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Determination of manning's *n* for subsurface modular channel

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ABSTRACT

This paper describes the laboratory test of a newly designed module used as subsurface conveyance system to provide better enhancement toward best stormwater management system. Three types of modular channel were tested in the laboratory at three different slopes. Data collected in these experiments include temperature, flow depth and flow velocity. In this paper, the hydraulic characteristics and Manning's *n* for this newly designed modular channel have been experimentally studied. Suitable equations in governing the Manning's *n* for this modular channel have been developed.

Keywords: Modular channel; Manning's *n*; hydraulic characteristics; regression analysis; genetic programming

1 Introduction

Modular tank or simply known as module is applied as rainwater harvesting system where rainwater will go through infiltration and filtration process to collect clean, clear and odorless water for various purposes. The other applications of modular tank in stormwater management include on site detention, filtration pond, bio-remediation and etc. In Malaysia, the application of modular channel as subsurface conveyance conduit has been applied in the Bio-ecological Drainage System (BIOECODS) in USM Engineering Campus (Zakaria et al., 2003; Ab. Ghani et al., 2004) and sustainable urban drainage system in Taiping Health Clinic completed in year 2005 (Ab. Ghani et al., 2008). The subsurface modular tank applied in BIOECODS is shown in Figure 1 while the modular tank applied in Taiping Health Clinic is shown in Figure 2. Modular tank applied in BIOECODS and Taiping Health Clinic has high roughness which provides flow attenuation. However, this roughness is not suitable for the design as conveyanve system because it causes problem such as localize water ponding as the stormwater flow is slower than the stormwater infiltration rate into modular tank.

Figure 1 Subsurface modular tank with dimension 405 mm x 465 mm x 607 mm

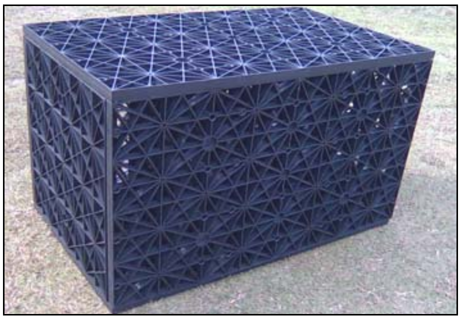


Figure 2 Subsurface modular tank with dimension 410 mm x 450 mm x 685 mm

In order to improve the hydraulic characteristic of subsurface conveyance conduit, River Engineering and Urban Drainage Research Centre (REDAC) has designed a new modular channel with unique pattern and internal structures. This modular tank will be formed by module plates as shown in Figure 3. This modular tank can provide flow attenuation with its suitability as conveyance system as this modular tank has larger surface opening. In this study, the newly designed modular channel is investigated under different arrangements, slopes and flow rate. The objectives of the present study include the following:

(a) Determination of hydraulic characteristics of modular channel
(b) Establishment of relationship between Manning's *n* with hydraulic parameters for modular channel

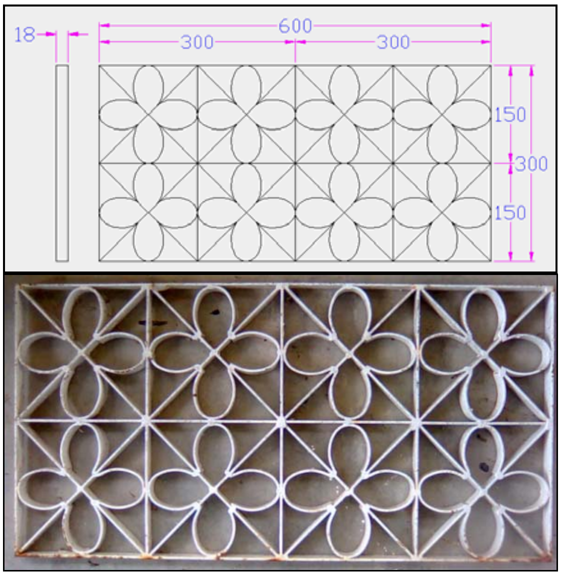


Figure 3 Modular plate (unit: mm)

2 Experimental setup

Laboratory tests were conducted at Physical Modeling Laboratory of River Engineering and Urban Drainage Research Centre (REDAC) at Universiti Sains Malaysia using a re-circulating flume with a working section length of 5.90 m. The schematic diagram of the experimental flume is depicted in Figure 4. The slope of this channel can be adjusted manually by using adjustable jack. Experiments were conducted in three bed slopes where, S = 1/1000, 1/750 and 1/500 combined with various discharges. Two pumps of maximum total discharge, 35 l/s, were used to supply water into the flume. The flume is equipped with upstream baffle to dampen the turbulence effect from pump.

