

Variations of Roughness Coefficients with Flow Depth of Grassed Swale

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Abstract: Grassed swales are the best management practice (BMP), which has been widely used to reduce the peak flow, reduce water pollution through vegetated filtration, and improve the groundwater recharge. Universiti Tun Hussein Onn Malaysia (UTHM) is using the approach of grassed swales recommended by the Department of Irrigation and Drainage Malaysia (DID) for reducing the risk of flooding and controlling the water pollution. This paper investigates the variations of roughness coefficients with the flow depth of grassed swales in the campus of UTHM. Fieldwork was carried out on the grassed swale to collect the hydraulic data, which including the levelling work, measuring the flow depth and flow velocity of the swale. The flow depth of swale was taken at three points divided along the width of swale and the flow velocity is captured three times at each of the point. The variations of roughness coefficients of grassed swales are presented in Manning's equation, and the results reveal that the n value increases with the increasing of flow depth. Manning's coefficient value found in this study is in the range of 0.110 to 0.756, which are higher than the value proposed by the Urban Stormwater Management Manual for Malaysia (MSMA). The relationships of flow depth and velocity at each section of the swale are portrayed in graphs, which show that the velocity increases with the decreasing of flow depth. The outcomes of this study can be concluded that the variation of Manning's coefficient value is influenced by the swale profile, flow depth, flow velocity, and as well as the vegetation used in the grassed swale concerned.

Keywords: Hydraulic parameters, swale profile, vegetation.

1. Introduction

Grassed swale is a vegetated, open channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality and quantity volume [1]. Grassed swales are increasingly being employed in developed countries under temperate climate as a stormwater best management practice (BMP) for runoff quantity and quality control. As runoff travels through a swale, the vegetation reduces peak velocity while infiltration reduces flow volume. Attenuation of runoff flow promotes pollutant removal [2].

Establishment of grassed swale is a potential solution wherever stormwater needs to be transported from impervious surfaces, slowed down, and allowed to infiltrate into soils. When properly designed to accommodate a predetermined storm event volume, a grassed swale results in a significant improvement over the traditional drainage ditch in both slowing and cleaning of water [3].

The urbanization has caused an increment in the imperviousness which produced increased peak flow and more runoff volume [4][5][6]. Schueler also mentioned that the occurrence of flooding generally due to the change of catchment hydrology via an increase in the impervious area and reduction in catchment storage [7]. Roesner et al. has claimed the effect to a reduction of catchment response time due to the development was the increase of maximum flow discharge by a factor of 2 to 10 or even more into the conventional drainage system thus increases the frequency of significant floods [8]. Depressional storage in urban areas can be reduced by a factor of 5 to 10 depending on the original state of the watershed and the degree of imperviousness generated from the urbanization [9].

Swales are environmentally-friendly drainage system, which is derived from the Manual Saliran Mesra Alam Malaysia (MSMA). MSMA is required in order to provide a systematic construction so that the



swales can be function properly to reduce the risk of flooding. This study was conducted in the campus of Universiti Tun Hussein Onn Malaysia (UTHM). The aim for this study is to investigate the variations of roughness coefficients with the flow depth of grassed swales in UTHM. The variations of roughness coefficients of grassed swales are presented in Manning's equation. Figure-1 shows the grassed swale in UTHM. The hydraulic parameters involved in this study are cross-sectional area (A) of swale, flow velocity (V), flow depth (Y), wetted perimeter (P), hydraulic radius (R), and longitudinal slope (S). The findings of this study give an extensive understanding to the hydraulic characteristics of grassed swale, where the suitable swale design can be proposed especially in the application of sustainable stormwater drainage system within UTHM campus.



Figure 1. Grassed swale in UTHM.

The roughness components in vegetated open channels are conceptually divided into three components, which are form roughness, soil grain roughness, and vegetative roughness. In most vegetated open channels, vegetative roughness characterized by vegetation density, grass height, and type of vegetation dominates the hydraulic resistance of channel [10]. Hydraulic resistance of the watercourse determines the water level and the flow distribution in the basin. Such resistance is commonly represented by parameters such as Manning's roughness coefficient (n), Chezy's resistance factor (C), or the Darcy-Weisbach friction factor (f), among which Manning's n is the most frequently used in the computation of open channel and overland flows [11][12]. Reliable results of flood routing and inundation simulation rely on an accurate of the resistance coefficient.

