FLOW STRUCTURE IN AN ASYMMETRIC COMPOUND CHANNEL FLOW

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ABSTRACT

During flood, movement of water occurs from main river stream to its both adjacent flood plains and vice versa. If the river has only one flood plain either side of it, then it is called as asymmetric compound channel. The difference in hydraulic resistances between the main channel and flood plain subsections causes the exchange of momentum between them. In recent centuries, a great deal of experimental investigations has been carried out in order to understand the complex turbulent flow structure in compound channel flow. The article reports the turbulence measurements undertaken in an asymmetric compound channel flow in the hydraulics laboratory, NIT, Rourkela. This experimental facility is designed in such a way that it characterizes a model of a river system with roughened floodplains. The principal focus in this study is on the nonlinear nature of flow structures in the shear layer region between the main channel and flood plain. The variation of secondary flow in lateral direction and influence of relative flow depths on flow structure were also investigated. The interaction phenomenon at junction between two subsections has been explored with respect to relative depth. The distribution of Reynolds stresses and friction factor across the cross channel distance of the compound channel have been studied and discussed widely. Different models for precise quantification of friction factors in subsections have been evaluated. The work will be of interest to hydraulics engineers associated with compound open channel flow in particular.
Keywords: *Asymmetric compound channel, turbulent flow, friction factor, momentum transfer*

1. INTRODUCTION

Generally, the flow in open channel is turbulent which is anisotropic in nature. Due to this reason secondary currents are produced and anisotropy in turbulence is caused due to boundary condition of the bed, side wall and the free surface, as well as the aspect ratio of the channel and channel geometry. Mainly the primary flow is the velocity along the flow direction and secondary flow is the resultant of transverse component and lateral component of velocity. These secondary flows or currents affect the primary mean flow producing a three dimensional structure. At the interface of the main channel and flood plain of a compound channel a lot of momentum transfer occurs due to the different flow velocities in the main channel and floodplain. This produces a transverse shear layer influencing the flow in both the river and the flood plain. The transfer of momentum is not only caused by the bed generated turbulence but also by free shear turbulence and secondary currents.

The objective of this paper is to study the flow structures by conducting experiments on an asymmetrical compound channel at Hydraulics Laboratory of NIT Rourkela, Odisha.

1.1 Literature survey

Knight and Demetriou (1983) derived equations using the experimental shear force results to calculate the lateral and vertical transfer of momentum within the cross section. Knight and Hamed in 1984 conducted experiments by considering roughened flood plains to observe the effect of differential roughness between the flood plains and the main channel in the lateral momentum transfer process. Parthasarathy and Muste (1994) measured velocity of flow was using 2D Laser Doppler Velocimeter and they observed that a lot of diffusion of momentum and kinetic energy took place from rough to smooth surface. Tsai and Ettema (1994) developed a modified eddy viscosity model for asymmetrical compound channels which can be used to estimate turbulent eddy viscosity in asymmetric channel flows. Sofialidis and Prinos (1999) developed a model which can predict the turbulence-anisotropy and secondary currents due to turbulence. When the model was compared with available measurements, they observed that the secondary currents were produced well. Al-Khatib and Gogus (2014) studied the flow structures of asymmetric compound channel for prediction of discharge but they did not focus on secondary currents produced in the channel.

