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Prediction of zonal and total discharges in smooth straight prismatic compound channels using regression modeling

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ABSTRACT

Experimental results are presented concerning the zonal and total discharge distribution and characteristics in a compound channel cross-section comprising one rectangular main channel and two symmetrical floodplains. The discharges in the main channel, floodplains, and total compound channel are found to be highly correlated to several dimensionless parameters defined using the compound channel cross-section geometry. Multi-variable regression analysis was utilized for developing predictive models that can estimate the main channel, floodplains and total discharges as a function of four different dimensionless parameters. The developed models to predict the zonal and total discharges in compound channels are found to be highly significant according to several major statistics including the model standard error, coefficient of determination (R^2), and *F*-statistic. The developed multi-variable regression-based models are also tested for validity using available experimental data. Several statistical tests applicable to the analysis of residuals have indicated the effectiveness of the developed predictive models.

1. Introduction

During the last centuries, many large urban communities have developed on the river floodplains due to the demographic pressure and consequently increased utilization of rivers. This has led to the deaths of many people and to the increase of economic costs when flooding occurs. In recent years, the disasters caused by floods constitute about one-third of the losses caused by natural disasters all over the world, which is the main cause of more than half of the deaths. Thorough analysis of the various trends of the damage caused by floods shows that these numbers have increased significantly in recent years [1].

There is a considerable range for the existence of errors in estimating the amount of water flow in the river channel when considering a compound channel that consists of two or three zones: one or two side floodplains and a central main channel [2–6].

Usually compound channels are formed in natural rivers that carry most of the water at the bottom of the channel, and higher flows above them. This results in the reduction of channel erosion at lower flows and self-forming low flow channels that strike banks [7,8]. Many practical problems in river engineering require accurate flow predictions in compound channels. Many practical applications in hydraulic engineering also require accurate predictions of flow in compound channels. It helps the practitioners in the development of vital information regarding flood protection plans, building of hydraulic structures, the economic development of floodplain areas for parks and agriculture, and prediction of sediment load so as to plan for effective preventive measures [1,5,9–11]. The water often flows in the main channel while the floodplains are dry most of the time, but they are of particular importance during flood events. Usually these floodplains extend laterally away from the main channel and increase the transmission capacity during flood events [12–14].

Strong lateral momentum exchange between the main channel and floodplains normally takes place across their interface surface according to the high gradient of flow velocity. This momentum transfer between main channel and floodplains significantly reduces the flow conveyance of compound channel [15–18]. This was also emphasized by the experimental studies which concluded that momentum transfer slows down the flow in the main channel while accelerating the flow in the floodplains [19,20]. This results in flow resistance and reduces the capacity of the compound channel [21–24]. When floodplains become submerged, the difference in flow velocities between the main channel and floodplains generates secondary currents and mixing patterns [25–27].

The estimation of discharge in compound channels with main channel and floodplains remains a major challenge to researchers

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Nomenclature

The following symbols are used in this paper:

B	bottom width of the main channel
B_f	floodplain channel width
B_O	bottom width of the upstream channel
CV	coefficient of variation
h	main channel water depth
L_e	entrance channel
L_{app}	approach channel
ln	natural logarithm function
MSE	mean squared errors
$MSPR$	mean of the squared prediction errors
Q_{mc}	mean main channel volumetric flow rate
Q_f	mean floodplain volumetric flow rate
Q_T	mean full cross-sectional volumetric flow rate
R^2	coefficient of determination
R_1	B_f/Z
R_2	B_o/B
R_3	y_f/Z
R_4	y_f/h
VIF	variance inflation factor
Y_r	independent variable representing relative depth $=y_f/h$
y_f	floodplain water depth
Z	step height
θ_1 and θ_2	entrance angles

[28–30]. The works by different researchers also stressed the importance of considering the main channel–floodplains interaction consequences [31–34].

