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The effect of ratio between rigid plant height and water depth on the manning's coefficient in open channel

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Abstract. One of the important factors in channel dimension is the Manning's coefficient (***n***). This coefficient is influenced not only by the channel roughness but also by the presence of plants in the channel. The aim of the study is to see the effect of the ratio between the height of the rigid plant and water depth on the Manning's coefficient (n) in open channel. The study was conducted in open channel with 15.5 m long, 0.5 m wide and 1.0 m high, in which at the center of the channel is planted with the rigid plants with a density of 42 plants/m^2. The flow was run with a discharge of 0.013 m^3/s at 6 ratios of H_{plants}/H_{water}, namely: 0; 0.2; 0.6; 0.8; 1,0 and 1,2, to obtain the velocity and water profiles. Then the value of ***n*** is analyzed using Manning's equation. The results showed that the mean velocity becomes decrease 17.81-34.01% as increase the ratio of H_{plants}/H_{water}. This results in increasing n value to become 1.22-1.52 times compared to the unplanted channel (n_o=0.038). So, it can be concluded that the ratio between the rigid plant's height and water depth in the open channel can affect the value of Manning coefficient.

1. Introduction

An important factor that greatly influences the calculation of discharge in the channel dimension planning is the Manning's coefficient. This coefficient describes the roughness of the material forming both at the base and wall of the channel. This roughness may increase the flow resistance, so that it can disrupt the flow in the channel. At present, the roughness at the base and wall of the channel is uniformly used in the Chezy or Manning equation as the basis for calculating the discharge and open channel dimensions [1]. However, another flow resistance occurring within the channel due to the presence of other obstructing objects is not included in analyzing the discharge. One of the most commonly encountered objects in the channel is the presence of plants in the channel. The presence of plants in the channel on one side can prevent scouring, but on the other side, the existence of plants in the channel can increase the flow resistance. [3] shows that the presence of plants causes an increase in flow resistance. The development of these research has been fully published in [2], [4], [5], [6], [7] dan [11]. Overall, the results of the study indicate that the presence of plants in both flexible, stiff and rigid characteristic, whether submerged or partially submerged in the water, may increase in flow resistance. However, the prediction of the vegetation resistance is very complex since there are many different species with their unique characteristics changing during the season. These plant characteristics are influencing the hydraulic resistance, which may vary significantly from place to place, and may also change in time. Beside that the inhomogeneous character of the vegetation in the field that is hard to take into account in a model of the equation. Moreover, the difference of type dan characteristic of vegetation might result in different flow resistance, although these vegetations are equally flexible, rigid or stiff vegetation. For example, mostly in irrigation channel are grown by water grass (Acorus Gramineus), water hyacinth (Eichhornia Crassipes), watercress (Ipomoea Aquatica Forsk), elephant grass (Pennisetum Purpureum) And jeringau (Acorus Calamus). These plants might be different characteristics of a different place. [9] has researched on a channel planted with jeringau (Acorus Calamus) which has flexible characteristics. Other research, [10] has also been done for elephant grass (Pennisetum Purpureum) which has rigid characteristics. The object of both researchers is the effect of plant density. The results showed that the flow resistance in the channel increased with increasing of plant density, which was indicated by the increase of Manning coefficient (n) due to the increase of plant density. Furthermore, [8] has also conducted a similar study by examining the effect of jeringau height (Acorus Calamus) on the flow resistance in the channel. The results also showed that the higher the plant in the channel the higher the increasing value of Manning roughness. Considering to the great influence of the presence of plants on the roughness in the channel, then it is necessary to do further research by studying at the different treatments and type of plants that grow in the channel to obtain the most suitable approach for general application.

This research is a continuation of previous research as mentioned in [8], [9] and [10]. This study aims to see the effect of the ratio between the height of the rigid plant and water depth in open channel on Manning coefficient (n).

2. Literature Review

2.1. Manning's equation

Flow resistance can be translated by incorporating velocity, hydraulic radius, base slope and roughness of base and wall of the channel, then formulated as called Manning's Equation [1].

$$V = \frac{1}{n} R^{2/3} \mathbf{S}^{1/2} \qquad (1)$$

where: n=Manning's coefficient; V=mean velocity (m/s); R=hydraulic radius (m); And S=the slope of the energy line.

2.2. Manning's coefficient in channel

The Manning's coefficient (n) as in the equations 1is normally derived from the roughness of materials forming channels. In fact that in nature the flow resistance is influenced by many factors, so the real Manning's coefficient can be obtained using the equation (2) as below.

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5 \qquad (2)$$

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In some cases, the values of n_1, n_2, n_3 can be ignored due to not significant, so equation (2) is dominated by the base roughness of channel and due to plants, as in equation (3).

$$n = n_0 + n_4 \tag{3}$$

where: n_0=the base roughness; n_1= the variation of channel surface; n_2=shape variation of channel section; n_3=obstacles due to the structure; n_4= due to plants; and m_5=correction factor for channel bend.

