Variation of Flow Profile along a Highly Sinuous Meander Path

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Abstract **: The course path developed by a meandering channel is comparatively synonymous to natural flow systems such as rivers, streams etc. This curvy shape of flow is basically followed by rivers to lessen the energy loss during their course of flow. This flow habit in channel bend is much more puzzling due to existence of secondary flows. The occurrence of secondary flow is forced by the variation of centrifugal force and pressure force at the surface and at the channel bed. It has also been seen that near to the inner wall and at the channel bed the pressure force outruns the effect of centrifugal force which in turn conveys water in a transverse direction towards the inner wall. Similarly the effect of centrifugal force dominates at the free surface thereby conveying the flow to the outer wall. This reciprocal action of the flow in the main channel and secondary flow brings into picture the so called helical flow at the bend. Understanding these characteristics of flow is quite effective in designing hydraulic structures at such locations. Knowledge of the characteristics of surface profile at different sections is important in flood modeling and forecasting which helps in the design of hydraulic structures. In this paper, an experimental investigation has been carried out to study the transverse profiles of water surface of a meandering channel at varying discharges. Investigation has been made at different sections along a meander path i.e. from one bend apex to another where the water surface profile changes its course at the cross-over.**

Keywords: **meander path, crossover, water surface profile, meandering channel.**

1. INTRODUCTION

Almost all natural rivers meander and have a tendency to erode the outer banks in their successive bends. Some fundamental engineering efforts are taken into account on rivers of all scales to stabilize the bank lines. Curved open channel flow is characterized by the existence of cross stream circulation cells i.e. secondary flows. Due to the existence of secondary flow, flow characteristics in channel bends are much more puzzling than those in straight channels. These flow characteristics in channel bends need to be discussed to increase flood capacity and to improve navigability. Some researchers have given a brief idea on flow characteristics in channels with different bend angels by considering the experimental and numerical models. Shino [1] worked on turbulence models and reviewed the behavior of secondary flows and centrifugal forces for straight and meandering channels. Blanckaert and Graf [2] analyzed channel bed level changes at a 120º sharp bend with a movable bed using an experimental setup. They concluded a minor secondary rotating flow cell at the outer wall of the bend.

The application of numerical hydraulic models can significantly reduce costs associated with the experimental models, so their use has been widely accepted in recent decades. Booij [3] and VanBalen [4] modeled the flow pattern at a mildly-curved 180º bend and assessed the secondary flow structure by means of large eddy simulation (LES). Bodnar and Prihoda [5] presented a numerical simulation of the turbulent free-surface flow by using the k-ε turbulence model and analyzed the nature of non-linearity of water surface slope at a sharp bend. Zhou et al. [6] with the help of two-dimensional depth-averaged model, simulated the flow pattern in 180° sharp bend and 270° mild bend, with and without consideration of the secondary flow and claimed that, given the effect of the secondary flow, the simulation results in the first state has a better agreement with the experimental results. Khatua [7] calculated evaluation of roughness coefficients in meandering channels. Dash and Khatua [8] formulated the roughness coefficient for meandering channels. Ottevanger et al. [9] studied bed and wall shear stresses in meander bend by taking into account a three-dimensional numerical model and then developed a correction factor in order to calculate shear stress related to velocity values. NajiAbhari et al. [10]

observed the flow pattern in a 90° mild bend numerically and experimentally. In this observation, they gave emphasis to the velocity distributions, the streamlines at different water levels and the distribution of shear stresses and they did not study water surface profiles. The results declared that the flow pattern in a channel bend is dominated by the effect of secondary flow and centrifugal force. Bonakdari [11] investigated the flow pattern at a 90º mild bend using numerical model, artificial neural network and genetic algorithm. But they only focused on the velocity components.

In this paper, the transverse surface profile is studied throughout a meander path of a highly sinuous meandering channel of sinuosity 4.11. The surface profile data are studied to locate the flow outline and validate that the water level increases towards the outer wall and decreases at the inner wall while moving over a curve. An additional area of study especially in this paper is to find the pattern of flow when the channel changes its sign at the cross-over.

