment-Train-Package Novel System for the Road Runoff Controlling in Urban Area

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Abstract

This study has improved the infiltration capability of the sidewalk by infiltrating rainfall into the road and buffer green areas using the Permeable Brick Pavement (PBP) and Vertical Infiltration Pipe (VIP) and through the permeable retention tank under the PBP. Rainwater on impervious surfaces goes through the initial rainwater treatment system and then the rainwater storage tank; this process enables the slow rainfall-runoff for rainwater utilization. The rainwater collected in the rainwater storage tank is used for landscape irrigation in nearby green areas. Through this process, the runoff reduction rate on the road has been analyzed. The data used for the research were collected by measuring actual rainfall patterns: more than 30 mm of rainfall or more than 15 mm/hr of rainfall intensity in July and August 2014. As a result, the total outflow reduction efficiency of the Treatment-Train-package (T2P) System was about 60~70%.

Keywords: *Low Impact Development (LID), Treatment-Train-Package System, Permeable Brick Pavement , Vertical Infiltration Pipes, initial rainwater treatment system*

1. Introduction

Cities have been suffered from related problems such as urban drought, urban flooding and heat wave. To resolve this problem, Low Impact Development, a process to manage the rainfall runoff as it occurs has been receiving attention [1]. Permeable areas shall be increased and the rainfall runoff shall be delayed and decreased. In cities, however, there are limited impervious surfaces that can be converted into permeable areas. In this context, it is necessary to develop an efficient and dimensional application of LID technology [2].

The study has conducted the trial application of T2P System in the Korea Institute of Civil Engineering and Building Technology (KICT) to develop LID technology applicable to urban areas. This system enables the utilization of limited space dimensionally by connecting the PBP, permeable retention tank, rainwater storage tank, VIP, green strips, etc. so as to retain, penetrate, process and use rainwater effectively on the road. This study is to evaluate the applicability and runoff reduction rate of the Treatment-Train-Package System on the road and walkways.

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2. Materials and Method

2.1. Structure and Principles of Treatment-Train-Package System

In T2P System, the rainwater is infiltrated into the ground and retained in an permeable retention tank installed under the PBP. The vertical infiltrator installed between pavement and planting area infiltrates rainwater from the pavement and supply water to the planting area. When the infiltration retention facility's infiltration ability decreases, rainwater is retained. If it goes over a certain water level of the facility, the rainwater finds its way into a rainwater storage tank. Runoff water on the impervious road is collected through the gutter and flows into the rainwater storage tank through the initial rainwater treatment system. The rainwater retained in the rainwater storage tank can be used for landscape irrigation in green areas. If the water level in the rainwater storage tank reaches a certain level due to continuous rainfall, the water is discharged through a storm sewer.

