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Computation Methods of Discharge in Compound Channels

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Abstract
Water which is one of the basic requirements for continuation life occasionally causes floods that threaten the living life. The floods which are after cloudburst in the summer months or with snow melt at the end of winter frequently occur with flood out of the main bed water. Sections which are the main channel and floodplains are called compound channels. Floodplains, which are at one or both sides of the main channel, only occur during flood time. The most important parameter in the design of flood protection structures is discharge. However, discharge of compound channels varies depending on many factors. Experimental methods, which are mostly developed considering the water levels in main and flood channels, are often used in flow calculations. In the study, the errors of calculated discharge with Single Channel Method (SCM), Divided Channel Method (DCM) and Exchange Discharge Method (EDM) were compared in symmetrical and two floodplains compound channels. Side slopes of main channels are designed trapezoidal and rectangular. Side slopes of floodplains have been constituted vertically. Comparing the performance of the methods for four different discharge between 9-27 L/s, SCM and DCM have been shown to reach over 10% relative error value in low discharge. At high discharges, the absolute relative error of DCM drops below 2%. Although the errors of the methods generally decrease with increasing discharge, the average absolute relative error of all methods is found to be over 5% in the compound channel which is trapezoidal of main channel side slope.

Keywords: Compound channel, Discharge calculation, One dimensional methods, Exchange Discharge Method

INTRODUCTION

Water, which is one of the most important requirements for the continuity of life, sometimes creates floods and damages living things, lands, structures and objects. Particularly as a result of prolonged heavy rains and snow melts, floods occur due to the rapid increase in the amount of water in the river beds. While the section where the water flows in the stream before the flood is the main bed, the part where the water flows on the main bed edges together with the flood creates the floodplains. Channels consisting of main bed and floodplain on single or double sides are defined as composite section channel. While only the movement of the water flowing in the main bed varies depending on many factors; In the case of a composite section channel, the secondary currents formed between the floodplain and the main bed and the resulting momentum transfer further complicate the explanation of the movement.

River discharge is the main parameter for hydroelectric power plants, dimensioning of flood protection structures, management of water resources and drinking, using and irrigation channels [1]. In open channel discharge calculation, generally experimental Manning and Chezy equations are used [2]. In the case of these equations are given wrong results for compound channels, one-dimensional modified equations which based on these equations are derived [3] and [4].

The flood models are generally based on the estimation of the maximum water level and the rate at which the flood will occur in the river after the precipitation. At the same time, it is necessary to correctly estimate the discharge to correspond to the precipitation. However, degradation of the precipitation regime with the climate change and the increasing flow of rainfall as a result of increasing urbanization make it difficult to establish a rainfall-runoff modeling. Hydraulic models aim to establish a relationship between water level, flood propagation mechanism, morphological results of floods based on known discharge. Here too, the complexity of the flow between the main bed and the floodplain creates problems [5]. In channels with the compound section, run of flow in both the main bed and floodplain causes turbulence. The discharge in the floodplain is lower than the discharge in the main channel. Due to the difference of velocity between the two beds, a slip layer is formed between the main channel and the floodplains. Vortexes are formed along the vertical and horizontal axis in the interaction zone (figure 1) where two beds meet [6].
The first study of between the main channel and the floodplains interaction in compound channels was done by Zheleznyakov, 1965 [7]. In his theoretical work, Myers, 1987 [8] reported that the velocity and discharge between the main and floodplains in compound channels were independent of the bottom slope and only depending on the geometry of the channel. Myers et al., 2001 [9] estimated the open channel discharge by using Divided Channel Method (DCM) and Single Channel Method (SCM). In the last decade, a number of studies have been conducted to determine the relationship between level-discharge and compound channel flow calculation. Moreta and Martin-Vide, 2010 [10] research the relationship between the main channel and the flood channel in the composite channel; Proust et al., 2009 [11] investigated the relationship between discharge and level with one-dimensional equations; Parsai et al., 2016 [2], Azamathulla et al., 2016, [4] and Fernandes et al., 2012 [12] investigated the performance of one-dimensional equations

for discharge calculation.

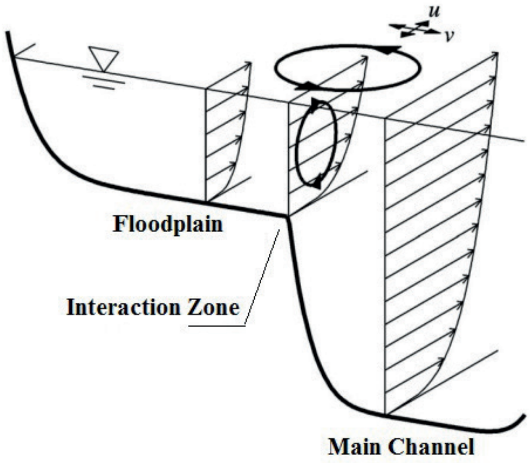


Figure 1. Turbulence formation in a compound section channel [6]

In this study, the performance of one-dimensional discharge calculation methods which take or doesn't take into account the momentum transfer between the beds for different channel cross-sections and different discharges are compared.

