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SELECTION OF INTERFACE PLANE IN THE ASSESSMENT OF DISCHARGE IN TWO STAGE MEANDERING AND STRAIGHT COMPOUND CHANNELS

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ABSTRACT

An investigation concerning the distribution of shear stress in the main channel and floodplain of meandering and straight compound channels are presented. Discharge in meandering compound channels is strongly dependant on the interaction between flow in the main channel and that in the floodplain. The usual practice in one dimensional analysis is to separate a compound section into subsections using 'divided channel method' through the assumed interface planes running from the main channel–floodplain junctions. Discharge for each subsections are calculated using Manning's equation and added up to get the total discharge of the compound section. If the assumed interface is wrong the resultant discharge becomes erroneous. The apparent shear force at the assumed interface plane gives an insight into the magnitude of flow interaction between the main channel and the adjacent floodplains basing on which the merits of the selection of the interface plains for discharge estimation are decided. Alternative uses of the traditional vertical interface plane for separation of compound channels are proposed. A set of smooth and rough sections is studied with aspect ratio varying between 2 to 5. The discharge results are compared with the results of variable-inclined interface method.

INTRODUCTION

Almost all natural rivers meander. Infect straight river reaches of lengths exceeding ten times its width is rather rare. Meandering is a degree of adjustment of water and sediment laden river with its size, shape, and slope such that a flatter channel can exists in a steeper valley. During floods, part of the discharge of a river is carried by the main channel and the rest are carried by the floodplains located to its sides. Once a river stage overtops its banks, the cross sectional geometry of flow undergoes a steep change. The channel section becomes compound and the flow structure for such section is characterized by large shear layers generated by the difference of velocity between the main channel and the floodplain flow. Due to different hydraulic conditions prevailing in the river and floodplain, mean velocity in the main channel and in the floodplain are different. Just above the bank-full stage, the flow in the main channel exerts a pulling or accelerating force on the flow over floodplains, which naturally generates a dragging or retarding force on the flow through the main channel. This leads to the transfer of momentum between the channel section and the floodplain. At the junction region between the main channel and that of the floodplain, Sellin (1964) and Knight and Demetriou (1983) indicated the presence of artificial banks made of vortices, which acted as a medium for transfer of momentum. At low depths over floodplain, transfer of momentum takes place from the main channel flow to the floodplain leading to the decrease in the main channel velocity and discharge, while its floodplain components are increased. As the depth of flow in the floodplain increases beyond a limiting depth, transfer of momentum does not takes place between the main channel and the floodplain. And at still higher depths over floodplains the process of momentum transfer reverses, the floodplain supplies momentum to the main channel. Due to the continuous stream wise variation of radius of curvature, the velocity and flow parameters are considerably more complex in a meandering channel than in a straight channel. The flow geometry in a meandering channel is in the state of either development or decay or both.

In the laboratory the mechanism of momentum transfer between the deep river section and shallow floodplain was first investigated and demonstrated by Zheleznvakov (1965) and Sellin (1964). While calculating discharge in compound channels, a method based on 'divided sections' is usually employed. Imaginary interface planes running from the junction between the main channel and floodplain are used to separate the main channel from the floodplain of the compound section. Momentum transfer between these subsections does not take place, when the shear stress at this fluid boundary is found to be zero. Yen and Overton (1973) used isovel plots to locate interface planes of zero shear. The data showed that the angle of inclination to the horizontal of the interface plane increased with depth over floodplain.

Following the previous work of Wormleaton et al. (1982), Knight and Demetriou (1983), Knight and Hamed (1984), and Myers (1987) on straight compound channels, with one to four types of geometries and smooth to six types of boundary roughness, the present study is aimed at understanding the general nature of the interaction between the main channel and the floodplain flows in meandering compound sections and propose suitable methods to calculate discharge in such channels.

Wright and Carstens (1970) observed that the calculation of discharge using the ''divided channel method'' for compound sections compared well with the observed values although segment discharges varied up to ±10%. They included the interface length in the wetted perimeter of the main channel subdivision only, as they considered that the slower flowing floodplain flow exerted a drag on the faster flowing main channel flow. Discharge assessment for compound sections between straight reaches also have been presented by Knight and Demetriou (1983), Knight and Hamed (1984), Wormleaton et al. (1982, 1985), Ackers (1993) covering smooth and rough boundaries.

There are limited reports covering investigation of a meandering channel with floodplains. Toebes and Sooky (1967) carried out laboratory experiments on two composite channel sections and showed that a nearly horizontal fluid boundary located at the junction between the main channel and floodplain would be more realistic than a vertical fluid boundary along the banks of the meandering channel in dividing the compound channel for discharge calculation. Using the data of the FCF at HR Wallingford, Greenhill and Sellin (1993) reported a method of estimation of discharge of meandering compound channels using Manning's equation and by extending the conventional divided channel method. The method assumed a fully developed shear layer at the interface between the main channel and the floodplain flows. For low over bank flow or for a very wide main channel, the method was found to give inaccurate results. Patra (1999), and Patra and Kar (2000) proposed a variable interface plane of separation of compound channel for a better estimate of discharge in meandering and straight compound river sections. The percentages of total flow carried by the main channel and floodplain of a compound section in terms of four dimensionless channel parameters were suitably modeled. The effect of flow interaction between the floodplain and main channel for various depths of flow over floodplain was adequately taken care.

