Calibrating Coefficients of Emerged Vegetative Open Channel Flow

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Abstract

Vegetation has a significant role in the river environment. It increases aesthetic value to revetments. Many experimental studies have been carried out to find flow resistance offered by vegetation in open channels. In vegetated channel, roughness coefficients are found to be vary with the cross-sections and depth of flow. This paper is about, a laboratory study carried out in emergent vegetation at Hydraulics Engineering Laboratory, NITR to analyse the outcome of vegetation. The Shiono Knight Method (SKM) has been applied to calculate depth-averaged velocity distribution and boundary shear stress distribution in an open channel flow. For this purpose, three calibrating coefficients such as bed friction (f), dimensionless eddy viscosity (λ) have been incorporated to modify the existing SKM. A mathematical model formulated to find the calibrating coefficients in the channel and also compared with SKM.

Keywords**:** open channel flow, emergent vegetation, drag coefficient, bed friction, eddy viscosity, secondary flow coefficient, depth-averaged velocity, SKM.

1. Introduction:

In an open channel, vegetation retards the flow by expending drag forces on it. Vegetation is an important factor in determining roughness because it affects the flow structure in a channel. Energy dissipation occurs in an open channel due to three factors: (1) Bed friction (2) Momentum transfer taking place because of interfacial turbulent exchange (3) Momentum transfer as a result of mass exchange between subsections Proust (2009).The most evident effect of vegetation is it increases the resistance offered to flow and reduces the conveyance capacity of the channel Muhammad Mujahid Muhammad (2018). The other vegetation characteristics which affects the flow in vegetated open channel are: (a) vegetation type (b) Pattern of distribution (c) flexible or rigid (d) submerged or partially submerged and (e) density of vegetation (solid volume) Abood et. al (2006). The present study is carried out on a straight simple vegetated rectangular channel. Vegetation in rivers strongly affects the resistance to flow, average velocity, turbulence and mass exchange Tsujimoto (1999). Flow resistance coefficient mainly depends on flow depth and discharge proven by Järvelä (2005) who carried out laboratory study.

Velocity profile shape gets modified in a stream-wise and vertical direction because of the vegetation roughness introduced in a flowing channel by vegetation Muhammad (2016). For applying SKM, one has to calibrate co-efficient like (f), (λ) representing bed friction, lateral shear. Liu &Yang (2013) showed that secondary flow affects the prediction of flow velocity and bed shear stress. Bed shear stress distribution affects the capacity of sediment and silt movement in the channel Yu & Smart (2003).

The present research conducts an experiment in laboratory rectangular flume with a rough bed at Hydraulics Laboratory Civil Engineering Department, National Institute of Technology, Rourkela.

2.Theoretical Background:

The Shiono Knight Method (SKM) is useful in finding out depth-averaged velocity. This method uses RANS model, i.e. 2D Reynold's Averaged Navier Stokes equation. The momentum equation is simplified and combined with the continuity equation, to get variation in boundary shear stress and mean velocity in lateral direction.

The streamwise momentum equation for uniform flow is given as follows

$$\frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho g S = \rho\left(U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} + W\frac{\partial U}{\partial z}\right) \tag{1}$$

Where x, y, z are the components in streamwise, lateral and vertical directions. τyx and τzx are the Reynolds shear stresses on the planes perpendicular to y and z direction, respectively; ρ is density of flow; g is the acceleration due to gravity; S is the bed slope; U, V, W are the components of velocity along x, y, z directions. Eq.(1) referred from Liu & Yang (2014).

3. Model parameters:

Depth-averaged velocity and boundary shear stress are obtained by experimenting in a laboratory using ADV. To get Darcy-Weisbach friction factor *f* is back calculation is done from experimental data Tang and Donald W.Knight (2009).

$$f = \frac{8gn^2}{R^{0.33}} \tag{2}$$

Where *f* is the Darcy-Weisbach friction factor; *n* is the manning's roughness coefficient; R is the hydraulic radius and g is the acceleration due to gravity.

Eddy viscosity is an imaginary concept. Dimensionless eddy viscosity is a constant given by expression as follows

$$\varepsilon_{yx} = \lambda H U_* \tag{3}$$

Where ε_{yx} depth-averaged eddy viscosity; U* is the local shear velocity; H is the water depth, and λ is the dimensionless eddy viscosity.

