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Flow Discharge Determination in Meandering Compound Channels Using Experimental Methods

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***Abstract*—**Determining the flow discharge in meandering channels with a compound cross section is associated with problems due to the complex hydraulic structure of the flow in the meander belt, which can be attributed to different and ever-changing geometric shapes of the meander. This research paper intends to study the accuracy of several one-dimensional experimental methods in determining the flow discharge. To this end, the results of laboratory data related to four meandering compound channels have been used, and the accuracy of three important methods to determine the flow discharge have been checked in these channels.

***Keywords*—**Flow discharge determination, meandering compound channel, compound section, meandering rivers.

I. Introduction

FLOW propagation in natural rivers is complicated by several factors: junctions and tributaries, variations in cross section, variations in resistance as a function both of flow depth and of location along the river, inundated areas and meandering of the river. The interaction between the main channel and the floodplain or inundated valley is one of the most important factors affecting flood propagation. Unsteady flow in natural meandering rivers in wide flood plains is complicated by large differences in resistance and cross-sectional geometries of the river and the flood plain [1]. Due to high importance of proper calculation of flow discharge in compound channels, especially in flood events, there is a critical need to develop an appropriate method to give optimal solutions [2]. The laboratory channel geometry is in a way almost identical to a natural river and it is expected that the results of this study can be generalizable to the real meandering rivers.

II. Materials and Methods

A. Ervine and Ellis Method (1987)

In this method [3], the meandering compound channel section is divided into three separate zones and the flow discharge for each zone is calculated separately, and then the partial flow discharge is added together to obtain the total flow discharge. The way of dividing the section into three different zones, in this method, is shown in Fig. 1.

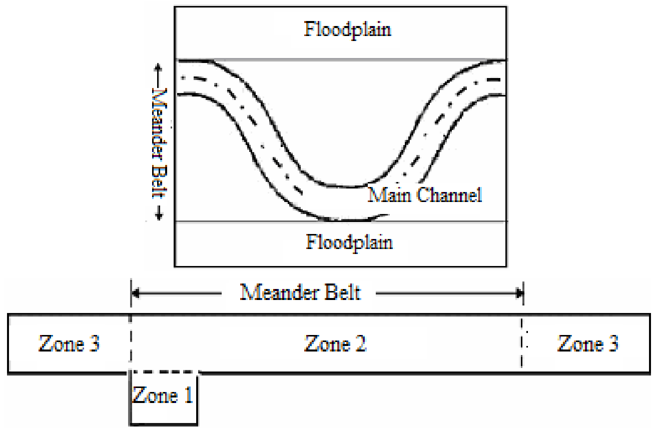

Fig. 1 Division of meandering compound channel section into three separate zones by Ervine and Ellis

Ervine and Ellis calculations for different zones are as follows:

1. The first zone (lower main channel section) is the zone below the bankfull level. This zone is separated from the second zone by a horizontal line. In this zone, the energy equation is written as:

$$k_{bf}\frac{V_a^2}{2g} + k_{sf}\frac{V_a^2}{2g} = \frac{S_0}{S_r} \tag{1}$$

where V_a is the mean flow velocity of the first zone, S_0 is the longitudinal slope of the channel, S_r is the sinuosity, g is the acceleration of gravity, k_{bf} and k_{sf} are dimensionless energy coefficients in m^{-1} that cause boundary friction and secondary flow, respectively are calculated by:

$$k_{bf} = \frac{f}{4R} \tag{2}$$

$$k_{sf} = (\frac{2.07+2.86\sqrt{f}}{0.565+\sqrt{f}}\left(\frac{h}{r_c}\right)^2\left(\frac{1}{h}\right) \tag{3}$$

where f is the Darcy-Weisbach friction coefficient for the entire section of the first zone, h is the bankfull depth, and r_c is the bend radius.