Review of the literature show that investigators propose alternatives interface planes to calculate the total discharge carried by a compound channel section. Either including or excluding the interface length in the wetted perimeter does not make sufficient allowance for discharge calculation for all depths of flow over floodplain. It results either overestimate or underestimate of the discharge results. The work presented in this paper is based on a series of six channel sections with depth ratio between floodplain to main channel flow up to 0.404. In one series of experiment all the surfaces of main channel and floodplains are roughened uniformly.

EXPERIMENTAL SETUP

Experimental data from six series of channels are presented in this paper. Summery of experiments conducted are given in Table 1. The ratio α between overall width B and main channel width b are varied from 2.13 to 5.25 for the six sets (series A to I) of observations, of which the series I is symmetrical, the series A is made with two unequal floodplains attached to both sides of the main channel, and the rest are asymmetrical channels with floodplain attached to one side only. The channel sections are made from Perspex sheets for which the roughness of floodplain and main channel are identical. All surfaces of the channels of series F and G are roughened with rubber beads of diameter 4 mm at 12-mm center to center. All observations are made at the section of maximum curvatures (bend apex) of the meandering channels. Plan forms of the types of meandering experimental channels with floodplains are shown in Fig.1

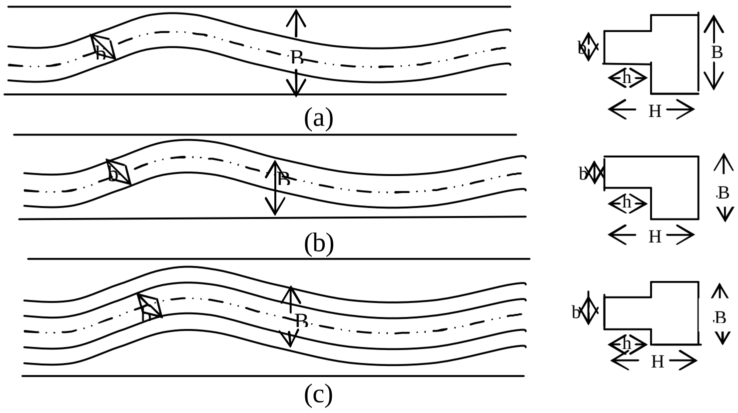


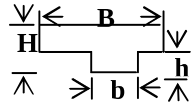
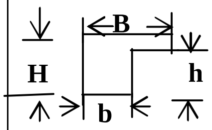
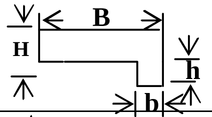
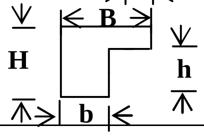
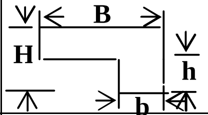
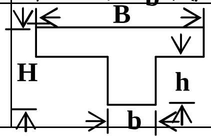
Fig. 1 Plan Forms of Meandering Experimental Channels with Floodplains

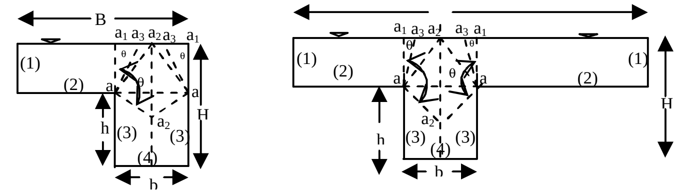
Details of the experimental setup and procedure concerning the flow and velocity observations in meandering channels with floodplains are reported earlier (Patra 1999, Patra and Kar 2000)[13,14]. Experiments are conducted utilizing the facilities available at the Water Resources and Hydraulic Engineering Laboratory of the Civil Engineering Department of the IIT Kharagpur, India.

THEORETICAL CONSIDERATIONS

The vertical, horizontal, and diagonal plains of separation of compound channel are represented by the interface lengths aa_1, aa, and aa_2 respectively where as the interface plane aa_3 is a variable and is located by measuring an angle θ it makes with the vertical plane aa_1 (Fig. 2). Various boundary elements of the compound channels are labeled from 1– 4 in Fig. 2. Label (1) denotes the vertical wall(s) of floodplain of length $[2(H - h)]$ and label (2) denotes floodplain bed(s) of length $(B - b)$. Label (3) denotes the two main channel walls and the bed of the main channel is represented by label (4).

Table 1 Summary of Experimental Runs for Meandering Channel with Floodplains

Experiment series/ Run No	Nature of Channel surface	Bed slope	Top width B(cm)	Main channel width b(cm)	Main channel depth h(cm)	Depth of lower main channel (cm)	$\alpha = B/b$	$\beta = (H-h)/H$	Sinuosity S_r	Amplitude/ width ratio (R)	Shape of the compound channel section
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A.1 A.2 A.3	smooth smooth smooth	0.0061 0.0061 0.0061	52.5 52.5 52.5	10 10 10	11.6 14.9 16.8	10 10 10	5.25 5.25 5.25	0.137 0.328 0.404	1.22 1.22 1.22	0.178 0.178 0.178	
C.4 C.5 C.6	smooth smooth smooth	0.004 0.004 0.004	21.3 21.3 21.3	10 10 10	12.19 13.81 15.24	10 10 10	2.13 2.13 2.13	0.180 0.275 0.343	1.21 1.21 1.21	(-)0.481 (-)0.481 (-)0.481	
D.7 D.8	smooth smooth	0.004 0.004	41.8 41.8	10 10	12.19 14.08	10 10	4.18 4.18	0.1796 0.2898	1.21 1.21	0.245 0.245	
F.9 F.10 F.11	rough rough rough	0.004 0.004 0.004	21.3 21.3 21.3	10 10 10	12.22 13.71 15.24	10 10 10	2.13 2.13 2.13	0.181 0.270 0.343	1.21 1.21 1.21	(-)0.481 (-)0.481 (-)0.481	
G.12 G.13 G.14	rough rough rough	0.004 0.004 0.004	41.8 41.8 41.8	10 10 10	12.49 14.23 15.84	10 10 10	4.18 4.18 4.18	0.209 0.301 0.369	1.21 1.21 1.21	0.245 0.245 0.245	
I.15 I.16 I.17	smooth smooth smooth	0.00278 0.00278 0.00278	138 138 138	44 44 44	29.5 30.7 31.6	25 25 25	3.136 3.136 3.136	0.1525 0.1857 0.2089	1.043 1.043 1.043	0.072 0.072 0.072	



