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LABORATORY STUDY ON EFFECTS OF VEGETATIONS ON THE OPEN CHANNEL HYDRAULIC ROUGHNESS (PENNISETUM PURPUREUM AND IPOMOEA AQUATICA)

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Abstract

Unrestricted growth of such vegetation in an open channel can lead to its complete loss of the hydraulic capacity which has potential to generate flood. A laboratory study has been conducted to analyze the effects of different types of vegetation to the velocity and on the Manning roughness coefficient (n) in an open channel, and to develop relationships between the characteristics of the vegetation (density, type and distribution) on the hydraulic roughness. Plants namely Napier grass and Ipomoea Aquatica have been selected for this study. From the conducted experiments, the roughness of Napier Grass is in the range of 0.0002 – 0.0073 and Ipomoea Aquatica is 0.0002-0.0062. It was also found that the Manning's n value has a linear relationship with flow depth, vegetation arrangements and density.

Keywords: *Manning's Coefficient, Napier Grass ,Ipomoea Aquatica, Open Channel, Flow Resistance.*

1. Introduction

Vegetation can be found growing naturally on the beds of channels or on the riverbanks or where it has been purposely planted. It is often classified by its shape and the locations where it grows. Vegetation growing on the river floodplains typically comprises various combinations of trees, herbs, shrubs, hedges, bushes and grasses.

The vegetation in channel usually consists of aquatic plants and these may be divided into four categories: *emergent*, *submerged*, *floating-leaf*, and *free-floating leaf*. The presence of vegetation in river channels provides both benefits and problems. From an environmental point of view, aquatic plants are essential parts of natural aquatic systems and form the basis of a water body's health and productivity. And from an engineering point of view, vegetation can improve the strength of bank materials through buttressing and root reinforcement.

However, invariably aquatic plants become over abundant or unsightly and require control. The obvious problems related to excessive growth are retardation, a reduction in hydraulic capacity and flooding. The effects of vegetation on the open channel vary depending on the species, distribution, density and size of vegetation. (Jain, 2001).

Although the flow capacity can be increased by complete or partial removal of vegetation, this solution will lead to erosion of the banks and increase the sediment load carried by flowing water. On the other way, unrestricted growth of such vegetation in an open channel can led to its complete loss of the hydraulic capacity. Many studies have been conducted in previous years to investigate the resistance to flow provide by the vegetation, using either artificial or real vegetation at the open channel. Fathi Maghadam and N. Kouwen (1997) used pine and cedar tree samplings to model the resistance to flow in a water flume.

This study was laboratory based and focused on the effects of local (tropical) plants namely Napier Grass (*Pennisetum Purpureum*) and Kangkung Air

(*Ipomoea Aquatica*) on hydraulic roughness and to develop empirical relationship between the characteristics of the flow and also the characteristics of the vegetations.

2. Experimental details

2.1. Materials and Methods

A series of experiments has been done to measure all the parameters (velocity, flow rate and channel slope) in order to get the Manning roughness coefficient, n for Napier Grass (*Pennisetum Purpureum*) and Kangkung Air ((*Ipomoea Aquatica*) Table 1 shows the details for Napier Grass (*Pennisetum Purpureum*) and Kangkung Air ((*Ipomoea Aquatica*). Therefore, the experiments were carried out in a channel of 10 m length, 0.30 m width and 0.46 m height. (Refer Figure (1a, 1b and 2) and Figure 3 shows the water lettuce planted in site. The 1: 500 ratios have been fixed as the channel slope of the experiments. Discharge is pumped through the open channel from the storage tanks. The flow and water level is controlled by the valve and flow meter.

Table 1 : Details for Napier Grass (*Pennisetum Purpureum*) and Kangkung Air ((*Ipomoea Aquatica*)

Vegetation		Family
Napier Grass	(*Pennisetum Purpureum*)	Poaceae
Water Lettuce (Kangkung Air)	((*Ipomoea Aquatica*)	Convolvulaceae

Figure. 1a:. General view of the flume

Figure. 1b:. General view of the flume with *Pennisetum Purpureum*

Figure. 2. Plan view of the flume with *Pennisetum Purpureum*

Flow is considered uniform only when the cross-section and flow-depth remain constant along the length of flume. The test stretch was 2.5 m long and located at a distance of 3.75 m from the inlet. The vegetation was planted in a wooden box which was filled with soil. The box had a dimension of 2.5 m length, 0.27 m width and a height of 0.08 m.

Figure 3: Water Lettuce planted in field

The schematic drawing of the experimental setup is shown on Figure 4. The mean velocities of flow in channel were measured using an area-velocity flow meter. The mean velocities were then used to compute Manning’s roughness coefficient using Manning’s equation.