2. For the second zone (upper layer within meander belt) the energy equation is written as:

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$$k_{bf}\frac{V_b^2}{2g} + k_{ex}\frac{V_b^2}{2g} + k_{co}\frac{V_b^2}{2g} = S_0 B_w L_w \quad (1)$$

where B_w is the width of the meander belt, V_b is the mean flow velocity in the second zone, L_w is the one wavelength of the meander channel, and k_{bf}, k_{ex}, and k_{co} are dimensionless coefficients of energy that respectively caused boundary friction, opening (expansion) and contraction.

3. For the third zone (upper layer outside the meander belt) only the boundaries friction is considered and the energy equation is written as:

$$k_{bf} = \frac{V_c^2}{2g} = \frac{f}{4R}\frac{V_c^2}{2g} = S_0 \quad (5)$$

where V_c is the mean flow velocity in zone 3, and R is the hydraulic radius of this zone.

By calculating the mean flow velocity in each zone, the flow discharge of each can be determined by multiplying the mean flow velocity by the area of each zone. The total flow discharge in the compound section of the meander is obtained from the sum of the flow discharge of each zone.

B. James and Wark Method (1992)

This experimental method [4] is presented to modify the previous method (Ervine and Ellis, 1987) and divides the meandering compound channel section into four separate zones. Of course, when the meandering compound channel is symmetrical with respect to the central axis of the main channel, only three zones are sufficient. Fig. 2 shows how this method divides the meandering compound channel section.

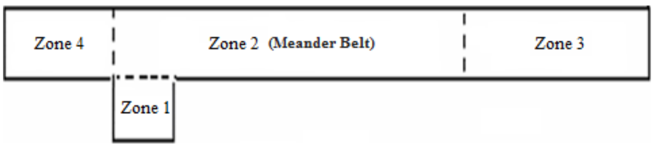

Fig. 2 The way of dividing an asymmetric meandering compound channel section by James and Wark

1. The flow discharge in first zone is calculated using the equation:

$$Q_1 = Q_{bf} C_1 \quad (6)$$

where Q_{bf} is the bankfull discharge, which needs to be multiplied by a reduction factor (C_1) due to the effect of the secondary flow caused by the exchange of momentum between the main channel and the floodplain. By multiplying the bankfull discharge by the coefficient C_1 the discharge of the first zone is calculated. C1 coefficient is given by (whichever is greater):

$$C_1 = 1 - 1.69y' , C_1 = my' - kc \quad (7)$$

where the experimental coefficient m is geometric factor, k is friction factor, and c is sinuosity factor, expressed as:

$$m = \frac{0.0147b^2}{A_{lmc}} + 0.032f' + 0.169 \quad (8)$$

$$K = 1.14 - 0.136f' \quad (9)$$

$$c = \frac{0.0132b^2}{A_{lmc}} - 0.302\, S_r + 0.851 \quad (10)$$

where b is the top width of the main channel section, A_{lmc} is the area of the first zone (lower main channel section), f' is the ratio of the friction coefficients of the second zone to the first zone, and y' is the dimensionless depth of the flow in the floodplain. This depth is expressed as:

$$y' = \frac{(H-h)}{(\frac{A}{B})} \quad (11)$$

where H is the total depth of flow, h is the bankfull depth, A is the total cross-section area (which is equal to the sum of the main channel and floodplain areas), and B is the upper width of the main channel section.

2. For the second zone, which is located in the meander belt, the flow discharge is calculated from the continuity equation; but in this equation the mean flow velocity is calculated with the help of a correction factor. Flow discharge for zone 2 can be computed using the equation:

$$Q_2 = A_2 V_2 \quad (12)$$

where V_2 is the flow velocity in the meander belt, and is obtained from:

$$V_2 = \left[\frac{2gS_0L}{\left(\frac{F_2L}{4R_2}\right) + F_1F_2K_e}\right]^{1/2} \quad (13)$$

where L is the meander wave length, R_2 is the hydraulic radius of this zone, F_1 is a correction factor for non-friction energy loss due to main channel geometry, and F_2 is a correction factor for non-friction energy loss due to main channel geometry. K_e is a correction factor due to the contraction and expansion of the flow is in the second zone.