DISCHARGE CALCULATION METHODS IN COMPOUND CHANNELS

Single Channel Method (SCM)

In order to calculate discharge in natural or artificial channels without velocity measurement, a number of experimental studies were conducted based on the estimation of the discharge by establishing a relationship between the water level and the discharge. Manning [13], using the water level (h), bottom width (B), wetted perimeter (P), roughness coefficient (n) and bottom slope (S) values as experimental,

$$U=\frac{1}{n}R^{2/3}S^{1/2} \tag{1}$$

In Equation 1, U represents mean velocity, R represent hydraulic radius (Wetted area / Wetted perimeter). Manning Equation which is one of the most applied formulas when calculating flow in uniform open channel flows is used as Equation 2 by multiplying velocity and area.

$$Q = AU=\frac{A}{n}R^{2/3}S^{1/2} = KS^{1/2} \tag{2}$$

Here, K is defined as Conveyance. The manning coefficient n varies according to the type of bed material. While Equation 2 allows a single value for manning coefficient, there is a need for a common coefficient to be determined as the main bed and the base material are different in the composite section channels. The SCM method, which can not be used in the case of non-uniform flow, does not take into account the transfer of momentum between beds.

Divided Channel Method (DCM)

Divided Channel Method (DCM) is based on the fact that the compound cross-section channel is divided and takes into account the specific characteristics of each part because SCM method requires a single Manning coefficient. As shown in Equation 3, the discharge of the composite section channel is calculated by summing the discharge of each part.

$$Q = \sum Q_i = \sum A_i U_i = \frac{A_i}{n_i} R_i^{2/3} S^{1/2} \tag{3}$$

In the DCM method, the cross-section can be divided into vertical, horizontal or diagonal lines with imaginary lines. However, it has been suggested to divide the section into a part including the surface where the momentum transfer occurs [14].

Exchange Discharge Method (EDM)

The Exchange Discharge Method (EDM) was obtained by modifying the DCM method by taking into account the momentum transfer seen in the interaction zone of the main channel and the floodplain in compound channels. The Exchange Discharge Method (EDM) is designed to be used for non-uniform flow. This method associates the momentum transfer across the surface with the velocity difference between beds. [15].

In the EDM method, the section is divided into sub-areas same as DCM, but the corrected conveyance (K_i^*) value is used when calculating the discharge of the parts.

$$Q = \sum Q_i = \sum K_i^* S^{1/2} \tag{4}$$

$$K_i^* = \frac{K_i}{(1+\chi_i)^{1/2}} \tag{5}$$

where χ,

$$\chi_1 = \frac{1}{gA_1}\left[\psi^t (H-h_1)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_1}\right) + \psi^t \kappa_{21}\frac{dK_1}{dx}\right].\left[\frac{R_1^{2/3}}{n_1} - \frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2}\right] \tag{6}$$

$$\chi_2 = \frac{1}{gA_1}\left\{\left[\psi^t (H-h_1)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{1/2} - \frac{R_1^{2/3}}{n_1}\right) + \psi^g \kappa_{12}\frac{dK_1}{dx}\right].\left[\frac{R_2^{\frac{2}{3}}}{n_2}\left(\frac{1+\chi_1}{1+\chi_2}\right)^{\frac{1}{2}} - \frac{R_1^{2/3}}{n_1}\right]\left(\frac{1+\chi_1}{1+\chi_2}\right) + \left[\psi^t (H-h_3)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2} - \frac{R_3^{2/3}}{n_3}\right) + \psi^g \kappa_{32}\frac{dK_3}{dx}\right]\left[\frac{R_2^{\frac{2}{3}}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{\frac{1}{2}} - \frac{R_3^{2/3}}{n_3}\right]\left(\frac{1+\chi_2}{1+\chi_2}\right)\right\} \tag{7}$$

$$\chi_3 = \frac{1}{gA_3}\left[\psi^t (H-h_3)\left(\frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2} - \frac{R_3^{2/3}}{n_3}\right) + \psi^g \kappa_{23}\frac{dK_3}{dx}\right].\left[\frac{R_3^{2/3}}{n_3} - \frac{R_2^{2/3}}{n_2}\left(\frac{1+\chi_3}{1+\chi_2}\right)^{1/2}\right] \tag{8}$$

In these equations, Q is discharge, K is conveyance, S is bottom slope, g is gravity acceleration, A is area of part, H is height from main channel bed, h is height from bed bottom, n is Manning roughness coefficient, ψ^g is coefficient of geometric exchange correction, ψ^t is coefficient of turbulence exchange model, dx is longitudinal unit length throughout each abscissa, R is hydraulic radius and χ is the rate of friction losses to additional losses due to momentum transfer [16].