3. Research Methods

3.1 Research preparation and design

This research was conducted at Hydrotechnics Laboratory, Faculty of Engineering, Syiah Kuala University. This study used a flume with a length of 15.5 meters, a width of 0.5 meters and a height of 1.00 meters. On the upstream side of the flume is placed the 90° Thompson water gate, to control the discharge, where the water level is set to a fixed depth of 45 cm. At a center of 3 m long of the channel is planted with elephant grass (Pennisetum Purpureum), as rigid plants, with a density of 42 plants/m^2. Six ratios of plant height (H_{plant}) and water depth (H_{water}), namely: (SP-0: 0, without plant), (SP-1: 0,2), (SP-2: 0.6), (SP-3: 0,8), (SP-4: 1,0) and (SP-5: 1,2), for more details the placement of plants with 6 variations in plant height can be seen in figures 1 and 2.

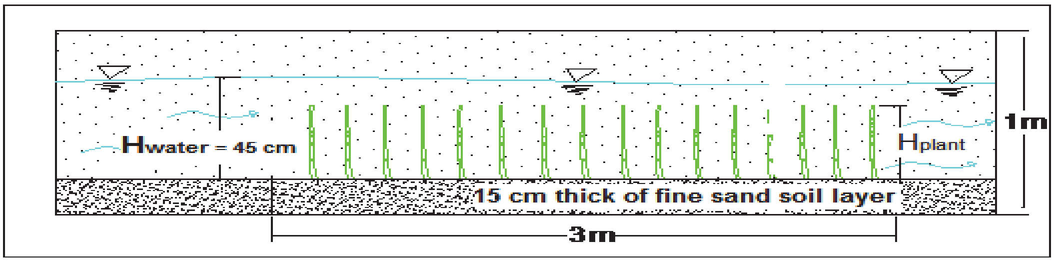

Figure 1. Side view of placement of plants in channels

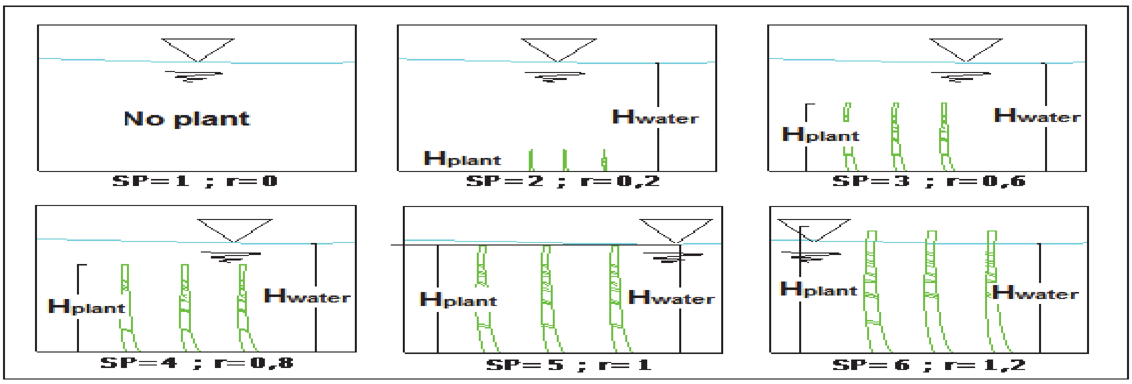

Figure 2. Variation of a ratio between plants height and water depth.

The parameters measured in this study were water level (h), flow slope (S_f) and mean velocity (V) which is measured in every ratio with a constant discharge of 0.013 m^3/s.

3.2 Data analysis

3.2.1 Distribution and mean velocity

There are 3 locations that be an object of measurements to analyze the distribution and mean velocity, namely: at the upstream, at the middle and the downstream of the channel. The velocity distribution is measured using a current meter on the flow surface, depth of 0.2h, 0.6h, 0.8h and a channel base. The mean velocity is calculated using the equation 10 as below.

$$\overline{V} = \frac{V_p + 3.V_{0,2h} + 2.V_{0,6h} + 3.V_{0,8h} + V_d}{10} \quad (4)$$

where: V = mean velocity (m/s); V_p = velocity at the surface (m/s); $V_{0.2h}$ = velocity at depth 0.2h (m/s); $V_{0.6h}$= velocity at depth 0.6h (m/s); $V_{0.8h}$ = Velocity at a depth of 0.8h (m/s); V_d = velocity at the base (m/s).

