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Analysis of Reduction Effects of Impermeable Concrete and Permeable Block Pavements using Rainfall Simulation Experiment

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Abstract: The expansion of impervious surfaces due to urbanization increases stormwater runoff and reduces infiltration, thereby intensifying urban flooding and disrupting the natural water cycle. Among the Low Impact Development (LID) practices developed to address these problems, permeable pavement is a representative measure that can reduce peak discharge and total runoff volume by allowing rainfall to infiltrate through the pavement surface and underlying layers. In this study, the hydrological performance of permeable block pavement was experimentally evaluated, and its rainfall–runoff characteristics were compared with those of impermeable concrete pavement. The experiments were conducted using an outdoor parking-lot-type demonstration facility installed at the Korea Green Infrastructure and Low Impact Development Center in Yangsan-si, Gyeongsangnam-do, Republic of Korea. Runoff hydrographs, peak discharge, and total runoff volume were analyzed using monitoring data. The results showed that the permeable block pavement reduced both peak discharge and total runoff volume compared with the impermeable concrete pavement. At inflow rates of 25 and 30 L/min, peak discharge was reduced by 40.99% and 42.27%, respectively, while total runoff volume was reduced by 8.61% and 11.00%, respectively. These findings indicate that permeable pavement can contribute to improving the urban water cycle and reducing stormwater runoff. Therefore, the selection of *pavement type should consider site conditions and stormwater management objectives.*

Keywords: Low Impact Development, permeable pavement, water cycle, rainfall simulation, peak runoff

I. Introduction

Globally, urban flooding damage has continued to increase due to rapid urbanization and the effects of climate change, including changes in rainfall patterns and the increasing frequency of localized heavy rainfall events [1,2]. As cities expand, natural land surfaces are replaced by roads, parking lots, buildings, and other impervious surfaces. This transformation reduces the infiltration of rainfall into the ground and increases surface runoff, runoff volume and peak discharge. It also shortens the time required for stormwater to reach drainage systems, thereby increasing the risk of urban flooding and placing greater pressure on existing drainage infrastructure. In addition, reduced infiltration can decrease groundwater recharge, disturb the natural balance of the urban water cycle, and contribute to stream depletion and water quality deterioration. Accordingly, the need for Low Impact Development (LID) techniques has been emphasized to protect human lives and property from flood-related disasters, promote sustainable urban development, and restore natural hydrological functions [3-5]. Unlike conventional drainage systems that rapidly collect and discharge stormwater through pipes, LID techniques manage rainfall near its source through infiltration, storage, filtration and delayed release. Representative LID practices include green roofs, rain gardens, infiltration trenches, vegetated swales, and permeable pavement. These techniques are intended to reduce runoff, delay peak flow, improve groundwater recharge, and restore water cycle processes altered by urbanization. Among the various LID techniques, permeable pavement has attracted considerable attention because it can be applied to roads, sidewalks, and parking areas while maintaining the function of the paved surface. Permeable pavement allows rainfall to pass through pores or joints in the surface layer and to be temporarily stored within the underlying pavement structure. This process can reduce surface runoff, delay runoff generation, decrease peak discharge, and contribute to groundwater recharge and urban water cycle restoration [6,7]. However, its hydrological performance may vary depending on pavement material, structural configuration, rainfall intensity, and site conditions. Therefore, experimental verification is necessary to quantitatively evaluate its effectiveness. Accordingly, this study aims to experimentally verify the effects of permeable pavement application on urban water cycle efficiency by comparing rainfall–runoff characteristics under permeable and impermeable pavement conditions. In particular, runoff hydrographs, peak runoff, and runoff volume are analyzed to evaluate the runoff reduction and delay effects of permeable pavement. The results are expected to provide basic data for selecting and applying permeable pavement as an effective LID technique for sustainable urban stormwater management.

