STUDY OF FLOW BIFURCATION AT THE OPEN CHANNEL JUNCTION WITH THE LARGE WIDTH RATIO OF BRANCH AND MAIN CHANNEL

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Key words: *flow separation, dividing streamline, dividing stream plane, flow contraction, water surface profile, surface of discontinuity, discharge division*

1. INTRODUCTION

The branch channel flow is being studied from the long before and still one of the interesting research subjects because of its common practice in the various engineering field. Because of the complex nature of the junction flow, the generalization of the phenomenon is much difficult to achieve. Most of the junction flow research have been performed in the laboratory flume with the equal width ratio of the main and the branch channel and very little have been studied with the other width ratio (Lakhsmana[6]-width ratio up to the 1:4,Grace[4]). Similarly the most investigated junction is the 90° and effect of the junction angle change (Bulle[1], Lakhsmana[6]) is also much less studied. In the study of the Bulle[1] with the different branching angles (30°, 45°, 75°, 90°, 120°and 150°) and the width ratio up to 1:2, about 93% of the incoming sediment have been diverted in the bifurcation channel. The present research is towards the understanding of the junction flow characteristics of 30° and 60° angle intersections with the large width ratio of the branch and the main channel (1:17), which will help to understand the mechanism of sediment bifurcation of the incoming sediment laden flow for this particular case.

During the experiments, flow dividing streamlines, dividing plane, surface of discontinuity, recirculation zone have been observed thoroughly with the various dynamic conditions at the junction through the manipulation of the tail-gates provided at the end of the channels. The most differing features observed as compare to the past experiments are, abrupt surface of discontinuity and the flow separation zone are formed at the downstream wall of the branch channel, which is just the opposite as in the past research with the small width ratio. In each flow condition at the junction, surface and the bottom dividing streamline did not end immediately at the corner of the downstream wall of the branch channel but extended up little ahead on the main channel extension and then returned back (Fig.4), causing flow to separate at this corner. In 30° junction , the recirculation zone was formed at the downstream side of the branch channel but in 60° junction at both the sides.

2. EXPERIMENTAL SETUP

The present experiment was carried out at the laboratory flume of rectangular shapes having main channel width 78 cm, branch width 4.5 cm, junction angle 30° and 60°. Main channel and branch channel slope was kept horizontal for both the junction flow experiment. The main channel is of 8.00-meter length and the bifurcation junction was at 3 meter far from the start of the flume. The length of the branch channel was of 2.00 meter and made of acrylic plastic. The bed of the main channel was made rough by uniformly sticking the sand of uniform diameter of 0.9 mm and roughness (n) was measured to be the 0.012. Branch channel wall and bottom both were kept smooth. The water surface level was measured with the point gage up to the accuracy of the 0.1mm and the branch water flow discharge was measured with the bucket and the stopwatch. Surface and bottom dividing streamline was pointed out with the help of the dye.

3. FINDINGS OF THE EXPERIMENTAL ANALYSIS

(1) The average water depth (d_8) is found to be approximately equal to 0.98 d_1 for the both the 30° and 60° junction. (Fig. 6)
(2) As the flow changes its direction sharply at the junction area, there exist the abrupt surface of discontinuity near the entrance of the downstream wall of the branch channel and curve water surface is formed by centrifugal action of the flow.

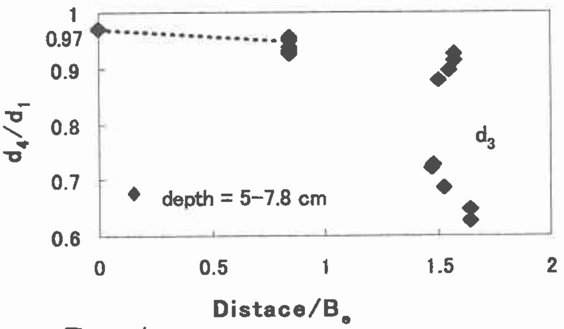

Figure 1
Variation of water surface level along the right wall (f-e Fig. 6) of the branch channel of the 30° junction

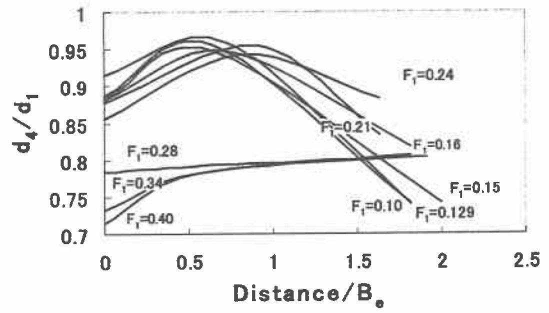

Figure 2
Variation of water surface level along the right wall (f-e Fig.6) of the branch channel of the 60° junction

