LABORATORY EXPERIMENTAL ANALYSIS OF STORMWATER RUNOFF DECREASE EFFECTS BY USING POROUS PAVEMENTS IN URBAN AREAS

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Abstract: As one alternative to alleviate damages caused by stormwater runoff, the effects of runoff quantity reduction are analyzed when porous pavement is used. Porous pavements with various depths, general pavement and an artificial rainfall generator are installed for laboratory experiments. Runoff changes are analyzed according to the various rainfall durations. The rainfall intensity of 150 mm/hr is generated for 30 minutes, 60 minutes, and 120 minutes. For porous pavements with 80 cm thickness, 100%, 93%, 56% of discharge is infiltrated through soil, respectively. For porous pavements with 20 cm thickness, 81%, 32%, 28% of discharge is infiltrated through soil, respectively. It is found that the porous pavements are able to decrease the runoff.

Keywords: porous pavement, effects of runoff quantity reduction, stormwater

1. INTRODUCTION

In Korea, average annual precipitation is around 1,283 mm of which 2/3 of total precipitation is concentrated between June and. This temporal unbalance makes management of water resources difficult. Also, urban population throughout the nation is continuing to grow at a rapid rate accounting for an increase in impervious portion of natural basins, causing permanent changes in the stormwater regime and leading to larger volume of runoff and higher peak flow rates in the drainage system. Flood risk increases as urbanization continues.

Field et al. (1977) grouped the known methods and techniques for the management of stormwater runoff into structural and nonstructural measures. Structural measures include runoff control, artificial washlands, flood storage reservoirs, channel improvements, and levees/embankments. Nonstructural measures include flood proofing, flood insurance, loss compensation, flood warnings, and property acquisition.

Kuo et al. (1991) developed the optimum pumping and sewage system design method to alleviate the urban floods. Olsen et al. (1998) stressed the importance of regional flood management rather than individual floodplain management.

Flood damages keep increasing in urban areas, despite the efforts the central government and local governments made such as construction of flood control reservoirs, levees and channel modifications. Especially, floods of Northern Kyonggi-Do occurred in 1996, 1998, and 1999 consecutively caused enormous damages to life, property and income. Rapid urbanization of Northern Kyonggi-Do is considered one of the main reasons of continuous flood occurrences. In this area, several alternatives are being tried to mitigate flood damages. The purpose of this study is to present the effects of flood mitigation by using porous pavements.

2. LABORATORY EXPERIMENTS

Porous pavements have a high capability to infiltrate stormwater, to remove both solid and fine particulate pollutants in urban runoff, and also to provide groundwater recharge, low flow augmentation, and streambank erosion control. Their use has generally been restricted to low volume parking areas and sidewalk, although considerable research has been carried out to increase the strength against heavy loads. They are only feasible on sites with gentle slopes, permeable soils, and relatively deep water tables. When these conditions are met, porous pavements are reasonably cost-effective alternatives for stormwater runoff decrease. The major shortcoming associated with porous pavements is that if they become clogged it is difficult and costly to rehabilitate. Also, the cost of porous pavements is higher than general pavements.

Since runoff infiltrates through the pores of the 5-10 cm porous asphalt layer into the underground stone reservoir, infiltration capacity is closely related to the void space of underground stone reservoir. Peak runoff can be reduced for rainfall smaller than the design rainfall. The limitation of porous pavement is a possibility of insufficient underground stone reservoir storage when rainfall larger than the design rainfall occurs.

In order to quantify the effects of porous pavements to runoff decrease, it is necessary to

