Analysis of Flow in Skewed and Converging Compound Channel

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Abstract - Flow characteristics in compound channels are complex and characterized by the transfer of momentum between the main channel and adjacent floodplain(s). This momentum transfer affects the total channel conveyance and should be accounted for in any flood management or engineering project. Two main process of momentum transfer may be identified as a turbulent exchange, linked to the shear layer development between the main channel and floodplain of a prismatic compound channel; and a geometrical transfer, linked to the mass and flow exchanged between subsections, when the floodplain wetted area is no more constant .This change in momentum and geometry force the researcher for investigating discharge variation Therefore various methods are developed for calculating the discharges by many researchers now-a-days. Generally flows in compound channels with geometries which lie in-between purely prismatic and fully meandering channels cases, namely: skewed channel, symmetrically converging, and diverging channels. We consider only skewed and converging channel for our present analysis. Based on the channel geometry, discharge and water level, SCM and DCM (interface methods) are applied to the both skewed and converging channel and the best suitable methods are discussed.

Keywords- *compound channels, momentum transfer, skewed , converging channels, SCM, DCM*

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I. INTRODUCTION

Compound channels are consist of generally a main river channel and floodplains adjacent to it, are very important for environmental, ecological, and design issues. Therefore, it is essential to understand the flow mechanism of rivers in both their in-bank and overbank conditions. In a flood event the discharge for a particular river may increase so rapidly that the bank-full condition is breached and the flow passes over onto the floodplain. The structure of the flow then becomes more complex by the momentum transfer between the floodplain and the main channel due to the significant dissimilar velocity distributions in these sub-areas. In this case, the prediction of discharge is more difficult than that when the river is flowing just in-bank [7]. The flow mechanisms in straight compound channels are now well-understood (Knight 1999). In the past two decades, many methods for computing overbank flow have been developed based on either one-dimensional (1-D), or two (2-D) and three-dimensional (3-D) hydrodynamic approaches. It is well-known that the single channel method (SCM) underestimates the discharge capacity for compound channels. Most divided channel methods (DCM) overestimate the discharge capacity. Nevertheless, SCM and DCM are still widely used in engineering practice, due to their simplicity in use, and can give satisfactory results under certain conditions. See Wright & Carstens (1970), Wormleaton *et al* (1982), Prinos & Townsend (1984), Wormleaton & Hadjipanos (1985), Myers (1978), Knight & Hamed (1984), Myers *et al* (2001), Cassells *et al* (2001), Seckin (2004) and Atabay (2006) for a comparison of the accuracy of such methods. Early work by Myers & Elsawy (1975), Myers (1978),Wormleaton, *et al* (1982), Knight & Demetriou (1983), Knight & Hamed (1984) indicated the importance of taking into account the main channel/floodplain interaction effects which were first recognized and investigated by Sellin (1964) and Zheleznyakov (1971). Ackers (1993) and Bousmar & Zech (1999) developed 1-D methods; Coherence method (COHM), 1-D Exchange Discharge method (EDM) respectively. Shiono & Knight (1989), Wark *et al* (1990), Lambert & Sellin (1996), Ervine *et al* (2000), and Prooijen *et al* (2005) developed 2-D methods; Shiono & Knight method (SKM), 2-D Lateral Division methods (LDMs), respectively[7]. All these methods take into account momentum transfer due to lateral shear and vorticity at the main channel/floodplain interface. Vertical and horizontal vortices may be induced in straight channels due to the steep velocity gradients at the main channel and floodplain interface for overbank flow. Horizontal interfacial shear is induced by two flows which are acting in different directions, such as the case in meandering or skewed channel flows, Shiono & Muto (1998) found that at low relative depths, Dr=(H-h)/H where *H* is the total flow depth and *h* the bank-full depth, (e.g. Dr=0.15), the out of bank flow in the main channel tended to follow the main channel flow direction, whereas at high relative depths (e.g. Dr=0.25), the out of bank flow was parallel to the floodplains[2]. Although there is many method developed for straight compound channel, converging and skew compound channel but they are complex in nature, since it consider momentum transfer between the main channel and flood plain. But by SCM and DCM (six interface method) method for particular relative depth ratio we are able to find some good results with the experimental value.

