# Dividing Streamline Formation Channel Confluences by Physical Modeling

Minarni Nur Trilita[1], Nadjadji Anwar[2], Djoko Legono[3], and Basuki Widodo[4]

***Abstract*****—Confluence channels are often found in open channel network system and is the most important element. The incoming flow from the branch channel to the main cause various forms and cause vortex flow. Phenomenon can cause erosion of the side wall of the channel, the bed channel scour and sedimentation in the downstream confluence channel. To control these problems needed research into the current width of the branch channel. The incoming flow from the branch channel to the main channel flow bounded by a line distributors (dividing streamline). In this paper, the wide dividing streamline observed in the laboratory using a physical model of two open channels, a square that formed an angle of 30º. Observations were made with a variety of flow coming from each channel. The results obtained in the laboratory observation that the width of dividing streamline flow is influenced by the discharge ratio between the channel branch with the main channel. While the results of a comparison with previous studies showing that the observation in the laboratory is smaller than the results of previous research.**

*Keywords*—**dividing streamline, confluence, channel, hydraulic, model**

## I. INTRODUCTION

Rivers use in Indonesia untill now still assumed have not optimal yet. This fact can be seen from most river use only used as transportation medium from one to another area since very difficult to use shore lane. Next, rivers used as livelihood for society around river flow area. Meanwhile river use as river resort, clean water source, electricity generation has not received great priority to develop. Many things are influenced river optimality such as river topography, geometric, and base materials.

River for the purpose of navigation and increasing in human activities generally required river control by conducting rectify measurement of river alteration has done. This is due to many rivers have natural trends to continually change on it river channels, for example, river meander and braided river and development effect surround them, as bridge construction, existence of urban around river, as port and so fort, which required steady river alignment in several places. These activities can generate bank erosion, erosion around bridge pillar, sedimentation in channel to navigation, and so on, that will be caused naturally river morphology change.

Natural phenomena above are most complex phenomena. Efforts to approach these phenomena until can be used as approach solution reference from river problems above, are by conducting researches.

Physical and mathematics model often used to estimate river morphology change. Until now there are many one-dimension morphology mathematics modeling have developed. One-dimension mathematics model is usually to estimate long term and long scale morphological change. To predict bend cut-off effect in channels that used as navigation, channel stability alignment effect, etc, on river morphology change is needed two-dimension morphology model application (horizontal). Likewise, the existence of water intake, outlet, tributary, flow confluence, bifurcation, and river bend, application of two-dimension morphology model is very relevant. In particular on confluence, distribution approximation of sediment transport and composition are very important. This is because these sediments will affect river morphology change in long term. In addition model development from one to two dimension, also developed morphology model based on Network River.

In Indonesia, up to now there have not appropriate model to estimate morphology change occurs as a result of natural effect or human activities along river. Therefore, morphology change model creation corresponded to natural characteristics in Indonesia is very needed. As initial step, as have seen, rivers in Indonesia have many tributary rivers; to study about effect of tributary river on main river, in this term this research was conducted on flow mechanism as dividing streamline event in confluence flow.

## II. THEORY

Confluence flow in river or channel found very much in nature river system, drainage system, irrigation system or in flowing system others. Previous studies on confluence open channel flows Taylor (1944); Webber and Greated (1966); and Gurram (1994) proposed theoritical approaches, based on conservation of mass and momentum, to solve for the upstream to downstream depth ratio [12]. Taylor (1944) investigated confluence of prismatic rectangular channel with angle 45 and 135 degree. The channels were of the same width and the bed was horizontal throughout. Subcritical conditions were maintained in the channels, and the depths, upstream and downstream, were measured for various combinations discharges. The experiment results were compared with calculated data derived from momentum considerations. Agreement was reasonably satisfactory for the $45^0$ junction, but not for that at $135^0$ [17]. Webber and Greated (1966) began the focus on the general flow characteristics at an open channel junction. Webber and Greated (1966) implemented the method of conformal mapping to define a theoritical flow pattern throughout

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the junction region. Using this method, they were able to locate the stagnation point at the upstream corner of the channel junction and delineate the zone of separation. Webber and Greated (1966) also included a method for estimating the relative energy loss across the junction.

