EXPERIMENTAL STUDY ON VELOCITY PROFILES IN SMOOTH AND ROUGH CHANNELS

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Abstract— An experimental investigation has been carried out in smooth, rough and movable bed to know the difference in vertical velocity distribution in each case. The classical log law is usually applied for every vertical velocity profile. All measured vertical velocity profiles are found to follow the logarithmic law near the bed. The difference in bed material influences the shape of this profile. To know the effect of bed materials on the vertical velocity profiles, experimental investigations has been carried out for different smooth, rough and mobile bed conditions with various flow depths. It has been studied that due to roughness effect the velocity near bed is decreasing as compared to the velocities near surface. A reduction in magnitude of near bed turbulence is also observed due to the decrease in velocity in such region in mobile bed. In mobile bed case due to the flow of bed particles are associated with the momentum for overcoming the resistance provided by bed. In such cases thevonKarman coefficient existing in logarithmic law decreases due to the upward movement of the virtual bed and the zero-velocity levels.

Keywords— Velocity profile, mobile bed, logarithmic law, roughness effect, von korman Coefficient.

I. INTRODUCTION

The total discharge directly depends on the velocity distribution by knowing the magnitude of velocity at each vertical interface across the flow cross-section. It is essential in many hydraulic engineering studies involving protection of banks, transporting of sediments, conveyance, water absorption and geomorphologic investigation. From the overview of geophysical thermodynamics, the transporting of sediments by the uniform flow is of heavy importance. Due to the communications of transported particles with the water and also with the bed mechanism of the flows over an immobile and mobile bed is quite different. Due to roughness elements, the vertical velocity profile has been used to examine the local effects (Nowell and Church 1979).The mass transport distribution and the momentum transfer is occupied by classical logarithmic velocity profile. Zippe and Graf 1983 showed that the log law could only be settledin the region of near-wall, and the logarithmic formula should beextended with a wake function for the water depth (Coles 1956). Many research studies give the characteristics of velocity profile regarding the effects of different roughness scales. Bathurst *et al.* (1981) defined roughness as small a scale as h/d_{50}> 7.5 or h/d_{84}> 4.0, (d_{50}, the particles for which 50% are finer; d_{84}, the particles for which 84% are finer); despite, Bray (1988) believed that the relative depth for small scale roughness is h/d_{50}> 20. Dong and Ding (1990) and Dong *et al.* (1992) studied the boundary roughness on flow characteristics for different value of h/k_s. He and Wang (2004) mentioned that the velocity profile on rough beds cannot be described with a single logarithmic formula.

An investigation involves two techniques of transporting of sediment. In the first technique, the immobile bed with no sediment transport is called clear-water flow; and the second one, a continuous sediment transport (as bed-load) was settled by the flow which is form a thin layer on the bed, is called mobile-bed flow. For both the techniques, the sediment bed should remain flat and rough with the sediment particles as the presence of bed-forms could add further confusion towards the bed-roughness and the flow characteristics as well (Gust and Southard 1983). Duringbed-load transport the particles connect with the flow as well as the bed. Bergeron and Carbonneau (1999) studied that the increase in flow resistance depends on the increase of the roughness due to the extraction of momentum from the flow in the presence of bed-load transport. Some researchers suggested that the transporting of bed-load is ultimately decreasing the flow resistance that resulting an increase of streamwise velocity. Carbonneau and Bergeron (2000) reported that the bed-load transport causes an increase invelocity, demonstrating that the effect of sediment transport on mean flow characteristics is rather complex. Regarding the *von Karman coefficient* κ, Gust and Southard (1983) and Bennett *et al.* (1998) for smooth andtransitionalsystem and Bennett and Bridge (1995) and Dey and Raikar (2007) for rough system reported that a decrease in κ from itsglobal value occurs due to the bed transportability. Bathurst 1988,studied that the velocity profile, may be represent as an S-shaped typewith near-surface velocities significantly greater than near-bed. Bray (1988) concluded that for small scale roughness the quantity of relative depth is h/d_{50}> 20 (where h is the flow depth and d_{50}, is the particles for which 50% are finer). Dong and Ding (1990) and Dong*et al.* (1992) studied that by changing the value of h/k_s the boundary roughness on flow characteristics is influenced. He suggested that the velocity profile is fitted by the logarithmic formula if h/k_s is less than 2.0 (k_s is 10 mm, the maximum diameter of bed materials), andthe wake function should be introduced if $h/k_s \geq 5.0$.

