Turbulence Characteristics And Velocity Response In An Open Channel Using Acoustic Doppler Velocimeter

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Abstract - Understanding of the hydraulics of flow over sudden change in bed roughness. A micro acoustic Doppler velocimeter ADV;Sontek is used to measure the flow velocity on different roughness for different discharge. Then influence of sudden change of bed roughness on flow parameter is analyzed. The observed velocity distribution for sudden change in the bed roughness were compared and analyzed. A new correlation is proposed that will help in better estimation on effect of flow parameters due to sudden change in bed roughness which ultimately will help in designing more efficient channel section and improving the economics of channel design.

Keywords - acoustic Doppler Velocimeter, Velocity Response

I. Introduction

Bed roughness is an inevitable part of the open channel flow. Whenever there will be any flow in the river, canal or lake, there would be resistance offered to the flow of the water by the bed surface. The bed roughness consists of different sizes of aggregate formed due to the weathering action of the bigger rocks, carried away by the flowing water. These aggregates effect's the flow parameters to great extent.[1] It has been observed that the velocity follows a logarithmic variation with the flow depth, with the maximum velocity occurring at a distance below the top free surface. The presence of bed roughness affects the curvature of the velocity profile. In order to understand the effect of bed roughness on flow parameters in a better way, this experimental study has been carried out[4].

In these experimental study efforts has been made to know how the sudden change in bed roughness effect the flow parameters, the series of experiments were performed in a rectangular hydraulic flume. The hydraulic flume was 3.47 m long, 0.622 m wide and 0.535 m deep. Four different kind of roughness was generated, each of length 0.63 m and 0.621 wide. An average height of roughness 13.5 mm, 28.5mm, 46.5 mm and vegetated mat were used to generate the roughness.

Acoustic Doppler velocimeter was used to find the velocity at each depth in the rectangular flume. The discharge was found with the help of sharp crested wear located at the downstream of the hydraulic flume. The observations were taken for sudden change in the bed roughness. The observed velocity distribution for sudden change in the bed roughness were compared and analyzed. A new correlation is proposed that will help in better estimation on effect of flow parameters due to sudden change in bed roughness which ultimately will help in designing more efficient channel section and improving the economics of channel design.

II. EXPERIMENTAL SETUP AND PROCEDURE:

The experimental work was carried out in laboratory of P.G Irrigation & hydraulic engineering PEC University of technology Chandigarh, India. The experimental setup consists of a tilting flume. A sharp crest weir was employed for measurements of discharge through the flume. SonTek's HorizonADV software (v1.20) with ADV system i.e. Acoustic Doppler Velocimeter is used for the measurement of velocity of water. Uniform flow was maintained in the flume with change in bed roughness. The sharp crest weir is connected to hydraulic circuit allowing the recirculation of stable discharge A weir is basically an obstruction in an open channel flow path. Weirs are commonly used for measurement of open channel flow rate. A weir functions by causing water to rise above the obstruction in order to flow over it. The height of water above the obstruction correlates with the flow rate, so that measurement of the height of the flowing water above the top of the weir can be used to determine the flow rate by the use of an equation, graph or table. The top of the weir, which is used as the reference level for the height of water flowing over it, is called the crest of the weir..

The flume is used for the experiments consists of rectangular flume having a length and width of 11.40 meters and 0.61 meter respectively. The walls of the flume were made of glass for making it visible. The inlet pipe which provide the discharge in the flume take water from the laboratory sump and supply to the overhead tank. Water was regulated by the valve provided on the inlet pipe. The supercritical flow depth was controlled by the sluice gate while the tail water depth was controlled by downstream gate[6]. In the downstream of the flume there is a sharp crested weir for the measurement of the discharge the hydraulic flume is shown in Figure 1[8].

The pointer gauge has an inverted scale attached to them with the help of which we can measure the exact depth of water at any section and various location of the flume.

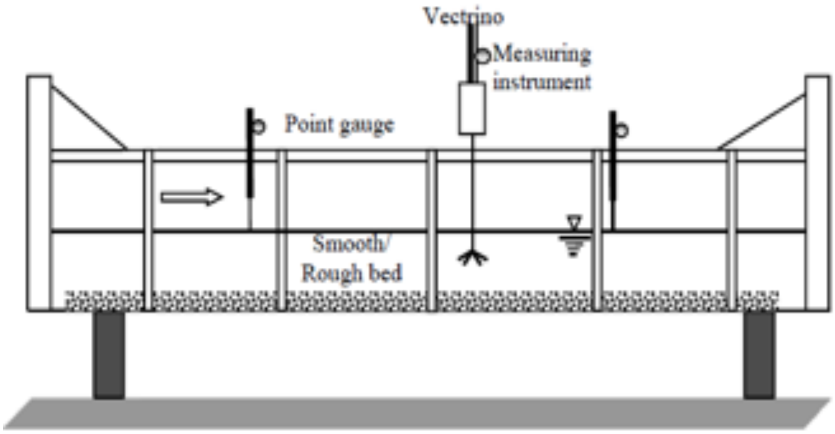

Figure 1 Longitudinal Section of rectangular flume

In this study, measurement of the instantaneous velocities using the two-component ADV was conducted along the centerline eof the flume. With this measurement, the mean and turbulent properties of the flows could be investigated. The sampling rate of the ADV is 50 Hz and the duration of the measurements for every position was set at 60 s[7].The velocity measurements were conducted using a micro acoustic Doppler velocimetre ~ADV; SonTek, ADVs operate using the pulse-to-pulse coherent processing technique (commonly called pulse-coherent or PC). They transmit one very short acoustic pulse, record its return signal (i.e. the reflection off particles in the fluid), and then transmit a second pulse, identical to the first, at a short time later. Each return is detected by acoustic receivers focused in a remote sampling volume (Fig. 1). The instrument measures the phase difference between the two returns and uses this to calculate the Doppler shift, which is directly proportional to the speed of the fluid. Velocity measurements made using pulse-coherent processing are highly precise, but have limited maximum measureable velocity[3].

