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STUDY OF FLOW BIFURCATION AT THE 30°OPEN CHANNEL JUNCTION WHEN THE WIDTH RATIO OF BRANCH CHANNEL TO MAIN CHANNEL IS LARGE

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The flow characteristics at the junction bifurcation with the large width ratio of the branch and the main channel differ with the junction flow having the small width ratio. This article reports the study of the 30° - model junction with the large width ratio for which the theoretical relationship was developed for the discharge division at the various flow conditions of the main and the branch channel. The smaller the froude number at the main and larger at the branch channel, the wider the bottom dividing streamline will be and more will the flow diverting in the branch channel. The understanding of the discharge division, flow-dividing streamline at the surface and the bottom could be used for the study of the mechanism of sediment bifurcation at the junction.

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, due to the involvement of many governing factors, the generalization of the phenomenon is much difficult to achieve. Many researchers (Bulle[1)], Taylor[2)], Dancy[3)], Grace[4)], Law and Reynolds[5)], Lakhsmana[6)], Ramamurthy[9)]) in the past have done lots of contribution on this topic and lots of the interesting characteristics of the junction bifurcation have been studied up to the practical level. 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 of 30° angle intersection with the large width ratio of the branch and the main channel (1:17), which will through light on the mechanism of sediment bifurcation of the incoming sediment laden flow for this particular case. The study of diversion of sediment from the small branch channel through the wide rivers for the purpose of reservoir sedimentation management requires the thorough understanding of the junction flow with the combination of the various junction angles, slopes and width ratios, which will help further for selection of effective junction intersection, slope of the branch channel, shape and size of the branch entrance and flow modification structures (guide-vanes) to ensure the effective sediment bypass.

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.5), causing flow to separate at this corner.

2. EXPERIMENTAL SETUP

The present experiment was carried out at the laboratory flume with the width 78 cm, branch width 4.5 cm, junction angle 30° and both the channels of horizontal slope and rectangular shape.

Table 1

Flow conditions

Expt.no.	d_1 cm	d_3 cm	Q_1 l/s	Q_3 l/s	Remarks
R-1	4.74	3.30	5.10	0.66	f.f
R-2	4.80	3.90	5.10	0.57	c.f
R-3	5.68	3.70	5.10	0.83	f.f
R-4	7.55	4.20	5.10	1.30	f.f
R-5	7.66	5.13	5.10	1.24	c.f
R-6	5.06	3.30	7.00	0.77	f.f
R-7	5.11	5.03	7.00	0.66	c.f
R-8	8.02	4.50	7.00	1.44	f.f
R-9	8.03	5.45	7.00	1.37	c.f
R-10	5.35	3.50	8.60	0.83	f.f
R-11	5.38	4.30	8.60	0.72	c.f
R-12	6.18	3.90	8.60	1.03	f.f
R-13	6.24	4.73	8.60	0.89	c.f
R-14	8.48	4.93	9.40	1.62	f.f

f.f – free flow at branch channel
c.f – control flow at branch channel

The main channel was 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. The paper confetti from the punching machine and the video camera were used to point out the direction of the surface dividing streams line. The bottom dividing streamline was pointed out with the dye.

3. FINDINGS OF THE EXPERIMENTAL ANALYSIS

(1)The water surface level along the dividing streamline started to decrease from the beginning of the draw down curve (which was approximately equal to one and half times branch channel entrance width B_e), and continued up to the distance $0.2B_e$ downstream from the corner of upstream wall of the branch channel and then after gradually increased up to end of the dividing streamline. The water depth (d_8) was found to be approximately equal to $0.98\ d_1$. (Fig 1), (Fig 7).

(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.

