FLOW CAPACITY OF A SINGLE MODULE FOR SWALE WITH SUBDRAINAGE CHANNEL

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ABSTRACT

Swale with a subdrainage channel is one of the components in the stormwater management system for control at source facilities. This paper will discuss the performance of flow capacity in a single module of the swale subdrainage channel. Using the new design of the REDAC module as a subdrainage channel, an experimental setup was carried out in a six-meter flume at the REDAC's Hydraulic Laboratory. It is found that the flow capacity in the subdrainage channel is inversely proportionate with water depth (y) for free and submerged flow conditions. Manning's roughness coefficient (n) is also found in the range of 0.002 to 0.020 under the flow conditions studied.

Key words: Manning's roughness coefficient, SUDS, Ecological subsurface module, hydraulic performance

INTRODUCTION

In tropical climate region, urbanization or any cause of land use changing (pervious to impervous surface) may lead to major stormwater problem like flash flood, water pollution and etc especially in the area that are already densely built. It happens due to the tropical climate region receives frequent and high amount of rainfall throughout the year. High rainfall depth may cause overflow from concreate drain due to the concepts of concrete drain is rapid disposal. It will cause flash flood in downstream area. To avoid these issues, stormwater management must be included in the planning for new development properly. In stormwater management, application of swale as one component of sustainable urban drainage system (SUDS) is worldwide practice. However, with tropical climate condition, surface swale only is believed cannot cater all the present runoff due to the previous sizing of swale's design was refered to the previous amount of runoff for that particular area. Thus it will cause flash flood the area. In order to increase the swale's sizing, it will need bigger area and it will increase cost. Thus, combinataion of surface swale with subdrainage module was suggested. In Malaysia, combination of surface swale and subdrainage module have been applied in order to control stormwater runoff quantity and quality. During the stormwater runoff, vegetation will absorb particulate pollutants and the flow will infiltrate through porous media into the subdrainage module. Then the water continuously flows in the module to downstream and at the same time the flow will also infiltrate into surrounded gravels and recharge the groundwater (Mohammadpour et al, 2019). This process is helping in slowing down the runoff to the downstream area and at the same time improve the quality of runoff water. Ayub et al (2005) found that that urban runoff pollutants can be controlled through the application of subdrainage module and it play a major role especially in urban areas. Most pollutants were trapped in the vegetation and porous media, and water that flow through subdrainage module will create turbulence due to the module design and that phenomenon will increace the concentration of dissolve oxugen in the subsurface runoff water.

The first pilot project in Malaysia that is related to SUDS was constructed in Engineering Campus Universiti Sains Malaysia. This project is known as Bio-Ecological Drainage System (BIOECODS) which was designed by River Engineering and Urban Drainage Research Centre (REDAC). The project was sponsored by the Department of Irrigation and Drainage Malaysia as a kick start and example for Malaysian practice that fulfills the Urban Stormwater Management Manual (MSMA) Guideline for Malaysia which was launched in 2001. Subdrainage modules become important and main part in constructing BIOECODS and manage to control water quantity and quality in urban and industrial area in a sustainable way (Zakaria et al, 2003).

RESEARCH BACKGROUND

Sustainable stormwater management has many terms like Low Impact Development (LID), Best Management Practices (BMPs), Green Infrastructure (GI) and Sustainable Urban Dariange System (SUDS). It is depending on the region and area but all these terms have the same meaning which is to promote the sustainable facilities or components that mimic to the nature. In Suzhou, China for example, the implementation of Sponge City strategy has been done incorporating LID to reduce stromwater runoff by using bio-retention cells, pearmeable pavement and stornwater gardens (Zhang et al, 2020). Similar to LID, SUDS in urban area also has many components or facilities like grass swale, green roof, on-site detention pond, bioretention, constructed wetland, detention ponds etc. Each facility will be designed based on the location of the facilities. There are three different locations to locate the facilities whether at source, site or regional. Grassed swale and green roof are components that are normally constructed at source of the runoff. Grass swales are low-cost of SUDS practices, easy to install and less maintenance. Selections of swale type are depending on the local climate, site constraints, available funding for design, construction and operation (Ekka et al., 2021). Combination of grass swales and subdrainage module will increase the capability of these facilities in attenuating runoff flow and decrease the peak flow drastically. Rizalihadi and Safiana (2015) found that, density of vegetation will affect the flow resistance in surface swale. However, flow attenuation in subdrainage module depends on the main parameter which is module roughness.

