Significance of Different Flow, Channel and Bed Conditions in Estimation of Open Channel Flow Resistance

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Abstract- *Open channel flow resistance is a topic of continued interest. Many works have been done on the resistance of flow in open channel. The three co-efficients, namely Chezy's co-efficient, Manning's co-efficient and Darcy's co-efficient are generally used in the calculation of flow resistance in open channel. In this paper an attempt has been made to study the various research works done to study the effect of different flow, channel and bed conditions on open channel flow resistance. The research works are done considering the three coefficients and also under different bed conditions.*

Key Words: *Chezy's co-efficient, Manning's co-efficient and Darcy's co-efficient.*

1. INTRODUCTION

The passage in which the liquid is not completely enclosed by a solid boundary, but has a free surface exposed to the atmosphere is called open channel and the flow of liquid in this open channel is called open channel flow. It flows under atmospheric pressure due to component of gravity with a free surface and so it is also called as free surface flow. The flow in open channel is governed by various forces, component of gravity due to bed slope, inertia force, surface tension, viscous force and force of resistance due to friction, shear-opposing gravity component due to surface roughness. The resistance due to surface roughness plays an important role in open channel flow.

In uniform flow, the average velocity of flow, V is expressed approximately by the uniform flow formula for hydraulic computation as:

$$V = CR^x s^y \qquad [1]$$

Where C is some coefficient dependent on channel roughness, magnitude of velocity V, viscosity, surface tension and on other factors, R is the hydraulic radius, s is the energy slope an x, y are exponents.

The most practical formulae for uniform flow in open channel after the French Engineer Antonie Chezy (1769) and Irish Engineer Robert Manning's (1891) are:

Chezy's formula

$$V = C\sqrt{Rs} \qquad [2]$$

Manning's formula

$$V = \frac{1}{n} R^{2/3} s^{1/2} \qquad [3]$$

Where C and n are known as Chezy's and Manning's coefficients respectively and their values for different surfaces with different roughnesses are determined by experiments. Although both are coefficients they are not dimensionless. From equations [2] and [3] the dimensions of C and n are obtained to be $L^{1/2}T^{-1}$ and $^{L-1/3}T$ respectively.

Out of the two roughness coefficients, Manning's n is popular and widely used by investigators. This n mainly depends on surface roughness and factors like vegetation cover, cross-sectiona irregularity, channel silting, scouring, obstruction and stage or depth of flow.

Another resistance coefficient is Darcy's coefficient of friction which is dimensionless. The equation is obtained to be

$$V = \sqrt{\frac{8g}{f}}\sqrt{Rs} \qquad [4]$$

Where V is velocity of flow, g is acceleration due to gravity and f is Darcy's coefficient of friction.

The three coefficients C, n and f can be related by the equation:

$$C = \frac{1}{n} R^{1/6} = \sqrt{\frac{8g}{f}} \qquad [5]$$

Equation [5] gives the relationship among C, n and f in open channel.

2. BASIC AREAS OF RESEARCH OF CHANNEL RESISTANCE:

Proper prediction of flow parameters requires proper identification channel resistance and extensive research of it is reported in literature in the following areas:

a) Research related to vegetated channel
b) Research related to Computation of Manning's n , Chezy's coefficient and Darcy's friction factor
c) Research related to resistance for mobile bed channel with sediment
d) Research related to compound channel resistance
e) Research related to meandering channel
f) Research related to effect of unsteadiness in Channel resistance

3. BACKGROUND

The research on channel resistance started as early as 1769 and has been a topic of interest to as recent as 2015. Different papers and journals have been brought forward by various researchers on the vegetated channel, resistance for mobile bed channel with sediment, resistance in compound channel, resistance for meandering channel and effect of unsteadiness in channel resistance

4. LITERATURE REVIEW

4.1. Literature related to effect of unsteadiness in open channel flow resistance

Zhou, J., and Zeng, C., (2009) proposed a hybrid LES-RANS model which combines the large eddy simulation (LES) model with the Reynolds-averaged Navier-Stokes (RANS) model to accurately predict the mean flow and turbulence characteristics of open channel T-diversion flows. The unsteady RANS model was used to simulate the upstream and downstream regions of a main channel, as well as the downstream region of a branch channel. The LES model was used to simulate the channel diversion region, where turbulent flow characteristics are complicated. The verification of the model with a classical case of fully developed open channel turbulent flow were carried out and then was used to simulate the flow in an open channel T-diversion. Comparison between the numerical results and the detailed velocity measurements showed that the hybrid model faithfully reproduces the mean flow characteristics, such as velocity profiles and mean flow patterns [13].