Compound Channel with one side floodplain Compound Channel with floodplain on both

FIG. 2 Notations

Shear Force on the Assumed Interface Planes

The shear force percentage carried by the floodplain surfaces (1) and (2) out of the four surfaces (1), (2), (3), and (4) of the entire compound channel shown in Fig.2 is represented by $\%S_{fp}$ and that for the main channel surfaces (3) and (4) is represented by $\%S_{mc}$. The shear force percentages carried by the floodplain with depth ratio β [= (H – h)/H] for all of the compound channels of varying geometries (α = 2.13 to 5.25) are given in col. (3) of Table 2. Following the previous work of Knight and Demetriou (1983), Patra and Kar (2000) proposed a general equation for the percentage of shear force carried by the floodplains of meandering compound channels as

$$\%S_{fp} = 48(\alpha - 0.8)^{0.289}(2\beta)^{m}[1+\alpha\,\mathrm{Re}^{-13.25\beta\delta}]\{1+1.02\sqrt{\beta}\,\log\gamma\} \qquad (1a)$$

where the exponent m can be calculated from the relation

$$m = \frac{1}{0.75\,e^{0.38(\alpha - R)}} \qquad (1b)$$

in which R = ratio of the amplitude ε of the meandering channel to the top width B of the compound section the values of which are given in col. (11) of Table 1, δ = aspect ratio of the main channel b/h, and γ = the ratio of Manning's roughness n of the floodplain to that for the main channel. For a straight channel the value of R is zero. A zero value of R reduces (1*a*) and (1b) to the form of Knight and Hamed (1984) and for channels with equal surface roughness in the floodplain and main channel (γ =1), equation (1) further reduces to the form proposed by Knight and Demetriou (1983). Using (1) the calculated percentage of total shear force carried by the floodplains is given in Table 2 (Column 4). Patra and Kar (2000) have reported the adequacy of equation (1).

Once the shear force carried by the floodplain is known, the apparent shear force acting on the imaginary interface of the compound section can be calculated. These apparent shear forces may then be used to get an idea of the momentum transfer between the different subsections of the compound channel. For any regular prismatic channel under uniform flow conditions the sum of boundary shear forces acting on the main channel wall and bed together with an ''apparent shear force'' acting on the interface plane between main channel and floodplain must be equal to the resolved weight force along the main channel.

Table 2: Shear Force and Discharge Results for Meander Channels with Floodplains

Experiment Series	Observed Discharge (cm^3/sc)	% S_{fp}		Apparent Shear Force Results								Discharge Results (cm^3/sec)				
		Experimental	Calculated	%ASF_v		%ASF_D		%ASF_H		%ASF_{VI}		Method-I Vertical interface	Method-II Diagonal interface	Method-III Horizontal interface	Method-IV Variable interface	Method-V Modified interface
				Calculated	Experimental	Calculated	Experimental	Calculated	Experimental	Calculated	Experimental					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
A.1	3960	64.1	66.2	14.6	13.6	12.5	11.5	20.6	18.5	2.1	0.01	4458	4291	4157	3973	3800
A.2	14000	67.0	68.9	5.3	4.4	1.9	0.9	-3.1	-5.0	2.0	0.07	14132	14018	14244	14039	13857
A.3	19500	67.4	71.2	4.0	2.1	0.3	-1.6	-6.9	-10.7	3.8	0.00	19620	19686	20321	19524	19385
C.4	5800	29.0	28.5	5.8	6.1	2.1	2.3	-3.4	-2.9	-0.5	0.03	6.57	5945	5809	5800	5823
C.5	8450	34.8	37.7	7.0	5.6	1.8	0.3	-6.9	-9.9	3.0	0.10	8563	8488	8524	8482	8298
C.6	11200	38.0	42.7	7.4	5.0	1.3	-1.2	-9.9	-14.7	4.9	0.06	11245	11207	11490	11302	10986
D.7	5800	592	55.0	9.3	11.4	6.5	8.5	7.2	11.4	-4.1	0.09	6.91	6006	5861	5878	5709
D.8	8450	59.9	593	5.7	6.0	1.9	2.2	-3.8	-3.1	-0.6	0.03	8471	8455	8517	8589	8362
F.9	5500	27.1	28.6	5.8	5.1	2.1	1.3	-3.4	-4.9	1.6	0.04	5738	5634	5507	5509	5517
F.10	8200	34.4	37.4	7.0	5.5	1.8	0.3	-6.7	-9.7	2.9	0.00	8319	8242	8263	8227	8056
F.11	10900	36.1	42.7	7.4	4.1	1.3	-2.1	-9.9	-16.6	6.6	-0.05	10944	10907	11182	10949	10692
G.12	5500	55.9	55.9	8.0	8.0	4.9	4.9	3.5	3.4	0.1	0.02	5693	5628	5521	5525	5414
G.13	8200	56.0	59.7	5.4	3.6	1.6	-0.3	-4.5	-8.3	3.8	0.07	8213	8202	8281	8239	8122
G.14	10900	60.0	62.8	4.4	3.0	0.2	-1.2	-8.2	-11.0	2.9	0.09	10918	10927	11252	11083	10921
I.15	94535	37.1	40.1	7.8	6.3	4.9	3.4	4.0	1.0	3.1	-0.02	110807	104717	100068	99456	103801
I.16	103537	42.8	42.8	7.3	7.3	3.9	3.9	1.2	1.2	0.1	0.03	117395	110867	106413	105861	110984
I.17	108583	46.1	44.6	6.9	7.6	3.3	4.0	-0.6	0.82	-1.4	0.02	120793	114185	110127	109835	114829

