Proceedings of the 37th IAHR World Congress
August 13 – 18, 2017, Kuala Lumpur, Malaysia

# IMPROVED DISCHARGE PREDICTION OF STRAIGHT COMPOUND CHANNELS BASED ON ENERGY TRANSITION

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## ABSTRACT

Accurate estimation of flow discharge in a compound river channel is increasingly important in river management and eco-environment design. In this paper, a new model is proposed to improve the prediction of flow based on Energy Concept Method (ECM) and Weighted Divided Channel Method (WDCM) along with the apparent shear stress at the interface between main channel and floodplain. The new model is compared with a wide range of our experimental data and the data available in the literature. The 26 datasets used include homogenously roughened symmetric channels (22 datasets) and asymmetric channels (4 datasets) with various aspect ratios [channel total width ($B$) at bankfull / main channel bottom ($b$) =1.5 ~ 15.8] and bed slopes ($S_o$ = 4.3x10$^{-4}$ ~1.3x10$^{-2}$). It is found that the new model has significantly improved the accuracy of flow prediction compared with the ECM and DCM methods against all the datasets, particularly for relatively low flow depths of floodplain where the flow discharge is most difficult to predict correctly. The new model predicts the total discharge well for both symmetric and asymmetric channels, within an averaged relative error of 5%.

**Keywords:** Overbank flow; compound channel flow; energy transition; zonal discharge; symmetric and asymmetric channel.

## 1 INTRODUCTION

Many natural rivers and man-made channels have a compound cross-section, which consists of one deep main channel bounded with one or two shallow floodplains. Such a compound channel will increase conveyance capacity of channel in times of floods when the flow is above the bankfull stage, or provide environmental friendly space in the floodplain where no flow exists in dry seasons. Conventional one-dimensional (1-D) channel divisional methods, namely the Single Channel Method (SCM) and the Divided Channel Method (DCM), are still widely used to predict discharge in practice because of their simplicity. However, it is well-known that these methods either under-estimate or over-estimate channel discharge (Wormleaton et al., 1982; Knight et al., 1984; Tang & Knight, 2007; Yang et al., 2007). When a floodplain is inundated, the velocity differences between the main channel and floodplain result in a mixing shear layer due to lateral momentum exchange. Sellin (1964) carried out experimental study on the mechanism of momentum transfer in a compound channel; afterward many other researches indicated the importance of taking into account the main channel / floodplain interaction effects in the prediction of compound channel discharge (Wormleaton et al., 1982; Knight & Demetriou, 1983; Knight & Hamed, 1984; Prinos & Townsend, 1984; Christodoulou, 1992).

Despite the availability of 2-D or 3-D approaches that takes into account the interaction between the main channel and floodplain, e.g. Krishnappan and Lau (1986), Shiono and Knight (1991), Cater and Williams (2008), Marjang and Merkley (2009), they are usually very complex and require more information and turbulence coefficients, which are not available. 1-D approach has still been developing ever since due to its simplicity and practical significance.

In the river management and environmental assessment, it is required precisely to predict not only the overall discharge but also zonal discharge (i.e. both main channel and floodplain discharge) in a compound river channel. Various 1-D methods have recently been developed to improve the prediction of flow discharge. These recently developed methods, for example, include the Weighted Divided Channel Method (WDCM) by Lambert & Myers (1998), the Interacting Divided Channel Method by Huthoff et al. (2008), the Energy Concept Method (ECM) by Yang et al. (2012), the Apparent Shear Stress Method (ASSM) (Wormleaton & Merrett, 1990; Christodoulou, 1992; Moreta & Martin-Vide, 2010), and the Modified Divided Channel Method (Khatua et al., 2012; Mohanty & Khatua, 2014; Devi et al., 2016). These methods have taken into account the effect of the lateral momentum exchange either directly or indirectly, and they were developed and validated based on their own limit data. Most recently, Tang (2016) compared these methods against a large set of data in homogenous compound channels and concluded that they predict the total discharge reasonably well within an averaged error of 8% for symmetric compound channels, but do not for asymmetric channels, particularly in the prediction of zonal discharge. Moreover, none of these recently developed methods can predict discharge well in relatively low flow depths of floodplain.

In this paper, we develop a new model to improve the prediction of flow discharge against a wide range of 26 datasets, based on the ECM and WDCM along with the apparent shear stress at the interface between the main channel and floodplain. These datasets include data of both symmetric and asymmetric compound channels with different bed slopes. The new model has significantly improved the accuracy of flow prediction compared with the ECM against all the datasets, particularly for relatively low flow depths of floodplain where the flows are most difficult to predict correctly.

## 2 METHOD

For the convenience of reference in the subsequent sections, Figure 1 shows the sketched cross-sections of symmetric and asymmetric compound channels, where $H$, $h$ and $h_f$ are the flow depths of main channel, bankfull, and floodplain (subscript *f*), respectively; $b$ and $b_f$ are the widths of main channel bottom and floodplain, respectively; $S_c$and $S_f$ are the side slopes of main channel and floodplain, respectively.