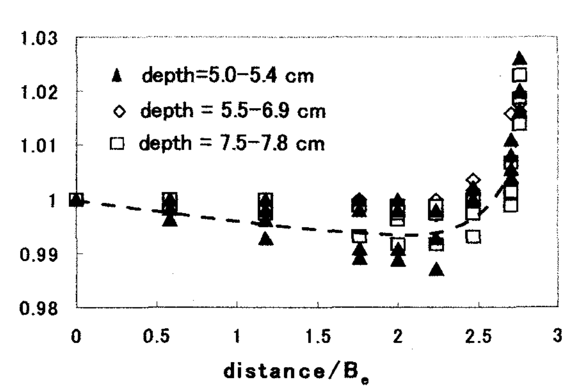

Figure 1 Variation of water surface level along the dividing streamline

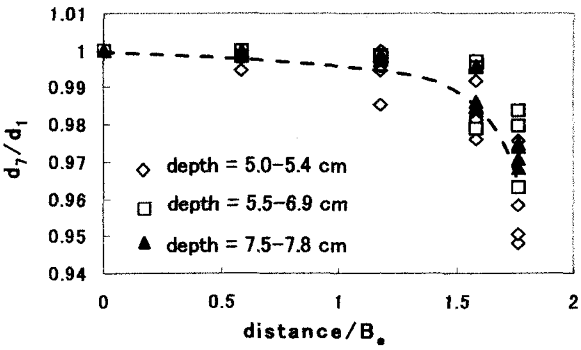

Figure 2 Variation of water surface level along the rightwall of the main channel

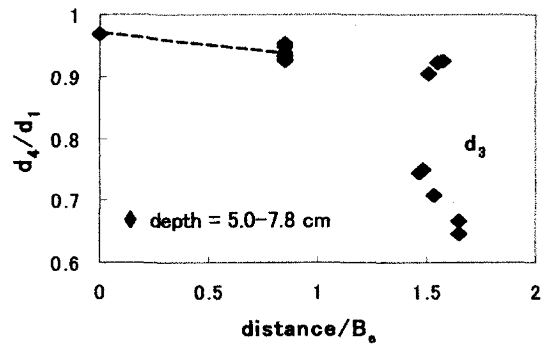

Figure 3 Variation of water surface level along the right wall of the branch channel

The formation of the jump was about b_b $(1+1/\tan\theta)$ distance far from the entrance wall of the branch channel, where the control section 3-3 was taken. The water depth at the downstream wall of the branch channel, beginning from the surface of discontinuity to the control section 3-3 is almost constant and equal to d_3.

(3) The water depth at the right wall of the main channel at the right corner of the branch inlet became 0.97d1 (Fig. 2) and at distance $b_b/\tan\theta$ from that corner, the depth of water became $0.93d_1$. (Fig. 3)

(4) The contracted width of branch flow is much wider at the bottom and goes on sharply decreasing towards the surface having the curve surface. (Fig. 6)

4. THEORITICAL ANALYSIS

As stated before the complex three dimensional nature of flow at the junction makes the theoretical analysis more complicate, so still there is not any complete theoretical analysis on these regards.

Most of the 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 varies according to the flow conditions. Due to the variation of centrifugal force the direction of the streamline also varies 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 section 1-1 and 3-3 acting at the bottom and the walls of the channels are assumed to be small with compare to the other forces acting at the control volume.