$$\rho g A_{mc} S = \int_{mc} \tau dp + ASF_{ip} \qquad (2)$$

in which g = gravitational acceleration, ρ = density of flowing fluid, S = slope of the energy line, A_{mc} = area of the main channel defined by the interface plane, $\int_{mc} \tau dp$ = shear force on the surfaces of the main channel consisting of two vertical walls and bed, and ASF_{ip} = apparent shear force of the imaginary interface plane. Because the boundary shear stress carried by the compound section (ρgAS) is equal to 100%, where A is the total cross section of the compound channel, the percentage shear force carried by the main channel surfaces can be calculated as

$$\% S_{mc} = 100 \frac{\int_{mc} \tau dp}{\rho gAS} = 100 \frac{\rho gA_{mc} S}{\rho gAS} - 100 \frac{ASF_{ip}}{\rho gAS} \qquad (3)$$

But since $\%S_{mc} = 100 - \%S_{fp}$; and $100(ASF_{ip}/\rho gAS)$ = percentage of shear force on the assumed interface, substituting the values, the apparent shear force on the interface plane can be calculated as

$$\% ASF_{ip} = 100 \frac{A_{mc}}{A} - \{100 - \% S_{fp}\} \qquad (4)$$

in which $\%ASF_{ip}$ = percentage of shear force in the interface plane. Having computed $\%S_{fp}$ through (1), it is easy to evaluate (4) for the assumed interface plane. For example, for vertical interface between the boundary of the floodplain and main channel shown by the lines aa_1 in Fig. 2, the value of A_{mc} is the area marked by a_1abbaa_1, which when substituted in (4), yields $\%ASF_{ip}$. Similarly for horizontal or diagonal interfaces, A_{mc} can be estimated from the areas marked as aabb or a_2abbaa_2, respectively, in Fig. 2. These apparent shear forces can be expressed as percentages of the total channel shear force using the following relations:

$$\% ASF_V = 100 \frac{50}{[(\alpha - 1)\beta + 1]} - \frac{1}{2}\{100 - \% S_{fp}\} \qquad (5a)$$

$$\% ASF_D = 100 \frac{25(2 - \beta)}{[(\alpha - 1)\beta + 1]} - \frac{1}{2}\{100 - \% S_{fp}\} \qquad (5b)$$

$$\% ASF_H = 100 \frac{100\ (1 - \beta)}{[(\alpha - 1)\beta + 1]} - \frac{1}{2}\{100 - \% S_{fp}\} \qquad (5c)$$

in which $\%S_{fp}$ can be calculated from (1). Percentages of apparent shear force for the assumed vertical, horizontal, and horizontal interface planes from series A to I are given in Table 2(columns 5 to 10). The table compares the measured shear force percentages carried by the floodplains in each case along with the computed values using equation (1) and (5).

For the assumed vertical interface plane the shear force is always positive for the ranges of α and β tested. A positive value indicates transfer of momentum from the main channel to the floodplain at the assumed plane indicating the floodplain flow retarding the main channel flow. This apparent shear stress is higher than the bed-shear stress at low floodplain depths and reduces gradually as β increases. For the diagonal and horizontal interface planes it can be observed that the apparent shear force is positive at low depths and changes sign as depth increases indicating that at higher depths over floodplain there is transfer of momentum from the floodplain to the main channel. A smaller value of apparent shear stress renders the interface plane more suitable, but a large negative value of apparent shear stress at higher depths makes the interface plane unsuitable for separating the channel into hydraulically homogeneous zones for calculating discharge of compound channels by the divided channel method. However, none of the above methods explain a boundary for which there is no transfer of momentum for all depths.

A Variable-Inclined Interface Plane

Patra and Kar (2000) proposed a method of selecting the interface plane for meandering channel for which the apparent shear stress is found to be nearly zero. This variable plane of separation can be located by an angle θ it makes with the vertical line aa_1 (Fig.2), and in radians it is expressed as

$$\theta = (\alpha - R\beta)\,(1-\beta)^{\beta}\,(5.25\,\beta\,)^{0.075}\,e^{-\beta\,(\alpha - R)} \qquad (6)$$

The angle is dependent on the depth of flow over the floodplain, the flowing out width of the floodplain, and the amplitude of the meandering channel. The adequacy of this interface plane for separating the main channel from floodplain for calculating discharge by divided channel method are explained by Patra (1999), and Patra and Kar (2000). Once the angle θ is known (from 6) the area of the main channel A_{mc} representing the area a_3abbaa_3 in Fig. 2 can easily be estimated. For regular and prismatic channels under uniform flow conditions, the apparent shear force percentage of this plane can be obtained from the equation given as

$$\%ASF_{VI} = 100\,\frac{100\,A_{mc}}{bH[(\alpha-1)\beta+1]} - \{100 - \%S_{fp}\} \qquad (7)$$

in which $\%ASF_{VI}$ = apparent shear force on the variable-inclined interface as percentage of total, b = width of main channel, and H = depth of flow over the main channel. Using (6) and (7) Patra and Kar (2000) had shown that (col. 11-12 of Table 2) the calculated shear force percentage at the variable interface are almost zero for all the channels shown in Table 1. Considering all 17 runs, the standard error between the measured and the estimated apparent shear force using the variable plane of interface is found to be 3 percent.