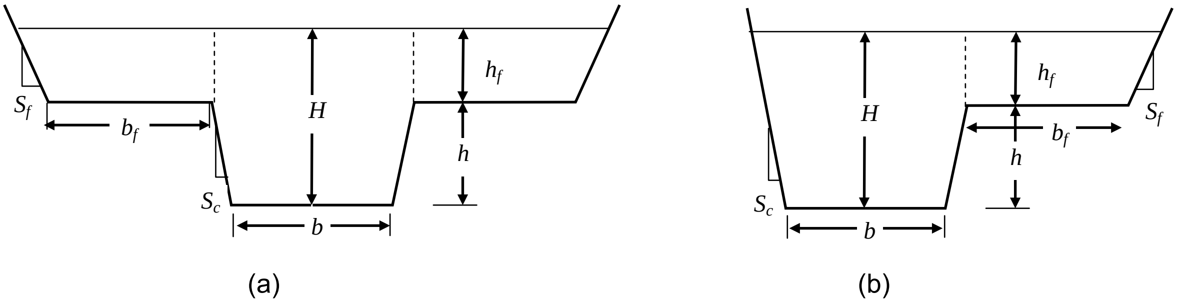


**Figure 1.** Sketched cross-sections of compound channels: (a) symmetric, (b) asymmetric cross-section.

In the present paper, the new developed model is based on the Energy Concept Method (ECM) proposed by Yang (2012), and the basic discharge is assessed based on the Weighted Divided Channel Method (WDCM) proposed by Lambert & Myers (1998). In the following section, it is necessary to briefly introduce the ECM, followed by the new model.

### 2.1 Energy concept method (ECM)

Consider a water body of unit length in an open channel, the total energy $E_t$ per unit time can be described by

$$E_t = \rho g S_f Q_t \qquad [1]$$

where $\rho$ is the density of water, $g$ is the gravitational acceleration, $S_f$ is the energy slope, and $Q_t$ is the total discharge.

In a compound channel, the energy loss and transition take place along both the vertical ($z$-direction) and transverse ($y$-direction) directions due to the existence of velocity difference, as illustrated in Figure 2. Based on energy conservation, $E_t$ has to be equal to the energy loss and transition along both directions, resulting in

$$E_t = E_{LV}^t + E_{TV}^t + E_{LT}^t + E_{TT}^t \qquad [2]$$

where $E_{LV}^t$and $E_{TV}^t$ are the total energy loss and transition along the vertical direction, respectively; $E_{LT}^t$ and $E_{TT}^t$ are the total energy loss and transition along the transverse direction, respectively. Replacing $E_t$ of Eq. [1] by Eq. [2] generates

$$Q_t = \frac{1}{\rho g S_f}(E_{LV}^t + E_{TV}^t + E_{LT}^t + E_{TT}^t) \qquad [3]$$

Referring to Figure 2, the energy loss and transition in Eq. [3] can be described as follows:

- In the vertical direction (see Figure 2a):

$$E_{LV} = \tau \frac{du}{dz}\ ; \quad E_{TV} = -\frac{d(\tau u)}{dz} \qquad [4]$$

where the shear stress ($\tau$) of steady uniform flow can be described as (Chow 1959)

$$\tau = \rho g(H - z)S_f \qquad [5]$$

Inserting Eq. [5] into Eq. [4], the total energy loss and transition become

$$E_{LV}^t = \int_0^H \int_0^B \tau du\, dy = \int_0^H \int_0^B \rho g(H - z)S_f du\, dy = \rho g S_f Q \qquad [6]$$

$$E_{TV}^t = -\int_0^H \int_0^B d(\tau u)\, dy = -B \int_0^H d(\tau u) = 0 \qquad [7]$$

where $H$ is the flow depth, and $B$ is the width of channel.

- In the transverse direction (see Figure 2b):

$$E_{LT} = \tau_a \frac{du_d}{dy}\ ; \quad E_{TT} = \frac{d(\tau_a u_d)}{dy} \qquad [8]$$

where $u_d$ is the depth-averaged velocity, and $u_d$ is the apparent shear stress.

By considering the mixing zone from $B_l$ to $B_r$ in the lateral direction with $H_i$ being the average depth of the zone, the total energy loss and transition can be expressed as

$$E_{LT}^t = \int_0^{H_i} \int_{B_l}^{B_r} E_{LT}\, dydz = \int_0^{H_i} \int_{B_l}^{B_r} \frac{\tau_a du_d}{dy} dydz \qquad [9]$$

$$E_{TT}^t = \int_0^{H_i} \int_{B_l}^{B_r} E_{TT}\, dydz = \int_0^{H_i} \int_{B_l}^{B_r} d(\tau_a u_d)\, dz \qquad [10]$$

In the mixing zone, it may be assumed that

$$H_i = \frac{H + h_f}{2}\ ; \quad \frac{du_d}{dy} = \frac{V_c - V_f}{B_i} \qquad [11]$$

where $B_i$ is the average width of the mixing zone, and $V_c$ and $V_f$ are the average velocities of main channel and floodplain, respectively.

Therefore, inserting Eq. [11] into Eqs. [9] and [10] gives

$$E_{LT}^t = \frac{V_c - V_f}{B_i} \int_0^{H_i} \int_{B_l}^{B_r} \tau_a\, dydz = \left(\frac{V_c - V_f}{B_i}\right) H_i \int_{B_l}^{B_r} \tau_a\, dy \qquad [12]$$

$$E_{TT}^t = \int_0^{H_i} \left[(\tau_a u_d)\big|_{B_l}^{B_r}\right] dz \qquad [13]$$