Komura (1973) review of the riverbed variation in confluence. The analysis is based on the depth of flow equilibrium in confluence. Basic equation of equilibrium flow depth in confluence is obtained by using motion and continuity equation for sediment transport, and the continuity equation and the friction velocity for water flow, with the assumption that the bottom of the river above and below the confluence achieves a dynamic equilibrium for the flow in confluence.

Best and Reid (1984) conducted experimental studies. Four different confluence angles 15, 45, 70, and 90 degree were studied. Study done for estimate dimension separation zone. This study result index of separation zone which defined as the ration of H/L, in which H and L, are width and length of separation zone respectively.

Best (1987) proposed a generalized model of flow at confluence channel that consists of six different zones, namely, regions of flow stagnation, flow deflection, flow separation, maximum velocity, flow recovery, and shear layers (Fig. 1).

Studied the characteristics of the lateral flow and the flow contraction in the tail water channel and determined expressions for the momentum correction coefficients and the lateral wall pressure force [9]. An equation for the ratio of flow depths in the lateral and in the upstream branches was provided [5].

Applied overall mass and energy conservation to the junction and momentum conservation to two control volumes in the junction and computed an energy loss coefficient as well as the depth ratio [10]. All of these studies were for an equal-width junction flow and by assuming the equality of the upstream and lateral depths.

Ettema et. al. (1999), study of ice jams in river confluences. Research conducted in the laboratory and in the field. The results obtained are complex processes in 3 ice jams. The third process is the merging of ice runs, hydrodynamic pressure from a confluent flow impacting an ice run from the second confluent channel, and ice congestion at a confluence bar.

Shabayek et. al. (2002), developed a one dimensional theoretical model providing the necessary interior boundary equations for combining subcritical open-channel junctions. The main advantage of this model is that it does not assume the equality of the junction's upstream depths. The dynamic treatment of the junction is so consistent with that of the reaches in a network model. The model is based on applying the momentum principle together with mass continuity through the junction. Shabayek, et.al. (2002), constructed an analytical approach that solve for the upstream-to-downstream depth ratio and the lateral-to-downstream depth ratio at the junction.

Ghobadian and Bajestan (2007) examined the dimensions of erosion and sediment at the confluence of the river. The study was conducted by using dimensional analysis and produce non-dimensional equation of erosion and deposition by a number of non-dimensional Froude densimetric. Kesserwani et.al., (2008), review of the simulation of subcritical flow at open channel junction. This study evaluated all Confluence flow models. Study results obtained that for Froude numbers < 0.35, can be used assuming the same water level in the meeting, for Froude numbers > 0.35 should use the principle of momentum equation.

Confluence morphology varies with differences in the relative magnitudes of water discharge, sediment-transport rate, and sediment size of the confluent channels. These factors are embodied in the sizes and slopes of the confluent channels. On the basis of channel size and slope, confluences can be discussed in terms of the following two general morphologic types [5]:

1. Confluences of concordant bed channels.

   Confluences of concordant bed channels is confluence channel with the bed levels of the two confluent channels are at about the same level and sufficiently similar in slope, so that water and sediment merge without deposition of sediment in the confluence. As depicted in Fig. 2a and b, which show the main flow and bathymetric features of this type of confluence, the distinguishing morphologic features are a bar formed in the flow separation zone and a deep scour beneath the zone of maximum flow velocity in the confluence.
2. Confluences of discordant bed channels.

   Confluences of discordant bed channels is confluence channel with the bed levels of the two confluent channels differ significantly in level and slope, so that the channel with the higher level and slope may develop a zone of sediment deposition, an alluvial fan, at its junction with the deeper and flatter channel.

### *A. Flow Features*

Flow through a typical concordant bed channel confluences, comprises the following principal features:

1. A flow separation zone.
2. A dividing streamline (or stream plane) that delineates the merging flows, and which actually is a shear layer.
3. A small zone of flow stagnation at the apex of the confluence.
4. A flow recovery zone

These flow features make confluence flows comparatively complex and subject to the influences of many parameters, such as confluence angle and the relative magnitudes of discharge in each channel. Consequent to confluence flow complexity, the bathymetry of confluent alluvial channels may also be complex, as is illustrated in Fig. 2b. The bathymetry is notable for the following principal features:

1. A bar, which more or less occupies the flow-separation zone and is formed of bed sediment deposited in that zone.
2. A zone of deep scour, which is approximately aligned with a portion of the dividing streamline.