(3)The formation of the jump is about b_b $(1+1/\tan\theta)$ distance far from the entrance wall of the branch channel, where the control section 3-3 is taken.(Fig. 6)
(4)The water depth at the downstream wall of the branch channel, beginning from the surface of discontinuity to the control section 3-3 was almost constant and equal to d_3.
(3) For 30° junction the water depth at the right wall of the main channel at the right corner of the branch entrance became $0.97d_1$ and at distance $b_b/\tan\theta$ from that corner, it became $0.93d_1$ up the flow conditions F_1 equal to 0.28. In the case of 60° junction, the water surface profile along the right wall of the branch channel vary much with the flow conditions. Taking the average depth throughout d_4 and d_5, their average ratio with the d_1 is found to be equal to 0.85 for the flow conditions F_1 up to the 0.28 and equal to 0.7, when F_1 up to the 0.4.
(4) The contracted width of branch flow was much wider at the bottom and goes on sharply decreasing towards the surface having the curve surface. (Fig. 5)

4. THEORITICAL ANALYSIS

Most of the junction flow formulas are of the semi theoretical nature with the empirical coefficient for the particular field condition. Ramamurthy[9], Law and Reynolds[5] have developed the theoretical relation for 90° junctions with the small width ratio for the free and the control flow condition at the branch channel through momentum, energy and the continuity equations.

In the case of large width ratio, at the branch entrance, flow takes the sharp turn at the downstream corner of the branch channel. There exist the centrifugal force, which varied according to the flow conditions. Due to the variation of centrifugal force the direction of the streamline also varied at that place. Much of the centrifugal force is directed along the X- direction and this effect is accounted on the momentum equation through the force correction coefficient (α). The friction forces between the control section 1-1 and 3-3, acting at the bottom and the walls of the channels were assumed to be small with compare to the other forces acting at the control volume. Momentum correction coefficient was assumed to be unity for the flow conditions.

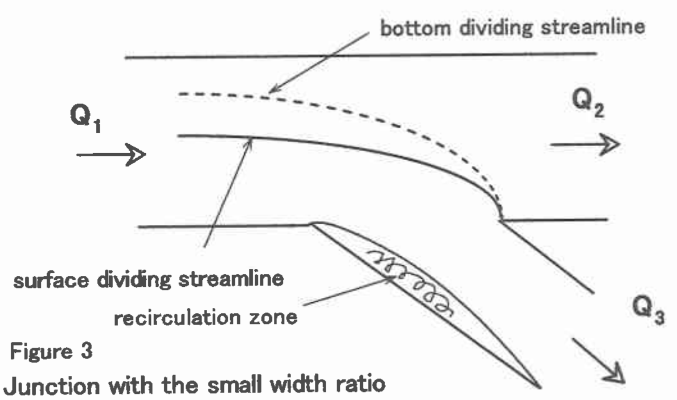

Figure 3
Junction with the small width ratio of branch and main channel

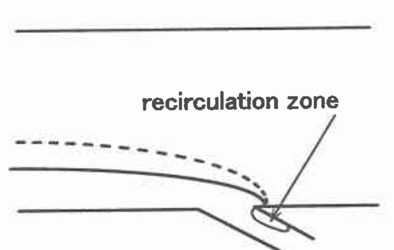

Figure 4
Junction with the large width ratio of branch and main channel

(Schematic figure)

