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"Flow Pattern and Hydraulic Characteristic for Subsurface Drainage Module"

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Abstract:

Grassed swales are low-cost storm-water best management practices (BMPs) which have been used extensively to reduce the peak flow of surface runoff, remove runoff pollutants by vegetation filtration as well as to enhance the groundwater recharge. Grassed swale system in Engineering Campus, Universiti Sains Malaysia (USM) is a part of Bio-Ecological Drainage System (BIOECODS) which usually being known as ecological swale. This ecological swale for BIOECODS is a dual drainage system which consist a surface swale and a subsurface drainage module in parallel arrangement. The subsurface drainage module is overlaid by a layer of porous media and a layer of top soil. A new drainage module has been produced with different pattern and internal structure recently. Apart from this, the porous media mentioned aboved which formed from clean river sand is being replaced by gravel in this current time. In previous study, the flow pattern inside the subsurface module is observed to be interesting as the flow varied between open channel flow and pipe flow. Further investigation for the flow pattern and hydraulic characteristic by subsurface drainage modules will be carried out in this study by conducting laboratory experiment under different discharge and slope conditions. Both of the pre-existing and the latest drainage modules will be evaluated. This paper discusses about the related studies, methodologies, and expected outcomes of this research. Result from this research is important in efficiency evaluation of ecological swale with subsurface drainage thus to provide information for future design of this dual drainage system.

Keyword: BIOECODS; subsurface drainage module; flow pattern; hydraulic characteristic

1. Introduction

As a result of increasing urbanization, storm water runoff problems become more severe. The urbanization has caused an increment in the imperviousness which produced increased peak flow and more runoff volume (Barber et al. 2003; Seilheimer et al. 2007; Ouyang et al. 2006). Untreated runoff which carries various pollutants such as toxins, nutrient, sediment and other pollutants has influenced the water quality in rivers and even destroyed the aquatic habitats.

In order to solve current problem, Department of Irrigation & Drainage (DID) Malaysia is embarking on a new approach of managing storm water runoff known as “control at source”. Best Management Practices (BMPs), which utilize a variety of different control measures and aim to reduce pollution problems, conserve natural water resources and also enhance the amenity value of watercourses in the urban environment, have been used for quantity and quality control. USM in collaboration with DID Malaysia, have constructed the pilot Bio-Ecological Drainage System (BIOECODS) at USM Engineering Campus, in Nibong Tebal, Penang. BIOECODS represents an alternative to the traditional hard engineering-based drainage system with the application of grass swales, subsurface modules (storage and conveyance), dry ponds, wet pond, detention pond, and constructed wetland to manage storm water quantity and quality for the campus (Zakaria et al. 2003).

Several studies had been carried out to determine the performance of the underground drains either by laboratory evaluation (Chiu and Shackelford 2000) or by field evaluation (Ahmed et al. 1997). Subsurface pipe flow dynamics studied by Ziemer and Albright (1987) proved that pipe flow occurred for nearly all of the discharge. The flow pattern in a pipe flow is a complex study where further research is needed for a deep understanding. A new storm water best management practice called an ecology ditch was constructed by using compost, sand and gravel as well as a perforated pipe drain (Barber et al. 2003). They did a modeling by modified existing unsaturated two-dimensional groundwater flow code to test the ecology ditch. It is observed that for larger storms, the ecology ditch managed a peak reduction in the range of 10 to 50%. Apart from this, a computer model for the analysis and design of grass swale and perforated pipe system is presented by Abida et al. 2007. It is obvious that these studies are more to the underground perforated pipe systems. However, the study of subsurface drainage module is hardly to be found in literature as it is still a new application as conveyance system in stormwater runoff management application.

2. Ecological Swale with Subsurface Drainage Module

When rain falls, the first drops of water will be intercepted by leaves and steams of vegetation. This is referred as interception storage. As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage). When depression storages are filled, water will start to flow and downstream runoff will be generated (Kamphorst et al. 2005; Deletic 2001; Critchley et al. 1991).

The ecological swale in USM is a dual drainage which consists of a surface swale and a subsurface module (Figure 1). The subsurface module is enclosed within a permeable hydro-net to prevent fines from entering the drainage system. Clean river sand which functions as porous media in increasing water quality is placed around the subsurface module. A layer of top soil is applied on top of the river sand essential for the grass planting which in this case is the plantation of native cow grass (Figure 2).

