DISCHARGE ESTIMATION IN MEANDERING COMPOUND CHANNELS BASED ON ENERGY CONCEPT

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Abstract

The discharge in a compound meandering channel is greatly affected by the interaction between the flow in the main channel and the floodplains. In this paper, the apparent shear stress formulae were suitably modified, and the energy concept method (ECM) was applied for the prediction of discharges in meandering channels. The meandering compound channel was divided into three sub-areas, namely the main channel below the bankfull level, the meander belt width above the bankfull level and a region outside the meander belt above the bankfull level for estimating the total discharge. The new model is compared with a wide range of experimental data and the data available in the literature. The error analysis was carried out, and the results were presented. This method was found suitable for predicting discharges in channels having smooth floodplains but showed significant errors in channels with rough floodplains.

1. Introduction

Most of the rivers in nature often exhibit a meandering path with a compound cross-section. During high floods, the berm becomes inundated, leading to overbank flow in the meandering compound channel. Estimating the capacity of a river channel is an important aspect of river valley management. The estimation of flood discharge is a major factor in the design of various hydraulic structures.

A more recent model, Energy Concept Model (ECM) was developed (Yang et al. 2012) to estimate the discharges in straight, symmetric, compound open channels based on energy concepts of the flowing water. In this method, the energy loss and transition mechanism have been analysed in which the momentum transfer mechanism is taken into account as a product of the apparent shear stress.

2. Methodology

$$Q_t = Q - \frac{(V_a - V_b)(H + h_f)\tau_a^m}{4\rho g S_0} \qquad (1)$$

In the Eq. (1), Q represents the total discharge in the channel without considering the effect of momentum transfer. The apparent shear stress (τ_a^m) is required to be evaluated for computing the total discharge in the channel. In the Eq. (8), the value of discharge (Q) is computed using Divided Channel Method (DCM). The above method was modified by Tang (2017) by considering the Weighted Divided Channel Method (WDCM) proposed by Lambert & Myers (1998), for estimating the value of discharge (Q).

The Energy Concept Method has not been applied for estimating the discharges in the meandering channels. So an attempt was made to apply the ECM to the meandering compound flows. The results indicated high percentage of errors in the estimation of discharge, as expected. In the new model described in this paper, the Energy Concept Method (ECM) has been further modified in such a way that it can be used for estimation of discharges in meandering compound channels.

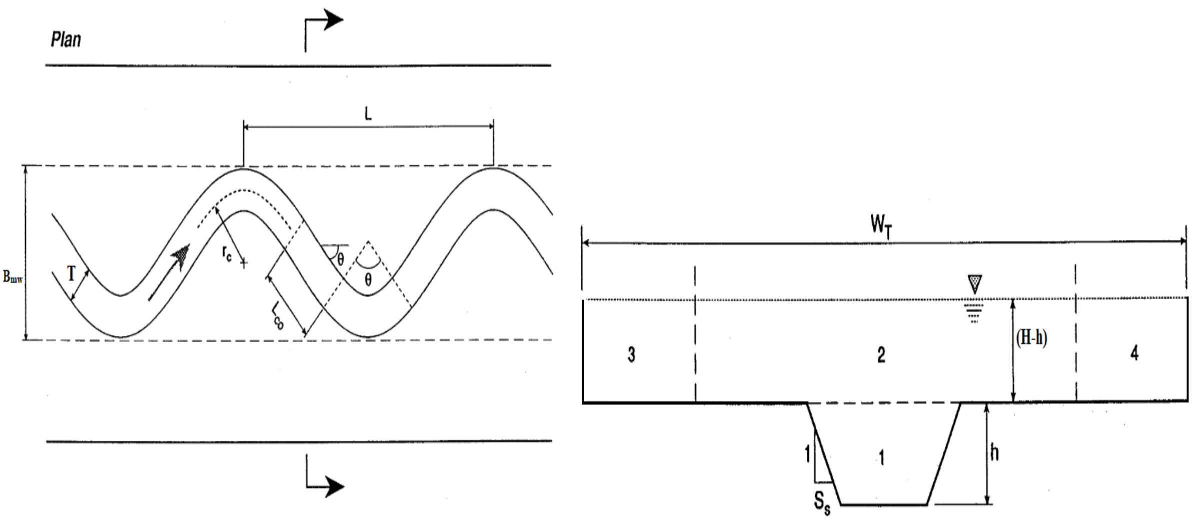

Figure 1. Cross section sub division for overbank flows (Ervine and Ellis, 1987)

