INVESTIGATION ON SECONDARY FLOW CHARACTERISTICSFOR TWO STAGE MEANDERING CHANNELS

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Experiments were conducted in two stage meandering compound channel with smooth floodplains for investigating the influence of sinuosity and geometry on the characteristics of secondary flows. Observations have been taken both at bend apex and cross over region of the two stages meandering compound channel flow. The experimental results In terms of the stream wise, upward and transverse velocities the secondary flow and primary flow were measured using Acoustic Doppler principle of Acoustic Doppler Velocity meter are presented. Results concerning both secondary flow vectors and primary flow vectors for different hydraulic conditions are presented

Keywords: Acoustic Doppler Velocity, meandering compound channel, bend apex, cross over.

1 INTRODUCTION

Alluvial rivers generally are composed of different compartments: typically one main channel with floodplains. Therefore, there is great significance and practical application value in studying compound channel flow. When floodplains are inundated, the momentum transfer between the main channel and floodplains is strong making the longitudinal, vertical and lateral velocity profiles are changed both in the main channel and on the floodplains. Therefore it has become important issue to provide an effective method to model the velocity distribution. The distinguished researchers in the field of meandering channels are [1-6].This paper presents detailed measurements of longitudinal velocity distributions, secondary flows in terms of lateral and vertical components of flow in the simple meander channel and meander channel with straight flood plain banks for overbank flow.

2 EXPERIMENTALSETUP, PROCEDURE AND INSTRUMENTATIONS

The experimental tilting flume was made of Perspex with a rectangular cross-section, whose dimensions were 18 m length, 0.6 m width and 0.5 m depth Details of the experimentations are given at Tables 1 and Figure 1. A recirculating system of water supply is established with pumping of water from an underground sump to an overhead tank from where water could flow under gravity to a stilling tank. From the stilling tank, water is led to the experimental channel through a baffle wall. A transition zone helped to reduce turbulence of the flow water. An adjustable tailgate at the downstream end of the flume is used to achieve uniform flow over the test reach in the channel for a given discharge. Water from the channel is collected in a volumetric tank for measuring the flow discharge, from where water runs back to the underground sump, thus establishing a closed circuit of flow. The channel sections are made from Perspex sheets for which the roughness of floodplain and main channel are taken as identical. The measuring devices consist of a point gauge mounted on a traversing mechanism to measure flow depths having a least count of 0.1 mm. Water surface slope measurement is carried out using a pointer gauge fitted to the traveling bridge operated manually having least count of 0.1 mm.. Point velocities are measured with a 16-Mhz Micro ADV (Acoustic Doppler Velocity-meter) at a number of locations across the predefined channel section. The point gauge and the 16-MHz micro-ADV attached to the traveling bridge can also move in both longitudinal and the transverse direction of the experimental channel at the bridge position. The micro-ADV readings A computer attached with the processor shows the 3-dimensional velocity data after compiling with the software package. With the statistical analysis using the installed software, mean values of 3D point velocities are recorded for each flow depth. Velocities is resolved into three orthogonal components (tangential, radial, and vertical) and are measured at 5 cm below the sensor head. The Micro ADV has features like, High sampling rates - up to 50 Hz, Small sampling volume - less than 0.1 cm3, Small optimal scattered, High accuracy upto1% of measured range, Large velocity ranges between 1 mm/s to 2.5 m/s, No recalibration needed etc. As the ADV is unable to read the data of upper most layer (up to 5cm from free surface), a micro-pitot tube of 4 mm external diameter in conjunction with suitable inclined manometer are used to measure velocity and its direction of flow at the pre-defined points of the flow-grid. Discharge in the channel is measured by the time rise method. For flow confined to simple meander channel and meandering channel with floodplain, two predefined sections, that is, AA and BB in Fig 2(A) along the meander path is selected for velocity measurements so as to get a broad picture of flow parameters covering half the meander wave length.

3 RESULTS AND DISCUSSIONS

The experimental results concerning the stage–discharge relationships are presented in Fig.2 (B).The in-bank stage-discharge is of different trend than that of overbank cases giving two different power functional relationships.

