DEPTH AVERAGED VELOCITY PREDICTION FOR HIGHLY SINUOUS MEANDERING CHANNELS

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Knowledge of flow and velocity distribution along the river cross section is essential in many hydraulic engineering studies involving bank protection, sediment transport, conveyance, water intakes and geomorphologic investigation. It is quite difficult to model flows in meandering trapezoidal channel as the inner and outer banks exert unequal shear drag on the fluid flow that ultimately controls the depth-averaged velocity. Continuous variation of channel geometry along the flow path associated with secondary currents makes the depth-averaged velocity computation difficult. Design methods based on straight channels are not appropriate while estimating the depth averaged velocity distribution in meandering channels. Due to complex flow phenomenon occurring in a meandering channel, Depth Averaged Velocity is not symmetrical and depends upon many non-dimensional hydraulic, and geometric parameters. The variation is not only due to the sinuosity but also due to other important parameters combining such as stage, slope and geometry. An experimental Investigation with the regression analysis has led to formulation of a mathematical model to predict Depth Averaged Velocity distribution for a highly sinuous meandering channel.

Keywords: Meandering Channel, Depth Averaged Velocity, Aspect ratio, Reynolds number, Froude's number.

1 INTRODUCTION

Flow in a meandering channel is a complicated process because of the variation in the shape of the cross section, sinuosity etc. which makes the flow structure very complex. These parameters make the predictions of the velocity distribution even more difficult [1-3]. The flow distribution is unsymmetrical because the inner and outer banks exert unequal shear drag on the fluid flow. Though, quasi two-dimensional methods [1,5&6] gave more information about the lateral distributions of depth-averaged velocity and discharge assessment. Shiono and Knight [7] used a method, which is a new approach for calculating lateral distribution of depth-averaged velocity for flows in straight prismatic channels taking secondary flow effect under consideration. Shiono et. al. expressed the friction factor of rough turbulent meandering flows as the function of sinuosity and position (which is determined by, among other factors, the local channel curvature). [9-10]

2 EXPERIMENTAL SET UP

For studying the different geometric, hydraulic parameter and sinuosity on prediction of flow variables of highly sinuous meandering channels, experimental setup was built in Fluid mechanics and Hydraulics Laboratory of NIT, Rourkela. Here the meandering channels were constructed with Perspex sheet of 6/10mm thickness representing smooth surfaces and Manning's *n* value calculated from channel in flume are found to be approximately 0.01. The channels were constructed in trapezoidal shape having bottom width 0.33m, depth 0.065m and side slope 1:1 and were placed inside a steel tilting flume of 4m wide. The total length of the flume is 15m. The flumes can be tilted for generating different slopes by gear and pinion arrangements. The slope was fixed as 1.165×10^{-3} to have subcritical flow. The channels were sine generated curves (Fig.1 shows the schematic diagram of experimental setup and Fig.2 represents the dimensions of channel with test section respectively).

By the help of series of centrifugal pumps of 15Hp capacity each, the required amount of water was supplied to the flume from an underground sump via an overhead tank. In all the experimental channels, the flow was maintained quasi uniform i.e. the water surface is parallel to bed of channel in line with the experimental work of [8,11]. This average stage of flow across the width of channel for each discharge is considered as normal depth, which can be assumed to carry a particular flow only under steady and uniform condition. Measuring devices like pointer gauges having least count of 0.1 mm were used to measure the flow depths, rectangular notch has been provided at the upstream end to monitor the continuous discharge passing through the channels, Five micro-Pitot tubes each of them having 4.6 mm external diameter with five manometers were used to measure velocity of flow in the channels.

All the observations were recorded at the central bend apex of the meandering channels. The details of geometrical parameters and hydraulic parameters of meandering channels are given in Table 1.

3 RESULTS AND MODEL DEVELOPMENT

From the experimental measurements interesting results regarding variation of depth average velocity distribution of a highly meandering channel along the width at bend apex has been found out. The variation for inner and outer part of the meander is plotted. The variations are of different trend as compared to any straight channels further the trend is different when compared outer part with inner part of the meander path. Here the midpoint of bend apex of the channel is chosen as the origin for distinguishing inner and outer region. The variation of U_d/U vs. lateral distance (X_r) are plotted in fig the (3-a) and (3-b) respectively. From the fig (3-a), it is seen that the depth average velocity increases and reaches maximum before the mid-section and then decreases giving a lowest value at the mid-section.(around 60-70% of maximum velocity). The reverse nature has been found out for fig (3-b). Further comparing to both the cases, the depth average velocity for inner maximum velocity is found to be higher than that of outer maximum velocity.

Fig (4), Fig (5) and Fig (6) represents the variation of U_d/U with the non-dimensional hydraulic and geometric parameters such as Reynolds number (R_e), Froude's number (F_r) and aspect ratio (δ), respectively. The depth average velocity distribution increases with Reynolds's number where as it decreases with Froude's number and aspect ratio.

