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Review on Flow Prediction, Resistance, Momentum Exchange and Sediments in Compound Channels

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Abstract - *The term 'compound' covers channel cross-sections having flood plains that come into action during high floods.. Compound channels have traditionally been analyzed by dividing the compound cross-section into relatively large homogeneous sub-areas. Most of the rivers have their cross sectional geometry in the form of a compound section where a deep main channel is along with shallow adjacent floodplains. The main channel flow is faster and the floodplain flow is slower comparatively. Although several studies have being carried out in the past, accurate prediction of compound channel flow parameters remains a difficult issue.*

Key Words*: *Compound channel, critical flow, flow prediction, flow Resistance, Momentum exchange.

1.INTRODUCTION

The compound channel consists of a main channel that carries flow in the dry season and floodplains on both sides that carries overbank flow. Naturally during the floods, which occurs for most the plain rivers. It is very important to understand the flow mechanism of rivers in both their in-bank and over-bank conditions. This paper attempts to effectively study the need of research in compound channel flows.

Fig-1 A compound channel section

2. BASIC AREAS OF RESEARCH OF COMPOUND CHANNEL FLOWS

Accurate predictions of flow parameters in compound channels extensive study on the following fields has been reported in literature:

a) Flow prediction.
b) Momentum exchange.
c) Critical flow study in compound channel.
d) Channel resistance.
e) Sediment flow transport.
f) Unsteady flow analysis.

2.1 Flow predictions in Compound Channel

The traditional method to study the flood inundation is based in an old approach that simply divides the total cross-section with vertical in the interface of the main channel and the floodplains (Chow 1959). The new 1-D approach takes into account the interaction between the flows in each subsection. In engineering, due to the amount of data required and the processing time, 1-D methods are often preferred.

When predicting the discharge in a compound channel using the Single Channel Method (SCM), the whole compound channel section is treated as a single section and the average velocity can be used to predict the discharge as:

$$Q = \frac{AR^{2/3}S_0^{1/2}}{n} = KS_0^{1/2} \quad \text{----------------------} \ (1)$$

where *K* is the section conveyance.

- **Dividend Channel Method (DCM):**

This method proposes the division of the channel in three sub-sections, namely the main channel and the lateral flood plains.

$$Q = \sum_i Q_i = \sum_i K_i R_i^{2/3} A_i S_0^{1/2} \quad \text{---------------------} \ (2)$$

in which *Q* stands for discharge; *K* for subsection roughness coefficient; *R* for the hydraulic radius; *A* for the cross section area and S_0 for the slope of the channel. Index *i* indicates each subsection.

- **Coherence Method (CM)**:

The Coherence Method improves the result DCM. The coherence (COH) is the relationship between the discharges obtained assuming only one section (Single Discharge

Method –SDM, average roughness coefficient and velocity for the whole cross-section) and the DCM:

$COH = \frac{Q^{SCM}}{Q^{DCM}}$ ----------------------------- (3)

It is essential to investigate the flow structures that exist in compound open channels to understand the distribution of flow and its variables. Flow modelling in a compound channel is a complex matter. Indeed, due to the smaller velocities in the floodplains than in the main channel, shear layers develop at the interfaces between these subsections, and the channel conveyance is affected and also due to possible geometrical changes in a non-prismatic reach. Channel meandering results in increased interactions and exchanges that should also be considered in the flow modelling.

2.2 Critical Flows in Compound Channel

Critical flows may occur at more than one depth in channels having compound cross-sections. The possibility of multiple critical depths affects the water-surface-profile calculations.

