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Experimental & Validation of Discharge Prediction Approaches In Straight Two Stage Compound Channels.

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Abstract
The flow pattern of a compound channel becomes complicated due to the transfer of momentum between the main channel and the adjoining floodplains. Experiments are conducted to measure the velocity as well as boundary shear along the wetted perimeter of a compound channel to quantify the momentum transfer along the assumed interfaces originating at the junction region between main channel and flood plain. This is helpful to evaluate of accurately the stage-discharge relationship for a compound channel. Discharge calculation can be done by using various hydraulic models. But the traditional discharge prediction models such as SCM, DCM fail to give accurate discharge as they don't consider the effect of momentum transfer. Therefore some new models are being developed which makes discharge prediction more accurate than the traditional method by considering the effect of momentum transfer. In this paper experimental data reported by other investigators as well as data from the present series of experiments are used through DCM, IDCM and MDCM to evaluate the discharge estimation and the results are compared with the experimental observations.

Keywords – Apparent shear stress, Discharge measurement, Momentum transfer, Secondary current effect, Shear force.

I. INTRODUCTION

During floods, part of the river discharge is carried by the main channel and the rest is carried by the adjacent flood plains. Once water in the river overtops the banks, the cross sectional geometry of flow goes on changing. The channel section becomes compound and the flow structure for such section is affected by large shear layers generated by the difference in velocities of water in the main channel and the floodplain due to the transfer of momentum between them. In a compound channel formation of vortices at the junction of main channel and flood plain was first shown [1]. In [3], authors have stated that the total dragging force on the main channel flow due to floodplain flow at the interfaces should be equal to the accelerating force on the floodplain flow due to the main channel flow due to which transfer of momentum occurs. At lower depths of flow over the floodplain, momentum transfer takes place from the main channel to the floodplain resulting in decrement of the main channel velocity and discharge, while its floodplain components are being increased and at higher depths of flow over the floodplains the process of momentum transfer is reversed, i.e. the momentum is supplied to the main channel from the floodplain and this momentum transfer makes the discharge prediction difficult. The effect of flow interaction between the floodplain and main channel for various depths of flow over floodplain should adequately take care while calculating discharge in the compound channel. There are various traditional methods (SCM, DCM) through which discharge can be predicted. In [7], authors proposed a variable interface plane of separation of compound channel which nullify the momentum transfer for a better estimate of discharge in straight compound river sections. In [6], authors proposed a method by making some correction to the DCM named as coherence method (COHM). In [8], authors parameterized the interface stress in terms of velocity of the main channel and floodplains. In [10], authors quantified momentum transfer in terms of interface length which makes discharge prediction more accurate. Apart from these one dimensional mathematical models, there are some 1D software such as HEC-RAS, SOBEK, MIKE 11, CES which also do better discharge prediction in a compound channel.

II. METHODOLOGY

2.1 Divided Channel Method (DCM)

This classical method employs division of the compound channel to two subsections i.e. the main channel (bank full) and floodplains (berms).The conveyance is calculated for each sub sections considering the interfaces. Again, this method is modified into a few versions distinguishing each other by the way how they consider verticals dividing the compound channel into sub-sections. This includes horizontal interface, vertical interface, diagonal interface, curved interface, variable interface as shown in Fig 1. However vertical interface and diagonal interface are the two methods which are commonly used. Discharge for each sub-section can be calculated by using the Eq.(1) given below.

$$Q = \sqrt{S}\left[\frac{1}{n_{mc}} A_{mc}^{\frac{5}{3}} P_{mc}^{-\frac{2}{3}} + \frac{1}{n_{fp}} A_{fp}^{\frac{5}{3}} P_{fp}^{-\frac{2}{3}}\right] \qquad (1)$$

Where Q = Discharge through the compound channel, A_{mc} & A_{fp} = Area of the main channel and floodplain respectively, P_{mc} & P_{fp} = perimeter of the main channel and floodplain respectively, S_0 = Bed slope of the channel, n_{mc} & n_{fp} = manning's co-efficient for main channel and flood plain respectively.

