FLOW DISTRIBUTION IN MEANDERING COMPOUND CHANNEL FLOW

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ABSTRACT

When the flows in natural or man made channel sections exceed the main channel depth, the adjoining floodplains become inundated and carry part of the river discharge. Due to different hydraulic conditions prevailing in the river and floodplain of a compound channel, the mean velocity in the main channel and in the floodplain are different. This leads to the transfer of momentum between the main channel water and that of the floodplain making the flow structure more complex. Reliable estimates of discharge capacity and its distribution for a compound channel are essential for the design, operation, and maintenance of open channels, more importantly for the prediction of flood and flood protection measures of a two-stage compound channel.

Results of some experiments concerning the velocity distribution, and the flow distribution in a compound meandering and straight channel are presented. Discharge distribution in compound channels is strongly dependant on the interaction between flow in the main channel and that in the floodplain. Laboratory test results are presented concerning the velocity, and discharge characteristics of compound meandering and straight river sections composed of a rectangular/trapezoidal main channel and floodplains disposed off to its sides. The influence of the geometry on velocity and flow distribution and different functional relationships are obtained. Dimensionless parameters are used to form equations representing the velocity distribution and flow distribution between main channel and floodplain subsections. A set of meandering and straight compound sections of rectangular and trapezoidal cross section is studied with width ratio varying between 2 to 16.08. The equations agree well with experimental discharge data. Using the proposed area method, the error between the measured and calculated discharge distribution for the meandering and straight compound sections is found to be the minimum when compared with that using other investigators.

Key wards: Meandering River, Flow Interaction, Vertical Interface, Flow distribution, Velocity Distribution, Discharge Distribution, Main Channel, Flood Plain, Over Bank Flow

1 INTRODUCTION

During floods, a part of the river discharge is carried by the main channel and the rest is 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 of flow 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. And at 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.

Information regarding the nature of flow distribution in a flowing simple and compound channel is needed to solve a variety of river hydraulics and engineering problems such as to give a basic understanding of resistance relationship, to understand the mechanism of sediment transport, to design stable channels and revetments. The flow and velocity distribution in compound sections have been investigated by many investigators (Knight and Demetriou 1983, Myer 1987, Kar 1977, Bhattacharyya 1995, Myer and Lyness 1997, Patra 1999, Patra and Kar 2000, Patra and Kar 2004, Khatua 2007. The zonal or sub-area flow distributions in the main channel and floodplain of compound channel mainly depend on the channel geometry and flow parameters. An investigation is made to obtain the flow distribution between main channel, lower main channel, and floodplain for both straight and meandering compound sections.

From the literature it is found that the investigators propose vertical interface planes to calculate the sub-area discharges that is, shared between main channel and in floodplains which are not properly addressed. If interaction mechanism and the meandering effect are not properly addressed, it results either overestimate or underestimate of the discharge results in subsections. The work done by previous investigators is also limited to either for low sinuosity and/or for compound channels of lesser width ratio, which is not fit for compound channels of higher sinuosity and/or of higher width ratio. The work presented in this paper is based on a series of eight channel sections with width ratio between 2 to 16.08 and the sinuosity is higher up to 1.91.

**EXPERIMENTAL SETUP AND PROCEDURE**

Using the fund from the department of science and technology, Government of India, the authors have built a numbers of flumes of lengths 12 m each and widths of 0.50 m, 0.60 m, 0.90 m, and 2.00 m respectively in the water resources and hydraulic engineering laboratory of the Civil Engineering Department of the National Institute of Technology Rourkela, India. Within the flumes, experimental meandering/straight channels with floodplains are built using Perspex sheets. The present work is based on the authors recent data observed using the experimental meandering compound channels at NIT Rourkela and also from the IIT Kharagpur, India. The present paper is based on the following channels for which the verified data are available

Type-I Channel: It has straight compound section has the main channel dimension is 120 mm×120 mm, and flood plain width B is 440 mm (Photo. P 1). The channel is cast inside
a tilting flume of 12m long, 450 mm wide, and 400 mm deep. The bed slope of the channel is kept at 0.0019.