Figure 1. Pre-existing subsurface drainage module with dimension 405 mm x 465 mm x 607 mm (Ab. Ghani et al. 2004).

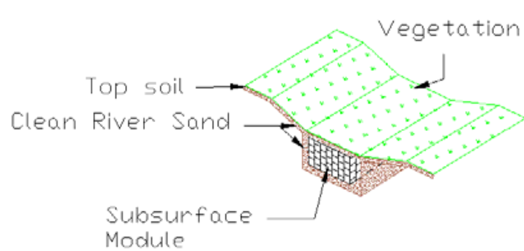


Figure 2. Isometric of ecological swale.

At the beginning of rainfall, the soil is not saturated and all the fallen water will infiltrate into the soil where 100% infiltration is considered to occur. Continuous rain will fill the grassed swale surface and storm water from the surface swale will then infiltrates into the subsurface drainage module through a layer of top soil and river sand. These processes are shown in Figure 3.

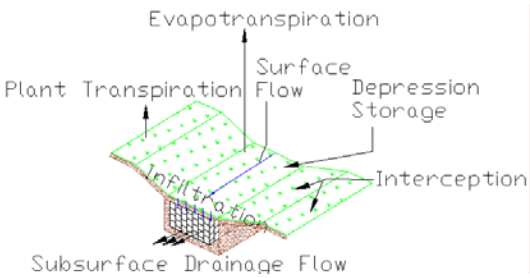


Figure 3. Processes occur in an ecological swale system.

Grassed swale produced two mechanisms to remove pollutants. First, the vegetation in the channel which provides roughness will slow the water and allow for settling that aiding in the removal of particulates and particulate-associated pollutants from the stormwater runoff. Secondly, aerobic decomposition and chemical sorption that occur within the porous media as the stormwater infiltrates can reduce pollutant loads in the runoff (Borst et al. 2007).

There are 3 types of swale system in USM namely, ecological swale Type A, ecological swale Type B, and ecological swale Type C, according to their sizes and capacities. As general, ecological swale Type A consisting a single module, ecological swale Type B consisting two numbers of single module while ecological swale Type C consisting 3 numbers of single module (Zakaria et al. 2003). The design criteria and component of an ecological swale are shown in Table 1 and Table 2 respectively.

Table 1. Design criteria of an ecological swale (Ab. Ghani et al. 2004).

Design parameter	Criteria
Longitudinal slope	1:1000
Manning roughness coefficient	Surface swale = 0.035 Subsurface drainage module= 0.1
Design rainfall	10-year ARI and check for 100-year ARI
Maximum period of surface water inundation at surface swale	24 hours

Table 2. Component of an ecological swale (Ab. Ghani et al. 2004).

Swale components	Specifications	Details
Module (ecological swale)	Dimension	405 mm x 465 mm x 607 mm
	Flow rate at 1% gradient	2280 l/min
	Compressive strength	8 tons/m2
	Material	Recycled polypropylene
Hydronet filter fabric	Permeability	9.30mm/s
	Screening capability	0.38 mm
Clean river sand	Sieve analysis according to BS1377	Mean size between 0.5 mm and 2.0 mm
Top soil	Thickness	One to two inches
Grass	Species	Cow grass

The latest subsurface module is shown in Figure 4. At this current time, a layer of gravel with mean size between 3 mm and 10 mm has been applied in current design of ecological swale to replaced clean river sand as porous media upon the subsurface drainage module (Figure 5). It is believed that gravel fastens the infiltration process thus increase the efficiency of the ecological swale. However, further research is needed to prove this efficiency.

Figure 4. Latest subsurface drainage module with dimension 410 x 450 x 685 mm.

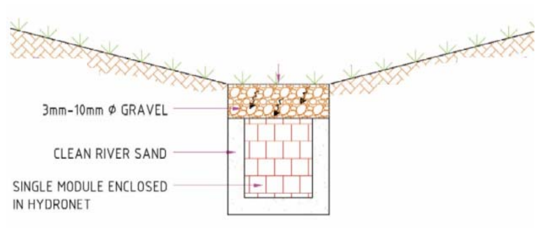


Figure 5. Gravel as porous media.