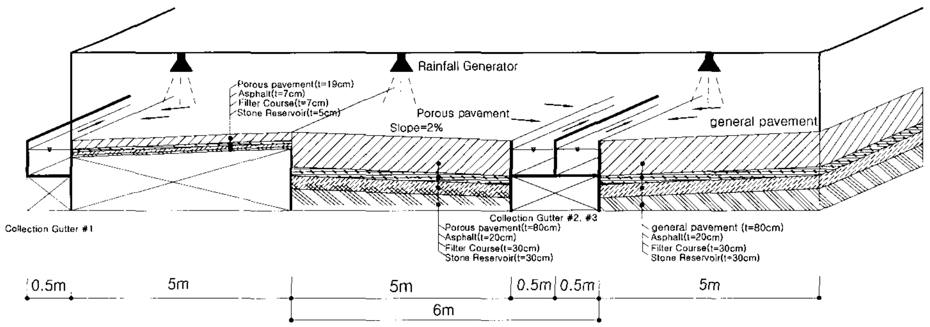
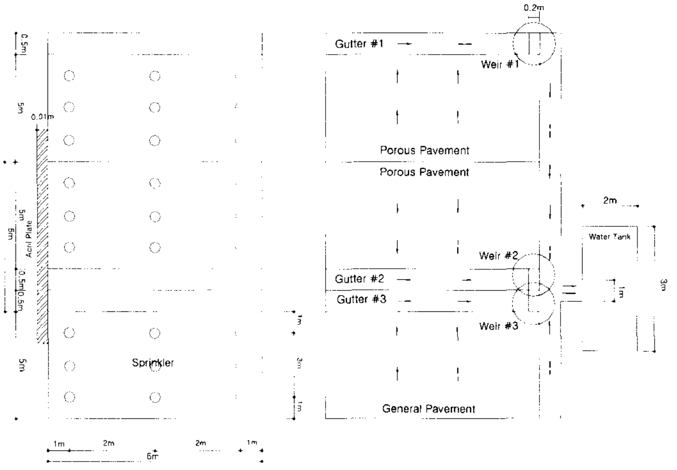


Figure 1. Schematic diagram of laboratory experiment facility



<Artificial Rainfall Generator> <Pavements>

Figure 2. Plain figure of laboratory experiment facility

identify the response characteristics of the overland flow to various types of pavements. Unfortunately, few of these data are presently available.

To investigate stormwater runoff response to various pavements, laboratory experiments were performed. A schematic representation of the experimental facility is shown in Figure 1 and 2. The facility consisted primarily of an artificial rainfall generator, three experimental surfaces (two porous pavements and one general pavement) and an arrangement for measuring the flow from the surfaces.

The artificial rainfall generator consisted of water tank, pump, flow control valve and nine discharge arms, each 6 m long, 5 m wide and 3 m high from the experimental surfaces. Each arm has three spray nozzles and is separated from the next arm by 1.5 m. Water is sprayed from the nozzles over the test surfaces. The generator can produce from minimum intensity of a 10 mm an hour to a maximum intensity of 150 mm an hour. The control valves can control the rainfall intensity.

Two porous pavements having different surface thickness and a general pavement were placed on the supporting base. The area of each pavement is 30m^2(5m by 6m). Each surface has 2% slope and three gutters are attached to surfaces to collect the overland flow from the surfaces. A standard 90°-V-notch weir is placed at the end of each collection gutter to measure the overland flow rate. The overland flow returns to the water tank and is reused as artificial rainfall.

The characteristics of pavements and artificial rainfall generator are summarized in Table 1 and 2 respectively. The result of infiltration test is also summarized in Table 3.

3. ANALYSIS OF STORMWATER RUNOFF DECREASE EFFECTS

3.1 Experiment Conditions

To compare the effects of runoff decrease for general pavement and porous pavements when the same rainfall intensity occurs over them, experiments are performed according to following conditions.

First, the experiments are performed for no antecedent rainfall condition. After an experiment, no experiment is performed for at least two days to dry the surfaces.

Second, the experiments are performed for the maximum rainfall intensity condition that is 150 mm/hr.

Third, the experiments are performed for rainfall duration of 30 minutes, 1hr, and 2hr conditions respectively.

Fourth, the records from three tipping bucket recording rain gages on each surface are averaged to get the accurate rainfall intensity.

Fifth, upstream water level in the gutter is set equal to the bottom height of V-notch weir before experiments to measure overland flow as accurate as possible.

Also, following assumptions are made for the experiments.