Single Channel Method (SCM)

The traditional methods for predicting the discharge conveyed by a compound channel are based on one of the well-known flow formulae, such as the Manning, Chezy or Darcy–Weisbach equations. When predicting the discharge in a compound channel using the Single Channel Method (SCM), the whole compound channel section is treated as a single section and the average velocity can be used to predict the discharge as shown in (1):

$$Q = A * V = \frac{1}{n} AR^{\frac{2}{3}}\sqrt{S_0} = K\sqrt{S_0} \qquad (1)$$

where *K* is the section conveyance, n is the overall roughness coefficients, V is the section mean velocity, R is the hydraulic -perimeter), $S0$ is bed slope.

Divide Channel Method (DCM)

A classical approach of discharge estimation by the river engineers follow is to decompose a compound channel section into reasonable homogeneous subsections by considering imaginary interface plains originating from the main channel and floodplain junctions in such a way that the velocity field in each subsection is taken as uniform. The total discharge is the sum of the sub-area discharges given as

$$Q = \sum_{i=1}^{n} \frac{A_i R_i^{2/3}}{n_i} \sqrt{S_0} \qquad (2)$$

where Q = total discharge, A_i = sub-area cross section area, R_i= sub-area hydraulic radius, n_i = sub-area channel roughness, S_0= the channel slope, and the subscript i stands for each sub- area. This is popularly known as divided channel method (DCM) and it gives us an option to select a division line in the form of a vertical, horizontal or a diagonal plane drawn from the junction between the main channel and the floodplains (Fig.3). Selection of the interface plane for the separation of the compound section to sub-areas can be made using the value of the apparent shear at the assumed interface plane [3]. The three interface planes are both excluded and included in the wetted perimeter of the main channel. But these planes are not considered in the flood plain case. It is the main difference in these methods whether the interface is included to or excluded from the wetted perimeter of the main channel. Once the individual discharges in the main channel and floodplain subsections for any assumed interface are computed, they are summed to obtain the total discharge of the compound channel. To perform the analysis, six different discharge calculation methods will be used as follows: EVIM, IVIM, EHIM, IHIM, EIIM, and IIIM. From the notation of name, E -interface is excluded from the wetted perimeter and I - interface is included to the wetted perimeter of the main channel. On the other hand, V, H and I represent vertical interface, horizontal interface and inclined interface respectively. IM stands for interface method.

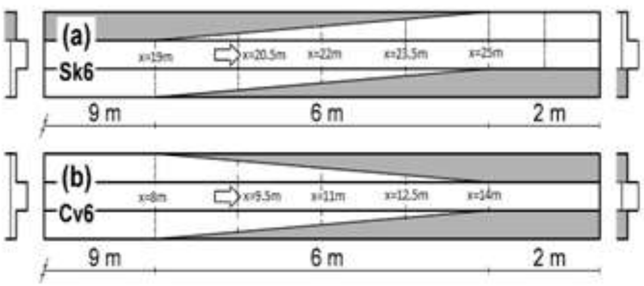

Fig 1: Configuration of the Experimental flume a) skewed b) converging

University of Birmingham flume

The University of Birmingham flume has a total length of 18 m, a depth of 400 mm and a 398 mm wide main channel which is 50 mm deep (Fig. 2). There are two floodplains which are each 398 mm wide. The flume has a bed slope of

radius (= A/P in which A is flow area and P is wetted 0.002003. This flume has been used to study a number of possible channel configurations including prismatic channels with symmetrical or asymmetrical floodplains (Atabay, 2001), non prismatic floodplains i.e converging channel (Rezaei, 2006) and skewed floodplains (Chlebek, 2009). All of the experiments were carried out with rigid boundaries. The non-prismatic geometries were built using movable vertical walls on the floodplains (Fig. 2). The lengh of the upstream prismatic reach was sufficient to ensure complete flow-