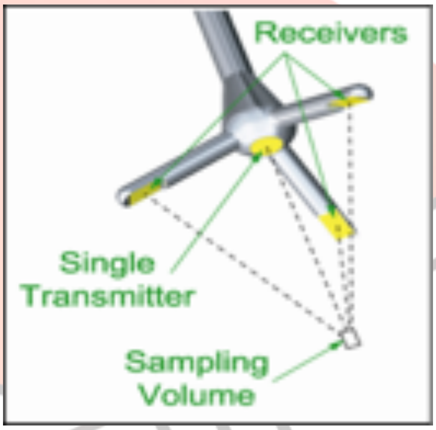

Figure 2 Basic ADV probe configuration, showing transmitter, receivers and sampling volume location. Illustration is for a 3D probe type[3]

The various materials used in the present investigation are of different sizes and shapes. The materials were sieved from bulk material in order to obtain the similar shape for each size, although it is not sure that the shape of separate grain be identical. The various sieves used in the sieve analysis are 63mm, 50mm, 40 mm, 31.5 mm, 26.5 mm 25 mm. 22.4 mm, 20 mm, 16 mm, 13.2 mm, 12.5 mm, 10 mm and 8 mm. To ensure the proper sieving 5 minutes were allowed to shake the material in each case so that uniform size material is allowed to pass through one sieve and retained in another sieve. After this material was weighted from each sieve and after calculation work percentage finer was plotted against grain size on semi log graph paper, based on which the various parameters like d50, d84 and d16 were found out. A mechanical sieve shaker was used to ensure proper and thorough sieving.

Formation of rough bed

For the formation of rough bed different gravel sizes (d50 0.0135 m, 0.0285 m and 0.0465m) and vegetated mat are used. The flume reach is divided into 5 parts of reach area (0.61 m *0.61 m) first reach is kept smooth then the max roughness 0.0465 m is used for second reach third reach is 0.0285 m of particles is used and the fourth reach is cemented with 0.0135m and then vegetated mat is fixed in the flume. These particles are cemented on the bed of flume to provide the roughness to it. For this a paste of cement and sand with the ratio of 1:3 is made so that it provides the sufficient strength to the cemented particles and the chances of the particles to flow away with the water is minimized. This paste is laid on the flume bed and the aggregates are embedded in it. Care is taken to make the bed uniform so the slope remains same at all levels and voids are minimized to increase the chance to provide maximum roughness. Bed was given a minimum time of 4 days to get a good strength for experimental work. The average height of roughness of material 1, 2, 3 and 4 obtained after cementing the aggregates are 0.0135 m, 0.0285 m and 0.0498 m and vegetated mate respectively. The four different types of roughness are shown in Figures 3 to 6 respectively

Figure 3 roughness 1 (0.0456 m)

Figure 4 roughness 2 (0.0285m)

Figure 5 roughness 3 (0.0135m)

Figure 6 Roughness 4 (vegetated mat)

Experimental procedure

In order to attain the above mentioned objective, following experimental procedure was adopted:

i. First of all, sieving was done in order to separate the desired aggregates from the bulk aggregates. After the sieve analysis, the aggregates 3 different sizes and vegetated mat were cemented in the hydraulic flume to generate with bed roughness.
ii. Thus, three different kinds of bed roughness and vegetated mat were installed in the rectangular hydraulic flume. After the installation of the bed roughness, uniform flow was maintained in the hydraulic flume.
iii. After the establishment of uniform flow in the hydraulic flume, reading for flow depth, flow velocity, discharge was recoded.
iv. Mean flow depth and mean flow velocity were estimated with the help of the experimental data recorded.
v. Effect of change of bed roughness on various flow parameters was studied.

RESULTS AND DISCUSSION

Effect of bed roughness on flow parameters

For the present study we have consider a number of flow parameter for analyzing the behavior of bed roughness

Effect of bed roughness on water depth

The lab experiment were performed for varying discharge to analyses the effect of bed roughness on water depth along the horizontal distance it is clearly shown in Figure 7 to 10 that along the length depth of flow showing varying trend as it decreases 0.353 m to 0.313 m in first 0.685m for next phase there is increase in the flow depth from 0.313 m to 0.333 m as the roughness decrease to 0.0285m as the roughness keep on decreasing to 0.0135 m the flow depth increase 0.333m to 0.344 m after 2.362 m there is a sudden increases of depth from 0.344m to 0.366 as the roughness decrease from 0.0135 m to vegetated mat.

