The presence of Jeringau (*Acorus calamus*) as flexible vegetation type in the channel against flow resistance

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Abstract

Flow resistance in the channel is influenced not only by material forming the bed and slope of channel, but also influenced by abstraction due to the presence of vegetation in the channel, so called vegetated channel. The presence of vegetation may greatly affect the conveyance of a channel. The study is aimed to investigate the effect of flexible vegetation density of jeringau (*Acorus calamus*) to flow resistance. The research is conducted in the laboratory by using a channel-flume with dimensions of 15.5 m length, 0.5 m width, and 1.0 m height in which in the central part of 1.4 m length of flume is planted with Jeringau in submerged condition. The vegetation density is set in 6 variations, namely: 0, 6, 12, 18, 30 and 42 plants/m². Flow velocity at surface, 0.2h, 0.6h, 0.8h and bed level are measured using micro-current meter to see velocity distribution profile in three parts of upstream, central (vegetating part) and the downstream of channel. At those point are also measured the water depth using point gauge to see the head losses for analyzing Manning’s roughness coefficient (n). Based on the measurements and analysis, it is obtained that the presence of Jeringau might change velocity distribution compared to unvegetated channel. The more increase the density of Jeringau, the more increase the head losses which result on increasing Manning’s roughness coefficient. The largest n value is 0.053, obtained from maximum density, and 0.022 for unvegetated channel. The result shows that n value increase 2.41 times due to the presence of Jeringau vegetation. It can be conclude that the presence of vegetation can increase the value of roughness coefficient affecting flow resistance, so as to disturb the water flow in a channel.

Keywords: Flow Resistance, Vegetated channel, Jeringau (*Acorus calamus*), Manning’s roughness coefficient.

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1. Introduction

Flow resistance in the channel is influenced not only by material forming on bed and slope of channel but also influenced by obstruction due to the presence of vegetation in the channel, so called vegetated channel. The presence of vegetation has a major effect on the flow resistance. Flow resistance due to vegetation may greatly affect the conveyance of channel, reducing flow velocity and consequently increasing head losses of energy and resulting on sediment deposition in the channel bed and banks, [1]. Thus, in order to cope with new management in hydraulics, the influence of vegetation in the channel becomes important.

### Nomenclature

| Symbol | Description |
|--------|-------------|
| C      | Chezy coefficient | $n_w$ | Sidewall Manning’s Coefficient |
| D      | Water depth | $n_v$ | Vegetative Manning’s coefficient |
| f      | Darcy-Weisbach coefficient | $R$ | Hydraulic Radii |
| g      | Gravity | $V_b$ | Velocity on bed of channel |
| $I_f$  | the slope of energy | $V_d$ | Downstream mean velocity |
| H      | Water depth | $V_{0.2}$ | Velocity on 0.2 of water depth |
| $H_u$  | Upstream water depth | $V_{0.6}$ | Velocity on 0.6 of water depth |
| $H_d$  | Downstream water depth | $V_{0.8}$ | Velocity on 0.8 of water depth |
| L      | length of test area | $V_s$ | Velocity on surface of channel |
| n      | Manning’s coefficient | $V_u$ | Upstream mean velocity |
| $h_f$  | Head losses | $V$ | Mean velocity |
| n      | Manning’s coefficient |

Many researchers have already been carried out in order to describe the relationship between flow resistance and the presence and spatial distribution of vegetation. They resulted and developed the theories and formulas dealing with the flow resistance due to the presence of vegetation, including roughness of vegetation, so called, Manning’s coefficient (n). [4–6] have carried out in developing resistance equation for channels with flexible and stiff vegetation in condition submerged or partially submerged plants. Also detailed plant characteristics (leaves, bending) with various combinations may have important influences on flow resistance [7–11]. However the prediction of the vegetation resistance is very complex since there are many different species with their own 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 characteristic of the vegetation in the field that is hard to take into account in model of equation. Another important aspect of describing vegetation is the flexible vegetation [12]. The bending of vegetation decreases the height of the vegetation influencing the resistance. Moreover, the difference of type dan characteristic of vegetation might result on different flow resistance, although these vegetation are equally flexible or stiff vegetation. Therefore the evaluation of flow resistance for different type and characteristic of vegetation is an essential task in open channel hydraulics in order to obtained the most suitable approach for general application.