Table 1. Existing and Modified Formulas of apparent shear stress

Existing Formula	Modified Formula
$\tau_a = 13.84\left(\frac{H}{h}\right)^{-3.123}\left(\frac{B-b}{b}\right)^{-0.727}\Delta U^{0.882}$	$\tau_a^{1,2} = 13.84\left(\frac{H}{h}\right)^{-3.123}\left(\frac{B_{mw}-T}{T}\right)^{-0.727}\Delta V_{1,2}{}^{0.882}$
$\tau_a = 0.874\left(\frac{H-h}{h}\right)^{-1.129}\left(\frac{B}{b}\right)^{-0.514}\Delta U^{0.92}$	$\tau_a^{1,2} = 0.874\left(\frac{H-h}{h}\right)^{-1.129}\left(\frac{B_{mw}}{T}\right)^{-0.514}\Delta V_{1,2}{}^{0.92}$
$\tau_a = 3.325(H-h)^{-0.354}(B-b)^{0.519}\Delta U^{1.451}$	$\tau_a^{1,2} = 3.325(H-h)^{-0.354}(B_{mw}-T)^{0.519}\Delta V_{1,2}{}^{1.451}$
$\tau_a = 0.005\rho\left(\frac{B}{b}\right)\Delta U^2$	$\tau_a^{1,2} = 0.005\rho\left(\frac{B_{mw}}{T}\right)\Delta V_{1,2}{}^2$
$\tau_a = 0.00025\rho(D_r)^{-1}\left(\frac{B}{b}\right)\left(\frac{h}{b}\right)^{-0.5}\left(\frac{n_f}{n_c}\right)^{0.33}(U_a^2 - U_b^2)$	$\tau_a^{1,2} = 0.00025\rho(D_r)^{-1}\left(\frac{B_{mw}}{T}\right)\left(\frac{h}{b}\right)^{-0.5}\left(\frac{n_f}{n_c}\right)^{0.33}(V_1^2 - V_2^2)$

3. Experimental Setup and Datasets.

Experimental investigations were conducted in a highly meandering trapezoidal channel of sinuosity 4.11, constructed at Hydraulic Engineering Laboratory, NIT, Rourkela. The channel has a side slope of 1:1 with 0.33m as the bottom width and 0.065m as the bank-full depth, the valley slope being 0.00165. The scheme for the experimental process is demonstrated in (Fig.2 and Fig 3).