3. For the third and fourth zones which are located outside the meander belt, only the bed friction coefficient is effective and other energy loss factors are not considered. To calculate the flow discharge in each of these two zones the Darcy-Weisbach equation is used for obtaining the flow discharge. The total flow discharge (Q_{total}) is calculated by the sum of the four flow discharges in the four zones.

C. Greenhill and Sellin Method (1993)

Greenhill and Sellin modified [5] the Divided Channel Method (DCM) to predict the flow discharge in meandering compound channels by changing division lines of different zones from vertical to 45°. The method divides the meandering compound channel section into four zones as the following:

- Zone 1. The main channel under the horizontal bankfull line.
- Zone 2. The floodplain and overbank main channel in the

meander belt.

- Zones 3 and 4. The floodplains outside the meander belt.

The way of dividing the meandering compound channel section in this method is shown in Fig. 3 and the total flow discharge (Q_{total}) is calculated using the equation:

$$Q_{total} = \sum Q_i = \sum \frac{1}{n_i} A_i R_i^{2/3} S_0^{1/2} \quad (13)$$

where S_0 is the longitudinal slope of the channel, A_i, R_i, and, n_i are the area, the hydraulic radius, and manning's roughness coefficient of zone i, respectively.

The main problem of this method for use in the meandering compound channels is the difficulty in determining the parameters of this method such as the width of the meander belt and the depth of overbank flow which are required for almost all methods of determining the flow discharge in the meandering compound channels.

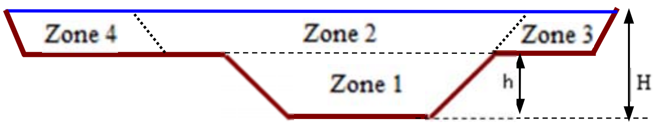

Fig. 3 Greenhill and Sellin (1993) DCM (GH5)

A. The Data Used

To evaluate the accuracy of the methods mentioned in the above sections four sets of data related to the four laboratory meandering compound channels have been used. The first and second sets of data are collected from two channels with a meandering compound section belonging to the University of Rourkela in India [6]. The third category is the data related to a channel with a meandering compound section used at the Loughborough University in England [7], [8]. The fourth category is the channel data with a meandering compound section related to the University of Glasgow [9].

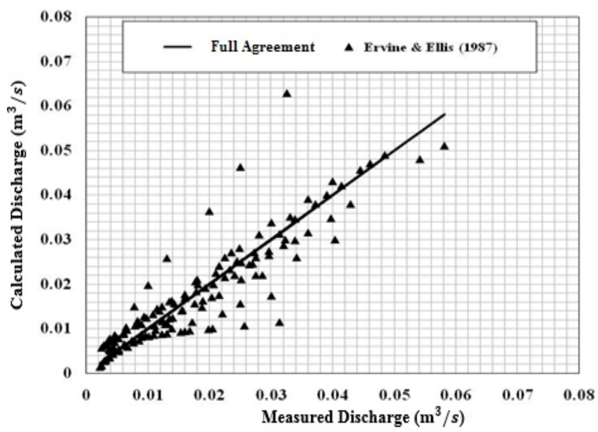

Fig. 4 The results of Ervine and Ellis method (1987) to calculate the flow discharge

III. Results

Flow discharge estimation results from experimental methods, Ervine and Ellis (1987), James and Wark (1992), Greenhill and Sellin (1993) in the meandering compound channels are provided in Figs. 4-6 [10].

