Hydraulic Jump Generation By Weir Model and Leap Length Study for Practice Purpose

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HYDRAULIC JUMP GENERATION BY WEIR MODEL AND LEAP LENGTH STUDY FOR PRACTICE PURPOSE

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ABSTRACT

A parameter that needed to design the stilling basin dimension in the downstream of the weir was the length of hydraulic jump. The parameter was needed as a basis to determine the stilling basin length that likely can reduce the water energy that fall from the top of the weir into stilling basin floor. The jump length function was developed based on hydraulic leap depth in the upstream and the downstream. The length was conducted experimentally in laboratory. The data of experiment result was analyzed by regression technic. The results are the hydraulic jump length in a function with variable is a ratio of downstream and upstream depth of the hydraulic jump.

Key words: Hydraulic, Weir, Jump, Length, Channel.

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1. INTRODUCTION

The construction of a weir in the river channel aims to increase the river water level with a specific purpose. For example the purpose is to divert the stream in the river into irrigation system in rice field. The weir can cause the flow pattern in the river will be change. In the upstream of the weir exist the slow flow (the flow velocity will be decrease and the flow depth will be increase). In the downstream, the flow velocity will be increase the flow depth will be decrease, and the flow pattern to be complicated. Sometimes the hydraulic jump generated in downstream of the weir.

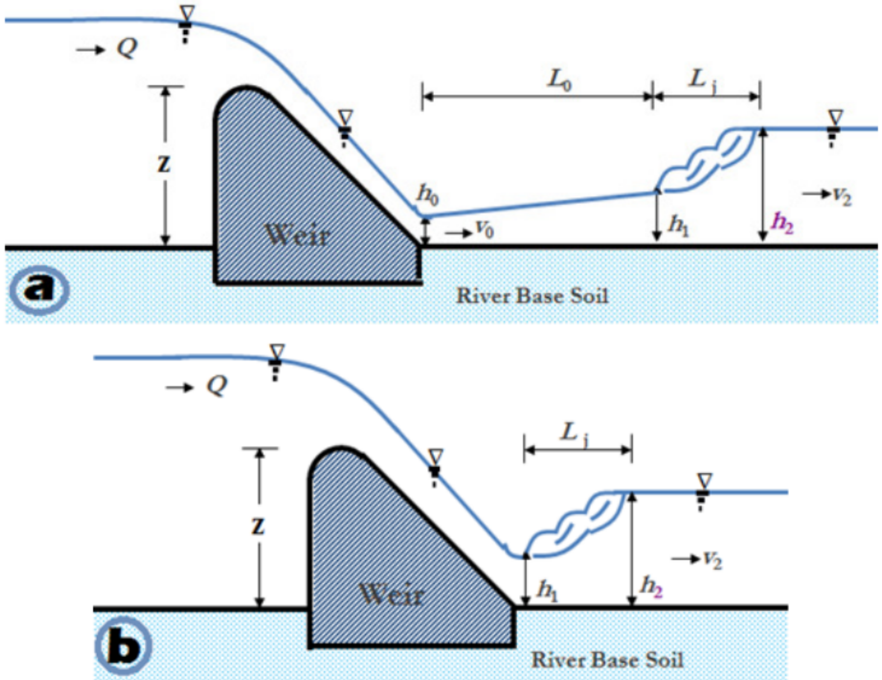

Figure 1 Flow pattern in upstream and downstream of the weir

The sketch of the flow pattern in upstream and downstream of the weir can be seen in Figure 1a and 1b.

In the Figure 1a, flow pattern in the downstream of the weir, imply that will be occurred flow with high velocity along hydraulic jump running with the length L_0 and the circular flow on along hydraulic jump with length L_j. The condition can scour the river base along L_0+L_j, if the place is not protected. In the Figure 1b the flow pattern in form of the hydraulic jump in the downstream of the weir shows that scouring will be occurred along the hydraulic jump only. So that the river base that need protection is along the hydraulic jump solely. The two conditions of the downstream weir flow pattern indicate that the hydraulic jump should be brought closer to the down-stream foot weir by hydraulics analysis (Figure 1b) so as the protection of the river base can be shorter and the cost of river protection will be cheaper.

Study of hydraulic jump or hydraulic jump length (L_j) as in Figure 1 was conducted by many experts in hydraulic engineering.

