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Flow Interaction in a Meander Channel with One-Sided Flood Plain

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ABSTRACT

The evaluation of an overall resistance coefficient for flow in a meander channel with one-sided flood plain has been made by hydraulically sub-dividing the cross-section of the compound channel, horizontally, at the junction of the flood-plain assuming uniform flow. It has been shown through a theoretical analysis that this evaluation can be made by synthesis of the resistance factors between the two sub-sections after incorporating the interaction loss parameter between the flow through these sub-section. Based on this theoretical analysis mean shear stress value has been computed and compared with the measured mean shear value obtained from the boundary shear stress distribution using a computer program for evaluation of the involved pressure-shear ratio in the Preston-tube measurements. A quantitative study has revealed that decrease in average boundary shear in the main channel due to interaction is significantly affected by the curvilinearity of the main channel.

length of the river. Again because of geological features and topography of the reach of river channel, the flood plain in a meandering river is sometimes located on only one side of it (Fig.1).

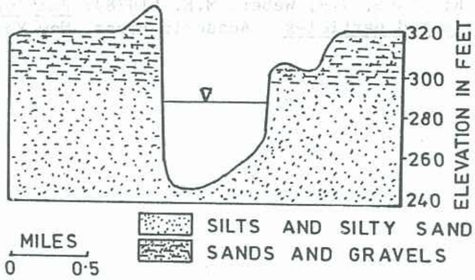

FIG.1. CROSS SECTION OF THE RIVER OHIO.LOWER FLOOD PLAIN ON ONLY ONE SIDE.(FROM GEOLOGICAL INVESTIGATION BY MISSISSIPI RIVER COMMISSION)

INTRODUCTION

Meandering of rivers often poses serious problems to the hydraulic engineers as it has been responsible for unpredictable damage to adjoining properties and also to the costly by-pass structures in irrigation. These devastating effects as well as the associated economic consequences of meandering have stimulated extensive research in this field resulting in a better understanding of the distribution of erosive forces which have helped in developing methods to stabilise natural streams.

The problems of river control are, however, all the more complicated in case of meander channel with flood plain as they are almost invariably encountered at those places where the flood section of the natural stream is of concern. The conventional uniform flow formulae cannot be directly applied for discharge computation of such over-bank flows which are of concern in such cases, as consideration of single channel leads to abrupt changes in hydraulic characteristics at locations just above the bank full stage. The general practice has therefore been the use of separate channel method. But the presence of a channel with flood plain introduces the complication of secondary currents associated with the exchange of flow between the channel and flood plain. The method of simple separation of channel fails to take care of this characteristic phenomenon and therefore the computed value of discharge by this method may not be a reliable one.

It often happens that the dimension of the flood plain continuously changes along the

Recently there has been a great interest to know more about the fluid flow resistance and boundary shear distribution in channels having irregular geometry and varying roughness distribution. It is rightly argued that in actual practice fluid flow in natural courses do not confine itself to simple geometrical boundary nor does it take place over boundaries having identical roughness distribution. Most of the flow in a river takes place in a movable bed and therefore non-linear interaction between the flow and granular media takes place. Such flow situations are hence very complex and can be effectively solved through hydraulic model study.

Laboratory model studies for flow in a straight channel with one-sided flood plain have been carried out by Myers and Elsawy (1975) for isolated and interacting conditions. The main feature in their studies is the interaction mechanism between the faster moving flow over the main channel and that over the flood plain. Toebes and Sooky (1967) have reported model studies on the kinematics of flow in a meander channel with flood plain on both sides. Based on their experimental study they have suggested a relationship between the river channel discharge and discharge over the flood plain after incorporating interaction loss parameter.

Experimental investigations on the boundary shear stress distribution in a meander channel with flood plain on both sides have started at Indian Institute of Technology, Kharagpur, about a decade ago. Ghosh and Kar (1975) have investigated the nature of the boundary shear stress distribution in a meander channel under interacting condition using a deterministic approach of hydraulically sub-dividing the compound section of the channel, horizontally, at the level of the flood plain assuming uniform flow.

This paper reports the work which is being continued on the river-flood plain interaction on a laboratory model of meander channel with one sided flood plain. The study attempts to evaluate the effect of geometry and roughness on flow resistance inclusive of interaction loss and the nature of boundary shear distribution across the flow section. The investigation is primarily directed towards understanding the underlying mechanism of flow interaction rather than simulating a prototype situation.