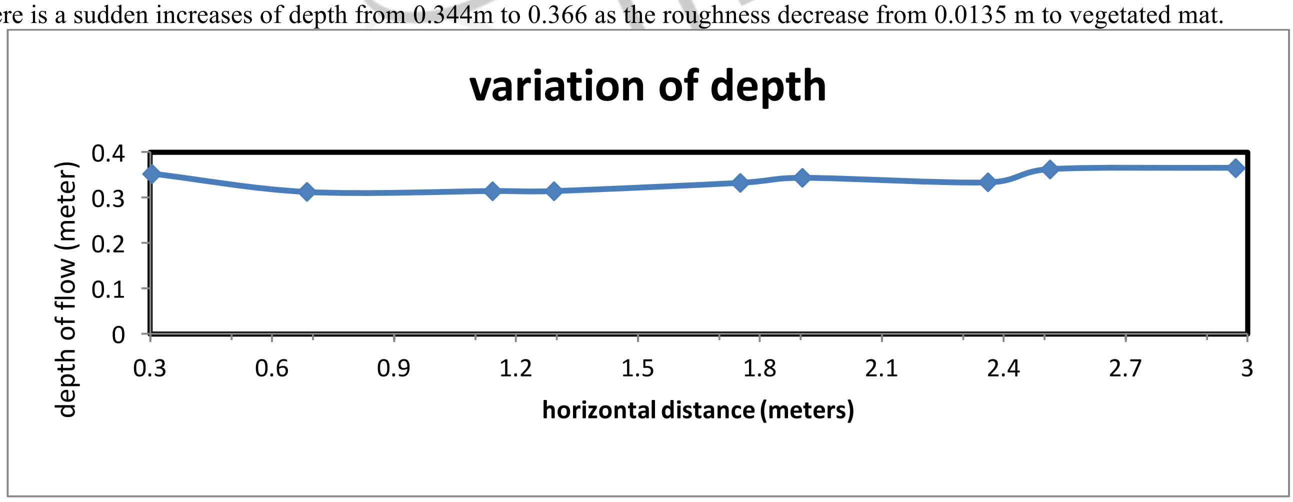

Figure 7 Effect of bed roughness on depth of flow for discharge 0.0567 m^3/sec

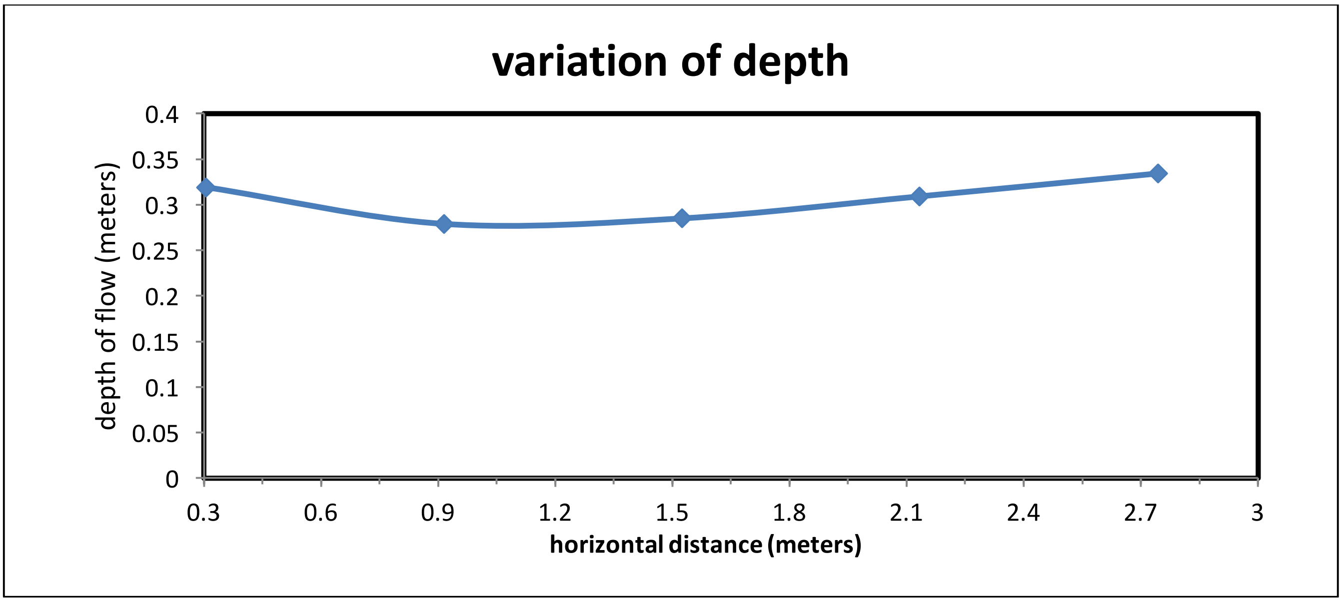

Figure8 Effect of bed roughness on flow depth for discharge 0.412 m^3/sec

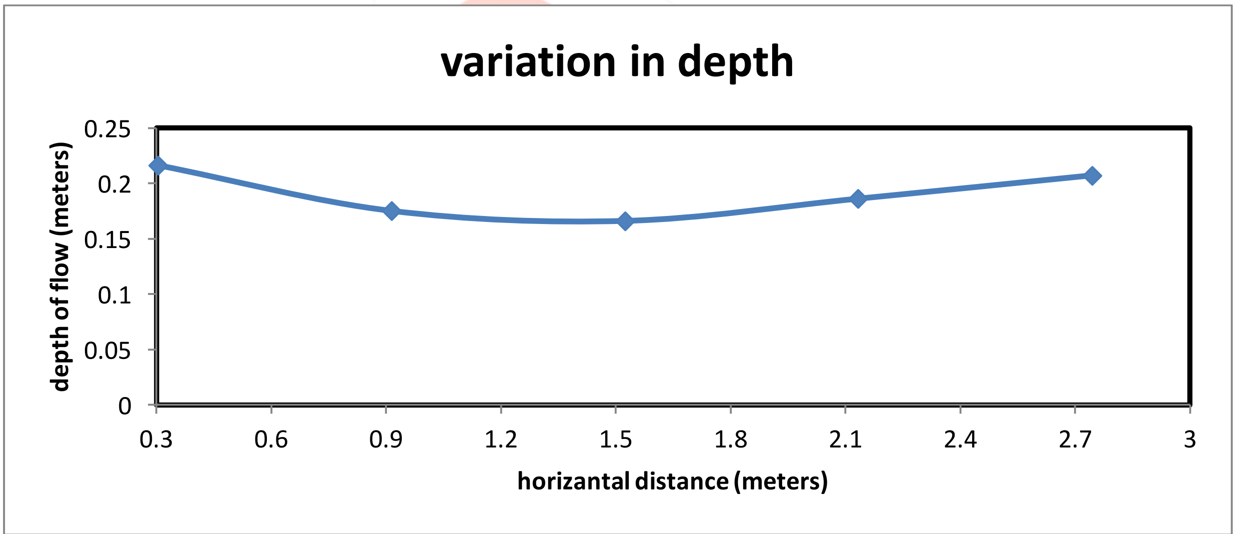

Figure9 Effect of bed roughness on flow depth for discharge 0.0389m^3/sec

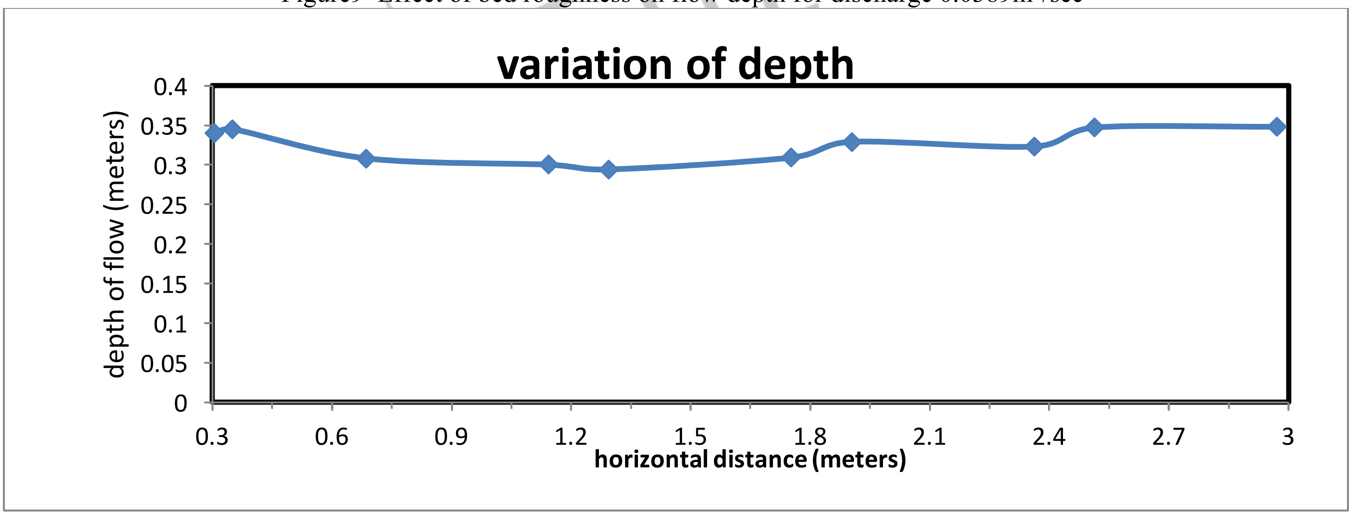

Figure 10 Effect of bed roughness on flow depth for discharge 0.0498m3/sec

Effect of bed roughness on velocity profile

Secondly the effect of bed roughness on velocity profile were analysed for varying discharge. Values and experimental results are shown in figure 11 and 12

