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Velocity distribution description in a sand bed branching channel with different angles and bed widths

Nashwan K. Alomari [1, 2], Badronnisa Yusuf [1, *], Thamer Ahmed Mohammed [1], Abdul Halim Ghazali [1]

[1]Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2]College of Engineering, Mosul University, Mosul, Iraq

Abstract: A branching flow is a hydraulic phenomenon presents in many rivers or manmade channels and has many practical hydraulic engineering applications such as in irrigation systems where water is diverted from a river to irrigation canals. A sand bed physical model was used in this study to investigate the velocity distribution at the branching channel junction. Different cases of the branch channel geometry represented by three branch channel angles (30˚, 60˚, and 90˚) and three branch channel width ratios (30%, 40%, and 50%) were examined to characterize the velocity distribution. Experimental work finding displays a low velocity region in the upstream side of the beginning of the branch channel occurred in all cases of the branch channel geometry. Branch channel with 60˚ angle recorded the maximum low velocity region length, then 90˚ branching angle, and the minimum length took place at 30˚ angle. Moreover, 30˚ branching angle recorded the lees different of the velocity values between upstream and downstream sides of the branch channel and the less flow impact on the downstream branch channel side wall.

Key words: Branch channel; Branching angle; Sand bed; Low velocity region

1. Introduction

Branching channel flow is indeed important in hydraulic engineering (Wang and Ni, 2003). The complexity of flow structure and velocity distribution at the junction region has become the interest of many researchers. Formation of a low velocity zone and re-circulation of flow produces a separation zone at the junction region (Neary et al., 1999). With time, due to the low velocity, a sedimentation area may appears in this zone (Barkdoll et al., 1999) and become a privilege area for fish and plant propagation (Mignot et al., 2014) that led to reduction of flow capacity. Many studies have been conducted experimentally (Ramamurthy, Qu and Vo, 2007) and numerically (Shamloo and Pirzadeh, 2007) mainly in the right angle branching channel flow .

Flow velocity properties of the branching flow were reviewed extensively by (Alomari et al., 2016) This review illustrated that the branching flow cases forming two separation zones in the junction region, one at the upstream side of branch channel entrance and another sometime occur in the downstream main channel. Neary and Odgaard (1993) studied the effect of the main channel bed roughness on the velocity and dividing streamlines. They stated that the velocity profile in the main channel across the depth is more uniform in smoother than the rough bed. In addition, the branching flow increases as increasing the main to branch bed roughness ratio up to a certain value (Khaleel et al., 2015).

The main aim of this study is to characterize the velocity distribution experimentally at the branching channel junction for different branch channel geometry. Beside that the study also investigating the effect of the bed topography on the velocity distribution by measuring the velocity at the cross sections of the main and branch channels near the junction region.

2. Materials and methods

2.1. Laboratory Setup

A branching channel system consisting of main and branch channels was used to carry out the experiments in this study. The main open channel is a 12.5 m long, 0.313 m wide and 0.6 m deep rectangular glass walls flume. The branch channel is 2.75 m long, 0.6 m deep with changeable part at the beginning to switch the width to 9, 12, and 15 cm and to change the branching angle. This study investigated three branch channel angles (θ) (30˚, 60, and 90˚) and three branch to main width ratio (Br) (approximately 50%, 40%, and 30%) at five different total discharges (Qt) range between 7.25 – 12.25 L.s-1 for each case. 18 cm thickness layer medium sand with d_{50}=0.4 mm, σ_g=1.46, and S_g =2.53 was used as mobile bed material. Each experiment was started with flat bed and tested for 12 hours.

* Corresponding Author.

Pitot tube was used to measure the flow velocity (V) based on the difference between total and static head, Δh from the equation (1).

$$V = (2g\Delta h)^{1/2} \quad (1)$$

3. Results and discussion

3.1. Velocity contour in the plan

Fig. 1 displays the velocity in the plan view of the branching channel junction for different branch channel angles (30˚, 60˚, and 90˚) in case of 40% branch to main channel bed width ratio, total discharge of 9.75 L.s^{-1}, and branch to main discharge ratio of (25.3±0.3)%. The velocity was measured near the water surface (about 30% from the water surface) .