Analysis of experimental data, measuredby an acoustic Doppler velocimeter with sampling frequency of 100 Hz, inclear-water and mobile-bed flows, allows an understanding the modifications in the vertical velocity profile due to difference in bed conditions. Here, the experimental data for clear water flows are used as a reference.

II. DETAILS EXPERIMENTAL

For present study, the experiment was conducted in the Hydraulic and Water Resources Engineering Laboratory at theDepartment of Civil Engineering, National Institute of Technology, and Rourkela, India. A rectangularlarge flume with MS bars was used for the experiments Fig. 1. It was 2m wide, 0.53 m deep and 12 m long. .

Fig.1:- Photos of *(i)*smooth channel *(ii)*rough channel *(iii)* hopper (*iv*) mobile bed

For smooth simple channel, the configuration of the channel is trapezoidal in shape with bottom width 33cm, height of 11 cm, and side slope of 1V:1H and Manning's roughness of 0.01 in bed. The longitudinal slope was given 0.001325 to flume so that water could flow under gravity.

For rough bed condition, utmost care was taken to ensure that the immobile-bedroughness became unchanged throughout the experiments. These experiments have been conducted in same channel with bottom slope 0.001 and Manning's roughness of 0.0122 in bed and 0.01 in side bank (Fig.1). The bed materials provided are small size gravels (6mm to 20mm) with the equivalent sand roughness (k_s) of 0.012 m to 0.018m.To prepare an immobile-bed, fabricated glue was sprayed on the surface of the flume bottom and then the gravels were spread uniformly to create a rough-bed.

For sediment sample, an experimental set runs for mobile-bed flow conditions. To achieve this mobile bed condition, sediment feeder which is operated by an electro-mechanical devicewas installed at the inlet of the flume, so that the sediments can easily feed into the flow. A hopper and aconveyer belt are the main components of the experiment.Fig.1shows the photograph of the sediment feeder apparatus. The depth of flow was controlled by an adjustable tailgate at the flume. The depth of flow was measured by the point gauges. The uniformly graded sediment was usedfor the experiments, with median diameters d_{50}= 1.0mm.Then, the mobile-bed flow structure was measured during the bed load transport of sediments at a certain rate corresponding to the same flow condition as that of the clear-water flow. The sediment was fed into the flow at a uniform rate through a hopper and a conveyer belt attached to a gearing system, as shown in Fig.1. The sediment transport capacity of the flows always equaled or exceeded the bed load feeding rates.The bulk of the bed-load transport occurred in the channel of the 0.33m wide river at a more or less uniform mean transport rate of 2.027 ton/day/meter of width. The sediments were transported right towards the flume outlet without developing bed-forms or deposition. The sediments transported by the flows were collected in a downstream box, called sediment collector. The Roughness height (Philip *et.al* 2012) of present study is 0.0954 and which was determined by the formula

$$k_s = \left(\frac{26}{MS}\right)^6$$

Where $k_s$is the Roughness Height
$MS$is the Manning's-Strickler number = $1/n$
Here the n value for sand is 0.026

A four-receiver acoustic Doppler velocimeter probe (manufactured by Nortek), working with an acoustic frequency of 16 MHz was used to measure the velocity components. The Micro ADV has a software package which is used for taking high-quality 3D velocity data at different points. By the ADV processor the data is received. A computer attached with the processor shows the 3-dimensional velocity data after compiling with the software package. At everypoint, the instrument records a number of velocity data per minute. With the statistical analysis using the installed software, mean values of 3D point velocities are recorded for each flow depth. At the top of the experimental flume, a traveling bridge is moved in the longitudinal direction of the entire experimental channel. Both point gauge and the micro-ADV attached to the traveling bridge is move in both longitudinal and the transverse direction of the experimental channel at the bridge position. A computer is kept on the bridge for taking the readings of velocity by micro-ADV. A sampling rate of 100 Hz was used for the data acquisition. The measurement within top 5 cm of the flow layer could not be performed dueto the limitation of the probe. The flow measurements were performed along the vertical over the centerline at a distance of 4 m from the inlet.