Bousmar and Zech [15] stated that ψ^g and ψ^t coefficients can be used as 0.16 and 0.5 respectively. Compound channel discharge is calculated by numerically solving equation 6-8 and the values are respectively replaced in Equation 4 and

Equation 5.

The Experimental Setup

The experiments were carried out on the open channel structure in Figure 3, which was installed in Bartin University Hydromechanical Laboratory. Two different section geometries are formed as shown in Figure 2, with the main channel of compound channel side slopes perpendiculars and 45 degrees inclined and the flood channel side slopes are perpendicular. There are symmetrical floodplains on both sides of the main bed in the prismatic compound channel. The main bed is made of concrete, floodplains made of the galvanized sheet. Manning roughness coefficient was determined as n = 0.014 for concrete channel and as n = 0.013 for sheet metal by the experiments performed for simple channel condition. The channel bottom is designed as 0.003 longitudinal bottom slopes.

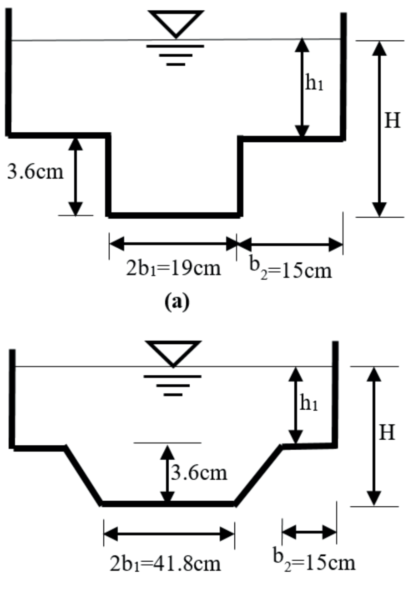


Figure 2. Compound channel sections used in experiments

Figure 3. Open channel structure

RESULTS AND EVALUATION

The discharge of channel is regulated by the valve placed at the outlet of the pump which provides water circulation to the channel and the discharge (Q_{ult}) entering the system is measured with the help of the ultrasonic flow meter placed in the pump inlet. Table 1 shows the water levels in the channels according to the channel section and the changing discharges.

Table 1. Main channel water levels according to discharge and cross section

Sections		Main channel water level (cm)			
Slope of Main Channel	Slope of Floodplains	Q=0.009 m^3/s	Q=0.015 m^3/s	Q=0.021 m^3/s	Q=0.027 m^3/s
90°	90°	6.1	7.7	9.1	10.4
45°	90°	4.6	5.4	6.4	7.3

As a result of the experiments, discharges read from the ultrasonic flowmeter and the discharges calculated by SCM, DCM and EDM methods are given in Table 2-3. Here h_1 is the water level in the flood channel, H is the water level in the main channel and D_r is the ratio of the flood channel water level to the main channel level and expressed as h_1/H.

Table 2. Measured and calculated discharges when the main and flood channel side slopes are 90°

h_1 (m)	H (m)	D_r	Discharges (m^3/s)			
			Q_{ULT}	Q_{SCM}	Q_{DCM}	Q_{EDM}
0.025	0.061	0.410	0.009	0.00809	0.00877	0.00829
0.041	0.077	0.532	0.015	0.01385	0.01458	0.01399
0.055	0.091	0.604	0.021	0.01964	0.02050	0.01975
0.068	0.104	0.654	0.027	0.02553	0.02657	0.02562

Table 3. Measured and calculated discharges in main channel side slope 45° and flood channel side slopes 90°

h_1 (m)	H (m)	D_r	Discharges (m^3/s)			
			Q_{ULT}	Q_{SCM}	Q_{DCM}	Q_{EDM}
0.010	0.046	0.217	0.009	0.00917	0.01042	0.00983
0.018	0.054	0.333	0.015	0.01333	0.01453	0.01383
0.028	0.064	0.438	0.021	0.01927	0.02050	0.01970
0.037	0.073	0.507	0.027	0.02524	0.02658	0.02564

The tables showing the absolute relative errors of the methods used in the calculation of the compound channel discharge are given in Table 4-5. Absolute relative errors were calculated with Equation 9.

