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Efficient Discharge Method to Estimate the Flow in Compound Open Channel

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Abstract- One typical arrangement for rivers is compound channels. Experts who need to know about flood mitigation, hydraulic structure construction, sediment load prediction, reservoir basin capacity, and other related topics can minimize losses by assessing flow variation during catastrophic events with the aid of dependable discharge capacity estimation in compound channels. The conventional techniques of treating the cross-section as a whole or segmenting it into non-interacting subareas along its vertical, horizontal, or diagonal axes have been extensively researched by numerous researchers.

Keywords— Efficient Discharge Method, Estimate the Flow, Compound Open Channel. Load Prediction.

INTRODUCTION

The capacity to forecast river channels with floodplains also known as compound channels accurately is a significant source of uncertainty in river channel research. These compound channels have deep main channels with relatively shallow floodplains on one or both sides. The floodplains are rougher, frequently vegetated, and have slower velocity than the main channels. Numerous investigations have revealed a bank of vertical vortices along the vertical interface between the main river and its floodplains when the water inundates the floodplains. The discharge capacity is determined using traditional methods at low depths, when the flow is exclusively in the main channel. However, the traditional formulae for estimating discharge capacity do not produce accurate results when overbank flow occurs, such as in the case of a flooded river. This could result in either a dangerous overestimation of discharge capacity or an underestimation of capacity, which could waste resources. Due to this issue, the flow mechanism in compound channels has been thoroughly investigated. This has resulted in works that either establish new computational approaches for an accurate discharge capacity prediction or include improving the traditional discharge estimation methods. Beyond only a convenience, a river is. It is a very valuable asset that provides a basic need for life and ought to be divided among those in positions of authority. It is a gift from God to all living things, helping us to be purified, sustained, and renewed. The greatest prehistoric societies developed along riverbanks. Many people still live on the banks of rivers today, relying on them for their life, and this is true all throughout the world. Nonetheless, river flooding is quite dangerous and has the potential to completely destroy an entire city, region, or shoreline, resulting in significant loss of life and property damage. It can also be quite harmful and has an excessive amount of erosive power. Floods vary in size and occur at unpredictable intervals. Consequently, it is critical that flood hazards be considered throughout the design process and controlled to minimize its negative social and economic effects. A river's main course is usually surrounded by flood plains. This form is very important since, in many circumstances, the main channel of a river cannot discharge the whole flow during flood occurrences. Thus, the adjacent fields, known as the floodplains, are overtaken by the water. Compound channels are crucial for concerns related to the environment, economy, and architecture. Typically, they consist of a main river channel and its floodplain. Studying the process of river flow in both in bank and overbank situations is therefore necessary. A compound part of a natural waterway often has a rougher and larger floodplain than the main channel. The flow process in open channel flow gets more complex at over bank stages because of the distinct hydraulic conditions that exist in the main channel and the nearby floodplains. For over bank stage, the resultant velocity distribution is often non-uniform over the cross section. The main channel has a higher velocity than the floodplain as long as the flood plain has a shallow flow depth that is not equivalent to the main channel's depth of flow. Shallow floodplains provide greater flow resistance than deep main channels, which results in a difference in velocity between these two sections. There is mass exchange and lateral momentum transfer as a result of these variations in flow velocities. Vertical vortices are produced along the interface between the main channel and floodplain as a result of this lateral momentum transfer. Accurate discharge capacity forecast in compound channels is necessary for many real-world river engineering challenges because it is crucial to include in flood mitigation plans. Sellin (1964) demonstrated that large-scale turbulence linked to substantial momentum transfer causes the section's overall conveyance to diminish. Quantifying the interplay between the floodplain and main channel has been attempted several times. Ackers (1991), Yen and Overton (1973), Myers (1978), Knight and Demetriou (1983), Zhonghua Yang Wei Gao et al. (2011), and others created an energy-based model to predict discharge by analysing the transition mechanism and energy loss.

REVIEW OF LITERATURE

Sellin (1964) conducted a no of experiments in compound channel and came to a result of momentum transfer mechanism in a compound channel which is due to the relative velocity in between main channel and flood plain. He studied about the vortices which are formed at the interface of main channel and floodplain. He analyzed discharge and velocities for compound and simple conditions. It was observed that the velocity found to be more in simple condition than that of compound condition.