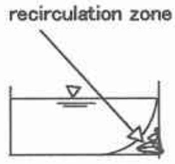

Figure 5

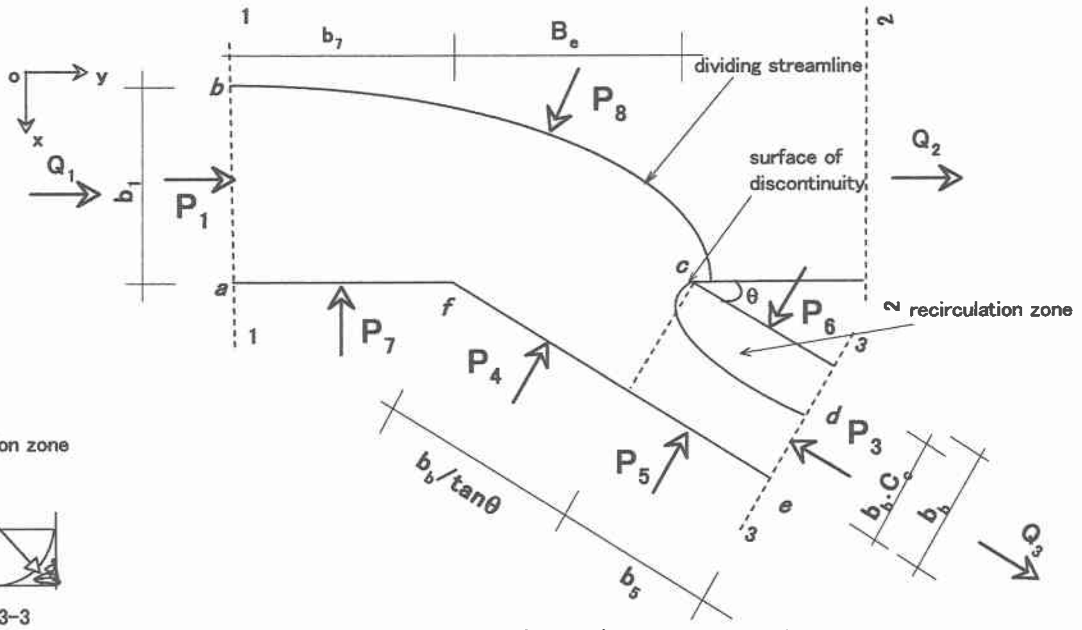

Figure 6 controll volume (*abcdef*) for the junction flow calulation with the various pressures on the controll surface

Momentum equation in the X- direction

$$P_1-P_{8-x}+P_{4-x}+P_{5-x}-P_{6-x}-\alpha P_{3-x}-\gamma F_3^2 b_b C_c d_3^2 \cos\theta+\gamma F_1^2 b_1 d_1^2=0 \quad (1)$$

Momentum equation in the Y- direction

$$P_{8-y}-P_7-P_{4-y}-P_{5-y}+P_{6-y}-P_{3-y}-\gamma F_3^2 b_b C_c d_3^2 \sin\theta=0 \quad (2)$$

Equation of continuity between section 1-1 and 3-3

$$F_1 b_1 d_1^{3/2}=F_3 b_b C_c d_3^{3/2} \quad (3)$$

Writing the equation (1) and (2) with respect to the corresponding water depths,

$$1/2\gamma d_1^2 b_1-1/2\gamma d_8^2 b_1+1/2\gamma d_4^2 (b_b/\tan\theta)\sin\theta+1/2\gamma\Delta_5^2 b_5 \sin\theta-\alpha 1/2\gamma d_3^2 b_b \cos\theta-\gamma F_3^2 b_b C_c d_3^2 \cos\theta+\gamma F_1^2 b_1 d_1^2=0 \quad (4)$$

$$1/2\gamma d_8^2 (b_7+B_e)-1/2\gamma d_7^2 b_7-1/2\gamma d_4^2 (b_b/\tan\theta)\cos\theta-1/2\gamma\Delta_5^2 b_5 \cos\theta-1/2\gamma d_3^2 b_b \sin\theta-\gamma F_3^2 b_b C_c d_3^2 \sin\theta=0 \quad (5)$$

Substituting the b_1 from (3) in (4), eliminating b_b and dividing by d_1^2 both the equations (4) and (5),we get

$$(d_4/d_1)^2(\sin\theta/\tan\theta)+(\Delta_5/d_1)^2\sin\theta-\alpha(d_3/d_1)^2\cos\theta+C_c\{(F_3/F_1)(d_3/d_1)^{3/2}[1-(d_8/d_1)^2+2F_1^2]-2F_3^2(d_3/d_1)^2\cos\theta\}=0 \quad (6)$$

$$(d_8/d_1)^2(1/\sin\theta)-(d_4/d_1)^2(\cos\theta/\tan\theta)-(\Delta_5/d_1)^2\cos\theta-(d_3/d_1)^2\sin\theta-2C_cF_3^2(d_3/d_1)^2\sin\theta=0 \quad (7)$$

where, *abcdef*- control volume, b_1-average width of the dividing stream plane at section 1-1, P_1,..P_8-water pressure at the control volume surface and d_1,d_2….d_8-corresponding water depths, $b_5 \approx b_b$, $d_7 \approx d_8$, Δ_5-head difference of P_5 and P_6(for 30° junction $\Delta_5/d_1=0.46-0.5d_3/d_1$), θ-branch angle, B_e-width of the branch entrance, b_b-branch channel width, γ-specific weight of water, Q_1, Q_2, Q_3-discharge at main, extension and branch channel respectively, C_c-coefficient of contraction, which is the ratio of the average effective width of the flow to the width of the branch channel, $F_1$and F_3- Froude numbers at the main and the branch channel ,calculated with the average velocity at the section d_1 and d_3.

As the relation between the depths $d_4/d_1$and d_8/d_1 for the 30° and 60° junctions have been established through the experiments, by equating the C_c of the both the equations of the (6) and (7), there remain the unknowns (F_3/F_1), α and (d_3/d_1). The equations are still unsolvable, hence the value of α was determined through the experimental analysis, with the iteration of the measured and the calculated Q_3.Then after corresponding C_c was evaluated. As the value of C_c was found to be not much scattering, average constant value could be taken for the further calculation. For 30° junction C_c could be taken equal to 0.95.In the case of 60° junction , the value of C_c could be taken as unity. With the known value of the C_c the other parameters of equation (6) and (7) could be calculated.