In actuality, the dividing streamline is not a simple curve as shown in Fig. 2a. It is a time-average representation of the plane between two merging flows. The plane lies in a shear layer marked by strong vortices that initiate mixing of the merging flows, as sketched in Fig. 2c. The vortices significantly affect the extent of bed scour in the scour zone [5].

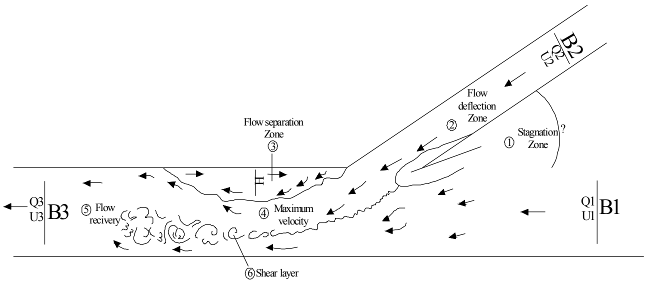

Fig. 1. Classification of zone at channel confluence [2]

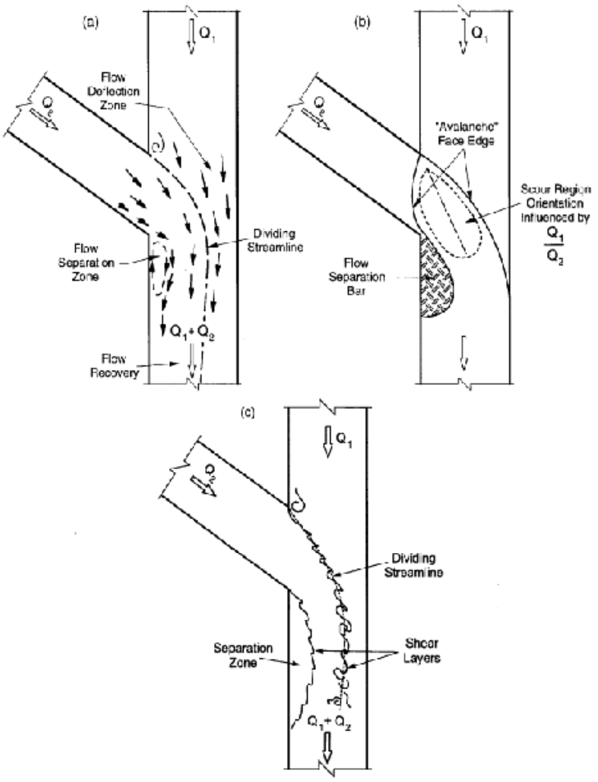

Fig. 2. Schematic of channel confluence with concordant bed levels:
(a) Main flow features (b) Main bathymetric features
(c) Illustration of the shear layers [5]

*B. Location of Dividing Streamline*

A method for estimating its position in a confluence of flat bottom channels, however, has been developed by Fujita and Komura (1986). They used a mathematical model developed earlier by Modi et al. (1981) to analyze flow in confluences of rectangular channels. By applying potential flow theory and conformal mapping, the location of the dividing and separating streamline is obtained through numerical integration of complex functions. The equations for the dividing streamline [5]:

$$x_d = \int_1^{\xi_2} F_R(\xi + i\eta_2)\,d\xi - \int_0^{\eta_2} F_I(1 + i\eta)\,d\eta \tag{1}$$

$$y_d = \pi + \int_1^{\xi_2} F_I(\xi + i\eta_2)\,d\xi + \int_0^{\eta_2} F_R(1 + i\eta)\,d\eta \tag{2}$$

For $-\infty \langle \xi \langle 1 \;\; dan \;\; 0 \langle \eta \langle \infty$ , $F_R$ and $F_I$ are the real and imaginary parts of the complex function:

$$F(\zeta) = \frac{b_c}{\pi}\exp\left\{\frac{2\alpha}{\pi}\ln\left[(\zeta - 1)^{1/2} + \zeta^{1/2}\right] - \alpha i\right\}\left(-\frac{1}{\zeta} + \frac{1 - Q_r}{\zeta + c_k} + \frac{Q_r}{\zeta - c_l}\right) \tag{3}$$

Where,

$Q_r$ = the ratio of the tributary channel to the downstream discharge.