In the branch channel, the branching water enters the branch channel with the momentum direction towards the main channel flow. Therefore, the branching flow concentrates at the second half of the branch channel as a result a low velocity region formation in the first half of the branch channel. The low velocity area is denoted as a separation zone; this zone of separation works in contracting the flow and reducing water way after the short distance from the branch channel entrance. Branching water hit the downstream branch channel wall. As a result of the water impact on the downstream wall, a reaction is generated. This reaction transfer water from downstream to upstream side and after a distance, the water amount is balanced along the branch channel width. During that, vortexes are generated and extended for a distance until reaching the water balance state. This indicated the ending of the separation zone.

Changing the branching flow momentum direction of the main flow to 60˚ branch channel is easier than changing it to 90˚. Therefore, the strength of water impact in 60˚ less than 90˚ branching angle, and the water needs a longer distance to move to upstream side and reaches the balance state.

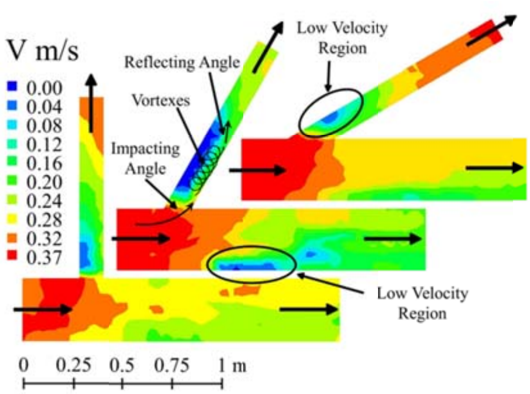

Fig. 1: Velocity contours in the plan view for different branching angle and 40% bed width ratio

Consequently, the vortexes in 60˚ are longer than 90˚ branching angle. Length of the vortexes at the downstream branch channel side plays a role of controlling the separation zone length because the water balance state cannot be achieved until the end of these vortexes. At the end of the vortex the separation zone ended

In the case of 30˚ branching angle, 40% bed width ratio and 9.75 L.s^{-1} total discharges as shows in Fig. 1, the flow separation length at the surface is reduced. Herein, the main reason for the reduction of the length of the separation zone was the increased of the branch channel entrance width. The entrance width in the case of 30˚ branching angle and 40% width ratio is equal to 24 cm compared to 13.86 cm and 12 cm for 60˚ and 90˚ branching angle, respectively.

The increased of the entrance width provided smoother entrance for the branching water and increased the uniformity of the water. In addition, it decreased the velocity at the beginning of the branch channel then decreased the momentum. That helped the branching water entered the branch channel much more uniform than other angles and reached the water balance state at the shortest distance. As the branch channel width increased to 50% bed width ratio in 30˚ branching angle, the velocity in the low velocity region increased and the difference between two halves of the branch channel velocities reduced due to increase of the width of the entrance as shown in Fig. 2.

In the main channel, the upstream main channel velocity was found to be always higher than the velocity of the downstream main channel. For subcritical flow, energy loss along the main channel is too small and can be neglected (Hsu et al., 2002). Therefore for the same total energy value the water depth increased as the unit discharge decreased due to some portion of the water was diverted towards the branch channel. In summary, water amount decreases and water depth increases in the main channel behind the branch channel junction. Therefore, velocity approach decreases at the downstream main channel.

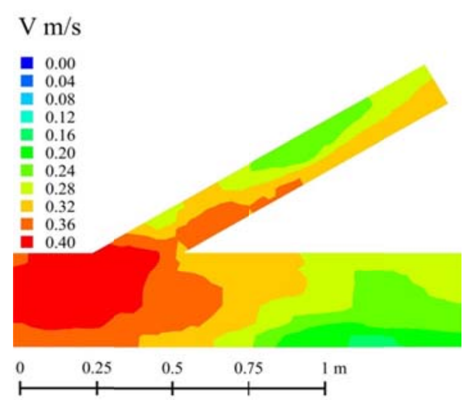

Fig. 2: Velocity contour in the plan (30˚, 50% width ratio and Qt=9.75 L.s^{-1}).

Another thing can be noted in the main channel was the appearing of the low velocity region in most of the cases at the opposite side of the branch channel intake just downstream of the branch channel. The low velocity region occurred due to the turning of flow streamlines towards the branch channel in order to feed it. After that, the flow returned to the balance and uniform state. This region formed in the transition area between the downstream edge of the branch channel junction and the beginning of the uniform flow area.