2. METHODOLOGY

2.1. Experimental Set up

Experimentation was carried out in the Fluid mechanics and Hydraulics Laboratory of NIT, Rourkela to conduct research on meandering channels. Meandering channel having trapezoidal main channel of bottom width 0.33m, depth 0.065m with side slope 1:1 was built inside a steel tilting flume of around 4 m wide and 15m long as seen in Fig.1. The bed and wall of channel was made with Perspex sheet (6 to 10 mm thick), having Manning's n value=0.01, cut to designed shape and dimension, glued with chemicals and put in position, as seen in Fig.2.

Figure 1: Photograph of the Experimental Channel

Figure 2: Photograph of the Meander Path

2.2. Position of Measurement

All observations are recorded along a meandering path from one bend apex to the next corresponding bend apex through the cross-over. Series of point gauges with moving bridge arrangements are made to measure the water depth at different points along the flow passage of the channel. The measurements are taken at different reaches along the meander path for every depth. Similar readings are taken for different discharge and different flow depths at steady state conditions. A section at crossover perpendicular to both the inner and outer curves of the meandering channel is drawn and extended unto the bend apex line. An angle of 120^0 is formed for both the curves. These curves are divided into 6 equal sections of 20^0 each to the centre line. Channel sections along the width are drawn at these points. The sections A through M are considered for measurement of the transverse profiles, as shown in Fig.3. A typical cross-section of the channel is shown in Fig.4.

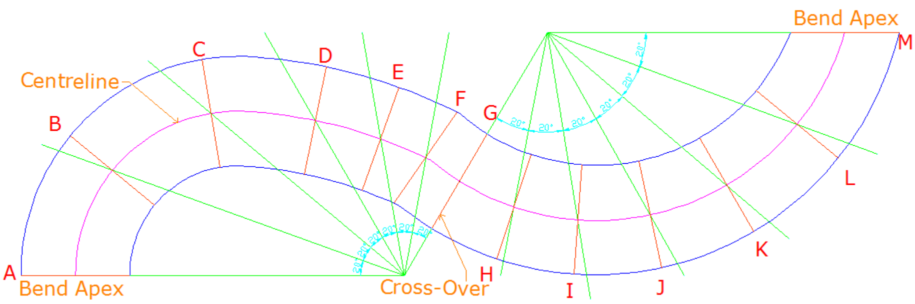

Figure 3: Defined cross-sections along the Meander Path.

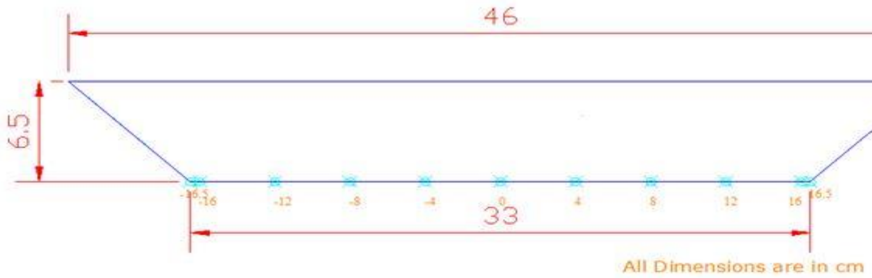

Figure 4: Typical section of the channel

3. DISCUSSION AND RESULT

Uniform discharge is maintained at a time and the surface profile data are taken throughout the meandering path across the channel. Experimentation is carried out at different discharges. Two such discharges are individually maintained to obtain water surface profile data respectively. The discharges Q1 and Q2 are maintained which are $3.5x10^{-3}$ m^3/s and $2.8x10^{-3}$ m^3/s respectively.

Initially from the sections A through F the height of water remains higher towards the outer wall i.e. the left hand side of the channel section with respect to the flow of water which can be observed in Fig. 5 and Fig. 6 which represent the transverse water surface depths along the channel section at two different discharges. Sections closer to the cross over section i.e. F and H, the water level to some extent levels itself.