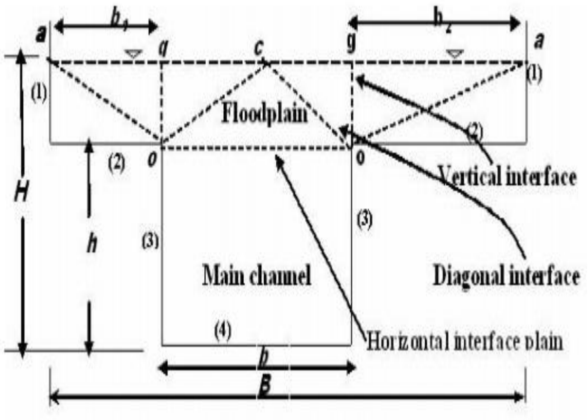


Fig 1: The vertical, horizontal, diagonal interface of a prismatic compound channel.

2.1.1 Vertical interface method

In this method the flood banks are separated from the main channel by means of vertical interface as shown in Fig 1, but the interface length is not included in the calculation of wetted perimeter of either of the over bank flow or main channel flow as this interface is considered as a surface of zero shear stress and no momentum transfer takes place through junction of main channel and flood plain.

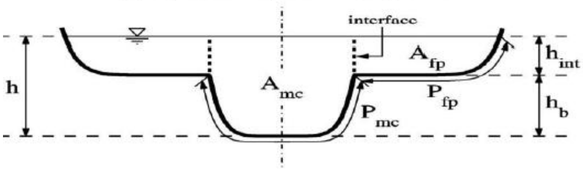
2.1.2. Diagonal Interface method

In this method a diagonal interface is considered from the top of the main channel bank to the centerline of the water surface. This interface is considered to be the surface of zero shear stress and due to that the length is not included in the calculation of wetted perimeter of the over bank flow and main channel flow. The problem with both the methods is, they overestimate the discharge to some extent. So to improve the discharge calculation of a channel, some new methods are being adopted i.e. IDCM and MDCM which give better discharge prediction as compared to the traditional methods like DCM.

2.2. Interacting divided channel method

In this method the channel is divided in to two parts by vertical interfaces and the effect of momentum transfer occurring at the junction of main channel and flood plain is considered in terms of interface stress (τ_{int}).

(a) Symmetric, two floodplains



(b) Asymmetric, one floodplain

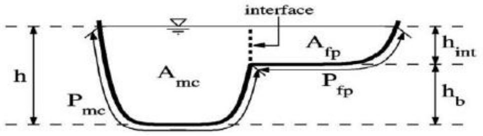


Fig 2: Cross section of a two-stage channel: (a) symmetric with two identical floodplains. (b) asymmetric with one side floodplain.

The following equations have been developed to find out the velocity of the main channel as well as flood plain given as

$$\tau_{int} = \frac{1}{2}\gamma\rho\left(U_{mc}^2 - U_{fp}^2\right) \qquad (2)$$

$$U_{mc}^2 = U_{mc,0}^2 - \frac{\frac{1}{2}\gamma N_{fp}\varepsilon_{mc}\left(U_{mc,0}^2 - U_{fp,0}^2\right)}{1+\frac{1}{2}\gamma\left(N_{fp}\varepsilon_{mc}+\varepsilon_{fp}\right)} \qquad (3)$$

$$U_{fp}^2 = U_{fp,0}^2 + \frac{\frac{1}{2}\gamma\varepsilon_{fp}\left(U_{mc,0}^2 - U_{fp,0}^2\right)}{1+\frac{1}{2}\gamma\left(N_{fp}\varepsilon_{mc}+\varepsilon_{fp}\right)} \qquad (4)$$

Where U_{mc} & U_{fp} are the velocities of main channel and the flood-plain respectively. γ= co-efficient of interface. N_{fp}= number of flood plains. $U_{mc,0}$ & $U_{fp,0}$ = velocities of the main channel and flood plain when $\gamma = 0$. τ_{int} = interface stress developed at the interface of the main channel and flood plain.