The apparent shear stress ($\tau_a$) can approximately be assumed as a linear variation on either side of the interface (Shiono & Knight, 1991). Therefore, Eqs. [12] and [13] become

$$E_{LT}^t = \frac{1}{4}\left(V_c - V_f\right)\left(H + h_f\right)\tau_a^m \qquad [14]$$

$$E_{TT}^t = 0 [15]$$

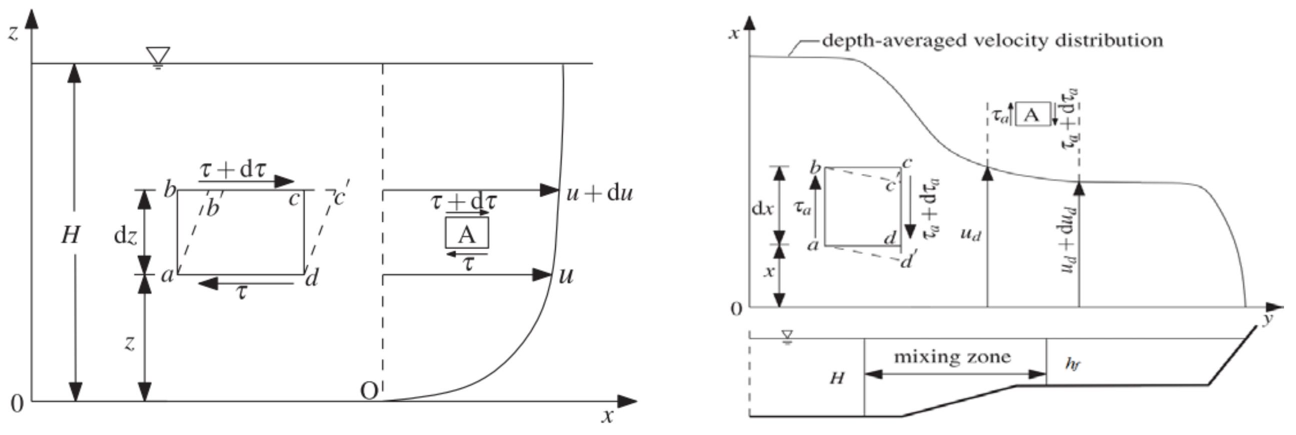
Thus, inserting Eqs. [6-7], [14-15] into Eq. [3], rearranging the resulting equation yields

$$Q_t = Q \quad - \frac{\tau_a^m (H + h_f)(V_{c,0} - V_{f,0})}{4\rho g S_o} \qquad [16]$$

where $Q$ is the discharge without considering the impact of momentum exchange, the subscript (,0) denotes the values using the DCM, and the apparent shear stress ($\tau_a^m$) at the interface may be evaluated by the following formula

$$\tau_a^m = \frac{1}{2}\rho \alpha_m (V_c^2 - V_f^2) \qquad [17]$$

or



(a) (b)

**Figure 2.** Shear stress over an element in a compound channel: (a) vertical, (b) lateral direction.

$$\tau_a^m = \frac{1}{2}\rho\alpha_d(V_{c,0} - V_{f,0})^2 \qquad [18]$$

where various values are proposed for the parameters ($\alpha_m$ or $\alpha_d$). Yang et al. (2012) evaluated Eq. [16] by examining various formulae of $\tau_a^m$, as given by Eqs. [17] and [18]. They recommended to use Eq. [18] with $\alpha_d$= 0.01$B/b$, which was proposed by Christodoulou (1992) due to its simplicity and accuracy in the calculation. Furthermore, they also used the DCM to evaluate $Q$ in Eq. [16]. Therefore, Yang et al. [2012] rewrote Eq. [16] as the following expression, called the ECM method in this paper.

$$Q_t = Q_{c,0} + Q_{f,0} - \frac{\tau_a^m(H+h_f)(V_{c,0}-V_{f,0})}{4\rho g S_o} \qquad [19]$$

2.2 New model

In the derivation of Eq. [16], $H_i$ was assumed as the averaged depth in the mixing zone, while $\tau_a^m$ was taken as the apparent shear stress at the interface between the main channel and floodplain. These two assumptions arguably are not consistent each other. Therefore, it would be appropriate to take $H_i$ as the depth ($h_f$) at the interface. Therefore, Eq. [16] can be expressed as

$$Q_t = Q \quad - \frac{\tau_a^m h_f(V_{c,0}-V_{f,0})}{2\rho g S_o} \qquad [20]$$

Furthermore, Yang et al. (2012) also recommended the DCM to calculate $Q$ on the right side of Eq. [16], but it is well known that the DCM method over-estimates discharge. In this paper, we thus recommended the $Q$ to be evaluated by the WDCM method that Lambert & Myers (1998) proposed, since the WDCM has been demonstrated to improve the prediction of total discharge over the DCM (Lambert & Myers, 1998; Atabay & Knight, 2006; Tang & Knight, 2007). To obtain the total discharge ($Q$), the WDCM method uses the improved velocities for the main channel and its floodplain calculated from both vertical divided method (DCM) and horizontal division method (HDM), respectively, through a weighing factor ($\zeta$), shown as follows:

$$V_C = \xi V_{C-DCM} + (1-\xi)V_{C-HDM} \qquad [21]$$

$$V_f = \xi V_{f-DCM} + (1-\xi)V_{f-HDM} \qquad [22]$$

where $\xi$ ranges from 0 to 1. Lambert & Myers (1998) recommended the $\xi$ value to be 0.5 for homogeneous compound channels, which was well established by Atabay & Knight (2006) and Tang & Knight (2007). Hence, 0.5 was used for $\xi$ in this paper.

Finally, for the consistence of comparison with the ECM, Eq. [18] was used for $\tau_a^m$ of Eq. [20] in the proposed new model and the corresponding parameter $\alpha_d$ was taken as the same as 0.01$B/b$ proposed by Christodoulou (1992).

