IDENTIFICATION OF CRITICAL DEPTH AND LATERAL FLOW REGIME IN SYMMETRICAL ROUGH COMPOUND CHANNEL

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Abstract: Critical depth in an open channel is most commonly known as the point of minimum specific energy, the point of minimum specific force, or the transition between supercritical and subcritical flow, where the celerity of a surface wave is equal to the velocity of the flow. In this paper, a new method to find out kinetic energy correction factor for determining critical depth in a compound channel is presented in Froude number and specific energy curve by conducting experiment in symmetrical rough compound channels. And also the types of lateral flow regime in present compound channel flow is identified at which the flow behaviour within the channel begins to change from one regime to another.

Keywords: Critical Depth, Froude Number Kinetic energy coefficient, Specific energy curve, Lateral Flow Regime

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INTRODUCTION:

Natural river channels are often of this type and represent a complex geometry to the flow with widely varying depths and roughnesses within the same cross section (Bousmer et al.1967 and Townsend 1999). In addition, artificial floodways with an overbank flow region are a useful means of conveying a large range of flood discharge magnitudes safely while providing channel storage. In both the natural and artificial channel, accurate computations of water surface elevations and of critical depth are of concern to the hydraulic engineer.

It was shown that the subdivision Froude number for the main-channel flow for their experimental section was equal to one at two different depths, thereby indicating that there is more than one critical depth. Because of this possibility of multiple critical depths, it is necessary to determine their values for correctly computing the water surface flow profiles. Lee et al., (2002) using the laboratory flow velocity distribution data considered the interaction effect into calculation. Lee et al., (2002) showed that the use of a turbulence model such as the mixing length model (Lambert and Sellin, 1996) to improve regional velocity prediction has the ability to more accurately predict the subsection Froude number than the conventional divided channel method (DCM) (Lotter, 1933).

BACKGROUND:

While Many researchers have been focused on uniform flow in compound channels in the past, a few work has been done on predicting critical depth in such channel configurations(Bakhmeteff1932;Petryk and Grant 1978;Blalock and Sturm1981;koneman 1982;Schoellhamer et al. 1985;Chaudhury and Bhallamudi 1988; Yuen and Knight 1990; Sturm and Sadiq 1996; Lee et al. 2002:Kordi et al.2007)

METHODOLOGY:

In compound channels, the kinetic energy correction factor using the traditional divided channel method with vertical divisions which was evaluated earlier (Blalock and Sturm 1981). The Manning formula was used to calculate the conveyance of each section and the boundary between the subsections was not included in the wetted perimeter of the subsections. Using this method, the kinetic energy correction factor(α) in compound channel was stated as

$$\alpha = \frac{\sum_{i=1}^{3}\left(\frac{K_i^{\,3}}{A_i^{\,2}}\right)}{\left(\frac{K_T^{\,3}}{A_T^{\,2}}\right)} \tag{9}$$

Where K_i is the conveyance of ith subsection given by, $Ki=1/n_i*A_i*R_i^{\,2/3}$

And Ai is the cross-sectional area, n_j is the Manning surface roughness coefficient, Ri is the hydraulic radius of the cross-section and K_T, A_T are the total conveyance and cross-sectional area for the entire channel respectively. Blalock and Sturm (1981) defined the energy correction factor as a function of flow depth in compound channel and proposed an equation for Froude number given as below:

$$F_{rc} = \frac{Q^2}{2gK_T^3}\sqrt{\frac{\sigma_1\sigma_2}{K_T}} - \sigma_3 \tag{10}$$

Where F_{rc} is compound channel Froude number, K_T is the total conveyance and σ_k is the kth subsection property given as below:

$$\sigma_1 = \sum_{i=1}^{3}\left[\left(\frac{K_i}{A_i}\right)^3\left(3T_i - 2R_i\frac{dP_i}{dH}\right)\right] \tag{11}$$

$$\sigma_3 = \sum_{i=1}^{3}\left(\frac{{K_i}^3}{{A_i}^2}\right) \tag{12}$$

$$\sigma_3 = \sum_{i=1}^{3}\left[\left(\frac{K_i}{A_i}\right)\left(5T_i - 2R_i\frac{dP_i}{dH}\right)\right] \tag{13}$$

In Eqs. (8) to (10), T_i is the top width of the ith section; and $\frac{dP_i}{dH}$ equals √ 2.0 for side slopes of 45°and 0.0 for the main channel and flood plain beds respectively.