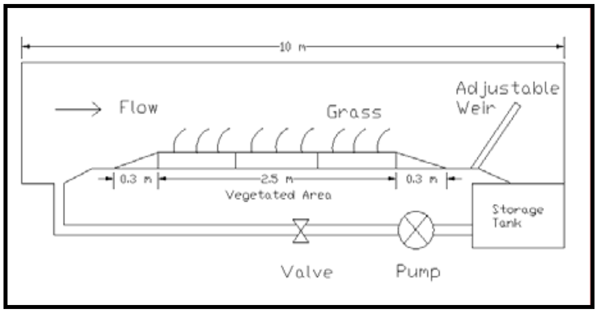

Figure. 4: Schematic drawing of the experimental setup

There were a few important factors needed to determine the effect of vegetation on the roughness of an open channel. (Density/quantities, distribution, flow-depth and vegetation physical characteristics). The test was also carried out without vegetation for control and checking mechanism. To investigate the relationship between flow depth and Manning’s *n*; a fixed set of three flow depths (0.18 m, 0.20 m and 0.22 m) was adopted. The different instrument depth (0.0035 m and 0.0070 m) also taken to see the effect of various depth clearly. Uniform flow is fixed by ensure that the flow depth is constant along the channel. The height and diameter of the vegetation (*Napier Grass*) used is fixed at 0.40 m height and 0.5 cm - 1.0 cm in diameter.

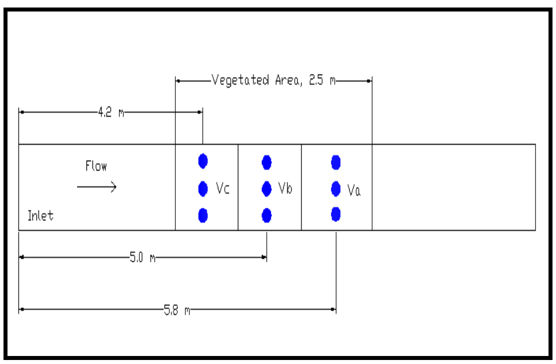

Figure .5 : Velocity measurement location for both specimens.

The mean velocity was measured in 6 different locations in the vegetated zone (Figure 5) (and the average of the mean velocity was used to calculate the Manning’s roughness coefficient, *n*. The experiments were then repeated with two different densities of plant vegetation; 5 veg/m^2 and 10 veg/m^2 with different flow depth to investigate the relationship between vegetation density and Manning’s *n*. To investigate the effects of vegetation arrangements on Manning’s *n*, two different vegetation arrangements were used. This first arrangement is used to simulate the vegetation in both sides and center of the channel; the second arrangement was used to simulate staggered distribution of vegetation across the channel length (vegetated zone). Figure 6 shows the vegetation arrangements for both densities. The flow velocity measurement was carried out at six different locations that have been divided into three sections. The distance of these locations from the flume inlet were 4.2 m, 5 m and 5.8 m.

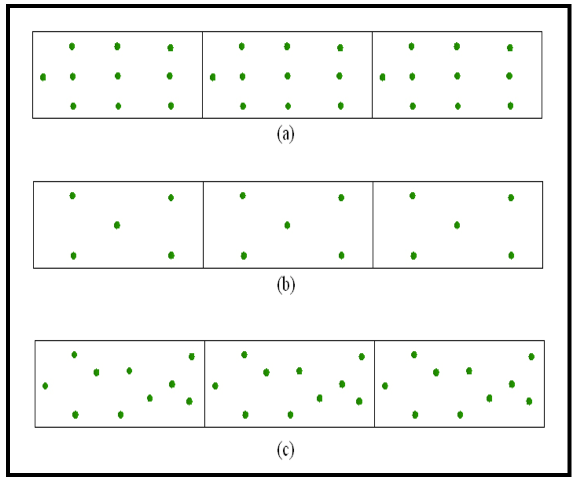

Figure 6 : Vegetation Arrangements for *Pennisetum Purpureum* ;

a. Type 1, both sided and center (10 veg/m^2)
b. Type 2, both sided and center (5 veg/m^2)
c. Type 3 , staggered (5 veg/m^2 dan 10 veg/m^2)

3. Results and discussion

3.1. Data Analysis

The results obtained from the laboratory experiment were then analyzed in order to get the Manning’s roughness value, *n*. Manning’s equation method have been used for the analysis. The method used are shown below:

i. Manning’s Equation :

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

Where: R = Hydraulic radius, in m
V = velocity of flow, in m/s

Analyses have been done after getting all the parameters needed from the experiments. The parameter measurement has been repeated a few times to reduce error towards the outcome / results by the end of analysis. The average for mean velocity, flow rate and Manning’s roughness coefficient, n were calculated using Manning's equation while the roughness coefficient contributed by the vegetation, n_{veg} were calculated using Soil Conservation Service Method (*SCS*). The summary of the data analysis is shown at Table 2 and Table 3 for . Napier Grass *(Pennisetum Purpureum)* and Table 4, 5 and 6 for Water Lettuce(*Ipomoea Aquatica)*