3.2.2 Slope of energy

Loss of energy can be calculated using the Bernoulli equation [1]. This value is obtained from the measurement of water depth in upstream (H_u) and downstream (H_d), as well as upstream (V_u) and downstream (V_d) velocities. The total energy losses can be written as in the equation below.

$$H_u + \frac{V^2{}_u}{2.g} = H_d + \frac{V^2{}_d}{2.g} + h_f \quad (5)$$

The slope of energy (S_f) can be calculated by the equation 6 where L is the length of the planted channel.

$$S_f = \frac{h_f}{L} \quad (6)$$

3.2.3 The Manning's Coefficient

The coefficient of Manning (n) is obtained using equation 1 above. The value of n in equation 1 is the total roughness produced by the channel and plant which can be formulated as in equation 7, so the roughness occurring due to the presence of the plant can be calculated by equation 8.

$$n = n_o + n_v \quad (7)$$

$$n_v = n - n_o \quad (8)$$

4. Result and Discussion

4.1. Profile of speed distribution to crop height

Flow velocity measurements at each depth downstream, center and upstream can be obtained from the velocity distribution profile to water depth, as shown in figures 3, 4 and 5. The graphs explain that the velocity decreases with increase in height ratio of plants compared to the unplanted channel. The presence of plants in the channel causes the flow to be blocked and cause backflow causing the increasing flow resistance, making the flow velocity becomes reduced.

Overall, this condition causes the mean velocity of each variation in the height ratio of plants in the channel to be changed, where the higher the ratio of plant height the smaller the mean velocity in the channel or it can be said that the mean velocity tends to decrease as increase the ratio of plant height, as shown in fig. 6. If compared to the unplanted channel, mean velocity becomes decreases in between 17.81-34.01% due to increasing the ratio of plant height.

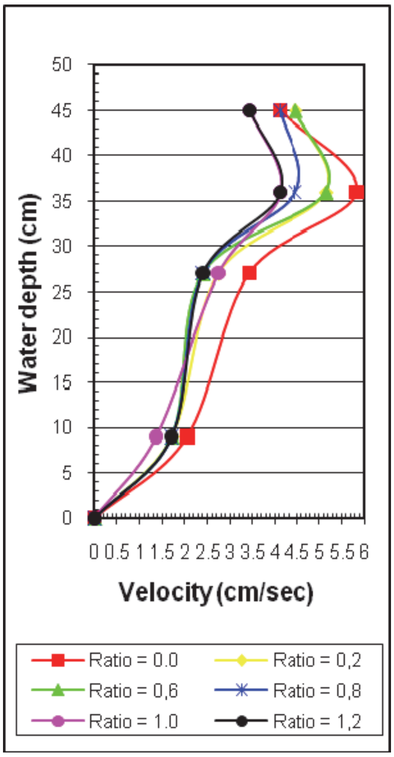

Figure 3. Velocity distribution at the downstream of channel

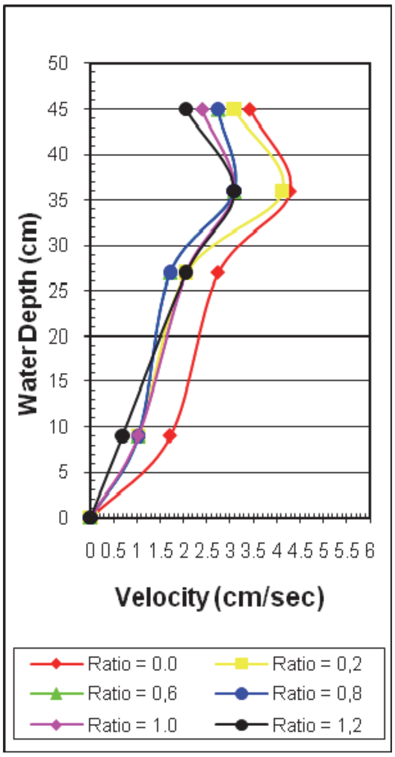

Figure 4. Velocity distribution at the central of channel

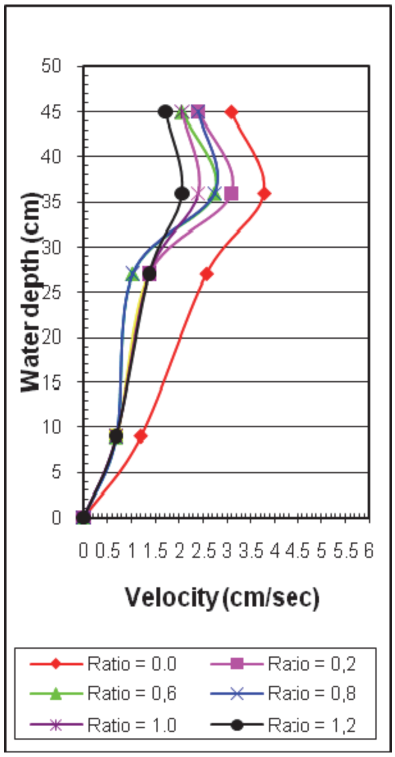

Figure 5. Velocity distribution at the upstream of channel

4.2. The relationship between the ratio of the plant height against the coefficient Manning

Using equations 1, 7, and 8, the results are shown in Table 1. The results showed that increasing the ratio of plant height result in increasing the total Manning's coefficient (n) . For more details, the trend of the relationship between the height of plant and the coefficient of Manning can be seen in figure 7, where the value of n keep increasing as increasing the ratio of plant height.

