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A Review of Studying the Flow Characteristics in Branching Open Channels

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ABSTRACT

The drinking water supply, as well as other water-related uses for humans, begins with extracting the "raw" water from different sources. Many plants treat the water by directly flowing raw water from the water resources to the nearby plants of the treated water through the side channels. Open channels in drainage and irrigation projects are the main water transport method. For more situations, channels had to branch into more secondary channels though they could provide ancillary items such as water and irrigation to municipal utilities and hydroelectric schemes. Many experimental and theoretical investigations of the branch open channels have been implemented to recognize the flow into their characteristics and convert them into a natural case of practical and theoretical investigations. This study's primary targets are reviewing the effect of physical features and models of branch channels by checking relevant kinds of literature. The flow quantity to branching channels is affected by many factors (angle of diversion, discharge of the main channel, slope of the bed leading to both the main and the branch channel etc.). The branch channel experiences a reduction in its velocity, momentum, and Froude number due to an increase in the upstream discharge of the main channel. It rises with increasing water depth upstream in the branch and the main channel bed width. Since diverting water flow to a branch channel reduces the downstream water depth in the main channel, the main channel's water depth is often greater than the branch channel's. This review concerns the boundary condition and angle diversion of branch channels to the vital case investigation, so as to the recirculation zone occurs at upstream branch channel decreasing with decreasing the diversion angle.

1. INTRODUCTION

Open channel flow diversions refer to a portion of the discharge diverted from the main channel to the branch channel. For such cases, channels will need to secondary out to branches channel for feeding any side projects, such as plants of water supply municipality, irrigation and hydropower generation plants [1-3]. Many parameters affect the flow profile in Branching channel flow, such as the main channel discharge, the variation in the main channel and branch channel bed levels, and the diversion angle [4-6]. A few different morphologies may be used to describe branching channels, including deltas, braided rivers, and alluvial fans. The hydro-morpho dynamic processes in the river result from these forms [7-9]. Investigating flow behaviour in branching channels and flow diversion locations is fundamental for managing water and morphological diversion downstream, [10-12]. To the practical engineer, understanding the overall behaviour of a dividing flow may be more interesting than realizing the local complexities of flow. However, an insight into the flow's details is essential to understand the problem's nature.

The mechanics of the river bed are impacted by the construction of the branch channel to transmit some of the water from the main channel, flowing to the main channel and bed form changes, especially the region of junction; these effects give rise to many problems, such as the erosion and sedimentation in the branch channel and the main channel will change the main channel slope [13, 14]. Many researchers take a rectangular channel shape in bifurcations of an open channel in a large body because it has a structure of simple and easy to measure [15, 16].

Many studies early focused on the features of the rigid boundaries hydrodynamics, which intended with the experiments didn't contain movable beds and sediment transport [17, 18] but received attention for their clarifications by using geometric forms and different parameters [19, 20]. The key characteristics of the hydrodynamic are the contraction region, the point of stagnation, and the separation zones. The region of low flow velocity and water recirculation creates a zone of separation [21-23], so these zones will cause the capacity of branching channel and reduction of the discharge inflow passing through it. For example, two main zones of separation result from the flow that affects irrigation networks supply municipal water and power plants operating in the branching channels.

Prior studies for the flowing to the branch channels have studied the characteristics of the flow, such as discharge of branching flow. For instance, the study of Taylor [17] is an exciting study earliest, that investigated many ways to estimate the flow discharge for the Branching channel. He suggested a graphical trial-and-error method for the free-flowing discharge flow of the Branching channel based on the results of his experiments. Using a flowing free-over type configuration, Grace and Priest [18] analyzed the bed width ratio (branch width to main width), so they tend to divide the regimes by two, with waves standing for a different Froude number (Fr) and without waves standing upstream branch channel.