Table 2 : Data Analysis Summary for Napier Grass

Qty.	Arrangement	Flow Depth (m)	Equipment Depth (m)	V (m/s)	Q (m^3/s)	n_{veg}
5 veg/m^2	Type 1	0.18 m	0.035m	0.4777	0.0258	0.0002
			0.070m	0.6506	0.0351	0.0004
		0.20 m	0.035m	0.5659	0.0340	0.0003
			0.070m	0.7265	0.0436	0.0008
		0.22 m	0.035m	0.5534	0.0365	0.0011
			0.070m	0.7586	0.0501	0.0018
	Type 2 (Rawak)	0.18 m	0.035m	0.4697	0.0254	0.0005
			0.070m	0.6417	0.0347	0.0006
		0.20 m	0.035m	0.5401	0.0324	0.0010
			0.070m	0.6906	0.0414	0.0014
		0.22 m	0.035m	0.5400	0.0356	0.0016
			0.070m	0.6306	0.0416	0.0042

Table 3 : Data Analysis Summary for Napier Grass

Qty.	Arrangement	Flow Depth (m)	Equipment Depth (m)	V (m/s)	Q (m^3/s)	n_{veg}
10 veg/m^2	Type 1	0.18 m	0.035m	0.4565	0.0246	0.0012
			0.070m	0.5636	0.0304	0.0023
		0.20 m	0.035m	0.5264	0.0316	0.0014
			0.070m	0.6469	0.0388	0.0024
		0.22 m	0.035m	0.5471	0.0361	0.0023
			0.070m	0.6661	0.0440	0.0034
	Type 2 (Staggered)	0.18 m	0.035m	0.3860	0.0208	0.0043
			0.070m	0.4675	0.0252	0.0055
		0.20 m	0.035m	0.4081	0.0245	0.0062
			0.070m	0.4770	0.0286	0.0070
		0.22 m	0.035m	0.5210	0.0344	0.0068
			0.070m	0.5158	0.0340	0.0073

Table 3 : Data Analysis Summary for Water Lettuce

Divided region in the channel	Vegetation densities in the channel	Experimental objective	Flow depth
Region 1.0	Less dense, Medium dense and Dense	Variation of Manning's n for smooth channel without vegetation	0.14 m, 0.16 m, 0.18 m
Region 2.0	Less dense, Medium dense and Dense	Variation of Manning's n for channel with vegetation	0.14 m, 0.16 m, 0.18 m
Region 3.0	Less dense, Medium dense and Dense	Variation of Manning's n for smooth channel without vegetation after pass trough channel with vegetation	0.14 m, 0.16 m, 0.18 m

Table 4 : Overall Summarize for Water Lettuce

Vegetation condition in channel	Height of perception velocity device (m)	Flow depth (m)	Manning's value, *n*		
			Region 1.0	Region 2.0	Region 3.0
Specimen densities ; less dense	0.065	0.14	0.0085	0.0088	0.0085
		0.16	0.0090	0.0093	0.0088
		0.18	0.0114	0.0116	0.0113
	0.110	0.14	0.0109	0.0113	0.0103
		0.16	0.0092	0.0094	0.0088
		0.18	0.0111	0.0116	0.0107
Specimen densities ; medium dense	0.065	0.14	0.0090	0.0097	0.0091
		0.16	0.0092	0.0094	0.0085
		0.18	0.0088	0.0095	0.0084
	0.110	0.14	0.0132	0.0167	0.0127
		0.16	0.0086	0.0093	0.0080
		0.18	0.0110	0.0124	0.0090
Specimen densities ; dense	0.065	0.14	0.0091	0.0098	0.0095
		0.16	0.0111	0.0117	0.0102
		0.18	0.0097	0.0106	0.0093
	0.110	0.14	0.0092	0.0154	0.0101
		0.16	0.0121	0.0144	0.0113
		0.18	0.0097	0.0112	0.0090

3.2 Variation of Manning's n with the Flow Depth.

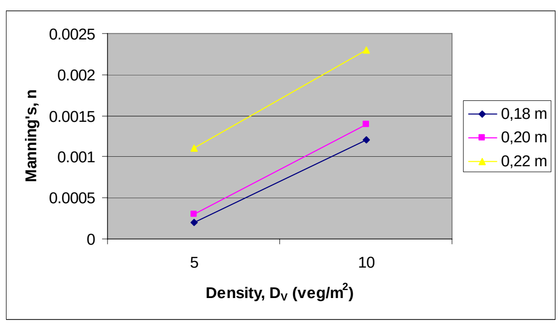

Figure 7 : Relationship between Manning's *n* and Flow Depth

From the graph above, it is shown that the value of roughness increases when the flow depth increasing (linear relationship). It is also found that the value of n increasing with the increasing of vegetation density. This results show an agreement with the statement of Jarvela (2002) which the roughness coefficient value is depending on the flow depth and increasing when the flow depth increases.