2. Methodology

2.1 Manning's Roughness Coefficient

The Manning's equation is an empirical formula estimating the average velocity of a liquid flowing in a conduit that does not completely enclose the liquid, such as open channel flow. All flow in so-called open channels is driven by gravity. Roughness coefficients represent the resistance to flood flows in channels and flood plains. The results of Manning's equation, an indirect computation of stream flow, have applications in flood-plain management, in flood insurance studies, and in the design of bridges and highways across flood plains [13]. Manning's equation is:

$$n = \frac{A}{Q} R^{2/3} S^{1/2} \quad (1)$$

Where;

n = Manning's roughness coefficient

A = cross-sectional area (m²)

Q = flow discharge (m³/s)

R = hydraulic radius (m)

S = longitudinal slope

Hydraulic roughness is the measure of the amount of frictional resistance water experiences when passing overland and channel features. An increase in this n value will cause a decrease in the velocity of water flowing across a surface [14]. Diaz claimed that the variations in the n values diminish when the slope

increases [15]. According to Warmink et al., the uncertainty due to bed form roughness in the main channel and vegetation roughness in the floodplains were shown to be the major contributors [16]. Differ from the study by Ding et al., where the parameter identification method based on optimal control theories for identifying Manning's n in shallow water equations is presented to obtain realistic and accurate flows in a natural environment [17].

For intermediate flows in which the flow depth is greater than the height of vegetation (the grasses submerged), Ree and Palmer have showed the n values decrease as average velocity increases [18]. The decrease of n is regarded as a result of the increase of plant bending and submergence when velocity increases. For unsubmerged vegetation, Temple et al. hypothesized that an increase in flow depth less than that required to top the vegetation causes little change in the mean velocity [10]. Therefore, flow resistance tends to increase with the depth. According to DID, the roughness coefficients, n , varies with the type of vegetative cover, longitudinal slope, and average flow depth [19]. The n value must be adjusted for varying flow depths. Manning's roughness coefficients for swales are provided in Table-1.

Table 1. Values of Manning's roughness coefficient [19][20].

Drain/Pipe	Manning's (n)
Grassed Drain	
Short Grass Cover (< 150 mm)	0.035
Tall Grass Cover (\geq 150 mm)	0.050

Vegetation

Swales are broad and shallow channels designed to store and convey runoff at a non-erosive velocity, as well as enhance its water quality through infiltration, sedimentation, and filtration. Swales may be covered by dense vegetation, usually grass to slow down flows and trap particles and remove pollutant [21].

Swales can use a variety of vegetation including grass, sedge and tufted grass. Grassed swales are useful in residential areas but need to be mown and maintained regularly. The grass species chosen for lining of swales must be sturdy, drought resistant, easy to establish, and able to spread and develop a strong turf layer after establishment. The most common grass that used for swales in UTHM is cow grass or called as *Axonopus Compressus*, which depicted in Figure-2.

Proper planting equipment and methods must be used in establishing an effective grass lining. The grass origins and strains are known to be adaptable to the site so that the grass can be tolerant to flooding and be able to survive and continue to grow after the inundation period. Grass height of 50 mm to 150 mm should be maintained with a maximum grass height not exceed more of 150 mm [22]. Heights, types, and conditions of the vegetation are the factors that contribute to changes in the flow characteristics of the swale and its roughness coefficient. As the submergence starts to occur in the swale, the vegetative roughness coefficient tends to remain constant or rise [11].



Figure 2. Cow grass (*Axonopus Compressus*).

Fieldwork

The length of swale is 100 meters and was divided into three sections (Section A, Section B, and Section C). The distance from Section A to Section B is 50 meters and distance from Section B to Section C is 50 meters as well. Each section is divided into three points, labeled as Left, Center, and Right, where measured from the left bank to the right bank of the swale according to each top width of the section. The flow depth and top width of swale for three sections are shown in Table-2. The measurements of flow velocity have been taken three times at each point by using the current meter. Levelling has been done on the swale beforehand to obtain the swale profile.