This laboratory test consisted of two phases as phase one was carried out in flume without module, and phase two in flume with modules. The modular plates which forming module in this laboratory tests were made up from painted steel as this is a new designed module which is not yet available in the market. The module studied in the laboratory test has a standard size of 300 mm x 600 mm x 685 mm. It consist of two end plates and one to three intermediate plates to form the standard size of module. Three different arrangements of modular are:

(a) Module A consists of one vertical intermediate plate (spacing 315.50 mm)
(b) Module B consists of two vertical intermediate plate (spacing 204.30 mm)
(c) Module C consists of three vertical intermediate plate (spacing 148.75 mm)

Figure 5 shows the modular plates installed in laboratory flume.

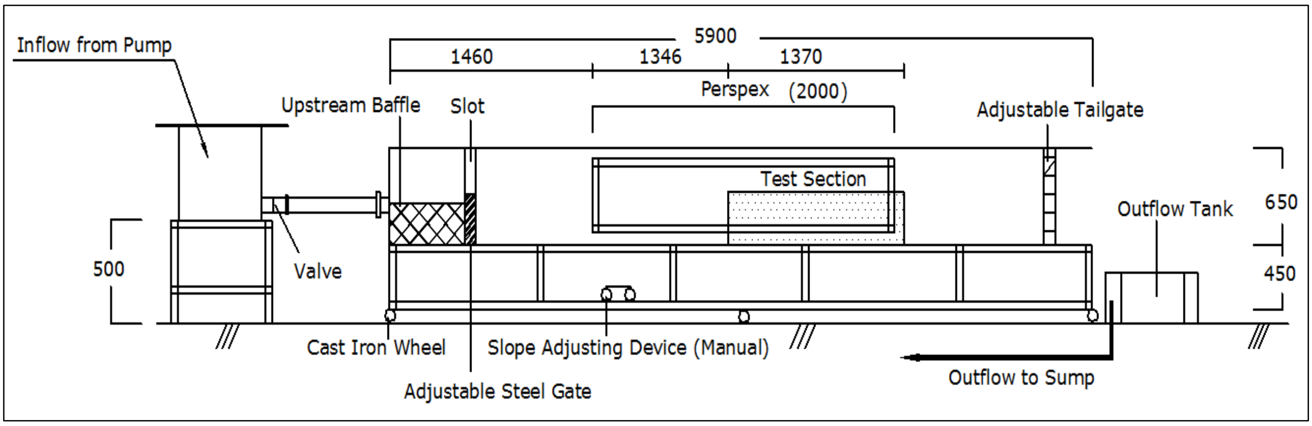


Figure 4 Schematic diagram of experimental flume (unit: mm)

Figure 5 Laboratory flume with modular

3 Experimental data collection program

Five observation positions were selected at the middle reach of the flume for all of the three arrangements. The measurements of velocity were taken at an interval of one-third across the channel width for the observation positions with spacing of around 150 mm. A total of 15 points were measured along the flume as marked in Figure 6. In every experimental run, flow depth and flow velocity data were measured. The velocity profiles were measured using a 10 mm-propeller current meter. The lowest position measured was 7.5 mm from the channel bottom. The current meter readings were taken from a digital counter that was set to give an average velocity over 10 seconds. For each measurement point, three readings were averaged to obtain the local mean velocity. Measurement of velocity was taken at 0.2Y, 0.6Y and 0.8Y (Y= flow depth) from water surface. These data were used to find the average velocity and average flow depth at the test section. Apart from this, velocity contours were obtained by taking detailed measurement on each 1 cm of flow depth from the channel bottom.