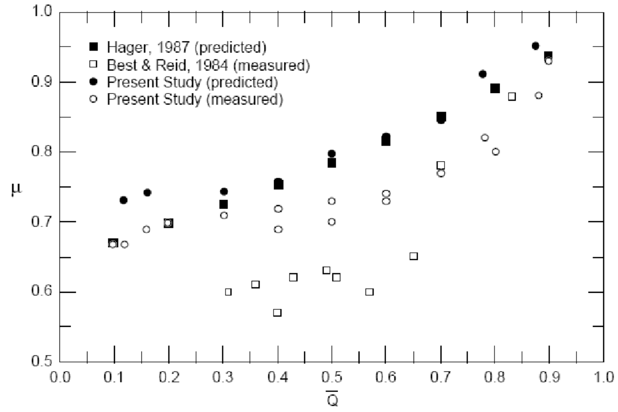

Fig. 3. Contraction coefficient at the maximum confluence constriction;

$\mu = b_c/b_3$, $\bar{Q} = Q_2/Q_3$ [8]

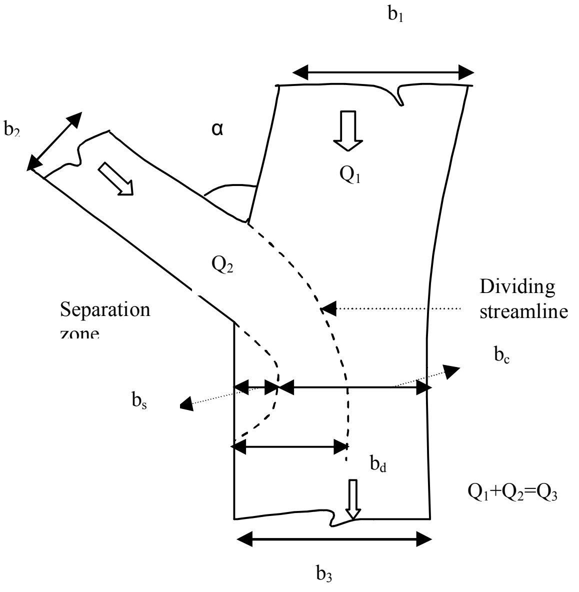

Fig. 4. Schematic of confluence flow

$b_c$ = the effective width of the channel (the width of the main channel diminished by the width of the separation zone, $b_c = b_3 - b_s$).

$\alpha$ = the confluence angle.

$c_k$, $c_l$ = functions of flow and confluence geometry.

$\zeta$ = the real axis of the upper half plane on to which the conformal mapping is represented.

$\varepsilon$, $\eta$ = the coordinates of the downstream corner of the confluent channels in the mapped plane obtained using the Schwarz-Christoffel theorem

*C. Extent of Flow Separation Zone*

Several studies have investigated flow separation at a confluence of rectangular channels. Theirs results are useful for estimating the likely contraction of the flow area within a confluence. In addition, the size of the separation zone approximately coincides with the size of the bar found in confluences of concordant channels [5].

In laboratory experiments, conducted using rectangular channels, to the following semianalytical equation for the maximum width of the separation zone [8]:

$$\frac{b_s}{b_3} = \frac{1}{2}\left(F_d - \frac{2}{3}\right)^2 + 0.45\left(\frac{Q_2}{Q_3}\right)^{1/2}\left(\frac{\alpha}{90^0}\right) \tag{4}$$

where,
$b_s$ = the width of the separation zone,
$b_3$ = the downstream width of the main branch,
$F_d$ = the tailwater Froude number,
$Q_2/Q_3$ = the discharge ratio between the lateral to the downstream discharges,
α = the apex angle of the confluence.