The purpose of this paper is to investigate the determination of the flow resistance caused by jeringau (Acorus calamus). The paper presents a practice-oriented procedure for determining Manning’s roughness (n). Emphasis is put on influencing the difference density of vegetation against flow resistance. The research is limited to the case of jeringau (Acorus calamus) as flexible typical vegetation with submerged condition with single flow depths of 45 cm and uniform jeringau vegetation of 30-40 cm tall.
2. Theoretical considerations

The resistance of a surface can be characterized with several hydraulic roughness coefficients. The most widely used are the Manning roughness coefficient \( n \) as in Eq. 1, the Chezy resistance factor \( C \) as in Eq. 2, and the Darcy-Weisbach friction factor \( f \) as in Eq. 3.

\[
V = \frac{1}{n} R^{2/3} I_f^{1/2}
\]

\[
V = C \sqrt{RI_f}
\]

\[
h_f = f \frac{L V^2}{2g}
\]

Manning’s \( n \) is most popular in computation of open channel, overland flows and soil erosion models, while using the Darcy-Weisbach \( f \) is more common than the other resistance formulations in experimental studies, [9]. Manning’s \( n \) is most popular in computation of open channel, overland flows and soil erosion models, while using the Darcy-Weisbach \( f \) is more common than the other resistance formulations in experimental studies.

In [8] is described that many published values of Manning’s roughness coefficients related to vegetated surfaces include the base resistance, \( n_0 \), as a part of the reported vegetation resistance. Thus, roughness coefficients reported herein include the effects of both the bed \( (n_0) \) and the vegetation \( (n_4) \), expressed as \( n_0 + n_4 \).

3. Method of research

3.1. Experimental set up

Experiments were conducted in a 15.5 m long, 0.5 m wide and 1.0 m deep glass-walled flume. The slope of the flume is set with fixed slope of 0%. Discharge of 5.53 l/s is conducted through one V-notch gate, in which water level of 45 cm can be maintained at a constant level. The soil forming bed flume was layered by fine sand with 15 cm thick to make the same condition as test area. The test area was set in the middle of flume with 3 m long and planted by jeringau (Acorus calamus). Jeringau is This plant has long thin leaf of 25-100 cm tall and 0.5-1.5 cm wide and flexible vegetation due to water flow. This plant is planted in the flume with 30-40 cm tall of jeringau in submerged condition, as depicted in Fig. 1, and is planted with 6 variations of density, namely; 0, 6, 12, 18, 30 and 42 plants/m², as shown in the Fig. 2.

![Fig. 1. Submerged vegetation layout](image)

3.2. The Series of measurements and analysis

The series of measurements under fixed discharge of 5.53 l/s is run on the test area with different trial test of vegetation density. The series of measurements are completely shown in in the Table 1. The velocity of flow was measured using micro currentmeter which was put at upstream 1 m before test area and at downstream 1 m after test area. The measured was conducted at bottom, 0.2h, 0.6h, 0.8h and surface level to obtain the profile of velocity distribution, and then by using Eq. 4 the mean velocity can be calculated.
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Fig. 2. Vegetation density layout

\[ V_{m} = \frac{V_{0.2} + 3V_{0.6} + 2V_{0.8} + 3V_{1.0} + V_{s}}{10} \]  
(4)

| Series of Measurements | Vegetation Density | Data          |
|------------------------|-------------------|--------------|
|                        | (plants/m²)       | Measurements | Analysis |
| VD-0                   | 0                 | (Hu, Hd, V)0 | 0         |
| VD-1                   | 6                 | (Hu, Hd, V)6 | 6         |
| VD-2                   | 12                | (Hu, Hd, V)12| 12        |
| VD-3                   | 18                | (Hu, Hd, V)18| 18        |
| VD-4                   | 30                | (Hu, Hd, V)30| 30        |
| VD-5                   | 42                | (Hu, Hd, V)42| 42        |

Water depth was recorded at the upstream and downstream of test area with a point gauge. Total head loss of energy was calculated using Bernoulli’s equation for elevation \( Z_1 = Z_2 \) as written in Eq. 5.

\[ H_u + \frac{V_{u}^2}{2g} = H_d + \frac{V_{d}^2}{2g} + h_f \]  
(5)

and slope of energy can be obtained using the following equation.

\[ I_f = \frac{h_f}{L} \]  
(6)

In this study, Manning’s \( n \) is used to denote the flow resistance, as stated in [12,13]. The total resistance of the testing flume is a result of the sidewall and bottom resistance, designated as \( n_w \) and \( n_b \), respectively. Since the bed resistance is dominated by the vegetative roughness rather than the surface friction of the bottom, \( n_b \) may well be used to represent the vegetative roughness coefficient (\( n_v \)). Meanwhile \( n_w \) is represented by \( n_o \) (The manning’s coefficient for unvegetated channel so called boundary friction). So the Manning’s coefficient (\( n \)) in Eq. 1 is the total boundary friction (\( n_o \)) and vegetated resistance of flow (\( n_v \)), as written in Eq. 7. By this, then the vegetative roughness of Manning’s coefficient (\( n_v \)) can be obtained using Eq. 8.