Type-II Channel: The meandering main channel has the dimensions of 120 mm × 120 mm in cross section with floodplains at both sides. It has overall width of $B$ is 577 mm, wavelength $L = 400$ mm, double amplitude $2A'$ of 323 mm giving rise to a sinuosity of 1.44. This meandering channel is placed inside a tilting flume of 12 m long, 600 mm wide, and 600 mm deep.

Type-III Channel: This meandering compound channel is trapezoidal in the main channel cross section of 120 mm wide at bottom, 280 mm at top having bank-full depth of 80 mm, and side slopes of 1:1(Photo. P 2). The floodplain width $B$ is measured as 1930 mm. The main channel has wavelength $L$ of 2185 mm and double amplitude $2A'$ of 1370 mm. Sinuosity for this channel is scaled as 1.91. The experimental setup along with plan forms of the meandering experimental channels with floodplain is shown in Fig.1(a and b). Details of the geometrical parameter and hydraulics parameter of the experimental channels are given at Table 1 and Table2 respectively.
Fig. 1 (a) Plan Form of Type-III Meandering Channel

Table 1 Geometry Parameters of the Experimental Compound Channels
Table 2 Flow and Flow Distribution for Over Bank Flow at Bend Apex of Experimental Channels.

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Item Description</th>
<th>Straight Type-I</th>
<th>Mildly Meander - Type-II</th>
<th>Highly Meander - Type-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Wave length in down valley direction</td>
<td>-------</td>
<td>400 mm</td>
<td>2185 mm</td>
</tr>
<tr>
<td>2.</td>
<td>Amplitude (α)</td>
<td>-------</td>
<td>162 mm</td>
<td>685 mm</td>
</tr>
<tr>
<td>3.</td>
<td>Geometry of Main channel section</td>
<td>Rectangular</td>
<td>Rectangular</td>
<td>Trapezoidal (side slope 1:1)</td>
</tr>
<tr>
<td>4.</td>
<td>Main channel width (b)</td>
<td>120 mm</td>
<td>120 mm</td>
<td>120 mm at bottom</td>
</tr>
<tr>
<td>5.</td>
<td>Bank full depth of main channel</td>
<td>120 mm</td>
<td>120 mm</td>
<td>80 mm</td>
</tr>
<tr>
<td>6.</td>
<td>Top width of compound channel (B)</td>
<td>440 mm</td>
<td>577 mm</td>
<td>1930 mm</td>
</tr>
<tr>
<td>7.</td>
<td>Slope of the channel</td>
<td>0.0019</td>
<td>0.0031</td>
<td>0.0053</td>
</tr>
<tr>
<td>8.</td>
<td>Meander belt width</td>
<td>-------</td>
<td>443 mm</td>
<td>1650 mm</td>
</tr>
<tr>
<td>9.</td>
<td>Minimum radius of curvature of channel centerline at bend apex</td>
<td>-------</td>
<td>140 mm</td>
<td>460 mm</td>
</tr>
<tr>
<td>10.</td>
<td>Ratio of top width (B) to channel width (b) = α</td>
<td>3.667</td>
<td>4.808</td>
<td>16.083</td>
</tr>
<tr>
<td>11.</td>
<td>Sinuosity</td>
<td>1.00</td>
<td>1.44</td>
<td>1.91</td>
</tr>
<tr>
<td>12.</td>
<td>Cross over angle in degree</td>
<td>-------</td>
<td>104</td>
<td>102</td>
</tr>
<tr>
<td>13.</td>
<td>Flume size</td>
<td>0.45m×0.4m×12m long</td>
<td>0.6m×0.6m×12m long</td>
<td>2.0m×0.6m×12m long</td>
</tr>
</tbody>
</table>

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 (Photo. P 3) for measuring the flow discharge, from where water runs back to the underground sump, this 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 smooth and identical. The observations are made at the section of maximum curvatures (bend apex) of the meandering channel geometries.