4.2. Literature related to vegetated channel

Huthoff, F., et.al., (2012) studied two cases of flows in natural vegetated water-ways, case 1: fixed point flow measurements in a Green river and case 2: vessel borne flow measurements along a cross-section with flood plains in the river Rhine to investigate the bed roughness properties and to compare these to predictions from the vegetation roughness model proposed by Huthoff *et al.* Analysis of the two cases revealed that the simple flow model is consistent with measured flow velocities and the present vegetation characteristics, and can be used to predict a realistic Manning resistance coefficient [7].

Hamimed, A., et.al., (2013) investigated the influence density and placement of emergent vegetation on flow resistance, water depth and velocity profile. Experiments using artificial vegetation were carried out in the laboratory flume instead of natural channel, and Manning's n is used to denote the resistance coefficient. The relationship between the drag coefficient "C_D" and roughness coefficient "n" is given as: $n = h^{0.5}\left[\frac{C_D\lambda}{2g}\right]^{0.5}$, where "h" is water depth and "λ" is vegetation density. The vegetation density was calculated as: $= n_p \frac{A_f}{\Delta Z}$, where, "n_p" is number of pants/m^2. The frontal area Af (m2) of ten randomly selected plants was estimated at centimeter intervals in the vertical, Δz = 1cm, by tracing the plant silhouettes onto grid paper. The result showed large variations in the Manning resistance coefficient with depth of flow and vegetative density. The flow resistance increased with the increase in vegetation density and drag coefficient reduced [6].
Folorunso, O.P., (2015) measured and quantified the hydraulic resistance of an open channel with grass and gravel bed placed alternately in the form of checkerboard configuration. The results indicated that Manning's "n" values vary between 0.016 and 0.025 for lowest and highest discharge respectively. The friction factor was found to be decreased with the increase in discharge. It was observed that more friction on the flow was exerted by the grass bed, whereas the friction for gravel bed was observed to be tending towards constant value [2].

Gao, G., et.al., (2011) investigated the effect of vegetation on the flow structure, and acquired accurate velocity profiles with the help of three dimensional model, using two layer mixing length model. Three open channel cases were studied viz., no-vegetation, submerged vegetation and emergent vegetation flows. A goo agreement has been obtained between the computed and the measured results in all the three cases. Thus, accurate complex velocity profile predictions can be produced [3].

4.3 Literature related to Manning's n

Ramesh, R., et.al. (2000) proposed a new approach in order to estimate roughness coefficients in a channel system for flow into a non-linear optimization model by directly embedding the finite-difference approximations of the governing equations as equality constraints. The SQP algorithm was used to minimize the nonlinear objective function based on least square error criterion. And proposed an embedded optimization model for estimating the Manning's roughness coefficients from unsteady flow measurement data in open-channel systems. The evaluation was limited to subcritical flow conditions [10].

Dash Saine S, et.al., (2013) presented experimental investigations concerning the loss of energy of flows for a highly meandering channel for different flow condition, geometry. Manning's "n" was calculated for various depths and the variation in the value of "n" was observed from the graph in figure. The plot indicated that with the increase in flow depth the value of "n" also increased, which was mainly due to increase in flow resistance for wider channel with shallow depth consuming more energy than narrower and deep channel. Meandering channel consume more energy as the flow depth increases. Thus, Manning's coefficient "n" not only denotes the roughness characteristics of a channel but also the energy loss in the flow [1].