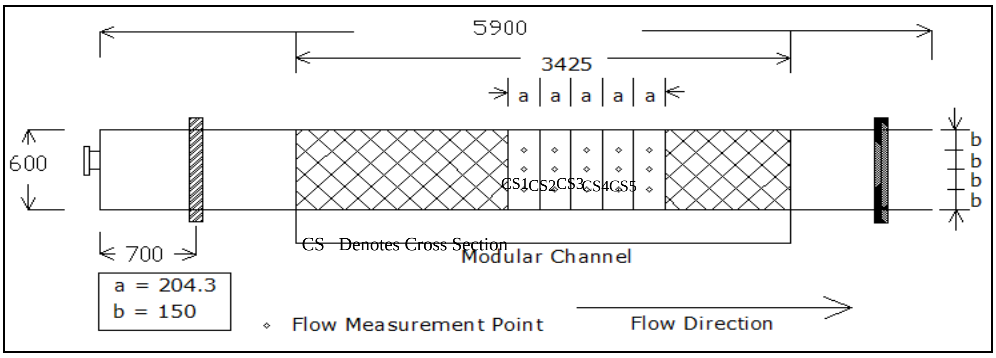


Figure 6 Flow measurement locations for modular channel (unit: mm)

All measurements were done under uniform flow where flow depth observed varies in a range of +/- 2 mm at each measurement point. This was achieved after about half to one hour of each experimental run after required flow rate or flow depth was adjusted. The vertical tail gate at the downstream of the flume was used to adjust the flow to give the required uniform flow when necessary.

4 Laboratory results and analysis

4.1 Flume without module

Experiment tests for flume without module were done as control case. The analysis of the laboratory result was based on the Manning formula in metric form where the Manning's n can be calculated from:

$$n = \frac{1}{V} R^{2/3} S^{1/2} \tag{2}$$

A summary of ranges of Manning's n for experimental runs conducted in flume without module under different slope conditions are detailed in Table 1. The Manning's n values calculated from laboratory tests for flume without module are ranging from 0.009 to 0.013. This range is near to the Manning's n suggested by Chow (1959) for painted steel which has the normal value of 0.012. In the similar study done by Vongvisessomjai et al. (2010), for a range of water depth between 0.02 m to 0.11 m, the Manning roughness coefficient for painted steel was found to be 0.0125 for clear water experiments without sediment.

Table 1 Laboratory tests for flume without module

Width of flume (mm)	Slope, S	Range of Manning's n	Average Manning's n
600	0.0010	0.009-0.010	0.010
	0.0013	0.010-0.011	0.011
	0.0020	0.011-0.013	0.012

4.2 Modular channel

Table 2 shows the summary of conditions investigated in the flume of modular channel. Froude numbers calculated for flow in modular channel are less than 1. Therefore, subcritical flow occurred in this flume where the flow is slow with low velocity (Chow, 1959). From the computed Reynolds number, most of the flow occurred as turbulent flow in modular channel.

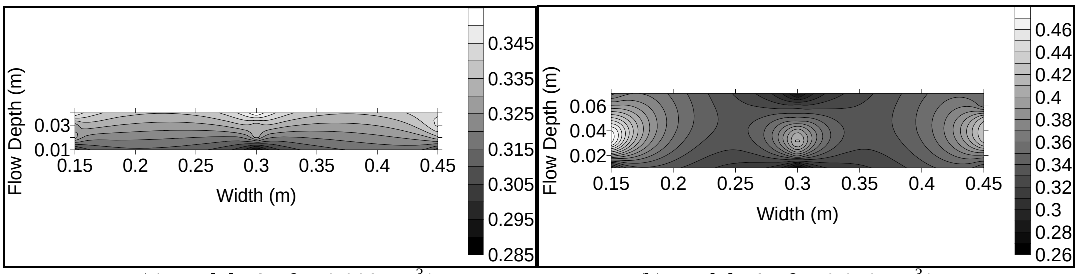
Two types of flow rate were chosen for obtaining the velocity contour throughout modular channel. Summary of the data collected is shown in Table 3. Velocity contours of slope 1:500 for three types of arrangement were shown in Figure 7. It is observed that most of the flow rates tested in all arrangement show that flow inside modular channel has highest velocity distributed at the middle vertical section of flow depth.

