Longitudinal Velocity Distribution in Straight and Curved Open Channels: A Model Study

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Abstract

This paper presents the experimental investigation regarding longitudinal velocity distribution in straight and curved reaches of an open channel. Extensive data has been collected in the laboratory flume with straight and sinusoidal path. Velocity data has been collected by Programmable Electro-Magnetic shunt meter at predetermined nodal points in both straight and curved reaches. The data has been collected for only one discharge Q as 20 l/s and single R/W value as 3.12. All the data has been carefully analysed and longitudinal velocities have been plotted. From these plots the actual variation of longitudinal velocities has been studied, in both straight and curved portions of the channel. It is found that there is significant effect of curvature on the velocity distributions.
Keyword- Curved Open Channel, Longitudinal Velocities, Curvature Ratio

I. INTRODUCTION

The prediction of velocity in streams and rivers helps in flood prediction and management, finding the resistance relationships (Manning's, Chezy's and Darcy-Weisbach friction factor) and for many other purposes. The velocity distribution in a channel section is mainly affected by its geometrical conditions such as shape, width, and curvature etc. (Open Channel Hydraulics V.T. Chow). In Curved open channel due to introduction of centrifugal force, a new velocity component known as transverse or lateral is developed. Due to lateral velocity or secondary current, there is re-distribution of mass, momentum, boundary shear stress and sediment transport which in turn plays an important role with respect to the water quality, velocity distribution and river morphology.

Many researchers such as Sarma et al. (1983), Nezu et al. (1986), Cardoso et al. (1989), Kirkgoz (1989), Gongalez et al. (1996), Lassabattere et al. (2012) and Faruque et al. (2014) carried out extensive works on velocity distribution in straight open channels. Sarma et al. (1983) developed 1/7th power law velocity profile. Albayrak (2011) carried out detailed study in straight channel and investigated the secondary cell patterns and its consequences. Yang et al. (2013) developed an analytical model to find the transverse variation of depth-averaged velocity and boundary shear stress in a rectangular compound channel. He compared his results with the experimental findings of other investigators Shiono and Knight (1991). Faruque et al. (2014) also found logarithmic law distribution of velocity. Also there is no effect of Froude number and aspect ratio on velocity distribution in inner region. However, friction coefficient is a function of both Reynolds number and surface roughness protrusion.

Sahu et al. (2011) carried out extensive experiments to predict instantaneous velocity in the downstream of the flow at various sections of meandering channel. He used pitot tube to measure instantaneous velocity and used ANN to verify results. Kashyap (2012) carried out experimental work in a 135˚ curved open channel to study the effect of curvature ratio and aspect ratio on velocity distribution. Gholami et al. (2014) carried out extensive experimental and numerical study to find out flow patterns such as water surface elevation, transverse and depth velocity distribution and secondary flow and separation zones in a strongly curved 90˚ open channel bend.

II. EXPERIMENTAL SETUP

Experiments have been carried out in Advanced Post Graduate Hydraulics Laboratory, Department of Civil Engg., Zakir Hussain College of Engg. & Tech., A.M.U, Aligarh. The data are collected in an open horizontal rectangular sinuous (meandering/curved) channel (0.35 m wide and 0.43 m deep) made up of 0.5 mm thick tin sheet, carefully installed in an open horizontal rectangular flume (0.76 m wide and 0.60 m deep and 10.5 m long) prismatic glass walled channel with cement plastered bottom. The schematic diagram and photographic view of the experimental setup are shown in Fig.1. The experimental channel consisted of 2.88 m long upstream and 2.11 m long downstream straight reaches. The model has a straight upstream reach of 2.88 m and a straight downstream reach of 2.1 m. In between the upstream and the downstream reach four sinuous bends having same dimensions are provided. The bends each 80° central radius are provided in series. Each bend has rectangular cross section with 0.35 m width, 0.43 m height and with 0.705 m radius of curvature at center line. The central radius of the channel (Rc) is 0.705 m. The width of the experimental model is 0.35 m with Rc/W (ratio of central radius to the width of channel) of 2.014. Since this ratio is less than

3, the bend is considered as a sharp bend[3]. A straight transition of 0.05 m is provided between each bends. Experiments were conducted for a discharge of 20 l/s.