3. Previous Research in USM

Flow pattern and hydraulic capacity in the drainage module had been investigated by Mohd Sidek et al. (2002). The experimental result shows that the flow velocity is varied along the module. Turbulence flow had been observed. This is believed to be caused by the pattern and internal structure of the module.

In general, all results show that the average velocity distribution, maximum velocity, minimum velocity and velocity beside the module are higher than the velocity inside the module. Figure 6 shows the typical velocity distribution across triple modules. Flow profile in the module was observed to resemble flow profile between open channel and pipe flow. Flow profile for open channel and pipe are shown in Figure 7. Conclusion had been made that the velocity distribution in the modules resembles closely as pipe flow.

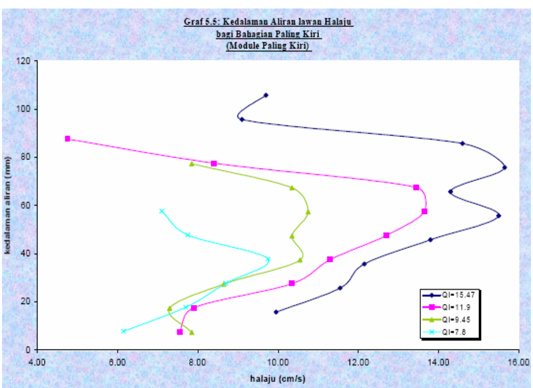


Figure 6. Relationship between flow depth and velocity in the drainage module (Mohd Sidek et al. 2002).

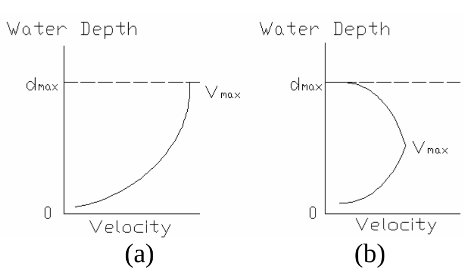


Figure 7. Relationship between water depth and velocity for: **(a)** open channel and **(b)** pipe.

Apart from this, the pollutants removal capability was also being tested. Results show that the drainage module could effectively increase the dissolved oxygen with respect of time, distance and velocity (Figure 8 and Figure 9). However, results showed that the drainage module did not have high metal removal, as low as Zinc (10.9%), Cuprum (38.7%), Nickel (33.3%) and Plumbum (15.9%). This probably is due to the slow chemical decomposition process which can be occurred in the drainage module.

However in this study, evaluation will be based on the water quantity efficiency only for the subsurface drainage module. The objective of this research is to provide the understanding of the flow characteristic in the subsurface drainage module. Manning's *n* values for the subsurface drainage module will be estimated for different flow and slope conditions.

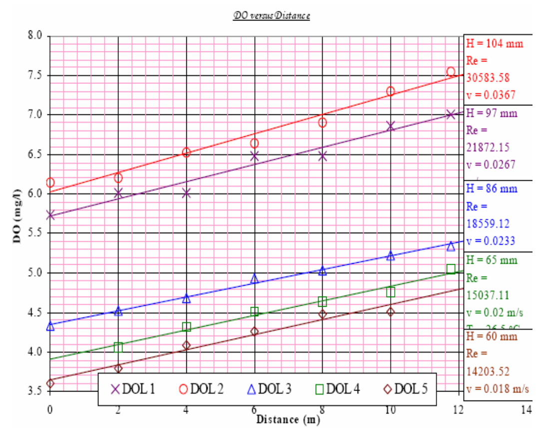


Figure 8. Relationship between dissolved oxygen and distance in the drainage module (Mohd Sidek et al. 2002).