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. Point velocities are measured using a 16-Mhz Micro ADV (Acoustic Doppler Velocity-meter) having least count of 0.001 m/s. Guide rails are provided at the top of the experimental flume on which a traveling bridge is moved in the longitudinal direction of the entire experimental channel. The point gauge and the micro-ADV attached to the traveling bridge can move in both longitudinal and the transverse direction of the experimental channel at the bridge position. The micro-ADV readings are recorded in a computer placed besides the bridge. (Photo. P 4) As the ADV is unable to read the data of uppermost layer (up to 5 cm 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 predefined points of the flow-grid. A flow direction finder is used to get the direction of maximum velocity with respect to the longitudinal flow direction. The Pitot tube is physically rotated normal to the main stream downward direction till it gives maximum deflection of manometer reading. The angle of limb of Pitot tube with longitudinal direction of the channel is noted by the circular scale and pointer arrangements attached to the flow direction meter. Using the data of velocities close to the surface of the channels, the boundary shear at various points on the channel bed at the predefined channel sections are evaluated from the logarithmic velocity distribution relationship.

SUB-SECTION DISCHARGE RESULTS

Due to transfer of momentum between floodplain and main channel, the percentage of flow carried by the main channel with depth does not follow simple area ratios. At lower depths of flow over floodplain, the difference between percentage of flow in main channel and percentage of area of main channel is positive indicating that the main channel carries a greater percentage of flow than the simple area percentage. As the depth of flow over floodplain increases, the percentage of flow in main channel reduces. Plots of the isovels for the longitudinal velocities are used to obtain the area-velocity distributions that are subsequently integrated to get the discharge of the main channel and floodplains sub-areas separated by assumed vertical interface planes. The total discharge of the compound channel is used as a divisor to calculate the percentages of discharge carried by the main channel and floodplain sub-areas or zones. When a vertical interface is used, the area of main channel is denoted by the area $a_1 a R S a_1$ (Fig.2). The flow percentage carried by this area is represented as $\%Q_{mc}$ with depth ratio $[\beta = (H–h)/H]$ for the compound channels for varying geometry ($\alpha = 3.67, 4.81$ and $16.08$) are given in Table 2.

![Fig.2 Division of a compound section into sub areas by an assumed vertical interface](image)
For straight compound channel data of Knight and Demetrious (1983) are used along with the data of present Type-I channel. So using the four types of straight compound channels \([\alpha = 2, 3, 3.67 \text{ and } 4 \text{ data}]\) the variation of percentage of flow in main channel with relative depths for different width ratios are shown in Fig.3. It is clear from the figure that main channel zonal discharges decrease with channel width ratio \((B/b = \alpha)\) and also with relative depth \([(H - h)/H = \beta]\) for the straight compound channels investigated.

![Fig.3 Variation of Percentage of Flow in Main Channel with Relative Depth for Straight Compound Channels](image)

Similarly for the present meandering compound channels (Type-II and Type-III) the values of \(\%Q_{mc}\) are plotted against depth ratio \([(H - h)/H = \beta]\) for different width ratios \((B/b = \alpha)\) in Fig.4. Two other types of meandering compound channel data of Patra and Kar (2000) having width ratio \(\alpha = 3.14\) and 5.25 are also plotted in the same figure for comparison. From Fig. 4 it can be seen that the main channel discharges decrease with the geometrical parameter of depth ratio and width ratio like straight compound channels while the increase of sinuosity \((S_r)\) further decreases the percentage of flow in the main channel.
THEORITICAL ANALYSIS AND MODEL DEVELOPMENT

Dimensional analysis is made to know the channel flow and resistance relationships leading to the carrying capacity of a compound section. Parameters governing resistance to flow in a straight compound channel having smooth surfaces under uniform flow conditions can be functionally expressed as

\[ \phi(F_m, \rho, \mu, V_{mc}, V_{fp}, R_{mc}, R_{fp}, g) = 0 \]  \hspace{1cm} (1)

where \( F_m \) = flow resistance in the main channel due to momentum transfer and other factors, \( \rho \) = density of water, \( \mu \) = dynamic viscosity of water, \( V_{mc} \) and \( V_{fp} \) = the mean velocities of main channel and flood plain sub areas respectively, \( R_{mc} \) and \( R_{fp} \) = the hydraulic radius of main channel and flood plain sub-sections respectively, \( g \) = acceleration due to gravity.