DISCHARGE RESULTS

Easily located vertical, horizontal or diagonal interface planes running from the main channel floodplain junctions are mostly used to separate a compound channel section into subsections. Discharges for each subsection are calculated using Manning's equation and added to get the total discharge of the compound section. To identify an accurate, simple, but practicable way of calculating discharge for meandering compound channels the cross section of the compound channel is divided into subsections by the preceding four easily identifiable interface planes running from the floodplain-main channel junction. In all the cases, the interface length is not included in the wetted perimeter. Discharge results for the channel sections using the above four interface planes are given in Table 2 (col.13-16). The percentage of error between the observed and calculated discharge results of Table 2 for the four interface planes are shown in Fig. 3. It can be seen in the figure that the error percentage is comparatively less for the variable-inclined interface plane. The error percentage increases gradually to a maximum for the vertical interface through horizontal and diagonal planes. Excluding the interface length in the wetted perimeter overestimates the discharge capacity of the channel even at higher depths of flow for the ranges of β tested. This is quite in agreement with the results given by Wormleaton and Hadjipanos (1982).

A look into the apparent shear force at the vertical interface (col.5, Table 2) shows that there is always transfer of momentum across this interface and therefore what adjustments are to be made to take care of the momentum transfer or shear force acting at this plane has been the subject of present research. In this paper alternative uses of the vertical interface planes are tested to give an insight to the flow processes and to propose the best discharge results.

ALTERNATIVE VERTICAL INTERFACE METHODS

Interface Plane Included to the Main Channel Perimeter

The effect of momentum transfer at low depths of flow over floodplain ($\beta<0.4$) is to decrease the velocity and discharges of main channel while its floodplain components are increased. It is argued that the interface length ($H-h$) should be included to the main channel perimeter only to take care of the momentum transfer so that the overestimation of the discharge is checked. Therefore in this method the interface length ($H-h$) is added to the main channel boundary only. Resulting discharge errors for the compound channels are shown as curves V_{ie} in Fig.3

Modified Vertical Interface Method

The vertical interface plain is neither shear free nor the apparent shear at this surface is equal to boundary shear of main channel surface or of the floodplain surface. Myer (1975), Wormelaton et. al. (1982), and Knight and Demetriou(1983) have shown that apparent shear in the vertical, horizontal or diagonal interface is many times greater than the boundary shear stress in main channel or floodplain at low floodplain depths. Therefore either excluding or including the interface length to the main channel/floodplain boundary does not fully take care of the interaction effect. It has been shown convincingly that failure to allow for the existence of such mechanism results in erroneous compound channel analysis.

Wormelaton et al. (1982) have shown that the total dragging force on the main channel due to floodplain at the interfaces must be equal to the accelerating force on floodplain due to the main channel. Therefore the wetted perimeter of the main channel needs to be increased suitably to take care of the net dragging force on the main channel. Similarly the wetted perimeter of the floodplain needs to be reduced by subtracting a suitable length of interface to account for the accelerating force on the floodplain due to the pulling of the main channel water. Net force at the assumed vertical interface should balance each other. Let X_{mc} be the interface length for inclusion in the main channel wetted perimeter and X_{fp} the length of interface length to be subtracted from the wetted perimeter of floodplain. By assuming the channel to be regular, prismatic, and flow under uniform conditions the sum of the boundary shear forces acting on the main channel plus the shear force on the assumed interface must be equal to the weight component of water of the main channel and is written as

$$(P_{mc}\tau_{mc} + X_{mc}\tau_{mc}) = \rho g A_{mc} S \tag{8a}$$

Similarly for the floodplain, equation (8a) is expressed as

$$(P_{fp}\tau_{fp} + X_{fp}\tau_{fp}) = \rho g A_{fp} S \tag{8b}$$

where P_{mc} = the wetted perimeter of the main channel, P_{fp} = the wetted perimeter of the floodplain, A = the area of cross section of the compound channel section = $A_{mc} + A_{fp}$, A_{mc} and A_{fp} = the area of cross sections of main channel and floodplain subsections respectively, τ_{mc} and τ_{fp} = the mean boundary shear stress in main channel and floodplain per unit length, and S = the longitudinal slope of the channel. Again for a compound section, the total boundary shear must be equal to the weight component of flowing fluid along longitudinal direction and is written as

$$\left(P_{mc}\tau_{mc} + P_{fp}\tau_{fp}\right) = \rho g A S \tag{9}$$

Since $\rho g A_{mc} S + \rho g A_{fp} S = \rho g A S$, the sum of weight components represented by (8a and 8b) must be equal to the weight component represented by (9) from which we get

$$X_{mc}\tau_{mc} = -X_{fp}\tau_{fp} \tag{10}$$

Equation (10) shows that the shear force on the main channel arising out of the assumed vertical interface must be equal and opposite to that considered for the floodplain by the divided channel approach. At the assumed vertical interface plane the term $X_{mc}\tau_{mc} = -X_{fp}\tau_{fp}$ is taken as the apparent shear force ASF_{ip}. Now from equation (8a) a general expression for X_{mc} for any interface is written as

$$X_{mc}\left(= \frac{ASF_{IP}}{\tau_{mc}}\right) = \frac{\rho g A_{mc} S - \tau_{mc} P_{mc}}{\tau_{mc}} \tag{11}$$