Later, the researcher investigated advanced branching channels with the theoretical equations exploration. Ramamurthy and Satish [15], Ramamurthy et al. [24], and Hsu et al. [25] developed a model for the flow to the branch channel based on theoretical considerations like a right angle. (900) with the main channel based on conservation principles of mass, momentum and energy. Assumptions show that there are no energy losses along the main channel. Hager [26], Kesserwani et al. [27] and Ghostine et al. [28] investigated their empirical equations for treating flow branching as a side flow over from side weirs zero high. Most of the flowing to the Branching channel would be studied with a right-angle branching and a rigid boundary, while a few researchers have studied by using different branching angles [29-31] or/with a condition of bed movable [32]. Herrero et al. [9] discovered a scour hole formed at the edge downstream to the entry of the branch channel in a diversion flow with (900) branching flow and a bed of movable sand.

The Branching angle is Another aspect of the influences on the branching channel system. The zone of separation at the system occurs in a branching channel at the wall downstream at 30° angle and at the wall upstream at 90° angle from the main.

Optimizing the quantity of the discharge from the main channel to the branch channel and from different angles uses 30°, 60°, and 90° shows that 60° is the optimum angle and more efficient [14, 30, 33, 34].

Finally, because so many variables, including the Froude number at the main and branch, channel gates end regulating, momentum and velocity characteristics, and the geometrical branching channel system, depend on the flow in the Branching channel, it is seen to be a highly complex situation [35]. Thus, it is crucial that this article should cover all of the impacts of the various geometries of the branching channel, such as the influence of branching angles on the flow in the branch and main channels. Moreover, it's a summary characterizing many papers concerning the diversion side flow for various conditions and geometrical channels, and attractive on occurring some of the phenomena that mathematical and physical models used in the diversion system for simulating the flow type.

2. CHARACTERISTICS IN BRANCH CHANNEL FLOW

2.1 Discharge ratio (Q_r)

The discharge ratio indicates the amount of water diverted from the main channel to the branch channel. It is determined by dividing the amount of water diverted through the branching side (Q_b) by the main canal (Q_u) [34, 36, 37]. It's essential to determine this ratio to analyze any branching channels. Many parameters rely on This ratio, such as (1) upstream and downstream Froude number to the channels (F_{ru}, F_{rd}, and F_{rb}, respectively), (2) how deep the water is in the branch channel and main channel upstream and downstream (y_b, y_u and y_d, respectively), (3) the slope of the bed (S), (4) angle of the Branch channel (θ), (5) ratio to the bed width (Br), the branch channel divided by the main channel bed width, (6) bed roughness, and (7) side weir, the crest's form, and the height of the weir if necessary [1]. There are many relationships between the ratio of discharge and other parameters, for this ratio relative to the bed width ratio (Br) [20, 38, 39], takes a constant width to the main channel of (20 cm) in all experiments laboratory, while taken bed width to the branch channel was changing several times (20, 15 and 10 cm), the effect on the flow by changes in bed width ratio (Br), the relationship between the bed width ratio, also known as Br, and the discharge ratio, also known as Q_r, for the many different values of the Froude number upstream of the main channel, Fu, and for all of the understudied angles of Branching that were considered. Furthermore, the ratio of the discharge (Q_r) increases as increasing the bed width ratio (Br). Table 1 summarises the properties of a typical physical model used to simulate branching channel flow.

Hsu et al. [25] and Huang et al. [40] characterized the flow diversion to the downstream and upstream main channel discharges (Q_d and Q_u), downstream and upstream depth of water to the main channel (y_d and y_u), gravitational acceleration (g) and main channel bed width (Bm) with the subcritical flow in 90o diversion channel, so there applied the energy equation for the one-dimensional divided flow model to find the discharge ratio as shown the Eq. (1):

$$\left(\frac{y_u}{y_d}\right)^3 - \left(1 + \frac{{F_d}^2}{2}\right)\left(\frac{y_u}{y_d}\right)^2 + \frac{{F_d}^2}{2\,(1-Q_r)^2} = 0 \quad (1)$$

