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An Integrated Approach of Profile Studies for Surface Water Velocity on a Steep Slope in a Rectangular Channel

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ABSTRACT
The flow velocity of water and its accurate surface profile estimation is important parameter as changes in climate increases the uneven rainfall patterns causing flood in downstream. It is important to know the velocity profile in steep open channel flows for solving the soil erosion, flooding and sediment transport problems in rivers or streams on steep slopes. A fixed bed laboratory experiment for a rectangular channel with steep slope is conducted to find the velocity profiles and surface profiles at different sections. Velocity profiles are presented at different sections in rectangular channel with steep slope. The outcome of the laboratory based experimental investigation shows that the velocity and surface profiles are influenced by the depth of flow of water and channel bed slope respectively.

Keywords: fluid mechanics, velocity profiles, rectangular channel, pitot tube, acoustic doppler velocity (ADV) meter.

INTRODUCTION

The estimation of velocity and surface profiles is regularly measured at different rivers and streams useful to forecast flow characteristics of water, flood alarming etc. Therefore measuring accurate water surface and velocity profile is important on time. A rectangular cross-section in open channel flow is defined as a section in which width and depth are different with a free surface which is open to the atmosphere flow condition [3, 4, 5, 6, 14]. To analyze water flow, mean velocity distributions in plane perpendicular to the solid boundary have a great interest estimate the surface resistance to flow, which has practical consequences, such as in the estimation of sediment transport rates in open channels. [1, 2, 7, 8, 10, 12, 15, 17] measured the velocity profiles in smooth thin-sheet flows, using a very small pitot tube of 0.92 mm in diameter. They found that the integral constant A of the log-law distribution became smaller with an increase of the Froude number and hence they introduced the Froude number into the resistance law of the thin-sheet flows. [2, 9, 11, 13, 16] have studied and measured the velocity distributions in smooth open-channel flows by making use of a laser-doppler anemometer (LDA). This main goal of this research work is to solve the stage discharge depth relationship for every open channel hydraulics system for instance: Natural River, artificial channels and this study helps the water sectors to reduce the existence of flooding for open channel flow with different flow condition.

METHODS

Experimental procedure

For the estimation of velocity profile and surface profiles the laboratory based experimental investigation was performed in the Hydraulic Engineering Laboratory of Arbaminch Water Technology Institute, Arbaminch, Ethiopia. Width of flume (B) is 0.60 meter and the length is 15.0 meter. The working length of the flume is 6.6 meter. Wall of the flume is made of glass. A rectangular notch was provided at the downstream of the flume. Discharge was controlled by the notch. The schematic view of the experimental set up of flow in a steep open channel is shown in Figure 1, where: (a) representing the plan view, (b) representing the side view, (c) representing the front view and d) representing the laboratory set up of rectangular channel with steep slope.

The depth of flow over the rectangular notch was measured and the discharge was measured using calibrated equation (1). Discharge and head were measured and is plotted to find out the relation between discharge and head. The calibration curve which was measured during discharge and head over the notch is given in Figure 2. The equation was derived through the plot of discharge and head over the notch as:

$$Q = 0.442H - 0.016 \quad (1)$$

where: Q – discharge and H – head over the notch.

A rectangular notch was provided at the downstream of the flume. Discharge is controlled by this notch. Experiments are done for