Fundamental to estimate module roughness in different channel may refer to the Manning's roughness coefficient (n) as suggested by Ab. Ghani et al (2007), Kee et al. (2011), Pradhan and Khatua (2018) and Kamali et al. (2018). Notable that parameters need to estimate Manning's coefficient in the subdrainange modul are hydraulic radius (R) channel width, flow depth and channel slope. Abd Elmoaty & El Samman (2020) were deduced two simple equations to predict the value of Manning's roughness coefficient in the vegetated channel and they concluded that field measurement managed to validate the equations. Limited studies have been done related to flow in the subdrainage module and their parameters. Based on experience in BIOECODS studies, it is difficult to determine flow depth in the subdrainage module unless installation of equipment is made in early stage of construction. Thus, to calculate or estimate flow capacity in subdrainage module is challenging due to the flows is underneath of the swales. The purpose of this paper, is to discuss and develop flow rating curve that summarize relationship between flow (Q) and water depth or flow depth (y) as one of the variables that influence flow capacity in a single modul subdrainage. The rating curve that is developed can be used as a reference to estimate flow capacity in a subdrainage channel with modules.

MATERIAL AND METHODS

The research was conducted in REDAC's Hydraulic Laboratory, Engineering Campus, Universiti Sains Malaysia and the data have been used to develop flow rating curve as the objective of this study.

Experimental setup

The experiments have been conducted in a 6-meter rectangular flume as shown in Figure 1. Five numbers of single modules designed by REDAC, with dimension of 400mm x 435mm x 710mm and thickness of 17.5mm were installed horizontally in the flume (Figure 2) as subdrainage modular channel underneath the swale. As from inlet to outlet, these modules were tag as Module 1 (M1), Module 2 (M2), Module 3 (M3), Module 4 (M4) and Module 5 (M5). To create a smooth flow in the flume, one module was installed vertically to play a role as energy dissipator at the inlet of flume, particularly to reduce the turbulence energy of flow through five single modules for velocity measurement. In order to achive flow depth (y) data, a stainless-steel control gate was installed at the end or outlet of the flume. This gate will be used in three conditions to create different flow depth namely gate fully open (GFO), gate partially open (2cm) (GPO2) from the bed flume and finally gate partially open (4cm) (GPO4) also from bed flume. Three bed slopes of 1:1000 (0.001), 1:750 (0.0013) and 1:500 (0.002), were applied in this experiment setup. Velocity and flow depth were taken at three points in the modular flume which are in module 2 (M2), module 3 (M3) and module 4 (M4). Measurement of velocity in each point were taken at 0.4y from the channel bed where y is flow depth using flowmeter. Flow discharges were calculated using Equation 1 (Eq. 1) and Manning's roughness coefficient, *n* for subdrainage module was calculated using Equation 2 (Eq. 2).

$$Q = VA \qquad \text{Eq. 1}$$

where, Q is the flow discharge (m^3/s), V is the velocity (m/s) and A (m^2) is the flow area of single module in flume.

$$n = \frac{R^{\frac{2}{3}} A}{Q}\sqrt{S} \qquad \text{Eq. 2}$$

$$R = (R1 \times R2)^{0.5} \; and \; A = (A1 \times A2)^{0.5}$$

where R is the hydraulic radius. Number 1 and 2 denotes as inflow and outflow, respectively.