A. PEMS Meter

Programmable electro-magnetic shunt meter (PEMS) velocity meter (Fig.2) is used to measure the velocity values at various points in the channel. PEMS is based on Faraday's Law of induction. It has a long vertical probe having sensor at its bottom. When current passes through the sensor the magnetic field is produced and any liquid movement is directly read in the form of voltage which in turn gives the values of velocities in two mutually perpendicular direction i.e. longitudinal and transverse directions. The PEMS may move in horizontal, vertical and longitudinal directions.

B. Experimental Procedure

Water is allowed to pass in the channel at a constant rate from a re-circulated water supply system. The PEMS is installed at pre-determined nodal points. After steady state conditions of flow are reached, the observations of measuring of longitudinal and lateral velocities have been started. At each well-defined sections and predetermined nodal points at least three readings were taken at 20 s interval. The average values of longitudinal and lateral velocities were recorded. There are three sections in straight reach of the channel where observations were performed. Similar procedure was adopted at various sections of curved channel (i.e. at θ=0°, 20o, 40o, 60o and 80o) for only one discharge i.e. Q) and one value of Rc/W value. θ is the angular displacement. Its value is 0o at the start of the curvature and increasing along the flow upto 80o as shown in Fig.3 and Fig.4.

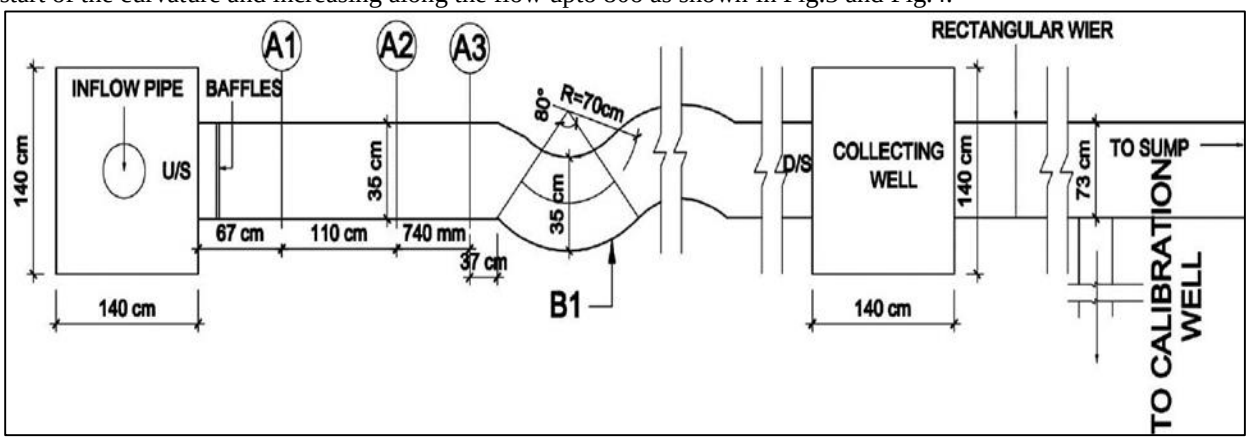

Fig. 1: Schematic view of the experimental setup

Fig. 2: Photogramatic view of PEMS meter

III. DATA ANALYSIS

The detailed analysis of data and results obtained there from are presented. The longitudinal velocity profiles are plotted and data are analyzed.

A. Velocity Distribution in Straight Reach

In straight reach three sections A1, A2 and A3 are fixed. Then at each section about 11 lateral positions are marked. The PEMS meter moves along both vertical and horizontal positions at each section. For steady state subcritical flow velocity components are recorded by PEMS meter along the vertical direction.