An empirical equation to determining the discharge ratio (Q_r) based on the Branching angle, branch channel water depth to the downstream main channel depth of water, the branch channel slope and downstream main channel Froude number was observed by [30]:

$$Q_r = 27.98[(S_b^{0.029} sin\theta^{0.053})/\left(\frac{y_b}{y_d}^{0.384} F_d^{0.0409}\right)] \quad (2)$$

2.2 Reverse flows

It is essential for many researchers to note that the term "reverse flow" has been used to designate the flow region along the wall or walls where the flow direction is opposite to the net flow in the channel. In reality, this reverse flow region composes of part of the recirculation region or eddy region caused by flow separation. This is equivalent that a recirculation region extending from the corner where the flow turns along the wall to the exit end of the channel. Alternatively, the term "recirculation region" is used when the eddying flows form a distinct part of the flow. For example, Figure 1 shows the branch channel reverse flow. This recirculation region grows in length rapidly for a relatively small change in the discharge ratio [21, 41].

Table 1. Typical physical model properties for branching channel flow

Where, Sb is the bed slope branch channel, and θ is the branch channel angle. They took branching angles (30°, 60°, and 90°) and branching channel bed slopes (0.001, 0.0015, 0.002, and 0.0025). Authors	Main Channel					Branch Channel							
	Cross section	Length m	Width m	Depth m	Slope $*10^{-3}$	Cross section	Length m	Width m	Depth m	Slope $*10^{-3}$	Branch channel angle	Total discharge L/S	Type of flow
Al Omari N.K. et al, 2012	Rectangular	10	0.3	0.45	0.25	Rectangular	2	0.15	0.3	0.25	30˚,60˚, 90˚	13 – 17.25	subcritical
Abu-Zaid T. S., 2022	Rectangular	7.2	0.45	0.6	0	Rectangular	2	0.45	0.6	0	30˚,60˚, 90˚	16.4	subcritical
Bulle H., 1926	Rectangular	8.6	0.2	0.3	3	Rectangular	3.2	0.2	0.3	3	30˚	5	subcritical
Barkdoll et al., 1998	Rectangular	19	0.15	0.3	0	Rectangular	4	0.15	0.3	0	90˚	11	subcritical
Barkdoll, B.D., 2004	Rectangular	19	0.15	0.3	0	Rectangular	4	0.15	0.2	0	90˚	16.4	subcritical
Vasquez J. A., 2005	Rectangular	5.4	0.152	0.31	1	Rectangular	2.5	0.152	0.31	0	30˚,90˚	11.6	subcritical
Riviere N. et al, 2011	Rectangular	2	0.3	0.25	0	Rectangular	2	0.3	0.25	0	90˚	3 – 12	subcritical
Mignot et al., 2014	Rectangular	4.9	0.3	0.2	0	Rectangular	2.6	0.3	0.2	0	90˚	4	subcritical
Alomari N. K. et al., 2016	Rectangular	10	0.3	0.45	1	Rectangular	2	0.15	0.3	0	30˚,60˚, 90˚	17.25	subcritical
Khaleel M. et al., 2014	Rectangular	10	0.3	0.45	0.25	Rectangular	2	0.15	0.3	0.25	30˚,90˚	7 – 17	subcritical
Ramamurthy et. al., 2007	Rectangular	6.198	0.61	0.305	0	Rectangular	2.794	0.61	0.305	0	90˚	47	subcritical
Albert H. et al., 2015	Rectangular	6	24.0	1.5	1	Rectangular	2.44	0.61	0.3	1	90˚	23 – 26	subcritical

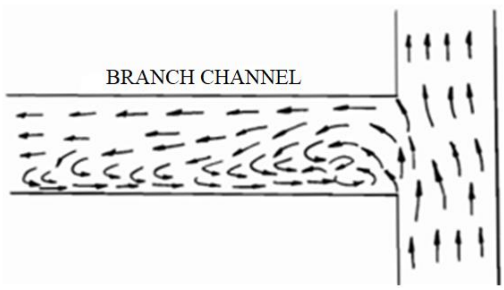

Figure 1. The reverse flow in the branch channel

2.3 Hydraulic jumps

Many researchers observed a hydraulic jump that can be determined in a channel only when the discharge ratio (Q_r) is high and the flow depth is relatively shallow. Then, on the striking corner of the junction at downstream, the fast inflow will be reflected and deflected into the main channel extension [42]. For example, Figure 2 shows three types of hydraulic jumps.