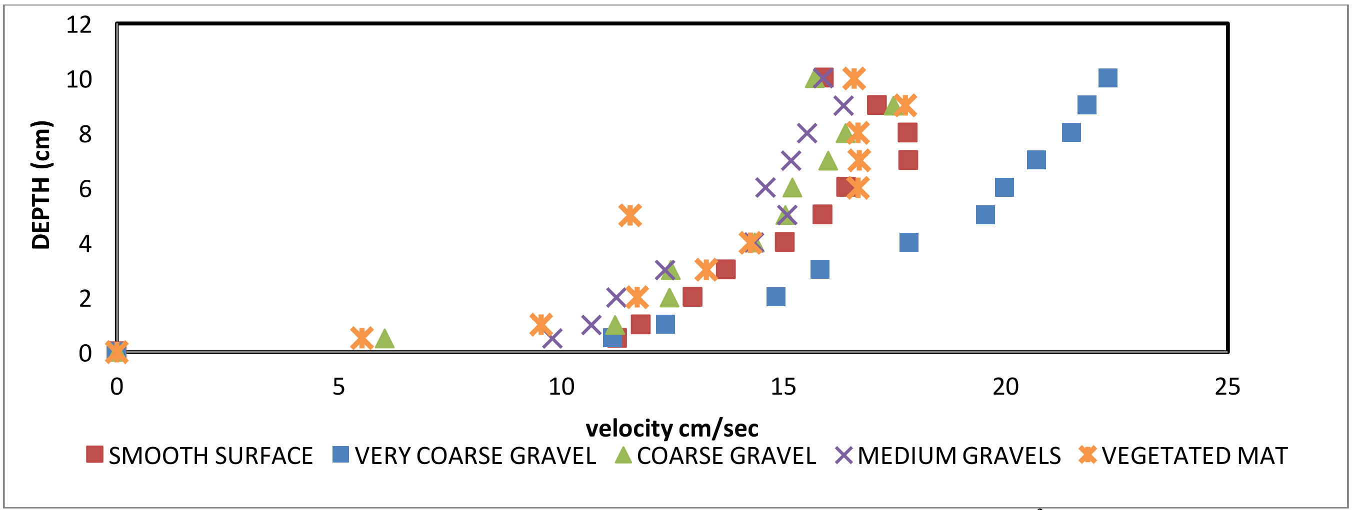

Figure 11 Effect of roughness on velocity profile at discharge 0.0589m^3/sec

As sudden change in roughness height from smooth roughness condition to 0.0456 m, 0.0285 m and 0.0135 m to vegetated mat the velocity suddenly increases from 0.159 m/sec to 0.218 m/sec and as the roughness decrease the velocity also decreases to 0.157 m/sec, and 0.151 m/sec respectively then when roughness decreases to transition state there is increase in velocity on vegetated mat 0.1650m/sec. Thus, based on the experimental data, it can be concluded that the mean flow velocity increases to a sudden increases in roughness as the depth decrease there should be increase in velocity.

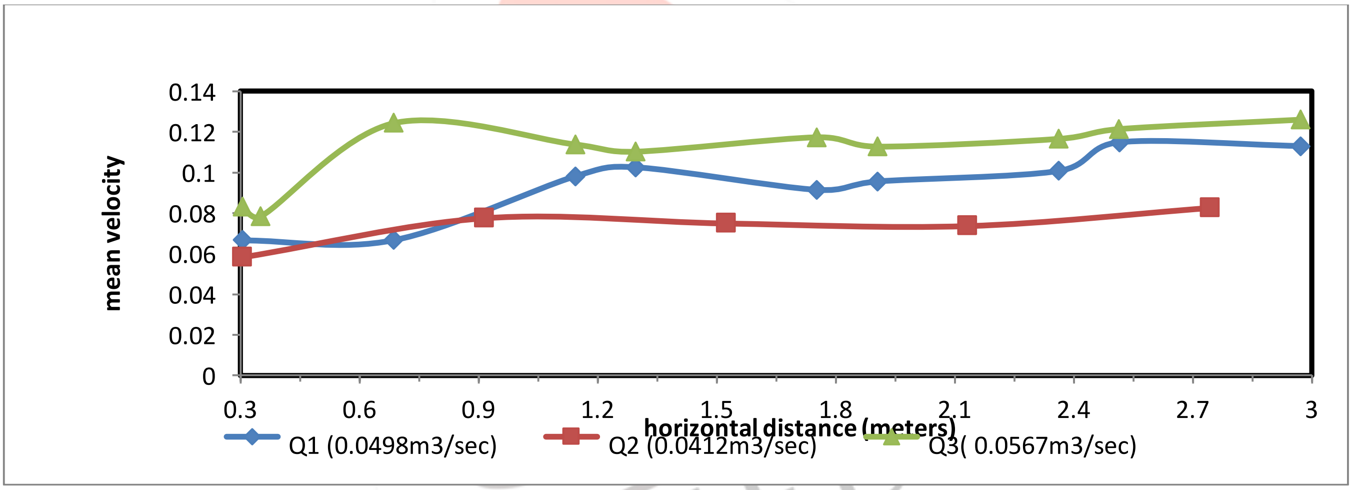

Figure 12 Effect of velocity profile with horizontal distance at varying discharges

The mean flow velocity in case of sudden bed change from no roughness condition to roughness 1 roughness 2 roughness 3 to vegetated mat are 0.66 m/sec 0.980 m/sec, 0.9142 m/sec, 0.90 m/sec, .0.1129 m/sec it is clear from figure 12 that when flow moves from no roughness condition to 0.0456 m, 0.0285 m and 0.0135 m to vegetated mat the velocity suddenly increases and then tends to decreases and finally increase on vegetated mate.