$$\%\epsilon = \frac{Q_{ULT} - Q_{Metot}}{Q_{ULT}} \quad (9)$$

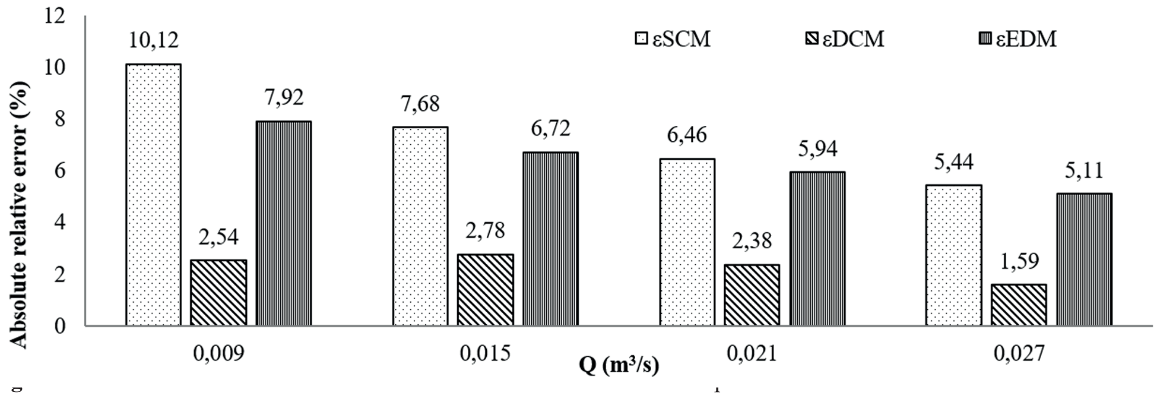
Table 4. Absolute relative errors when main and floodplain side slopes 90° degree

Q_{ULT}	Absolute relative error (%)		
	ε_{SCM}	ε_{DCM}	ε_{EDM}
0.009	10.12	2.54	7.92
0.015	7.68	2.78	6.72
0.021	6.46	2.38	5.94
0.027	5.44	1.59	5.11
Avarage	7.43	2.32	6.42

Table 5. Main channel side slope 45° floodplain side slopes

90° degree absolute relative errors

Q_{ULT}	Absolute relative error (%)		
	ε_{SCM}	ε_{DCM}	ε_{EDM}
0.009	1.92	15.81	9.27
0.015	11.16	3.16	7.78
0.021	8.26	2.37	6.19
0.027	6.51	1.55	5.05
Avarage	6.96	5.72	7.07



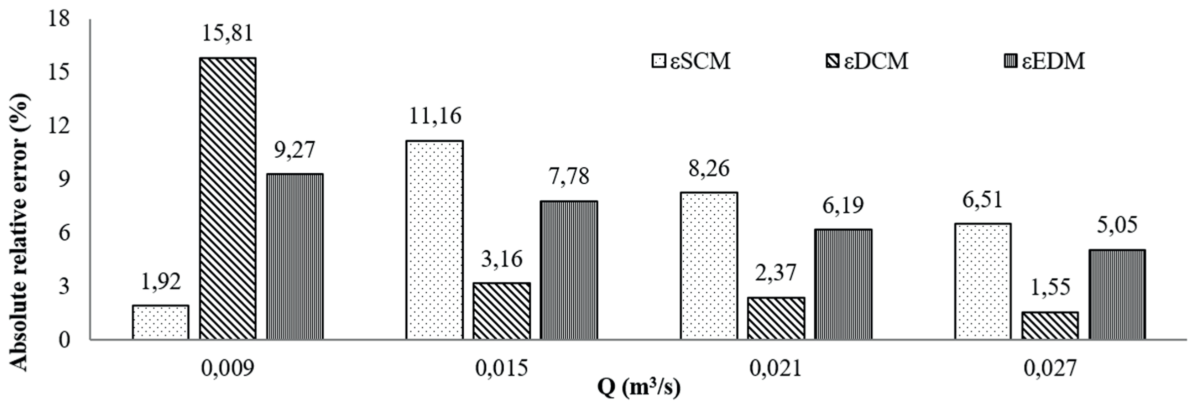


Figure 5. Absolute relative errors in main channel slope 45° and flood channel side slopes 90°

According to Figures 4 and 5, as the discharge increase, it is seen that the relative error values of the methods are generally decreased. Apart from the situation where main channel is trapezoid and the channel discharge of 0.009 m^3/s, DCM yielded better results than other methods. The errors of the EDM method are less than 10% for all cross-sectional shapes and discharge.

CONCLUSION

In general, with increasing discharge, errors are reduced, but in the calculation of the discharge of the compound channels, SCM is useless according to other methods with more than %5 error rate. The DCM method generally calculated the discharge with less than 4% error in both channel cross-sections. For both cross-sectional conditions at high discharges, errors were found to be both low and very close to each other. EDM calculates the discharge more accurately than the inclined side slope if the main channel side slope is perpendicular and relative error drops to 5% in high discharges for EDM.

In general, the best performance was obtained with DCM for the section and flow values used in this study, while the EDM gave acceptable errors and the SCM calculated the discharge with high errors.

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