LABORATORY MODEL

Experiments have been conducted in a meander channel as stated above for both in-bank and over flow condition. A sinusoid has been chosen to represent meander channel. The asymmetric flood plain has been provided by means of a straight wall on one side and a sinusoidal guide wall along the edge of the meandering channel on the other side. The channel and flood plain bottoms have been made of 0.0032 m thick perspex sheet while the side walls, demanding more flexibility, are made of 0.0016 m thick perspex sheet. To facilitate fabrication the whole of the channel length has been made in several blocks such that the assembled blocks provide an overall length of 6.6 meters. The details of the sinusoid and the model cross section have been furnished in Fig.2 along with the test sections, namely AA, BB and CC. The model is then placed within a tilting flume 10 m long and 0.60 m wide, designed with a metal frame and glass walls. The model is adequately supported on suitable masonary and timber frames at 0.30 m intervals on the flume bottom. Considerable effort has been taken to ensure that the channel is uniform with level beds after which it is laid on a slope of 4.0 x 10^{-3} by tilting the flume. The channel surface made of perspex sheet has been considered to represent smooth boundary and artificial roughness on it has been simulated by fixing 0.004 m diameter plastic beads at 0.0125 m centre to centre. The surface roughness has been incorporated over the entire cross section, over the flood plain only and over the river bottom only. In all these cases, the velocity and shear measurements

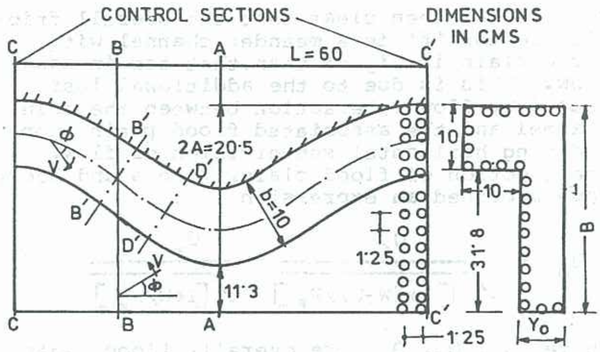

FIG.2. DEFINITION SKETCH SHOWING MEANDER CHANNEL WITH AND WITHOUT FLOOD PLAIN ALONG WITH THE ROUGHNESS DISTRIBUTION

have been carried out over the test reach at sections AA, BB and CC (vide Fig.2).

ANALYSIS

1. The main distinguishing feature of the motion of a stream comprising of river beds with flood plain is the interaction of flow over the river with that over the flood plain. Such a flow interaction leads to wide difference between the average velocities at different sub-regions of the cross section resulting in a strong lateral momentum transfer mechanism in between the flow in the river channel and that over the flood plain. Zheleznyakov (1965) refers to this phenomenon as the kinematic aspect of pressureless flow. Because of the controlling influence of momentum transfer mechanism the nature of the velocity distribution at the junction of the flood plain shows a distinct variation from the corresponding nature with respect to straight open channel compound as shown in Fig.3. It is evident that the lateral velocity gradient gives rise to circulation and hence vorticity which are generally oriented normal to the direction of flow and this is rather of a complex nature for the meander channel geometry. It is also observed that the depth over the flood plain at which the flowing out of the stream into the flood plain can be considered to be complete,