For uniform flow condition, since the total gravitational force is equal to the total resisting force, the term \( g \) is excluded. Re-arranging the terms and applying Buckingham \( \Pi \) theorem, we can express (1) in a non-dimensional term as

\[ \frac{F_m}{\rho V_{mc}^2} = \phi \left( \frac{\mu}{\rho V_{mc} R_{mc}}, \frac{V_{fp}}{V_{mc}}, \frac{R_{fp}}{R_{mc}} \right) \]  \hspace{1cm} (2a)
where \( \frac{F_m}{\rho V_{mc}^2} \) is the resistance coefficient \( f_{mc} \) of main channel sub-section. If \( N_{mc} \) and \( N_{fp} \) are taken as the Reynolds’s number of main channel and flood plain sub-sections respectively, and by denoting \( N_r \) as the Reynolds number ratio \( (N_r = \frac{N_{fp}}{N_{mc}}) \), equation (2a) is simplified as

\[
 f_{mc} = \phi(N_{mc}, \frac{N_{fp}}{N_{mc}}) \text{ or } f_{mc} = \phi(N_{mc}, N_r)
\]  

(2b)

Similar dimensional analysis can be made to show that the resistance coefficient of floodplain sub-area \( f_{fp} \) and for total cross section of the compound channel \( f \) are also functions of respective Reynolds’s number and the Reynolds’s number ratio and can be expressed as

\[
 f_{mc} = \phi(N_{mc}, N_r), \quad f_{fp} = \phi(N_{fp}, N_r) \quad \text{and} \quad f = \phi(N, N_r)
\]  

(2c)

where \( N \) is the Reynolds’s number of compound section. Reynolds number ratio \( (N_r) \) is a significant parameter that influences the flow resistance and therefore the carrying capacity for smooth compound sections. Experimental observations by Myer (1987) show that the Reynolds number of a channel, its floodplain, and the Reynolds’s number ratio are independent of channel slopes and depends only on the channel geometry. Hence the carrying capacity of main channel, flood plain subsection, and the total carrying capacity of the compound channels are the functions of channel geometry only. Therefore the ratio of carrying capacities of main channel or floodplain subsection to the total is proportional to the dimensionless compound channel geometry. In a compound channel, the two significant dimensionless channel geometries are the width ratio \( (\alpha) \) and the relative depth \( (\beta) \). Finally for a straight compound channel with smooth surfaces under uniform conditions, the percentages of ratio of flow in main channel to the total flow can be written as

\[
 \%Q_{mc} = \phi(\alpha, \beta)
\]  

(3)

where \( \%Q_{mc} \) = the percentage of flow in the main channel subsection of a compound channel obtained by the imaginary vertical interface plains of separation. Knight and Demetrious (1983) for their straight channel data have presented an empirical equation for flow carried by the main channel \( (\%Q_{mc}) \) of a compound section separated by vertical interface plane as
\[
\%Q_{mc} = \frac{100}{[(\alpha - 1)/\beta + 1]} + 108 \left( \frac{\alpha - 1}{\alpha} \right)^{\frac{1}{3}} (3.3\beta)^{\frac{4}{\alpha}} e^{-9.9\beta} \tag{4}
\]

where \(\alpha\) and \(\beta\) have their usual meanings defined before. Patra and Kar (2000) modified equation (4) for their meandering compound channel and proposed \(\%Q_{mc}\) as

\[
\%Q_{mc} = \frac{100}{[(\alpha - 1)/\beta + 1]} + 108 \left( \frac{\alpha - 1}{\alpha} \right)^{\frac{1}{3}} (3.3\beta)^{\frac{4}{\alpha}} e^{-9.9\beta} \left[ 1 + 36\beta Ln(S_r)/\delta \right] \tag{5}
\]

where \(S_r\) = the sinuosity of the meandering channels and \(\delta\) = the aspect ratio of main channel = \(b/h\), \(b\) = width of main channel and \(h\) = bank full depth of main channel.