Figure 2. Photograph of the University of Birmingham's experimental flume with a skewed geometry

-development. Discharges were measured using a Dall tube, a Venturi meter and an Electromagnetic flow meter. Both local and depth averaged velocities were measured with a mini-propeller meter together with boundary shear stress (using a Preston and Pitot tube arrangement). In the non-prismatic sections, the channel had a total of 6 measuring sections; one at the start of the transition, three intermediate sections, one at the end and one 1m downstream of the end of the transition (Fig 1a). Surface water level data was taken at regular intervals along the entire length of the flume using a pointer gauge, which was fixed onto an instrument carriage which could be read to 0.1 mm. In the skewed channel experiments, the normal depth was set upstream of the transition by adjusting the three tailgates. The actual relative depths corresponding to the discharges were fixed to Dr = 0.205, 0.313, 0.415 and 0.514. Similarly for converging channel experiment (Fig 1b), the actual relative depths corresponding to the discharges were fixed to Dr = 0.224, 0.323, 0.427, and 0.516. Further details on the measuring instruments, procedures, and full data results may be found in Atabay (2001), Rezaei (2006) and Chlebek(2009).

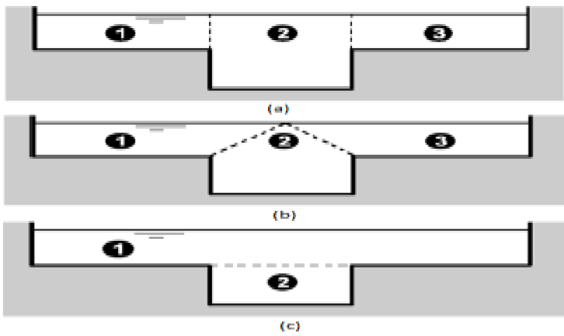

Fig 2: DCM: Possible subsection division a) vertical b) Inclined c) Horizontal

Wormleaton et al. Vertical, horizontal and inclined division planes are used for dividing the compound channel to estimate the capacity. However some assumptions are there

