Investigation of Characteristic of Flow over Porous Surface for the Application in Sustainable Urban Drainage (SUDs) Infrastructure

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***Abstract*—Characteristics of flow over porous surface is investigated in this study. A dam-break flow model is used to release flow onto porous surface in the experiment. Initial water depth in the reservoir and the porosity of the porous media are related to the longitudinal and lateral propagation of the flow on the porous surface. For the wetting process, the longitudinal propagation is found to be proportional to time to the power of 0.9 for the porosities of 0.227 and 0.286 used in the study. In the draining stage, the longitudinal flow length is proportional to time to the power of -2.4 and -2.9 for porosities of 0.227 and 0.286 respectively. In lateral direction, only draining characteristic was observed. The flow retracts with time to the power of -0.5. The findings from this study will provide better understanding of flow over porous media which can contribute to efficient design of Sustainable Urban Drainage System (SUDS).**

Keywords—porous surface, SUDs, flow propagation, dam-break flow model

I. INTRODUCTION

Sustainable Urban Drainage System (SUDS) is a new green approach to manage the quality and quantity of storm water by mimicking natural drainage process such and infiltration, evapotranspiration and vegetation (CIRIA, 2015). In comparison with traditional drainage system, SUDS is regarded as a more sustainable infrastructure in terms of its long-term impact on environment and social (Zakaria, 2003).

From the aspect of stormwater quantity, SUDS components such as swale, filter strip and porous pavement are used to control of stormwater runoff by attenuating the runoff peak discharge. The process of flow peak attenuation relies on control at source techniques such as retention of flow and infiltration process (Hamel et al., 2013).

Today's drainage solutions highlight the need to embrace multi-disciplinary approach in urban water management, such as surface runoff quality, visual amenity, water quality, and also biodiversity (Green, 2019). Implementing porous surface as a part of sustainable urban drainage system in places mentioned above can reduce flooding and water stagnation problems in places mentioned above. In most urban areas, only the conventional drainage systems are used. This leads to the need to increase the drainage capacity as the city activities and population grow.

In designing porous pavement for carpark and public spaces, the lateral spreading or distribution of flow plays an important role to avoid water ponding. Lateral distribution of flow on spatially contrasting permeability was studied numerically by Thompson et. al (2011). Collins et al. (2009) conducted experimental studies to investigate the performance of four types of permeable pavement and standard asphalt. They found that permeable pavement performed substantially better than standard asphalt in terms of runoff reduction and peak flow mitigation. It was pointed out that permeable pavement allows designer to have flexibility to modify porosity to suit a given location, e.g. a ponding-prone section on the road shoulder, pedestrian walkway or car park.

In this research, experimental method is used to investigate the characteristic of flow over porous media. In the next Section, the experiment setup and flow parameters measured in the experiments will be described. The temporal changes of the flow parameters are used to characterize the flow over porous media

II. METHODOLOGY

This section discusses the methods used to achieve the objective of this study. A physical experiment was carried out by releasing a fixed volume of water from a reservoir onto a porous slab The flow spreading on the porous slab was recorded by video camera and the observation results were analysed.

A. *Experimental setup*

To simulate flow over porous slab, a fixed volume of water was released instantaneously from a reservoir. The instantaneous release of water from a reservoir is also known as the dam-break flow model (Jain, 2001 and Tah et al., 2018) as shown in Figure 1. The dam-break flow model was chosen because it can be setup and conducted in the laboratory easily as it doesn't require any difficult boundary conditions and does not involve much manpower to operate. Besides, the model is very simple to operate and the materials required to build this model can be obtained easily and relatively cheap.

B. *Experimental procudure*

This experiment was carried out by first placing the porous slab on top of the porous modular. The porous modular acts as support for the slab and did not affect the outflow from the porous slab. The reservoir was filled up to initial reservoir depth Ho. When the reservoir water become still, the reservoir gate was pulled up instantaneously to release the water onto the porous slab. A video camera was installed above the porous surface to record the motion of the flow.

To investigate the effect of initial reservoir depth and porosity on the propagation of flow, four cases were considered in the experiment as shown in Table 1. Each case was repeated five times and the representative average are used to report the result in this study. Image frames of 0.2 seconds interval were extracted from the video. The longitudinal flow length at the center line, measured from the reservoir gate, L and the maximum lateral spreading length b_{max} were measured in the digital image as shown in Figure 2.