- Related to hydraulic jump phenomenon some researchers have given the results of their study. *i*) Chanson and Montes (1995) perform experimental research of undular hydraulic jump in a rectangular channel. Visual and photographic observations result indicated five types of undular jumps. One of the main flow characteristics is the presence of lateral shock waves for Froude numbers larger than 1.2. The other results show that the disappearance of undular jump occurs for Froude numbers ranging from 1.5 to 2.9 and that the wave length and amplitude of the free-surface undulations are functions of the upstream Froude number and the aspect ratio of critical flow depth and width of channel. *ii*) Chanson (1996) studied hydraulic jump which was characterized by free-surface undulations that develop downstream of the jump for low upstream Froud numbers. Experimental study was performed in rectangular cross section flume with fully-developed upstream flows. The result show a major three-dimentional flow redistributions immediatly upstream of the wave crest. Velocity and pressure distributins were recorded at very close intervals in that region. They provide some understanding of the flow redistribution mechanisms. A dominant features of the undular jump flow is the presence of lateral shockwave superposed over the free-surface undulations. *iii*) Alikhani et al. (2010) performed experimental study to evaluate effects of a single vertical continous sill and its position on control of depth and length of a forced jump in stilling basin without considering tailwater depth which is variable and totally controlled by downstream river conditions. The hydraulic characteristics of the jump were measured and compared with the classical hydraulic jump under variable discharges. Results of experiments confirmed significant effect of the sill on dissipation of energy. A new relationship was developed between sill height and position, sequent depth ratio, and length of stilling basin. The advantage of the proposed relationship in practice is its capability to design stilling basin where tail water depth is unpredictable.

- Associated with the hydraulic jump length equations some researchers have given the results as follow.

Bakhmeteff and Matzke (1936)

$$L_j = 5(h_2 - h_1) \quad (1)$$

Ivanchenko (1935)

$$L_j = 10.6\ (h_2 -.h_1)\ (F_{r1}{}^2)^{-0.185} \quad (2)$$

Kinney (1935)

$$L_j = 6.02(h_2 -.h_1) \quad (3)$$

Smetana

$$L_j = 6(h_2 -.h_1) \quad (4)$$

Sulistiono and Makrup (2017)

$$L_j = (6.3273 + 0.5974 h_1/h_2)\ (h_2 - h_1) \quad (5)$$

Wu (1949)

$$L_j = 10(h_2 -.h_1)\ (F_{r1})^{-0.16} \quad (6)$$

Woicicki (1931)

$$L_j = (8 - 0.05 h_2/h_1)\ (h_2 - h_1) \quad (7)$$

In this paper the equation of hydraulic jump length was developed associated with Figure 2, equation (8), and (9).

$$L_j = a\frac{h_2}{h_1} + b \quad (8)$$

$$L_j = c\left(\frac{h_2}{h_1}\right)^d (h_2 - h_1) \quad (9)$$

Where *a*, *b*, *c*, *d*, and *e* are constants that can be found by regression analysis, h_1 and h_2 are upstream and downstream water depths of hydraulic jump respectively (Fig 2). The variable h_2/h_1 is the ratio of water depth in subcritical flow condition in downstream of hydraulic jump and water depth in supercritical flow condition in upstream of hydraulic jump.

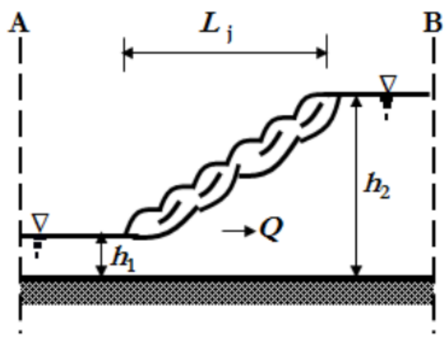

Figure 2 Hydraulic jump

where,

L_j = length of hydraulic jump

h_1 = water depth in section A

h_2 = water depth in section B

Q = discharge of the flow

2. HYDRAULIC JUMP EQUATION

Hydraulic jump can be occurred if the flow in the river changes from the supercritical flow to the subcritical flow (Figure 2). Hydraulic jump equation was derived by experts with flow type was steady flow or rapid varied flow as in Figure 2 and 3.

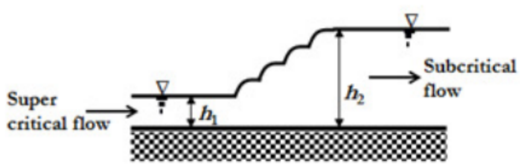

Figure 3 Rapid varied flow

From Figure 2 can be found that the pressure force (F_p) between section A and B is,

$$F_p = \tfrac{1}{2}\rho g(h_2^2 - h_1^2)b \qquad (10)$$

and the velocity force (F_v) between section A and B is,

$$F_v = \rho Q(V_1 - V_2) \qquad (11)$$

For the along rapid varied flow Figure 3 the two forces were balance so,

$$\tfrac{1}{2}\rho g(h_2^2 - h_1^2)b = \rho Q(V_1 - V_2) \qquad (12)$$

where the section A is the supercritical flow and section B is subcritical flow, and,