At the crossover the water surface behaves as a straight channel with uniform transverse profile. In the sections following the crossover, the water surface profile increases on the right hand side of the channel section which is now the outer wall of the meander path.

The graphs inset into Fig. 5 and Fig. 6 are the bend apex sections A and M, the crossover section G and two intermediate sections. The surface profile is not level at the bend apex sections as the channel continues as a sine generated curve. The difference in the height of water can be observed due to the difference in discharges among them. It is also observed that the surface profile variation is higher at a higher discharge.

From the above illustration it is observed that the transverse surface profile at the outer wall always remains higher than the inner wall. It is also observed that the water surface profile in and around the crossover maintains a level height.

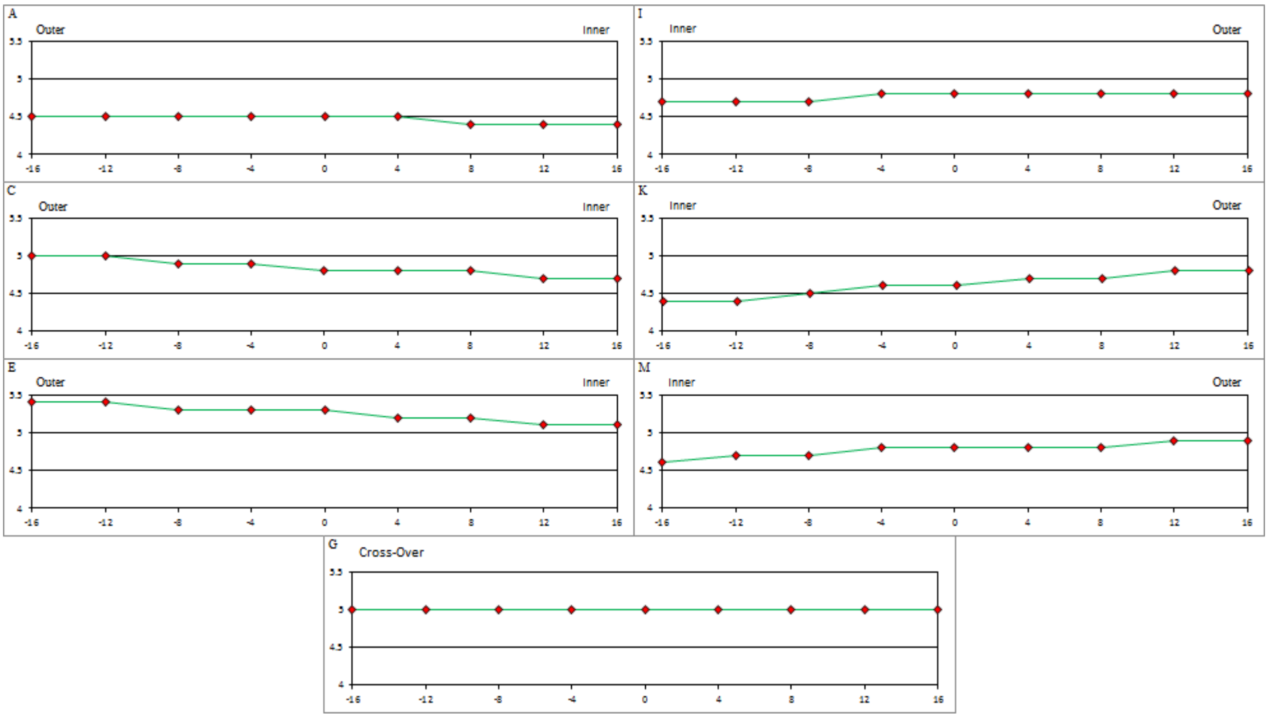

Figure 5: Transverse Water Surface Profile at different sections for Q_1

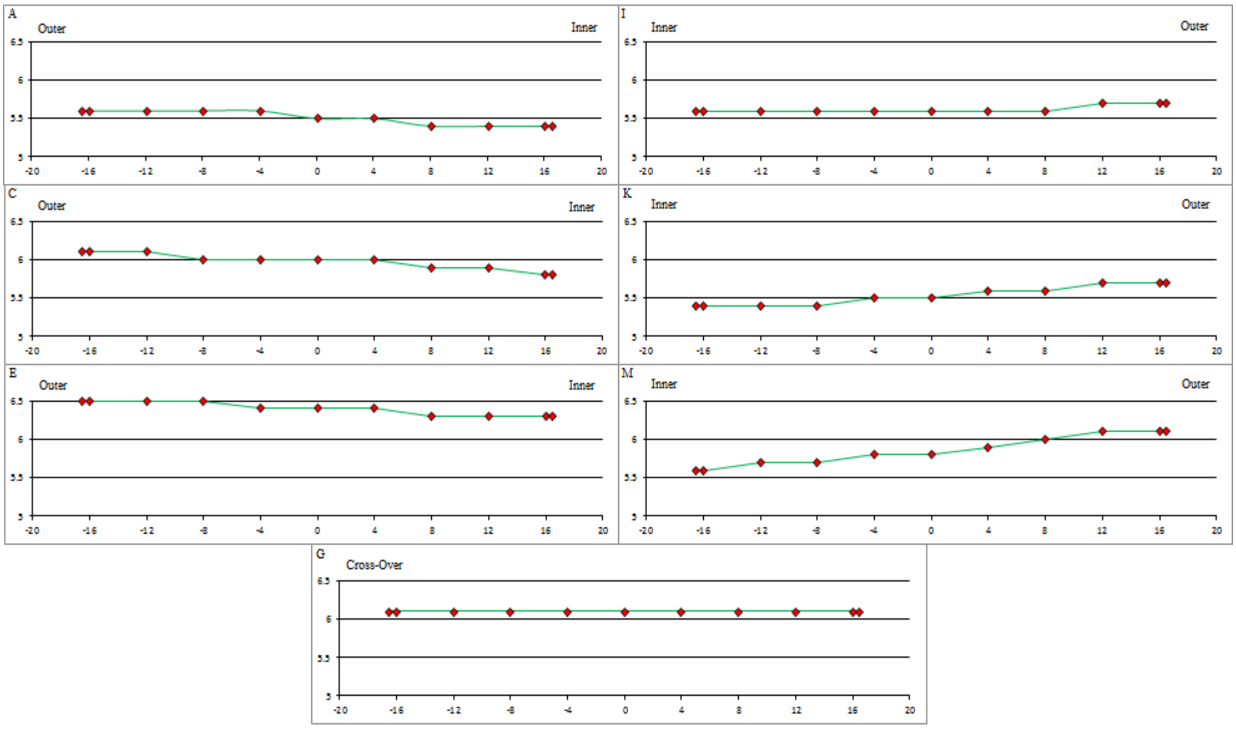

Figure 6: Transverse Water Surface Profile at different sections for Q_2.

4. CONCLUSIONS

The following conclusions can be presented in this work

1. An experimental investigation has been carried out to measure the depth of flow at different points along the meander path of a meandering channel to the impact of meandering effect on flow depths of a meandering channel for the two different discharges.
2. The wavelength of the experimental reach of meandering channel has been divided into different sections along the centerline to study the change in flow depth at each individual flow.
3. From the flow profile study of the meandering channel it is seen that when the discharge increases, the depth of flow at both the inner and outer wall increases, however for the same discharge, the depth of flow at the inner wall is always less as compared to that at the outer wall.
4. Difference in the height of water is observed because of the differences in the discharge. It is also observed that the variation of surface profile is more irregular and erratic at a higher discharge.
5. It is also observed that the water surface profile in and around the crossover region maintains its water level similar to a straight channel.
6. This methodology can be applied to calculate the flow profile and depth of a meandering river. This will help for flood prediction and flood management purpose.
7. The present research work is providing information for getting water surface profile of a meandering channel of sinuosity more than 4.

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