## 3 DATA FOR ANALYSIS

To test the new model in Section 2.2, we used a wide range of different experimental data in homogeneous compound channels. These data are from www.flowdata.bham.ac.uk (created by the author of this paper) and the literature. 26 datasets used includes 22 datasets of symmetric compound channel and 4 datasets of asymmetric compound channel, with the aspect ratio ($B/b$) being 1.5 ~ 15.8 and the bed slope being $S_o$ = 4.3x10$^{-4}$ ~1.3x10$^{-2}$. The datasets also cover various channel cross-sections (rectangular or trapezoidal) either symmetric or asymmetric. The details are shown in Table 1, where $N_f$ is the number of floodplain, $N$ is the number of experiment runs, $D_r$ is the relative depth of floodplain (= $h_f/H$), $n$ is the Manning coefficient, and other notations see Figure 1.

We chose the abovementioned datasets as they are widely used to validate various other methods in the literature. So those datasets were used to test the robustness of the new model proposed in this paper.

**Table 1.** Details of experimental datasets of homogeneous compound channels.

| Series | $N_f$ | $N$ | $n$ | $h$ (m) | $b_f$ (m) | $b$ (m) | $B/b$ | $S_c$ | $S_f$ | $Q_t$ (m$^3$/s) | $D_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FCF data (1992), $S_o$= 0.001027 | | | | | | | | | | | |
| **FCF1** | 2 | 8 | 0.01 | 0.15 | 4.10 | 1.50 | 6.67 | 1 | 0 | 0.2082-1.0145 | 0.056-0.400 |
| **FCF2** | 2 | 10 | 0.01 | 0.15 | 2.25 | 1.50 | 4.20 | 1 | 1 | 0.2123-1.1142 | 0.041-0.479 |
| **FCF3** | 2 | 10 | 0.01 | 0.15 | 0.75 | 1.50 | 2.20 | 1 | 1 | 0.2251-0.8349 | 0.051-0.500 |
| **FCF6** | 1 | 8 | 0.01 | 0.15 | 2.25 | 1.50 | 2.70 | 1 | 1 | 0.2240-0.9290 | 0.052-0.503 |
| **FCF8** | 2 | 8 | 0.01 | 0.15 | 2.25 | 1.50 | 4.00 | 0 | 1 | 0.1858-1.1034 | 0.050-0.499 |
| **FCF10** | 2 | 9 | 0.01 | 0.15 | 2.25 | 1.50 | 4.40 | 2 | 1 | 0.2368-1.0939 | 0.051-0.464 |
| University of Birmingham (2001), $S_o$=0.002024 | | | | | | | | | | | |
| **BU-S** | 2 | 11 | 0.0091 | 0.05 | 0.4073 | 0.398 | 3.05 | 0 | 0 | 0.0154-0.0552 | 0.162-0.475 |
| **BU-A** | 1 | 13 | 0.0091 | 0.05 | 0.4073 | 0.398 | 2.02 | 0 | 0 | 0.0150-0.0499 | 0.184-0.529 |
| Knight and Demetriou (1983), $S_o$=0.000966 | | | | | | | | | | | |
| **KD83A** | 2 | 6 | 0.0090 | 0.076 | 0.076 | 0.152 | 2.00 | 0 | 0 | 0.0052-0.0171 | 0.108-0.409 |
| **KD83B** | 2 | 5 | 0.0093 | 0.076 | 0.152 | 0.152 | 3.00 | 0 | 0 | 0.0050-0.0234 | 0.131-0.491 |
| **KD83C** | 2 | 6 | 0.0097 | 0.076 | 0.229 | 0.152 | 4.00 | 0 | 0 | 0.0049-0.0294 | 0.106-0.506 |
| Bahram (2006), $S_o$=0.002003 | | | | | | | | | | | |
| **BD01** | 2 | 10 | 0.0091 | 0.05 | 0.10 | 0.398 | 5.26 | 0 | 0 | 0.0120-0.0451 | 0.053-0.536 |
| **BD02** | 2 | 11 | 0.0091 | 0.05 | 0.20 | 0.398 | 5.26 | 0 | 0 | 0.0120-0.0500 | 0.051-0.522 |
| **BD03** | 2 | 11 | 0.0091 | 0.05 | 0.30 | 0.398 | 5.26 | 0 | 0 | 0.0120-0.0501 | 0.062-0.487 |
| **BD04** | 2 | 9 | 0.0091 | 0.05 | 0.40 | 0.398 | 3.83 | 0 | 0 | 0.0121-0.0501 | 0.086-0.468 |
| Khatua et al. (2012), $S_o$=0.0019 | | | | | | | | | | | |
| **KH01** | 2 | 5 | 0.0108 | 0.120 | 0.16 | 0.12 | 3.67 | 0 | 0 | 0.0087-0.0391 | 0.118-0.461 |
| Mohanty and Khatua (2014), $S_o$=0.0011 | | | | | | | | | | | |
| **KH02** | 2 | 6 | 0.01 | 0.065 | 1.745 | 0.330 | 11.97 | 1 | 0 | 0.0150-0.1062 | 0.073-0.115 |
| Patra et al. (2012), $S_o$=0.000311 | | | | | | | | | | | |
| **Patra** | 2 | 7 | 0.0098 | 0.08 | 0.805 | 0.12 | 15.75 | 1 | 0 | 0.0494-0.0958 | 0.111-0.136 |
| Prinos and Townsend (1984), $S_o$=0.0003 | | | | | | | | | | | |
| **PT01** | 2 | 5 | 0.011 | 0.102 | 0.381 | 0.203 | 5.26 | 0.5 | 0 | 0.0066-0.0205 | 0.089-0.328 |
| **PT02** | 2 | 5 | 0.011 | 0.102 | 0.381 | 0.305 | 3.83 | 0.5 | 0 | 0.0106-0.026 | 0.089-0.328 |
| Noutsopoulos and Hadjipanos (1983), $S_o$=0.0015 | | | | | | | | | | | |
| **NH-A1** | 2 | 5 | 0.01 | 0.075 | 0.425 | 0.15 | 6.67 | 0 | 0 | 0.0090-0.0450 | 0.186-0.459 |
| **NH-A3** | 2 | 6 | 0.01 | 0.075 | 0.325 | 0.15 | 5.33 | 0 | 0 | 0.0150-0.0370 | 0.285-0.468 |
| **NH-A4** | 3 | 5 | 0.01 | 0.075 | 0.225 | 0.15 | 4.00 | 0 | 1 | 0.0100-0.0300 | 0.248-0.479 |
| Wormleatonet al. (1982), $S_o$=0.00043 | | | | | | | | | | | |
| **W-A** | 2 | 7 | 0.01 | 0.12 | 0.460 | 0.29 | 4.17 | 0 | 0 | 0.0134-0.043 | 0.115-0.367 |
| Al-Khatib et al. (2012), $S_o$=0.0025 | | | | | | | | | | | |
| **AK10-6** | 1 | 10 | 0.015 | 0.06 | 0.30 | 0.10 | 3.0 | 0 | 0 | 0.003-0.014 | 0.592-0.818 |
| **AK15-6** | 1 | 7 | 0.015 | 0.06 | 0.30 | 0.20 | 1.5 | 0 | 0 | 0.004-0.014 | 0.385-0.640 |