Table 2 Experimental study for modular channel

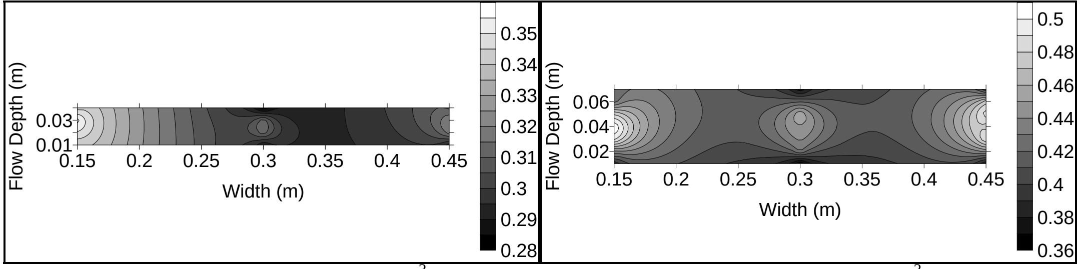
Flow Parameter	Range		
	Module A	Module B	Module C
Flow Rate, *Q* (m^3/s)	0.0040-0.0216	0.0025-0.0199	0.0034-0.0193
Velocity, *V* (m/s)	0.221-0.514	0.134-0.390	0.176-0.418
Flow Depth, *Y* (m)	0.030-0.080	0.030-0.086	0.032-0.097
Hydraulic Radius, *R* (m)	0.027-0.063	0.027-0.067	0.029-0.073
Channel Slope, *S*	0.001-0.002	0.001-0.002	0.001-0.002
Reynolds Number, *Re*	28571-136368	17853-123849	23794-119682
Froude Number, *Fr*	0.389-0.620	0.243-0.491	0.310-0.483

Table 3 Summary of detailed data collection for modular channel

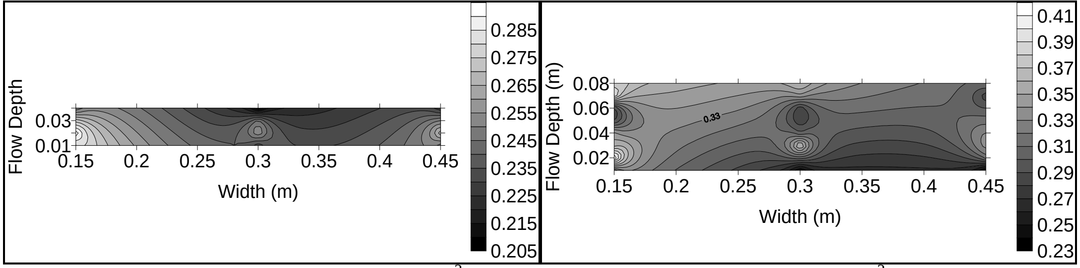
Parameter	Exp. No.	Module A			Module B			Module C		
		Slope			Slope			Slope		
		0.002	0.0013	0.001	0.002	0.0013	0.001	0.002	0.0013	0.001
Flow Rate, *Q* (m^3/s)	1	0.008	0.008	0.008	0.001	0.009	0.009	0.006	0.007	0.006
	2	0.020	0.019	0.019	0.019	0.017	0.017	0.019	0.017	0.017
Flow Velocity, *V* (m/s)	1	0.320	0.311	0.307	0.327	0.293	0.281	0.253	0.250	0.240
	2	0.443	0.416	0.407	0.371	0.358	0.343	0.336	0.321	0.323
Flow Depth, *Y* (m)	1	0.044	0.044	0.046	0.050	0.051	0.052	0.042	0.044	0.045
	2	0.008	0.008	0.008	0.086	0.081	0.083	0.092	0.088	0.086



(a) Module A: $Q = 0.0084$ m^3/s (b) Module A: $Q = 0.0204$ m^3/s



(c) Module B: $Q = 0.0099$ m^3 (d) Module B: $Q = 0.0192$ m^3/s



(e) Module C: $Q = 0.0064$ m^3/s (f) Module C: $Q = 0.0185$ m^3/s

Figure 7 Velocity contour at Cross Section 3: (a) Module A: $Q = 0.0084$ m^3/s; (b) Module A: $Q = 0.0204$ m^3/s; (c) Module B: $Q = 0.0099$ m^3/s; (d) Module B: $Q = 0.0192$ m^3/s; (e) Module C: $Q = 0.0064$ m^3/s and (f) Module C: $Q = 0.0185$ m^3/s

Apart from this, dimensionless analysis was done in order to obtain an equation in governing the Manning's *n* of modular channels. Yen (1992) stated that the Manning formula in Equation 2 can be modified by replacing the coefficient of 1.486 (English units) or 1 (SI units) by $\sqrt{g}$ such that:

$$V = \frac{\sqrt{g}}{n_g} R^{2/3} S^{1/2} \qquad (3)$$

In Equation 3, it shows that the new Manning's *n* (n_g) has the dimension of $L^{1/6}$, where *L* represents dimension of length. Therefore, the dimensionless form of n_g can be expressed by roughness parameter, $n_g / R^{1/6}$ This roughness parameter was then being related to aspect ratio (*B/Y*) and slope (*S*) in regression analysis and genetic programming. Analysis of genetic programming was done by using GPTIPS which is a genetic programming tool for the use in MATLAB (Searson, 2009).