$$\varepsilon_{mc} = \frac{h_{int}}{f_{mc}P_{mc}}, \varepsilon_{fp} = \frac{h_{int}}{f_{fp}P_{fp}} \qquad (5)$$

$$U_{mc,0}^2 = \frac{gR_{mc}S}{f_{mc}}, U_{fp,0}^2 = \frac{gR_{fp}S}{f_{fp}} \qquad (6)$$

$$R_{mc} = \frac{A_{mc}}{P_{mc}}, R_{fp} = \frac{A_{fp}}{P_{fp}} \qquad (7)$$

Where f_{mc} & f_{mc} are co-efficient of friction. P_{mc} & P_{fp} are the perimeter of the main channel and flood plain respectively. A_{mc} & A_{fp} are the area for main channel and flood plain respectively. R_{mc} & R_{fp} are the hydraulic radius of main channel and flood plain respectively. h_{int} =difference between the water depth and the full bank level (Fig.2).

After finding out the velocities, discharge (*Q*) of the total section can be predicted through inter acting divided channel method by using equation (8).

$$Q = A_{mc} U_{mc} + N_{fp} A_{fp} U_{fp} \qquad (8)$$

2.3. Modified divided channel method (MDCM)

This method [12] quantified the momentum transfer in terms of interface length. Here the main channel boundary shear to be increased and that of the floodplain decreased suitably to account for main channel and floodplain flow interaction. Let X_{mc}= the interface length for inclusion in the main channel wetted perimeter and X_{fp}= the length of interface to be subtracted from the wetted perimeter of the floodplain (termed as interaction length)

So according to this method, the value of X_{mc}, X_{fp} are found out from Eq (9) and Eq (10).

$$X_{mc} = \frac{100 P_{mc}}{(100 - \%S_{fp})[1 + (\alpha - 1)\beta]} - P_{mc} \qquad (9)$$

$$X_{fp} = P_{fp} - \frac{100(\alpha - 1)\beta}{(\%S_{fp})[1 + (\alpha - 1)\beta]} P_{fp} \qquad (10)$$

Where α = width ratio = B/b; β = relative depth = $\frac{H-h}{H}$, b = width of main channel bottom; B = total width of compound channel; h = bank full depth; and H = total depth of flow. $\%S_{fp}$= percentage of shear force in the flood plains. Knowing $\%S_{fp}$ and the channel geometry, the interface lengths X_{mc} and X_{fp} are evaluated. Next, the discharges for the main channel and floodplain are calculated using Manning's equation and added together to give total discharge as

$$Q = \sqrt{S}\left[\frac{1}{n_{mc}} A_{mc}^{\frac{5}{3}} (P_{mc} + X_{mc})^{-\frac{2}{3}} + \frac{1}{n_{fp}} A_{fp}^{\frac{5}{3}} (P_{fp} + X_{fp})^{-\frac{2}{3}}\right] \qquad (11)$$

Where S = bed slope of both main channel and floodplain (assumed to be the same in 1D models) and n_{mc}, n_{fp} = manning's co-efficient of main channel and floodplain subsections respectively. For rectangular channel and floodplains having homogeneous roughness (i.e., Manning's n value is equal for both the main channel and floodplains). $\%S_{fp}$ is calculated from the Eq (12).

$$\%S_{fp} = 4.105 \left[\frac{100\beta(\alpha - 1)}{1 + \beta(\alpha - 1)}\right]^{0.6917} \qquad (12)$$

So by putting the value of %S*fp*, the value of X_{mc} and X_{fp} can be calculated. After finding out the values of interface length the discharge of the straight compound channel can be estimated.

