DETERMINATION OF MANNING'S COEFFICIENT FOR MODULAR CHANNEL

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Saluran subpermukaan bermodular merupakan sebahagian daripada sistem dwisaliran mesra alam yang terdiri daripada lapisan parit berumput di sebelah atas dan saluran air di bawahnya. Sistem Saliran Bio – Ekologikal (BIOECODS) telah mengaplikasikan konsep ini untuk saluran ekologikalnya yang telah dibina di sekitar Kampus Kejuruteraan, Universiti Sains Malaysia. Kajian dan pembangunan yang berterusan telah dijalankan oleh Pusat Penyelidikan Kejuruteraan Sungai dan Saliran Bandar (REDAC) bagi penambahbaikan modul BIOECODS. Kajian makmal telah dijalankan terhadap modul dengan reka bentuk terbaru dan juga modul sedia ada. Kajian yang dilakukan adalah bertujuan untuk menentukan pekali Manning n dan juga untuk mengenalpasti keadaan atau corak aliran bagi setiap modul berdasarkan graf kadar aliran. 21 set data kajian yang diperoleh adalah berbeza mengikut kedalaman aliran dan keadaan cerun. Modul – modul tersebut telah diuji di bawah tiga cerun iaitu 1:500, 1:750 dan 1:1000 dengan perbezaan kedalaman yang bermula dari 10 – 40 cm. Kedua-dua modul yang dilabelkan sebagai Modul 1 (reka bentuk sedia ada) dan Modul 2 (reka bentuk baru) telah menunjukkan perbezaan dari segi aliran dan pekali Manning, n. Perbandingan juga dibuat antara Modul 2 yang mempunyai susunan secara bertiga dengan kajian terdahulu yang menggunakan jenis modul yang sama tetapi menggunakan susunan secara tunggal. Modul dengan reka bentuk baharu menunjukkan kadar aliran yang lebih baik daripada modul sedia ada. Pekali Manning n yang diperoleh pada akhir kajian ini akan digunakan untuk kajian yang lebih lanjut pada masa hadapan. Maklumat yang dilaporkan dalam kajian ini merupakan salah satu faktor penting dalam menentukan kebolehan saluran bermodular untuk berfungsi secara baik dalam sistem saliran subpermukaan. Kajian ini diharap dapat menyumbang kepada penambahbaikan sistem saliran mesra alam terutamanya dalam menyelesaikan masalah air larian permukaan semasa aliran puncak.

ABSTRACT

A subsurface modular channel is a part of an environmental friendly dual drainage system comprises of grassed swale on top and a conveyance conduit beneath it. Bio – ecological Drainage System (BIOECODS) has implemented this concept for ecological swales that were built around Engineering Campus, Universiti Sains Malaysia. Constant researches and developments have been carried out by River Engineering and Urban Drainage Research Centre (REDAC) to improve the application of BIOECODS. Laboratory tests on a newly – designed as well as pre – existing module were carried out to determine its Manning's coefficient and to study the behaviour of the flow for each module through the flow rating curves. 21 sets of experiments were done based on different flow depths and slope conditions. The modules were tested under three different slopes; 1:500, 1:750 and 1:1000 with flow depths varying from 10 – 40 cm. Both of the modules labelled as Module 1 (existing design) and Module 2 (new design) had shown differences in terms of flow and Manning's n. A comparison has also been made between Module 2 which was a triple arrangement module with previous study that used the same type of module but only had a single arrangement. The newly – designed module was observed to have better flow than Module 1. Manning's n determined from this study will be used for future design and further study. This research is important for efficiency evaluation of a modular channel to act in subsurface drainage system thus to help in solving surface water runoff problems especially during peak flow.