2. EXPERIMENTAL SETUP AND PROCEDURES

The experimental flume was made up of mild steel bars and plates. For supplying water into the experimental channels a large reinforced cement concrete (R.C.C) overhead tank was constructed on the upstream side of the flume inside the laboratory. A volumetric tank was built at the downstream end of the flume for measuring the discharge of each flow depth. A large underground sump located outside was used for maintaining continuous water supply to the overhead tank. Two centrifugal pumps of 10 HP capacities fitted with suction and delivery pipes for recirculation of water supply to the channels in the flume. A stilling chamber fitted with an adjustable head gate and flow strengtheners were provided in the entrance region of the flume to maintain the flow uniform entering the channel. On the downstream side of the channel an adjustable tail gate was fitted to control depth of flow and to maintain the uniformity of the flow throughout the length of the channel. The cross section of main channel is trapezoidal in shape with bottom width (b) 0.33m, height (h) 0.11m and side slope 1:1 ($H:V$) over a length of 12m. Total width of the compound channel is 1.19m for acquiring width ratio (α) 3.6 and the longitudinal slope of the flume is maintained at 0.001 by adjusting wheel and gear arrangement provided at inlet of the channel. Experiments were carried out in asymmetric compound channel with differential roughness having smooth main channel and rough flood plain, by using plastic mat of thickness 15 mm having manning's n value 0.024 on the flood plain bed. A uniform roughness was maintained in whole main channel with side slope and another roughness was considered for flood plain to investigate the momentum transfer and secondary current effect in compound channel.

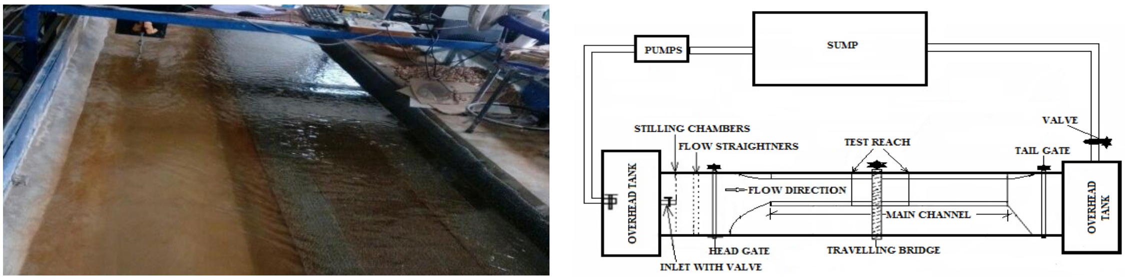

Figure 1. Layout Experimental setup for Asymmetric Compound Channel

3. THEORETICAL ANALYSIS

Secondary Flow Phenomena

Secondary current is caused by anisotropic of turbulent velocity.Further, turbulent structure such as secondary current (which is generally driven by the anisotropy and in-homogeneity of turbulence) creates velocity dip and affects the flow. Hence in this study an effort has made to recognize the affect of the turbulence in simple open channel.

3. REUSULTS AND ANALYSIS

3.1 Depth Averaged Velocity

The depth averaged velocities(U_d)were calculated for all flow depths of asymmetric rough compound channels. Using the equation

$$U_d = \frac{1}{H}\int_0^H U dz \tag{1}$$

where U is the point velocity at a vertical line. Depth averaged velocity distribution is a plot which is plotted by joining the obtained value of U_d along the lateral direction of a channel.

3.2 Depth Averaged Velocity Distribution

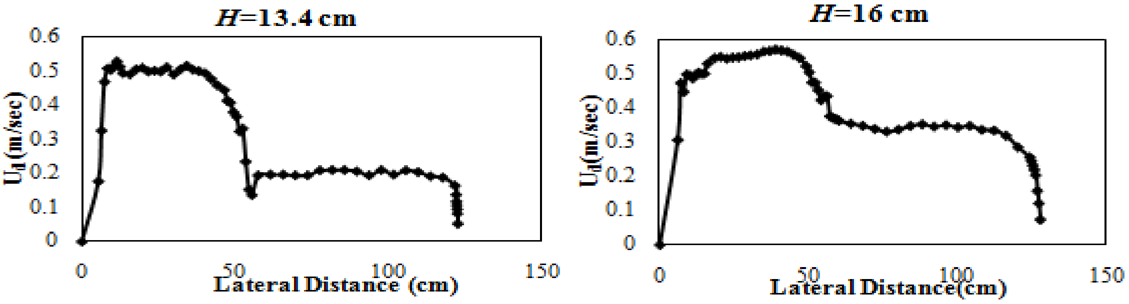

Figure 2. Depth averaged velocity distribution for different flow depths along lateral distance

3.3 SECONDARY FLOW STRUCTURES

The secondary current vectors which are the resultant of lateral and transverse direction velocity components were calculated by using the equation:

Resultant vector = $\sqrt{V^2 + W^2}$ (9)

The secondary currents were calculated only for main channel only as the depth of flow on flood plain was less than 5 cm for which the ADV cannot be used to measure the velocity of flow on the flood plain.