B. Longitudinal Velocities along Vertical Direction across the Channel

Fig. 4 shows the variations of longitudinal velocities at various positions across the channel along vertical direction. It is found that the longitudinal velocity varies with flow depth, minimum at the channel bed, increasing gradually, attaining maximum values approximately below the mid depth of flow. The longitudinal velocity profile follows logarithmic law. It is also clear from this graph that velocity is decreasing at the side of the channel. Since in straight channel the axial velocity is dominating hence only longitudinal velocity data are appreciable and lateral velocities values are almost nil or slightly negative.

C. Longitudinal Velocity Profile along Lateral Direction

At sections A1 and A2, longitudinal profile is also plotted for constant z values such as (2 cm, 4.4 cm and 8.8 cm above channel bed) as shown in Fig.5. It is clear from these two plots that velocity is logarithmic in nature for all z values. Also, the velocity values are maximum at the center of the channel.

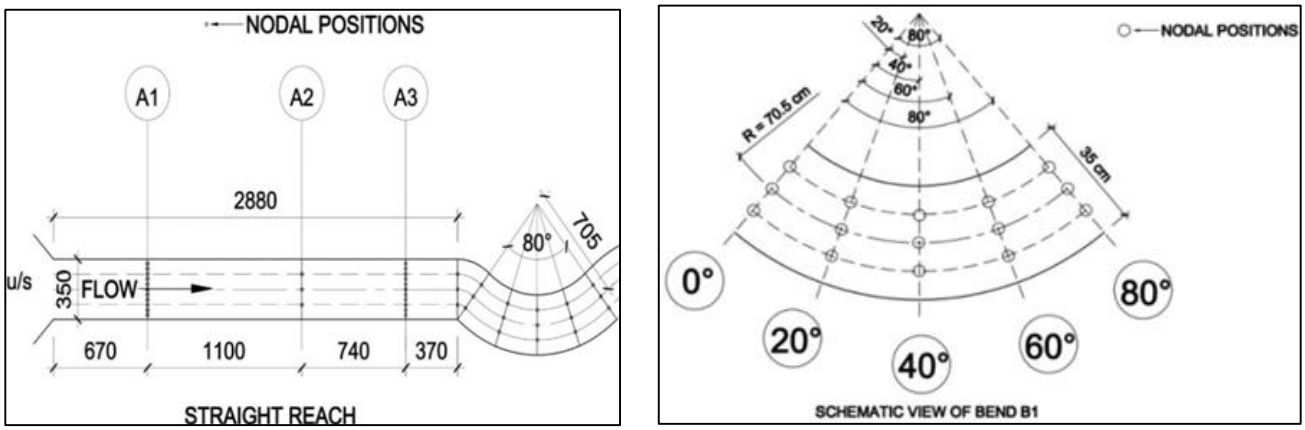

Fig. 3: Schematic diagram of grid points in straight and curved reaches

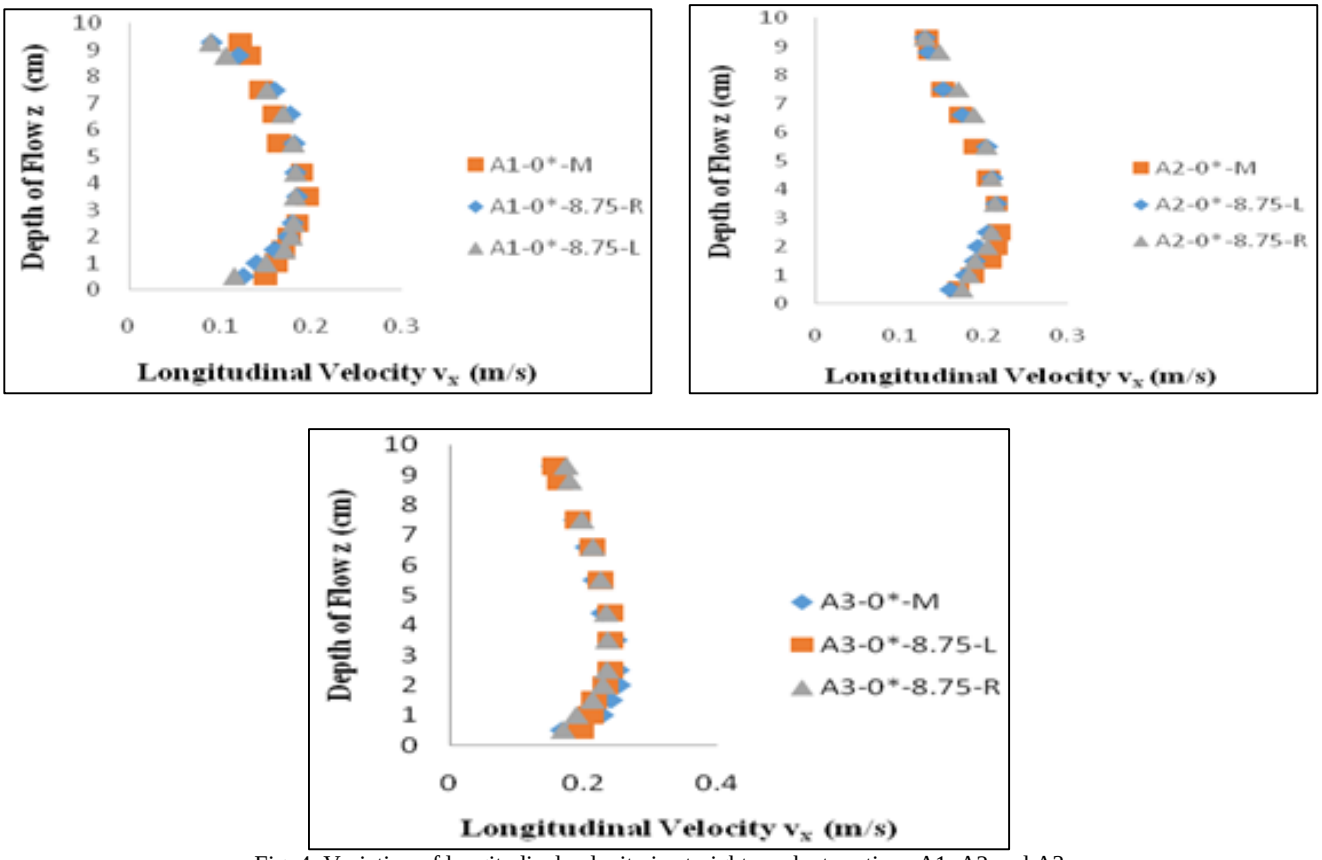

Fig. 4: Variation of longitudinal velocity in straight reach at sections A1, A2 and A3

D. Longitudinal Velocity Profile along Lateral Direction at Various Positions of Section A1