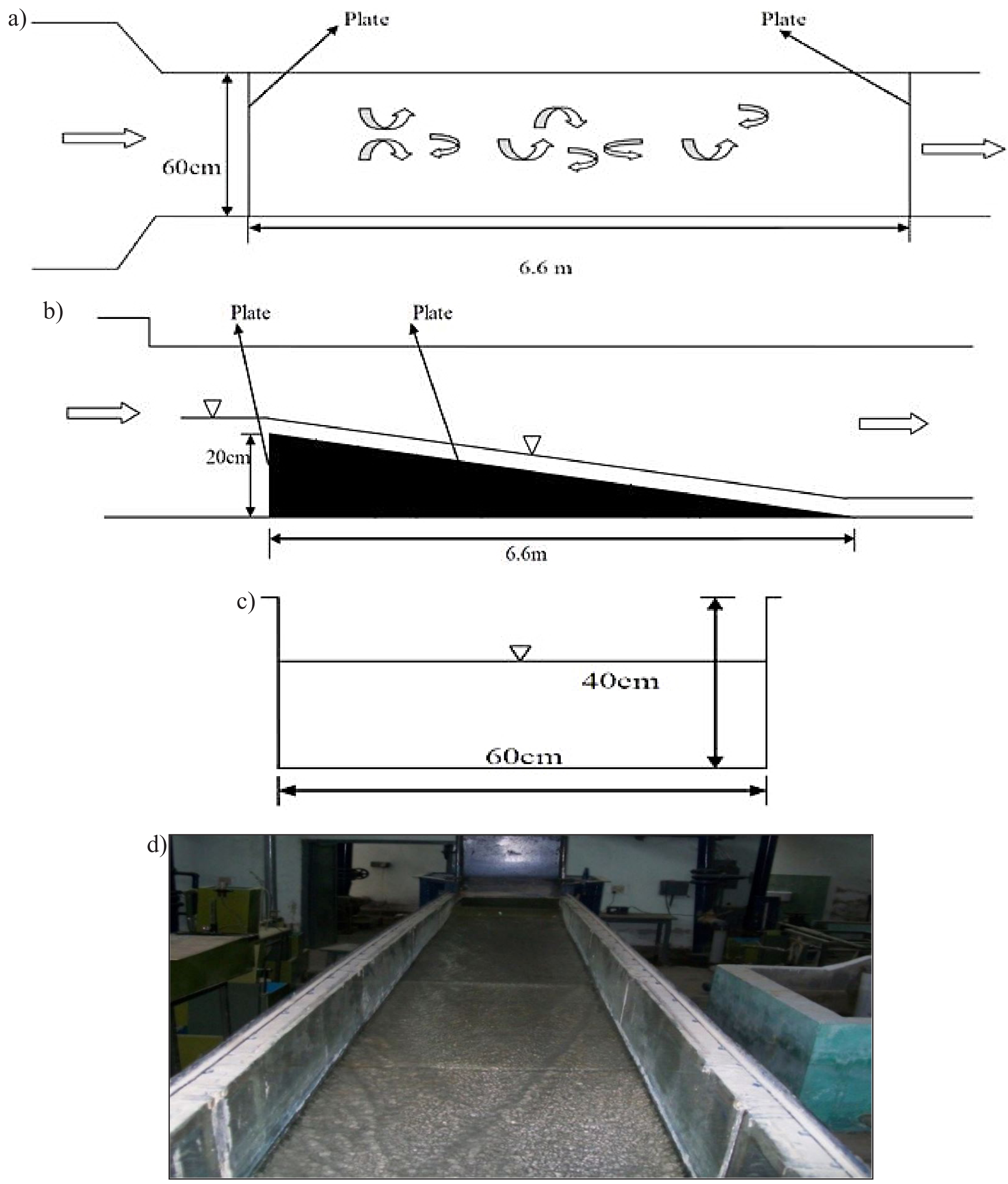

Fig. 1. Cross sectional view of Rectangular channel (a) plan view, (b) side view, (c) Front view, (d) Experimental set up of rectangular channel with steep slope