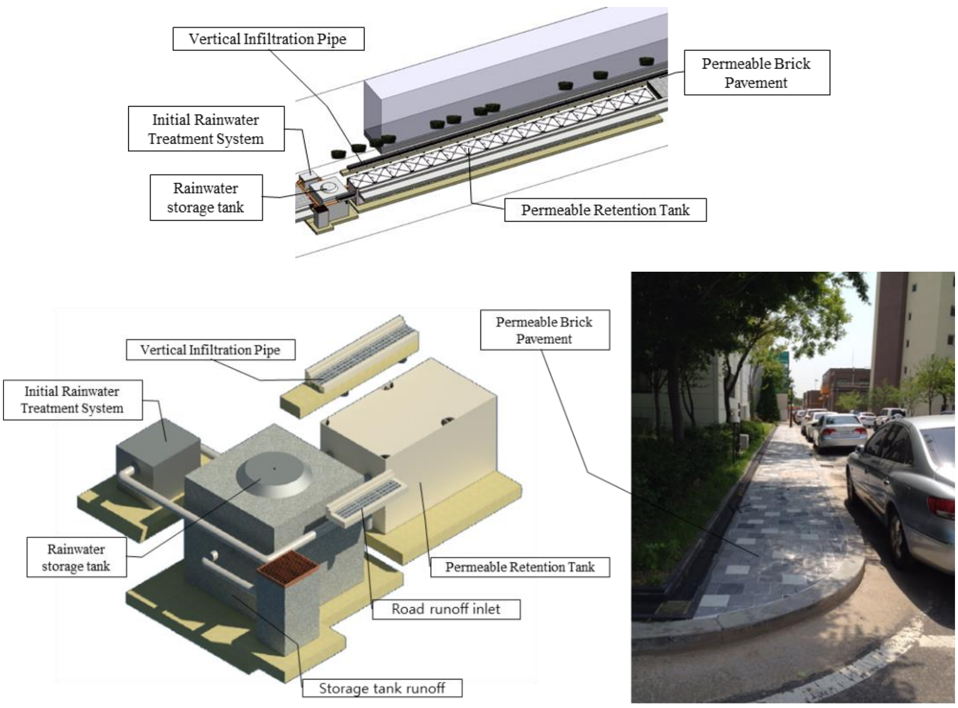


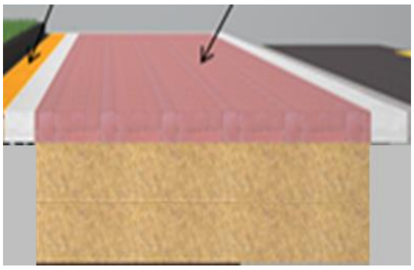
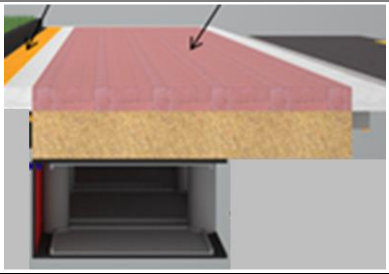
Figure 1. Design of Treatment-Train-Package System

In order to analyze the volume of rainwater inflows/outflows, the data of rainfall event with more than 30 mm of rainfall or more than 15 mm/hr of rainfall intensity in July and August 2014 were collected. The catchment area for the road surface was 62.7 m^2, PBP 38.4 m^2, and the catchment base in total area is 101.1 m^2. The capacity of the permeable retention tank, initial rainwater treatment system and rainwater storage tank was 12 m^3, 0.13 m^3, 1 m^3 respectively. The overflow drain connected to the sump was installed at a height of 70 cm height inside the rainwater storage tank. Rainfall data used the data of rain gauges installed in the T2P System.

2.2. Infiltration Capacity of the Permeable Brick Pavement

The field permeability of the PBP was tested with permeable retention tank and without permeable retention tank. The field permeability test was carried out to evaluate the infiltration capacity of the permeable brick through the formula (1) using a KS F 2394 in the Korean Standards Service Network [3]. The field permeability test can be carried out after 24 hours of antecedent precipitation and this experiment was carried out the experiment after 4 days of a dry period, and the life of the permeable brick is about 9 months. The measurement was conducted by selecting two points at 1m intervals in two sections.

Table 1. Experimental Section of PBP Infiltration Capacity

A1, A2 : General PBP section	B1, B2 : The PBP section with Permeable Retention Tank
	

$$I = \frac{K \times M}{D^2 \times t} \tag{1}$$

I : Infiltration capacity (mm/sec)
M : Weight of water (kg)
D : The inner diameter of the penetration ring (mm)
t : Time required to complete the infiltration (sec)
K : Unit conversion coefficient, 1273240.56 (mm^3/kg)

2.3. Infiltration Capacity of Vertical Infiltration Pipe

A rectangular impermeable stick pin that can include a water pipe was installed in the VIP test. The test was performed on 2 groups: Installed VIP and Non-installed VIP (control group). The test was performed based upon the infiltration capacity test method (ASTM C 1701) and used by the formula (2) to evaluate the retention capacity of the permeable brick. The details are as follows [4]. A prewetting work was performed on the road prior to performing this test. Water was injected into the center part of the road until the infiltration water is occurred in both water pipes (water quantity used: 3.6 kg). In this test, the water was supplied before the overflow of the water pipe and the measurement was performed based on the quantity of water used, 5 and 10 kg in order. The experiment was performed twice in January 2015 (winter) and July (summer). Both experiments dry period lasted more than 24 hours.