The 3-dimensional velocity components have been taken by using micro-ADV. The instrument uses the sign convention for 3-dimensional velocity as positive for ENU (east, north and upward) and negative for WSD (west, south and down ward) directions respectively for the longitudinal (V_x), radial (V_y) and vertical components (V_z). For the experimental channel position, east refers to the direction of longitudinal velocity. The east probe of ADV is kept in the longitudinal flow direction. Accordingly the other two flow directions are referred. In the experiments for meandering simple and compound channels, the readings are taken at the bend apex with tangential velocity direction taken as east. For radial velocity, positive stands for outward and negative stands for inward radial velocity direction. Similarly for vertical component of velocity when the ADV readings shows positive, then the velocity component is upward and if negative, it is in the down-ward direction. The present experimental investigation on meandering channels with and without floodplains having different geometries and flow conditions shows many interesting results. The results are in terms of the longitudinal components, lateral components and vertical components are given below.

3.1 Results of Tangential Velocity

The distribution of tangential velocity in simple meander channel sections in contour form at the locations AA and BB are obtained and for a typical depth of 7.11cm the same has been presented in fig.3. The contours of tangential velocity distribution indicate that the velocity patterns are skewed with curvature. The minimum skewing of the velocity occur at geometrical crossover. Higher velocity contours are found to concentrate gradually at the inner bank between geometrical cross over to bend apex. The thread of maximum velocity is found to occur near the inner wall of bend apex. At the cross over location BB (location of reversal curvature), the thread of maximum velocity gradually shifts to the channel center confirming the findings of [7-8]. At the cross over location BB (location of reversal curvature), the thread of maximum velocity gradually shifts to the channel center. This is strikingly different from the findings of other investigators on shallow meandering channels. For shallow meandering channels the thread of maximum velocity is located near the outer bank at the bend apex. It indicates that the effect of secondary circulation is predominant in shallow channels and is less effective in deep channels. From the contours of tangential velocity at these sections, it can be observed that the distribution of tangential velocity does not follow the power law or the logarithmic law. Under ideal conditions these theoretical velocity distribution laws gives the maximum velocity at the free water surface, whereas the flow in any type of natural or laboratory channels do not show such a distribution. Similarly the isovels of tangential velocity for the meander channel floodplain geometry of, a typical flow depth of 3.28cm is given in fig.4. Distribution of tangential velocity in the main channel portion is somewhat similar to the patterns observed in the simple meander channels except at the main channel-floodplain junction regions. This is mainly due to the flow interaction between the main channel and floodplain. At the bend apex of meandering compound channels, the maximum velocity contours are found near the inner wall junction for low over bank depth. For higher over bank depths the maximum velocity contours are found at the inner wall of flood plain. At the section of geometrical cross over region where the radius of curvature is the minimum, the thread of maximum velocity is found to deviate from near the channel centerline to the inner bank. For higher over bank depths at this location, one region of maximum tangential velocity is found near the inner bank of the floodplain. There is significant difference in the mean value of tangential velocity of the main channel when compared to flood plains sub-areas. When the flow overtops the main channel and spreads to the adjoining floodplains, the section mean velocity in the main channel reduces. At low over bank depths, the section mean velocity in the floodplain is found to be less than the main channel. As the depth of flow in the floodplain increases, the section mean velocity in the floodplain also increases. At still higher depths of flow in the floodplain, the section mean velocity of the floodplain is found to be higher than the section mean velocity of the main channel.