Table 1. Depths of porous pavements and general pavement

	Asphalt (cm)	Filter Course (cm)	Stone Reservoir (cm)	Total (cm)	Remark
Porous Pavement	20	30	30	80	Driveway
General Pavement	20	30	30	80	Driveway
Porous Pavement	7	7	6	20	Footway

Table 2. Characteristics of artificial rainfall generator

	Specification	Amount
Pump	2 HP	1
Pipes	80~100 mm	200 m
Nozzles	Large, Medium, Small (3 Sets)	81
Valves		4

Table 3. Infiltration test of each layer

	Number of Test	Time (sec)	Initial Head (cm)	Final Head (cm)	Depth (cm)	Hydraulic Conductivity (cm/s)
Stone Reservoir (General Pavement)	2	133.89	50.3	49.8	30	6.2×10^{-3}
Stone Reservoir (Porous Pavement)	2	163.98	48.5	47.5	30	10.5×10^{-3}
Filter Course (Porous Pavement)	2	10.27	47.3	38.8	30	156.1×10^{-3}
Filter Course (Porous Pavement)	2	2	48.8	38.8	7	223×10^{-3}
Asphalt (Porous Pavement)	2	10.8	48.8	38.8	20	117.9×10^{-3}
Asphalt (Porous Pavement)	2	4.4	48.8	38.8	7	101.1×10^{-3}

First, the effects caused by soil types in filter course, stone reservoir and below stone reservoir are ignored.

Second, the experiments are performed on quiet day to ignore the effects of winds.

Third, all losses except infiltration are ignored.

(1) Determination of Rainfall Intensity

The amount of total rainfall produced from an artificial rainfall generator can be computed from equation (1) considering measured rainfall intensity, area of each pavement and duration of rainfall.

$$Q = C \times I \times A \times T \qquad (1)$$

where Q is total rainfall amount generated on experimental areas (m^3); C is unit conversion factor, I is rainfall intensity (mm/hr); A is area of pavement (m^2); T is duration of rainfall (hr).

(2) Determination of Overland Flow Rate

Weirs are hydraulic structures to measure flow in sewers, streams, drains and open channels. Various types of weirs such as uncontracted horizontal weir, contracted horizontal weir, V-notch weir, and trapezoidal weir exist. They are generally classified by shape. Weirs are used for controlling upstream surface level or for measuring discharge or for both. The advantages of using weirs for measuring flow are easy maintenance and simple structure. Also, weirs have disadvantages of not being able to make accurate measurements. Since it is not essential to make very accurate measurements in this experiment, V-notch weir is used to measure overland flow rate. The discharge equation for a V-notch weir is given as

$$O_t = C_{dt} \frac{8h_t^2}{15} \tan\frac{\theta}{2} \sqrt{2gh_t} \qquad (2)$$

where O_t is discharge from V-notch weir during time t (m^3/s), C_{dt} is flow coefficient, h_t is flow head on weir (m), θ is weir angle, g is gravitational constant (9.81 m/s^2). Total volume is obtained by accumulating discharge for total runoff duration.

(3) Determination of Infiltration

Since general pavement is impervious, total generated rainfall results in discharge at the weir. On the contrary, only part of total generated rainfall results in discharge at the weir in porous pavements. Since it is assumed that no other losses exist, total amount of infiltration for runoff duration is determined by equation (3).

$$F = Q - \sum_{t=0}^{n} O_t \qquad (3)$$

where F is total amount of infiltration (m^3).

3.2 Experiments Results and Analysis

(1) In Case of 150 mm/hr Rainfall Intensity and 30 minutes Rainfall Duration

The experiment of 150mm/hr rainfall intensity and 30 minutes rainfall duration is performed on October 20, 2000 for general pavement, October 19, 2000 for porous pavement with 20 cm thickness, October 20, 2000 for porous pavement with 80 cm thickness, respectively. Total rainfall amount generated on each surface is measured 2.25 m^3, and discharges measured from V-notch weir are 2.21 m^3 for general pavement, 0.43 m^3 for porous pavement with 20 cm thickness, 0 m^3 for porous pavement with 80 cm thickness, respectively. These results are shown in Figure 3.

For general pavement, the peak discharge is observed about 10 minutes after start of rainfall, the peak discharge is maintained until the end of rainfall duration, and discharge begins to recede after the stop of rainfall.

For porous pavement with 20 cm thickness, no discharge is observed until 19 minutes after the start of rainfall. That means all rainfall infiltrates to soil through porous pavement. Discharge is increased until the end of rainfall, and it is decreased afterwards.

For porous pavement with 80 cm thickness, no discharge is observed at all. That means all rainfall infiltrates to soil through porous pavement.