III. DATA COLLECTION

Experimental discharge data has been collected from FCF (Large scale Flood channel facility created at Wallingford UK) series data (S-1, S-2, S-3, S-8, S-10) and Kinght & Demetriou (1983) (K&D-1, K&D-2, K&D-3) data with varying width ratio α (*B/b*). Stage discharge is calculated by using the Vertical Interface Method (DCM) as well as interacting divided channel method and Modified Divided Channel Method. The results of the all the methods are then compared with the actual discharge (observed discharge) of the collected data set.

IV. RESULTS AND DISCUSSION

By using the given equations for all the above three models, discharge is being computed for each channel cross section (both trapezoidal as well as rectangular straight prismatic channel) with varying depth with different width ratio α (B/b) and the stage discharge curves are generated. Here also the graphs are plotted between relative depth (β) and percentage of error with respect to observed discharge. At lower depth all the three methods gave poor discharge measurement but as the depth of water goes on increasing both IDCM and MDCM performed well.

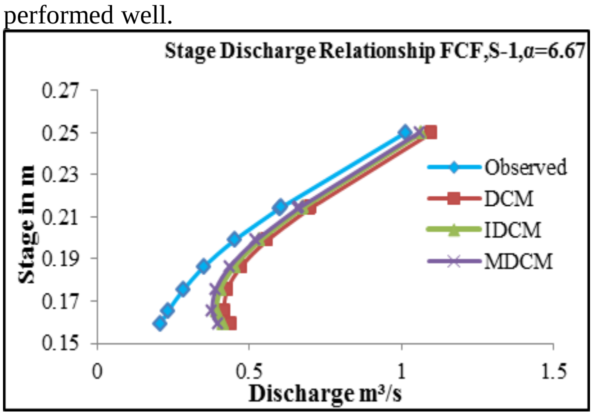
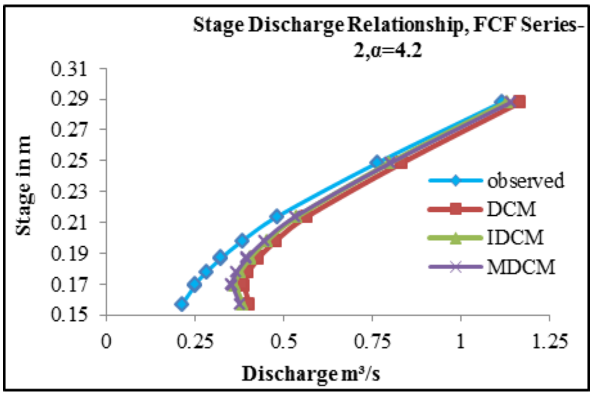


Fig.3



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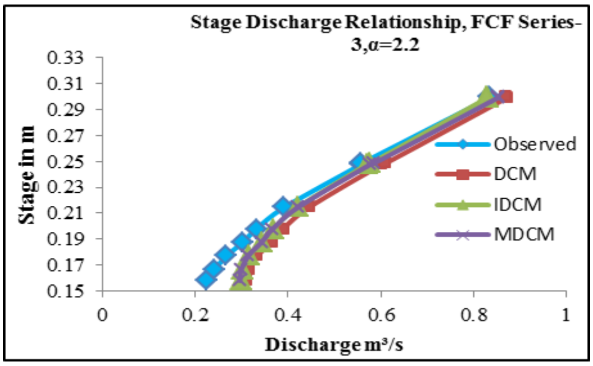

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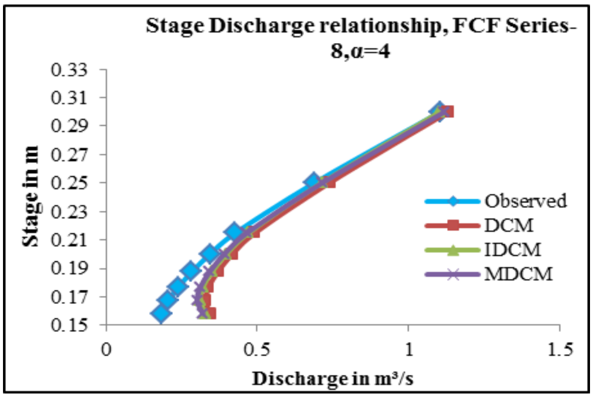