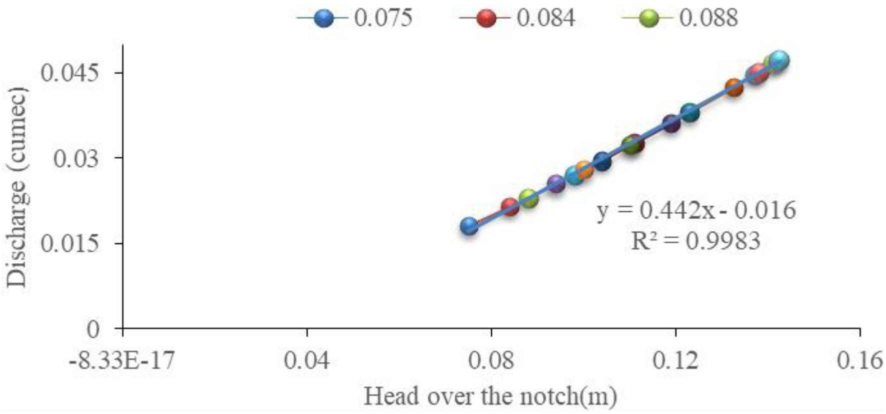

Fig. 2. Calibration curves for rectangular notch

three different depths. Velocity profiles are measured by a Pitot tube. Diameter of Pitot tube is 1 mm. Before doing the experiment, the Pitot tube is calibrated with vectrino which is an acoustic Doppler velocity meter. The coefficient (c_d) ($Q=c_d(2gh)^{0.5}$) is found to be 0.60. Surface profile and depth are measured by a point gauge. Three different discharges (46 l/s, 36 l/s, 37.48 l/s) are used to study the velocity profiles in the steep rectangular channel. Pattern of flow was rapid varied unsteady flow. Section of the rectangular channel used in current research. A honeycomb was provided at the upstream of the channel so that flow becomes stable which is consisted of wood. It has rectangular hole opening, when flow pass through these holes velocity of flow become slow. Rectangular channel is considered Symmetric; measurements are recorded only in the half of the section. The width (30 cm) section of the channel is divided into 15 points which are at an interval of 2 cm. The first section is 3.0 meter from upstream and section two is 50 cm away from the first section. In a similar fashion four different sections are used for the study of velocity profiles. Section of the rectangular channel with steep slope used in current research is shown in Fig. 1c. Velocity profiles and Elevations of the water surface are measured by the Pitot tube and point gauge, respectively. For the surface profiles measurement stream wise length is divided into 30 points which are at an interval of 10 cm. Velocity is measured at 0.6 of depth, from the water surface. Three different flow conditions pertaining to depths 3.9, 4.8, 5.7 cm are used to study the velocity profiles in steep rigid channel. The data collected from the experimental run conducted on rectangular channel with steep slope under different flow condition are analyzed and various aspects are discussed below. The flow conditions for flow in rectangular cannels with steep slope are given in Table 1.

Table 1. Flow conditions for flow in rectangular cannels with steep slope

S. No.	Bed Slope (%)	Depth (sec-1) (cm)	Mean Velocity (sec-1) (m/s)	Froude No. (sec-1)
1	3	3.9	1.70	2.75
2	3	4.8	1.67	2.43
3	3	5.7	1.86	2.49

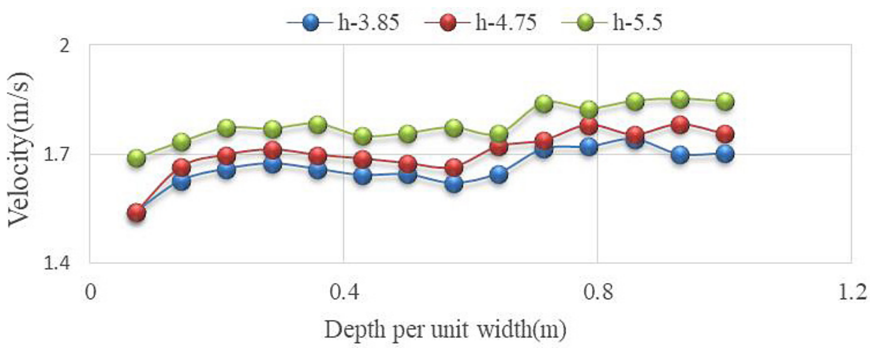

Fig. 3. Velocity distribution in section-1, rectangular channel

Figure 3 shows the distribution of the average velocity along the width. Channel was considered symmetric, so measurement was performed only in the half of the section. Depth (h) of flow is measured 3 meter from the upstream. Velocity increases from the boundary to the center of the channel .As depth increases in the steep open channel the average velocity also increases. At this section large depth has higher velocity and vice-versa. Velocity profiles are fluctuating because of fluctuating nature of flow in high gradient channel. This type of behavior of flow is occurred in mountainous river.