Hydraulic jumps are beneficial because they enable efficient energy dissipation in hydraulic structures like spillways and energy dissipators. This helps to prevent structural damage and minimize erosion. Other benefits of hydraulic jumps include: Facilitating mixing of chemicals and Reducing the energy of water while the discharge downfalls a spillway.

Surface ripples are similar to those formed on the bow of a boat sailing in water [43]. These surface ripples are called "bow waves " As the discharge ratio (Q_r) of the main channel extension increases, the flow at the junction accelerates, and undular jumps start to form; the standing waves pattern can be distinguished in the main channel extension. As the flow into the channel increases further, a simple hydraulic jump called a weak jump is formed, and the amplitudes of the standing waves diminish [44]. When more than 90% of the total inflow passes into the main channel extension, no hydraulic jump will be formed here.

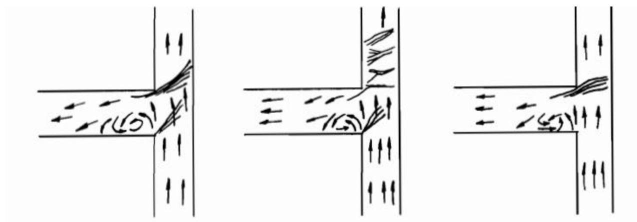

Figure 2. Types of hydraulic jump (a) Bow waves, (b) undular jump, and (c) weak jump

2.4 Stagnation point

A stagnation point is a point where the velocity is minimal, and the pressure and flow depth are highest in the flow system. For example, a branching channel system contains one stagnation point at the entrance of the downstream edge of the branch flow, as shown in Figure 3 [1, 6].

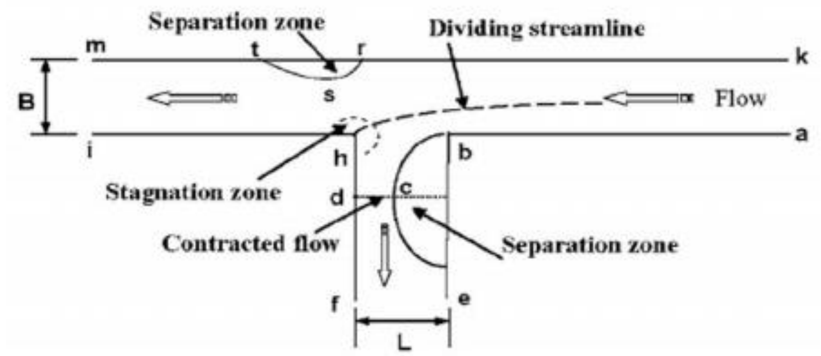

Figure 3. Zone of stagnation point and contraction flow

2.5 Contraction coefficient (Cc)

The contraction coefficient (Cc) is equal to the ratio width of contraction to branch channel width; Figure 3 illustrates how this coefficient rises linearly with increasing discharge ratio and decreasing channel width ratio [39, 45-47].

3. BRANCHING FLOW MODELLING

3.1 Mathematical and numerical modelling

When dealing with Saint Venant equation-based open channel operation-type problems, Shamaa [48] and Chung-Chieh Hsu et al. [49] employed the finite difference Preissmann implicit model (FDPIM). An implicit scheme is applied to the discretization in time because long time increment can be used and stability is superior than the explicit scheme. The Crank -Nicolson method is applied to the momentum equation and the continuity equation is implicitly expressed. In comparison to an explicit model, the implicit finite difference method model exhibited more accuracy and less oscillation.