Analytically and experimentally investigated flow in the confluence of two equally wide, rectangular channels oriented $90^0$ to each other [10]. Their research resulted curve for estimating the maximum width of the separation zone, as shown in Fig. 3. In that figure, contraction efficient $\mu = b_c/b_3$ and $\bar{Q} = Q_2/Q_3$.

### *D. Estimation of Dividing Streamline Position*

Based on the foregoing method of estimating the extent of the separation zone, an approximate estimation is possible of the position of the dividing streamline that delineates flows merging from channels 1 and 2. If constant depth is assumed through the confluence, the dividing streamline location is proportional to the discharges of the contributing channels:

$$\frac{b_3 - b_d}{b_d - b_s} = \frac{Q_1}{Q_2} \tag{5}$$

$$b_d = \frac{Q_1 b_s + Q_2 b_3}{Q_1 + Q_2} \tag{6}$$

### *E. Bathymetry of Concordant Bed Confluences*

The bathymetry of concordant bed confluences includes zones of sediment scour and sediment deposition. The zones reflect regions of greater or reduced flow velocity. Best (1988) and Biron et. al. (1996) provide useful descriptions of the bathymetry of concordant bed channels. Their descriptions are based on laboratory flume experiments and field observations [5].

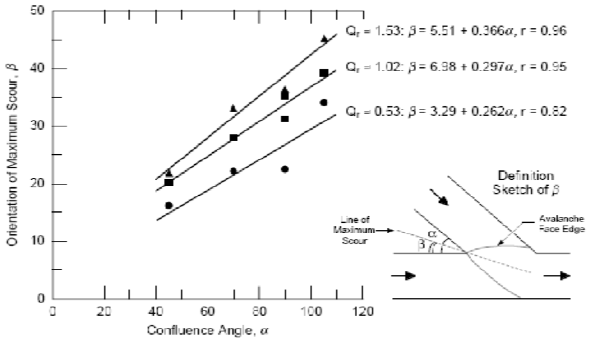

Fig. 5. Relationship between the orientation of the maximum scour depth, β, confluence angle, α, and discharge ratio, $Q_r = Q_1/Q_2$ [3]

An important bathymetric feature is the zone or line of maximum scour, whose position is closely related (if not identical) to the position of the dividing streamline. Fig. 5 indicates the approximate relationship between the orientation of the line of maximum scour depth, $\beta_s$, and confluence angle, α, for several discharge ratios, $Q_r = Q_1/Q_2$.

## III. RESEARCH METHODS

Research carried out by using physical models in the laboratory. Physical model combining the two channels form an angle of 30°. Channel 1 as the main channel, has a width of 0.3 m, channel slope 0.00001, and 0.5 m high channel Channel 2 as a branch channel, has a width of 0.15 m, the slope of 0.000048 channels, and height 0.5 m. The channel wall made of glass, while the bottom channel is made of wood. At the end of the channel 1 and 2 is equipped with reservoirs and flow meter. Similarly, at the end of the channel. Flow meter is used in the form of Thomson gauge. At the bottom of the channel given the sand as base material channels. Sand size used D50 was 0.55 mm. Fig. 6 shows the layout of physical models used in the study.

The steps undertaken in this study are:

1. Before the experiment started, first to calibrate flow measuring instrument.
2. Then give the sand in the bottom two channels as the sediment bed material.
3. Then the water flows in both channels. (see Fig. 9a).
4. After several times, the flow stopped. Then wait for the water decreased gradually until the basic look and then made the contour lines to determine the basic channel height. (see Fig. 9b).
5. From bed change channels, see the flow path of the branch channel. Flow path of the branch channel known as dividing streamline. Then measure the width of dividing streamline (see Fig. 9a and 9b, dashed line shows the line meetings or dividing streamline flow).
6. For the next experiment repeat steps b to e. The flow variations used are listed in Table 1.
7. Experimental results obtained are then compared with the research conducted by Gurram.