III. RESULTS AND DISCUSSION

Velocity profiles presented in this article were measured at a distance 4 m from the inflow cross section where the condition of steady uniform flow was confirmed. The velocity profile of the longitudinal velocity component was located to the vertical axis of the channel cross section. For three conditions (smooth, rough and mobile bed),the vertical velocity profile curves are plotted for some typical flow depths and shown in Fig.2-4.

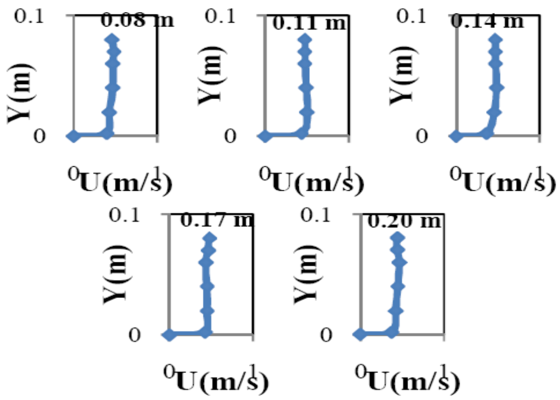

Fig.-2 Vertical Velocity profiles for Smooth Channel

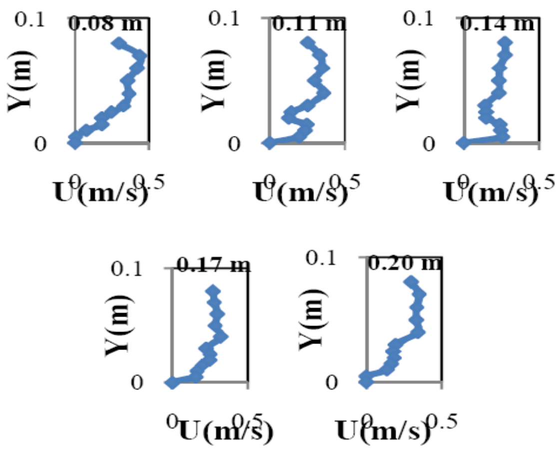

Fig.-3 Vertical Velocity profiles for Rough Channel

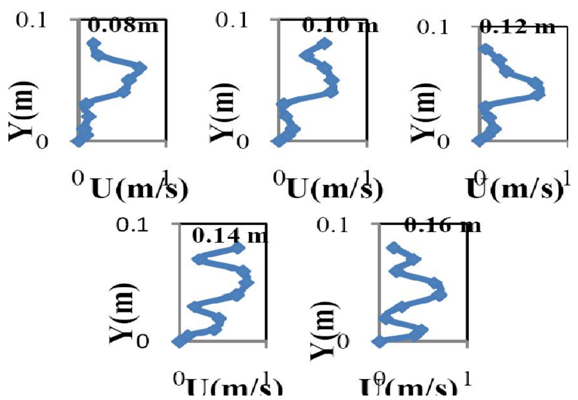

Fig.-4 Vertical Velocity profiles for Mobile Bed Channel

The vertical velocity profiles for smooth channels provided here are of logarithmic in nature (Fig 2).These plots of velocity indicate a zero value at bed and increases with height. The maximum velocity occurs nearer to free surface of flow. The maximum value of velocity is 40cm/sec at center of the channel and then widens towards bank. But a disturbance in vertical velocity variation can be seen in Fig.3 due to the roughness on bed. So at near bed region the velocities are minimum as the resisting force due to rough bed is higher than that of smooth one and then a sudden rise in value occurs towards upper region. The maximum value of velocity is also 40 to45cm/sec near the free surface. For mobile bed case also the same decrease in velocity at near bed region can be seen in Fig.4 due to the presence of moving sediment at lower portion. But a clear difference between rough and mobile bed case is the magnitude of velocity is very low for a particular height in mobile bed case but there is a fluctuation in velocity in case of rough channel.

The depth averaged velocity (U_d) for all the cases were measured for the straight simple channel. $U_d$is the depth averaged velocity calculated by integrating local point stream wise velocities (U) over a flow depth H. The depth-averaged velocity U_d is defined by the following equation

$$U_d = \frac{1}{H}\int_0^H U\,dy$$

The depth averaged velocities (U_d) have been demonstrated for two typical flow depths i.e., 8cm and 9cm for each of three bed conditions. Fig.5 Fig.6 and Fig.7 show the lateral depth averaged velocity measurements for smooth, rough and mobile bed conditions.