Akbari and Firoozi [50] investigated the Preissmann and Lax diffusive schemes through their study. These are two separate numerical models for the numerical solution of the Saint Venant equations, which determine how flood waves travel across natural rivers. These equations regulate the movement of floodwaters. Therefore, they wanted to achieve a deeper comprehension of the propagation process. According to these studies in the flood wave propagations, the hydraulic factors significantly influence these waves.

Kerssens and van [32] employed a one-dimensional mathematical model (RIVMOR). They verified it with experimental data to examine the effect of water removal from open channels on the bed channel and water levels. This mathematical model was constructed using the foundation of sediment and water continuity equations. According to the observations, the bed increased in level downstream of the water withdrawal, whereas it decreased in level upstream of the water withdrawal.

The Saint Venant equations were then used by Pirzadeh and Shamloo [51] to investigate fluid flow in open channels and a lateral inflow channel. The equations were then numerically solved using the finite difference method.

3.2 Experimental modelling

Researchers sometimes use laboratory channels to find the parameters governing main and branch channels. In the Civil Engineering Department of Assiut University in Egypt, Sayed [38] performed irrigation and hydraulics lab experiments. The main and branch channels were the two available routes in the channel laboratory. The length of the main channel was 8.0 meters, 20 centimeters wide, and a depth of 20 centimeters; the corner that divided the main channel from the branch channel had a pointed edge. The branch channel was 3.0 m long, 20 cm depth, and had widths of 10, 15, and 20 cm at three different points. The volumetric weight approach would be used to quantify the flows coming from the primary (Qu) and secondary (Q_b) channels. At the end of each (main and branch) channels was necessary to ensure that the downstream flows were subcritical [52], morphological features Al Omari et al. [30] looked into how water flows when branches are in an open channel. Using a main channel with a branching channel connected by three angles (30°, 60°, and 90°) and four-bed slopes (0.001,0.0015,0.002,0.0025), five discharge values (13, 14, 15, 16, and 17.25) were passed in the main channel. In each experiment, five water depths were given for each discharge in the Branching channel.

Vasquez [4] conducted two simulated laboratory experiments, the first involving a 30° lateral channel with a width-depth ratio of 2.8. This redirects 50% of the flow that is coming in, and the second of which involves a narrow 90º lateral channel with a width-depth ratio of 0.5 that diverts 81% of the flow.

A branching Tigris River near Missan, Iraq, was chosen by Hydar et al. [53] for the examination of the scouring and depositing zones. For the purpose of managing the morphological features, a single vane has been installed for the examined junction. This vane has an inclination angle of 90º on the flow direction of the Tigris River.

Abderrezzak et al. [54] and Barkdoll et al. [55] conducted an experimental investigation into the features for splitting critical flows at a 90-degree open channel junction constructed by three horizontal equal-width branches. This research determined four distinct flow patterns by analyzing the distribution and magnitude of the hydraulic jump between the main and lateral channels. The next stage reliably reproduces the previous experiment's results to establish the correlation between the tailwater Froude number and the discharge division ratio.

Abdalhafedh and Alomari [56] studied the effect of separating streamline behavior when the sharp edge of the diversion channel entry was changed to a circular edge (either upstream, downstream, or on both sides). The study accounted for a range of circular edge diameters (7.5% to 30% of total discharge) across five distinct diversion discharge ratios.