## 4 RESULTS AND DISCUSSION

To evaluate the error of the method against the experimental data, the percentage of error in predicted discharge was used as a criterion for the purpose of precision. The percentage of error in predicted discharge of each flow depth is calculated by

$$\%E_{Q,i} = \frac{Q_{cal,i} - Q_{exp,i}}{Q_{exp,i}} \times 100\% \qquad [23]$$

where $\%E_{Q,i}$ is the relative error percentage of predicted discharge, and $Q_{cal,i}$ and $Q_{exp,i}$ are the predicted and observed discharge at $i^{th}$ flow depth, respectively.

Therefore, the average error of the method for an experiment is calculated by

$$\%E_Q = \frac{1}{N}\sum_{i=1}^{N}(|\%E_{Q,i}|) \qquad [24]$$

where $N$ is the total number of runs of an experiment.

Table 2 shows the average percentage errors of predicted discharge by the new model for all 26 datasets, where subscript $t$ denotes the values for the total channel. For the comparison, the results using the other methods, such as the DCM and ECM (used by Yang et al. 2012), are also given in Table 2. The corresponding results of $\%Q_t$ for each experiment are given in Figure 2. For convenience, in the subsequent figures, Sym = symmetric channels, Asym=asymmetric channels, Mean = the average for all channels.

**Table 2.** Summary of averaged percentage errors of methods for predicting discharges.

| **Experiments** | $\%Q_t$<br>**DCM** | <br>**ECM** | <br>**New Model** |
|---|---|---|---|
| **FCF1** | 11.02 | 3.72 | 2.53 |
| **FCF2** | 8.49 | 3.58 | 0.48 |
| **FCF3** | 6.33 | 4.43 | 0.93 |
| **FCF6** | 7.19 | 5.72 | 2.73 |
| **FCF8** | 10.71 | 5.21 | 3.13 |
| **FCF10** | 8.17 | 4.81 | 1.20 |
| **BU-S** | 6.84 | 3.90 | 2.26 |
| **BU-A** | 9.65 | 8.04 | 5.22 |
| **BD1** | 5.19 | 2.57 | 1.33 |
| **BD2** | 5.04 | 2.54 | 1.31 |
| **BD3** | 5.24 | 2.03 | 1.81 |
| **BD4** | 9.32 | 5.28 | 2.70 |
| **KH01** | 4.15 | 2.27 | 1.88 |
| **KD83A** | 9.70 | 4.58 | 3.23 |
| **KD83B** | 11.68 | 5.95 | 5.68 |
| **KD83C** | 7.60 | 3.28 | 3.06 |
| **KH02** | 14.83 | 8.32 | 5.68 |
| **Patra** | 7.67 | 5.27 | 4.22 |
| **PT01** | 11.01 | 2.34 | 4.98 |
| **PT02** | 9.96 | 2.26 | 1.52 |
| **NH-A1** | 5.63 | 4.11 | 3.38 |
| **NH-A2** | 1.94 | 2.90 | 0.80 |
| **NH-A4** | 9.03 | 3.53 | 6.29 |
| **W-A** | 3.73 | 6.81 | 6.53 |
| **AK10-6** | 4.60 | 4.53 | 4.20 |
| **AK20-6** | 8.18 | 7.55 | 6.00 |

As shown in Table 2, compared with the DCM, both the ECM and the New Model showed an overall improved prediction of total discharge ($Q_t$) for all the datasets, particularly the new model. Figure 3 demonstrated that the new model has the best results with a combined average percentage of error less than 3% in the range of 0.5% – 6%, whereas the ECM had an average percentage of error less than 5%, but with the range of 2.3% -8.3%. However, the DCM over-estimated the discharge with the combined average percentage of error larger than 8%. Furthermore, two methods showed slightly better prediction for symmetric channels than for asymmetric channels, but the DCM had reverse results (Figure 3).