At sections A3, longitudinal Velocity profile is also plotted for various vertical sections across the width such as (3 cm, 6 cm, 8.75 cm, 11.5 cm and 14.5 cm) on both side of the longitudinal axis of the channel as shown in Fig. 6. It is clear from this plot that

velocity is logarithmic in nature for all z values. Also, the velocity values are maximum near the mid depth of flow in the channel. This finding is in full agreement with the graphs presented in general books of Hydraulics (V. T. Chow).

E. Velocity Distribution in Curved Reach of the Channel

Data for velocity in longitudinal and lateral (radial) directions are measured by PEMS meter for same hydraulic conditions at various (θ) values varying from 0° to 80° in similar way as was done for straight reach.

F. Longitudinal Velocity on Each Section (Θ) Values

The longitudinal velocity profiles are plotted at various positions as shown in Fig. 7 and Fig.8. Along vertical direction, the longitudinal velocity profile is almost similar as obtained in straight reach. From these figures it is found that the longitudinal velocity is always smaller at outer curve except at start of bend (θ=0°). This may be attributed that there is transition between straight reach and curved reach of channel. From all these plots it is clear that longitudinal velocities are less at inner wall of the bend and minimum at the outer wall. This variation is conforming the free vortex motion condition as obtained in mechanics of fluids.