4. Experimental Setup:

The experiment is conducted in a rectangular flume at hydraulic engineering laboratory, Civil Engineering Department National Institute of Technology, Rourkela. Rectangular flume is 12m long, having width 0.6m and depth 0.6 m (see Fig.2). The flume has a testing section made up of glass and rests walls and bottom of flume are made up of mild steel. Rigid grass is fix along the bed of a channel to impart rough bed. A longitudinal slope (S_0) of 1.2cm in 10m was given and kept constant throughout the experimental work. The plan view of experimental channel is given in Fig.1. To measure the depth of flow point gauges are fixed. From upstream side, test section is selected at 10 m distance, where flow stabilises and uniform flow is observed.

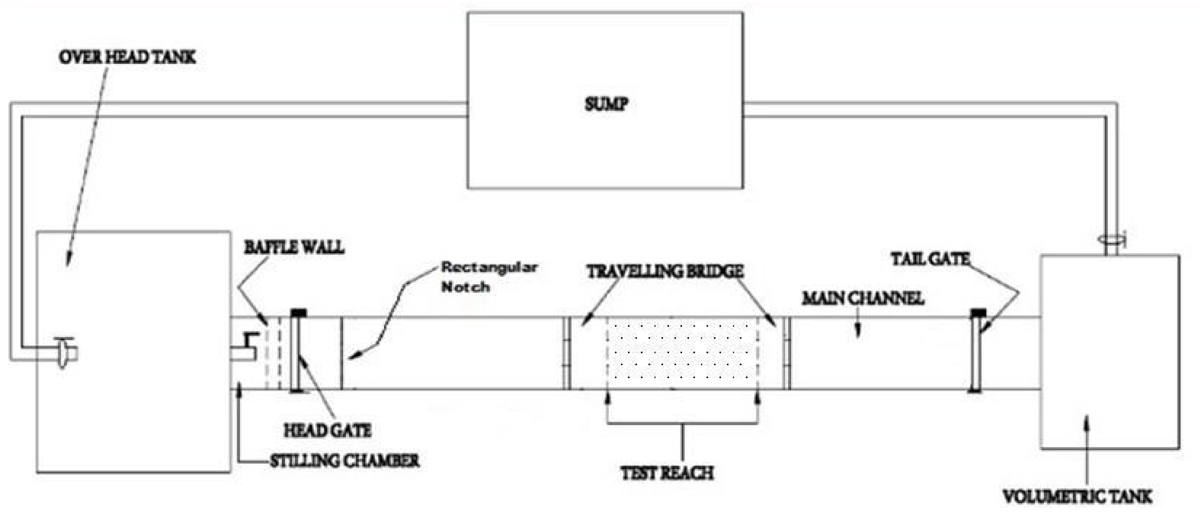

Figure.1: Plan view of channel, National Institute of Technology, Rourkela

To determine flow fields, a SonTek Micro Acoustic Doppler Velocimeter (ADV) having frequency 16-MHz is used. ADV records the directional velocities of water *U*, *V* and *W* in *x, y, z* direction, i.e., along flume bottom, lateral to flume bottom and vertical to flume bottom respectively. Steady flow condition maintained throughout the experiment. Geometry and roughness factors are given in Table 1.

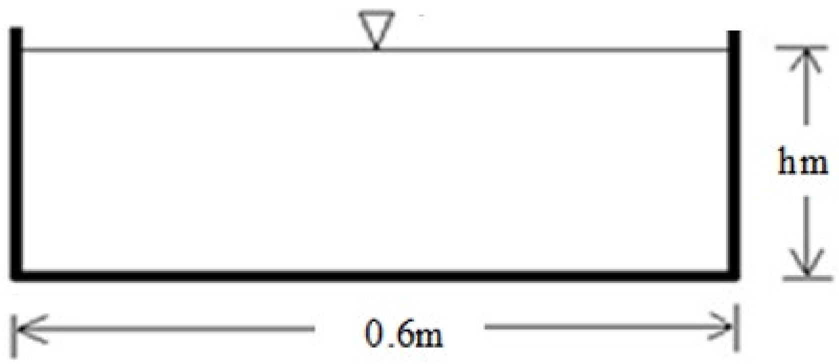

Figure.2: Cross-section of (experimental) rectangular channel

Table1. Geometry and roughness parameters

Serial number	Parameters	Data
I.	Type of channel	Straight
II.	Geometry of channel	Rectangular
III.	Base width of channel section(b)	0.6m
IV.	Channel depth	0.6m
V.	Bed slope (S_0)	0.0012
VI.	Flume length	12m
VII.	Length of test channel (X)	10m
VIII.	Nature of bed surface	Rough (Fixed rigid grass)
IX.	Flow condition maintained	Steady