Another factor is the branching stems and leaves of the Napier Grass and Water Lettuce itself.

3.3 Variation of Manning's *n* with Density

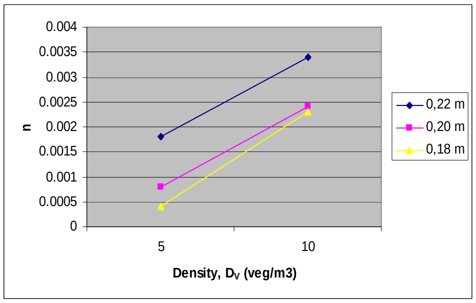

Figure 8: Relationship of Manning's, *n* with Density

From the graph above, it is found that the value of densities have a linear relationship with the Manning's roughness coefficient, n. For this study, two densities were used to investigate the effects of low and high density vegetations which are 5 veg/m^2 and 10veg/m^2 for Napier Grass. The roughness value increases along with the increment of quantity/density of vegetation in an open channel. In this case, it were found that on 0.18 m depth, the value of n increases about 475%, 200% at 0.20 m depth and 90%

3.4 Comparison of Manning's, *n* Inside Channel

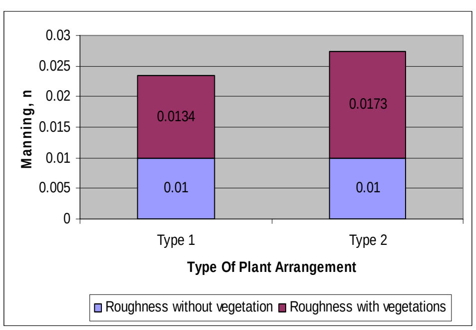

Figure 8 : Comparison of Manning's *n* Inside Channel

The bar chart shows the comparison of Manning's *n* for two different conditions; roughness value with and without vegetations, Comparison also been made by considering two different types of arrangements; Type 1 and Type 2. From the chart, it is found that the channel's roughness coefficient with vegetation increased significantly by 34% from channel's roughness without vegetation for Type 1 arrangement, while there was 73% increment for Type 2 arrangement. This situation shows that the roughness coefficients in an open channel are more contributed by the vegetation depending on the type, densities and arrangement of the vegetation.

3.5 Comparison with Kangkung Air (*Ipomoea Aquatica*)

Comparisons were made between Napier Grass (*Pennisetum Purpureum*) and Kangkung Air (*Ipomoea Aquatica*) to see the effect of both vegetations on the hydraulic roughness of an open channel. The ranges of Manning's roughness coefficient value for both vegetation are shown below:-

Table 5 : Manning's, *n* Value For Vegetation

Vegetation	Manning's, *n*
Napier Grass	0.0002-0.0073
Kangkung Air	0.0002-0.0062

Based from the information above, it is found that Napier Grass (*Pennisetum Purpureum*) recorded a value of Manning's *n* is 17.8% more than Kangkung Air (*Ipomoea Aquatica*). The factor that contributed to these phenomena is type of plant which Napier Grass is an emergent plant while *Kangkung Air* is a free floating plant. *Napier Grass* acts more to reduction from beneath to surface while *Kangkung Air* is more on the surface. The physical properties of *Napier Grass* also contributed to this situation (Branching stems, leaves)

4. Conclusion

This study presents the effect of vegetation on the Manning's, n in an open channel. The vegetation selected for this experiment is Napier Grass (*Pennisetum Purpureum*). From the experiment conducted that the roughness of Napier Grass is in range of 0.0002 – 0.0073. It is also found that the increasing of Manning's *n* value is depending on the increasing of flow depth. The vegetation arrangement/distributions also founded to be affected the value of Manning's n where for vegetation arrangements; Type 2 (Staggered) recorded increment for Manning's value at 34%-195% rather than Type 1 arrangements. This is probably caused by almost two third of the flow area has been resisted than Type 1 arrangements. The increasing of Manning's n value also identified when density of vegetation increased. The values of velocity and flow rate were proportionally inversed with Manning's n. The physical structure of Napier Grass with branching stems and leaves is the main factor that effects the velocity distributions of flow.

Napier Grass contributed 34%-73% to the overall channel roughness depending on the quantities and arrangements. Napier Grass (*Pennisetum Purpureum*) recorded the Manning's *n* value of 17.8% more than Water Lettuce (*Ipomoea Aquatica*.). As the conclusion, vegetation really giving effects to the open channel on roughness value, velocity and flow. The vegetation roughness value in an open channel is depends more on density, distribution, type and physical characteristics of vegetation

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