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Comparison of Experimental Relationships to Determine Flow Discharge in Meandering Compound Channels Using M5 Decision Tree Model

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Abstract**—**This research compares results of major methods of determining the flow discharge using experimental relationships with results from the M5 decision tree model in meandering compound sections in several laboratory channels. It was found that the M5 decision tree model enjoyed greater accuracy of statistical parameters compared to methods to the said methods. This suggested that the M5 decision tree model has highly improved the calculated accuracy of the flow discharge in meandering compound channels.

Keywords**—**Stage-discharge relationship, M5 decision tree model, compound section, meandering compound channel.

I. Introduction

COMPOUND sections combine a main deep section and one or two wide floodplains. Floodplains are mostly arid and usually have a higher roughness coefficient than the main section. Compounding sections usually fill the main section with water and enter floodplains when flooding. In this state, due to the difference in the flow depth and roughness coefficient parameters in the main section compared to the floodplains, the flow mechanism will significantly change, with various phenomena entering the hydraulic analysis of these sections. Because of the different nature of the flow hydraulics at the compound sections compared to simple sections, many researchers have conducted [1]-[3], large -scale studies on compound section hydraulics; however, fewer studies have been performed on the flow hydraulics of the meandering compound sections compared to direct compound sections. In the meantime, in nature, flood rivers are seldom subjected to the direct path, and because the rivers are alluvial and have low longitudinal slopes, the rivers will have a meandering state, with numerous twists and turn noted across the river course. Laboratory and desert studies on meandering compound sections are limited because of the lack of accurate stage-discharge data and the complexity of the physical modeling of these rivers.

Ervine and Ellis (1987) divided meandering compound channels into three regions to provide a technique to calculate the stage-discharge relation of these channels. They tested their methods based on laboratory data and found good results [4].

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Greenhill and Sellin (1993) used the Manning-Strickler relation to minimize the division of the regions at a meandering compound section, concluding that the compound channel could be divided into three regions under the best conditions [5].

McLeod (1997) investigated the efficacy of artificial neural networks to estimate the flow discharge of the meandering compound channels, evaluating the accuracy of these models as appropriate. Also, they provided a novel method to estimate the flow discharge at these channels [6].

Spooner and Shiono (2003) presented a two-dimensional mathematical model with curvilinear coordinates, discarding the effects of energy loss caused by the centrifugal force and secondary flow to predict the transverse velocity distribution and shear stress of the bed in meandering compound channels [7].

In addition to the above hydraulic studies, there have been limited studies in the field of application of intelligent methods such as artificial neural networks, genetic search method, genetic programming, decision tree models in the straight compound sections.

Zahiri and Dehghani (2009) used artificial neural networks to extract the flow-Echelon relationship of laboratory compound sections and rivers with the straight section. They used QNET2000 software for this purpose. Their results showed that among the dimensionless input variables, the relative flow depth and relative width are most important and the side slope variables of the main section and floodplains are least important in estimating the flow discharge of compound sections [8].

Zahiri et al. (2012) presented a suitable relationship for estimating the total flow discharge in laboratory channels with a compound section. They used seven dimensionless parameters to derive this relationship [9].

Zahiri and Ghorbani (2013) presented detailed relationships for calculating the total flow discharge in straight compound channels using the decision tree model [10].

Consistent with research carried out to derive a stage-discharge relation, it is frequently needed to simultaneously measure the profile of the transverse flow velocity and acquire the river cross-section at the hydrometric station (using Molinet). The time and costs of performing field operations (especially for hard-to-pass rivers and alluvial rivers with wide floodplains) are significant, as floods and river bursts may also threaten the situation.