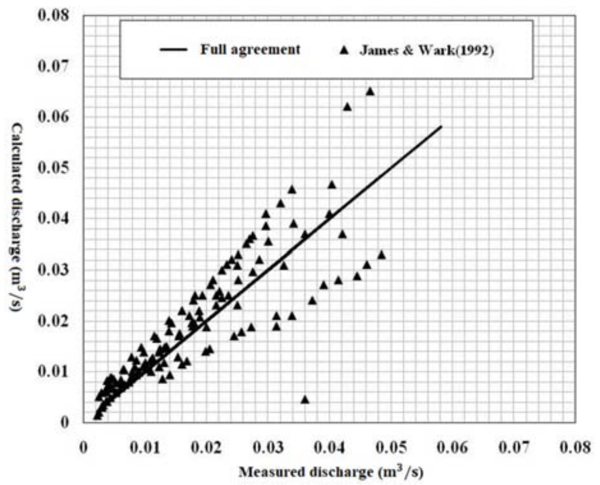

Fig. 5 The results of James and Wark method (1992) to calculate the flow discharge

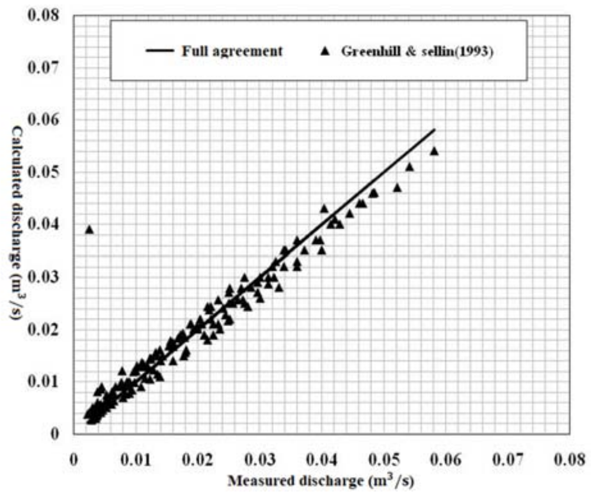

Fig. 6 The results of Greenhill and Sellin method (1993) to calculate the flow discharge

IV. Statistical Methods

This research used the root mean square error (RMSE), average error (AE), coefficient of determination (R^2), and the mean absolute deviation (MAD or δ) as evaluation criteria for the results. These parameters are expressed as:

$$R^2 = \left(\frac{\sum xy}{\sqrt{\sum x^2 \sum y}}\right)^2 \quad (15)$$

$$RMSE = \sqrt{\frac{\sum (X-Y)^2}{n}} \quad (16)$$

$$AE = \frac{\sum \left(\frac{X-Y}{X}\right) * 100}{n} \quad (17)$$

$$MAD = \frac{\sum |X-Y|}{\sum X} * 100 \quad (18)$$

where $x = \mathrm{X} - \bar{\mathrm{X}}$, $\mathrm{y} = \mathrm{Y} - \bar{\mathrm{Y}}$, X is the observed value, Y is the calculated value, $\bar{\mathrm{X}}$ is the average observed value, $\bar{\mathrm{Y}}$ is the average calculated value, and n is the number of data.

IV. Conclusion

In this research work, the accuracy of three important methods to determine the flow discharge in the meandering compound channels (Ervine and Ellis method 1987, James and Wark method, 1992 and Greenhill and Sellin method, 1993) was evaluated in several laboratory channels. According to the flow discharge estimation results from experimental methods, provided in Figs. 4-6, and the statistical parameters, provided in Table I, Greenhill and Sellin method (1993) performs better than Erwin and Ellis method (1987), and James and Wark method (1992) to determine the flow discharge in the meandering compound channels with RMSE, AE, and MAD to 0.37, 0.922, 26.25%, and 10.81, respectively.

TABLE I
STATISTICAL PARAMETERS OF THE RESULTS OF EXPERIMENTAL METHODS FOR CALCULATING THE FLOW DISCHARGE IN THE MEANDERING COMPOUND CHANNELS

Flow discharge calculation method	R^2	RMSE	AE%	MAD
Ervine and Ellis	0.783	0.62	26.16	20.39
James and Wark	0.735	0.63	28.61	26.86
Greenhill and Sellin	0.922	0.37	26.25	10.81

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