(2) In Case of 150 mm/hr Rainfall Intensity and 60 minutes Rainfall Duration

The experiment of 150mm/hr rainfall intensity and 60 minutes rainfall duration is performed on October 31, 2000 for general pavement, November 1, 2000 for porous pavements with 20 cm thickness and 80 cm thickness, respectively. Total rainfall amount generated on each surface is measured 4.5 m^3, and discharges measured from V-notch weir are 4.41 m^3 for general pavement, 2.99 m^3 for porous pavement with 20 cm thickness, 0.32 m^3 for porous pavement with 80 cm thickness, respectively. These results are shown in Figure 4.

For general pavement, the peak discharge is observed about 10 minutes after start of rainfall, which is almost same as the case of 30 minutes rainfall duration. The peak discharge is maintained until the end of rainfall duration, and discharge begins to recede rapidly after the stop of rainfall. Little disturbances shown in the figure is considered as a result of winds effect.

For porous pavement with 20 cm thickness, no discharge is observed until 18 minutes after the start of rainfall. All rainfall infiltrates to soil. Discharge is increased until it reaches the peak discharge about 29 minutes after start of rainfall, the peak discharge is maintained until the end of rainfall duration, and discharge begins to recede after the stop of rainfall. Since the peak discharge from porous pavement with 20 cm thickness is little less than the peak discharge

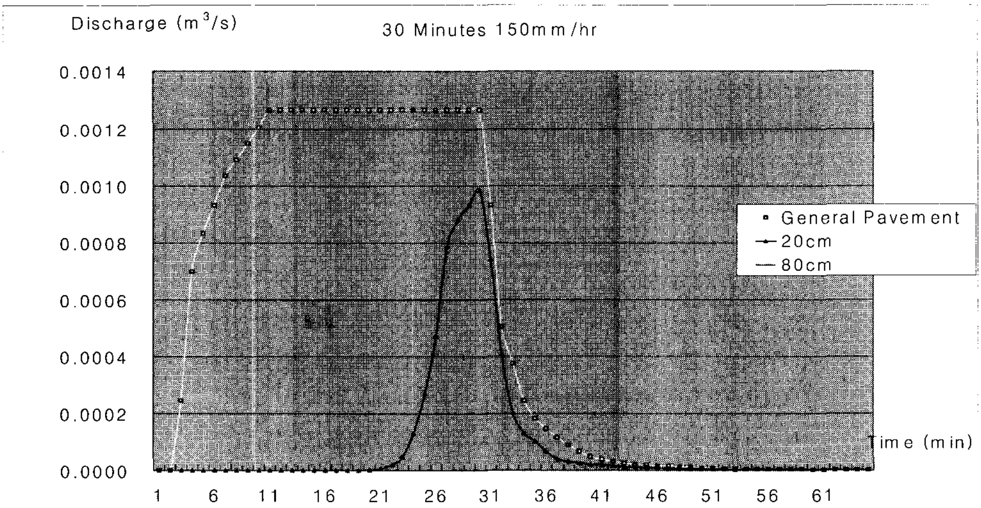


Figure 3. Results of 150 mm/hr rainfall intensity and 30 minutes rainfall duration