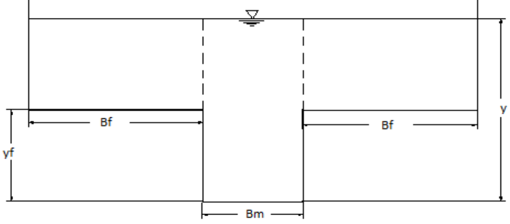

Fig-2: Compound channel cross-section

Presently available algorithms determine only one of the critical depths which may lead to large errors.

$$y_r = \frac{y}{y_f}$$

$b_r = \frac{B_f}{B_m}$ -------------------- (4)

$$b_f = \frac{B_f}{y_f}$$

$n_r = \frac{n_m}{n_f}$ ------------------- (5)

We obtain $\frac{gB_m^2 y_f^3}{Q^2}$; C is the function of y_r, n_r, b_r and b_f. For 2.4 channel cross-section, value of y_r at which $\frac{gB_m^2 y_f^3}{Q^2}$ are the critical depths for flow over the plain.

2.3 Channel Resistance

The flow in compound open-channel is characterized by a complex flow structure due to the interaction between the main channel and floodplain which channel and flood plains. Rouse (1965) classified flow resistance into four components:

a) surface or skin friction,
b) form resistance or drag,
c) wave resistance from free surface distortion, and
d) Resistance associated with local acceleration or flow unsteadiness.

By using the Weisbach resistance coefficient *f*, he expressed the resistance as the following dimensionless symbolic function:

f = F(R, K, η, N, F, U) ------------ (6)

In which R=Reynolds number; K=relative roughness, usually expressed as Ks/R, where Ks is the equivalent wall roughness and R is hydraulic radius of the flow; η =cross sectional geometric shape; N=channel non uniformity; F=Froude number; U=degree of flow unsteadiness.
The most frequently used formulas relating open-channel flow velocity to resistance coefficient are:

a) **Manning Equation (1891):** Most popular in U.S. for open channels.

$V = \frac{1}{n} R^{2/3} S^{1/2}$ ------------------ (7)

b) **Chezy equation (1768):** Introduced by Antoine Chezy in 1768.

$V = C\sqrt{RS}$ --------------------- (8)

c) **Darcy-Weisbach equation (1840):**

$V = \sqrt{\frac{8g}{f}}\sqrt{RS}$ ------------------- (9)

In which n, f, and C are the Manning, Darcy-Weisbach and Chezy resistance coefficients respectively; R=hydraulic radius; S=slope; g=gravitational acceleration; and K=1 m1/2/s in SI units.

2.4 Unsteady flow Analysis in compound channels

Unsteady flow in open channels differs from that in closed conduits in that the existence of a free surface. The analysis of unsteady flows is usually more complex than that of steady flows because unsteady-flow conditions may vary with respect to both space and time.

3. BACKGROUND

The research on compound channel started as early as 1932-1933 and has been a topic of interest to as recent as 2015. Different papers and journals have been brought forward by various researchers on the discharge computation, flow resistance, momentum exchange, and critical flow of a compound channel and sediment transport in compound channel.

4. LITERATURE REVIEW

To ensure a high-quality product, diagrams and lettering MUST be either computer-drafted or drawn using India ink.

4.1 Literature related to flow prediction

Many practical problems in river engineering require accurate prediction of discharge capacity in compound channels as it is extremely essential to imply in flood mitigation schemes.

Sellin (1964) showed that Large-scale turbulence associated with significant momentum transfer leads to the decrease in total conveyance of the section. Several attempts have been made at quantifying the interaction between the main channel and floodplain Sellin, 1964; Zheleznyakov, 1971; Yen and Overton, 1973; Myers, 1978; Rajaratnam and Ahmadi, 1981; Knight and Demetriou, 1983; Ackers, 1991; 1993. Sellin (1964), Zheleznyakov (1965), Van Prooijen (2005) noted experimental studies indicating that lateral momentum transfer occurs between the main channel and flood plain and generally slows down the flow in the main channel while accelerating the flow into the flood plain. Ivanova (NERC 1975; Tingsanchali 1976, 1988; Cungeet al. 1980; Yen 1987) concluded the peak of the flood wave attenuates along the channel and a hysteresis occurs in the stage-discharge curve. Shiono & Knight (1989), Wark et al., (1990), Lambert & Sellin (1996), Ervine et al., (2000), and Prooijen et al., (2005) developed 2-D methods; Shiono & Knight method (SKM), 2-D Lateral Division methods (LDM) respectively. All these methods take into account momentum transfer due to lateral shear and vorticity at the main channel/floodplain interface. Knight and Brown, 2001; Lyness *et al.*, (2001) have focused on discharge prediction in straight mobile bed compound channels, examining the impact of sediment movement in the main channel on the discharge capacity of the main channel and floodplain.

