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Experimental Study of Force Balance and Interaction between Flow in the Main Channel and on the Floodplains in Skewed Compound Channel with Inclined Floodplains

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1. Introduction

Investigation of the flow field in compound channels is an important issue for river engineers. In nature, due to topography conditions and geometry changes, most rivers have a non-prismatic compound cross-section. One of the non-prismatic compound channels is the skewed compound channel. In skewed compound channels, one of the floodplains is convergent, and the other is divergent. Along skewed compound channels, the flow leaves the converging floodplain and enters the main channel; on the other side, the flow from the main channel enters to the diverging floodplain. Therefore, the flow characteristics in skewed compound channels is highly complicated.

In this research, the flow field in skewed compound channels with inclined floodplains experimentally is investigated. In addition, the apparent shear forces on the vertical interface between the main channel and floodplains are studied by analyzing the force balance in the control volumes on the floodplains. The results of apparent shear forces are then compared with the skewed compound channel with horizontal floodplains.

2. Material and Methods

Experiments were performed on a flume of 18 m long, 1.2 m wide, 0.6 m deep, and bed slope of 1.63×10^{-3}, at the hydraulic laboratory of Bu-Ali Sina University, Department of Civil Engineering. This flume has a compound cross-section, consists of a rectangular main channel with 0.4 m wide and 0.05 m deep in the middle, and two inclined floodplains of 0.4 m wide and lateral side slope of 0.075(4.29^o) (see Figure 1).

Experiments were performed in compound channels with two skew angles of 11.31^o and 3.81^o (see Figure 2), and three relative depths ($D_r=\overline{H_{fp}}/H$, where $\overline{H_{fp}}$ is the average water depth on floodplains and H is the total flow depth in the main channel) of 0.2, 0.3, and 0.4.

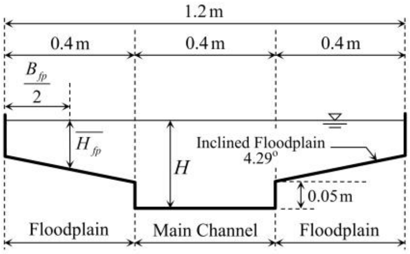

Figure 1. Cross-section of compound channel

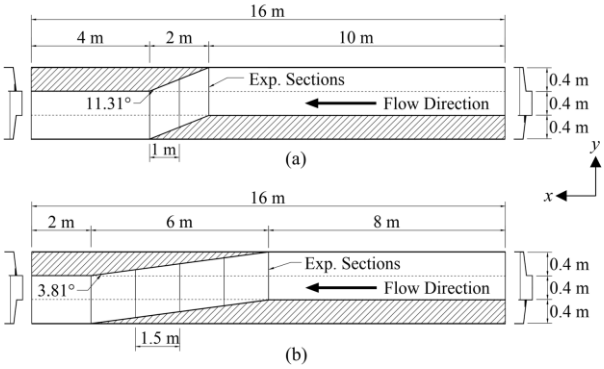

Figure 2. Plan view of the skewed compound channel with the skew angle of (a) 11.31^o (SCIF-2) and (b) 3.81^o (SCIF-6)

Using a three-dimensional (3D) Acoustic Doppler Velocimeter (ADV), flow velocity were measured at different sections along the skew part of the flume. Also, boundary shear stress measurements, were performed by use of 4 mm Preston tube. Measurements were performed at three and five sections along the skew part for the compound channel with the skew angle of 11.31^o and 3.81^o, respectively.

3. Results and discussions

Lateral distribution of depth-averaged velocity (U_d) and boundary shear stress (τ_b) at different sections for the skew angle of 3.81^o (SCIF-6) are shown in Figure 3.

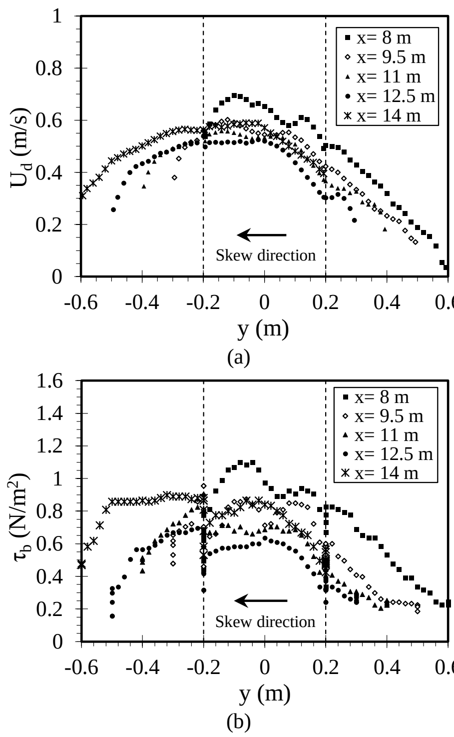

Figure 3. Lateral distribution of (a) depth-averaged velocity (U_d) and (b) boundary shear stress (τ_b) in different sections for the compound channel with the skew angle of 3.81^o (SCIF-6)

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The figure show that the lateral distributions of the depth-averaged velocity and boundary shear stress are asymmetric and follow the same trend.