Velocity increases from the boundary to the center of the channel. As we are moves towards to downstream of the channel depth will be decreased and velocity will be increased. Initially depths were 3.85 and 4.75. As we are reaching to section -2 depths will be reduced to 3.45 and 4.70. At the section-2 lower value of depth has higher velocity profiles. Depth was increased to larger value that depth has higher velocity profiles as shown in Figure 4 This is indicating that velocity is increasing in downstream direction at lower depth. But fluctuation is reducing at the section-2 compare to section-1 because of turbulence is reducing as moving towards downstream.Section-2 has 10% lower value of depth compare to section-1.

Figure 5 indicates that depths are again reducing as moving from section-2 (5.5) to section-3(4.95), Velocity reached more than 2 m/s. As we are going away from the side wall velocity profiles will be increased than fall down and reached maximum at the centre of the channel. This type of pattern is same for all three depths. As depth will increased at this cross section velocity profiles will also be increased. Higher depth has higher velocity profiles but lower depth has higher velocity profiles compare to medium depth.

Figure 6 is showing the different behavior compared to other section. Here at the higher value of depths has lower velocity & vice versa. X axis is Longitudinal distance which was scaled with the semi width of the channel. Y axis is depth average vertical velocity distribution.

The downstream behaved differently compare to upstream of the channel. Here depth was