Table 2. Flow depth and top width of the swale.

Section	Flow depth, Y (m)			Top width, T (m)
	Left	Center	Right	
A	0.360	0.390	0.385	1.8
B	0.375	0.380	0.320	2.2
C	0.210	0.225	0.205	2.1

3. Results and Discussions

Table-3 shows the characteristics of swale for Section A, Section B, and Section C. The values of Manning's roughness coefficients, n are calculated by using the Equation 1. The cross-sectional area (A) of swale is determined based on the average of flow depth and subsection width of the swale by applying the mid-section method. The flow discharge (Q) of swale is the multiplication of average velocity with cross-sectional area. The hydraulic radius is a cross-sectional area divided by wetted perimeter, which obtained by hydraulic equation. According to Table-3, the values of wetted perimeter considerably vary due to the flow depth at each section of swale, which shows the irregularities of swale. The relationship of flow depth and velocity in each section of the swale is shown in Figure-3.

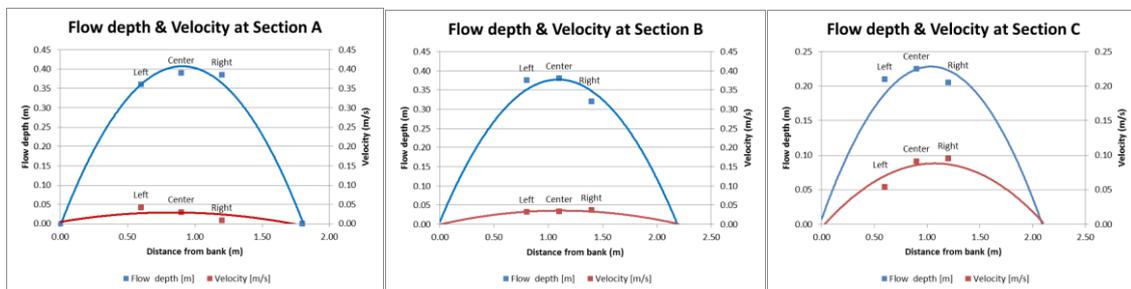


Figure 3. Flow depth and velocity of swale at Section A, Section B, and Section C.

Table 3. The characteristics of swale for each section.

Section	Wetted perimeter, P (m)	Area, A (m^2)	Average velocity, V (m/s)	Flow discharge, Q (m^3/s)	Hydraulic radius, R	Slope, S	Manning's, n
A	2.277	0.452	0.020	0.0091	0.193	0.002	0.756
B	2.220	0.254	0.026	0.0058	0.279	0.002	0.462
C	1.817	0.116	0.048	0.0075	0.204	0.002	0.110

Based on Figure-3, at Section A, the flow depth of 0.390 m has captured lower velocity of 0.030 m/s compared to the flow depth at 0.360 m has captured the velocity of 0.042 m/s. At Section B, the flow depth of 0.380 m has captured lower velocity of 0.033 m/s compared to the flow depth at 0.320 m has captured the velocity of 0.037 m/s. Meanwhile at Section C, the flow depth of 0.225 m has captured lower velocity of 0.091 m/s compared to the flow depth at 0.205 m has captured the velocity of 0.095 m/s. From these results it shows that the decrease of flow depth will increase the flow velocity of swale.

The variations of roughness coefficients are plotted to show the relationship of flow depth with Manning's roughness coefficients at each section of the swale as shown in Figure-4. Based on Figure-4,

Section A has the deepest flow depth (0.170 m) with the highest value of n (0.756), followed by Section B which has flow depth of 0.161 m with n of 0.462. Section C has the lowest value of n (0.110) with the shallow flow depth (0.098 m). These results show that the roughness coefficients will increase with the increase of depth. This is contrary to the finding by Ahmad et al., where the n value is slightly decrease with increment in flow depth [23]. However, they have observed that the n value is slightly increase with increment of flow depth higher than 0.10 m. Arcement and Schneider also found that the n value decreases with increasing depth [13]. They added that if the channel banks are much rougher than the bed or where dense brush overhangs the low-water channel, the n value is not constant with the flow depth.