And for the vertical interface equation (11) is simplified to

$$X_{mcV} = \frac{100\ P_{mc}}{(100 - \%S_{fp})\{1 + (\alpha - 1)\beta\}} - P_{mc} \tag{12}$$

Following the above steps, the equivalent decrease in length of floodplain wetted perimeter for any interface can be written similar to (11) as

$$X_{fp} = P_{fp}\left[\frac{100}{\%S_{fp}}\left(\frac{A_{mc}}{A} - 1\right) - 1\right] \tag{13}$$

And for vertical interface, equation (13) is written as

$$X_{fpV} = P_{fp} - \frac{100(\alpha - 1)\beta}{(\%S_{fp})\{1 + (\alpha - 1)\beta\}} P_{fp} \tag{14}$$

Where the percentage of shear force ($\%S_{fp}$) carried by the floodplains can be calculated from equation (1).

Knowing $\%S_{fp}$ and channel geometries parameters the interface lengths X_{mcV} and X_{fpV} are calculated. Next the discharge for main channel and floodplain are calculated using Manning's equation given as

$$Q = \frac{\sqrt{S_f}}{n} A_{mc}^{5/3}\left(P_{mc} + X_{mc}\right)^{-2/3} + A_{fp}^{5/3}(P_{fp} - X_{fp})^{-2/3} \tag{15}$$

The lengths in terms of (H–h) times X_{mcV} and X_{fpV} are plotted against β in Fig. 4. The percentage of error between observed and calculated discharges for all the channels are shown as curves M in Fig.3.

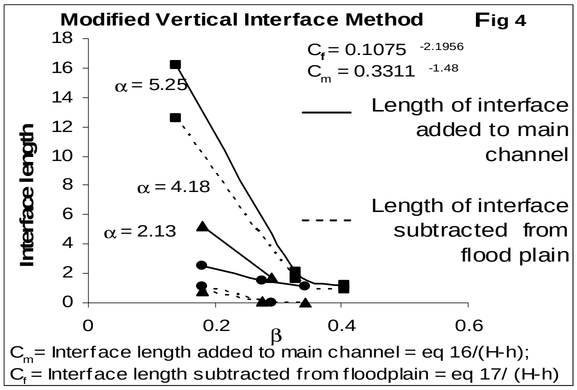


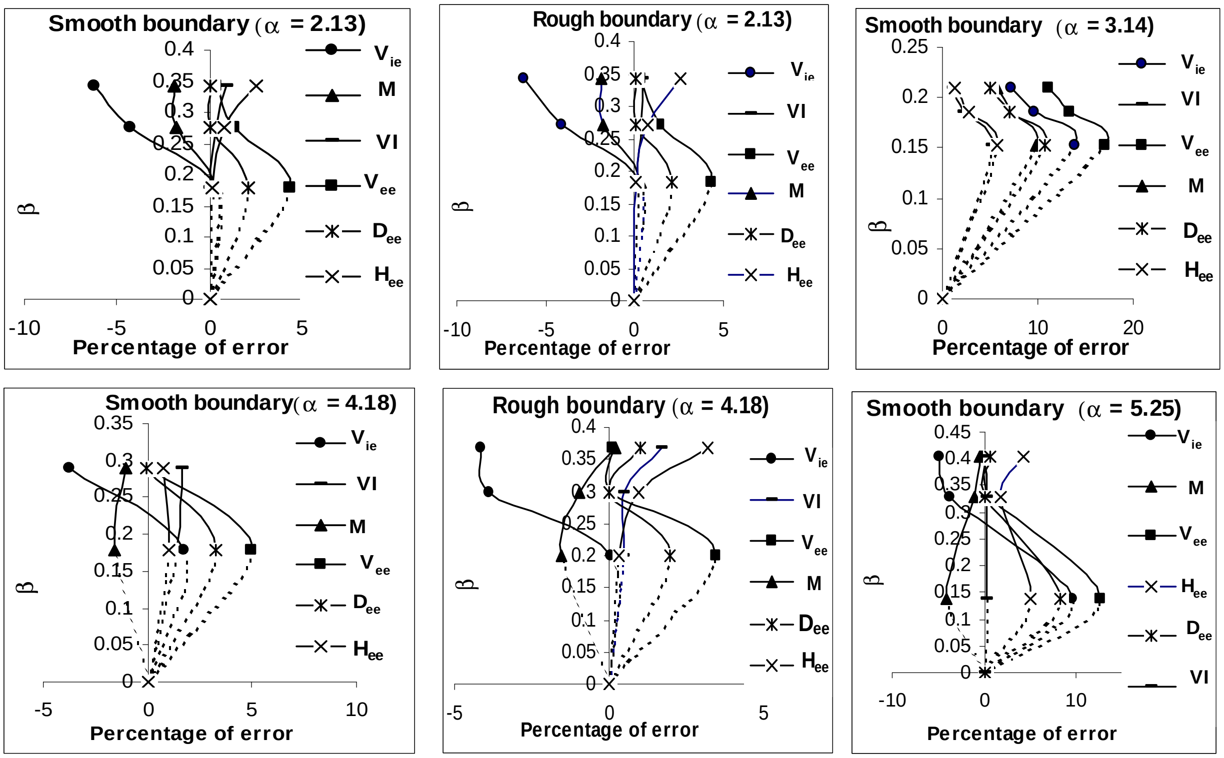
Fig. 4 Variation of interface length with β

Validation of the Methods for Straight Channel: The methods are tested with experimental data of Knight and Demetriou (1983) for the three types of straight compound channels (α = 2, 3, and 4). The three channels give similar results as in the case of meandering sections. The results of Knight and Demetriou (1983) are presented in Fig. 5. Curves H_{ee} and D_{ee} are plotted in the same figure for comparison.