$$I = \frac{K \cdot M}{a \cdot b \cdot t} \tag{2}$$

I : Infiltration capacity (mm/sec)
M : Weight of water (kg)
a : Width of waterproof wall
b : Length of waterproof wall
t : Time required to complete the infiltration (sec)
K : Unit conversion coefficient, 1273240.56 (mm^3/kg)

2.2. Water Quality Monitoring

Te pH, turbidity and daily amount of rainfall flow in the retention facility from April to September 2014 was monitored. As for the rainfall on the 12th Jun. 2014, rainwater at the side of the road right before flowing into the system and was retained in the retention facility was sampled to measure turbidity, chromaticity, general bacteria, *colon bacillus group*, T-N, T-P, heavy metals (Cu, Fe, Cd, Hg), etc. Rainwater that has flowed into the rainwater storage tank passes through four wooden chip filter plates built vertically.

3. Results and Discussion

3.1. Treatment-Train-Package System

As shown in Figure 2, in PBP, infiltration and retention was prevalent. The changes of levels in the permeable retention tank were from 0 to 9 mm and it was mostly infiltrated into the underground. As rainwater from the road went through the T2P System, there was some loss of residual water and the sudden inflow caused an overflow. When the initial rainfall was more than 5 mm/10min rainwater, the flows were measured on the initial-rainwater treatment system. When it comes to the total runoff reduction, around 60~70% of efficiency was observed.

Table 2. Runoff Area and Amount of Collected Water: Total Catchment Area on the Road (M^2): 101.1, Coefficient of the Runoff : 0.8

Rainfall event	Rainfall depth (mm)	Rainfall intensity (mm/hr)	Total runoff amount (m^3)	Infiltration and retention amount (m^3)	Runoff reduction (%)
2014.07.09	41.0	30.8	3.3	2.4	72.6
2014.07.23	20.0	20.0	1.6	1.0	60.0
2014.07.24	59.2	8.1	4.8	2.9	60.5
2014.07.25	50.0	25.0	4.0	2.4	59.5
2014.08.10	42.5	28.3	3.4	2.3	67.6
2014.08.29	34.8	20.8	2.8	1.9	67.0

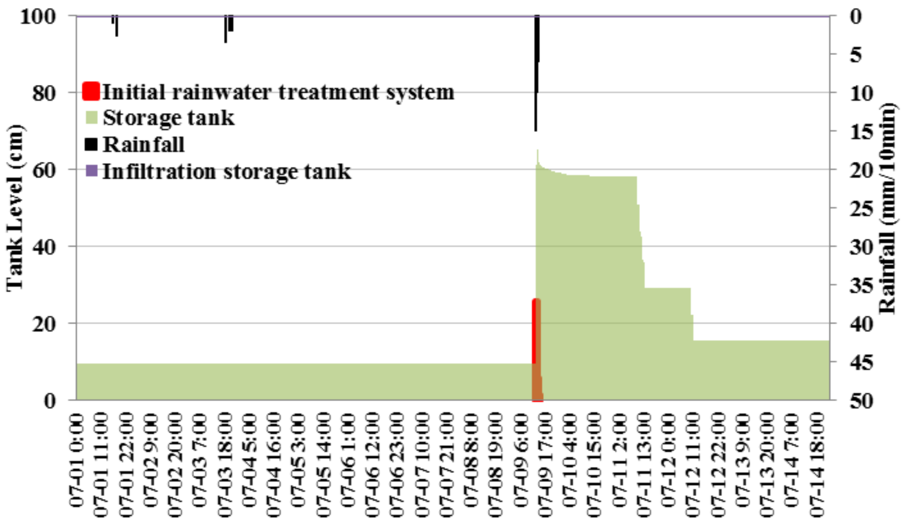


Figure 2. Variation of Water Levels in the Treatment-Train-Package System Depending on the Rainfall Depth; (Rainfall on the 9th July 2014, Rainfall Depth: 41 Mm, Rainfall Intensity: 30.8 Mm/Hr,)