TABLE I. EXPERIMENT CASES

Case	***Porosity of slab Ø***	***Initial reservoir depth H_o (cm)***
1A	0.227	5.0
1B		10.0
2A	0.286	5.0
2B		10.0

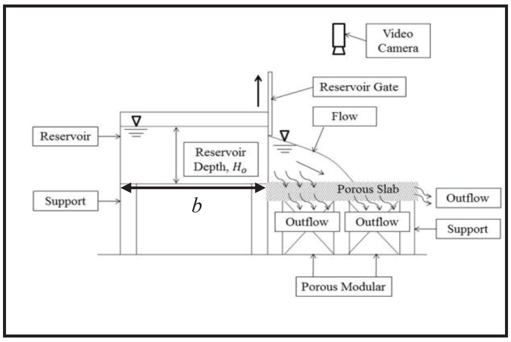

Fig. 1. Experiment setup

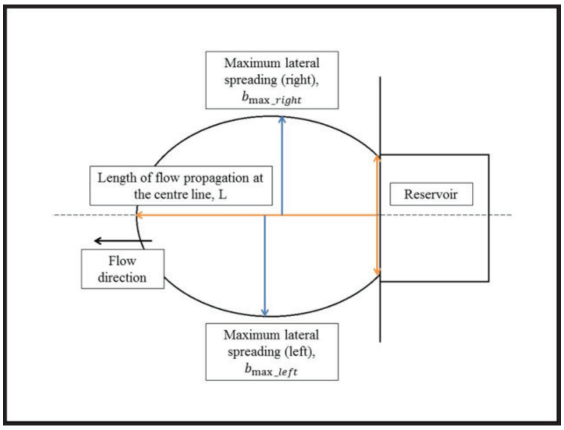

Fig. 2. Definition of L and b_{max}

In this study L and b_{max} are used as parameters to define the flow characteristics. Since the lateral spreading was not always symmetry due to uneven surface roughness and gate pulling effect, b_{max} was calculated by taking average of the left lateral spreading length b_{max_left} and right lateral spreading length b_{max_right}.

$$b_{max}=1/2(b_{max\_left}+b_{max\_right}) \qquad (1)$$

Measurement of L and b_{max} were carried out for the wetting and draining stage of the flow. Wetting stage refers to the stage where the flow is propagating forward (L is increasing). Draining stage refers to the stage where the flow is contracting (L is decreasing). By using these data, L and b_{max} were plotted against time and their characteristics slope were analysed for each cases. Therefore from the slope of the graphs, the relationships between the flow spreading

III. RESULTS AND DISCUSSION

From the experiment, it was observed that the flow propagates in longitudinal direction and at the same time spreads in the lateral direction.

The longitudinal propagation, L and maximum lateral spreading, b_{max} achieved maximum lengths before they started to retract. The flow spreading was not exactly symmetrical due to gate pulling effect (uneven pulling force) as well as non-uniform surface roughness of porous slab.

For Case 1A and 1B under similar porosity of 0.227, the maximum longitudinal propagation, L is shorter for Case 1A (L=31cm) than for Case 1B (L=63cm). The same phenomenon was observed for Case 2A and 2B under similar porosity of 0.286. L is shorter for Case 2A (L=39cm) than for Case 2B (L=61cm). Longer L in both Case 1B and 2B is because of higher initial reservoir depth, H_o. Higher reservoir depth provides larger inflow discharge from the reservoir into the porous slab, thus longer propagation length in longitudinal directions. In the case of lateral spreading b_{max}, higher H_o contributes to longer b_{max} as shown in Figure 5 for Case 1A and 1B. However, this phenomenon is not obvious for Case

2A and 2B (Figure 7). Flow in lateral spreading is thin and its propagation is dominated by surface roughness rather than inertial. High surface roughness in Case 2A and 2B might explain the slight difference in lateral spreading.