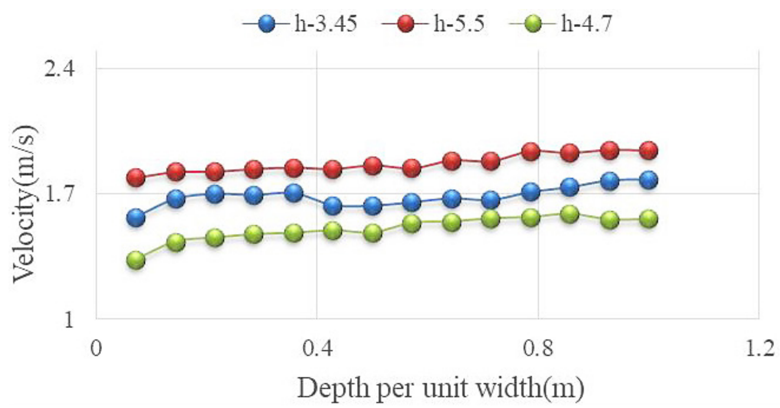

Fig. 4. Velocity distribution in section-2, rectangular channel

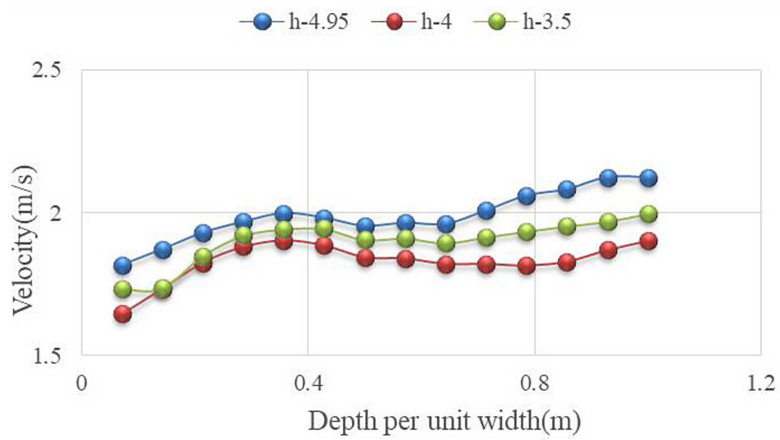

Fig. 5. Velocity distribution in section-3, rectangular channel

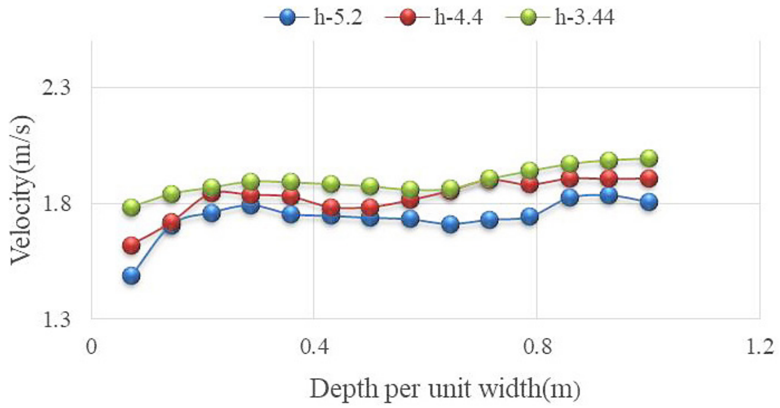

Fig. 6. Velocity distributions at various depths at section-4

increased in 4%. At downstream of the channel higher depth had lower value of velocity profiles compare to medium velocity profile. Lower velocity profiles had maximum velocity at the downstream of the channel.

Figure 7 shows that as we are moving to the downstream of the channel velocity is increasing. Section- first was 3 m from the upstream. Section two was 50 cm from the first section and similarly other sections was 50cm from each other. As we are moving from section first- section-four velocity is increasing. At the downstream (sec-four) was showing higher velocity profiles. Maximum velocity was found at the center of the channel.

Surface profiles were taken at the center of the channel. Reading was taken from the upstream of the chosen sections. Water surface was fluctuating. Flow in non-uniform. Depth is decreasing from the upstream to downstream of the channel. So velocity will be increasing from upstream downstream

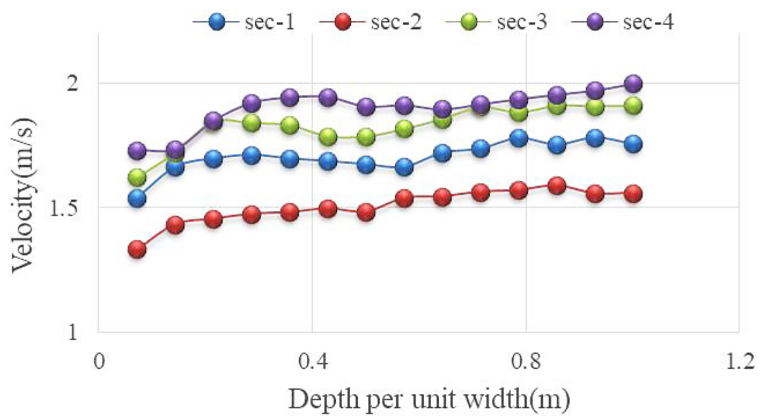

Fig. 7. Velocity distributions at various sections for depth of 3.9 cm

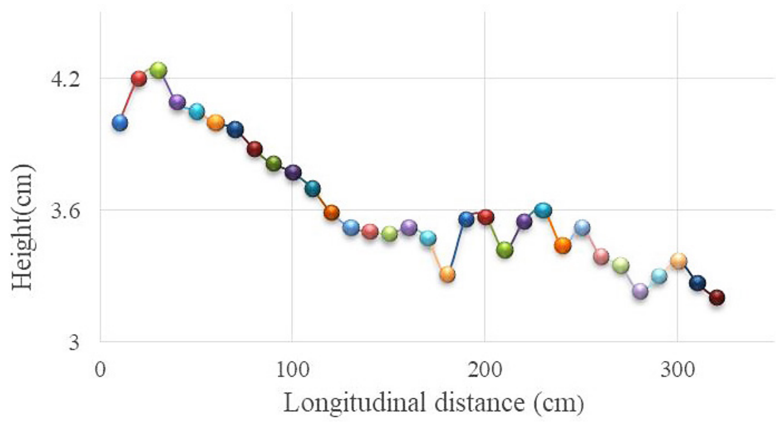

Fig. 8. Longitudinal surface profiles for depth of 3.9 cm

of the channel as shown in Figure 8. Depth was decreasing from the upstream to downstream in the channel. Flow has high turbulence. Surface was changing very rapidly as shown in Figure 9.

Figure 10 is indicating that the flow is non uniform in the channel. Depth is decreasing in the downstream direction. Water surface is fluctuating in the channel. At low depth has more fluctuating in the channel. At the higher depth fluctuating in the channel was low comparatively in the channel. Surface profiles were measured by the point gauge. Pattern of flow was in steep open channel look like a gradually varied flow. Similarly velocity was also changing from point to point in steep open channel flow. Behavior of flow was super critical in the nature.