Zheleznyakov (1971) studied the interaction junction between main channel and adjoining floodplain. He conducted a no of laboratory experiments and presented the momentum transfer effect. He expressed that because of momentum transfer the overall rate of discharge is decreased for lower floodplain depth and the impact of momentum transfer in decreased as the floodplain depth goes on increased. Due to faster moving main channel flow and slower moving floodplain flow a relative drag and pull is created which actually gave rise to the momentum transfer at junction which is called “kinematics effect”.

Wormleaton et.al. (1982) Studied in straight compound channel and conducted a series of laboratory experiments in compound channel with symmetrical floodplains to measure discharge. He used divide channel method to calculate discharge. For choosing the method to be best method of dividing the channel for calculation of discharge an apparent shear stress ratio was suggested. Satisfactory results were obtained by the horizontal and diagonal interface divided channel method than the vertical interface divided channel method.

Stephenson and Kolovopoulos (1990) analysed various methods to estimate the discharge prediction solution by taking shear stress variation between main channel and floodplain comparing to different flow conditions. They predicted discharge based on the previously published data and came to a conclusion that in predicting discharge the most reliable method is “area method”.

Abaza and Al-Khatib (2003) conducted experiment of five different types of boundary shear stress distribution, viz., shear stress at the bottom of main channel centreline, maximum shear stress at the bed of the floodplain, maximum shear stress at bottom of the main channel, average shear stress at the bed of the floodplain, average shear stress at the bottom of the main channel considering six different types of symmetrical rectangular compound channel. For the prediction of five shear stress which are measured experimentally as a function of three dimensional parameters a generalized regression model of multiple variables are derived. A regression model based on single multivariable was presented for the estimation of mean shear stress at the bottom of the rectangular compound channel average values of obtained regression coefficients of the multiple variable regression models.

Knight et al(2010) proposed a model which is useful for analyzing a range of practical problems in river engineering based on lateral distribution of shiono & Knight method(SKM). The model is very useful in prediction of depth averaged velocity, stage discharge relationship, lateral distribution of boundary shear stress, study of sedimentation and vegetation issues.

APPROACHES TO CALCULATE AN OPEN CHANNEL'S DISCHARGE CAPABILITY

(i) Single Channel Method (SCM)- The single channel method (SCM), which treats the channel as a single unit with suitable friction coefficient averaging, is the most basic model for calculating uniform flow in a complex channel. This SCM assumes that the velocity is constant over the whole cross-section and discards the channel's composite nature. The Manning equation and the Darcy-Weisbach equation are inappropriate for compound channels, as demonstrated by several experimental findings. The calculated discharge of a compound channel will be smaller than its actual discharge if it is handled as a single channel; if it is divided into many subsections and the standard equations are applied to each one, the total discharge of the subsections will exceed the actual discharge. Clarifying the characteristics of flow resistance in compound channels is therefore essential. Numerous academics have researched resistance to flow in compound open channels. Models for composite friction factor were established by Myers and Elsawy (1975), Krishnamurthy and Christensen (1972), and Lotter (1933). Through experiments, Wormleaton (1982) found that the Darcy-Weisbach and Manning equations are inappropriate for use with compound channels. The work of Knight and Demetriou (1983) was expanded to rough floodplains by Knight and Hamed (1984). Pang (1998) studied the effects of isolation and interaction on compound channels in straight reaches. It was discovered that the discharge distribution between the floodplain and main channel matched the flow energy loss, which is represented by the flow resistance coefficient. In their 2005 study, Yang et al. examined the Mannings and Darcy-Weisbach equations and found that, although the functional connection differs from single channel, the Darcy-Weisbach resistance factor is a function of Reynolds number based on a large amount of experimental data. Myers and Brennen (1990) have demonstrated that the uniform velocity assumption used in this model's application results in a considerable underestimation of the discharge capacity at low overbank flow depths.

(ii) Divided Channel Method (DCM)- The DCM approach, which divides the compound cross-section into hydraulically homogenous sub-areas so that the velocity in each subsection may be considered to be uniform, is the most often used technique for computing discharge in compound channels. According to Bousmar and Zech (1999), the division lines between the sub-sections might be vertical, horizontal, or diagonal. Vertical division lines are the most popular and useful option. The main channel and flood plain are divided in VDM by drawing vertical division lines on their interfaces; however, VDM-I differs from VDM-II in that the wetted perimeter is calculated taking into account a vertical line. In a same vein, the HDM-I and HDMII are not anticipated to vary from one another. Since it was first believed that these hypothetical division interfaces were shear-free, they were left out of the wetted perimeters of the nearby subdivisions during the computation of discharge. Myers (1978) demonstrated that these division planes were not shear free due to a turbulent interaction between the main channel and floodplain using boundary shear stress measurements. This indicates that an apparent shear force is necessary to produce a balance between the gravitational and boundary resistance forces. The problem of composite roughness is resolved by divided channel approaches, which allow floodplains and the main channel to utilise different roughness values in their respective computations. The compound channel section is split into subsections with the aid of these division interfaces. The discharges of each subsection are then determined using Manning's or Chezy's equations, and the sum of the individual discharges equals the total discharge carried by the compound channel.