The flow velocity has suddenly increase as move from smooth surface to rough is due to the change of flow depth as the depth decreases so there is an increase in velocity and the it decreases due to the formation a boundary layer, which creates a drag in the boundary layer, preventing the fluid from flowing smoothly, thus increasing the flow resistance and as a result the flow velocity decreases. The reduction in the flow velocity is more near to the bed surface as compared to the top surface as the boundary layer formed is not extended to the full depth and is formed in the near body zone only.

To Check the Applicability Of Existing Relationship

To check the applicability of existing relationship presented in the literature for smooth rough boundary based on thickness of laminar sub-layer and analyses of particles as smooth and rough boundary conditions when ks/ð is greater than or equal to 6.0 the roughness projections are much larger than the computed thickness of the laminar sub-layer. As such, the laminar sub-layer is destroyed and the turbulent eddies are indirect contact with the roughness projections such boundary is known as a rough boundary. At values of ks/ð' between 0.25 and 6.0, the roughness projections may come in contact with the turbulent eddies and at the same time the laminar sub-layer is also not completely destroyed. Such a boundary is known as a boundary in transition.[4]

For rough surface $\frac{U}{U^*} = 5.75 \frac{Log\, Y}{K_s} + 8.50$ (1)

For transition surface $\frac{U}{U^*} = 5.75\, Log 12.2\, R_X/K_s$ (2)

For Rough Boundary

(U/U*) was calculated for rough boundary from Eqn. 5.1 and also from the observed experimental data $(U/U^*)_{Cal}$ was plotted against the $(U/U^*)_{Obs}$ and the comparison between observed and calculated (U/U*) using Eqn(5.1) shown in figure 13

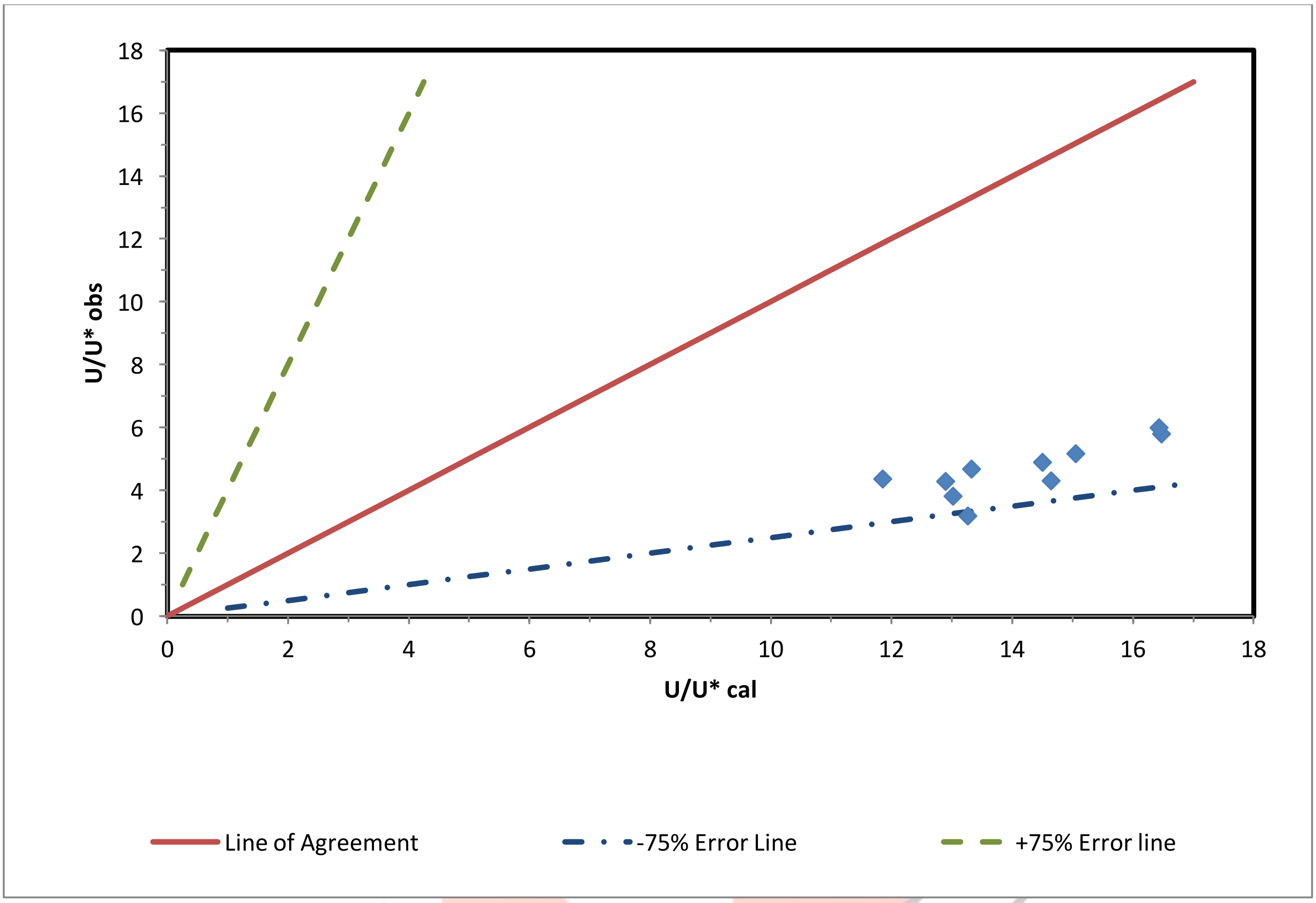

Figure 13 Comparison of (U/U*)obs and (U/U*) cal and by using Eqn. (1)

It can be clearly shown In Figure 13 that the data point was underestimated or lies below the line of agreement.