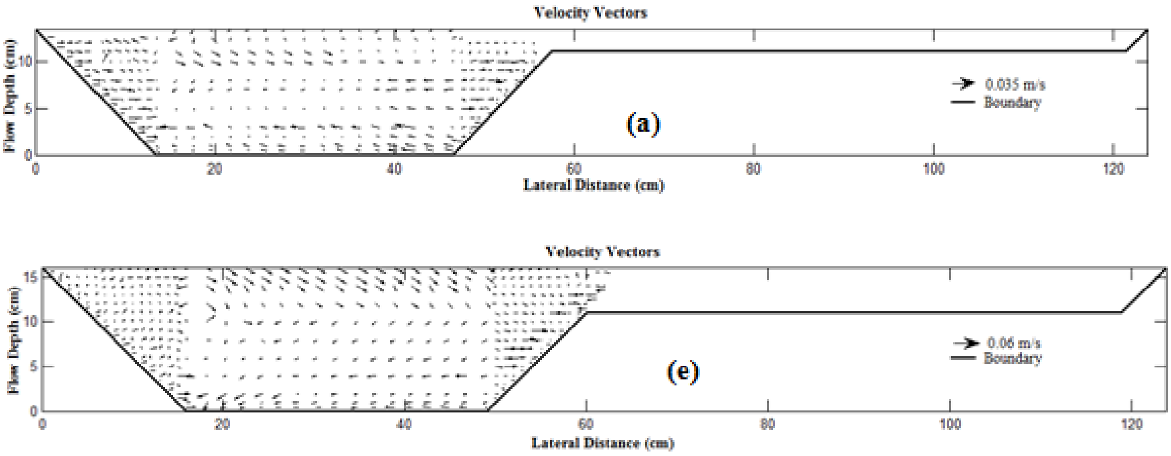

Figure 3. Secondary flow structures for different flow depths (a) 13.4 cm (e) 16 cm

Observations

From Figure 2, it is observed that the U_d increases, as the depth of flow increases. Also one can find that in shallow flow depth cases, the value of U_d at junction fluctuates and become uniform when flow depth rises.

It is also observed that for higher over bank flow depths the difference in velocity between main channel and flood plain is less in comparison to shallow flow depth cases.

At the junction between the variable flow domains of the main channel region there is a fluctuation of velocity is also found. The fluctuation is more for lower flow depths as compared to higher flow depths.

Figure 3 represents the secondary flow vectors for the asymmetric compound channels of different relative flow depths. Due to limitations of micro ADV, the three dimensional velocity data of the main channel regions are only possible.

In all the areas of figure 3, three types of circulations are found. Two circulations are found at variable flow depth domains, which is located at each side of main channel with counter clockwise rotation and one circulation found at central main channel of constant flow depth domain with clockwise rotation.

All the three circulations are found opposite in nature with respect to consecutive circulations. For the higher flow depths, high magnitudes of transverse velocity are found at the junction between the main channel and flood plain. Whereas for lower flow depths the transverse velocity component is low, because at lower flow depths friction of the flood plain compensates the secondary flow velocity whereas for higher flow depth the secondary velocity dominates the friction of flood plain.

4. CONCLUSION

Experiments have been conducted for the asymmetrical compound channel to analyze the depth averaged velocity distribution in the main channel and floodplain and also the secondary flow structure between the subsections of an asymmetric compound channel.

It is found that the depth averaged velocity increase as flow depth increases. A fluctuation of velocity is also found at the junction of variable and constant flow depth domain of main channel.

It is seen that higher values of secondary velocity are found for lower flow depths. It is also observed that the secondary flow velocities directed towards flood plain region for higher flow depth.

In all the flow depths, three types of circulations are observed.

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