II. Experimental Section

Experimental Facility and Comparison Groups

The experiment was conducted using a parking-lot-type Low Impact Development (LID) demonstration facility installed at the Korea GI&LID Center on the Yangsan Campus of Pusan National University in Yangsan-si, Gyeongsangnam-do, Republic of Korea. Each experimental section was constructed as an isolated box measuring 10.85 m in length, 2.3 m in width, and 0.9 m in height (Figure 1). This box-type configuration prevented rainfall from infiltrating into the surrounding soil or the underlying native ground, thereby allowing the runoff generated from each pavement section to be measured independently.Two pavement types with the same surface area were compared under identical inflow conditions. The impermeable concrete pavement was used as the control because it did not provide infiltration or storage functions. The permeable block pavement was used as the experimental section because rainfall could pass through the pores and joints of the surface layer, be temporarily stored within the underlying layers, and be discharged with a time delay. This design enabled direct evaluation of differences in runoff generation, peak discharge, total runoff volume, runoff duration, and runoff delay caused by pavement type.

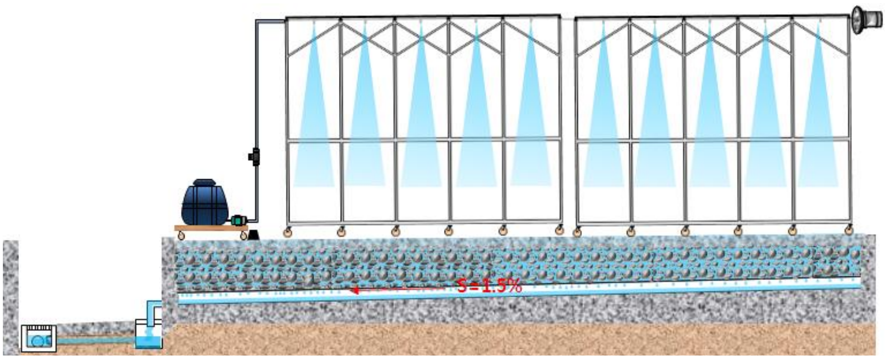

Figure 1: Concept of permeable pavement experiment

Permeable Block Pavement and Impermeable Concrete Pavement

The impermeable concrete pavement prevented rainfall from passing through the surface layer. Therefore, the applied rainfall was rapidly converted into surface runoff and conveyed toward the drainage outlet. This response generally produced a steeper rising limb of the runoff hydrograph and a higher peak discharge than those observed for the permeable block pavement.The permeable block pavement consisted of a permeable surface layer, a sand layer, and a crushed-stone subbase. Rainfall infiltrated through the pores and joints of the surface layer and was then distributed and partially filtered within the sand layer. The infiltrated water was temporarily stored in the crushed-stone subbase before being discharged through the drainage system. Consequently, runoff from the permeable block pavement was delayed, and its peak discharge was reduced compared with that from the impermeable concrete pavement (Figure 2).