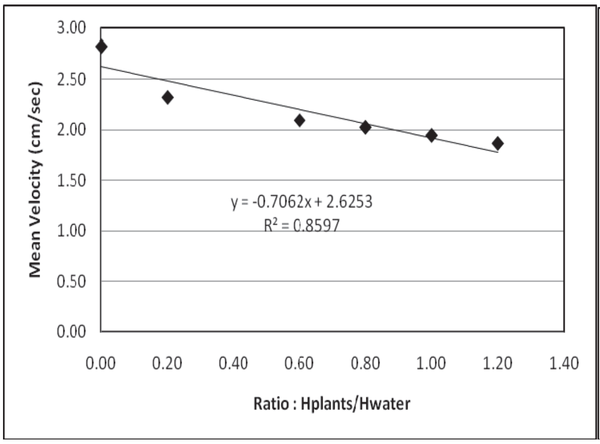

Figure 6. Mean velocity in the channel for every ratio of the plant height

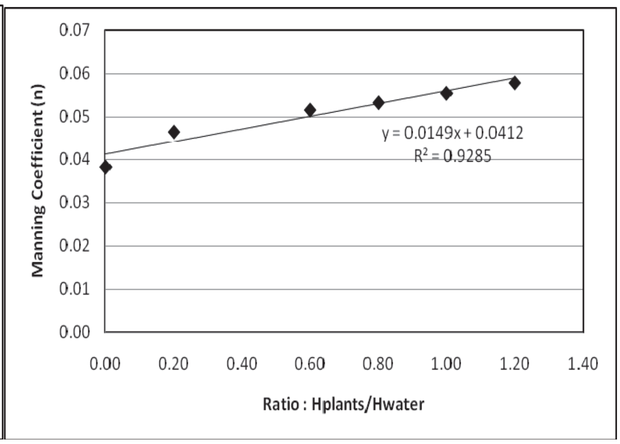

Figure 7. Relationship ratio of plant height and Manning coefficient (n)

In addition, table 1 also explains that the Manning's coefficient (n) ranges from 0.0464-0.0578, while the Manning coefficient for the unplanted channel (n_0) = 0.0381. Furthermore, by using equation 8 additional values of Manning's coefficient due to the presence of crop (n_v) is in between 0.0083-0.0196 or increase the value of Manning coefficient (n) between 21.625-51.534% by the increase Ratio of plant height. So that the total coefficient of Manning (n) is increasing 1.22 up to 1.52 times compared to the unplanted channel (n_0) = 0.038. This result shows that the Manning's coefficient obtained above is almost similar as previous research for the variation of ratio height of jeringau (acorus calamus) as published in [8], where the Manning's coefficient increase 1.30 to 1.94 times compared with the unplanted channel. This indicates that the presence of plants with increased height and type of plants can increase the value of Manning coefficient.

Table 1. Roughness of Manning (n)

Ratio Elevation of Plants	Manning Roughness Total N	Initial n_0	Plant n_v
0	0,0381	0,0381	0,0000
0,2	0,0464	0,0381	0,0083
0,6	0,0514	0,0381	0,0133
0,8	0,0532	0,0381	0,0151
1,0	0,0554	0,0381	0,0173
1,2	0,0578	0,0381	0,0196

The invention is expected to be input in hydraulics science when applying in the channel planning for both irrigation and drainage. This needs to be our concern in the operational and maintenance (OM) of irrigation and drainage network systems, since the impact of increased flow resistance may affect the flow discharge to affect the irrigation system or the drainage itself.

5. Conclusion

The result of this research can be concluded that the presence of elephant grass (Pennisetum Purpureum) as rigid plant characteristics with various ratio plant height inside the channel can affect the flow velocity distribution where the greater the height of plant causing the smaller flow velocity, which is indicated by the mean velocity decrease of 17,81-34,01 %. This condition leads to an increase in the flow resistance shown by the increase in the coefficient of Manning (n) ranging from 0.0464-0.0578 compared to the unplanted channel (n_0 = 0.0381) or an increase of 1.22-1.52 times. So it can be concluded that the height ratio of rigid plants and the height of water in the open channel can affect the value of Manning coefficient. It is suggested that further research is required by including additional characteristics such as; density, diameter and leaf width of the plant or other types of plants so that the flow resistance due to the presence of plants can be modeled more perfectly for the development of the science of hydraulics in the future.

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