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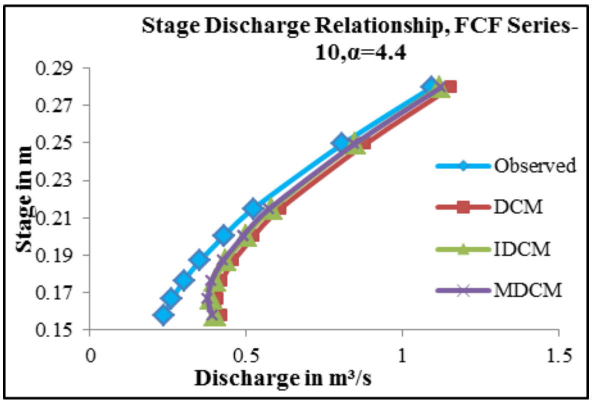

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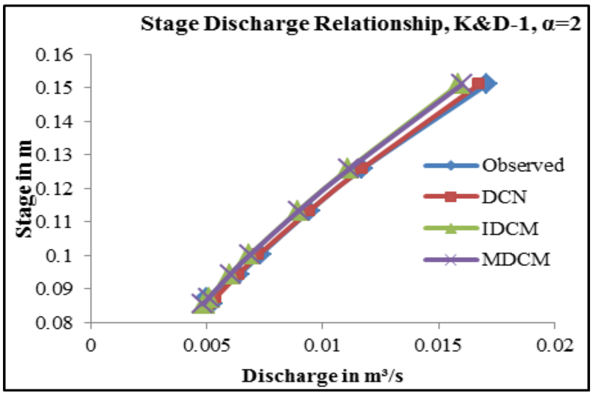

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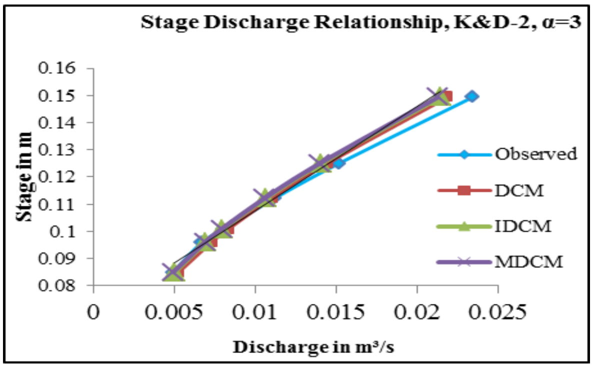

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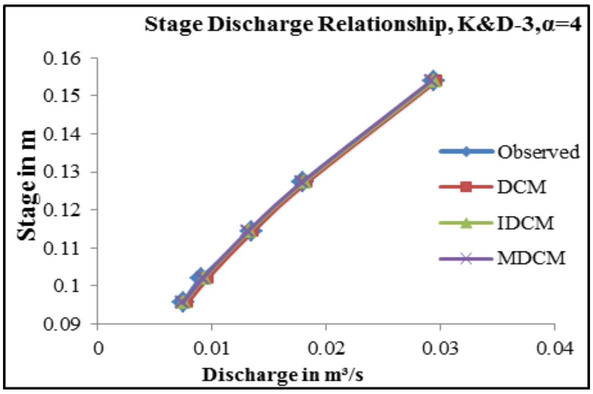

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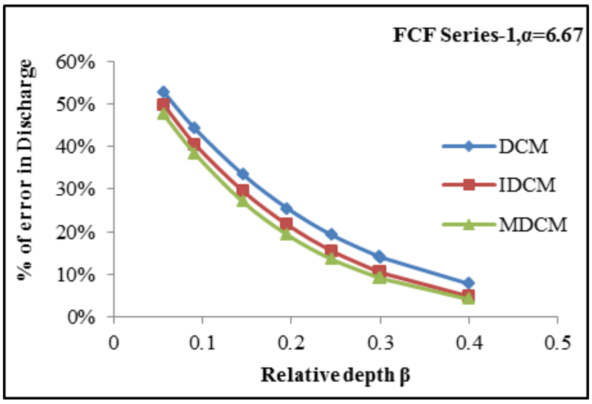