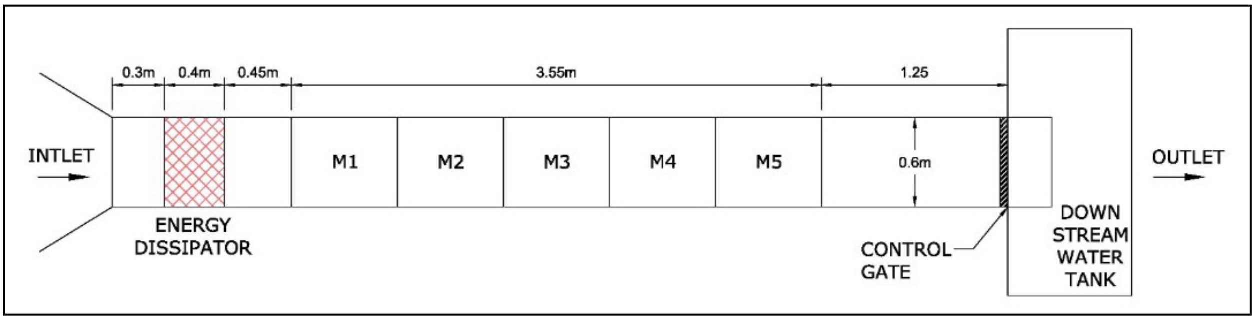

Figure 1 Plan view of the experimental setup in this study (not to scale)

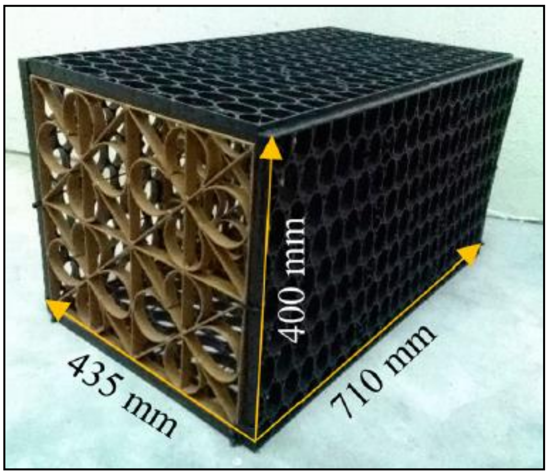

Figure 2 Bunga Cengkih vertical part design for single REDAC module (Mohammadpour et al, 2019).

Figure 3 Experimental setup in REDAC Physical Laboratory, (1) Installing single REDAC module horizontally; (2) Velocity measurement for gate fully open (GFO) and (3) Front view of gate partially open with 2cm height (GPO2)

RESULTS AND DISCUSSION

Data gained from these experiments show that the flow depth (y) varies the flow capacity in a single modul subdrainage channel depending on the gate opening conditions. The data was plotted and summarized in Figure 4. It is clearly shown that flow is inversely proportionate with flow depth with $R^2 = 0.97$ for different gate openings. It is also observed that flow condition with GFO has the highest value of flow capacity followed by GPO4 and GPO2 recorded has lowest value flow capacity.

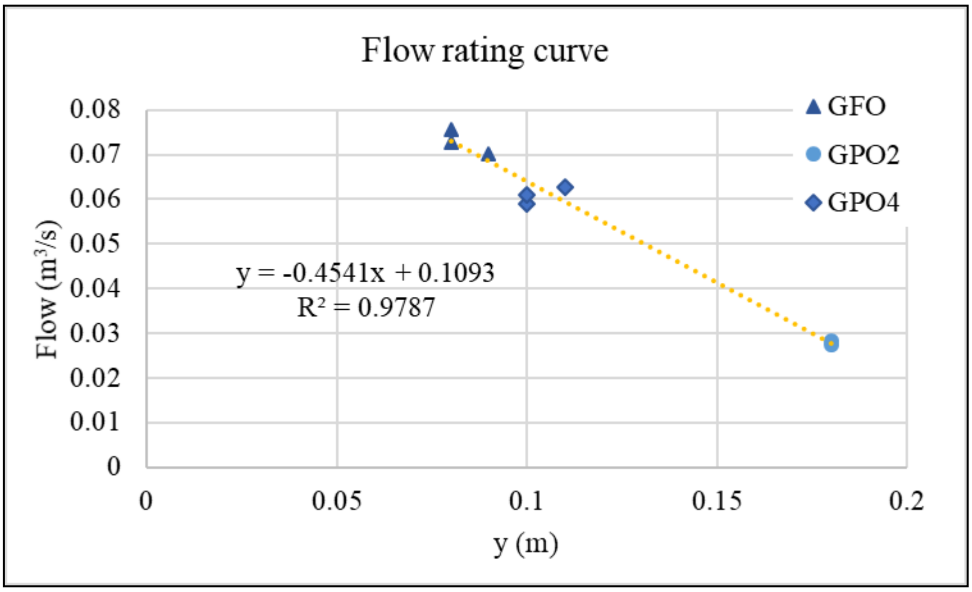

Figure 4 Correlation between flow capacity in a subdrainage single module and flow depth