(iii) Lotter Method- It was developed in 1930 by G. K. Lotter, who assumes that the friction slope in all subsection is same. The total discharge equals the sum of the constituent discharges. This method holds good for irregularly shaped open channels such as natural floodplain.

EXPERIMENTAL CHANNEL DESIGN

(i) Tilting Flume- A straight compound channel was employed in this investigation. An experimental setup was constructed in the NIT, Rourkela Fluid and Hydraulics Laboratory. The compound channel, measuring 15 metres long by 1.9 metres broad by 0.275 metres, has a tilting flume.Concrete and cement is used to make the canal. In order to dissipate energy and minimise turbulence before the water body crosses the channel, a series of baffle walls were erected immediately after the intake at the start of the flume and before the head gate (also known as the stilling chamber). In order to prevent waves from forming in the water body before they cross the channel, the head gate is essential. We are able to maintain gravity flow or an open channel by managing the incoming flow in this manner. Every place on the compound channel design could be reached for measuring purposes thanks to a travelling or moveable bridge that could be moved both span- and stream-wise. There was a platform that was almost 1.9 metres wide to facilitate experimental work. The purpose of the rectangular notch facility was to locate discharge for every run. An above tank supplies water to the flume from an underground sump with the aid of a 15 horsepower centrifugal pump. For calibration purposes, this water is recirculated via the downstream volumetric tank equipped with closing valves. An upstream rectangular notch created especially to measure discharge in a laboratory channel this broad allowed water to enter the channel through the bell mouth part. An adjustable tail gate was installed at the downstream end to regulate the flow depth and keep the channel's flow consistent.