The performance of observed and predicted Manning's *n* models was evaluated by using coefficient of determination (R^2) and root mean square error (RMSE).

$$R^2 = \left(\frac{\sum_{i=1}^{N} \left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum_{i=1}^{N} \left(O_i - \bar{O}\right)^2 \sum_{i=1}^{N} \left(P_i - \bar{P}\right)^2}} \right)^2 \qquad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i-1}^{N} \left(O_i - P_i\right)^2}{N}} \qquad (5)$$

where O_i = observed values; $\bar{O}$ = mean of O_i; P_i = predicted values; $\bar{P}$ = mean of P_i; and N = number of samples. The model with the smallest RMSE has the smallest total uncertainty, and the model with R^2 value near to 1 is generally considered the most appropriate model for describing the observed data.

5 Manning's *n* equation assessment

The hydraulic characteristic of modular channel under different slope and flow rate was investigated as shown from Figure 8 to Figure10. It is concluded that:

(a) Flow velocity varies proportional to flow rate. This result agrees the finding with research done by Bakry (1992) where a relationship was drawn as:

$$V = 0.097Q^{0.322}$$

(b) Flow rate varies proportional to flow depth. This agrees with the nature of rating curve and finding in research done by James et al. (2004) where discharge increases with increment in flow depth.

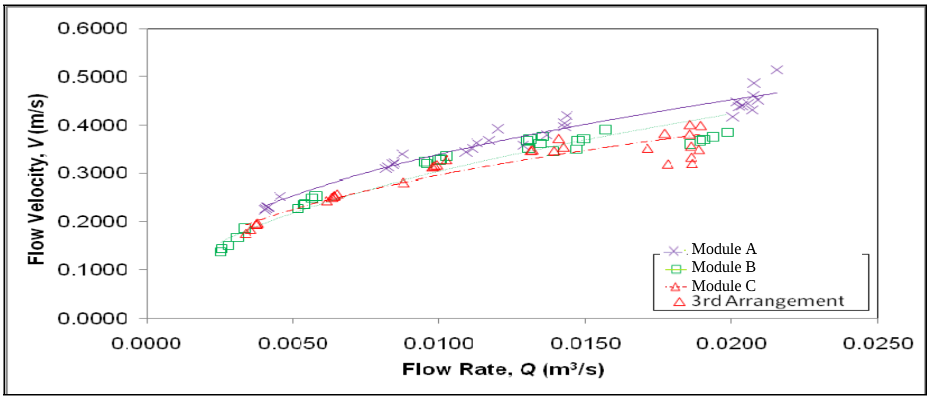


Figure 8 Flow velocity versus flow rate

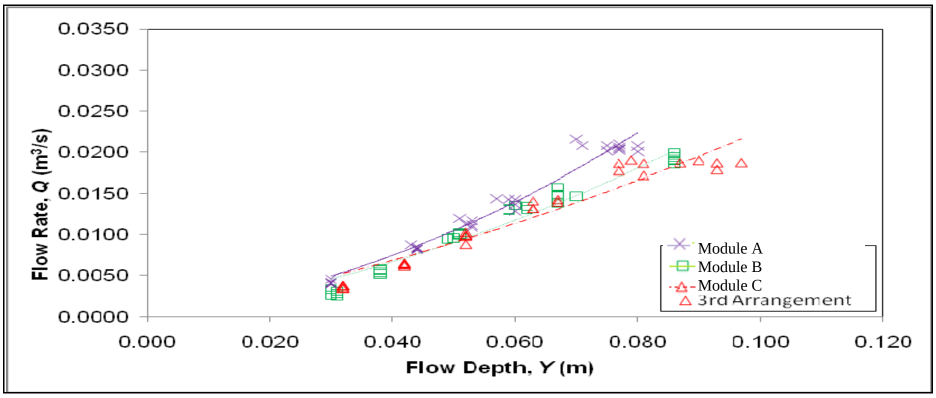


Figure 9 Rating curve

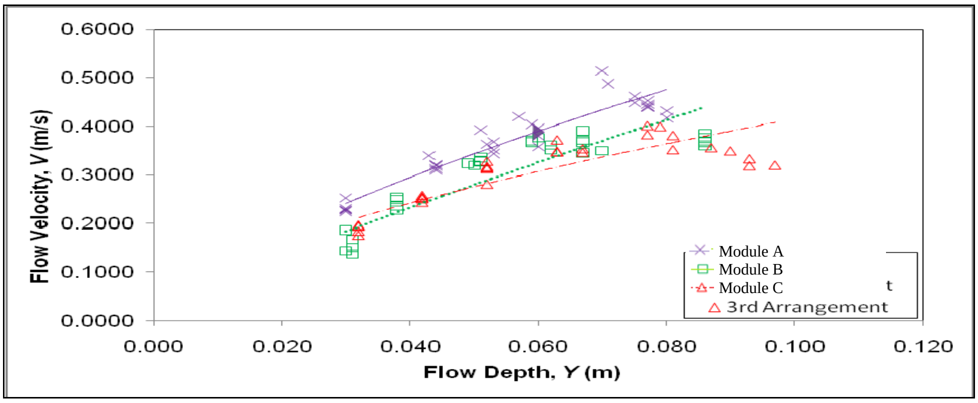