Fig.3: Photograph of the straight rectangular flume at Hydraulic Engineering Laboratory, Civil Engineering Department National Institute of Technology, Rourkela

The variation of depth averaged velocity advancing in a lateral distance of rectangular straight channel is obtained by using Conveyance Estimation System (CES) software. It depends on 1-D RANS (Reynold's Averaged Navier Stokes) approach.

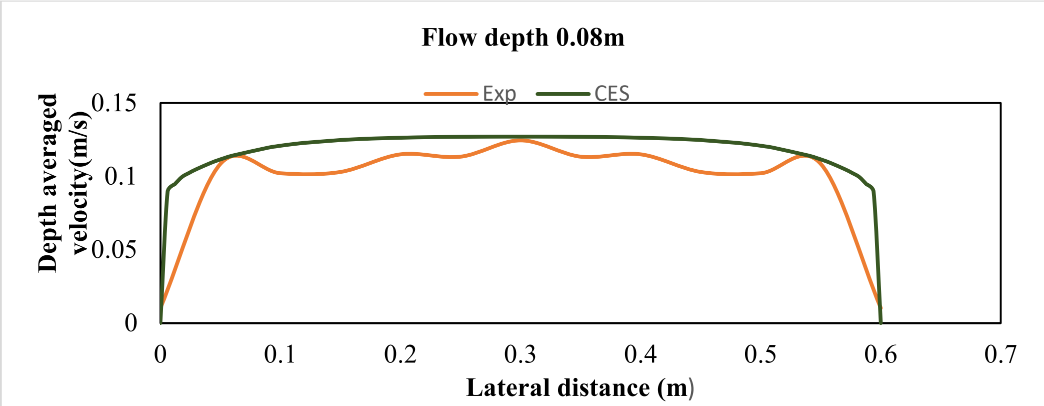

Fig.4: Variation of Depth averaged velocity in rectangular channel for flow depth 0.08m

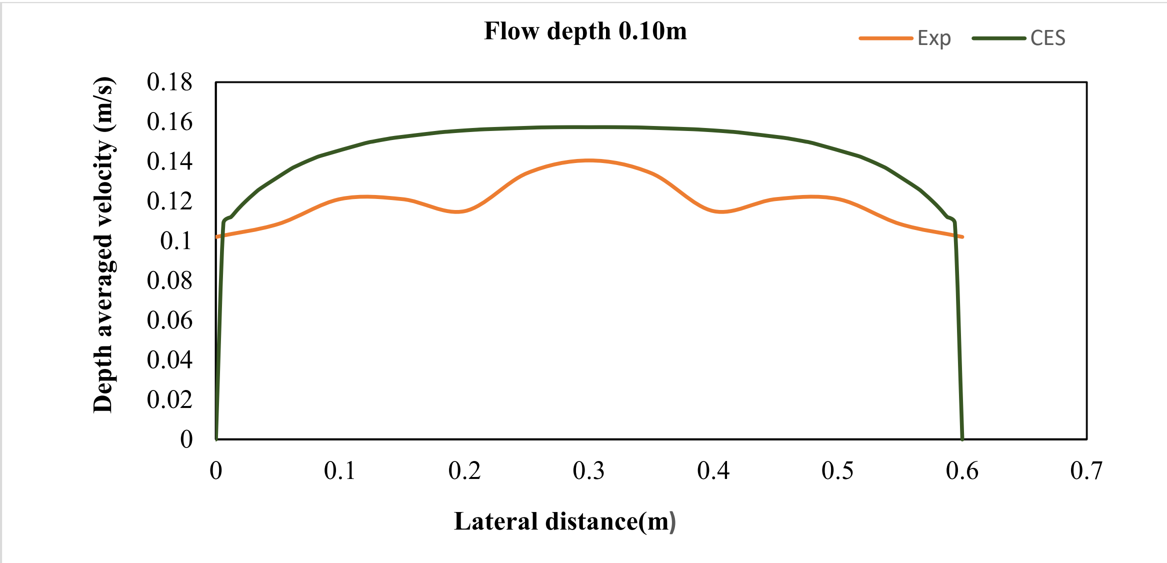

Fig.5: Variation of Depth averaged velocity in rectangular channel for flow depth 0.10m