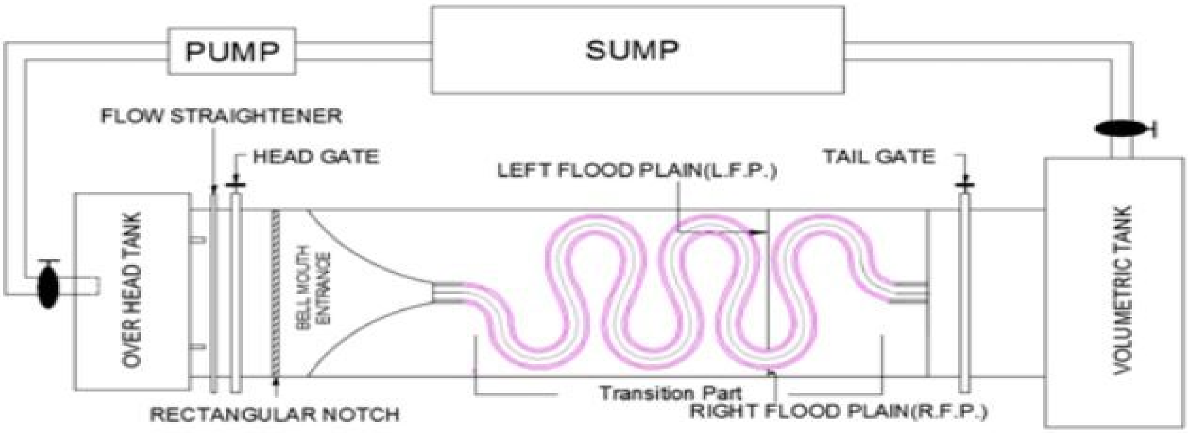

Figure 2 Planform of the channel setup

Figure 3 Meandering channel setup photograph

To validate the present model, we have used the stage-discharge data for meandering compound channels from various researchers. The data sets taken into consideration in this paper are; the United States Army Corps of Engineers (1956) which conducted a series of experiments on meandering compound channels at Vicksburg. Two, 1:0.5 trapezoidal channels were constructed with 0.305 m and 0.610 m main channel widths with varying sinuosity and floodplain widths. Experimental investigations were carried out at the SERC Flood Channel Facility during 1990-1991 on large-scale meandering channels (Phase B) in Wallingford, UK, termed as FCF B (1990- 1991). The data sets were obtained from the website http:// www.birmingham.ac.uk/ and from different reports and articles such as James and Wark

(1992), Willetts and Hardwick (1993) Greenhill and Sellin (1993), Shiono (1999), and Kiely(1989). In the table (Table 2), the parameters α, β, s and λ represent the width ratio, relative depth, sinuosity and floodplain to main channel roughness ratio, respectively.

Table 2 Datasets used for model validation

Data Source	Series	h (m)	b (m)	T (m)	B_{mw} (m)	S_0	α	s	λ
US Army (1956)	II-1	0.1524	0.30	0.457	3.048	0.001	30	1.33	1
	II-2	0.1524	0.30	0.457	3.048	0.001	30	1.33	2.083
	II-3	0.1524	0.30	0.457	3.048	0.001	30	1.33	2.916
	IIa-1	0.1524	0.30	0.457	3.048	0.001	30	1.255	1
	III-1	0.1524	0.30	0.457	3.048	0.001	30	1.33	1
	III-2	0.1524	0.30	0.457	3.048	0.001	30	1.33	2.083
	III-3	0.1524	0.30	0.457	3.048	0.001	30	1.33	2.916
	IIIa-1	0.1524	0.30	0.457	3.048	0.001	30	1.255	1
	IIIa-2	0.1524	0.30	0.457	3.048	0.001	30	1.255	2.083
	IIIa-3	0.1524	0.30	0.457	3.048	0.001	30	1.255	2.916
	IIIb-1	0.1524	0.30	0.457	3.048	0.001	30	1.255	1
	IIIb-2	0.1524	0.30	0.457	3.048	0.001	30	1.255	2.916
	IV-1	0.1524	0.30	0.457	3.048	0.001	30	1.22	1
	IV-2	0.1524	0.30	0.457	3.048	0.001	30	1.22	2.083
	IV-3	0.1524	0.30	0.457	3.048	0.001	30	1.22	2.916
FCF Smooth (1990-1991)	B-21	0.15	0.9	1.2	6.107	0.000996	11.1	1.37	1
	B-26	0.15	0.9	1.2	6.107	0.000996	11.1	1.37	1
	B-31	0.15	0.9	1.2	6.107	0.000996	6.78	1.37	1
Kiely (1989)	Kiely	0.05	0.2	0.2	0.77	0.001	6	1.224	1
Hardwick and Willetts-(1993)	AB-104	0.05	0.139	0.174	1	0.00062	8.63	2.043	1
	AB-101	0.05	0.139	0.174	1	0.001	8.63	1.21	1
	AB-102	0.05	0.139	0.174	1	0.001	8.63	1.40	1
Shiono-Al-Knight (1999)	1a	0.053	0.165	0.259	0.75	0.001	7.27	1.372	1
	1b	0.053	0.165	0.259	0.75	0.002	7.27	1.372	1
	1c	0.053	0.165	0.259	0.75	0.0005	7.27	1.372	1
NITR (2007, 2018)	KKK	0.12	0.12	0.12	0.443	0.0031	4.80	1.91	1
	Present-1	0.065	0.33	0.46	3.65	0.00165	11.9	4.11	1
	Present-2	0.065	0.33	0.46	3.65	0.00165	11.9	4.11	2.8

4. Results

Discharge prediction is carried out for each individual data by using Eq. (12), and for different modified formulae for evaluating the apparent shear stress. ($\tau_a^{1,2}$). The five formulae considered for estimating the apparent shear stress were already presented in Table 1. For the sake of simplicity, the apparent shear stress models are named as W-model, PT-model, WM- Model, C-Model and CH-Model respectively as arranged in Table1. For each dataset, the discharge is estimated by using the aforementioned apparent shear stress models and the results are presented.