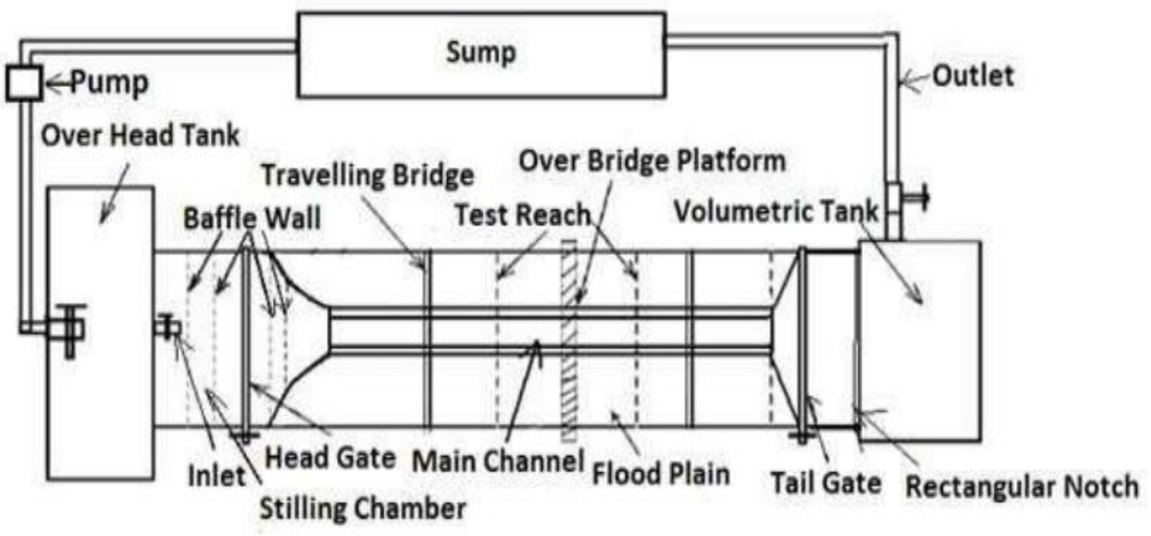

Figure 1- Schematic drawing of whole experimental system with tilting flume

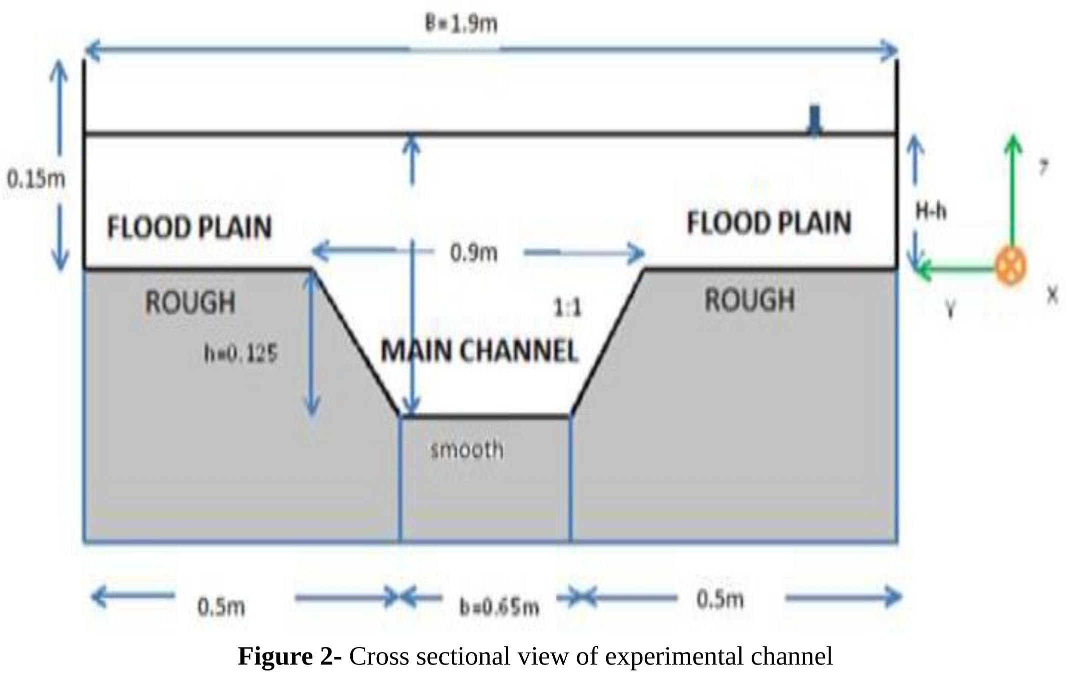

Figure 2- Cross sectional view of experimental channel

(ii) Experimental Compound Channel- The compound channel utilised in this experiment is composed of a symmetrical floodplain with a width of 50 cm and zero side slopes, as well as a main channel with a trapezoidal cross section that is 65 cm wide at the bottom and 90 cm wide at the top, with a depth of 12.5 cm and a side slope of 1:1.

(iii) Water Supply System- An overhead tank provided the water for the experiment, and a water level indicator was fixed to the tank to ensure a steady water level. Two parallel pumps were constructed in order to pump water from a subterranean sump to the above tank.Water from an above tank was transported to the stilling chamber, where it flowed across a trapezoidal channel to ensure that flow under gravity ceased at the end of the flume in a volumetric tank. The flow was left to return to an underground sump from the volumetric tank. The water supply system's recirculation is preserved.

Table-1 Detailed geometrical features of the experimental channel

Sr No.	Item Description	Present Experimental Channel
1	Channel type	Straight compound channel
2	Geometry of the main channel section	Trapezoidal(side slope 1:1)
3	Geometry of the floodplain section	Rectangular(side slope 0)
4	Floodplain type	Symmetric
5	Main channel width base width(b)	0.65m
6	Top width of compound channel(B)	1.9m
7	Depth of the main channel(h)	0.125m
8	Flood plain width	0.5m
9	Width ratio(α=B/b)	2.923
10	Aspect ratio(δ=b/h)	5.2
11	Bed slope of the channel	0.0022

CONCLUSION

In comparison to other existing approaches, the Lotter method appears to be the most promising approach for predicting discharge using the composite roughness method. It is shown that the coherence technique yields the best results when it comes to forecasting the discharge capacity within a reasonable standard deviation range. The following findings may be obtained from laboratory tests conducted to evaluate the effect of differential roughness on flow characteristics during overbank flow in a compound channel. Based on the stage-discharge relationship data, it can be stated that: Discharge rises as flow depth increases; Discharge reduces when differential roughness increases for a given flow depth. The discharge capacity in straight compound channels can be predicted using the aforementioned approaches, but it's vital to note that more compound channel methods need to be examined using a larger variety of data sets in order to identify an effective approach.

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