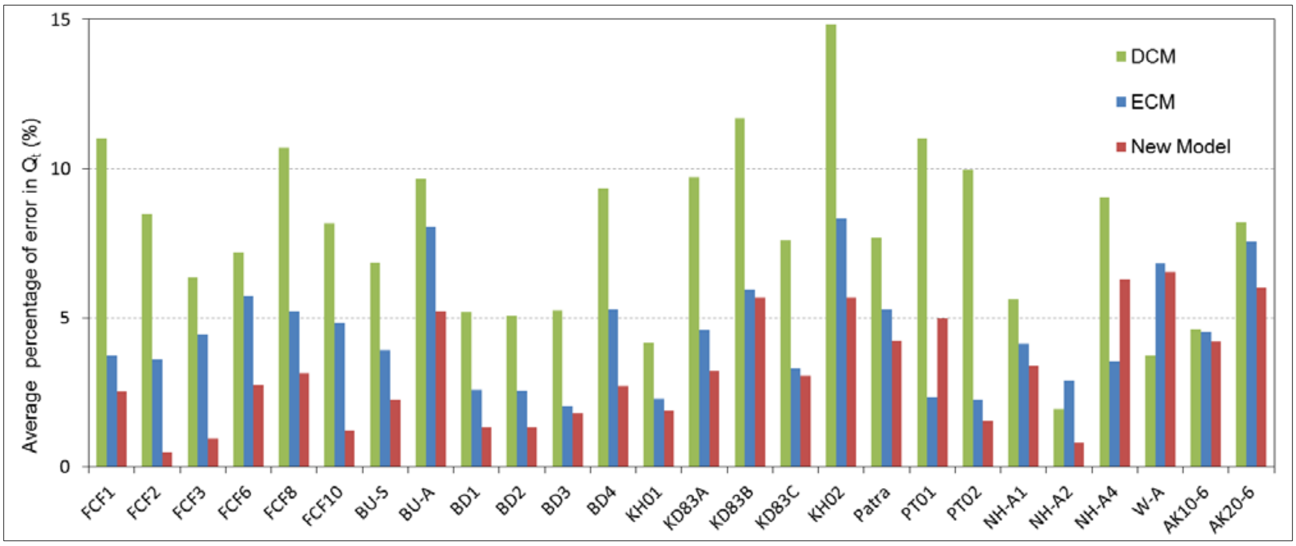


**Figure 2.** Averaged percentage error of total discharge ($\%Q_t$) by four methods in homogeneous channels.

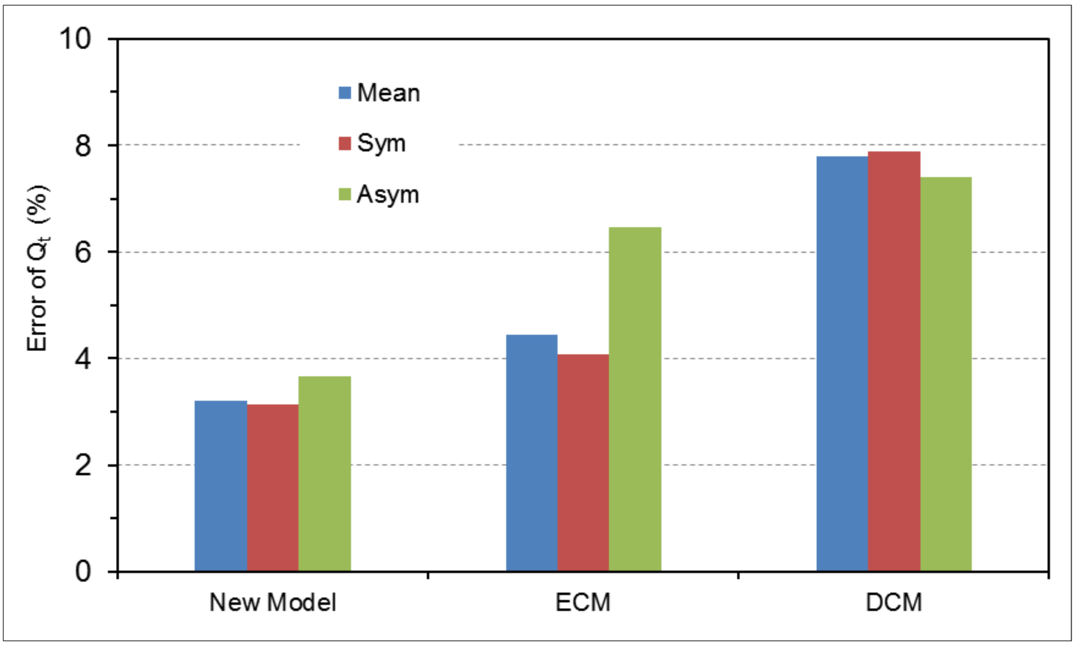
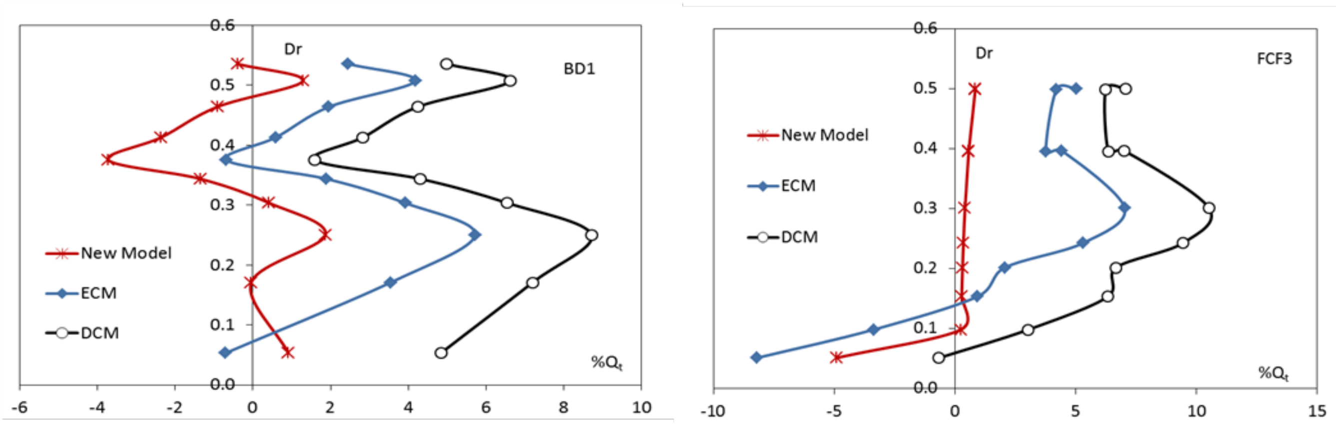