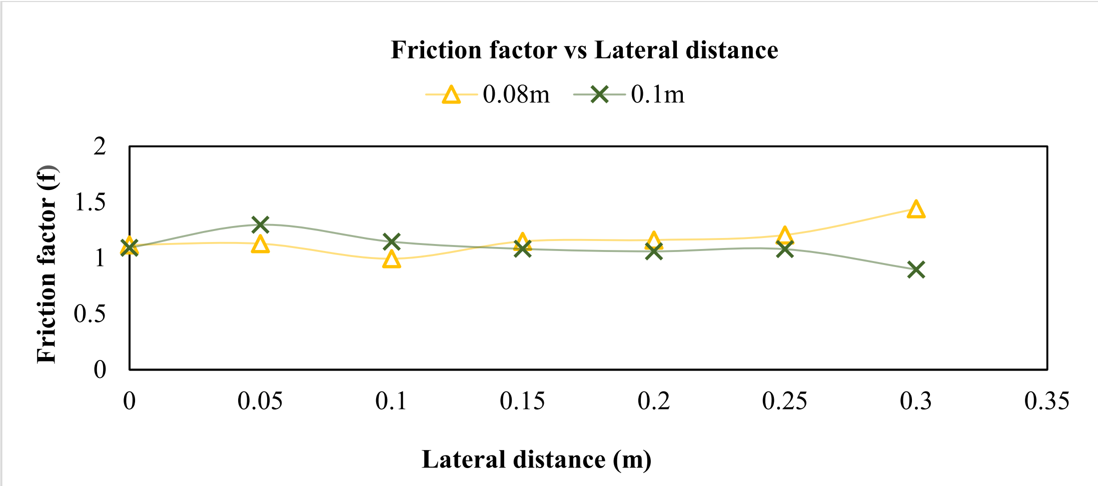

Fig.6: Variation of friction factor against lateral distance

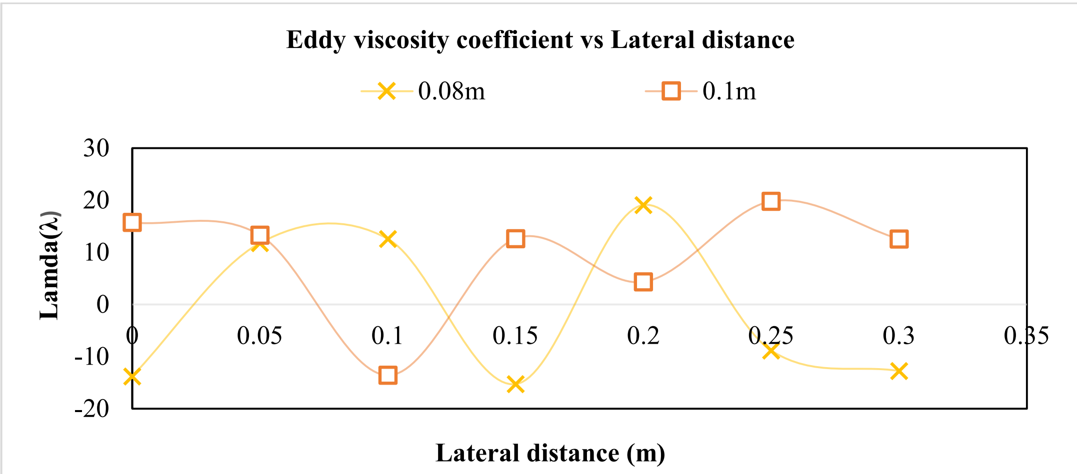

Fig.7**:** Variation of eddy viscosity against lateral distance

Conclusions:

The experimental study gives concluding points as follows:

1. Experiment on emergent vegetative open channel flow has been performed to find the calibrating coefficients used in the RANS equation.
2. The friction factor is found to be of uniform value in a lateral direction of the channel. The value of friction factor is higher for low depth of flow and lower for high depth of flow.
3. An abrupt change in eddy viscosity is observed for low depth of flow.
4. The results for depth-averaged velocity obtained using RANS equation has been compared with results from CES software.

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