RESULTS AND DISCUSSIONS

Errors in the percentage of discharge between observed and computed values of the compound channel sections are found to be the maximum (up to 17%) for β values between 0.13 and 0.2 when the interface plane is not included in the wetted perimeter of both main channel and floodplains. The error percentage curves then decreases to a minimum when β≈0.4. This shows that momentum transfer is maximum at β = 0.15-0.2 and the transfer of momentum across the vertical boundary is complete at around β = 0.4.

When an interface length equal to the depth of floodplain is included in the main channel only of the compound section, the error in discharge between observed and computed values are found to be less than the method excluding it (up to 14 %). However, at higher depths of flow over floodplain (β>0.2), large negative values of discharge errors are obtained (up to –8 %) indicating that when the momentum transfer between main channel with that of floodplain is nearly complete at these depths, the method gives inaccurate results.



V_{ee}=Interface Excluded from MC and FP, V_{ie} = Interface Included in MC and Excluded from FP, M = Interface Length of (*H-h*) times Included in MC and Subtracted from FP, VI = Variable Interface Plane Method, H_{ee}=Horizontal Interface Excluded both from MC and FP, D_{ee}=Diagonal Interface Excluded both from MC and FP

Fig. 3 Error Percentages Between Calculated and Observed Discharges for Various Interface Plains

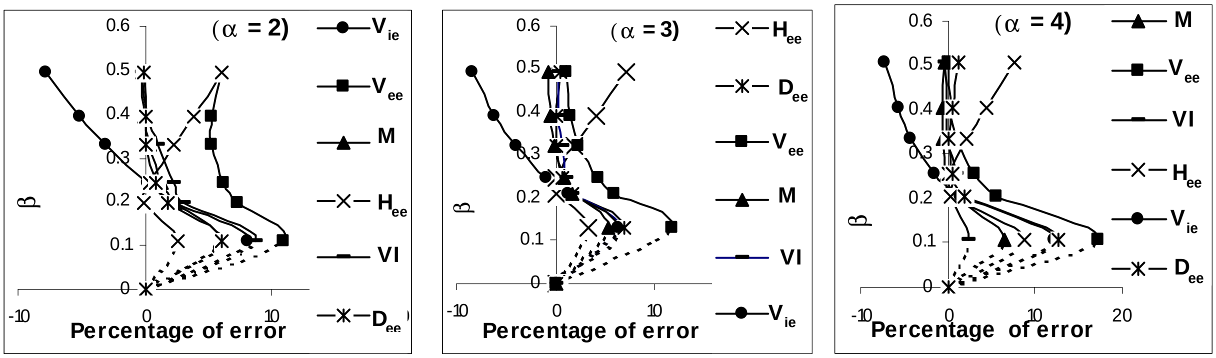


FIG. 5 Error Percentages Between Calculated and Observed Discharges for Various Interface Plains for the Channel of Knight and Demetriou (1983)

Modified vertical interface method gives good results of discharge estimates for the compound channels having narrow floodplains (α = 2.13) and for β up to 0.2. But for channels with narrow flood plains carrying flow at higher depths or for wider channels (α = 5.25) carrying lower depths of flow, the method gives higher percentages of errors in discharges (up to –5 %). From the plots between β and the length of interface added to main channel and subtracted from floodplain the lengths of interfaces are modeled as

Interface length added to main channel is given as C_m×(*H-h*) where $C_m = 0.3311\beta^{-1.48}$ (16)

Interface length subtracted from floodplain is given as C_f×(*H-h*) where $C_f = 0.1075\beta^{-2.19563}$ (17)

The Variable Inclined Interface plane method proposed by Patra and Kar (2000) is based on the theoretical background of locating interface plane of zero shear. The method gives good results but is not as straight forward as the above vertical interface planes.

CONCLUSIONS

The following conclusions can be made from the above discussions

1. Either by including or excluding the length of interface equal to the depth of floodplain to the wetted perimeter of the main channel or to the floodplain does not make sufficient allowance for discharge calculation for all depths of flow over floodplain. These methods either overestimate or underestimate the discharge results.
2. By balancing the magnitudes of shear force at the vertical interface (named as Modified Vertical Interface Method) gives better discharge results (maximum error up to + 9% and – 4% respectively at $\beta = 0.15$.This is an improved method of discharge estimation for compound sections. However the method lacks in giving good results for the main channel and the floodplains subsection discharges.
3. The Variable Inclined Interface plane method proposed by Patra and Kar (2000) is based on the theoretical background of locating interface plane of zero shear. The method gives good discharge results but involves more steps in identifying the interface plane and the subsequent discharge estimation.