Under the same reservoir initial depth $H_o = 10$cm, both Case 1A and 2A reported almost similar maximum L of 63cm and 61cm respectively. However, when H_o = 5cm, larger differences in maximum L between Case 1A and 2A are observed, with 31cm and 39cm respectively. This larger difference might be due to thinner flow during spreading for H_o= 5cm where surface roughness plays a dominant role in flow spreading.

The maximum duration of wetting t_{max} coincides with the time when the draining process starts as depicted in Figure 4 and Figure 6. Cases with lower H_o have longer t_{max}. This phenomenon can be explained by using the classical dam-break flow model. The time t_c for first negative wave c propagating toward the upstream wall behind the gate (after the gate is pulled up) is given by the following equation (Jain, 2001],

$$t_c=b/(gH_o)^{1/2} \qquad (2)$$

b is the length of the reservoir as shown in Figure 1. Based on the classical dam-break flow solution, the depth at the gate is constant as long as the negative wave c has not reached the upstream wall (Puay, 2010). Therefore, for cases with lower initial reservoir depth H_o, t_c is longer which means the flow depth at the gate remains constant for a longer time compared with the case with higher H_o. Longer duration of constant flow depth at the gate infers longer duration of constant inflow discharge onto the porous surface. Thus, the wetting stage or maximum L can be maintained for a longer duration for cases with lower initial reservoir depth H_o.

From the temporal propagation plot of L and b_{max} in Figure 4, 5, 6 and 7, three main characteristic regions namely the ascending slope, flat slope and descending slope can be observed. The ascending slope represents the wetting stage. In the wetting stage, the flow propagates along the longitudinal direction and spreads in the lateral direction, to cover a larger area. During wetting stage, the total volume of fluid entering the porous media zone is more than the total volume of fluid infiltrated through the surface of the porous media. By denoting the rate of outflow discharge through the porous media as $Q_{outflow}$ and the rate of inflow discharge into the porous media surface as Q_{inflow}, the wetting stage (ascending slope) is characterized by $Q_{inflow} > Q_{outflow}$. During the wetting stage, L will reach a constant maximum value. This is the stage where the flow propagation achieves maximum length. This stage is characterized by $Q_{inflow} = Q_{outflow}$ and represented in the graph as a flat slope region. When $Q_{inflow} < Q_{outflow}$, the L starts to decrease. The retracting of L is reflected in the graph as the descending slope. This stage is referred to as the draining stage where the rate of outflow discharge is more than the rate of inflow discharge ($Q_{outflow} > Q_{inflow}$). The time when L starts to retract is represented by t_{max} in the graph, which is also the time where the rate of inflow is lower than the outflow rate. The wetting and draining stage conditions are summarized in Figure 3.The characteristic of flow propagation on porous surface can be described using the longitudinal propagation of flow, L and the maximum lateral spreading, b_{max} relation with time, t, such as follows,

$$L \,\alpha\, t^m \text{ and } b_{max} \,\alpha\, t^n \qquad (3)$$

Here, m and n are the characteristic coefficient. Characteristic coefficient for the propagation of L and b_{max} can be observed from their temporal plot in Figure 4,5,6 and 7 as the slope of the graph. For wetting stage, the longitudinal spreading is proportional to time to power of m=0.9 for both Case 1 and 2 with porosity of 0.227 and 0.286 respectively. Meanwhile for the draining process, the longitudinal flow is retracting with time to the power of n=-2.4 and 2.9 for the porosity of 0.227 and 0.286 respectively. It can be concluded that initial reservoir depth H_o does not affect the characteristics coefficient of the wetting and draining processes. It was found that in the wetting stage, both Case 1 and 2 with different porosity showed same flow characteristic with m=0.9. However, in the draining stage, the flow characteristic coefficient was affected by porosity as can be seen from the different value of n for Case 1 and 2. For lateral spreading b_{max} in the wetting stage, a clear general characteristic slope, m couldn't be observed. However, a characteristic slope of n=-0.5 was observed in the draining stage of the lateral spreading.