The new estimated kinetic energy correction coefficient was applied in the Eqs. (10-13) for finding out Froude number. The Froude number as well as the specific energy were evaluated for three different discharges to find out the critical depth.

RESULT AND DISSCUSSION:

The energy coefficients were calculated from the Eq. (9) and distribution of them gives in Fig. 3. As shown in Fig. 3 the energy coefficients are constant versus the flow depth until the discharge flows only in the main channel. By increasing the flow depth the value of the energy coefficients are increased rapidly. This change in distribution is related to intense non-uniformity in distribution of velocity and entering the properties of floodplains such as area and flow depth in computation process of energy coefficients.

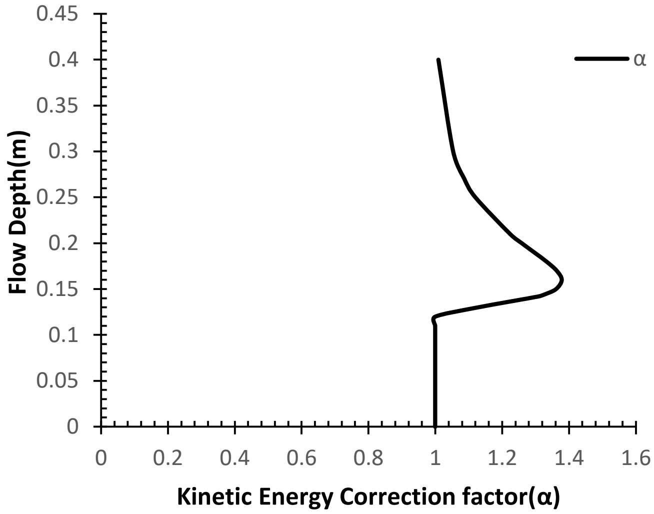

Fig. 3 Distribution of energy coefficient by DCM-D versus the flow depth

Figures 4 and 5 shows the distribution of Froude number versus the flow depth. Figure 4 shows Considering the energy coefficient to calculate the Froude number cases of appears more Froude number in constant flow depth. The critical depth is increased with the increase in discharge where the Froude number equals to unity.

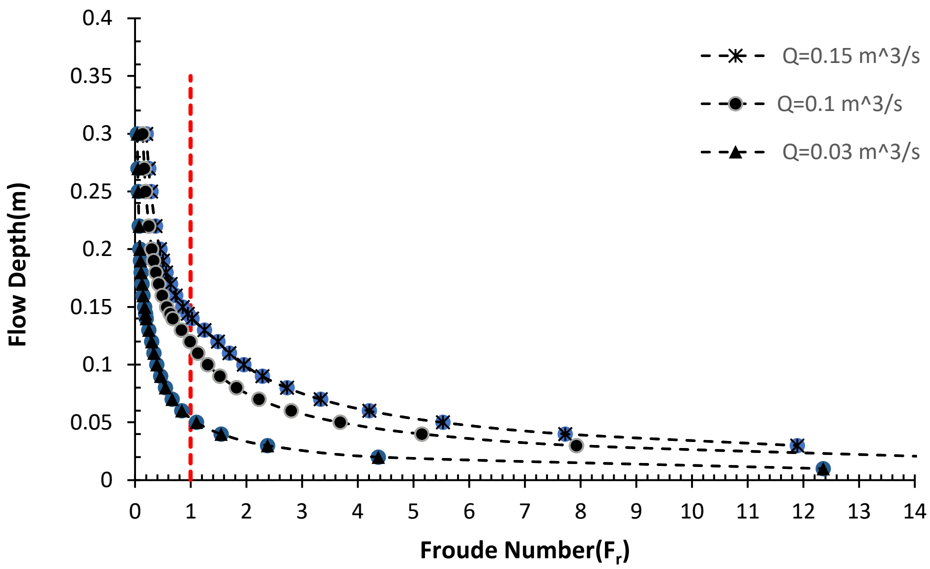

Fig. 4 Distribution of Froude number versus flow depth without energy coefficient