3.2. Permeable Brick Pavement

In the case of Zone A, the infiltration capacity of Experiment 1 point A1 was 25% higher than the A2 point and the Experiment 2 point A1 was 5% higher than the A2 point. The infiltration capacity of the Ex. 3 point A1 was 8.3% lower than the A2 point. In the case of Zone B, the infiltration capacity of the Ex. 1 point B1 was 38.5% higher than the B2 point. The infiltration capacity of the Ex. 2 point B1 was 7.7% lower than the B2 point. The infiltration capacity of the Ex. 3 point B1 was 38.5% higher than the B2 point. The Ex. 3 showed that the same infiltration capacity of B1 and B2. When comparing the average of the infiltration capacity of the experiment zone A and B, the zone A infiltration capacity of the Ex. 2 was reduced from about 48.5% compared to the infiltration capacity of Ex. 1. The Zone B infiltration capacity of Ex 2 was reduced 45% compared with Ex. 1. The infiltration capacity in the Ex. 3 of zone A, B was reduced approximately 66.7%, 57.6% respectively, than that of the Ex. 1. The average infiltration capacity of the zone A was 0.23 mm/sec and zone B is 0.34 mm/sec. It appeared that the infiltration capacity of the section of the permeable retention tank is better.

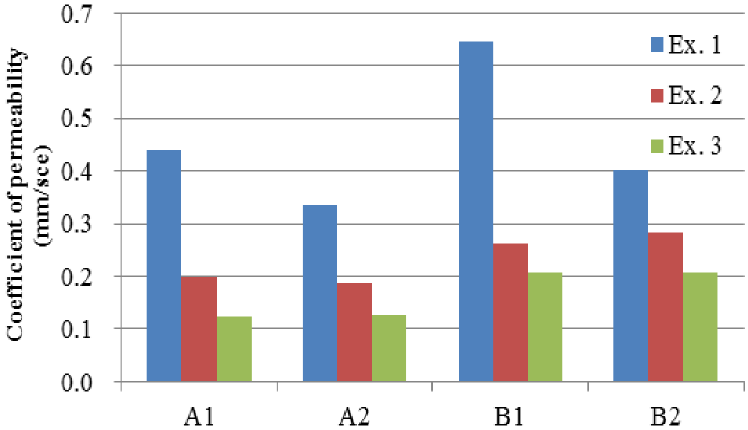


Figure 3. Coefficient Permeability of Permeable Bricks in Accordance with each Section

3.3. Vertical Infiltration Pipe

3.6 kg (prewetting), 5 kg and 10 kg were injected to areas with the VIP and without the VIP. As a result, in January, the infiltration capacity (mm/sec) of one VIP was measured to be about 0.285~0.332 mm/sec, and this confirmed that the capacity has increased by about 21.4% compared to the non-installed VIP. In July, the infiltration capacity was measured to be about 0.279~0.326 mm/sec, which has increased by about 26% compared to the non-installed VIP. Except for the non-installed VIP prewetting, the infiltration capacity in January results shows that it is higher than in July.

Table 3. Infiltration Capacity Installed in Accordance with the VIP.

	Infiltration capacity (mm/sec)				Hours required to complete infiltration (min)			
	Non-installed VIP		Installed VIP		Non-installed VIP		Installed VIP	
	JAN	JUL	JAN	JUL	JAN	JUL	JAN	JUL
Prewetting (3.5 kg)	0.392	0.416	0.478	0.475	5.1	4.8	4.2	4.2
1st (5 kg)	0.25	0.255	0.332	0.326	11.0	11.1	8.5	8.7

	7							
2nd (10 kg)	0.228	0.195	0.285	0.279	24.8	29.1	19.8	20.3

3.4. Water Quality

June 12, 2014 at 30 mm/day rainfall, the water quality of rainwater was analyzed before entering the initial-rainwater treatment system and rainwater storage tank. Turbidity, Chromaticity, General Bacteria, Total Colon Bacillus Group, T-N, T-P were removed by about 25~59%, and the T-N and T-P increased by 20~46%. After this was mixed with previous rainwater in the storage tank it was determined that the concentration is increased.