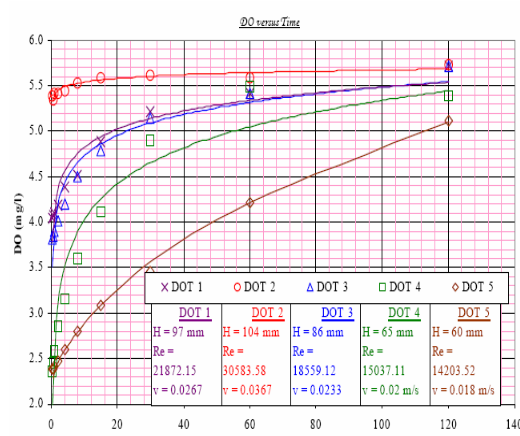


Figure 9. Relationship between dissolved oxygen and time in the drainage module (Mohd Sidek et al. 2002).

4. Laboratory Test

Laboratory test will be conducted at Civil Engineering Hydraulic Laboratory, USM. Subsurface drainage module will be placed into an open channel with water supplied by using different gravitational flow rates. In this research, the value of velocity and water depth for each condition will be measured. These measurements will be done by using a flow meter with sensor which is an extremely versatile flow measurement system. The concept of this measuring system is shown in Figure 10.

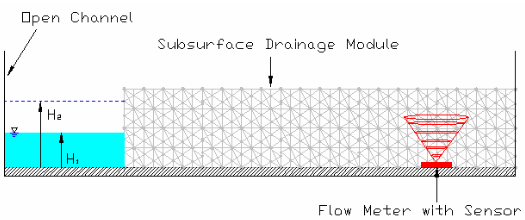


Figure 10. Conceptual view of the automatic velocity measurement system for flow in subsurface drainage module.

First of all, the flow conditions will be measured without drainage module in the open channel as a measure control. Then, subsurface drainage modules will be placed inside the open channel. One part of the subsurface drainage module will be opened out for the purpose to insert the flow meter into it to get the measurement of water depth and velocity for the flow passing along it. This laboratory test is illustrated in Figure 11.

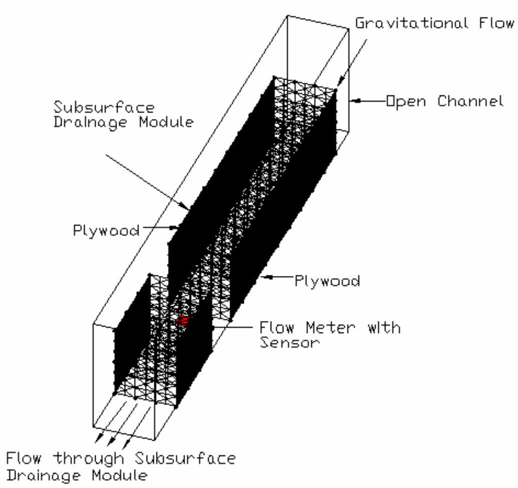
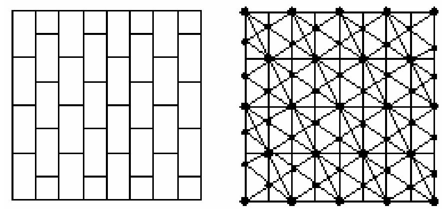


Figure 11. Laboratory test for subsurface module.

In this laboratory test, both pre-existing and the latest drainage modules will be tested. The pattern of pre-existing drainage module and latest drainage module are shown in Figure 9 (a) and 12 (b).



(a) (b)

Figure 12. Side view of drainage module pattern for: **(a)** pre-existing subsurface drainage module (size 405 x 465 x 607) and **(b)** latest subsurface drainage module (size 410 x 450 x 685).

Objectives for this laboratory test are:

a. To evaluate the efficiency of the drainage module under different flow rate condition.
b. To compare the efficiency of pre-existing and latest drainage modules in flow attenuation.
c. To compare the relationship between flow discharge and water depth under condition with or without drainage module.
d. To estimate Manning's *n* value for the drainage module under different slopes, discharges and flow depth condition.

5. Conclusion

The goal of this research is to increase the understanding of the flow pattern in a subsurface drainage module and its hydraulic characteristic under different discharge and slope conditions. The result which delineates the type of flow in the subsurface drainage module either to be open channel or pipe flow is important in stormwater catchment modeling. Result from this laboratory test will further verify the simulation of subsurface drainage module flow by INFOWORKS CS 8.5 in the future. From the result of this simulation, it is believed that this study is useful to provide information for future design of ecological swale with subsurface drainage module.

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