FOR TRANSITION

U/U* was calculated for transition boundary from theoretical Eqn 2 and also from the observed experimental data U/U^*_{Cal} was plotted against the $(U/U^*)_{Obs}$ and the result is shown in Figure 21

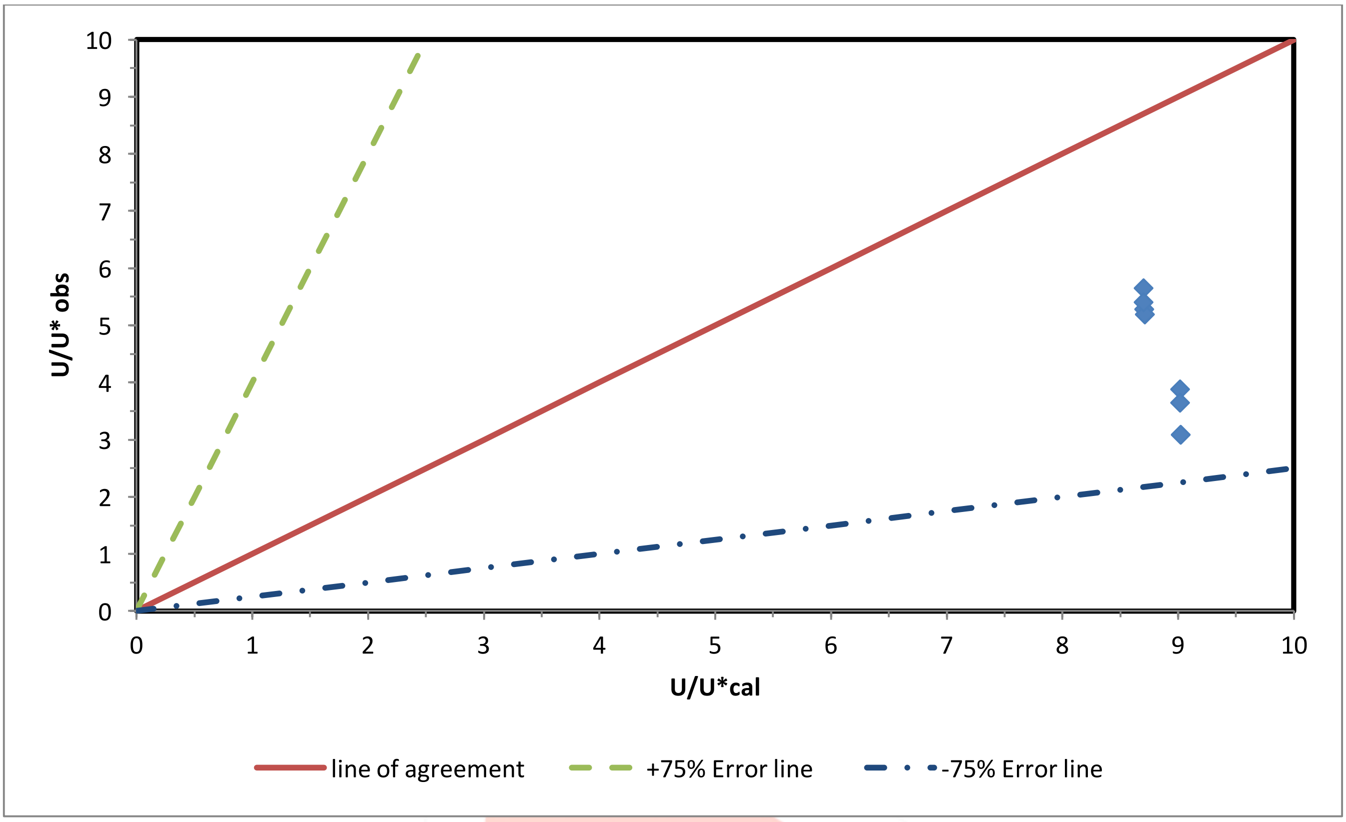

Figure 14 Comparison of (U/U*)obs and (U/U*) cal and by using Eqn. (2)

It can be clearly shown in Figure 14 that the data point was underestimated or lies below the line of agreement.

New relationship proposed

Based on above analysis, It was attempted to purpose a relationship for (U/U*) obtained from the theoretical equation do not coincide with the (U/U*) obtained experimentally. Hence there is a need to modify the theoretical equation and an attempt is made to propose a new relationship. In order the modify the equation (U/U*) is plotted against Y/K_s for rough boundary and for transition boundary U/U* is plotted against log R/k_s as in transition boundary U/U* depends on log R/Ks the result is shown in figure 15 and 16

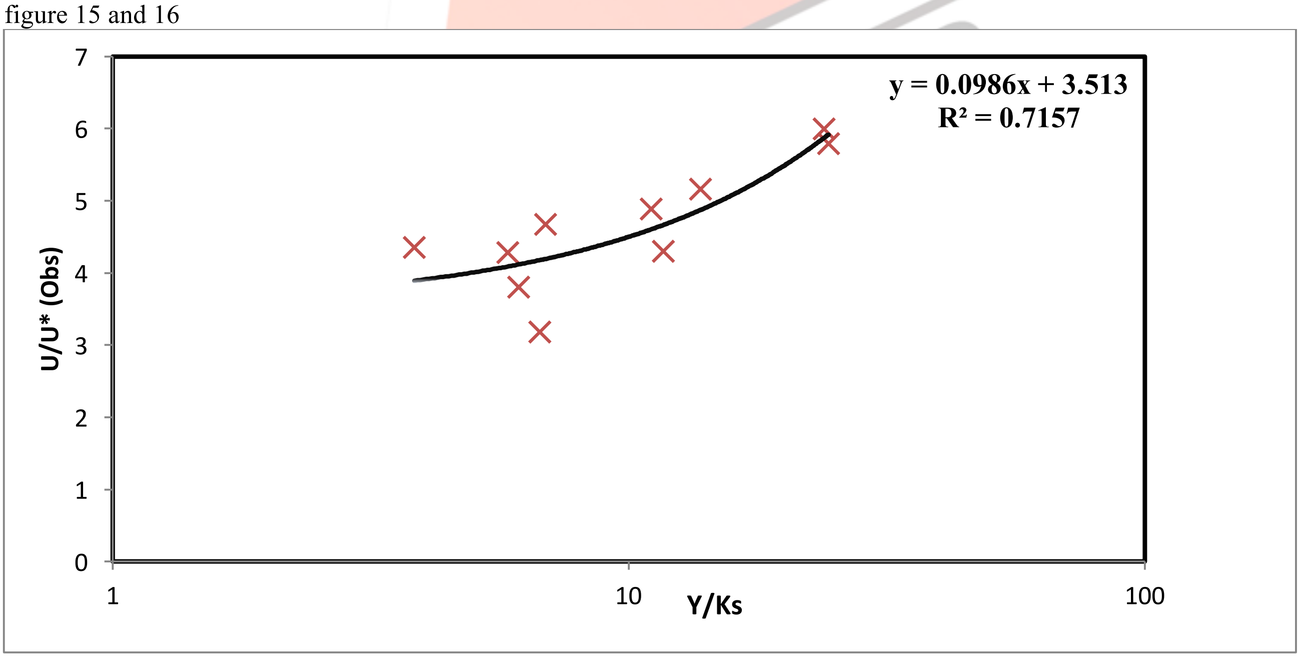

Figure 15 relationship between observed U/U* and Y/Ks for rough boundary

The new proposed relationship between U/U* and Y/k_s has shown good correlation with a coefficient of determination (R^2) as 0.71.