APPENDIX I: NOTATIONS

The following symbols are used in this paper:

A = total cross-sectional area of compound channel;
B = top width of compound channel;
b = width of main channel;
C_m= Interface length added to main channel using equation 16/(H-h)
C_f = Interface length subtracted from floodplain using equation 17/(H-h)
g = gravitational acceleration;
H = depth of flow in main channel;
h = height of main channel up to floodplain bed;
m = exponent used in Eq. (1a);
n = Manning's roughness factor;
R = ratio of amplitude of compound channel to top width B;
S_f= energy slope line;
s_r= sinuosity of meander channel = (l_s/l_c);
α = width ratio = B/b;
β = relative depth = $(H - h)/H$;
γ = ratio of floodplain roughness to main channel roughness;
δ = ratio between main channel width to its depth (b/h);
ε = amplitude of meander channel;
ρ = density of flowing liquid;
τ = boundary shear stress;
$\int_{mc} \tau dp$ = shear force on surfaces of main channel;
%ASF = percentage of total channel shear force carried by assumed interface planes;
%ASF_H = ASF on horizontal interface (aa) as percentage of total shear force;
%ASF_{ip} = ASF on an interface plane as percentage of total shear force;
%ASF_V = ASF on vertical interface (aa_1) as percentage of total shear force;
%ASF_{Vi} = ASF on variable-inclined interface (aa_3) as percentage of total shear force;
ASF_{IP} = Apparent shear at the interface
P_{mc} = the wetted perimeter of the main channel,
P_{fp} = the wetted perimeter of the floodplain,
A = the area of cross section of the compound channel section and
A_{mc} = are the area of main channel
A_{fp} =flood plain subsections respectively,
τ_{mc} = the mean boundary shear stress in main channel per unit length longitudinally
τ_{fp} = mean boundary shear stress in flood plain per unit length longitudinally
S = the longitudinal slope of the channel.
τ_{av} = is the average shear stress in the assumed vertical interface whose interface length is $l_v = H-h$
% S_{fp}= the percentage of shear force carried by the floodplains
%S_{mc}= the percentage of shear force carried by the floodplains
Q = Calculated discharge.
X_{mc}=Length of interface added to main channel subsection subsection
X_{fp} = Length of interface subtracted from flood plain subsection
X_{mcv}=Length of vertical interface added to main channel subsection
X_{fpv} = Length of vertical interface subtracted from flood plain subsection

APPENDIX II: REFERENCES

Ackers, P.,(1993), "Flow Formulae for Straight Two Stage Channels", *Journal of Hydraulic Research*, IAHR Vol.31, No.4, pp.509-532.

Greenhill,R.K,and Sellin, R.H.J.,(1993),"Development of a Simple Method to Predict Discharge in Compound Meandering Channels ", *Proc. Of Instn. Civil Engrs Wat. Merit. and Energy,* 101, paper10012,march,pp.37-44.

Knight, D.W., and Demetriou, J.D., (1983), "Flood Plain and Main Channel Flow Interaction". *Journal of Hyd. Engg., ASCE* Vo.109, No.8, pp-1073-1092.

Knight, D.W., and Hamed, M.E.,(1984), "Boundary Shear in Symmetrical Compound Channels", *Journal of the Hydr. Eng., ASCE,* Vol.110, No.HY10, Paper 19217, pp.1412-1430.

Myers, W.R.C., and Elsawy, (1975), "Boundary Shear in Channel With Floodplain", *Jr. of Hydr. Division, ASCE,* Vol.101, HY7, pp. 933-946.

Myers, W.R.C., (1987), "Velocity and Discharge in Compound Channels", *Jr. of Hydr. Engg., ASCE,* Vol.113, No.6, pp.753-766.

Patra,K.C,(1999)),") Flow interaction of Meandering River with Flood plains ", Thesis Presented to the Indian Institute of Technology, Kharagpur, at Kharagpur, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Patra,K.C.,Kar,S.K.,(2000) Flow interaction of Meandering River with Flood plains *Journal of Hydr. Engineering, ASCE,* Vol., 126, No.8, pp.593-603.

Sellin, R.H.J.,(1964),"A Laboratory Investigation into the Interaction Between Flow in the Channel of a River and that of its Flood Plain", *La Houille Blanche,* No.7, pp.793-801.

Toebes, G.H., and Sooky, A.A., (1967),"Hydraulics of Meandering Rivers with Flood plains", *Journal of the waterways and Harbor Div., Proc. of ASCE,* Vol.93, No.WW2, May, pp. 213-236.

Wright and Carstens (1970) ,"Linear momentum flux to over bank sections", *Journal of Hydr. Division., ASCE,* Vol.96, NoHY9, pp.1781-1793.

Wormleaton, P.R., Allen, J.,and Hadjipanos, P.,(1982), "Discharge Assessment in Compound Channel Flow", *Journal of the Hydr. Division, ASCE,* Vol.108, No.HY9, pp.975-994.

Wormleaton, and Hadjipanos, P.,(1985), "Flow Distribution in Compound Channels", *Journal of the Hydr. Engg., ASCE,* Vol.111, No.7, pp. 1099-1104.

Yen, C.L., and Overton, D.E.,(1973),"Shape Effects on Resistance in Floodplain Channels", *Journal of Hydr. Division., ASCE,* Vol.99, No.1, pp.219-238.

Zheleznyakov, G.V.,(1965),"Interaction of Channel and Floodplain Streams", *Proc. 14th Congress of IAHR,* 5, Paris, France, pp. 144-148.

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Author(s) PROF. KANHU CHARAN PATRA & MR. K.K. KHATUA

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