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LIST OF ABBREVIATIONS

BMP	**B**est **M**anagement **P**ractices
BIOECODS	**Bio** – **Eco**logical **D**rainage **S**ystem
DID	**D**epartment of **I**rrigation and **D**rainage
GEP	**G**ene **E**xpression **P**rogramming
MASMA	**Ma**nual **S**aliran **M**esra **A**lam
PECBs	**P**re-cast **E**cological **C**oncrete **B**locks
REDAC	**R**iver **E**ngineering and Urban **D**rainage **R**esearch **C**entre
USM	**U**niversiti **S**ains **M**alaysia

NOMENCLATURES

A	Area
c	Sediment concentration
C	Chezy’s coefficient
d	Representative sediment
F	Darcy – Weisbach’s roughness coefficient
F	Function
F	Froude’s number
g	Gravitational acceleration
K	Relative roughness
K_s	Equivalent wall surface roughness
N	Non-uniformity of the channel
n	Manning’s roughness coefficient
η	Cross – sectional geometric shape
Q	Flow rate
Re	Reynold’s number
R	Hydraulic radius
S	Slope
U	Degree of flow unsteadiness
Y	Flow depth

CHAPTER 1

INTRODUCTION

1.1 Background

The rapid growth of development gives a significant effect to hydrological cycle in Malaysia. It gives impacts on receiving water flow, infiltration, groundwater storage and runoff pattern especially in urban areas. The urbanization has increased the imperviousness which produced increased peak flow and more runoff volume (Barber et al., 2003). Increment in stormwater runoff had contributed to an increase in the amount of high pollutants such as toxins, sediment and nutrient straight into the water sources. Flood has also become one of the highest occurrence of disaster that happened in Malaysia. Over years, these issues had given an adverse impact to the water quality, fisheries, aquatic and wildlife habitats.

Department of Irrigation and Drainage Malaysia (DID) has introduced the first urban stormwater manual which is known as Planning and Design Procedures NO.1: Urban Drainage Design Standard and Procedures for Peninsular Malaysia in 1975. The manual became a guideline for engineers to design the urban stormwater drainage system until Urban Stormwater Management Manual for Malaysia (MASMA) been produced on 1st January 2001. The new approach applies integrated process of infiltration, detention, self – cleansing to control quality and quality of runoff from developing area remains as before the development. Conventional drainage system has long been in practice for many years that it is time for new changes that recognize the need for a system that is sustainable and able to protect water resources and its ecosystem even when developments are widely emerging in Malaysia.

Universiti Sains Malaysia(USM) in collaboration with DID have taken a major initiative to overcome the problem by introducing an alternative to the conventional drainage system with something more sustainable and effective. The change of using conventional drainage made from concrete or engineering-based material to something more sophisticated aims to reduce pollution problems by mean of increasing the infiltration rate of storm water runoff and enhance the amenity value of watercourses in urban area.

1.2 Problem Statement

A dual drainage system consists of modular channels as subsurface conveyance conduit together with grass swales on top. The subsurface module is enclosed within a permeable hydro – net to prevent fines from entering the drainage system. Clean river sand functions as porous media in increasing water quality. It is placed around the subsurface module whereas a layer of topsoil is applied on top of the river sand essential for the grass planting (Kee et al., 2011) When rain falls, the first drop of water will be intercepted by leaves and stems 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 it is filled, water will start to flow and downstream runoff will be generated (Lai et al., 2009; Hin et al., 2010)