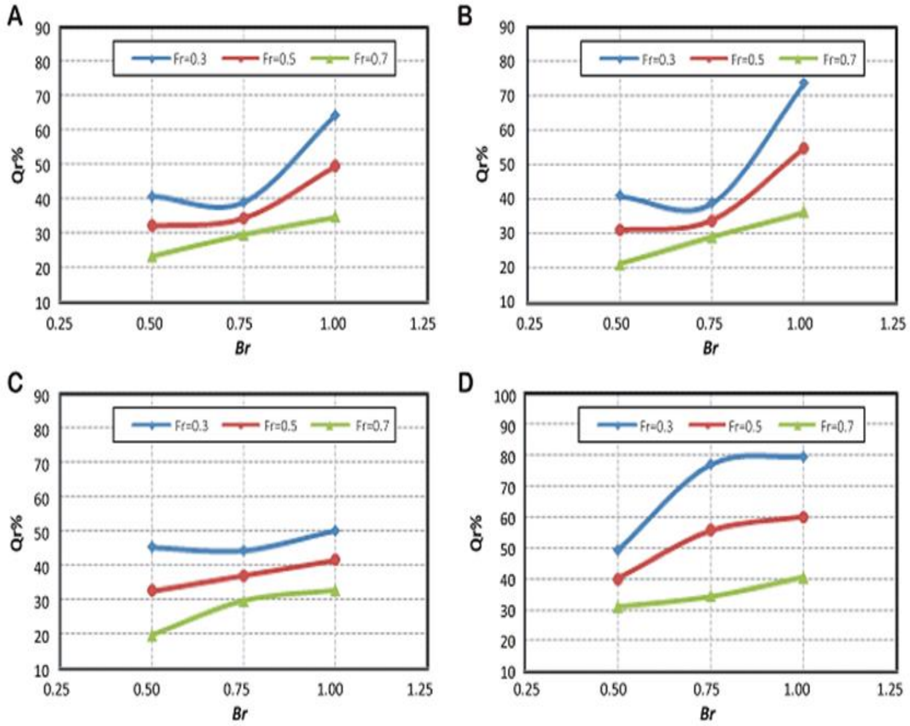

Figure 4. Effect bed width ratio (Br) on the flow for different branch angles: Ɵ=90°, (B) Ɵ=75°, (C) Ɵ=60°, (D) Ɵ=45°

In order to illustrate how modifying (Br) impacts flow, Figure 4 displays the relationship between the discharge ratio (Q_r) and the bed width ratio (Br) for varied values of the Froude number upstream of the main channel (Fru) at all angles of Branching. Figure 5 shows how Sayed [38] illustrates the link between the discharge ratio (Q_r) and the Branching angle (Ɵ) for a variety of values of the Froude number upstream of the main channel.

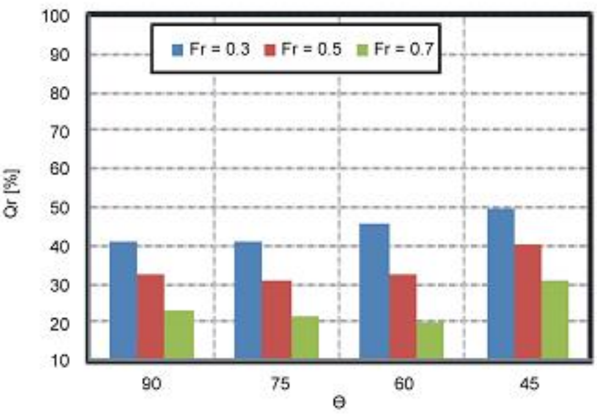

Figure 5. The impact of branching angle (Ɵ) for various bed width ratios on flow division

4. CONCLUSION

The physical features of the branching flow and its flow pattern were the primary emphases of this review work. In addition, a variety of the experimental and mathematical features of the model of the diversion flow were investigated. The conclusion from studies on the impacts of varying the branch channel flow's angle, cross-sectional area, velocity, and length is that:

1. The velocity of water flowing through the main open channel will not always rise in proportion to an increase in the angle of the lateral inflow channel.
2. The flow velocity in the primary open channel decreases as the cross-sectional area of the branch channel rises.
3. With regard to flow characteristics, the branching discharge (Q_b) decreases when the upstream main channel flow's Froude number, velocity, and momentum increase. Also, it develops by raising the bed width of the branch channel and the water depth of the main channel upstream.
4. The water depth in the branch channel is frequently lower than the water depth in the main channel when there is subcritical flow.
5. Because the branch channel's increased flow, the main channel's water level decreases further downstream.
6. With the increasing discharge at the main channel, the separation zone will decrease.
7. The separation zone will decrease with decrease the branch angle.

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