Seckin (2004) applied for 1-D methods to a major coverage of both experimental and field data obtained from a prototype compound channel (Main river) and concluded that both EDM and COHM gave better predictions than the SCM and DCM. It is well-known that 3-D models require more information and turbulence coefficients and are at present not immediately useful for design purposes due to calibration requirements. Galip Seckin et al., (2008; revised in 2009) analyses two-dimensional (2-D) formulae for estimating discharge capacity of straight compound channels. Zhonghua Yang Wei Gao et al., (2011) based on the energy concept developed a model to estimate discharge in which energy loss and the transition mechanism were analyzed. Md. Abdullah Al Amin et al., (2013) concluded that that the discharge always increases with the increase of depth ratio in compound meandering channel i.e. At low depth ratio, discharge decreases with the increase of width ratio but for higher depth ratio, discharge increases with the increase of width ratio. J.N. Fernandes et al., (2015) assessed the accuracy of 1-D methods by comparing their predictions with a large experimental dataset and thus concluded that those methods that account for the momentum transfer between the main channel and the floodplains shows considerably better results than the traditional methods.

4.2 Literature related momentum Exchange

Experimental studies indicate that lateral momentum transfer occurs between main channel and floodplain and generally slows down the flow in the main channel while accelerating the flow into the flood plain Sellin (1964), Zheleznyakov (1965).

Prinos and Townsend (1984) have described the lateral momentum transfer by introducing an interface shear stress between adjacent main channel and floodplains and the channel dimensions. Ackers (1992, 1993) has proposed a set of empirical equations based on coherence concept considering momentum transfer between main channels and flood plains. A modified expression to predict the boundary shear stress distribution and stage discharge in compound channels is derived by Khatua et al. (2011). The practical method is taking due care of the momentum transfer. During flood it is very difficult to do field investigations, so investigators generally choose experimental approaches in laboratories to understand the complex phenomenon with ease. Thus, a computational approach can be handy to provide a complementary tool.

Simulations have been performed by Krishnappan and Lau (1986), Larson (1988), Kawahara and Tamai(1988) and Cokljat (1993). More detailed numerical modeling has been undertaken by Thomas and Williams (1995a; 1995b; 1999) and Shi et al. (2001) to examine the detailed time dependant three dimensional nature of the flow in compound channels.

4.3 Literature related to critical flow study

Using the momentum principle, Boussinesq (1877) first defined critical flow as the transition between “tranquil” and “shooting” flows, based on the singularity of the backwater equation, thereby including the effect of non uniform velocity distribution through the momentum correction coefficient. Boussinesq (1877) never used the term “critical flow,” but referred to it as a “stability principle,” which was never defined formally. Later, based on the energy equation and the analogy of the velocity distributions between a current “free vortex” i.e., irrotational flow with circular streamlinesand contracted weir flow. All previous developments were made without the current formal definition of specific energy, a concept allowing for the physical interpretation of critical flow.

Paul Böss' discussion included the equivalence for the computation of critical flow with parallel streamlines, and the relation between the critical flow depth and the vertical surface profile.

Rouse (1932) also demonstrated that in a rectangular channel the critical flow depth of curvilinear-streamline flow differs

Blalock and Sturm (1981), (1983); Konemann (1982); Petryk and Grant (1978) have analytically and experimentally shown that there may be more than one critical depth for channels with overbank or floodplain flow.