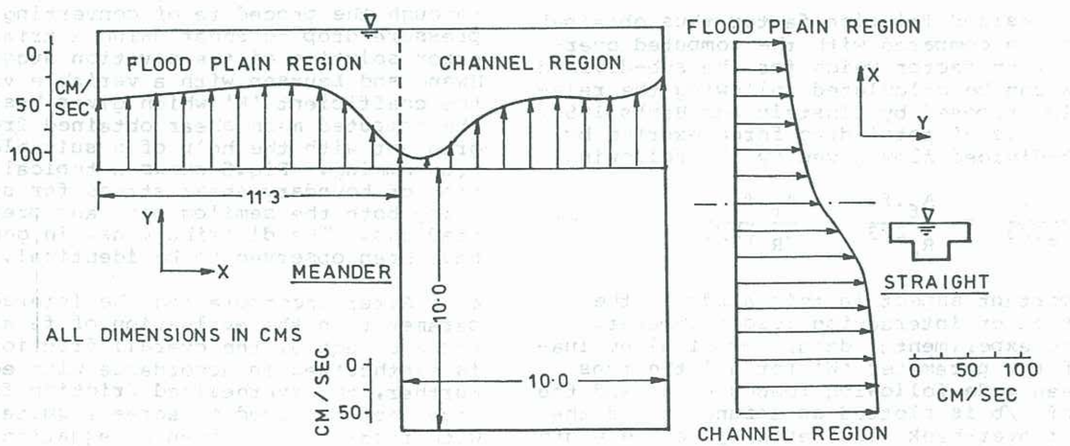

FIG.3. VARIATION OF LONGITUDINAL VELOCITY AT THE JUNCTION OF FLOOD PLAIN

increases with the increase in the ratio of the river bed to that of the flood plain.

2. It has been clear that the overall friction factor 'f' in a meander channel with flood plain is higher than that for in-bank flow. This is due to the additional loss caused by flow interaction between the main channel and the associated flood plain. Considering horizontal sub-division of flow, at the junction of flood plain, Toebes and Sooky have provided an expression

$$Q_o = \frac{Q_f}{\sqrt{[1+(W-b)/P_f]}} + \frac{Q_r}{\sqrt{[1+W/P_r]}} \qquad \text{(i)}$$

where Q_o, Q_f, Q_r are overall, flood plain and river discharges respectively.

W is the interactional loss parameter
P_f, P_r are wetted perimeter of flood plain and main river section respectively.
b is the width of main river channel.

Incorporating the interaction loss parameter, the overall resistance factor 'f' is now related to the resistance factor for main channel (f_r) and that over the flood plain (f_f) in the following way :

$$A\left(\frac{R}{f}\right)^{1/2} = A_r\left[\frac{R_r}{f_r\left(1+\frac{W}{P_r}\right)}\right]^{1/2} + A_f\left[\frac{R_f}{f_f\left(1-\frac{W-b}{P_f}\right)}\right]^{1/2} \qquad \text{(ii)}$$

$$\text{and} \quad f_r = \frac{8g\,A_r^3\,S}{Q_r^2\,(P_r+W)} \quad \text{and} \quad f_r = \frac{8g\,A_f^3\,S}{Q_f^2\,(P_f+W-b)} \qquad \text{(iii)}$$

where A_r, A_f are the flow areas corresponding to river and flood plain respectively.
R, R_r, R_f are the hydraulic radii for the entire section, the main river and flood plain sections respectively.
S is the energy gradient
and g is the acceleration due to gravity.

The synthesized friction factor thus obtained can then be compared with the computed overall friction factor which for the sub-divided regions can be calculated following the relationship proposed by Einstein and Banks (1950) on the basis of total drag force exerted by the sub-divided flow given by the following.

$$\frac{A.f}{R^{2/3}} = \frac{A_f.f_f}{R_f^{2/3}} + \frac{A_r.f_r}{(R_r)^{2/3}} \qquad \text{(iv)}$$

The important aspect in this study is the evaluation of interaction loss parameter. From the experimental data, numerical evaluation of the parameter 'W' for all the runs have been made following Toebes et al and the ratio of W/b is plotted as a function of the ratio of over-bank flow depth Y_o to the width of flood plain 'B'. This has been shown in Fig.4 along with the observations made by Ghosh and Kar for meandering channel with flood plain on both sides. From the figure it is clear that interaction loss is dependent

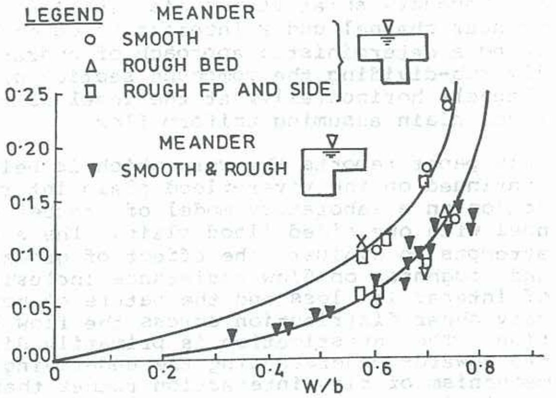

FIG.4. VARIATION OF INTERACTION LOSS PARAMETER AS A FUNCTION OF DEPTH OF FLOW OVER FLOOD PLAIN

upon the over-bank depth and also on the channel geometry. Roughness distribution for a particular channel cross section does not have any influence on the interaction loss and, therefore, the idea of hydraulic sub-division of flow at the level of the flood plain appears to be sound.