In term of Manning's *n* values, result obtained were compared to Manning's *n* values in modular channel as calculated in Mohammadpour et al (2019). Present study show that the values were affected by gate opening at the outlet of flume. Flow through the single module with GFO is recorded to have the lowest values of n with a range of 0.0025 – 0.0030. For case GPO4, *n* value increases in the range of 0.0038-0.0054 and GPO2 has the highest value of n and it was recorded in the range 0.011-0.022. The present study confirms the finding by Mohammadpour et al (2019) where GPO conditions lead to higher values of Manning's *n* compare to GFO condition. This study also found that Manning's n is inversely proportionate with velocity (V) which have same trend as Mohammadpour et al (2019). The summary of present study is depicted in Table 1. The present study indicates that free flow is the best condition for the modules to act as a flow conveyance. Submerged flow conditions as simulated by the GPO in the present experimental studies show that flow resistance increases with submerged conditions.

Table 1 Summary of Manning's n calculation for the subdrainage single module (Present Study)

Case	Slope	y	A_1 (m^2)	A_2 (m^2)	A (m^2)	R_1 (m)	R_2 (m)	R (m)	V m/s	Q m^3/s	Manning's *n*
GFO	0.001	0.09	0.0387	0.0344	0.0365	0.0634	0.0583	0.0608	0.4078	0.0701	0.0025
	0.0013	0.08	0.0344	0.0344	0.0344	0.0583	0.0583	0.0583	0.4233	0.0728	0.0025
	0.002	0.08	0.0344	0.0344	0.0344	0.0583	0.0583	0.0583	0.4400	0.0757	0.0030
GPO2 (2cm)	0.001	0.18	0.0774	0.0774	0.0774	0.0980	0.0980	0.0980	0.1644	0.0283	0.0182
	0.0013	0.18	0.0774	0.0817	0.0795	0.0980	0.1009	0.0994	0.1589	0.0273	0.0223
	0.002	0.11	0.0344	0.0473	0.0403	0.0583	0.0728	0.0651	0.1422	0.0245	0.0118
GPO4 (4cm)	0.001	0.10	0.0430	0.0430	0.0430	0.0683	0.0683	0.0683	0.3433	0.0591	0.0038
	0.0013	0.10	0.0430	0.0430	0.0430	0.0683	0.0683	0.0683	0.3544	0.0610	0.0042
	0.002	0.11	0.0473	0.0430	0.0451	0.0728	0.0683	0.0705	0.3644	0.0627	0.0054

CONCLUSIONS

Attenuation of flow in urban area becomes crucial in order to combat flash flood. Subdrainage channel with single module which is located underneath of the swales is proven able to slow down the flow. The present study is carried out to evaluate the flow performance of a single module. The rating curve that is developed can be used as a reference to estimate flow capacity in a subdrainage channel with module. Two flow conditions were studied during the present experiments namely the free flow condition (GFO) and submerged flow condition (GPO2 and GPO4). Flow through the single REDAC module created the lower Manning's *n* values with free flow condition (0.0025 – 0.0030) followed by submerged flow condition, GPO4 (0.0038-0.0054) and, GPO2 (0.011-0.022). The present study indicates that free flow is the best condition for the modules to act as a flow conveyance. Submerged flow conditions as simulated by the GPO in the present experimental studies show that flow resistance increases with submerged conditions.This suggests that application of REDAC module as subdrainage channel for swale can reduce stormwater quantity in urban drainage due to low Manning's coefficient gained in this study. Implementation of swale with REDAC module as subdrainage channel for new developing area is very competent in stormwater management in order to avoid flash floods.

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