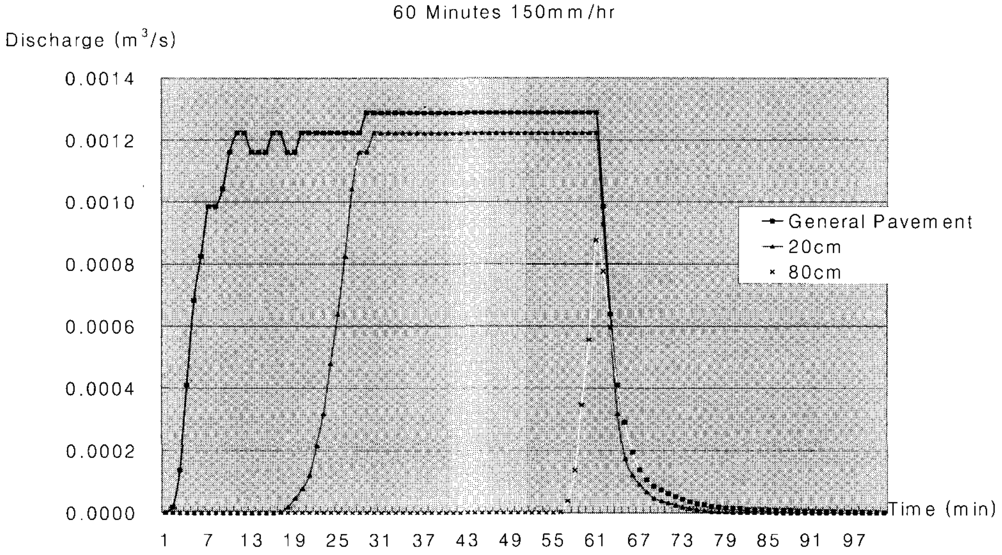


Figure 4. Results of 150 mm/hr rainfall intensity and 60 minutes rainfall duration

from general pavement, it is considered that small quantity of infiltration is continued.

For porous pavement with 80 cm thickness, no discharge is observed until 56 minutes after the start of rainfall. Discharge is increased until the end of rainfall duration, and discharge begins to recede after stop of rainfall.

Since there is big difference between maximum discharge observed in 60 minutes after the start of rainfall from porous pavement with 80 cm thickness and the peak discharge observed from porous pavement with 20 cm thickness, soils below porous pavement with 80 cm thickness is considered not to reach the saturated condition yet.

(3) In Case of 150 mm/hr Rainfall Intensity and 120 minutes Rainfall Duration

The experiment of 150mm/hr rainfall intensity and 120 minutes rainfall duration is performed on November 2, 2000 for general pavement, November 3, 2000 for porous pavements with 20 cm thickness, November 14, 2000 for 80 cm thickness, respectively. Total rainfall amount generated on each surface is measured 9 m^3, and discharges measured from V-notch weir are 8.86 m^3 for general pavement, 6.35 m^3 for porous pavement with 20 cm thickness, 3.93 m^3 for porous pavement with 80 cm thickness, respectively. These results are shown in Figure 5.

For general pavement, the peak discharge is observed about 10 minutes after start of rainfall, which is almost same as the case of 30 and 60 minutes rainfall durations. The peak discharge is maintained until the end of rainfall duration, and discharge begins to recede rapidly after the stop of rainfall.

For porous pavement with 20 cm thickness, no discharge is observed until 21 minutes after the start of rainfall. All rainfall infiltrates to soil. Discharge is increased until it reaches the peak discharge about 33 minutes after start of rainfall, the peak discharge is maintained until the end of rainfall duration, and discharge begins to recede

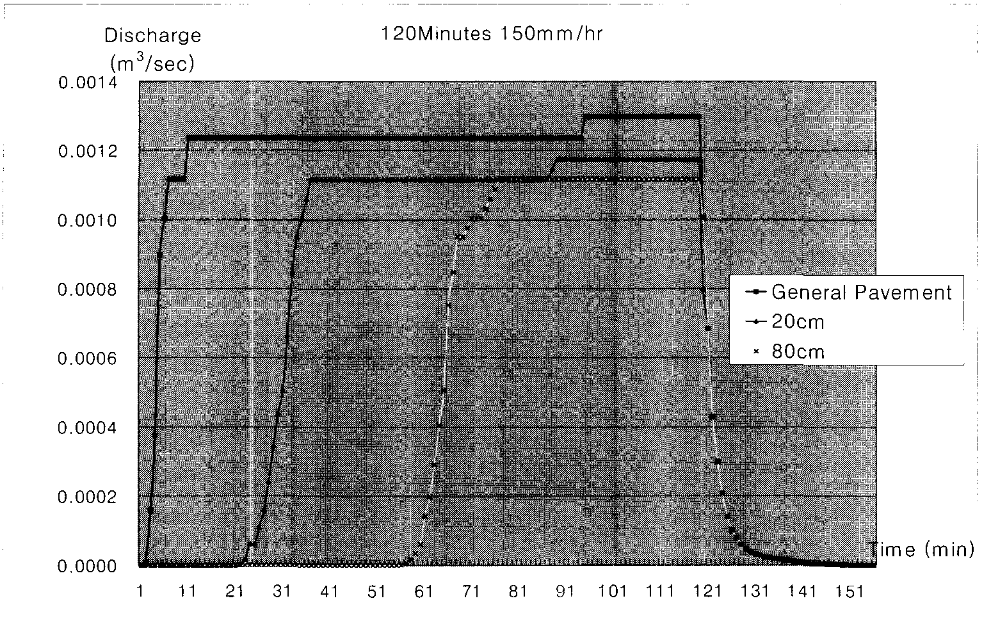


Figure 5. Results of 150 mm/hr rainfall intensity and 120 minutes rainfall duration