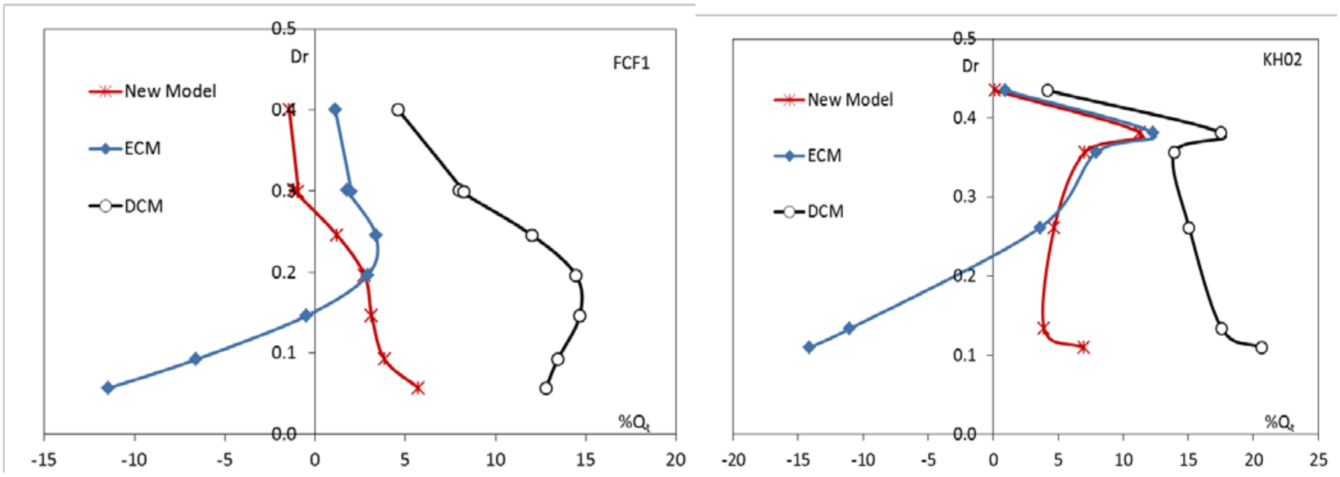
**Figure 3.** Averaged percentage errors of $Q_t$.

Although the ECM has shown a relatively small percentage of error within 5% on average for all the datasets, it could not predict well for flow discharge with relatively low flow depths of floodplain, as shown in Figure 4. Moreover, it appears that the ratio of $B/b$ has some impact on the prediction precision of the ECM, whose errors increase as increasing $B/b$, particularly in the lower depth of floodplain (i.e. smaller $D_r$), see Figure 4. However, the results of the new model are less affected by $B/b$. The same conclusion is true for asymmetric channels (see Figure 5).

Finally, although the ECM method predicts the total discharge well with the average percentage error less than 5% for symmetric channels, it should be taken care when this method is used to predict the discharge for flows with relatively low flow depths of floodplain. For example, when $D_r < 0.15$, in a channel with a wide floodplain ($B/b > 6.7$), the ECM could have a very large error, as shown Figures 4(c) & 4(d). In these cases, although the average percentage errors by the ECM are small, this method significantly underestimates the discharge at small relative flow depths of floodplain ($D_r$). Unlike the ECM, the new model is less influenced by $B/b$ and has been shown to have a higher prediction precision of discharge with an overall error of less than 5% over various relative depths, or 7% even in very low relative depths of floodplain (e.g. $D_r < 0.15$), where the discharge is extremely difficult to predict correctly. The new model predicts discharge well for all the datasets, see Figure 6.