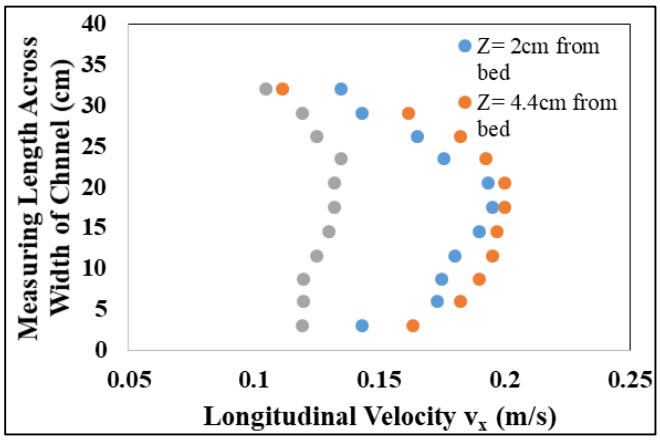

Fig. 5: Longitudinal velocity in straight reach at sections A3 at various Z-values

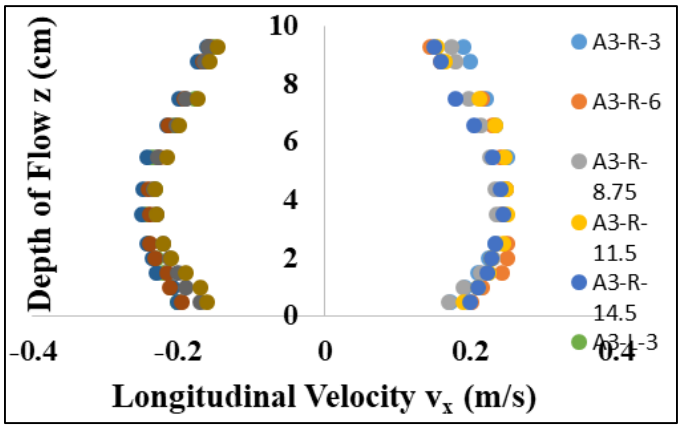

Fig. 6: Longitudinal velocities at various vertical positions across the width of the channel

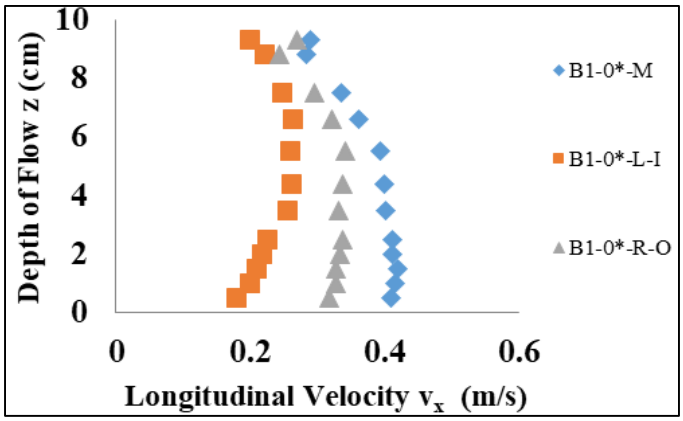

Fig. 7: Variation of longitudinal velocity at various vertical positions across the width of the channel at section A3