Schoellhamer, Peters and Larock (1985) showed that the Froude number for the main channel and for their experimental section was equal to 1 at two different depths, thereby indicating that there is more than one critical depth. Chaudhry and Bhallamudi (1988) showed that the flow may be critical even when the specific energy is not minimum. They presented an algorithm that first determines the possible number of critical depths in a cross section for a given discharge and then computes their values one by one in an efficient manner.

4.4 Literature related to channel resistance

Research concerning resistance to flow in compound open channel has been studied by many scholars, such as Lotter (1933), Pavolvoskii (1932), Einstein and Banks (1950), Krishnamurthy and Christensen (1972), Myers and Elsawy (1975) developed models for composite friction factor. Habersak et al. studied flow resistance caused by wooden sticks representing vegetation in floodplain with flood flows condition.

Posey (1967), Worm-eaten (1982) have experimentations and observed that the Manning's equation and the Darcy-Weisbach equation are not suitable for compound channels. Knight and Hamed (1984) extended the work of Knight and Demetriou (1983) to rough floodplains. Pang (1998) conducted experiments on compound channel in straight reaches under isolated and interacting conditions. It was found that the distribution of discharge between the main channel and floodplain was in accordance with the flow energy loss, which can be expressed in the form of flow resistance coefficient.

Yang et al. (2005) presented the study of Manning‘s and Darcy‘s Weisbach equation and through vast number of collected experimental data indicated that Darcy‘s Weisbach resistance factor is a function of Reynolds number but the functional relationship is different from single channel.

4.5 Literature related to unsteady flow Prediction

Wormleaton et al. (1982), Knight and Demetriou (1983), and Stephenson and Kovlopoulos (1990) have studied in detail the flow pattern and the distribution of the boundary shear stresses in a double rectangular channel.

Quintela (1982) briefly discussed the shapes of flow profiles in a compound channel. He illustrated the occurrence of rapidly-varied flow when the slope of the channel bottom changes. Shiono and Knight (1991) have broadened the analysis to all shapes of channels that can be discretised into linear elements. In addition to Shiono and Knight (1991), at least Prinos et al. (1985), Shimizu and Tsujimoto (1993), Lambert and Sellin (1996), and Sofialidis and Prinos (1999) have studied the structure of turbulence. Myers and Lyness (1997) have researched the discharge ratios of compound channels, finding two significant key ratios to explain the flow behaviour: total-to-bankfull discharge and main-channel-to flood plain discharge.

According to Myers (1987; ref. Stephenson and Kovlopoulos, 1990), used 1D flow computation of channels with floodplains so that floodplains are considered only as storage areas with zero longitudinal velocity.

According to Nuding (1991, 1998), the friction factor of the boundary depends on the relationship of the ideal velocity in the main channel without the effects of interaction and floodplain velocity, the relationship between the hydraulic radius of the floodplain and the depth of the imaginary boundary and relationship between the contributing width of the floodplain and the computational main channel width.

4.6 Literature related to sediment flow transport

Chunhong Hu et al., (2010) gave an analytical solution concerning lateral distribution of the depth-average velocity and sediment concentration in a compound channel indicating that the distribution of longitudinal velocity with depth in the main channel and the flood plains has a logarithmic component. Fraselle and Bousmar et al., 2010 studied the lateral sediment transfer and patterns of subsequent deposition during overbank flows using digital imaging. Relevant dependence between longitudinal and lateral distribution was observed. K.C. Patra, N. Sahoo et al., 2012 The flow resistance by the channel boundary is revealed in the form of distribution of boundary shear along its periphery. They analyzed equations of shear stress distributions across the channel boundary. Mazlin Jumain, Zulhilmi Ismail, et al.,(2013) showed that the maximum velocity profile is observed in the main channel where sediment transportation takes place which leads to change in bed formation and erosion occur at the channel bed influenced by the higher velocity in the main channel.

5. CONCLUSION

Although till date many researchers have carried out many researches on the various flow parameters like discharge, channel friction, flow prediction etc. still many aspects have remained uncovered like momentum exchange, channel resistance, sediment flow transport etc. But as the topic of interest till date are more details about the computation of discharge of a compound channel is expected to found out.

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