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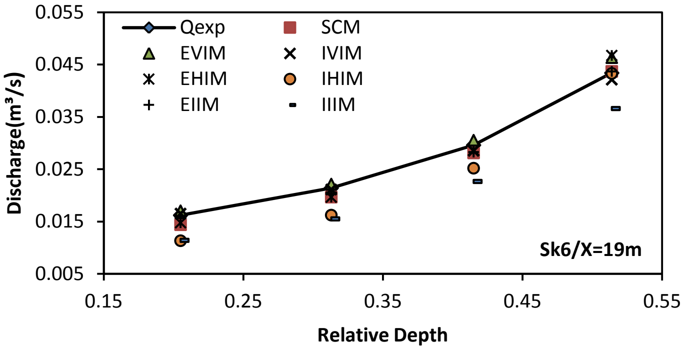
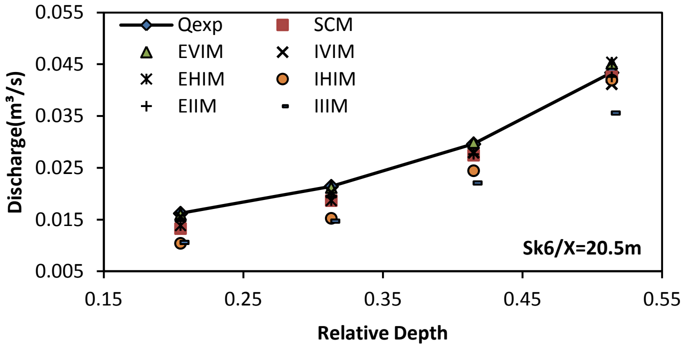
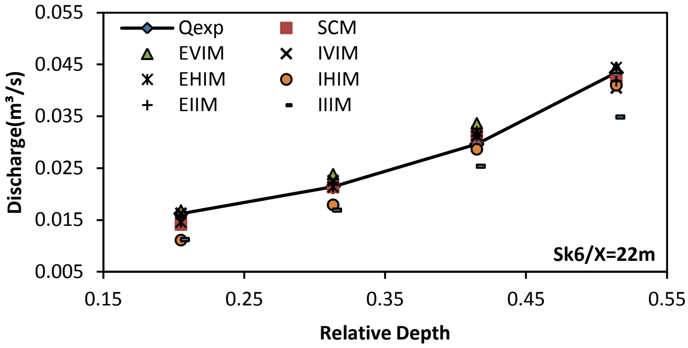
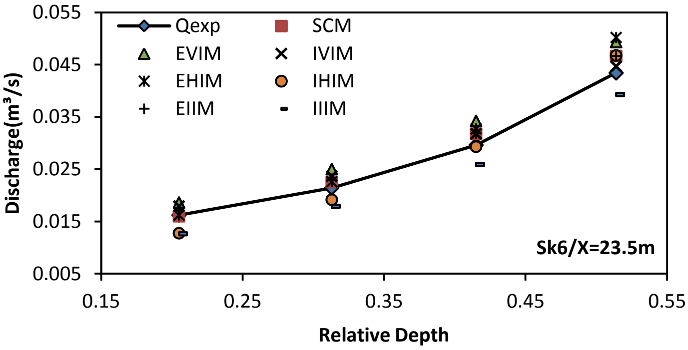
for making of subdivision which make different in this six methods regarding the location of the imaginary interface plane [8]. The most chosen location of those subdivisions is shown in Fig. 3. The uniform flow equation i.e. manning's equation is adopted for finding out the flow rate in every sub divisional cross section and the equation for main channel and flood plains are given in (3) and (4)









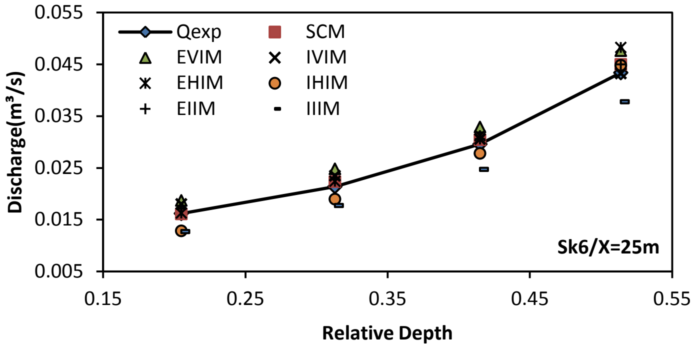
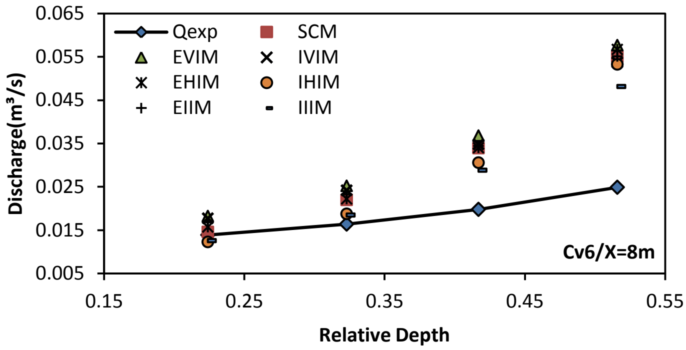
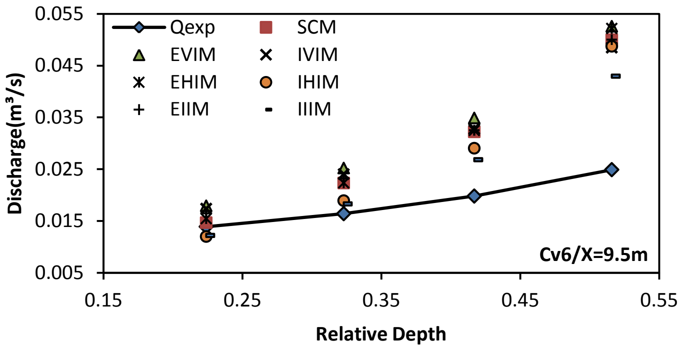
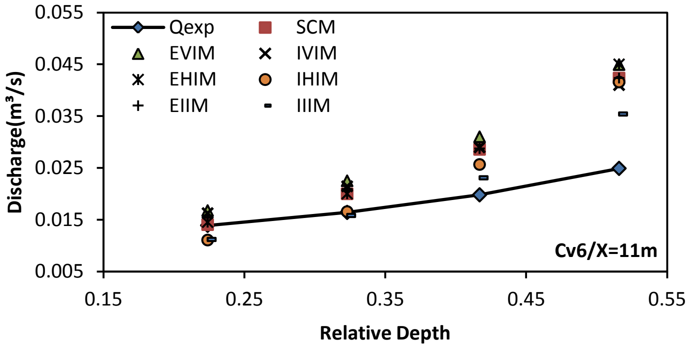