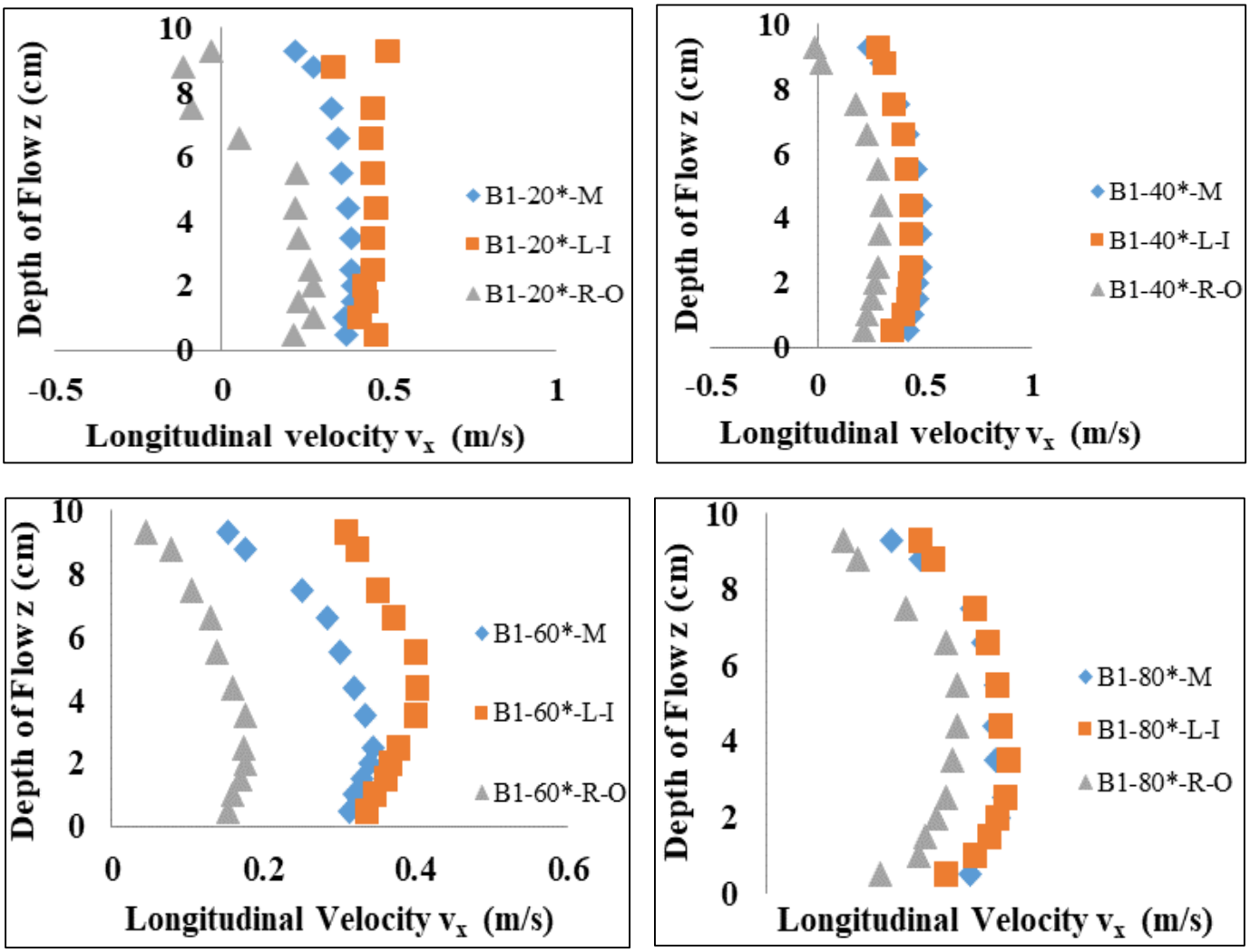

Fig. 8: Variation of Longitudinal velocity for curved reach at various angular displacements

IV. Conclusion

Following conclusions are drawn from above study:

1) In straight as well as curved reaches of the channel, the longitudinal velocity profiles are similar and along vertical as well as horizontal directions following logarithmic law of velocity distribution.
2) In straight reach the longitudinal velocity along vertical direction is logrithemic in nature as obtained for general flow conditions in any open channel flow.
3) Throughout the length of the straight reach the longitudinal profile remains unchanged. However there is slight change in velocity values due to presence of reverse curve (transition) as flow enters from straight to curved reach.
4) There are considerable effects of angular displacement (θ) on longitudinal velocities. Almost at all θ values, the free vortex law is valid for longitudinal velocity.

Acknowledgement

The authors are thankful to Chairperson and all staff of Hydraulic Section, Department of Civil Engineering, ZHCET, AMU, Aligarh for their kind suggestion and assistance throughout the study of this work. The authors are also thankful to UGC for providing Maulana Azad National Fellowship and GATE Scholarship.

Disclosure Statement

There is no conflict among the authors of this paper.

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