**(a) BD1: B/b =1.5** **(b) FCF3: B/b = 2.2**



**(c) FCF1: B/b = 6.67** **(d) KH02: B/b = 11.97**

**Figure 4.** Variation of percentage errors of $Q_t$. with relative depth $Dr$ for symmetric channels.

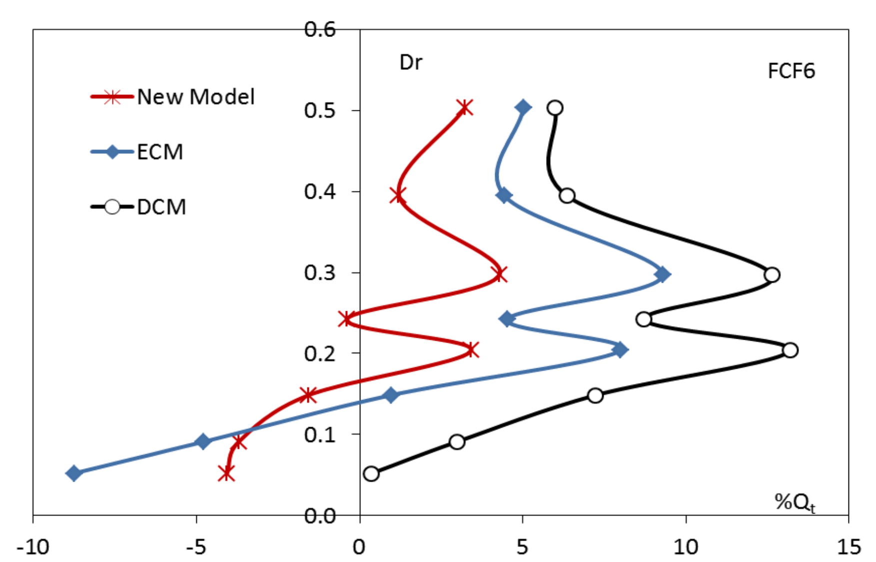


**Figure 5.** Variation of percentage errors of $Q_t$ with relative depth $Dr$ for asymmetric channel (FCF6).

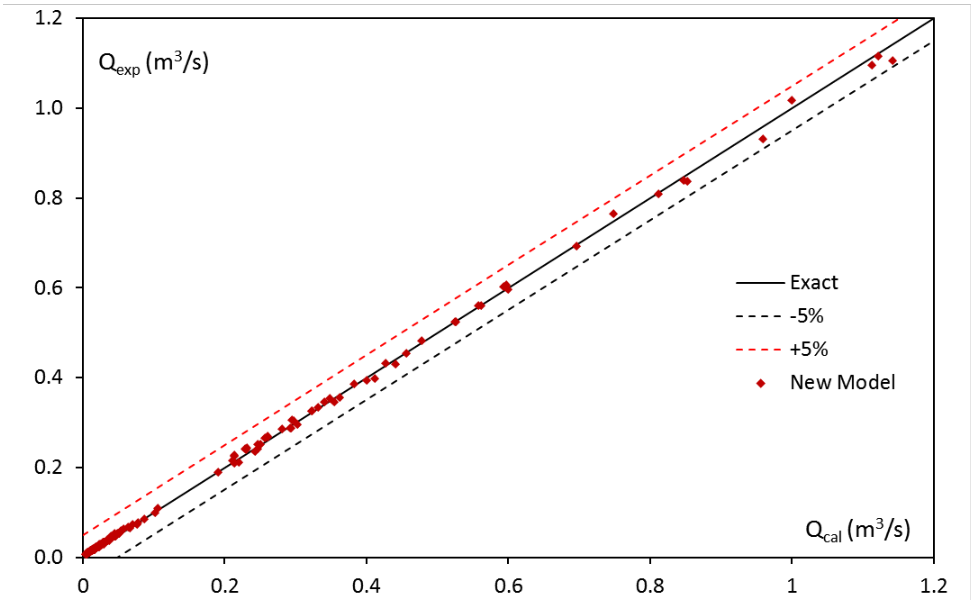


**Figure 6.** Comparison of the discharge prediction for all datasets.

## 5 CONCLUSIONS

Through the comparison against a wide range of data in homogeneous compound channels, the new proposed model along with the DCM and ECM shows that:

- Compared with the DCM, the ECM and new model predict the total discharge with the precision within 5% on average for homogeneous compound channels, whereas the DCM has an averaged error over 8%, and the new model gives the best overall results.
- Although the ECM method can predict the discharge reasonably well for channels with small aspect ratios of $B/b$ and high relative depths of floodplain (for example $D_r$>0.15), both the ECM and DCM methods are not recommended to use for channels with large $B/b$ (e.g. > 6.7) and lower depths of floodplain (e.g. $D_r$<0.15).
- In general, the new proposed model predicts the discharge well within a combined averaged error of 3% for a wide range of aspect ratio ($B/b$ up to 16). This method significantly improves the prediction of discharge in relative low depths of floodplain, where the discharge prediction with high precision is most difficult to predict.

## NOTATION

$\tau_a^m$= apparent shear stress at the interface
$B$= width of main channel at bankfull
$b$ = width of main channel bottom
$D_r$= relative depth of floodplain,= $(H\text{-}h)/H$
$g$ = acceleration of gravity
$H$= main channel depth
$h$ = bankfull height
$h_f$= flow depth of floodplain
$n$ = Manning's coefficient
$N_f$= number of floodplain
$Q$= discharge of cross-section
$S_o$= bed slope of channel
$V$= mean velocity of cross-section
$\alpha_m$= interface coefficient (also $\alpha_d$)
$\rho$ = density of water
$\tau$ = averaged shear stress of boundary
$\xi$ = weighting factor

Subscripts:
,0= reference values based on DCM
$c$ = main channel
f = floodplain
t = total

ISSN 1562-6865 (Online) - ISSN 1063-7710 (Print)

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