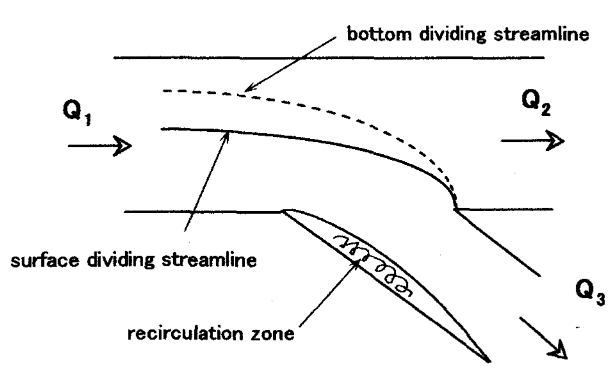

Figure 4
Junction with the small width ratio of branch and main channel

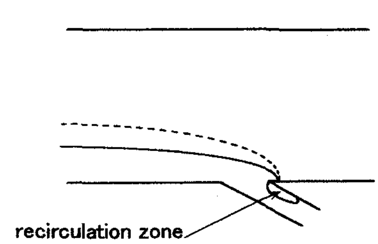

Figure 5
Junction with the large width ratio of branch and main channel

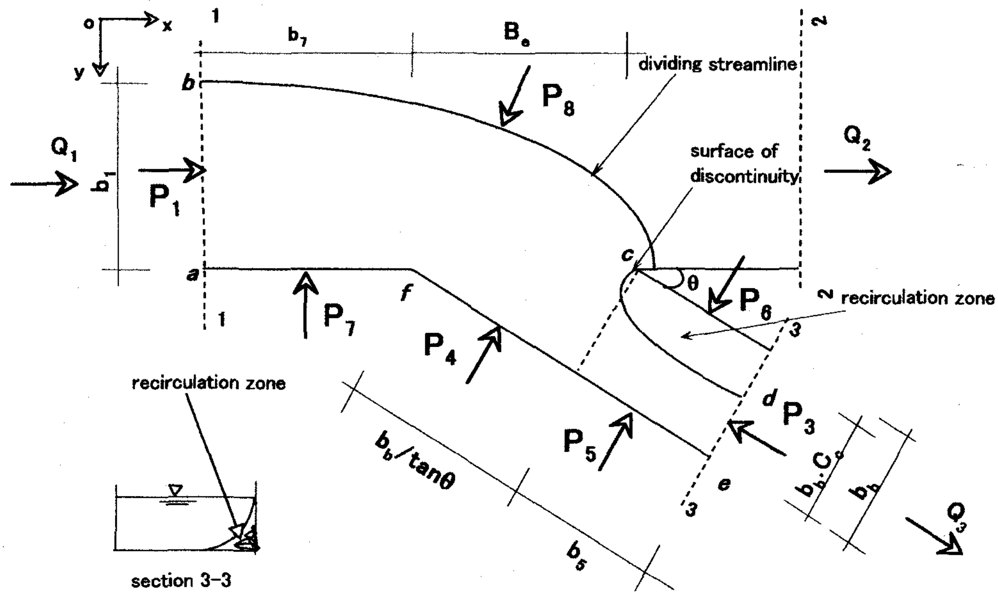

Figure 6 Figure 7 Controll volume (*abcdef*) for the junction flow calulation with the various pressures on the controll surface

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 b_1 from equation (3) in (4), eliminating b_b and dividing both the equations (4) and (5) by d_1^2,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 $d_1, d_2 \ldots d_8$-corresponding water depths, $b_5 \approx b_b$, $d_7 \approx d_8$, Δ_5-head difference of P_5 and P_6(Δ_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 depth d_4 and d_8 have been related with the d_1 through the experiments, by equating the C_c of the both the equations of the (6) and (7), there remains the unknowns

(F_3/F_1), α and (d_3/d_1). The equations are still unsolvable; hence the value of α is determined through the experimental analysis with the iteration of the measured and the calculated Q_3.Then after corresponding C_c is evaluated. Their values are plotted in figure (8), (9) and (10). Comparing the scatter ness of the values of α and C_c, it is seen that C_c is less scattered and the average constant value of the C_c could be taken for the further calculation. In the case of control flow at the branch channel, due to the gate at the channel end, the intensity of the centrifugal force will be decreased at the junction and increased pressure force caused by the increase of death at the section 3-3 will push against the turning streamline at junction resulting the decrease of the effective width of the branch flow. 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. (11) and (12) and has the fair agreement between the theoretical and the measured value. Fig. (13) shows the relationship of theoretical value of the average width of the dividing streamline (b_1), measured width of the surface dividing streamline (b_s) and the measured width of the bottom dividing streamline in the case of free flow condition at the branch channel, which are normalized by the width of the branch channel entrance (B_e) at the various flow condition. It is observed that the ratio of the bottom and the surface 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 and consequently the sediments too.