Greco, M., et.al., (2013) investigated the direct dependence of Manning's roughness n on the entropy parameter for low depth and proposed the equation $\left(\frac{y_0}{y_m}\right)_{calibrated} = 0.094 i\% e^{[0.445 l_n(i\%) - 0.278]\left(\frac{D}{d}\right)}$ knowing slope and submergence, where $\left(\frac{y_0}{y_m}\right)_{calibrated}$ is the ratio between the positions where velocity is zero and maximum. The equation was verified by deriving $n_{computed}$ using the above equation and comparing the result with observed Manning's n and good agreement was observed [5].

Rhee, D.S., et.al., (2007) used three Korean natural vegetations Zoysia matrella (Korean zoysia), Pennisetum alopecuroides (L.) Spreng. (Korean native vegetation) and Phragmites communis Trin. (Korean reed) in flume tests to see the effect of vegetation in the channel on flow resistance. It was observed that the resistance coefficients are higher when plants are green rather than when they are dormant. The Manning's "n" values for green state tend to a constant value of about 0.012, whereas for dormant state it was observed to be about 0.001 [11].

Kahrizeh, H.G., et al., (2015) obtained effective dimensionless parameters using dimension equation. N= f (sf, R/ks ,Re*,Fr), where sf, y / ks, Re *, Fr are dimensionless parameters. The equations for different percent slopes are obtained with an without vegetation. It was observed that Manning's roughness coefficient is higher for higher particle and higher discharge. Also in a constant hydraulic condition the existence of river-side trees increases Manning's roughness coefficient [8].

4.4. Literature related to Darcy's friction factor

Gilley, J. E., et.al., (1992) conducted a laboratory study to measure Darcy-Weisbach roughness coefficient for selected gravel and cobble materials. Darcy-Weisbach roughness coefficient was calculated using flow measurements. In order to relate roughness coefficient to percentage of surface cover and Reynold's number, regression relationships were developed using laboratory data for values of Reynold's number 500 to 16,000. By adding the roughness contributions of individual size classes, close agreement between predicted and measured Darcy-Weisbach roughness coefficient was obtained [4].

4.5. Literature related to resistance for mobile bed channel with sediment

Simoes, F. J. M., (2010) presented a resistance law for surface resistance, for the cases of flow in transition and turbulent flow regimes, and also observed that the law is sensitive to bed movement. Three equations based on the values of Shield's parameter "Θ" was obtained, $k_s = d_{50} d_{50}^{*}(a + b\theta + c\exp(-\theta))$, for Θ≥1, where a= -0.716, b= 0.473, c=0.920, $k_s = 1.08 d_{50}^{0.968} 5390^{\theta}$, for Θ<0.2 and $k_s = \exp(-10.5R + 70.6 d_{50} + 10.5S - 4.49)$, for 0.2≤Θ<1, where ks is Nikuradse's equivalent grain roughness, d_{50} is the diameter of the 50 percentile of the particle size distribution, d_{50}^{*} is dimensionless mean grain diameter, S is the specific density of sediment and R is hydraulic radius. Darcy –Weisbach friction factor "f" was calculated from the resulting equation $\sqrt{\frac{8}{f}} = a + b\theta R + \frac{c}{\sqrt{\theta R}}$, where a=16.2, b= 3.03, c=-0.117. A good agreement was found when computed and measured values were compared [12].

4.6. Literature related to resistance for straight and meandering channel

Priyadarshinee, k., and Mohanty, L., (2015) investigated variation of roughness by MATLAB. The variation of roughness coefficients for both straight and meandering channel was studied. It was observed that Manning's roughness coefficient "n" decreases with the increase in depth in both straight and meandering channel, whereas Chezy's coefficient "C" increases with the increase in depth in both straight and meandering channel and the variation of the friction factor "f" was found to be similar with Manning's "n" [9].

5. CONCLUSION

Many researchers have carried out many researches on the various areas such as the vegetated channel, resistance for mobile bed, channel with sediment flow, resistance in compound channel, resistance for meandering channel and effect of unsteadiness in channel resistance till date. Still many aspects such as effect of unsteadiness in channel resistance for mobile bed, channel with sediment flow, need more extensive study.

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