Fig.11

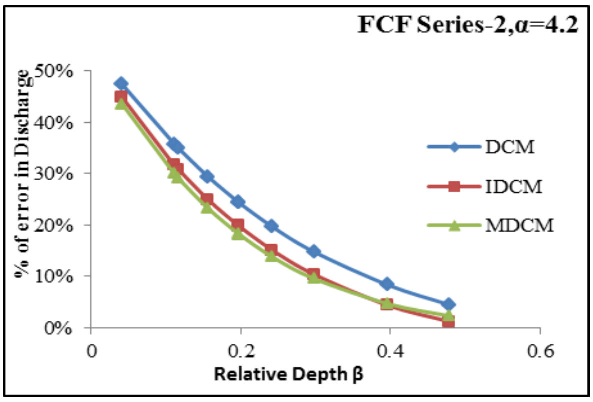

Fig.12

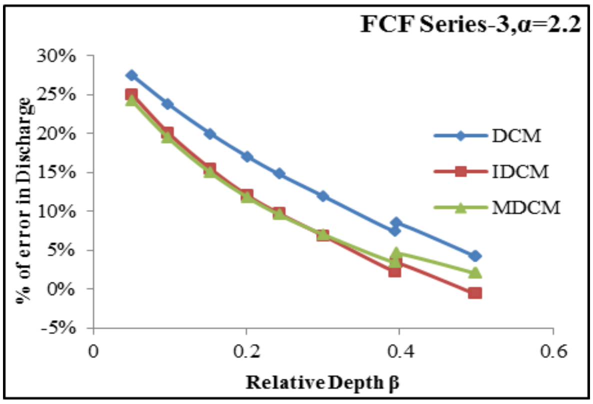

Fig.13

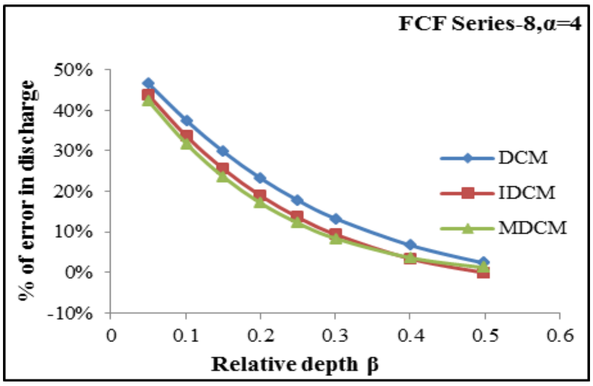

Fig.14

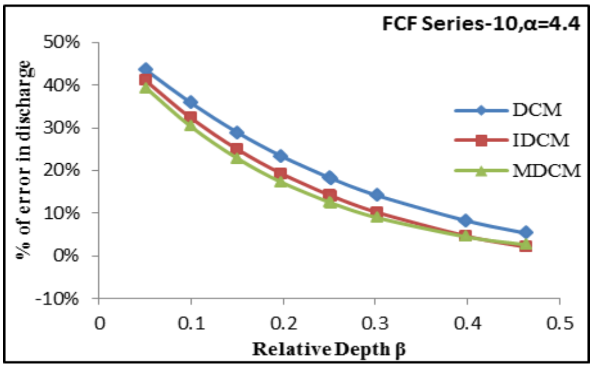

Fig.15

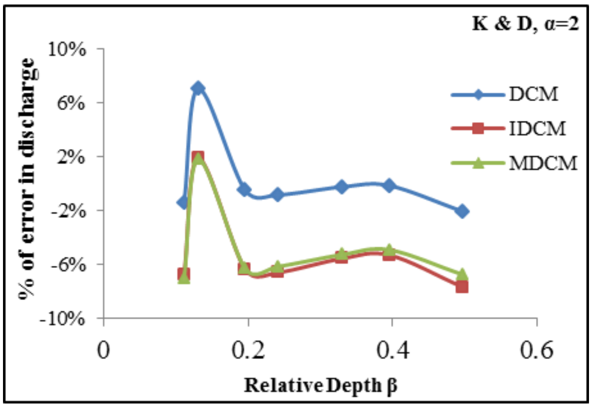

Fig.16

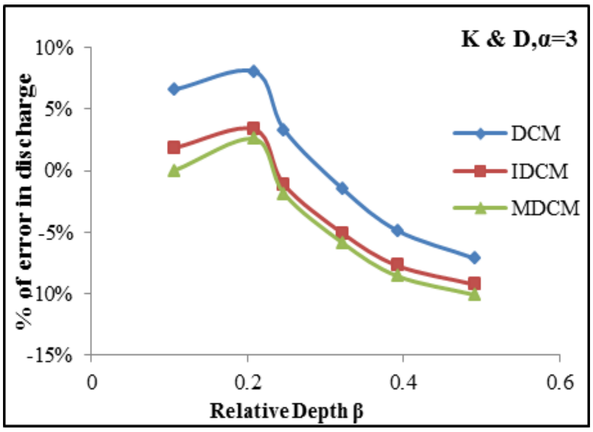

Fig.17

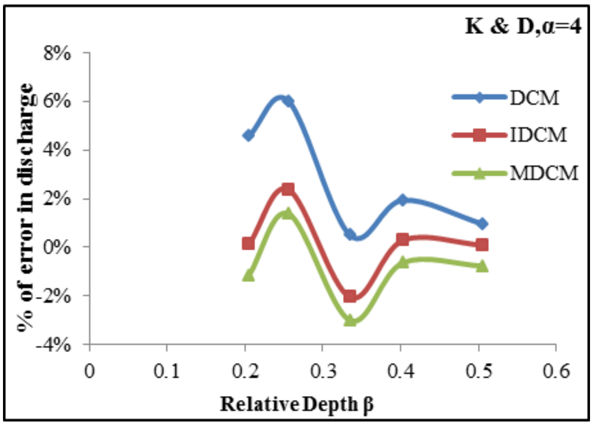

Fig.18

In the Fig 3, Fig 4,…Fig 10 and in Fig 11, Fig 12,…Fig 18 α=width ratio=B/b. B= bottom width of the compound channel, b= bottom width of the main channel.

Fig 3, Fig 4,…Fig 10 show the plot between the depth and discharge . Similarly Fig 11, Fig 12,…Fig 18 show the plots between the relative depth and % of error in discharge with respect to actual discharge

By using the equations of the given models, discharge has been calculated for each channel cross section with varying depth. From the graph it is clearly visible that divided channel method is giving less accurate result than both interacting divided channel method (IDCM) as well as modified divided channel method. Both MDCM and IDCM are giving more or less 5% error between observed and calculated discharge whereas DCM is giving around 10% error. Here positive error shows the over estimation of discharge while negative error shows the under estimation of discharge with respect to the actual discharge.

V. CONCLUSION

By considering different channels with varying cross section and with different width ratio, discharge has been computed through three different methods. Then the results are compared with the actual data that has been collected from different sources.

From the comparison study we got that both IDCM and MDCM gives better discharge prediction as compared to DCM as both IDCM and MDCM considers the effect of momentum transfer in terms of interface stress and interface length respectively, at the junction of the main channel and the flood plain whereas DCM does not consider this effect.

Between MDCM and IDCM, we can say that from the calculation point of view MDCM is much better than IDCM, as it has less number of computational steps for calculation of discharge which leads to less computational error.

One of the limitation of the present study is that ,the work is applied to straight prismatic channels only, while its applicability to other channels such as meandering, curved channel needs to be incorporated and tested.

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