Using the experimental data and based on the force and momentum balance for control volume on the converging and diverging floodplains, the apparent shear forces at the vertical interface between the main channel and floodplains are calculated. The perspective view of the control volume on the converging floodplain is shown in Figure 4.

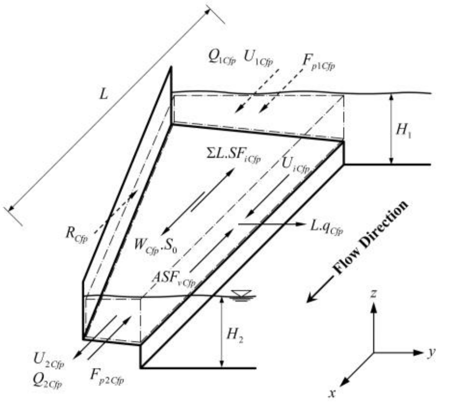

Figure 4. Control volume between two consecutive sections on the converging floodplain

The force balance for the control volume on the converging floodplain (Figure 4) is as follow:

$$\begin{aligned} &F_{p1Cfp} - F_{p2Cfp} + W_{Cfp}S_0 - \sum LSF_{iCfp} - R_{Cfp} - ASF_{vCfp} \\ &= \rho\beta_{2Cfp}U_{2Cfp}Q_{2Cfp} - \rho\beta_{1Cfp}U_{1Cfp}Q_{1Cfp} + \rho U_{iCfp}q_{Cfp}L \end{aligned} \tag{1}$$

where F_p is the hydrostatic pressure force, W is the weight force, S_0 is the bed slope, L is the control volume length, SF is the shear force per unit length, R is the wall reaction force, □ is the momentum correction coefficient, □ is the water density, U is the average velocity, Q is the flow discharge, U_i is the velocity at the interface between the main channel and the floodplain, q is the lateral flow per unit length, and ASF_v is the apparent shear force at the interface between the main channel and floodplain. Also the subscript Cfp refers to converging floodplain,

The apparent shear forces acting at the vertical interface between the main channel and floodplains for the skew angels of 11.31° (SCIF-2) and 3.81° (SCIF-6) and different relative depths are calculated and shown plotted in Figure 5.

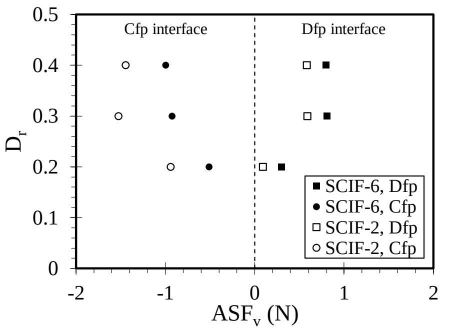

Figure 5. The apparent shear forces at the vertical interface between the main channel and floodplains for SCIF-2 and SCIF-6

Also the effects of floodplains lateral slope on force and momentum balances in the main channel and on the skewed floodplains have been investigated. To do so, the apparent shear forces at the vertical interface between the main channel and floodplains for different discharges and the skew angle of 3.81° (SCIF-6) have been calculated and compared with Chlebek (2009) (experimental study on skewed compound channels with the horizontal floodplains). See Figure 6.

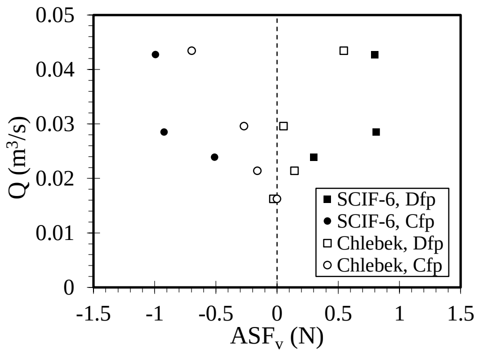

Figure 6. The apparent shear forces at the vertical interface between the main channel and floodplains for the compound channel with the skew angle of 3.81o (SCIF-6) and Chlebek's results (2009)

4. Conclusion

An experimental study of flow field in skewed compound channels with inclined floodplains was conducted. Experiments were performed in compound channel with two skew angles of 11.31° and 3.81°, and three relative depths of 0.2, 0.3, and 0.4. Using the experimental data and based on force balance, the interaction between flow in the main channel and on the floodplains were studied. Some of the most important results of the research are given as follows:

1. In the skewed compound channels, the lateral distribution of depth-averaged velocity and boundary shear stress at the middle of the skewed portion is asymmetric.
2. On the diverging floodplain, flow velocity and shear stress are always greater than those values on the converging floodplain at the same section.
3. Apparent shear force at the vertical interface between the main channel and converging floodplain has a negative value and at the interface between the main channel and diverging floodplain has a positive amount. Therefore, the lateral flow that exchanges between sub-sections accelerate flow in both the main channel and diverging floodplain.
4. A comparison between the present results with Chlebek (2009) shows that the apparent shear forces at the vertical interfaces between the main channel and inclined floodplains are bigger than those in the skewed compound channels with the horizontal floodplain.