$$\frac{U}{U^*} = 0.0986\ Log\frac{Y}{K_S} + 3.513 \quad (3)$$

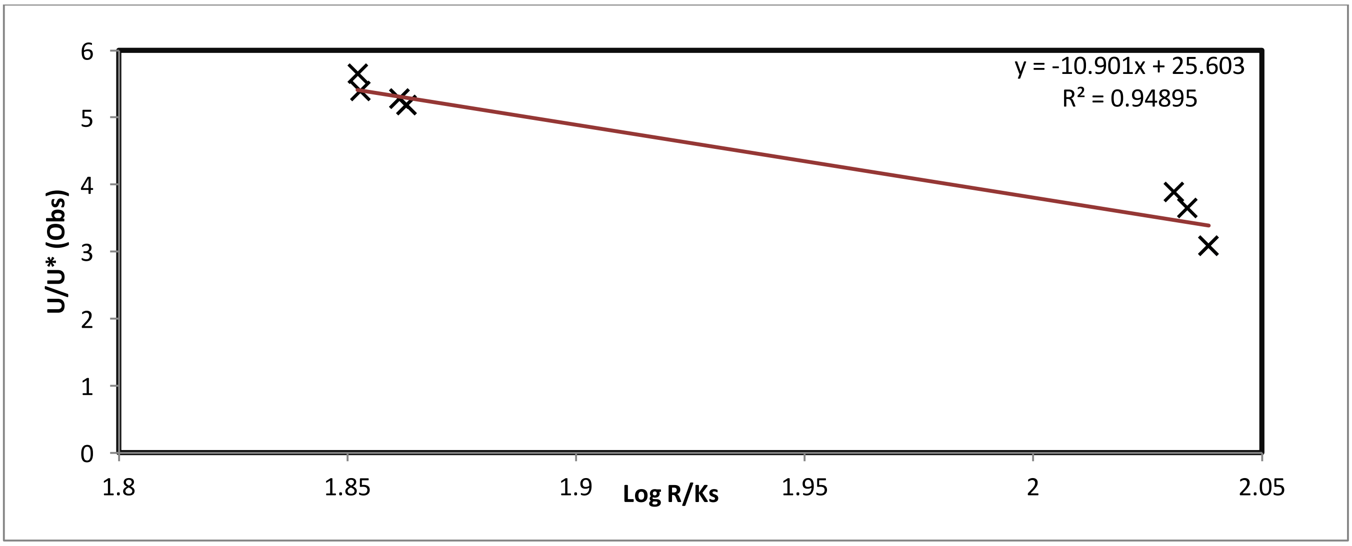

Figure 16 relationship between U/U* and log R/Ks for transition boundary

The new proposed relationship between U/U* and log R/k_s has shown good correlation with a coefficient of determination (R^2) as 0.94

$$\frac{U}{U^*} = -10..901\ Log\frac{R}{Ks} + 25.603 \quad (4)$$

Validation of proposed relationship

Further the observed value U/U* were compared with those computed by using new Eqns. (3) and (4) for rough and transition respectively and these comparison is shown in figure 17 and 18

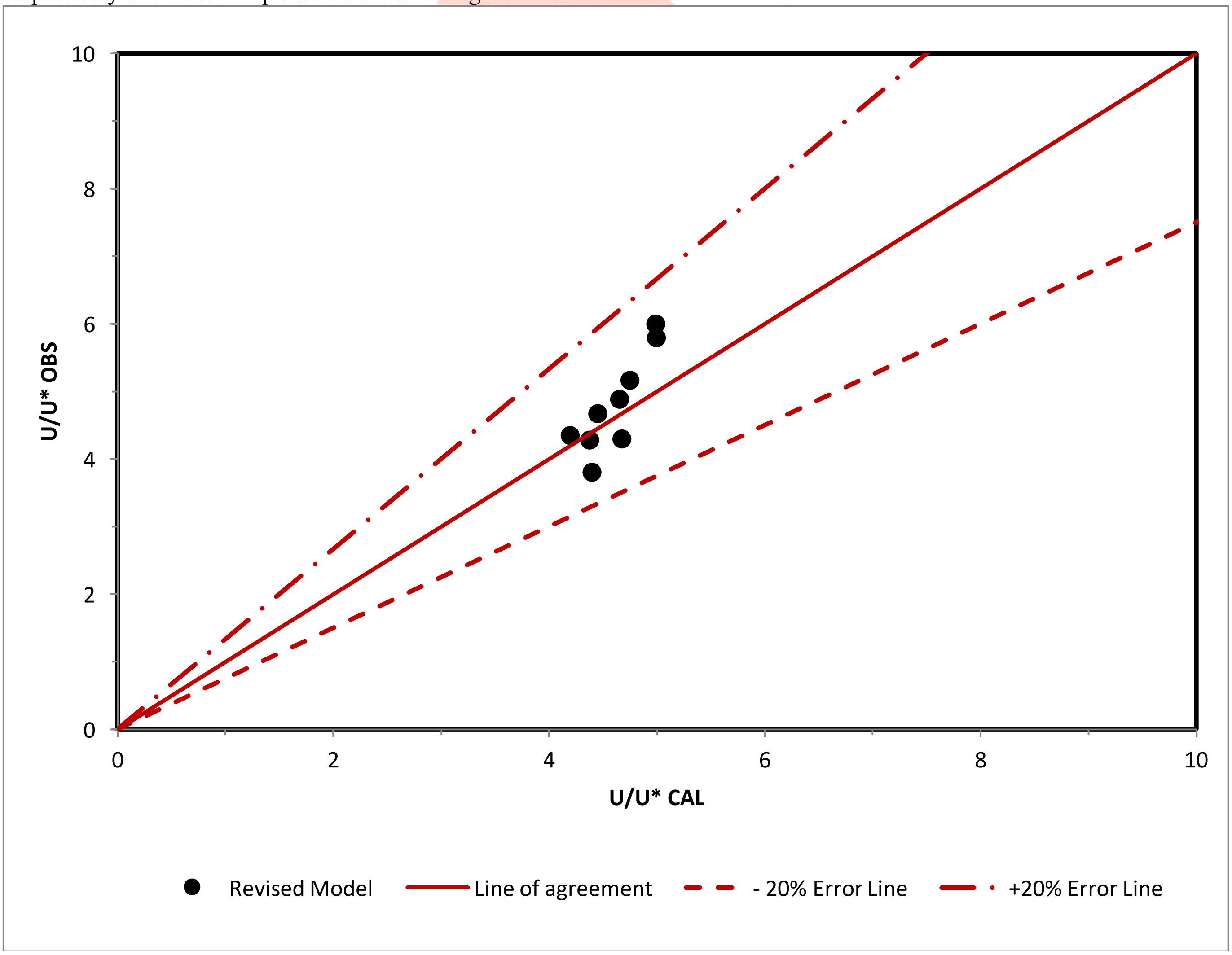

Figure 17 Comparison of observed U/U* and calculate U/U* for rough boundary by using Eqn. (3)

This comparison shown in figure17 indicated that the proposed relation produced result with maximum error of +/- 20 % error.