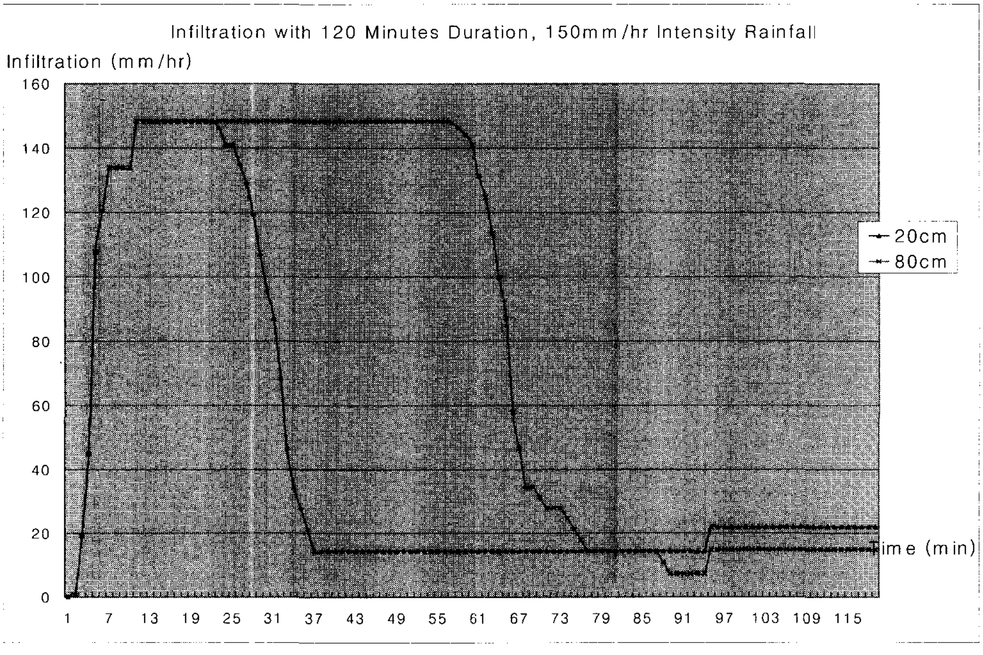


Figure 6. Infiltration through porous pavements with 20 cm and 80 cm thickness

after the stop of rainfall. Small differences compared to the case of 60 minutes rainfall duration are considered as a result of winds effect and measurement error.

For porous pavement with 80 cm thickness, no discharge is observed until 57 minutes after the start of rainfall. Discharge is increased until it reaches the peak discharge about 78 minutes after start of rainfall, the peak discharge is maintained until the end of rainfall duration, and discharge begins to recede after the stop of rainfall. Since the peak discharge from porous pavement with 80 cm thickness is little less than the peak discharge from general pavement, it is considered that small quantity of infiltration is continued.

Figure 6 presents the infiltration through porous pavements with 20 cm and 80 cm thickness with 120 minutes rainfall duration and 150mm/hr rainfall intensity. It is estimated that the initial infiltration capacity is 148.3mm/hr at the start of rainfall and the ultimate minimum infiltration capacity is 14.4mm/hr.

4. CONCLUSIONS

In this study, stormwater runoff decrease effects using porous pavements are tested and analyzed. The rainfall intensity of 150 mm/hr is generated for 30 minutes, 60 minutes, and 120 minutes. For porous pavements with 80 cm thickness, 100%, 93%, 56% of discharge is infiltrated through soil, respectively. For porous pavements with 20 cm thickness, 81%, 32%, 28% of discharge is infiltrated through soil, respectively. It is demonstrated that the porous pavements are able to decrease the runoff. Also, they are able to delay the time when peak discharge occurs. Accordingly if porous pavements can be used broadly, flood damage alleviating effects will be obtained by decreasing total and peak runoff as well as delaying peak time.

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