From the relationships of non-dimensional depth averaged velocity distribution of this highly meandering channel, formulation of a mathematical model is attempted to present their relationships. The Multiple Linear Regression analysis (MLR) is applied for the purpose. At first the functional relationships which are providing the maximum coefficient of determination are fixed for each dependency parameter. The non-dimensional geometric parameters considered here are Aspect ratio (δ), Lateral Distance (X_r), and the hydraulic parameters are Reynolds no (R_e) and Froude's no (F_r).

The dependency of depth average velocity distribution with those parameters can be written in the form

$$U_d/U = f\,(f_1, f_2, f_3, f_4) \qquad (1)$$

Where f_1, f_2, f_3 and f_4 are the respective functional relationships of inner and outer regions.

The linear coefficients for these regions are found out from the plots fig3 (a-b), fig4, fig5 and fig6 and after regression unstandardized coefficient for inner and outer respectively presented in table2 (a) and, table2 (b) respectively.

From the plots and regression analysis the relationships for both the regions can be written as

$$\left(\frac{U_d}{U}\right)_{inner} = -1.1561 + 0.563 * F_r + 0.02\delta + 0.471 * R_e + 1.242 * X_r \qquad (2)$$

$$\left(\frac{U_d}{U}\right)_{outer} = -0.5464 + 0.571 * F_r + 0.233\delta + 0.6308 R_e + 0.728 X_r \qquad (3)$$

Now compiling the individual functional relationships of each independent variable for inner and outer the equation is simplified as

$$\left(\frac{U_d}{U}\right)_{inner} = -0.383\begin{pmatrix} 1 - 3.34e^{-2.015F_r} \\ -\,0.106\delta^{-0.488} \\ -\,0.457e^{6E-05R_e} + \\ 4.87X_r(2.16X_r + 1) \end{pmatrix} \qquad (4)$$

$$\left(\frac{U_d}{U}\right)_{outer} = -0.016\begin{pmatrix} 1 - 81.25e^{-2.015F_r} \\ -\,29\delta^{-0.488} \\ -14.68e^{6E-05R_e} + \\ 22.37X_r(4.09X_r + 1) \end{pmatrix} \qquad (5)$$

Using equation (4) and (5) we founf the value of U_d/U for inner and outer section.

At any point along the width of meander part can be evaluated, Fig. 7 and Fig. 8 for inner and outer presents the variation of observed U_d/U Verses predicted U_d/U showing the efficacy of the developed model.

4 CONCLUSION

An experimental investigation has been carried out to find the depth averaged velocity distribution of a highly meandering channel. The variation is found to be complex and very much different from any straight channel cases. The velocity distribution for inner part is again different from outer part of the meandering channel.

A Mathematical Model has been proposed for predicting depth average velocity distribution of meandering channels for inner and outer. For the present experimental work, flow in meandering channels has been investigated.

The functional relationships of depth averaged velocity of a highly meandering channel with different non-dimensional geometric and hydraulic parameters such as Aspect ratio (δ), Lateral Distance (X_r), and the hydraulic parameters are Reynolds no (R_e) and Froude's no (F_r) are found out

Regression analysis has been carried out to formulate a mathematical model to predict depth average velocity distribution for inner and outer part of the highly meandering channel. The model is found to give good result with the experimental findings.

The accuracy of models has also been studied and the R^2=0.96 are found for the inner section and R^2=0.989 for outer section of meandering channel. By using this model the depth averaged velocity distribution of any meandering channel of higher sinuosity i.e. S_r>4.11 can easily be evaluated.

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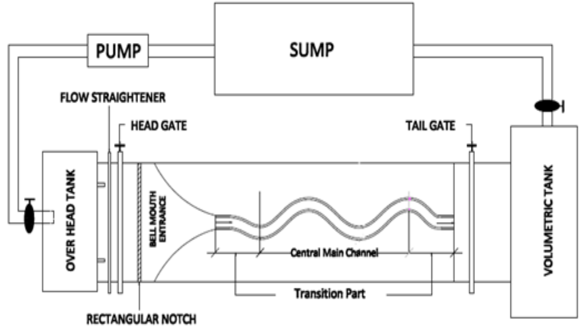