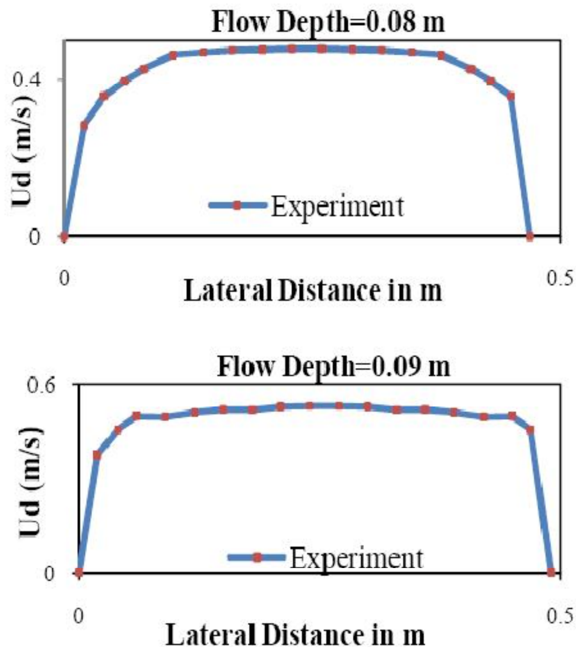

Fig.-5 Depth averaged velocity distributions for smooth channel

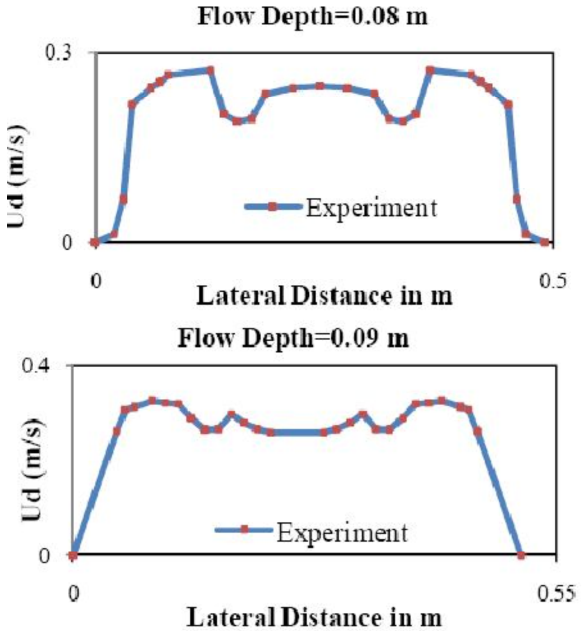

Fig.-6 Depth averaged velocity distributions for roughchannel

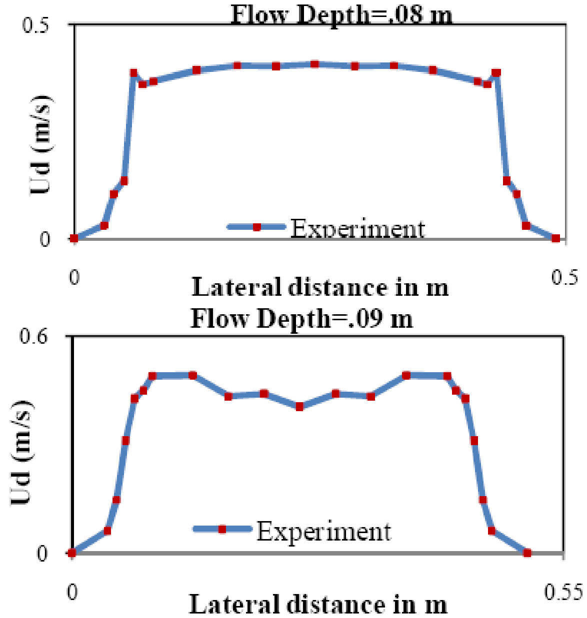

Fig.-7 Depth averaged velocity distributions for mobile bed channel

For a particular depth of flow, the depth averaged velocities in lateral direction of the flow in smooth channels are much higher than that of other two cases. In rough channel, it has been found that the distribution of depth averaged velocity is roughness depended. So a disturbance in variation of velocities occurs at transition region between constant flow depth domain(bed) and variable flow depth domain (bank). The velocities over bed are also lower than that of the velocities over bank due to the difference of roughness at these two regions. But a smooth trend of velocities is obtained in mobile bed cases as the sediments are uniformly flowing over entire flow depth. A reduction in value of the velocities can be seen in mobile bed and rough channel case.