3.2 Results of Radial Velocity

The distribution of radial velocity in contour form for the same typical meander section of flow depth 7.11cm is given in fig.5. The radial velocity is observed to be smaller than tangential velocity. Higher radial components are found which is of the order of 67 % of longitudinal velocity. At the bend-apex, the micro-ADV readings for radial velocity directions are found to be mostly negative indicating that it is pointing inward direction. At the geometrical cross-over region, the radial components are towards in-ward direction having lesser magnitudes when compared to that at the bend-apex, indicating a phase lag between channel cross-over and flow cross over. At the bend apex (AA) of meandering compound channel fig.6 the micro-ADV reading shows negative signs of the radial velocity indicating the flow direction is towards inner flood plain. The radial velocity at geometrical cross over region is found to be more than that at bend-apex showing almost 90^0 phase lag between channel geometry and flow geometry. At the bend apex AA, the thread of larger in-ward radial components are found just above the bed of the main channel. At higher over-bank depth, higher magnitude of inward radial velocity is observed near the inner side of floodplains.

3.3 Results of Vertical velocity

The distribution of vertical velocity component of the same meandering channel in contour form at the locations AA and BB has been provide in fig.7. For in-bank flow, maximum upward components are found at outer wall and maximum down-ward components are found at inner wall. With increase in flow depths, the values of vertical velocity are found to decrease. At the geometrical cross-over region, the vertical components of velocity are mostly towards down-ward direction. With increase in flow depth the magnitude of vertical velocity decreases. Magnitude of vertical velocity component is found to be the order of around 14% for such channel of the corresponding longitudinal velocity. At the bend-apex for meandering compound channel fig.8 the direction of vertical components are upward in outer region and down-ward at inner regions of the main channel. The threads of upward vertical velocity are found near the inner wall and down ward components are found near the outer wall of the main channel. The magnitudes of vertical velocity in the floodplain regions are observed to be less than the main channel area at the bend-apex as well as at the geometrical cross-over.

5 CONCLUSION

On the basis of the present experimental investigation supported by theoretical observation in deep and rigid channels with and without floodplains, the following conclusions are drawn.

1. For the meandering channels, the contours of tangential velocity distribution indicate that the velocity patterns are skewed with curvature. Maximum skewing of the longitudinal velocity can be observed at the point of minimum radius of curvature (bend apex) and minimum skewing of the velocity occurs at the geometrical cross over.
2. At the bend apex of meandering compound channels, the maximum velocity contours are found near the inner wall junction for lower depths and at the inner wall of flood plain for higher over bank depths.
3. At low over bank depths, the section mean velocity in the floodplain is found to be less than the main channel. As the depth of flow in the floodplain increases, the section mean velocity in the floodplain also increases. At the highest depth of flow in the floodplain, the section mean velocity of the floodplain is found to be higher than the section mean velocity of the main channel.
4. The radial velocity at the bend apex is found to be mostly negative indicating that the velocity is in the inward direction. Higher velocity contours are seen near the inner bank and lower contours at the outer banks. The radial component at cross-over region are directed in-ward with lesser magnitude as compared to that at the bend-apex, indicating a phase lag between channel and flow cross over.
5. The magnitudes of vertical velocity components of meandering channels are found to be the order of around 14%. The maximum upward vertical components are found at outer wall and maximum down-ward components are found at inner wall. With increase in flow depths, the values of vertical velocity are found to decrease. At the geometrical cross-over region, the vertical components of velocity are mostly in down-ward direction. With increase in flow depth, the magnitude of vertical velocity decreases.

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Figure 1: Experimental details of the meandering compound channels

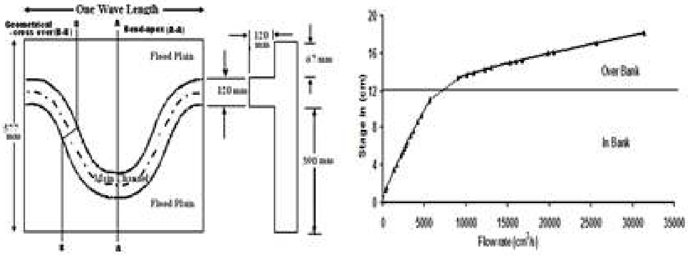


Figure2: (A) Bend apex AA and geometrical cross over BB (both for in-bank and over bank conditions) of meandering channel. (B) Stage discharge relationships for the experimental channel

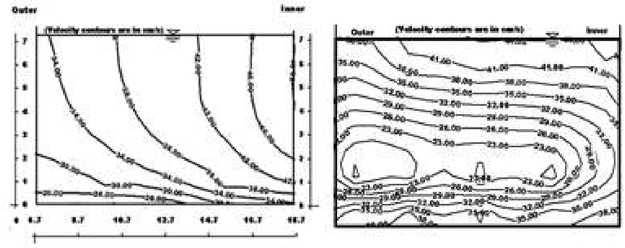


Figure 3: Distribution of tangential velocity for in bank depth 7.11 cm (at bend apex and cross over).