In (Fig 5)., every three points correspond to a dataset from US-Army III-1 to US-Army III-b-2 (8 datasets x 3 = 24 points.). It is observed that the relative error is less for the datasets having smooth floodplains when compared to datasets having rough floodplains. Similar error analysis is carried out for other datasets, and the results are presented as follows

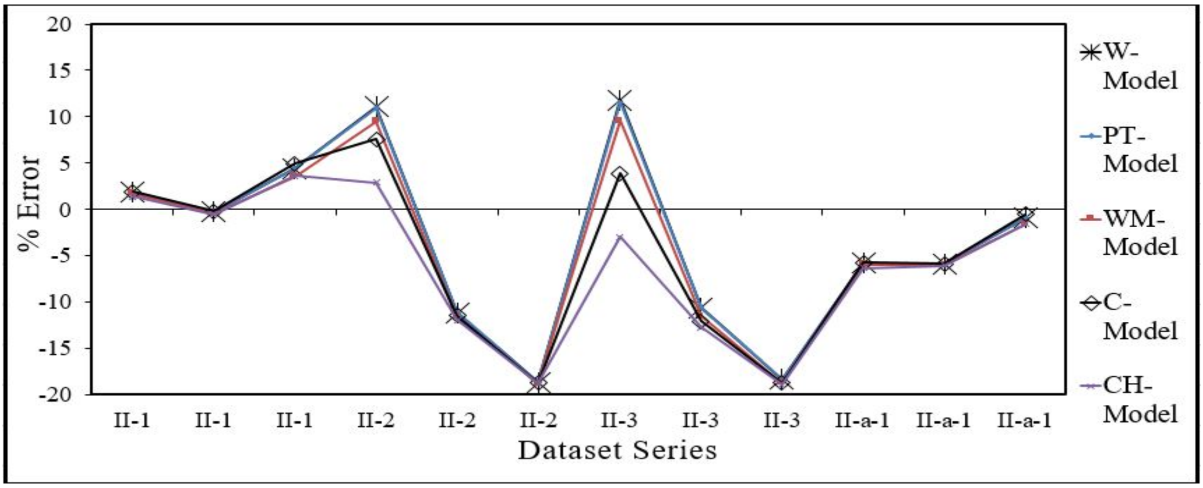

Figure 4 Relative percentage error in discharge for US-Army Datasets (II-1 to II-a-1)