TABLE 1.
VARIATIONS OF THE MODEL RUNNING

| Experiment | $Q_1$ (l/sec) | $Q_2$ (l/sec) | $Q_3=Q_1+Q_2$ (l/sec) | Ratio $Q_2/Q_3$ |
|---|---|---|---|---|
| 1 | 2.9 | 1.2 | 4.1 | 0.293 |
| 2 | 2.39 | 1.2 | 3.59 | 0.334 |
| 3 | 0 | 1.2 | 1.2 | 1 |
| 4 | 2.5 | 0 | 2.5 | 0 |

TABLE 2.
WIDTH OF DIVIDING STREAMLINE POSITION (MM)

| Experiment | Ratio | Observation | Gurram |
|---|---|---|---|
| 1 | 0.293 | 163.56 | 178.7 |
| 2 | 0.334 | 179.85 | 237 |
| 3 | 1 | 290.56 | 300 |
| 4 | 0 | - | - |

## IV. RESEARCH RESULT

From several experiments conducted hydraulic characteristics obtained as shown in Fig. 7. In Fig. 7, note the velocity contours for experiments 1, 3 and 4. For experiment 1, water flows from the two channels, the maximum velocity obtained occurs at the right point of the flow. As for experiment 3, where the water flows from the branch channel, the velocity will decrease at the time was the main channel. Experiment 4, where the water flows from the main channel only, the velocity does not change after the meeting.

In Fig. 8, is a form of flow occurs. From this figure it can be seen wide dividing streamline, as shown in Fig. 8a.