Fig 4: Computed Discharges for five different section in the skewed compound channel for relative depth *Dr* = 0.205, 0.313, 0.415 and 0.514







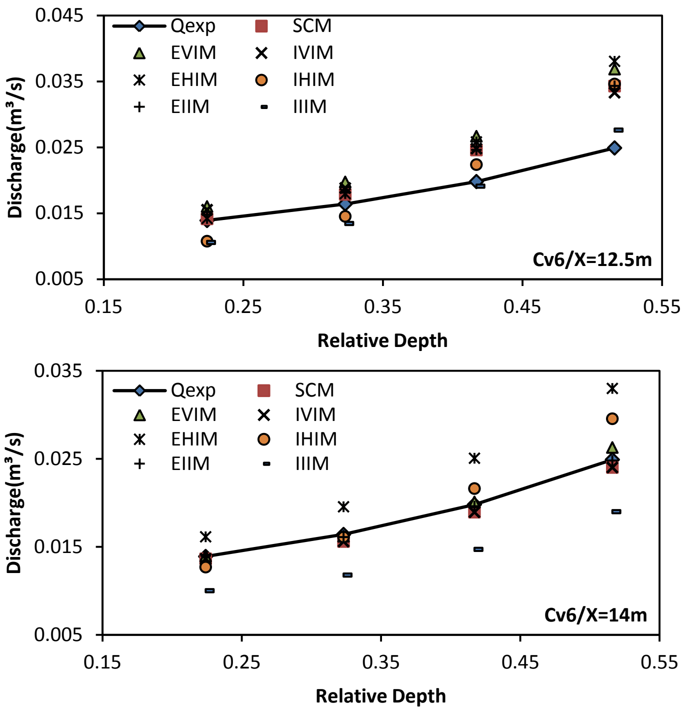


Fig 5: Computed Discharges for five different section in the converging compound channel for relative depth *Dr* = 0.224, 0.323, 0.427, and 0.516

$$Q_{mc} = \frac{A_{mc}}{n_{mc}} R_{mc}^{\frac{2}{3}} \sqrt{S_0}$$

$$Q_f = \frac{A_f}{n_f} R_f^{\frac{2}{3}} \sqrt{S_0} \quad (4)$$

Where:Q_{mc} = Rate of flow of the main channel; A_{mc}=Area of the main channel; R_{mc}=hydraulic radius of the main channel; n_{mc} = Manning's roughness coefficient of the main channel; nf = Manning's roughness coefficient of floodplain; Q_f = Rate of flow of the flood plain; A_f=Area of the flood plain; Rf = Af/Pf = hydraulic radius of the flood plain; S_0=bed slope Then the total discharge capacity for an asymmetric compound channel is found out by adding the flow through main channel and flood plain.