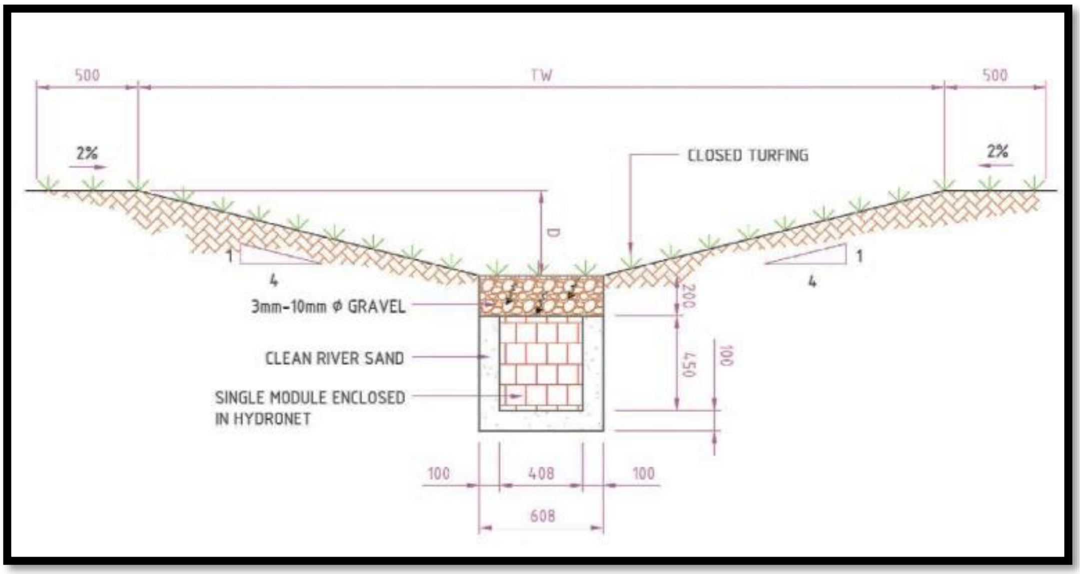

Figure 1.1: Cross section area of a Subsurface Conveyance Conduit (Lai et al., 2009)

In Malaysia, this application had already been implemented in Taiping Health Clinic and Bio – Ecological Drainage System (BIOECODS) in USM Engineering Campus. However, the current type of modular tank used in these areas have high roughness that provides flow attenuation and barely unpractical to be designed as conveyance system since it causes problems such as localized water ponding. This is due to storm water flow which is higher than the storm water infiltration rate into modular tank.

Hydraulic characteristics and flow resistance for the designed modular tank need to be improved in order to serve its purpose at higher efficiency level. Therefore, River Engineering and Urban Drainage Research Centre (REDAC) at USM has been working on the newly designed modular plate pattern (Module 2) with different internal structures. With the design that has changes in surface opening, it is believed that the flow inside the modular channel will be improved compared to the existing one (Module 1).

Figure 1.2: Newly designed modular tank (Module 2)

Hydraulic characteristics of flow under the newly designed modules will be compared with existing module design to evaluate the efficiency between those two in improving flow. The results will justify the differences between newly designed module and existing design in terms of its efficiency to act as subsurface conveyance conduit.

The study of subsurface drainage module as conveyance system in storm water runoff management is still a new approach in this country. The development of this research will help in deep understanding of the flow pattern and hydraulic characteristics of subsurface drainage module under different discharge and slope conditions therefore enhancing the potential performance of subsurface modular tank to act as a sustainable drainage system. This research could be one of the significant measure to overcome the issue of flooding and pollution in river.

1.3 Objectives

The aim of this study is to gain further understanding on the hydraulic characteristics and flow pattern of a modular channel to serve as subsurface conveyance conduit. Detailed objectives of this study include:

i. To determine Manning's roughness coefficient, n for the modules under different slopes and flow depth condition.

ii. To develop a flow rating curve based on Manning's n value

1.4 Dissertation Outline

This dissertation consists of five chapters starting from the introduction, literature review, methodology, research and analysis, and conclusion. The background of this study is stated in Chapter 1 and followed by relevant studies and previous research regarding the topic.

Chapter 3 describes the research methodology which includes the experimental set up and procedures throughout the whole process of the study. It emphasizes on detailed test equipment and characteristics of the modular channels that will be investigated.

Results and analysis of the experimental work are presented in the subsequent chapter. This chapter discusses the relationship between hydraulic parameters for each module tested as well as comparison made with previous study. Finally, chapter 5 summarizes the conclusions obtained from the present study with several recommendations suggested at the end of the chapter. Last but not least, all the relevant references are listed followed by appendices attached at the end of the dissertation.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Before proceeding with the research study, some desk studies have been made regarding relevant research in order to gain deep understanding of the concept of this study and to know the scope that will be focused more. According to Chaudhry (2008), liquids are transported from one location to another using natural or constructed conveyance structures. The cross section of these structures may be open or closed at the top. The structures with closed tops are referred to as closed conduits and those with the top open are called open channels. One of the commonly used equations governing Open Channel Flow is known as the Manning's Equation. It was introduced by the Irish Engineer Robert Manning in 1889 as an alternative to the Chezy Equation. The Manning's equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope (Chow, 2009).