\[ n = n_o + n_v \]  
(7)

\[ n_v = n - n_o \]  
(8)

4. Results and discussions

4.1. The profile of velocity to water depth

The velocity were measured at bottom, 0.2h, 0.6h, 0.8h and surface level to obtain the profile of velocity distribution, the results is shown in the Fig. 3. The figure showed that the profile of velocity with no vegetation give the logarithmic relationship to water depth. But due to the presence of plants, the profile of velocity turns into tow
distinct layers, in which significantly change in water depth of 0.2 to 0.6h, as in Fig. 3. So the profile of velocity can not fit a logarithmic except in the unvegetated layer. The result is quite relevant to [2,3,7,14], they stated that For submerged conditions the vegetation is relatively high in relation to the flow depth, as a consequence the velocity profile changes a lot over depth, as shown in Fig. 3. At the bed of the channel, the velocity is influenced by the bottom roughness. Inside the vegetation from the bed and the top of the vegetation, the velocity is tending to be uniform. Near the top of the vegetation there is a transitional profile between the velocity inside the vegetation and the higher velocities above the vegetation. Because of the difference in velocity in these two layers, descriptions for submerged vegetation are often based on a two-layer approach. The two-layer approach describes the velocity inside the vegetation layer separately from the velocity inside the layer above the vegetation, the so called surface layer. Above the vegetation often a logarithmic profile is assumed for the velocity distribution in the surface layer. This shows that the presence of jeringau can also influence the profile of velocity.

![Fig. 3 The Profile of Velocity for Variation of Density to Water depth](image)

**4.2. Flow resistance against vegetation density**

As stated above that the flow resistance was denoted by Manning’s coefficient (n). Using Eq. 7 the roughness coefficient of Manning on the basis of mean velocity for every density of vegetation can be obtained. Fig. 4(a) is the curve of the Manning’s coefficient on the basis of mean velocity against vegetation density. The curve shows that the more dense of vegetation the more increase of Manning’s coefficient. This condition is caused by flow retardation due to the presence of vegetation. So that the velocity in this layer tend to be decreasing as Fig. 3., affecting on increasing the flow resistance which significantly relate to increasing on Manning’s coefficient. The Manning’s coefficient is also plotted against the water depth, as shown in Fig. 4(b). The figure reveals that the curves have a consistent pattern of variation compared to Fig.3. With the increase of water depth and vegetation density, the Manning’s coefficient or flow resistance tend to be increasing to the depth.

![Fig. 4. (a) The Vegetation Density to Manning’s Coefficient; (b) The Water Depth to Manning’s Coefficient](image)
Table 2. The Total, bed and Vegetated Roughness of Manning’s Coefficients.

| Vegetation Density (plants/m²) | Manning’s Coefficient | Total (n) | Bed (n_b) | Vegetation (n_v) |
|-------------------------------|-----------------------|----------|-----------|-----------------|
| 0                             | 0.022                 | 0.022    | 0         |
| 6                             | 0.033                 | 0.022    | 0.011     |
| 12                            | 0.034                 | 0.022    | 0.012     |
| 18                            | 0.038                 | 0.022    | 0.016     |
| 30                            | 0.046                 | 0.022    | 0.024     |
| 42                            | 0.053                 | 0.022    | 0.031     |

The above result shows that Manning’s n, representing the total resistance induced by the boundary friction and vegetation. The Manning’s coefficient due to vegetation (n_v) can be subtracted using Eq. 8 and the results can be seen in Table 2. It can be described that the more increasing density of vegetation the more increasing the Manning’s coefficient (n_v), giving additional roughness in between 0.011 up to 0.031. Or in total, the Manning’s coefficient due to the presence of jeringau increase in between 0.033-0.053. If compared to unvegetated Manning’s coefficient of 0.022, in total the Manning’s coefficient increase in between 1.5 up to 2.41 times. The results showed that the presence of jeringau (Acorus calamus) can increase the flow resistance which is denoted by increasing the Manning’s coefficient. Therefore, the flow resistance of estimation is becoming an essential task of hydraulic engineer in order to avoid not only miscalculation of flow variables, such as the water depth, velocity, and shear stress, but also the prediction of their derivative outcomes, such as the time of concentration, flow distribution in a basin and the transport of sediment.

5. Conclusions

An experimental study has been conducted using jeringau (Acorus calamus) as flexible type of vegetation to investigate the flow resistance. Based on the result can be concluded as follows:

1. The presence of different density of jeringau can change the profile of velocity compared to unvegetated channel.
2. The flow resistance is converted into the roughness coefficient with the aid of Manning’s equation. The presence of jeringau can effect the flow resistance, in which the more increase density of jeringau, the more increase the Manning’s coefficient (n). Totally the manning’s coefficient increase between 1.5-2.41 times.

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