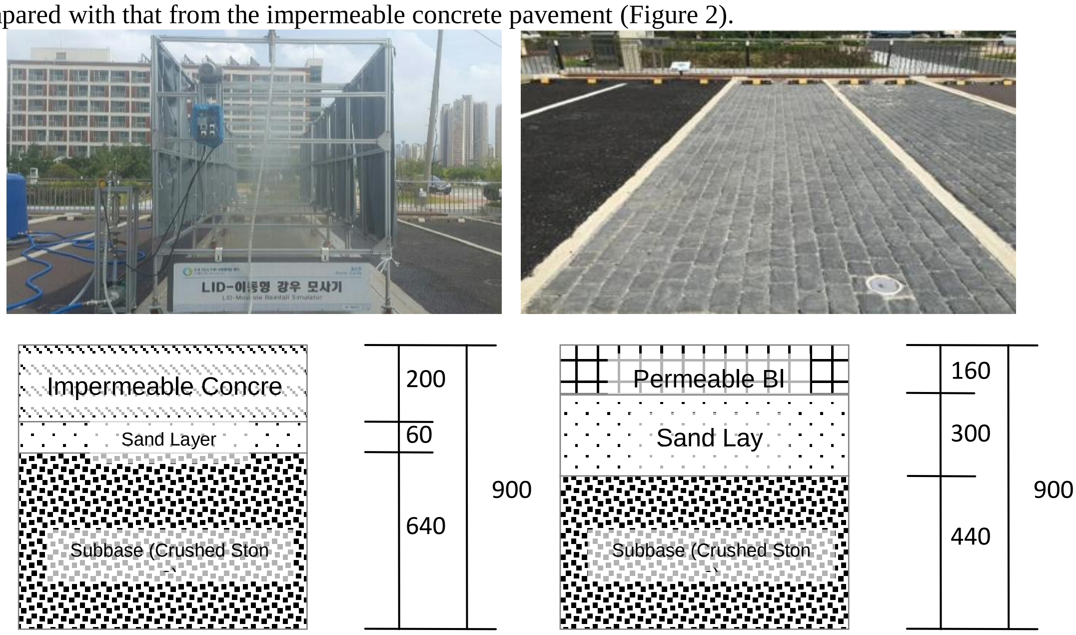

Figure 2: Impermeable concrete and permeable block pavement

Rainfall Simulator

Artificialrainfall was applied using a movable and modular rainfall simulator designed to distribute water uniformly over the pavement surface (Figure 3). The basic frame consisted of 2 m × 2 m units, and multiple units could be combined to form rainfall areas of 2 m × 6 m or 2 m × 4 m, depending on the experimental section. Multiple spray nozzles were installed along the upper pipeline, and side screens were used to minimize spray loss caused by wind during outdoor experiments.Water stored in the tank was supplied to the nozzles using a pump. The target inflow rate was controlled using a flow meter, a regulating valve, and a bypass line. The simulator was capable of applying inflow rates from 15 to 30 L/min. The same inflow rates of 25 and 30 L/min were applied to both pavement types.

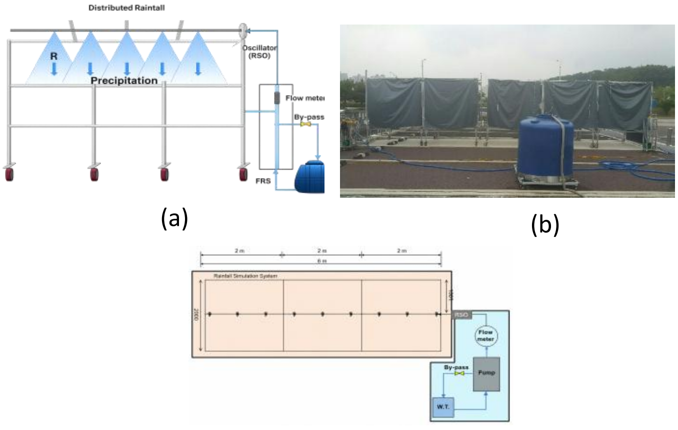

Figure 3: (a). rainfall simulator, (b). experimental site and, (c). plan view and hydraulic system

Experimental Procedure

The storage tank, pump, flow meter, bypass valve, pipelines, and spray nozzles were first checked to confirm that the rainfall simulation system was operating normally. After the equipment inspection, the target inflow rate was set to either 25 or 30 L/min using the flow meter, regulating valve, and bypass line, and the system was operated until a stable flow condition was achieved. Artificial rainfall was subsequently applied to both the impermeable concrete pavement and the permeable block pavement under the same inflow-rate and experimental-area conditions. During the rainfall simulation, time-series runoff data were continuously recorded using the monitoring system, and the collected data were converted into 5-min intervals for the construction of runoff hydrographs. After the rainfall supply was stopped, runoff monitoring was continued until the discharge had sufficiently decreased in order to capture the delayed drainage characteristics of the permeable block pavement. Finally, the peak discharge, total runoff volume, runoff duration, and runoff delay were calculated for each experiment and compared between the two pavement types.

III. Results

The differences between impermeable concrete and permeable block pavement were summarized using graphs and tables based on the 5-minute interval experimental dataset and the previously compiled experimental results. The comparison was conducted under the common inflow conditions of Q = 25 and 30 L/min.