Figure 10 Flow velocity versus flow depth

Manning’s *n* for modular channel were computed by using Equation 2 as shown in Table 4. The Manning’s *n* computed for all slopes ranging from 0.009 to 0.030 where slope of 1:500 has the highest Manning’s *n* distribution. In the investigation of Manning’s *n* for modular channel, relationships between this roughness coefficient with hydraulic parameters were drawn. The hydraulic parameters included in the investigation include of flow velocity and flow depth as shown in Figure 11 and Figure 12 respectively. The Manning’s *n* is observed to decrease with increment in flow velocity. This agrees with the Manning’s equation where Manning’s *n* varies inversely with flow velocity. This relationship also has similar trend with the study done by Bakry (1992), Trout (1992), Chen et al. (2009), and Chang et al. (2010) in the investigation of hydraulic roughness. Apart from this, Manning’s *n* is observed to decrease with flow depth initially while increase with increment in flow depth afterwards. This shows that Manning’s *n* is larger for very shallow flow. This is because the roughness at the channel bottom becomes significant for very shallow flow. This phenomenon agrees with natural bed formed river.

Table 4 Manning’s *n* for modular channel

Manning’s *n*	Module A			Module B			Module C		
	1:1000	1:750	1:500	1:1000	1:750	1:500	1:1000	1:750	1:500
Maximum	0.014	0.015	0.018	0.014	0.015	0.018	0.017	0.021	0.024
Minimum	0.009	0.011	0.013	0.009	0.011	0.013	0.012	0.014	0.017
Average	0.012	0.013	0.016	0.012	0.013	0.016	0.015	0.017	0.020