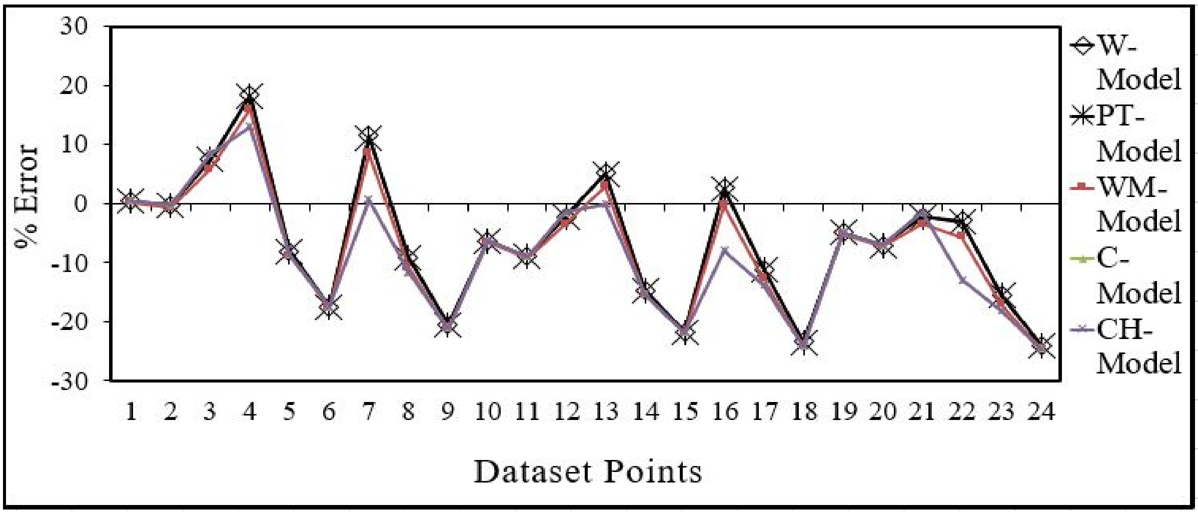

Figure 5 Relative Percentage error in discharge for US- Army datasets (III-1 to III-b-2)

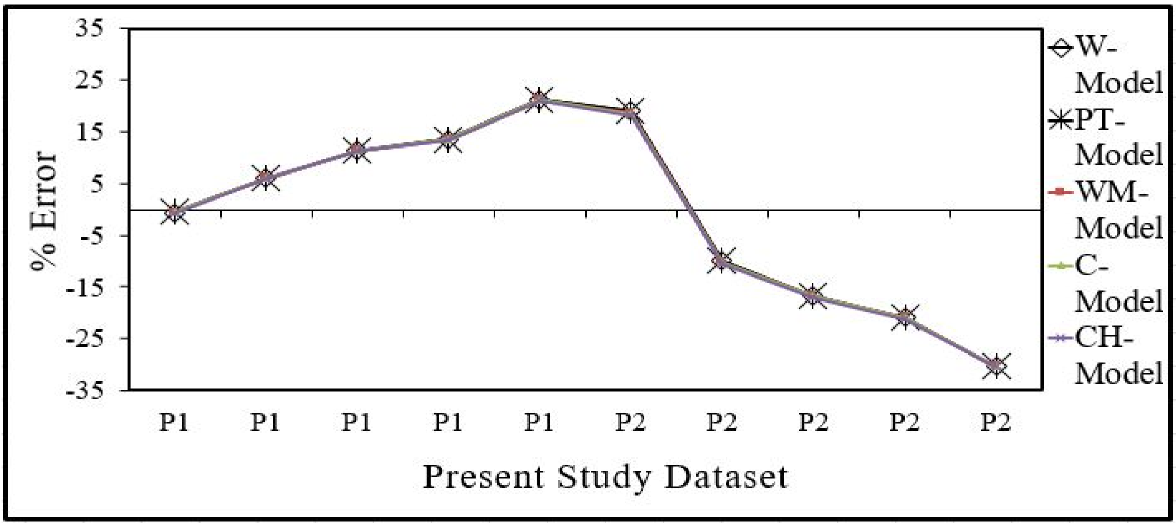

Figure 6 Relative Percentage Error in Discharge for Present Study (P1= Smooth and P2= Rough Floodplains)

5. Conclusions

The results show that the accuracy of the present discharge estimation model depends on the performance of apparent shear stress models. The percentage errors are relatively higher for the Kiely (1989) and Shiono-Al-knight (1999) datasets.

Table 3. Absolute Errors (Percentage) in discharge for different datasets

Dataset	W-Model	PT-Model	WM-Model	C-Model	CH-Model
Kiely (1989)	11.28	12.11	9.89	11.16	11.08
Hardwick and Willets (1993)	8.37	8.72	8.84	8.48	9.14
Shiono-Al-Knight (1999)	17.33	17.77	14.97	14.69	16.46
Khatua (2007)	4.12	4.23	5.63	4.32	5.88

Even though the Energy Concept Method was developed for estimating the discharges in straight channels, it can be applied to meandering channels with suitable modifications. By modifying the geometrical parameters in the apparent shear stress formulae, we have estimated the apparent shear stress and used those values for discharge estimation. These modified apparent shear stress formulae presented in Table1. give us reliable estimates for use in discharge prediction. However, more research is needed to model the apparent shear stress in meandering channels, and further modifications to the ECM are necessary for estimating discharge in meandering compound channels with minimum errors.

6. References

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