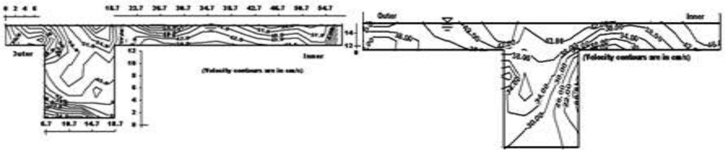


Figure 4: Distribution of tangential velocity For Over-bank depth (H- h) = 3.28 cm (bend apex and cross over)

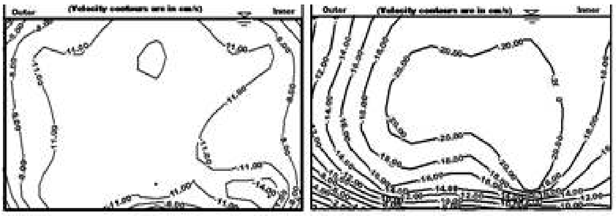


Figure 5: Distribution of radial velocity at bend apex and at crossover (in-bank depth *h’* = 7.11 cm)

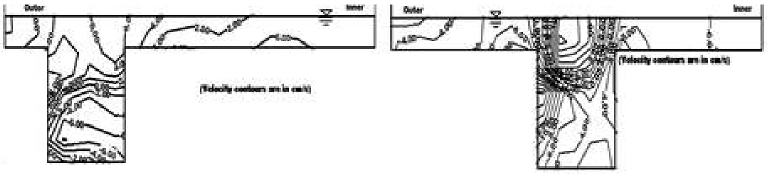
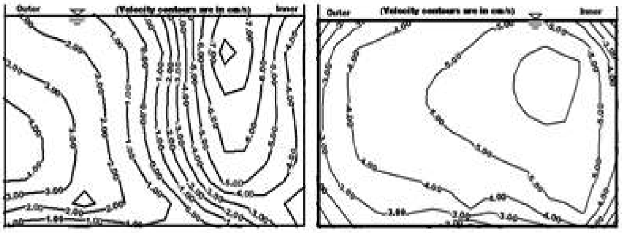


Figure 6: Distribution of radial velocity For Over-bank depth (*H- h*) = 3.28 cm (bend apex and cross over)



and crossover of (in-bank depth *h’* = 7.11 cm)

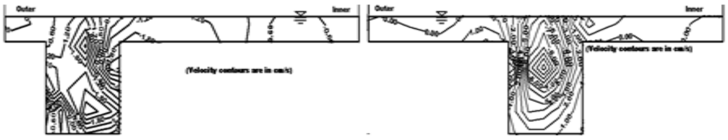


Figure 8: Distribution of vertical velocity For Over-bank depth (*H- h*) = 3.28 cm (bend apex & cross over)

Table 1 Details of geometrical parameters of the experimental channels

Item Description	***Meandering compound channel***
Wave length in down valley direction	400 mm
Amplitude (λ)	162 mm
Geometry of Main channel section	Rectangular
Main channel width(*b*)	120 mm
Bank full depth of main channel	120 mm
Top width of compound channel (*B*)	577 mm
Slope of the channel	0.0031
Meander belt width	443 mm
Minimum radius of curvature at bend apex	140 mm
(*B/b*) =Ratio of top width (*B*)to channel width (*b*)	4.808
Sinuosity	1.44
Cross over angle in degree	104
Flume size	0.6m×0.6m×12m long