Table 4. Water Quality Before and after Entering the Initial-Rainwater Treatment System

Water Quality Constituents	Unit	Before entering the system	Rainwater Storage Tank	Removal
Turbidity	NTU	28.6	17.3	40%
Chromaticity	Degree	16	12	25%
Total Colon Bacillus Group	MPN/100mL	37	15	37%
General Bacteria	CFU/mL	347	219	59%
T-N	mg/L	0.54	1.79	-46%
T-P	mg/L	0.05	0.06	-20%
Cu	mg/L	0.00	0.00	-
Fe	mg/L	0.000	0.000	-
Cd	mg/L	0.00	0.00	-
Hg	mg/L	0.00	0.00	-

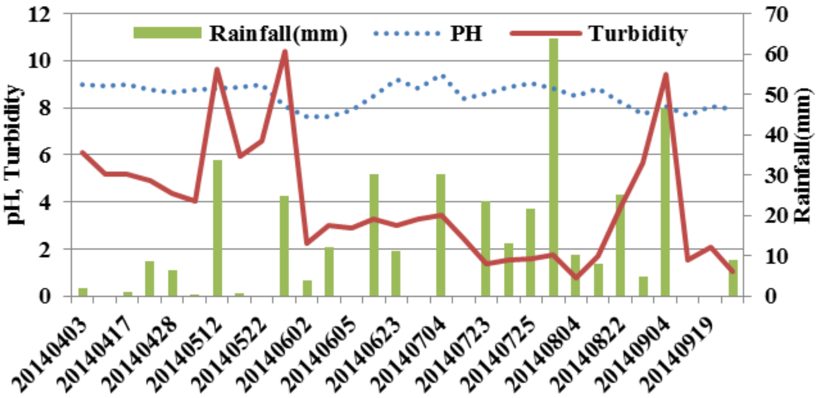


Figure 4. The Ph and Turbidity Variations According to the Amount of Retained Rainwater in T2PS

The pH, turbidity and daily amount of rainfall flow in the retention facility was monitored. As for the pH, it had the alkalescence with a range of 7.4~9.4 at the beginning, but it showed a relatively stable pH within a range of the neutral pH as the monitoring developed. This is considered to be due to the concrete elements inside the manhole affected the pH level since the facility was completed in August 2013.

4. Conclusion

1) The data of rainfall event with more than 30 mm of rainfall or more than 15 mm/hr of rainfall intensity in total catchment area 101.1 m^2, the outflow reduction efficiency of T2P System was found to be 60~70%. The rainfall management systems can be effective, but the road surface rainwater flows was measured from the relatively copious rainfall of 5 mm/10min. This result was expected that the rainwater might have caused a loss of the system flows. Later, it is determined to require a supplement to the structure of the system.
2) The average infiltration capacity of the permeable bricks without the permeable retention tank and with the permeable retention tank was 0.23 mm/sec and 0.34 mm/sec. However, the amount of rainwater infiltration was not nearly stored in the storage tank. It is necessary to improve the storage function of the permeable retention tank for more effective reuse of rainwater. The VIP installed between pavement and planting area infiltrates rainwater from the pavement area. It is determined to be a more efficient management of runoff by combining the VIP and PBP.
3) The rainwater stored in the system was expected to be appropriate for use in landscaping water and road washing water. Therefore it will have to study ways to increase the storage efficiency of the permeable retention tank.

The various research are needed to solve the problems such as urban drought, urban flooding and heat wave through the stormwater runoff management of the T2P System. T2P System, it is necessary to increase the water collecting and storage efficiency by improving the structure. Also the connection systems with other LID facilities and the more detailed effect verification are required. This study is being continued even now for the efficient application of the urban areas of the LID facility.

Acknowledgements

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