CONCLUSIONS

Velocity profiles are measured at different sections on a simple rigid bed channel. Velocity and surface profiles are influenced by depth of flow. Surface profiles were changing very rapidly from upstream to downstream of the channel. From the above summary, for the same discharge downstream of the channel has maximum velocity, so maximum sediment transport from the downstream of the channel. Maximum velocity was found at the center of the cross- section of the channel. Minimum velocity was near the wall of the flume. At the upstream the higher depth has higher velocity profiles. When moving towards downstream of the channel, depth of flow was reducing and velocity is increasing. At the upstream of the channel large depth has large velocity profiles and vice-versa. Surface profiles were changing gradually. When moving towards the downstream of the channel, depth of flow was decreasing, velocity is increasing according to law of Bernoulli's. At the downstream of the channel, maximum depth has minimum velocity profiles and vice-versa.

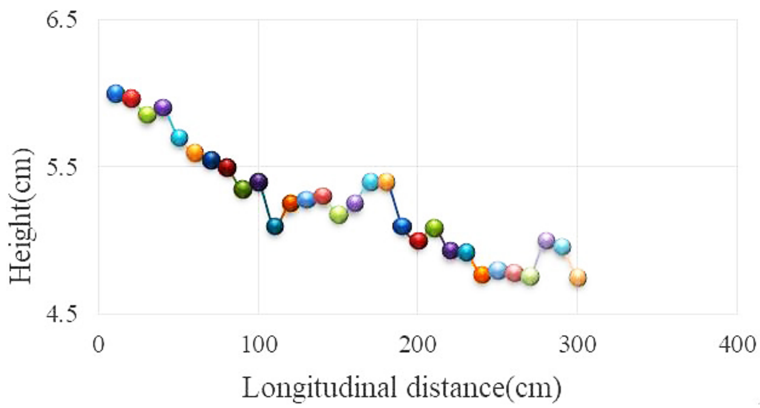

Fig. 9. Longitudinal surface profiles for depth of 4.8 cm

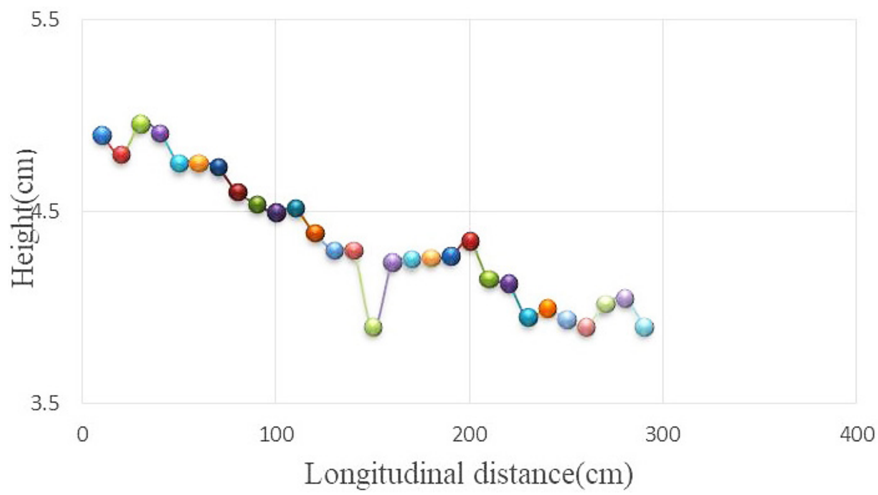

Fig. 10. Longitudinal surface profiles for depth of 5.7 cm

Acknowledgments

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Notations

B	Semi width of the rectangular channel.
H	Head over the notch.
h.	Depth of flow in channel
Q	Discharge at the downstream of the channel.
S	Bed slope in channel.
Ŭ	Shear velocity of steep open channel.
v	Depth averaged vertical velocity.
V	Average velocity of rectangular channel.
x	Transverse distance of channel.
X	Longitudinal (Stream wise) distance.
Cd	Coefficient of discharge of Pitot tube

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