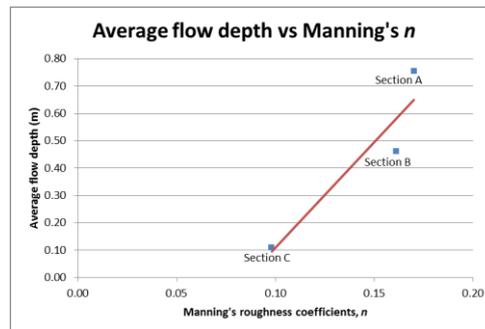


Figure 4. Relationship of flow depth with roughness coefficients.

Arcement and Schneider have produced an adjustment factors for channel n values [13]. The channel irregularities, alignment, obstructions, vegetation, and meandering have influenced the roughness of a channel. The value for n must be adjusted accordingly by adding increments of roughness to the base value for each condition that increases the roughness.

As for irregularity wise, Chow and Benson & Dalrymple showed that severely eroded and scalloped banks can increase n values by as much as 0.020 [20][24]. Larger adjustments may be required for very large, irregular banks that have projecting points.

Habitually, the greater roughness is associated with alternating large and small cross sections and sharp bends, constrictions, and side-to-side shifting of the low-water channel, and not affected significantly by relatively large changes in the shape or size of cross sections if the changes are gradual and uniform. A maximum increase in n of 0.003 will result from the usual amount of channel curvature found in designed channels and in the reaches of natural channels used to compute discharge [24].

Arcement and Schneider stated that the effect of obstructions on the roughness coefficient is a function of the flow velocity [13]. When the flow velocity is high, an obstruction exerts a sphere of influence that is much larger than the obstruction because the obstruction affects the flow pattern for considerable distances on each side. The sphere of influence for velocities that generally occur in channels that have gentle to moderately steep slopes is about three to five times the width of the obstruction.

Aldridge and Garrett have modified an adjustment values for factors that affect the roughness of a channel [25]. In wide channels having small depth-to-width ratios and no vegetation on the bed, the effect of bank vegetation is small, and the maximum adjustment is about 0.005. If the channel is relatively narrow and has steep banks covered by dense vegetation that hangs over the channel, the maximum adjustment is about 0.030. According to Chow, meanders can increase the n values by as much as 30 percent where flow is confined within a stream channel [20]. The meander adjustment should be considered only when the flow is confined to the channel. There may be very little flow in a meandering channel when there is flood-plain flow.

4. Conclusions

The values of Manning's roughness coefficient, n found in this study is in the range of 0.110 to 0.756, which are higher than the values proposed by the Urban Stormwater Management Manual for Malaysia (MSMA). According to MSMA (2012), the value n for the short grass cover is 0.035 and for the tall grass cover is 0.050. This may be due to several factors in terms of the swale cross-sections, the flow depth and velocity, the irregularities of the swale, and the height of vegetation at each section of the swale. The high value of n showed the less movement of flow within the swale. The swale should be maintained by mowing the vegetation to prevent any blockage for the water flows. Based on the modified adjustment values for factors that affect the roughness of a channel by Aldridge and Garrett, the channel conditions is very large with the n value adjustment in the range of 0.050 to 0.100, where turf grass growing and the average flow depth is less

than half the height of the vegetation [25].

Vegetation with suitable characteristics plays as a factor of roughness in a channel which act as an agent to slow down the flow velocity, thus reduced the flow discharge. An effective grassed swale would convey the stormwater runoff to the detention pond or river, which then prevent flooding from occurred. Swales should be able to carry their design flow without overtopping or eroding. If the flow velocity is too high for grass cover in the swale but the slope and cross section cannot be adjusted, the swale can be reinforced with rip-rap or turf reinforcement matting, which can withstand a higher flow velocity. Water velocities associated with a two-year design storm should not scour out vegetated materials nor should be matted down by water. In that situation, the grass must be in good and firm seed bed. It is recommended to water the grass as required until it is established and fertilizes according to the needs of the grass and soils.

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