3. The distribution of boundary shear stress along the wetted perimeter of the channel section has been investigated from the velocity distribution and also from the dynamic pressure drop measured by Preston tube following Hwang and Laursen (1963). The vertical distribution of the tangential/longitudinal component of velocity has been observed to be very much affected because of high depth to width ratio which gives rise to a three-dimensional flow situation. The spiral nature of the secondary circulation and the effect of wall shear appear to modify the nature of the vertical distribution of the longitudinal/tangential velocity. It has been observed from the plotted velocity distribution that in the region of our interest, the vertical distribution of the longitudinal/tangential velocity can be roughly approximated to follow a logarithmic law with Karman's turbulent coefficient (K) equal to 0.4 for both smooth and rough boundary. The mean shear has been computed along the channel perimeter from the slope of the semilong plot of the velocity distribution and has been observed to agree reasonably well with the mean shear estimated from the energy gradient. The distribution of boundary shear has again been obtained through the procedure of converting dynamic pressure drop to shear using a trial and error solution of the equation suggested by Hwang and Laursen with a variable value of the coefficient 'K' which gives best fit to the computed mean shear obtained from energy gradient with the help of a suitable computer programming. Fig.5 shows a typical distribution of boundary shear stress for section AA using both the semilog plot and preston tube readings. The distributions, in general, have been observed to be identical.

4. After incorporating the interaction loss parameter in the evaluation of f_f and f_r in terms of eqn.3, the overall friction factor is synthesized in accordance with eqn.2. Further, the synthesized friction factors have been observed to agree , quite well, with relationship given by equation 4. The computed values of synthesized friction factor together with the calculated and measured mean shear values have been furnished in Table 1, for four typical runs involving smooth and rough boundaries at section BB.

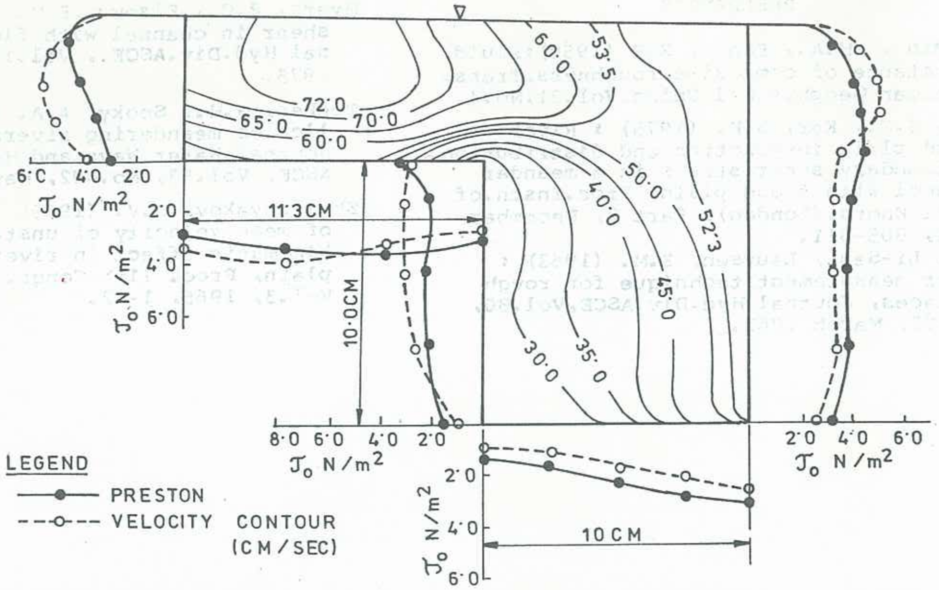

FIG. 5. CONTOURS SHOWING THE LONGITUDINAL VELOCITY AND A TYPICAL DISTRIBUTION OF BOUNDARY SHEAR IN THE MEANDER CHANNEL WITH ONE-SIDED FLOOD PLAIN