2.2 Open Channel

Open channels are defined in which water flows with a free surface such as natural streams and rivers as well as man – made channels such as drainage ditches, irrigation and navigation canals and spillways. The primary factor in open channel flow analysis is the location of the free surface, which is unknown beforehand. The free surface rises and falls in response to perturbations to the flow (e.g. changes in channel slope or width). The main parameters of a hydraulic study are the geometry of the channel (e.g. width, slope and roughness), the properties of the flowing fluid (e.g. density and viscosity) and the flow parameters (e.g. velocity and flow depth) (Chanson, 2004).

Open channel flows are observed in small – scale as well as large – scale situations. For example, the flow depth can be between few centimetres in water treatment plants and over 10 m in large rivers. The mean flow velocity may range from less than 0.01 m/s in tranquil waters to above 50 m/s in high – head spillway. The range of total discharges may extend from Q ~ 0.001 l/s in chemical plants to more than 10 000 m3/s in large rivers or spillways (Chanson, 2004). Figure below shows a sketch of an open channel flow.

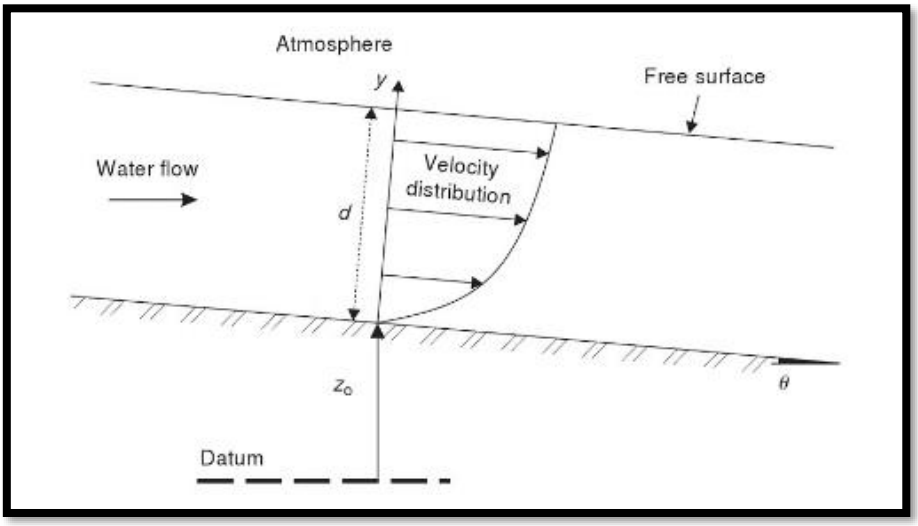

Figure 2.1: Open Channel Flow (Chanson, 2004)

2.2.1 Flow Resistance in Open Channel

In open channels, there are three equations usually been used in calculating flow resistance. The Darcy equation used the method of using hydraulic diameter as equivalent pipe diameter and it is the only sound method to estimate the energy loss according to Chanson (2004). For various reasons, empirical resistance coefficients (e.g. Chezy coefficient) were and are still used. The Chezy coefficient was introduced in 1768 while the Gauckler – Manning coefficient was first presented in 1865. Historically, both the Chezy and the Gauckler – Manning coefficients were expected to be constant and functions of the roughness only. But it is now well recognized that these coefficients are only constant for a range of flow rates (Chow, 2009).