ρ = mass density of water

g = gravity acceleration

V_1 = flow velocity in section A

V_2 = flow velocity in section B

b = width of the rectangular chanal

Equation (12) can be rearrange to find the hydraulic jump equation to determine downstream depth of hydraulic jump, Equation (13) dan (14).

$$\frac{h_2}{h_1} = ½\left(\sqrt{1+\frac{8q^2}{gh_1^3}}-1\right) \qquad (13)$$

or

$$\frac{h_2}{h_1} = ½\left(\sqrt{1+8F_{r1}^2}-1\right) \qquad (14)$$

where

$$F_{r1} = \sqrt{\frac{q^2}{gh_1^3}} \qquad (15)$$

or F_{r1} can be derived from Equation (13) to be

$$F_{r1} = \sqrt{\frac{(2h_2/h_1+1)^2-1}{8}} \qquad (16)$$

3. METHODS

Experiments were performed in a 10-m long channel of uniform rectangular section made of glass (bottom and sidewalls), located in the Hydraulic Laboratory of the Islamic University of Indonesia (Figure 4). The channel width is 0.10 m and the sidewall height is approximately 0.40 m. The channel is supported on an elevated steel frame which spans between main supports. The channel slope can be adjusted using a geared lifting mechanism but for the study was done in horizontal channel condition. Tail water levels are controlled by a radial gate fitted at the downstream channel end. The weir model can be seen in Figuer 5. The water discharge was measured typically using a bend, installed in below of the end of the channel flume (Figure 6). The three quantitative measured discharges were gauged by the bend i.e. 0.001462 m^3/s, 0.002043 m^3/s, and 0.002744 m^3/s, The three discharges were used in this study.

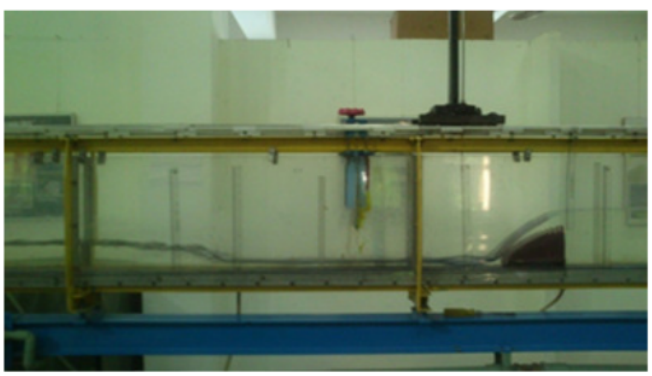

Figure 4 Channel flume in hydraulic laboratory of Islamic University of Indonesia

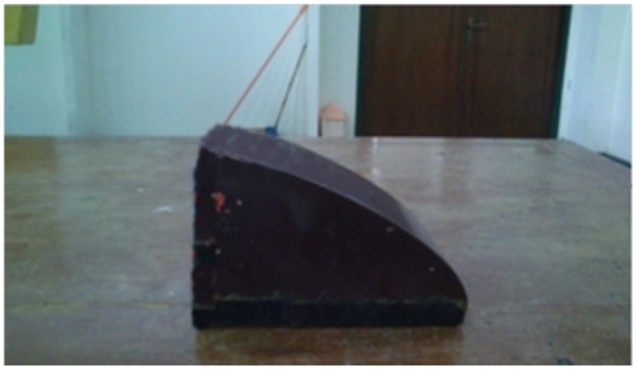

Figure 4 The weir model

Figure 5 Bend for discharge measurement

Longitudinal flow depths are measured using a rail mounted pointer gauge positioned over the channel (Figure 4). During the experiments, the location of the hydraulic jump was controlled by the downstream gate. For one discharge value, the hydraulic jump parameters were measured for 4 times.

4. HYDRAULIC JUMP PARAMETERS MEASUREMENT

The three parameters of the hydraulic jump which were measured are upstream depth (h_1) and downstream depth (h_2) and length (L_j) of hydraulic jump. The measurement result can be seen in Table 1, 2, 3, 4, and 5. Table 5 is correlation of hydraulic jump depth and length.