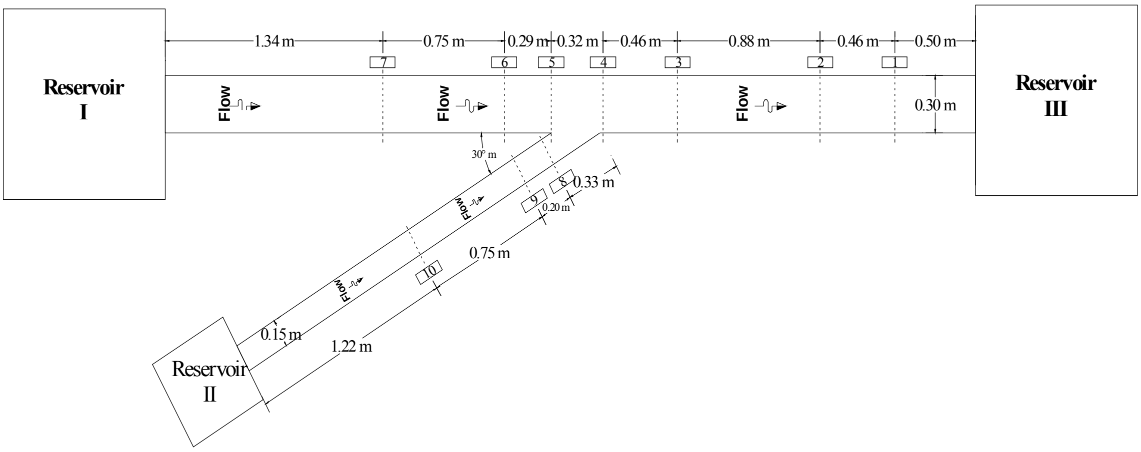

Fig. 6. Lay out a physical model of the channel meeting with an angle of 30°

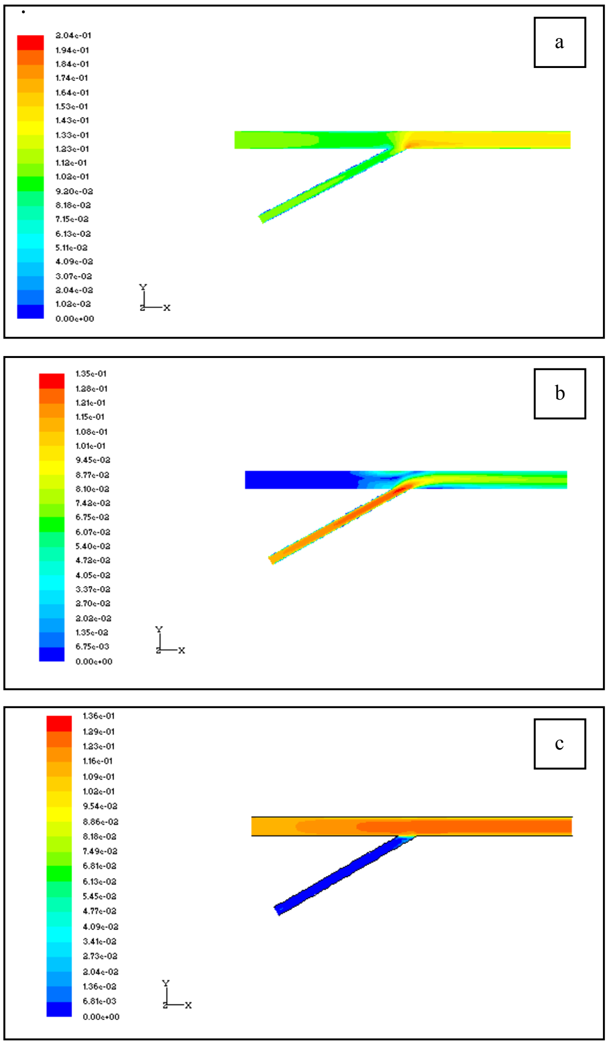

Fig. 7. The velocity contour of Confluence Flow.
a. Experiment 1; b. Experiment 3; c. Experiment 4

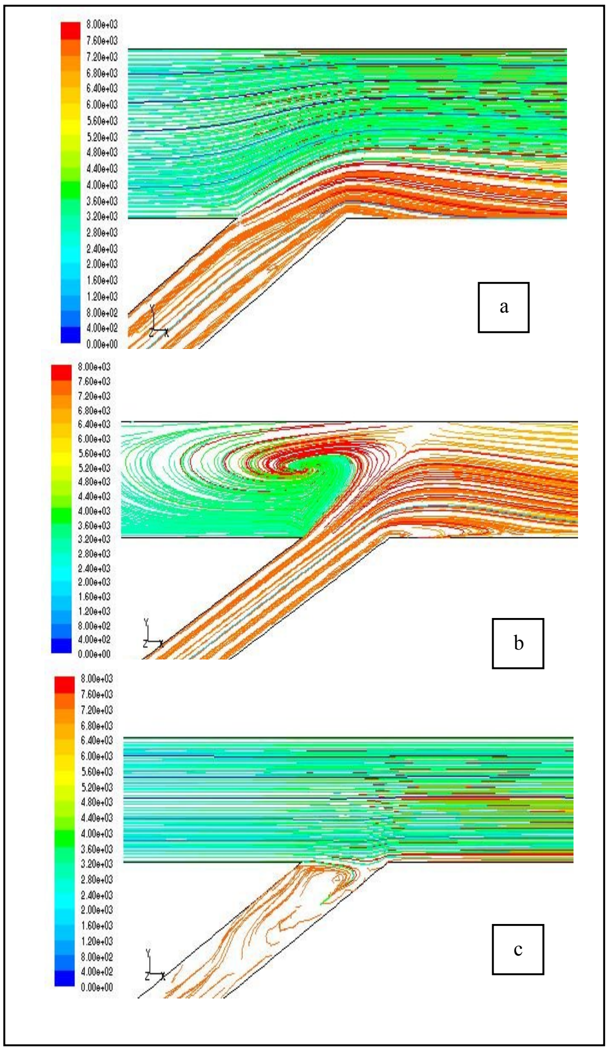

Fig. 8. Stream Line
a. Experiment 1; b. Experiment 3; c. Experiment 4

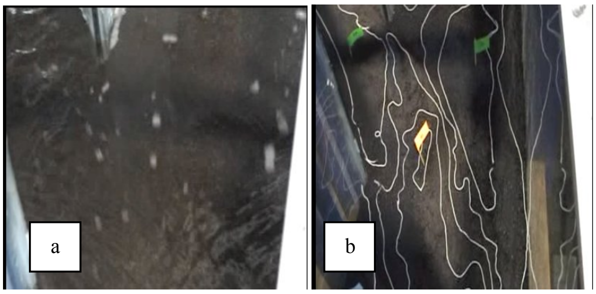

Fig. 9. Experimental view

The observation in the laboratory can be seen in Fig. 10. On Fig. 10 shows dividing streamline position with various discharge ratios. It was known that the higher the discharge ratio (Q2/Q3), the wider the dividng streamline. The lower the discharge ratio (Q2/Q3), the narrower the dividing streamline.