Adequacy of equations (4 and 5) for flow distribution in straight and meandering compound channel for the range of \(\alpha\) up to 5.25 and for sinuosity \((S_r)\) up to 1.22 are discussed by the respective authors. For the present Type-III channel having width ratio \(\alpha = 16.08\) and sinuosity \(S_r = 1.91\), equation (5) gives higher percentages of error between observed and calculated discharges. Though the equation gives satisfactory results for Type-I channel \((\alpha = 3.67)\) and lesser satisfactory for Type-II channel \((\alpha = 4.8)\), it gives very large error for \(\%Q_{mc}\) for Type-III channel. Therefore, the models developed by previous investigators are not valid for channels having very wide floodplain \((\alpha = 16.08)\).

Using the present compound channel data, further analysis is made here to improve equation (4 and 5) for better generalization of equations.

The equations developed by Knight and Demetriou (1983) and Patra and Kar (2000) shows that the percentage of flow carried by the main channel follow linearly to the simple area ratios \((\%A_{mc})\). To know the dependency of \((\%Q_{mc})\) with the area ratio \((\%A_{mc})\) for straight compound channels, the variation of \((\%Q_{mc})\) with the area ratio \((\%A_{mc})\) for the present straight compound channel Type-I and the straight channel of Knight and Demetrious (1983) are plotted in Fig.5. From the plots the best fit power function is found instead of a linear function. The equation for \(\%Q_{mc}\) for a straight compound channel is therefore modeled as

\[
\%Q_{mc} = 1.2338(\%A_{mc})^{0.9643} \tag{6a}
\]

Since for a rectangular main channel \(\frac{A_{mc}}{A} = \frac{1}{(\alpha - 1)/\beta + 1}\) substituting in (6a) we get

\[
\%Q_{mc} = 1.2338 \left[ \frac{100}{(\alpha - 1)/\beta + 1} \right]^{0.9643} \tag{6b}
\]
Fig. 5 Variation of Percentage of Flow in Main Channel ($\%Q_{mc}$) Against Corresponding area of Main Channel for Straight Compound Channels

Fig. 6 (a,b and c) Variation of the difference factor for flow in main channel with relative depth($\beta$), sinuosity($S_r$) and width ratio($\alpha$)
Distribution of zonal flow in a meandering compound channel is further affected by sinuosity. The \( \%Q_{mc} \) of Type-II and Type-III channels is calculated using (6a) and (6b) and is compared with the observed values given in Table 3. From the table, it is seen that due to meandering effect the \( \%Q_{mc} \) decreases with sinuosity. The difference factor due to sinuosity is found out and the variation of this factor with relative depth (\( \beta \)), sinuosity (\( S_r \)), and with width ratio (\( \alpha \)) for \( \%Q_{mc} \) are plotted in Fig.6 (a, b, and c). The best fit functional relationships for \( \%Q_{mc} \) with the parameters are obtained and is given as

\[
\text{Difference factor for } \%Q_{mc} = F_1(\beta^{0.6457}) = F_2\{\ln(1.82\alpha)\} \quad \text{and} \quad F_3\{\ln(1.32S_r)\} \tag{7}
\]

### Table-3 Comparison of Percentage of Flow in Main Channel and Lower Main Channel of Type-II and Type-III with and without Meandering Effect

<table>
<thead>
<tr>
<th>Type-II</th>
<th>( \beta )</th>
<th>0.1228</th>
<th>0.1678</th>
<th>0.2146</th>
<th>0.2537</th>
<th>0.298</th>
<th>0.338</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinuosity ( S_r = 1.44 )</td>
<td>%( Q_{mc} )(With out meandering)</td>
<td>72.30</td>
<td>64.99</td>
<td>58.83</td>
<td>54.53</td>
<td>50.35</td>
<td>47.07</td>
</tr>
<tr>
<td></td>
<td>%( Q_{mc} )(Actual)</td>
<td>70.30</td>
<td>61.79</td>
<td>55.04</td>
<td>50.46</td>
<td>45.65</td>
<td>42.27</td>
</tr>
<tr>
<td>Type-III</td>
<td>( \beta )</td>
<td>0.0846</td>
<td>0.178</td>
<td>0.193</td>
<td>0.2133</td>
<td>0.268</td>
<td>0.28</td>
</tr>
<tr>
<td>Sinuosity ( S_r = 1.91 )</td>
<td>%( Q_{mc} )(With out meandering)</td>
<td>63.63</td>
<td>45.44</td>
<td>43.56</td>
<td>41.32</td>
<td>36.32</td>
<td>35.41</td>
</tr>
<tr>
<td></td>
<td>%( Q_{mc} )(Actual)</td>
<td>61.39</td>
<td>41.44</td>
<td>39.36</td>
<td>36.92</td>
<td>31.62</td>
<td>30.61</td>
</tr>
</tbody>
</table>