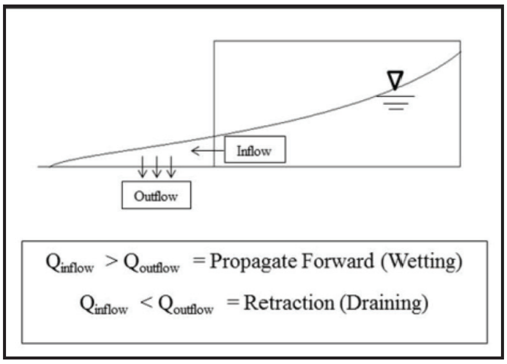

Fig. 3. Definition of Q_{inflow} and $Q_{outflow}$

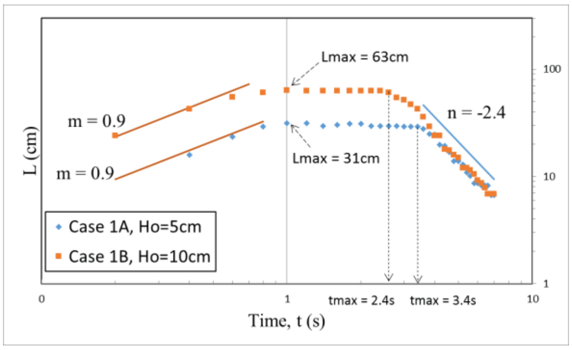

Fig. 4. Temporal propagation of L for case 1A and 1B

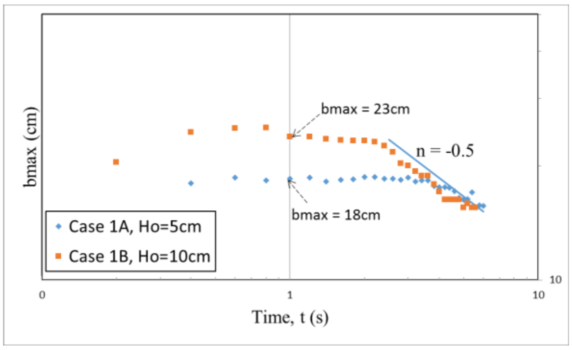

Fig. 5. Temporal propagation of b_{max} for case 1A and 1B

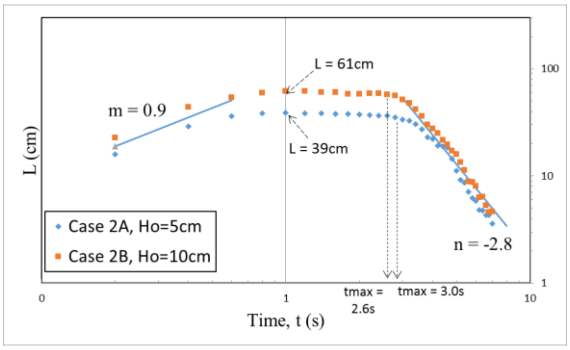

Fig. 6. Temporal propagation of *L* for case 2A and 2B

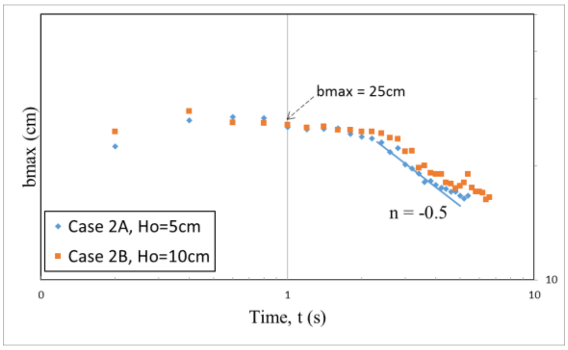

Fig. 7. Temporal propagation of b_{max} for case 2A and 2B

IV. CONCLUSION

In this study, the characteristic of flow over flow over porous surface was investigated by using an simple experimental setup of dam-break flow model. Flow released from the reservoir onto the porous surface was analyzed in terms of its longitudinal and lateral flow propagation. It was found that the characteristic zone or stage representing the wetting and draining process do exists. It was shown that the characteristics of the longitudinal propagation of flow in the wetting and draining stages are not affected by the initial depth of the reservoir. In addition, the wetting stage flow characteristic is not influenced by the porosity of the surface. On the other hand, in the draining stage, the flow showed different characteristic under different porosities.The authors wish to conduct additional experiments with different porosities to further confirm the findings established in this study and to include the effect of surface roughness.

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