Table 1 Result of hydraulic jump parameter measurement with discharge 0.001462 m^3/s and high of weir model is 0.11 m

Q (ltr/s)	High of Weir Model (cm)	Measurement number	Depth		Length of Hydraulic Jump L_j (cm)
			upstream h_1 (cm)	downstream h_2 (cm)	
1.462	11	1	2.0	6.5	30.8
		2	2.0	5.8	25.0
		3	2.1	5.3	23.7
		4	2.3	4.6	14.3

Table 2 Result of hydraulic jump parameter measurement with discharge 0.002043 m^3/s and high of weir model is 0.11 m

Q (ltr/s)	High of Weir Model (cm)	Measurement number	Depth upstream h_1 (cm)	Depth downstream h_2 (cm)	Length of Hydraulic Jump L_j (cm)
2.043	11	1	2.5	7.8	33.8
		2	2.6	6.9	29.2
		3	2.9	5.7	18.4
		4	3.2	5.5	15.9

Table 3 Result of hydraulic jump parameter measurement with discharge 0.002744 m^3/s and high of weir model is 0.11 m

Q (ltr/s)	High of Weir Model (cm)	Measurement number	Depth upstream h_1 (cm)	Depth downstream h_2 (cm)	Length of Hydraulic Jump L_j (cm)
2.744	11	1	2.7	9.0	37.4
		2	2.8	8.3	31.9
		3	3.3	7.5	25.8
		4	3.5	6.7	22.3

Table 4 Correlation of hydraulic jump depth and length

Hydraulic jump depth Upstream h_1(cm)	Hydraulic jump depth Down stream h_2(cm)	Hydraulic jump Length L_j(cm)
2.0	6.5	30.8
2.0	5.8	25.0
2.1	5.3	23.7
2.3	4.6	14.3
2.5	7.8	33.8
2.6	6.9	29.2
2.9	5.7	18.4
3.2	5.5	15.9
2.7	9.0	37.4
2.8	8.3	31.9
3.3	7.5	25.8
3.5	6.7	22.3

Table 5 Correlation of h_2/h_1 and h_2-h_1 to hydraulic jump length

No.	Ratio of h_2/h_1	Differences h_2-h_1 (cm)	Hydraulic jump Length L_j(cm)
1	3.2500	4.5	30.8
2	2.9000	3.8	25.0
3	2.5238	3.2	23.7
4	2.0000	2.3	14.3
5	3.1200	5.3	33.8
6	2.6538	4.3	29.2
7	1.9655	2.8	18.4
8	1.7188	2.3	15.9
9	3.3333	6.3	37.4
10	2.9643	5.5	31.9
11	2.2727	4.2	25.8
12	1.9143	3.2	22.3

5. DATA ANALYSIS AND RESULTS

As mentioned in above paragraphs that the hydraulic jump length functions which desired are such as in Equation (7) and (8). In each equation of L_j were a function of h_2/h_1 ratio and difference of downstream and upstream hydraulic jump depth (h_2-h_1) respectively. Therefore to find the constants of a, b, c, and d of the both equations are required regression analysis. The data for the analysis is in Table 5 which derived from Table 4.

Results of regression process in linear form Equation (8) are in Equation (17) and in Figure 6 and in power form of Equation (9) are in Equation (18) and in Figure 7.

$$L_j = 0.1152(h_2/h_1) - 0.0369 \quad (17)$$

with correlation coefficient, $r = 0.9058$.

$$L_j = 7.1652(h_2/h_1)^{-0.1017}(h_2-h_1) \quad (18)$$

with correlation coefficient, $r = 0.9994$.

The two equations produced L_j value which different between one and another. It is caused by independent variable that different too.