Combining all the parameters the difference factor for \( \%Q_{mc} \) is written as

\[
\text{Difference factor} = F_1(\beta^{0.6457}) = F_2\{\ln(1.82\alpha)\} = 5.05\beta^{0.6457}\ln(1.82\alpha)\ln(1.32S_r) \tag{8}
\]

The final dimensionless equation of \( \%Q_{mc} \) for straight compound channel is modeled as

\[
\%Q_{mc} = 1.2338\left[\frac{100}{[(\alpha - 1)\beta + 1]}\right]^{0.9643} - 5.05\beta^{0.6457}\ln(1.82\alpha)\ln(1.32S_r) \tag{9}
\]

The equation is meant for the compound sections for smooth boundaries or with equal roughness in the floodplain and in the main channel. For the meandering compound channel with different roughness the (9) is further written as

\[
\%Q_{mc} = 1.2338\left[\frac{100}{[(\alpha - 1)\beta + 1]}\right]^{0.9643} - 5.05\beta^{0.6457}\ln(1.82\alpha)\ln(1.32S_r)\left[1 + 36\delta\frac{\ln(S_r)}{\delta}\right] \tag{10}
\]

Using (10) the value of \( \%Q_{mc} \) for meandering compound channels can be evaluated.
The variation of computed percentage of flow in main channel with the observed value of Type-I along with channels of Knight and Demetrious (1983) is shown in Fig. 7. Similarly the variation between computed and observed values for Type-II and Type-III meandering compound channels along with results of compound meandering channels of Patra and Kar (2000) is plotted in Fig. 8. Figs. 7 and Fig. 8 show the adequacy of equations 9 and 10 for straight and meandering compound channels for the evaluation of $\%Q_{mc}$ respectively.
CONCLUSIONS

The following conclusions are drawn:

1. The distribution of discharge between the main channel and floodplain sub-sections of a straight and meandering compound channels are examined and a reasonable relationship to predict the sub-section discharge for the types of geometry is proposed.

2. A set of straight and meandering compound channel data of different width ratio varying from 2.00 to 16.08 and depth ratio tested up to 0.4 is studied. The study is also extended to a meandering compound channel of higher sinuosity (1.91) with higher width ratio of (16.08).

3. For a compound channels the important parameters effecting the flow distribution are relative depth ($\beta$) and the width ratio ($\alpha$), Sinuosity ($S_r$) and the relative roughness ($\gamma$). These four dimensionless parameters are used to form general equations representing the total discharge percentage carried by main channel.

4. The proposed analytical model is simple but more reliable and found to gives reasonable results for the compound channel of all types of geometry and sinuosity. The proposed equations give less error for estimation of sub-section discharges for the present channels. The models also have been validated well to the data of Knight and Demetrious (1983) and the data of Patra and Kar (2000).

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;
- $g$ = gravitational acceleration;
- $H$ = depth of flow in main channel;
- $h$ = height of main channel up to floodplain bed;
- $R$ = ratio of amplitude of compound channel to top width $B$;
- $S_r$ = sinuosity of meander channel
- $\alpha$= width ratio = $B/b$;
- $\beta$ = relative depth = $(H-h)/H$;
- $\gamma$= ratio of floodplain roughness to main channel roughness;
- $\delta$= ratio between main channel width to its depth ($b/h$);
- $\rho$ = density of flowing liquid;
- $A_{mc}$ = are the area of main channel
- $A_{fp}$ =flood plain subsections respectively,
- $\tau_{mc}$ = the mean boundary shear stress in main channel per unit length longitudinally
- $\tau_{fp}$ = mean boundary shear stress in flood plain per unit length longitudinally
- $S$ = the longitudinal slope of the channel.
- $%Q_{fp}$= the percentage of shear force carried by the floodplains
- $%Q_{mc}$= the percentage of shear force carried by the floodplains
REFERENCES