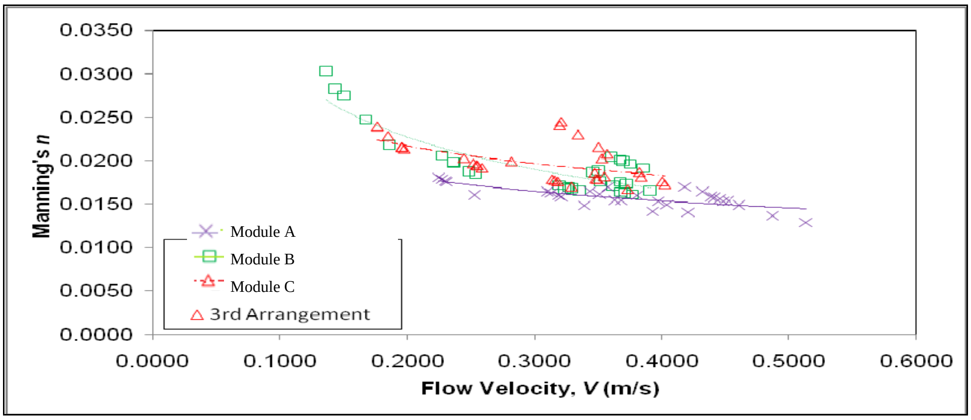


Figure 11 Manning’s *n* versus flow velocity

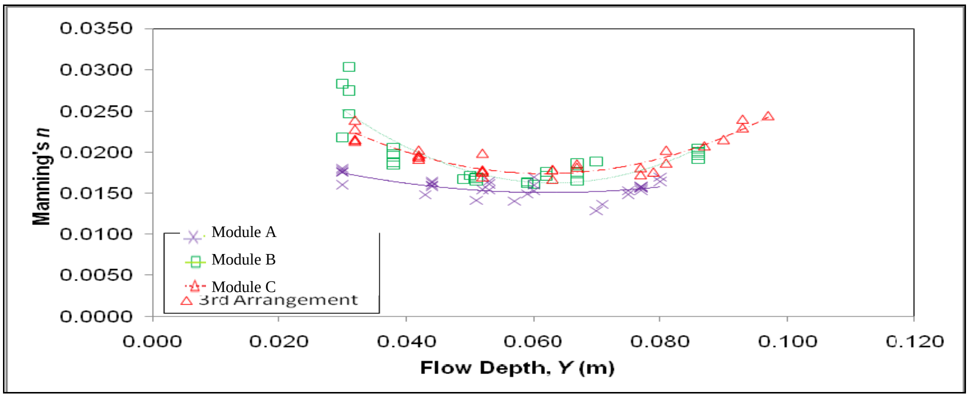


Figure 12 Manning’s *n* versus flow depth

Module A has the lowest Manning’s *n* followed by Module B and Module C has the highest Manning’s *n*. This is because Module A has only one intermediate plate which creates the least hydraulic roughness towards the flow.

Development of Manning’s equation for modular channel was done by using regression analysis and genetic programming with the following relationship:

$$\frac{n_g}{R^{1/6}} = f\left(\frac{B}{y}, S\right) \tag{6}$$

A total of 90 sets laboratory data were used for each arrangement of modular channel. Equations developed by using regression analysis are shown in Table 5 with correlation of determination, R^2 more than 0.63 and root mean square error, RMSE of less than 0.012. In order to improve the R^2 for developed equations, genetic programming was performed by using the same data sets. 80 % of the data were used for training and 20 % of the data were used for testing. Using the functions of ‘plus’, ‘minus’, ‘times’, and ‘square’, equations in predicting roughness parameters were generated as shown in Table 6. Results show that genetic programming predicts better than regression analysis by improving the coefficient of determination (R^2) to not less than 0.72 for all types of modular channel.

Table 5 Regression analysis in predicting roughness parameter ($n_g/R^{1/6}$) for modular channel

Modular Channel	Relationship	Coefficient of Determination, R^2	Root Mean Square Error, RMSE
Module A	$\frac{n_g}{R^{1/6}} = 0.479\left(\frac{B}{Y}\right)^{0.279}(S)^{0.391}$	0.816	0.005
Module B	$\frac{n_g}{R^{1/6}} = 0.269\left(\frac{B}{Y}\right)^{0.49}(S)^{0.348}$	0.686	0.012
Module C	$\frac{n_g}{R^{1/6}} = 0.714\left(\frac{B}{Y}\right)^{0.235}(S)^{0.401}$	0.638	0.010

Table 6 Genetic programming in predicting roughness parameter ($n_g/R^{1/6}$) for modular channel

Type of Modular Channel	Relationship	Coefficient of Determination, R^2	Root Mean Square Error, RMSE
Module A	$\frac{n_g}{R^{1/6}} = 19.18S + 6.801\times10^{-5}\left(\frac{B}{Y}\right)^2 + 0.0345$	0.958	0.005
Module B	$\frac{n_g}{R^{1/6}} = 20.86S + 1.336\times10^{-4}\left(\frac{B}{Y}\right)^2 + 0.0389$	0.772	0.010
Module C	$\frac{n_g}{R^{1/6}} = 23.99S + 8.232\times10^{-5}\left(\frac{B}{Y}\right)^2 + 0.0438$	0.725	0.008

5 Conclusions

Generally, the hydraulic characteristics investigated in modular channel appear to be agreed with Manning's equation. Manning's *n* relationships with hydraulic parameters are found to be agreed with study done by previous researchers. A high correlation of more than 0.72 was obtained for equations developed by genetic programming for each type of modular channel in flow depth of not more than 10 cm. Therefore, equations relating roughness parameters to dimensionless hydraulic parameters drawn by genetic programming are useful in determining the Manning's *n* for flow depth in modular channel.

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