This process repeats at least once or twice a month, and the number of measurements is higher in flood situations. Considering the considerable costs and time as well as possible dangers, it is required to present new and alternative solutions to extract a stage-discharge relation for rivers. The use of modern and advanced equipment, such as an electronic speedometer (flow meter) and mathematical models of good accuracy, are solutions to this problem. The use of modern measurement devices not only incurs costs but also requires proficient users so that the measurements are performed with the least errors. Mathematical models may enjoy much complexity and involve a longer period. These cases restrict two- and three-dimensional mathematical models (e.g., MIKE-21, SSIIM, FLOW-3D, FLUENT, TELEMAC and CCHE-2D). Although these models simulate the flow physique and mechanism very accurately, they are just advised to be used to study the flow patterns in the proximity of hydraulic structures (e.g., water intakes, pumping stations, spillways, breakwaters, bridge foundations, etc.) due to the need for accurate information on flow boundaries, constant coefficients, and velocity field of flow measurements in longitudinal and transverse directions, and more importantly, high volume of computer memories.

On the other hand, users of this software need knowledge of complicated theories and basics of three-dimensional flow hydraulics to accurately interpret the results; these subjects usually fall under hydrodynamic debates, which is where most students and hydraulic engineers face problems. One-dimensional mathematical models of flow (e.g., HEC.RAS, MIKE-11, ISIS, etc.) also confront limitations while being simple. These models only calculate the hydraulic variables of the flow in the longitudinal directions and do not consider the variables' cross-sectional and depth distribution. These models also fail to consider the specific hydraulics of the flow mechanism in compound sections, thus yielding erroneous results for the rivers with floodplains. Thus, the best solution to determine the stage-discharge relation of floodplain rivers is to use experimental relations offered by different researchers, which should be based on their accurate assessments. The M5 decision tree model can be a more appropriate solution to determining the stage-discharge relation.

II. Materials and Methods

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 [11]. Table I gives the geometric specifications of these channels. The geometric form of section 1 is rectangular, while section 2 is trapezoidal, with a lateral slope of 1:1. The width of both channels is 0.12 m in the main section, while the total width of channels 1 and 2 are 0.577 m and 1.93 m, respectively. The width of the meandering belt in these channels are 0.43 m and 1.65 m, respectively, and their ranges are 0.162 m and 0.685 m, respectively. Figs. 1 and 2 illustrate schematic of these channels.

TABLE I
Data and Specifications of Laboratory Channels

Section	1	2
Degree of sinuosity	1.44	1.01
n_f	1.11	1.112
n_{mc}	1.11	1.112
H (m)	1.12	1.13
Q (cm^3)	313-31313	248-43483
S_0	1.1131	1.1113
H′	1.112-1.1311	1.1111-1.1111

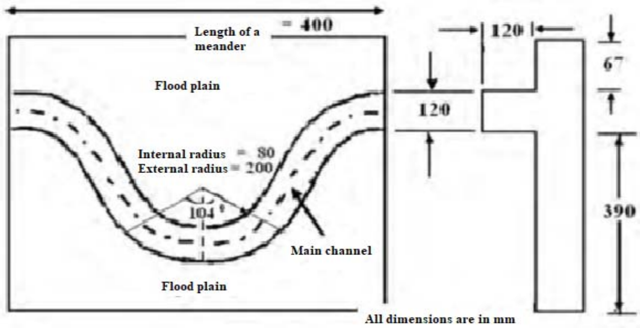

Fig. 1 The meandering channel with a compound section 1

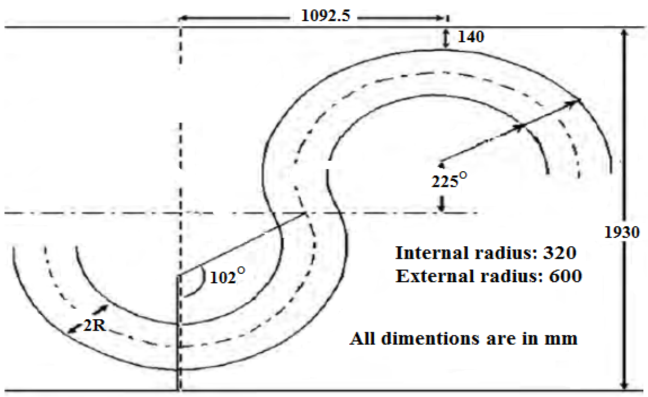

Fig. 2 The meandering channel with a compound section 2

Where S_0 is the longitudinal slope of the channel, n_f is the manning's roughness coefficient of the floodplain, n_{mc} is the manning's roughness coefficient of the main channel, H is the full depth, H′ depth limit, and Q is the discharge limit.