Therefore, the need for accurate and simple methods to estimate the total and zonal discharges in compound channel cross-sections is consequently important. In this paper, an experimental study was carried out for the purpose of estimating the three discharge components in the main channel, floodplains and total compound channel. The results of the experimental work were used to develop multi-variable regression models that can predict the three discharge components in symmetrical compound channels.

2. Experimental setup and experiments

A series of experiments was conducted at the Hydromechanics Laboratory of the Middle East Technical University, Ankara, Turkey, to measure the total discharge in a smooth straight prismatic compound channel. The experiments were conducted using a glass walled laboratory flume with 11.0 m length, 0.67 m width, 0.75 m depth, and 0.005 bottom slope. In this study, it is assumed that the channel bed slope is equal to the energy gradient slope. A recirculation system of water supply is established, in which water is pumped from an underground sump to an overhead tank from where water can flow to the flume; it passes through the experimental channel under gravity and is allowed to flow over a rectangular sharp crested suppressed weir mounted in the inlet box of the flume. From the volumetric tank, water flows back to the underground sump. Head measurements over the crest of the weir were done by a point gage of 0.01 cm accuracy and a predetermined calibration curve of the weir was used to determine the discharges. The point gauge was used along the centerline of the flume for head measurements. All depth measurements were done with respect to the bottom elevation of the flume. The maximum capacity of the system was around 110 l/s.

Six prismatic Plexiglass models having rectangular compound channel cross-section with two equal floodplains, two different step heights (Z) and three main channel widths (B) were tested. A symmetrical cross-section with a center channel section was thus created. The ratio of the overall channel width (B_o) to the width of the main channel (B) thus ranged from 1.49 to 3.35 as provided in Table 1. The ratio (B_o/B) was varied by adding adjustable side walls to each of the flood plains in pairs to give a symmetrical cross-section as required.

The models were placed at about mid-length of the laboratory flume. Fig. 1 shows the plan view and cross-section of the typical model with symbols designating important dimensions of the model elements. A total of 6 model combinations were tested using 3 different main channel widths (B) and 2 different step heights (Z). Table 1 provides the values of all channel dimensions used in the 6 tested models along with several dimensionless parameters to be used in the analysis of experimental results and in the development of multi-variable regression-based prediction models. In this study, the tested model types are denoted by *BiZj* (i=20, 30, 45; j=5, 10). The subscripts i and j designate the numerical values of (B) and (Z) in centimeter used in this study, respectively. The required experiments were first conducted in the models with the smallest B (=20 cm) and varying Z values (= 5 cm and 10) and then B was increased to 30 cm at the required amount of Z (= 5 cm and 10), and finally for B=45 cm with the same two values of Z. The entrance angles (θ and β) were 26.565° and 153.35°, respectively. The transition length was twice the floodplain width (B_f).

In order to determine the velocity distribution in the rectangular compound cross-sections, the channel cross-section was divided into a number of successive lines normal to the direction of the flow. Then, the total and static heads were measured at several points along these normal lines by the use of a pitot (Preston) tube with an external diameter of 7 mm. Additional points were taken close to the channel boundary while the distances between the points were increased towards the free surface. The velocity area method was used to find the discharge for each zone of the cross-section, which could then be summed up to give the full cross-sectional discharge in all models.

3. Presentation and discussion of results

In this section, the impact of several channel cross-section geometric parameters on the three discharge components will be investigated for the purpose of identifying the potential parameters to be included in the development of the proposed multi-variable regression models. These cross-section geometric parameters include the relative depth (Y_r), mean channel width (B) and step height (Z), and the dimensionless ratio y_f/Z.

3.1. Variation of discharge with y_f/h

For any prediction model to be adequate, it must accurately describe not only the total cross-sectional discharge (Q_T) but also the main channel and floodplain discharges Q_{mc} and Q_f, respectively. The average discharges in the main channel (Q_{mc}), floodplains (Q_f), and total channel cross-section (Q_T) for the six different models, *B20Z5*, *B20Z10*, *B30Z5*, *B30Z10*, *B45Z5* and *B45Z10*, in order, are shown in Fig. 2–7. These discharges are depicted in