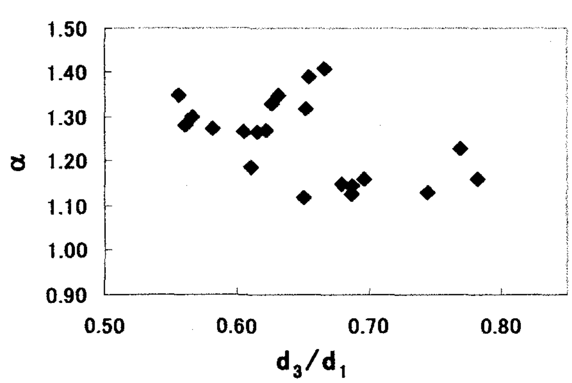

Figure 8 Value of α

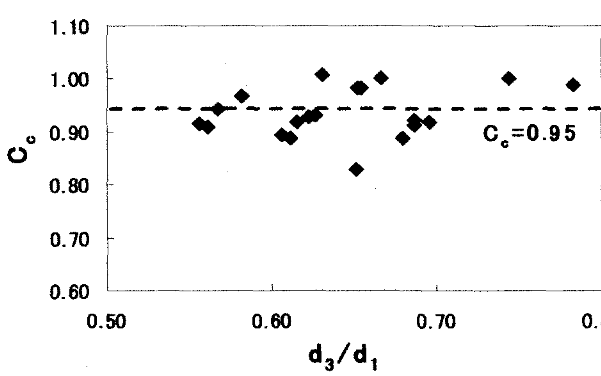

Figure 9 Value of C_c of free flow condition at branch channel

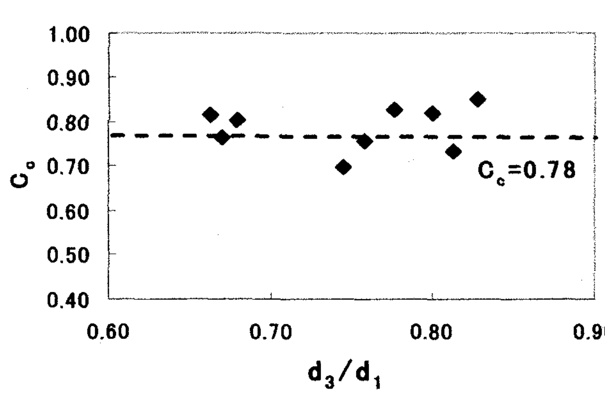

Figure 10 Value of C_c of control flow condition at branch channel

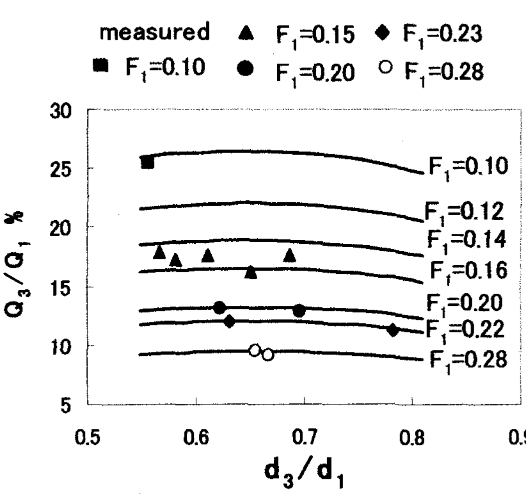

Figure 11 Theoritical relationship for free flow at the branch channel

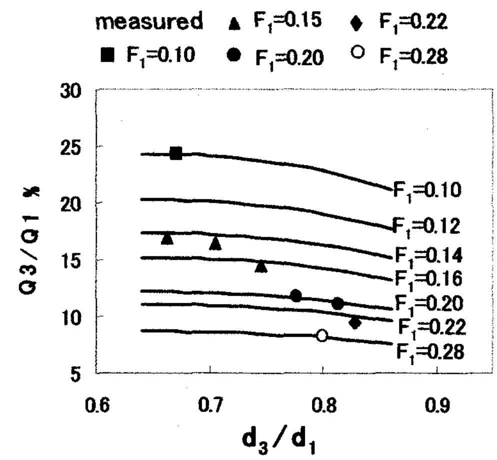

Figure 12 Theoritical relationship for control flow at the branch channel

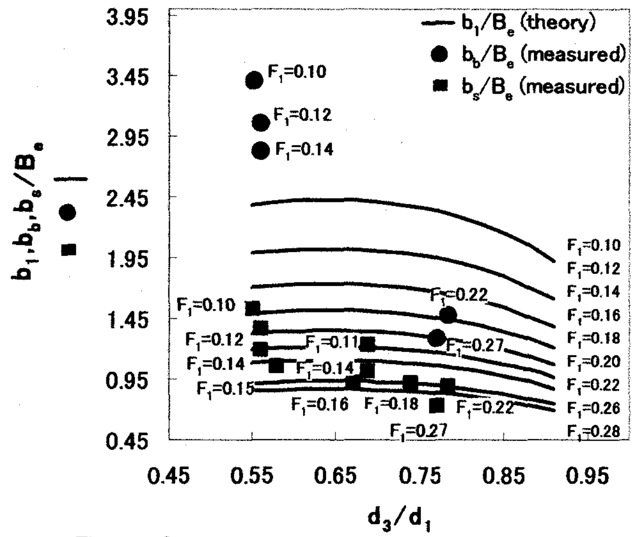

Figure 13
Change of the width of the bottom(b_b),average(b_1) and surface (b_s)dividing streamline with the flow condition

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. Semi theoretical formula was developed with the momentum and the continuity equation for the 30° model junction at free and control flow condition at the branch channel, when the width ratio of branch to main channel is large. The characteristics of the junction flow having the large width ratio differs much with the junction flow with the small width ratio. 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.

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