The third category is the data related to a channel with a meandering compound section used at the Loughborough University in England [13]. This rectangular channel is 13 m long, 2.4 m wide and 0.3 m deep, and made of glass and perspex with a fixed longitudinal slope of 0.002. The width of the main section is 0.4 m, while the depth of the full section is 40 mm. Fig. 3 illustrates a schematic of this laboratory channel.

Fig. 3 The meandering compound channel of Loughborough University

The fourth category is the channel data with a meandering compound section related to the University of Glasgow. The degree of curvature of the channel is 1.374 m, longitudinal slop is 0.001, the upper width of the water level is 0.2 m, the length of a meandering wave is 2 m, and the width of the meandering strop is 1.01m.

B. Parameters Used

A list of the parameters which are used in this research to construct a M5 decision tree model has been placed in Table II.

TABLE II
LIST OF PARAMETERS USED IN THE RESEARCH

Parameter	Description
S_0	Longitudinal slope of the channel
L_w(m)	Length of a meandering wave from the channel
B_w(m)	Width of the meandering belt
F_w(m)	Total width
S_r	Degree of curvature of the channel (sinuous)
b(m)	The upper width of the main channel
h(m)	Depth of the full section of the main channel
S_{mc}	Slope of the walls
n_c	Manning's roughness coefficient of the main channel
n_f	Manning's roughness coefficient of the flood plain
H(m)	Total depth of the flow
Dr	Relative depth
Qm	Discharge measurement

C. Ervine and Ellis Method (1987)

In this method [4], the meandering compound 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.

D. James and Wark Method (1992)

This experimental method [12] 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.

E. 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. 4.

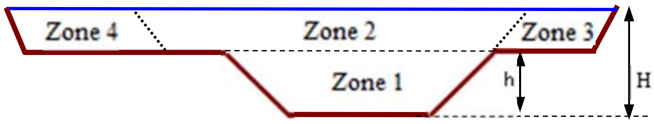

Fig. 4 Greenhill and Sellin (1993) DCM (GH5) [5]

D. Statistical Methods

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

$$R^2 = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \quad (1)$$

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

$$AE = \frac{\sum\left(\frac{X-Y}{X}\right)*10}{n} \quad (3)$$

$$\delta = \frac{\sum |X-Y|}{\sum X} * 100 \quad (4)$$

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

E. M5 Decision Tree Model

In modeling phenomena, the presence of local conditions may cause the use of a general relation not to produce good results and thus the model fails to demonstrate local changes. If possible, identifying homogenous limits and providing simple linear relations for each of these limits will increase the accuracy of models. Accordingly, the models are divided into simpler and smaller problems to solve complicated problems, and the obtained answers will be combined. This simple idea can be applied to decision tree models. For this aim, the input data values are divided into several sub-intervals or sub-regions, and an appropriate model is extracted for an appropriate model or equation.

III. Results

This research examined major methods to determine the flow discharge using experimental relationships (methods by Ervine and Ellis (1987), James and Wark (1992), and Greenhill and Sellin (1993)) in meandering compound sections in several laboratory channels. First, the M5 model calibration and validation data results were computed to determine the flow discharge in meandering compound channels using various parameters, then the comparative computational results from these methods with laboratory results, RMSE, coefficient of determination R^2, and mean absolute deviation (δ) of each method, as the most optimal method were selected. Also, the M5 decision tree model, the most applicable method to determine the stage-discharge in meandering compound channels, was used, and its accuracy compared to other methods of determining flow discharge of the compound channels was examined.