Fig. 11 show the compared of result observation and numerical simulation. Numerical simulation in this study use CFD software. In Fig. 11, laboratory results can be viewed larger than the numerical simulation.

This difference occurs because of software limitations in simulating phenomena that occur in the physical model. In software assumed that the flow of uniform flow conditions, but in the physical model of flow conditions that occur are not uniform. Besides the physical model have velocity at changing, the software, which the velocity is uniform.

In addition Fig. 11, a pattern dividing streamline laboratory results with numerical simulations. Dividing streamline pattern of the numerical simulation results obtained from the CFD simulation software in terms of the flow.

While dividing streamline pattern of laboratory results obtained from measuring changes in eroded base, which it is based on the opinions of Ettema (1999), that the eroded area at the confluence of the channel closely related to the dividing streamline.

Width of dividing streamline position according Gurram and observation can see Table 2. By recognizing the width of dividing streamline in accordance with observation and according to Gurram, the discharge ratio (Q2/Q3) and width ratio ($b_d/b_3$) could be known (see Fig. 12). From the figure, it was recognized that the higher the discharge ratio, the higher the width ratio.

From the Fig. 12, the observation in the laboratory is smaller than the calculated according Gurram. Differences occur between 3-30%. The biggest difference occurred in the experiment 2. The difference occurs because the calculation method of Gurram assumes that same water level in both the upstream and downstream channel confluence, whereas in fact the water level upstream and downstream different. This method causes the Gurram not match reality happens. Therefore still required further study of the parameters that affect the formation of dividing streamline patterns

## V. CONCLUSION

From the analysis of the data obtained the following conclusions:

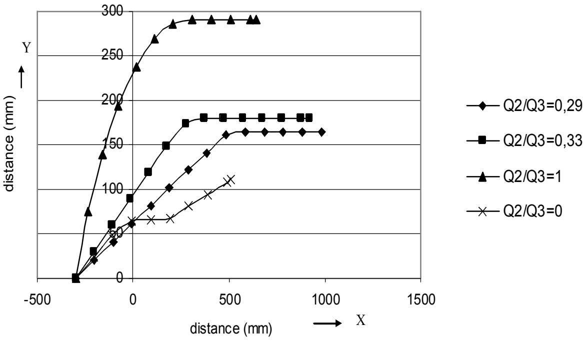

Fig. 10. Dividing streamline at confluence flow with 30 degree angle.

1. Width dividing streamline flow is influenced by the discharge ratio between the flow channel branches and the main channel after confluence.
2. The greater the ratio of the flows dividing streamline wider, this can be seen in Fig. 10.
3. The results of comparative study with previous studies in mind that the observations in the laboratory are smaller than the results of previous studies. So that further research is needed to determine other parameters that affect the wide dividing streamline.

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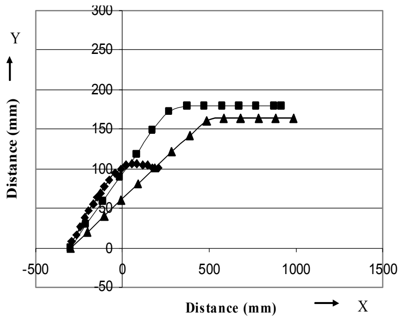

Fig.11. Dividing streamline from result observation and numerical simulation

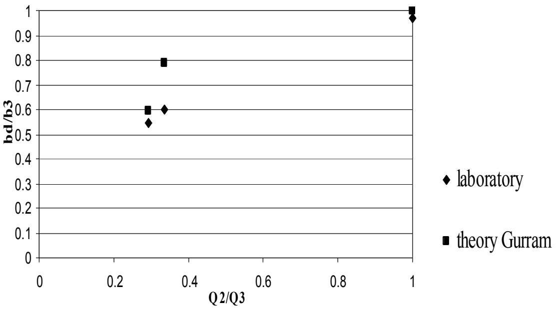

Fig. 12. The relation between width of dividing streamline and discharge ratio

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