The theoretical plot of the quantity of the flow entering the branch channel at the various F_1 and d_3/d_1 is shown in Fig. (7) and (8) and has the fair agreement between the theoretical and the measured value. It was observed that the ratio of the bottom and the surface dividing streamline width varies with the various flow conditions, so the dividing plane changes from the plane surface to the curve with the increase of F_1 of the flow condition. As the width of the dividing streamlines goes on increasing towards the bottom, there is always tendency of entering of the much flow from the bottom layer flow and consequently the sediments too.

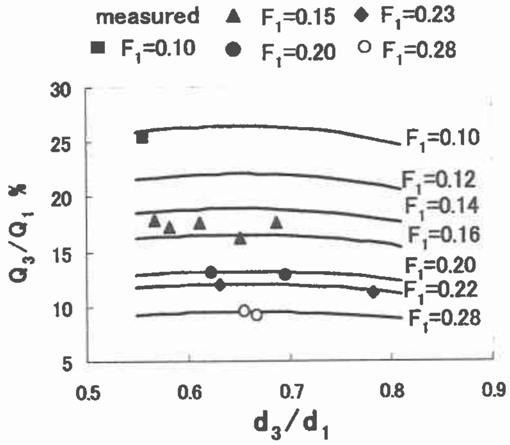

Figure 7
Theoritical relationship for discharge division for 30° junction

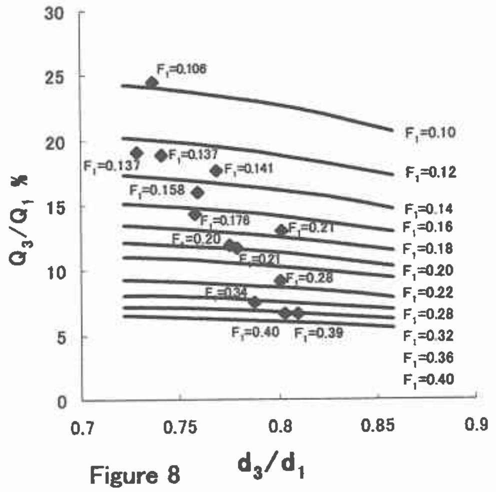

Figure 8 d_3/d_1
Theoritical relationship for discharge division for 60° junction

5. CONCLUSION

Because of the large width ratio of the junction, the effective width of the flow at the branch could be considered not varying much with the flow conditions and the Q_3 solely depends upon the approaching velocity and the d_3/d_1 ratio. Similarly the discharge division at the branch channel is also found to be not differing much with the angle change, with slightly more in 30° junction. Furthermore, the understanding of the change pattern of the bottom and the surface dividing streamline, recirculation zone, discharge division at the various flow conditions could be used for the analysis of sediment bifurcation at the junction.

REFERENCES

(1) Hermann Bulle "Untersuchungen Uber Die Geschie beableitung Bei Der Spaltung Von Wasserlaufen" 1926, Berlin

(2) Taylor, E.H. "Flow characteristics at Rectangular Open Channel Junction,"Transcation, ASCE, Vol.109, 1944.

(3) Albert Guy Dancy"Thesis submitted to the Graduate Faculty for the Degree of Master of Science"1947,Iowa State College

(4) John L Grace, Jr.and Melville S. Priest." Division of flow in open channel junction" Alabama Polytechnic Institute, Bulletin no.31, 1958,June

(5) Shiu Wai Law, Alan J. Reynolds" Dividing Flow in Open Channel"Proceedings, ASCE, 1966

Discussion by N.S Lakshamana Rao and K. Sridharan

(6) Lakshmana R.N.S, Sridharan K." Division of Flow in open Channels" Journal of the Central Board of the Irrigation and Power, Vol. 24,No 4,1967

(7) Lakshamana R.N.S., Sridharan K., Baig M.Y.A. " Experimental study of the division of flow in an open channel" Australian Conf. on Hydraulic Mechanics, Sydney Australia

(8) Amruthur S.Ramamurthy, Mysore G.Satish" Division of Flow in Short Open Channel Branches." Journal of Hydraulic

(9)Amruthur S.Ramamurthy, Duc Minh Tran, Luis B. Carballada "Dividing Flow in Open Channels"Journal of Hydr.. Engineers ..ASCE, 1990,116(3)

(10) Vincent S. Neary, A Jacob Odgaard "Three Dimension Flow structures at Open Channel Junction" Journl of Hydr. Engineers. ASCE, 1993,119(11)

(11) Ashok S. Shettar " A numerical study of division of flow in open channels" Journal .of Hydr. Research 1996.