$$Q = Q_{mc} + Q_f \quad (5)$$

TABLE-I Error Analysis For Skew Channel

Relative Depth	Percentage of Error						
	SCM	EVIM	IVIM	EHIM	IHIM	EIIM	IIIM
0.205	8.80	8.13	5.66	6.81	27.85	5.63	27.73
0.313	6.19	9.70	6.47	6.26	18.23	6.05	22.67
0.415	5.55	8.89	5.04	6.69	8.54	5.50	18.44
0.514	3.49	7.29	3.64	8.30	4.04	3.50	15.16

TABLE-II Error Analysis For Converging Channel

Relative Depth	Percentage of Error						
	SCM	EVIM	IVIM	EHIM	IHIM	EIIM	IIIM
0.224	3.04	19.31	16.61	9.35	15.41	11.38	18.66
0.323	21.18	33.31	28.88	24.46	8.79	24.28	14.80
0.417	41.38	50.98	43.43	47.95	30.57	41.71	25.38
0.516	66.65	75.38	62.43	80.65	66.83	66.07	48.53

II. RESULTS AND DISCUSSION

A series of converging and skew experimental data have been collected from The University of Birmingham flume [2, 6]. Discharge data, relative depth and dimensions are considered for present analysis. Then discharge is calculated by using Single channel method as well as divided channel method with excluded and included interface methods. The results of the both method is then compared with the actual discharge of the collected data for the both non prismatic channel. The graphical representation is to study the effect of flow variables for skew and converging compound channels. Discharges of a single skew part with varying relative depth (0.205, 0.313, 0.415 and 0.514) are shown in the Fig 4 for five different cross section such as x=19m, 20.5m, 22m, 23.5m, and 25m. The percentage of error of each method is presented in TABLE I. From Fig. 4 for all section it was found that SCM, EHIM and IVIM measure well for skew channel. And other methods are under estimating the flow but for high relative depth they are over estimating (IIIM under estimating) with a large error. From TABLE I it was found that, for lower relative depth i.e. 0.2 and 0.3, EIIM and IVIM and for higher relative depth *Dr* = 0.4, SCM, IVIM and EIIM and for *Dr*=0.5, SCM, IVIM, IHIM and EIIM gives best result with minimum error less than 6%. Similarly discharges of a single converging part with varying relative depth (0.224, 0.323, 0.427, and 0.516) are shown in the Fig 5 for five different cross section such as x=8m, 9.5m, 11m, 12.5m, and 13m. The percentage of error of each method is presented in TABLE II. It has been observed from Fig. 5 that for lower relative depth 0.2 all method measures well except EHIM and IIIM. As the converging part goes on increasing and with the higher relative depth ratio, no method gives satisfactory discharge value. From TABLE II, for lower relative depth i.e. 0.2, SCM and for 0.3, IHIM and for higher relative depth Dr=0.4 and 0.5, no methods can be applied. Hence only SCM gives good agreement with the discharge value for lower depth ratio *Dr*=0.2 with error of 3%.

III. CONCLUSION

By considering skew and converging channels with varying cross section with different relative depth, discharge has been computed through seven methods. The results are well compared with the actual data that has been collected from different paper. From the comparison of result as shown in the graphs, EIIM do better discharge prediction in skew channel. But no method should be applied in fully converging part if we consider for higher relative depth. It is due to the momentum transfer in terms of interface stress at the junction of the main channel and the flood plain. But at the end up of the converging part, (Fig. 5, at section x=14m) SCM and vertical interface methods (IVIM and EVIM) are suitable for measuring the discharge.

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