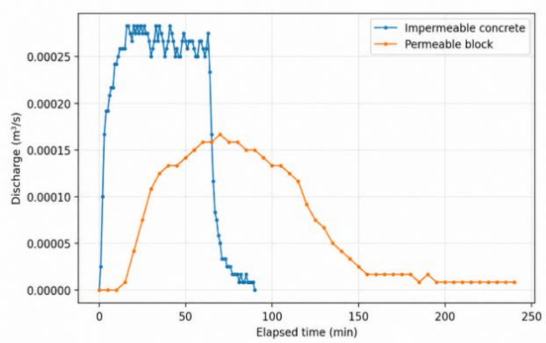

Figure 4: Comparison of runoff hydrographs for impermeable concrete and permeable block pavement at Q =25L/min

For the impermeable pavement, peak discharges of 0.000283 and 0.000317m³/s were measured at inflow rates of 25 and 30L/min, respectively, while the corresponding runoff volumes were 5.11 and 6.00m³. Both peak discharge and runoff volume increased with the inflow rate, indicating that rainfall applied to a pavement surface without an infiltration function was rapidly converted into direct runoff (Figure 4).

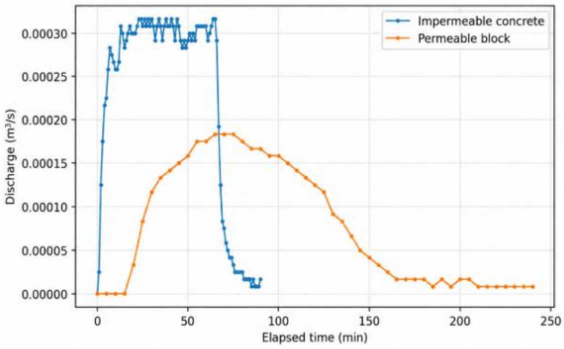

Figure 5: Comparison of runoff hydrographs for impermeable concrete and permeable block pavement at Q = 30 L/min

The runoff from the impermeable concrete pavement increased rapidly and reached the peak within a relatively short period. In contrast, the permeable block pavement showed a lower peak discharge and a tendency to delay runoff over a longer period (Figure 5).

Table 1: Summary of experimental results for impermeable concrete

Q (L/min)	Rt (mm)	Qp (m³/s)	V (m³)
30	72.13	0.000317	6.00
25	60.11	0.000283	5.11

Table 2: Summary of experimental results for permeable block pavement

Q (L/min)	Rt (mm)	Qp (m³/s)	V (m³)
30	72.13	0.000183	5.34
25	60.11	0.000167	4.67

Table 3: Comparison between impermeable concrete and permeable block pavement

Q (L/min)	Impermeable concrete Qp (m³/s)	Permeable block pavement Qp (m³/s)	Peak-discharge reduction (%)	Impermeable concrete V (m³)	Permeable block pavement V (m³)	Runoff-volume reduction (%)
25	0.000283	0.000167	40.99	5.11	4.67	8.61
30	0.000317	0.000183	42.27	6.00	5.34	11.00

IV. Conclusion

This study experimentally evaluated the hydrological performance of permeable block pavement by comparing its rainfall–runoff characteristics with those of impermeable concrete pavement under identical rainfall simulation conditions. The experiments were conducted using a parking-lot-type LID demonstration facility at inflow rates of 25 and 30 L/min.The experimental results showed clear differences in runoff characteristics between the two pavement types. The impermeable concrete pavement generated runoff rapidly and exhibited a relatively high peak discharge, whereas the permeable block pavement showed a lower peak discharge and a delayed response due to infiltration and temporary storage within the pavement structure. At an inflow rate of 25 L/min, the peak discharge decreased from 0.000283 m³/s for the impermeable concrete pavement to 0.000167 m³/s for the permeable block pavement, corresponding to a reduction of 40.99%. At 30 L/min, the peak discharge decreased from 0.000317 to 0.000183 m³/s, corresponding to a reduction of 42.27%. The total runoff volume was also reduced from 5.11 to 4.67 m³ at 25 L/min and from 6.00 to 5.34 m³ at 30 L/min, resulting in runoff-volume reductions of 8.61% and 11.00%, respectively.

V. Acknowledgements

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