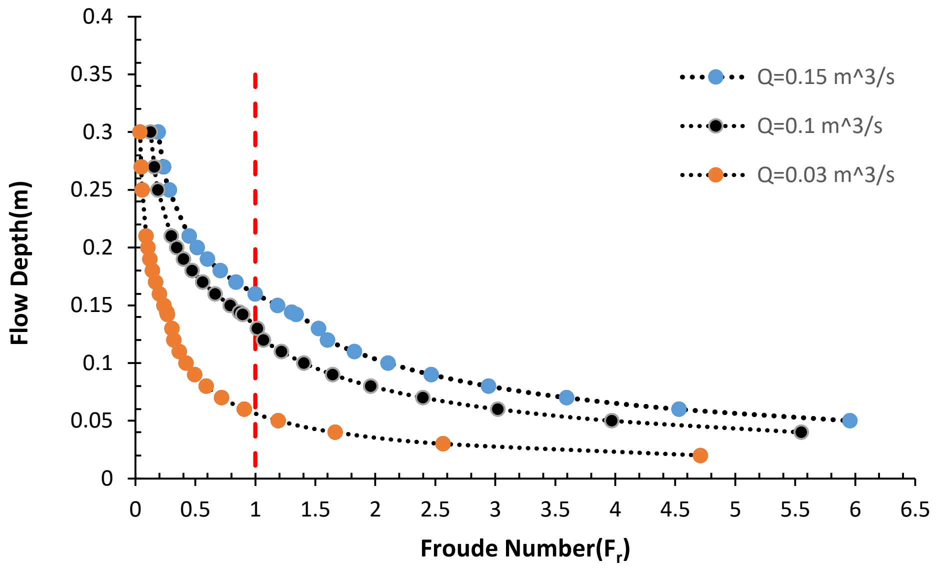

Fig. 5 Distribution of Froude number versus flow depth with energy coefficient(DCM-D)

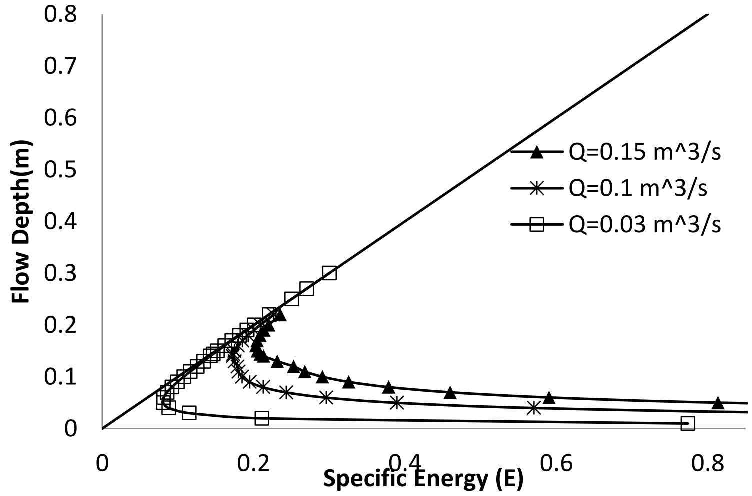

Fig. 6 Distribution of Specific Energy versus flow depth without energy coefficient