3.2. Velocity contour in cross sections

Velocity contours at ten cross sections were plotted across the branching junction for the maximum and minimum total discharge (7.25 $L.s^{-1}$ and 12.25 $L.s^{-1}$) in order to investigate the velocity distribution in this complex flow. Figs. 3 and 4 show the velocity contour of the cross sections in case of 60˚ branching angle, 40% bed width ratio, and 12.25 $L.s^{-1}$ total discharges.

From Fig. 3 the velocity of the flow at the upper layers starts to increase towards the branch channel intake side due to orientation the flow towards the branch channel. The increased of the velocity at the upper layers led the flow to continue at these layers towards the downstream main channel due to the high momentum in the main flow direction. As a result, the lower layers flow diverts more than that of the upper layers as display in Fig. 5.

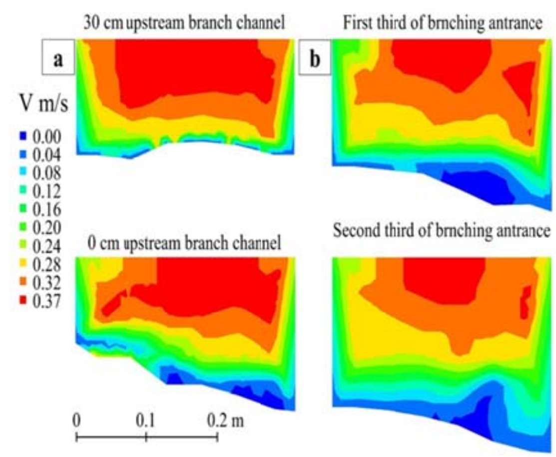

Fig. 3: Velocity distribution at cross section of a: upstream main channel, b: along the branch channel entrance, (θ=60˚, Br =40%, and Qt = 12.25 $L.s^{-1}$)

Because of the orientation the flow toward the branch channel and this orientation continue for some distance downstream junction region, as shown in Fig. 4a, the low velocity region, separation zone, at the right side wall just downstream the junction region is formed. In the branch channel, it is clear that most of the branching water enters the branch channel from a second half of the branch channel in the high velocity region as shown in Fig. 4b. For this reason, a region of separation happens in the first half of the beginning of the branch channel.

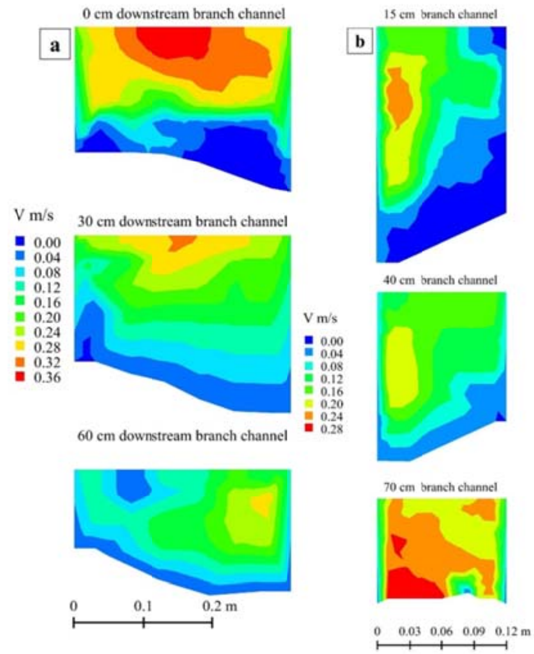

Fig. 4: Velocity distribution at cross section of a: downstream main channel, b: branch channel, (θ=60˚, Br =40%, and Qt = 12.25 $L.s^{-1}$).

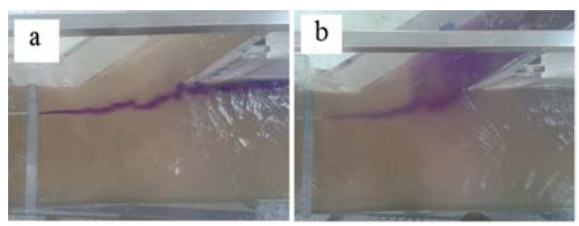

Fig. 5: Dye movement to illustrate the upper and lower layers behavior at junction region, at a: 80%, b: 20% from the water depth.

4. Conclusions

The main concluding from this investigation is the 30˚ branching angle show more flow uniformity and minimum low velocity region than other angles. This gave an advantage of reducing the branching flow impact on the downstream branch channel side wall and protecting the entrance from plants and fish that may be propagated in this region and reduce the flow capacity and obstruct the water way.

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