Fig 1. Schematic diagram of Experimental meandering channels with setup

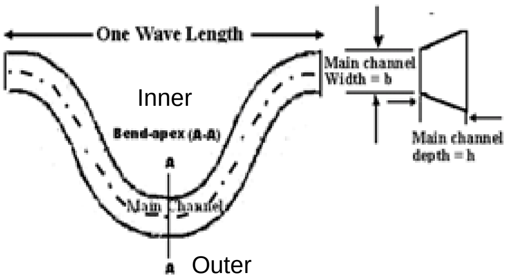

Fig 2. Dimension of the meandering

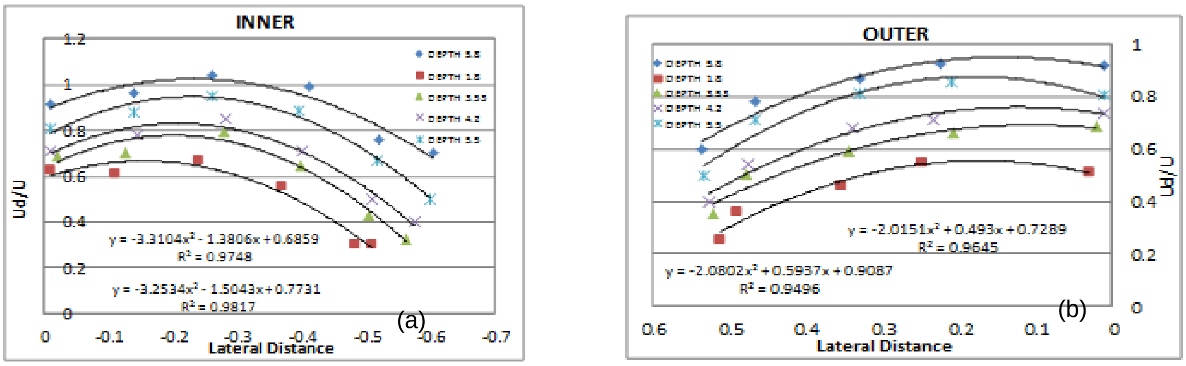

Fig 3. U_d/U vs. lateral distance (a) inner meander (b) outer meander portion

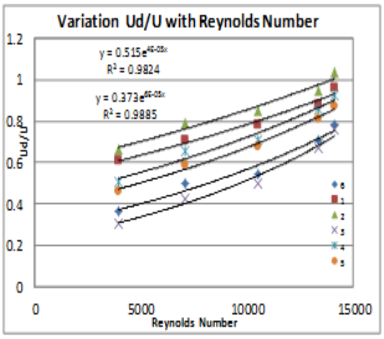

Fig 4. Variation of U_d/U vs.Reynold's Number

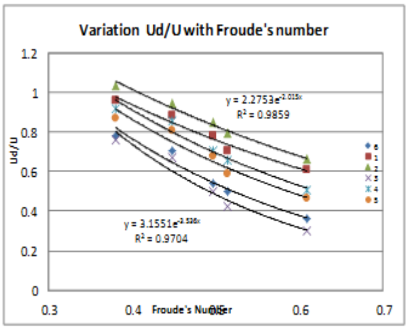

Fig 5. Variation of U_d/U vs.Froude's Number

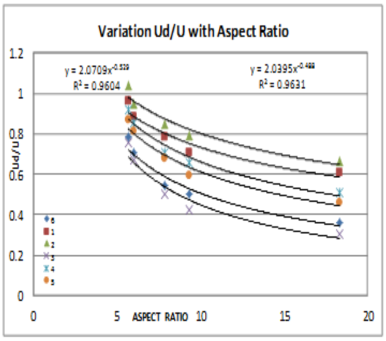

Fig 6.Variation of U_d/U vs. Aspect Ratio

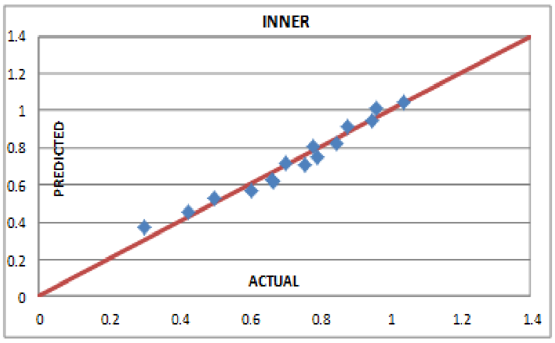

Fig 7. Actual vs. Predicted for inner part *Ud/ U*

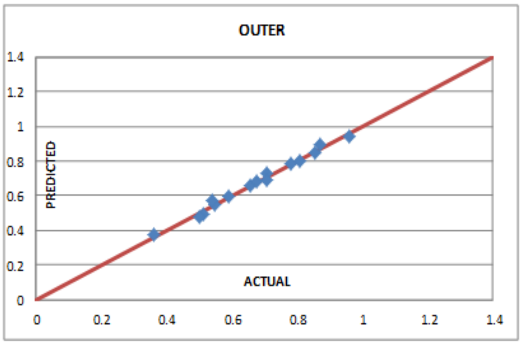

Fig 8. Actual vs. Predicted for outer part *Ud/U*

Table 1: Details of Geometrical parameters of the meandering channels

Sl No	Item description	Present Experimental Channels
1	Channel Type	Meandering 1
2	Flume size	4.0m×15m×0.5m long
3	Geometry of Main channel section	Trapezoidal (side slope 1:1)
4	Nature of surface of bed	smooth and rigid bed
5	Channel width	33cm at bottom and 46 cm at top
6	Bank full depth of channel	6.5cm
7	Bed Slope of the channel	0.00165
8	Sinuosity	4.11

Table 2: Unstandardized Coefficient by Linear Regression Analysis (a) inner meander part (b) outer meander part

Inner (a)	*Coefficients*
Intercept	-1.1561
f_1	0.563201
f_2	0.020065
f_3	0.471554
f_4	1.242584

Outer (b)	*Coefficients*
Intercept	-0.54649
f_1	0.571516
f_2	-0.23393
f_3	0.630869
f_4	0.728066