To ensure the accuracy of the proposed model, parameters of the longitudinal slope and relative roughness of the compound sections were also added to the previous five parameters, and the M5 model was again implemented. The results suggested that a significant increase in the accuracy in statistical parameters was not achieved; for this, consistent with statistical parameter results of M5 models for the validation and calibration data, it was decided to introduce the M5 model with various parameters of D_r, H_m, n_f, S_r, and L_w as the optimal model.

Fig. 5 illustrates the calculation results of the optimal M5 decision tree model created from among 13 models compared to results from all three studied experimental relationships by Ervine and Ellis, James and Wark and Greenhill and Sellin, it is clear that the M5 decision tree model has highly improved the accuracy of the flow discharge in meandering compound channels [1]-[13].

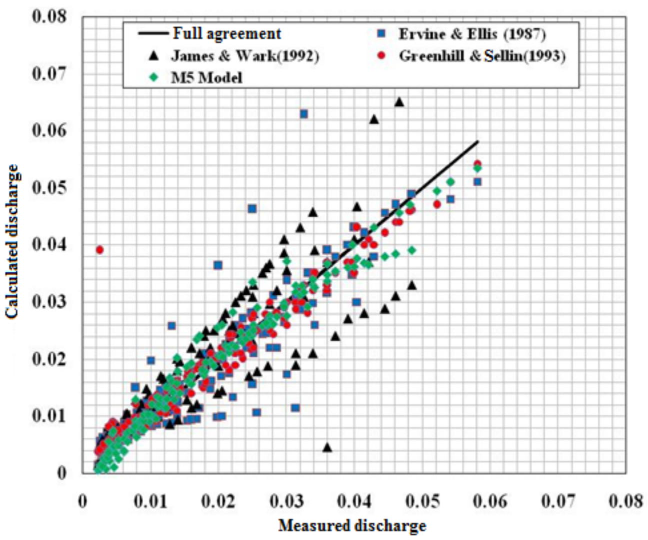

Fig. 5 The comparison of results of various methods under study to calculate the flow discharge in meandering compound channels using the M5 decision tree model

Table II calculates statistical parameters for all the methods to better examine this issue. These results were obtained for the entire validation and calibration data. An examination of the results of this table indicates that the M5 decision tree model has significantly increased the accuracy of calculations in terms of statistical parameter.

TABLE III
Statistical Parameters of the Results of Experimental Methods and M5 Decision Tree Model for Calculating the Flow Discharge in the Meandering Compound Channels

Discharge calculation method	R^2	RMSE	AE%	δ
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
M5 Decision Tree	0.983	0.25	16.58	9.70

IV. Conclusion

In Erwin and Ellis method in the case when flow enters into the floodplains due to the low depth of initial flow, the discharge is calculated less as far as the depth of discharge in floodplains. When the flow depth has been reached to the relatively modest height, due to less interaction flow and the lateral momentum transfer, the discharge calculation was close to the measured value. Where the flow depth of the floodplain reached to the maximum value, the computational discharge is equal to measured discharge.

Greenhill and Sellin method is in contrast with Erwin and Ellis method, when the depth of flow in floodplains is low, amounts of computational discharge with the measured discharge is close together and with increasing the depth of floodplains, the accuracy of this models is reduced and computational amount is less than the observed discharge.

James and Wark method in floodplains with low depth of flow has better performance than more depth of flow in discharge calculation.

According to the flow discharge estimation results from experimental methods, provided in Fig 1, and the statistical parameters, provided in Table II, the M5 decision tree model has produced more accurate results than the methods proposed by Ervin and Ellis (1987), James and Wark (1992) and Greenhill and Sellin (1993), with the RMSE, coefficient of determination R^2, mean absolute deviation (δ) and average error (AE%) of this model amounting to 25%, 0.983, 9.70 and 16.58%, respectively. This suggests that the M5 model has highly improved the calculation accuracy of the flow discharge in meandering compound channels.

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