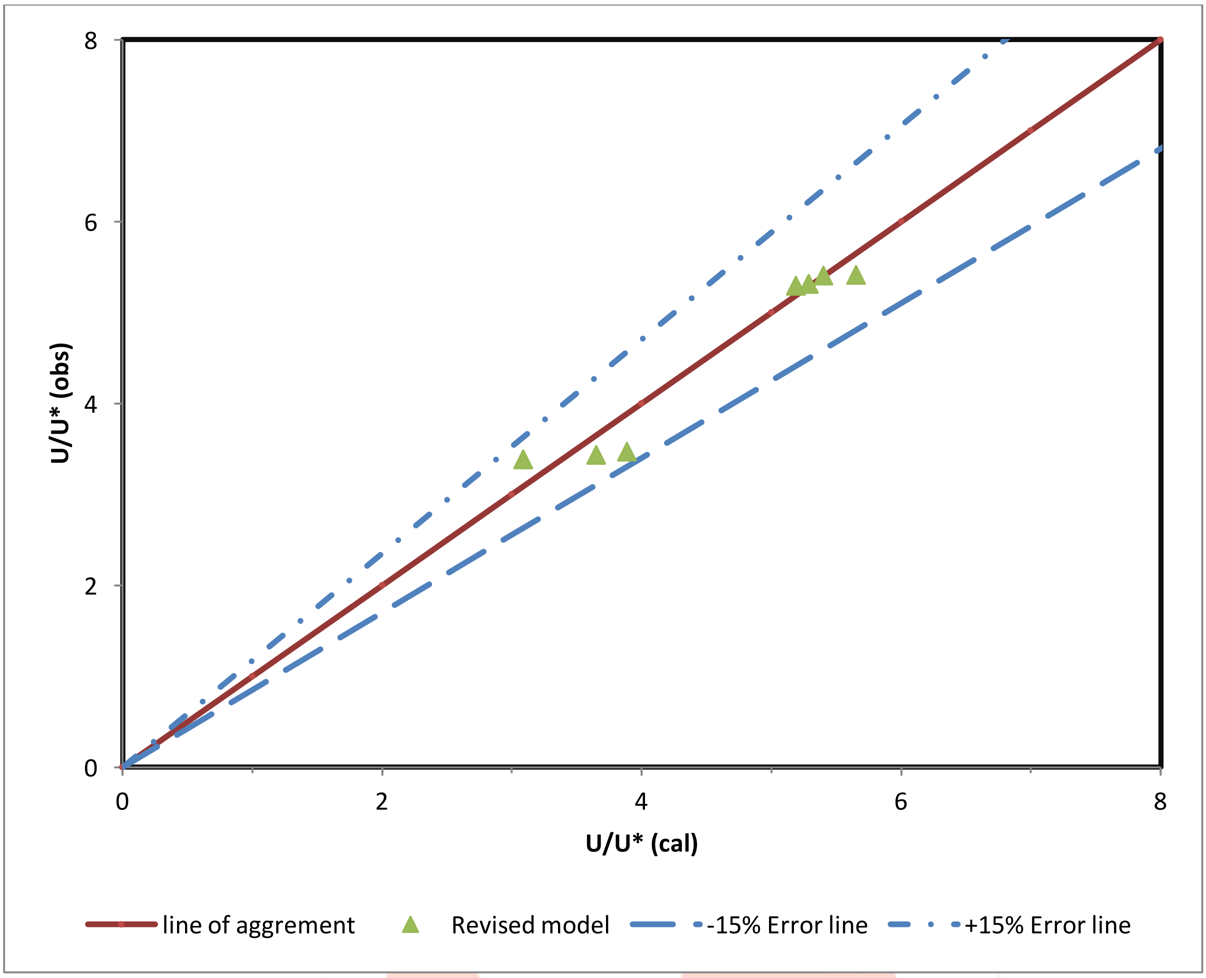

Figure 18Comparison of observed U/U* and calculate U/U* for Transition boundary by using Eqn. (4)

This comparison shown in figure 18 indicated that the proposed relation produced result with maximum error of +/- 15 % error.

CONCLUSIONS

The present study was conducted to understand the effect of sudden change of bed roughness on uniform flow parameters. Experiments were performed in a rectangular hydraulic flume with 4 different beds consecutively. The response of velocity and turbulence characteristics due to sudden change in bed roughness was estimated and new correlation is proposed which can be useful for designing of channel. on the basis of analysis in this study the following conclusion has been drawn :

i. Due to sudden change in roughness the depths of the flow decrease and there is sudden increase in the velocity.
ii. As the roughness decreases along the length of the flume the mean flow velocity also decrease i.e when there is sudden change from no roughness to0.0456m the velocity suddenly increases and with the decrease in bed roughness the velocity decreases and there is increase in velocity when roughness changes form 0.0135m to vegetated mat
iii. The new proposed relationship between U/U* for both rough and transition boundaries. The final modified equation is as follow:

For rough boundary $\frac{U}{U^*} = 0.0986\ Log\frac{Y}{Ks} + 3.513$

For transition boundary $\frac{U}{U^*} = \ -10..901\ Log\frac{R}{Ks}$ +25.603

Future scope

Following suggestion are made for further investigation in open channel flow for better understanding of the effect of sudden change in bed roughness on flow parameter:

i. The present study was confined to rectangular flume. Further studies can be extended to different shape of the flume in order to understand the effect of channel shape on flow parameter
ii. In the present study, the bed roughness ranged from 13.5 mm to 46mm so roughness size can be further extends for the different shapes of channel.
iii. Different aspect ratio can be used for further study of the effect of bed roughness of parameters.

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