Run No.	Energy slope	Mean Shear Stress measured (N/m^2)	Overall friction factor	Mean Shear Stress calculated (N/m^2)	f_f	f_r	$\frac{\bar{A}_f f_f}{(\bar{R}_f)^{2/3}} + \frac{\bar{A}_r f_r}{(\bar{R}_r)^{2/3}}$	$\frac{\bar{A}_f}{(\bar{R})^{2/3}}$	$\bar{A}_f (\frac{R_f}{f_f})^{1/2} + \bar{A}_r (\frac{\bar{R}_r}{f_r})^{1/2}$	$\bar{A} (\frac{\bar{R}}{\bar{f}})^{1/2}$
1	.0070	2.66	0.170	3.11	0.144	0.208	16.0	15.2	1141.6	1140.7
2	.0061	2.29	0.121	2.60	0.097	0.163	12.1	11.0	1390.5	1390.2
3	.0048	1.80	0.122	2.13	0.109	0.140	11.2	10.9	1356.6	1355.0
4	.0050	1.74	0.130	2.23	0.108	0.163	12.4	11.7	1312.1	1311.4

Table 1. Comparison of the overall friction factor with that estimated from synthesis of the friction factors for sub-sections considering interaction loss between section BB and AA.

5. The effect of the interaction mechanism has been studied quantitatively in Fig.6 where the percentage decrease in average channel shear is plotted with respect to the depth of flow for two typical sections, namely, CC (b/B = 1/4.18) and AA (b/B= 1/2.13) for smooth and rough boundaries. The figure also includes the experimental data of Myers and Elsawy for straight composite channel with flood plan on one side. It has been observed that with the lowest depth considered, the average reduction in shear is 55% at section CC, while at section AA, the average reduction is about 25% which is comparable to the findings of Myers and Elsawy (21%).

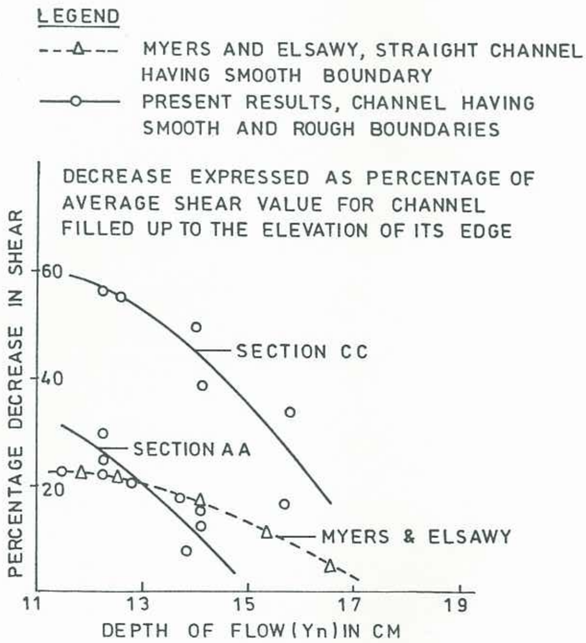

FIG.6. DECREASE IN AVERAGE BOUNDARY SHEAR IN THE MAIN CHANNEL DUE TO INTERACTION AS A FUNCTION OF DEPTH OF FLOW.

REFERENCES

Einstein , H.A., Banks, R.B (1950):Fluid resistance of composite roughness,Trans. American Geophysical Union,Vol.31,No.4.

Ghosh, S.N., Kar, S.K. (1975) : River flood plain interaction and distribution of boundary shear stress in a meander channel with flood plain, Proc.Instn.of Civil Engrs.(London), Part 2, December, 1975, 805-811.

Hwang, Li-San., Laursen, E.M. (1963) : Shear measurement technique for rough surfaces, Journal Hyd.Div.ASCE,Vol.80, No.HY2, March 1963.

Myers, R.C., Elsawy, E.M. (1975) : Boundary shear in channel with flood plain, Journal Hyd.Div.ASCE., Vol.101,No.HY7, July, 1975.

Toebes, G.H., Sooky, A.A. (1967) : Hydraulics oc meandering rivers with flood plain, Journal Water Ways and Harbour Div., Proc. ASCE, Vol.93, No.WW2, May,1967, 213-236.

Zheleznyakov, G.V. (1965) : Relative deficit of mean velocity of unstable river flow, kinematic effect in river beds with flood plain, Proc. 11th Congr. IAHR, Leningrad, Vol.3, 1965, 1-12.