Application of Surfer

The most common application of Surfer is to create a grid based map from an XYZ data file. The Grid or Data command uses an XYZ data file to produce a grid file. The grid file is used by the most of the Map menu commands to produce maps.

The longitudinal velocity contours (isovel) have been demonstrated in Fig.8, Fig.9 and Fig.10 for smooth, rough and mobile bed channels of water depths of 0.09m. The dimensionless stream wise velocities are formed by dividing the measured velocities with the average velocity of the flow (Q/A), where Q is the discharge and A is the cross sectional area of flow. Stream wise velocities in terms of U/U_{avg} are plotted for entire cross sectional area for all three types of the bed demonstrated in Fig.8, Fig.9 and Fig.10.

It has been clearly seen from Fig.8 that the maximum velocity occurs at central upper region of the smooth channel. Minimum velocity appears at the upper side corners. The velocities decrease from the central portion of the channel to the sides.

The velocity profiles of rough channels (Fig. 9), it has been clearly observed the maximum velocity occurs at central upper region and spreads a larger portion as compared to smooth channels. Same results as rough channel can be observed for movable bed case. In these two cases, the velocities are minimum at bed region and suddenly rise at a certain height due to the presence of rough material at bed.

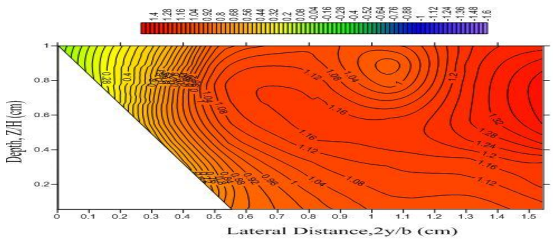

Fig.-8 Dimensionless stream-wise velocity isovel for smooth channel

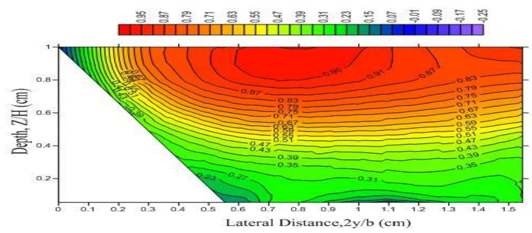

Fig.-9 Dimensionless stream-wise velocity isovel for rough channel

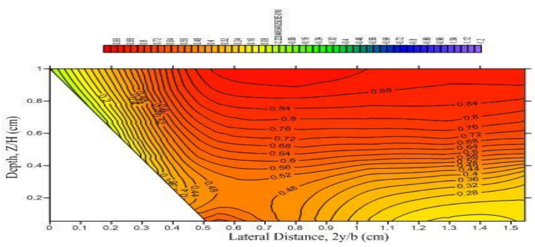

Fig.-10 Dimensionless stream-wise velocity isovel for mobile bed channel

CONCLUSIONS

Experimental investigations have been carried out in smooth, rough and mobile bed channels to study the changes of flow variables with differential roughness. For three conditions (smooth, rough and mobile bed), the vertical velocity profile curves are plotted for some typical flow depths for studying the effect of roughness materials in vertical distribution of velocity. The vertical velocity profiles for smooth channels provided here are of logarithmic in nature. These plots of velocity indicate a zero value at bed and increases with height. But a disturbance occurs in vertical velocity variation in case of rough bed. So at near bed region the velocities are minimum as the resisting force due to rough bed is higher than that of smooth one. For mobile bed case also the same decrease in velocity at near bed region has been studied due to the presence of moving sediment at lower portion. Likewise a clear difference between rough and mobile bed case is the magnitude of velocity is very low for a particular height in mobile bed case but there is a fluctuation in velocity in case of rough channel.

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