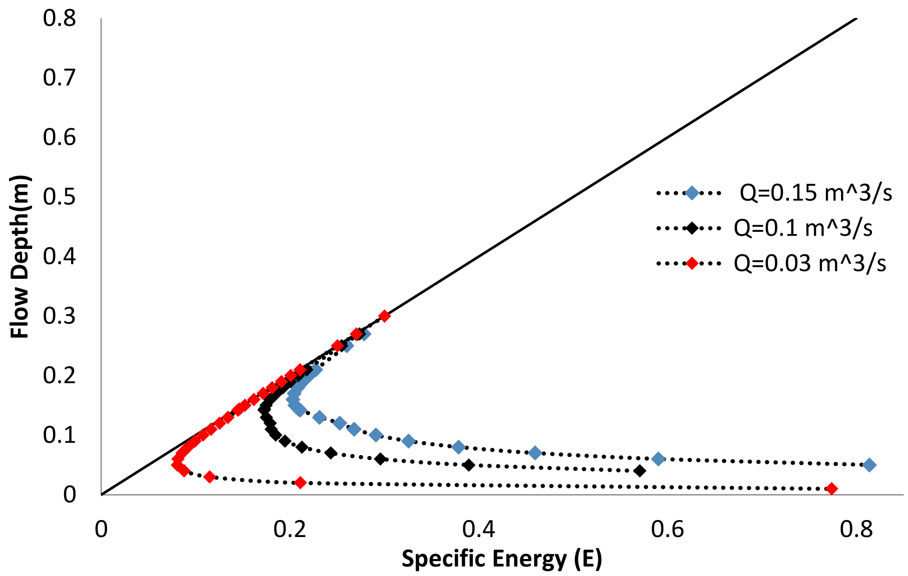

Fig. 7 Distribution of Specific Energy versus flow depth with energy coefficient(DCM-D)

Both of Figs. 6 and 7 shows the distribution of specific energy versus the flow depth. Specific energy increases by increasing the discharge of flow.

Lateral Flow Regime:

To accurately predict the point of critical depth transition in a compound channel, the nature of this transition in a compound channel must be properly understood. Experiments were conducted where the discharge of the compound channel was gradually increased with fixed geometry and slope, and the variation in local

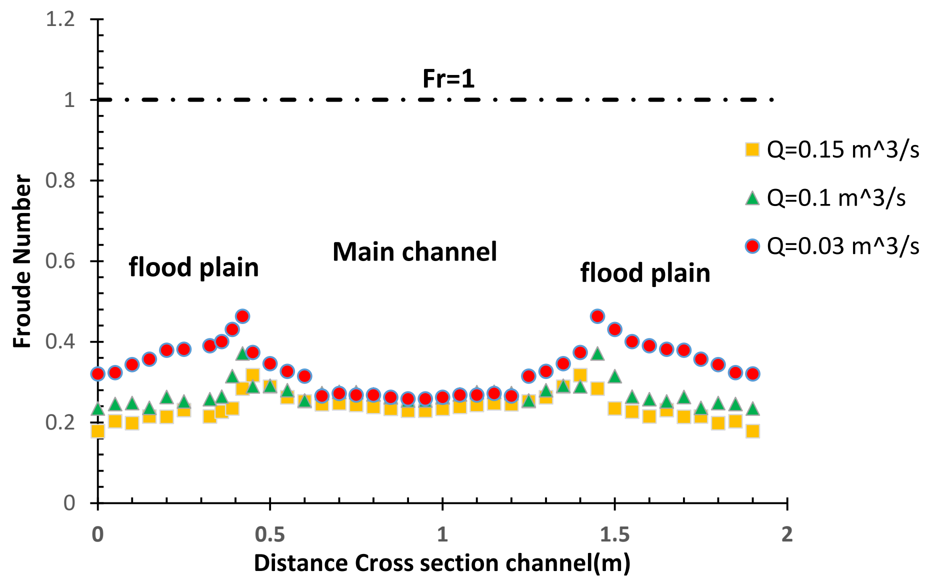

Fig.8 Variation of local Froude Number across the compound channel with rough floodplain

In Fig. 8, for all three set discharges of 0·15 m3/s, 0.1 m3/s and 0.03 m3/s depicts a compound channel where both main channel and the floodplains are sub critical, with averaged subsection Froude numbers of 0·4 in main channel and 0.5 for floodplain.

CONCLUSION:

This study has found that the critical depth for various discharges are increased as the discharge increases. Froude number has evaluated to identify the critical depth without considering kinetic energy coefficient(α), it was found that the critical depth occurred for the higher discharge at 0.13m of flow depth which is in main channel flow while 0.16m of flow depth with considering α, calculated using DCM-D is in overbank flow Accurate critical depth prediction is essential for the correct prediction of flow profiles within an open channel and the design of appropriate control structures for purposes such as flood mitigation. The existence of a mixed-flow region in compound channels complicates the calculations of these flow profiles which are normally undertaken by proceeding upstream for sub critical flow and downstream for supercritical flow. The control boundary conditions for a mixed regime flow will require further investigation.

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