The most frequently used formulas relating open – channel flow velocity, *V*, to resistance coefficient are

$$V = \frac{K_n}{n} R^{2/3} S^{1/2} \quad \text{(Manning)} \qquad (2.1)$$

$$V = \sqrt{\frac{8g}{f}} \sqrt{RS} \quad \text{(Darcy – Weisbach)} \qquad (2.2)$$

$$V = C\sqrt{RS} \quad \text{(Chezy)} \qquad (2.3)$$

in which *n*, *f* ad *C* are the Manning, Weisbach and Chezy resistance coefficients respectively; *R* = hydraulic radius; *S* = slope; *g* = gravitational acceleration; and K_n = 1 $m^{1/2}$/s for *V* and *R* in SI units, 1.486 $ft^{1/3}$ -$m^{1/6}$/s for English units and $\sqrt{g}$ for dimensionally homogeneous Manning formula (Yen, 2002).

Eventhough Darcy friction factor, *f* and Chezy coefficient could be obtained by experimental data available, it is only possible to estimate such data in standard geometry and material. However, these data do not apply to natural rivers with vegetation, trees, large stones, boulders and complex roughness patterns and with movable boundaries (Chanson, 2004).

The Darcy equation could only be applied to simple standard geometry while complex channel bed roughness is mostly estimated by Chezy or Manning’s equation. (Chanson, 2004). Yen (2002) stated that Rouse (1965) classified flow resistance into four components: (1) surface or skin friction, (2) form resistance or drag, (3) wave resistance from free surface distortion and (4) resistance associated with local acceleration or flow unsteadiness. By using the Darcy resistance coefficient, *f*, he expressed the resistance as the following dimensionless symbolic function:

$$f = F\ (R, K, \eta, N, \mathrm{F}, \mathrm{U}) \tag{2.4}$$

in which R = Reynolds number; K = relative roughness, usually expressed as k_s/R. where k_s is the equivalent wall surface roughness *R* is hydraulic radius of the flow; η = cross – sectional geometric shape; N = nonuniformity of the channel in both profile and plan; F = Froude number; U = degree of flow unsteadiness; and *F* represents as a function. The symbolic relationship of Eq. 2.4 can also be applied to the Manning resistance coefficient n in the form of $n/{k_s}^{1/6}$, or to a flow resistance slope, S.

Flow resistance describes the influences of friction to the flow due to channel characters. Roughness equations are used for its quantification. Magnitude of the resistance can be described as a resistance coefficient. Flow resistance in open channel is a very complicated concept but the factors that have the greatest influence on the coefficient of roughness are described below. It should be noted that these factors are to a certain extent interdependent. The factors affecting flow resistance are: (Chow, 2009)

a. ***Surface roughness*** is represented by the size and shape of the grains of the material forming the wetted perimeter and producing a retarding effect on the flow. Bottom irregularity has also been a great influence to the retarding effect.
b. ***Vegetation*** markedly reduces the flow capacity of the channel and retards the flow. This effect depends mainly on height, density, distribution, stiffness and

type of vegetation. Seasonal change affects the growth of aquatic plants, grass, weeds, willow and trees in the channel or on the banks.

c. ***Channel size, shape and irregularity*** refer to variations in the channel cross – section, shape and wetted perimeter along the longitudinal axis.

d. ***Sedimentation and erosion*** may change a channel either to more irregular or more regular form. The effects depend on the soil material.

e. ***Obstructions*** such as fallen trees, debris flows, stones, bridges and log jams can have a significant impact on the flow resistance.

f. ***Stage and discharge*** are normally affecting the flow resistance such a way that when those increase, the roughness coefficient decreases.

2.3 Manning’s Formula

The water surface elevation in a stream defines the cross – sectional area of flow. If the velocity is also known, the discharge can be calculated using the equation of continuity:

$$Q = AV \tag{2.5}$$

Where,

Q = discharge in cubic meter per second (m^3/s)

A = area of the cross section of flow in square meters (m^2)

V = average velocity of flow through the cross section in meters per second (m/s)

Over the years, considerable empirical and theoretical research has been conducted on the relationship between channel features and the velocity of the channel (Robert et. al,