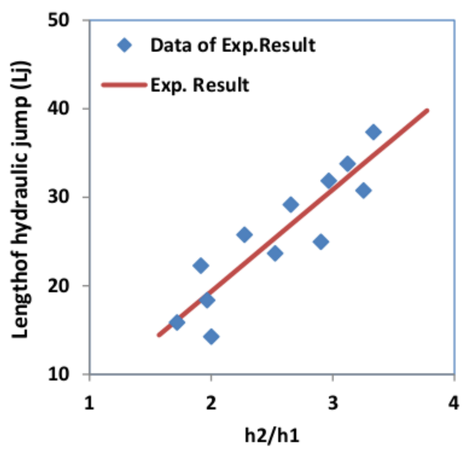

Figure 6 Relation of L_j and h_2/h_1 in linear form

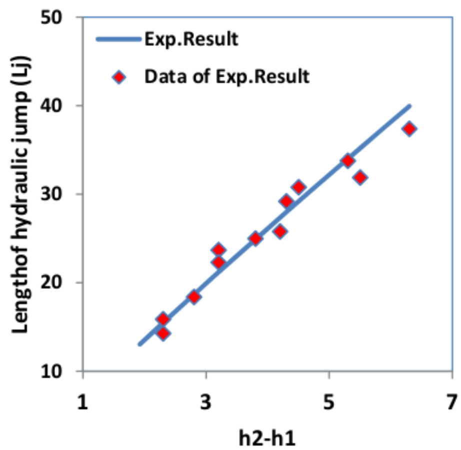

Figure 7 Relation of L_j and h_2-h_1

6. DISCUSSION

Based on the literature review which mention above that researchers such as Bakhmeteff and Matzke, Ivanchenko, Kinney, Smetana, Sulistiono and Makrup, Wu, and Woycicki have used hydraulic jump parameters h_1 and h_2 to compute the length of hydraulic jump. Each of the researcher gave the L_j equation that different beetwen a researcher to another and different much beetwen result of above researchers and the result of this study.

6.1. Comparison of the two study results

Comparison of Equattion (17) and (18) as results of this study can be seen visually in Figure 8.

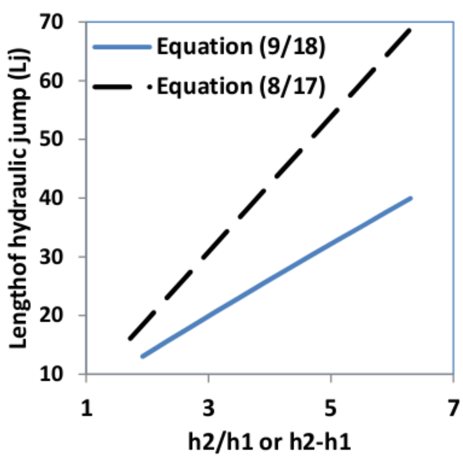

Figure 8 Comparison of the two experiment result

The figure shows that length of hydraulic jump (L_j) from Equation (17) tends to greater than Equation (18). After it was carried out many calculations, so it was found that L_j value from Equation (17) to be unrealistic if variable h_1 and h_2 are out of the experiment result. Besides that correlation of the Equation (18) better than Equation (17) so the Equation (18) will be used as basis in the next discussion.

6.2. Comparison of the study results and the research results before

The research results of experts which will be compared to the study are the Ivanchenko, Smetana, Sulistiono and Makrup, Woicicki, and Wu results. For Bakhmeteff and Matzke, and Kinney results are represented by Smetana result, because the hydraulic jump length coefficients of both equations (Bakhmeteff-Matzke and Kinney, 5 and 6.02 respectively) little bit different to Smetana had i.e. 6. Visually comparison of study result to the Ivanchenko, Smetana, Sulistiono and Makrup, Woicicki, and Wu results can be noticed in Figure 9, 10, 11, 12, and 13 respectively.

From Figure 9, 12, and 13 show that the results of Ivanchenko, Woicicki, and Wu generally greater than the result of the study. From Figure 11 can be seen result comparison of the study and Smetana had. From the figure can be noticed Smetana line closer to the study line but Smetana result tend to smaller than the study result. Comparison of the study and Sulistiono and Makrup result can be seen in Figure 10. From the figure can be noticed that the two lines result very close and nearly coincide.

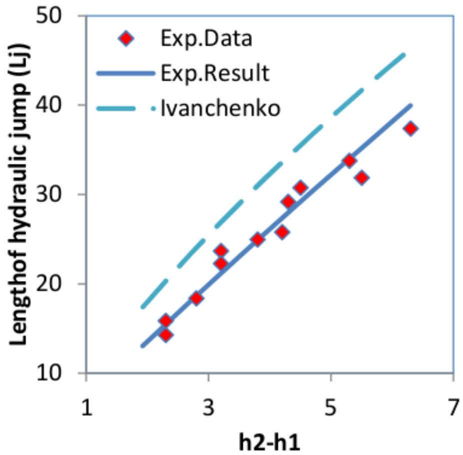

Figure 9 Comparison of experiment result and Ivanchenko

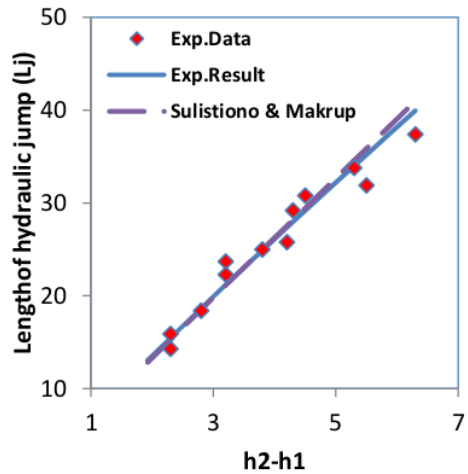

Figure 10 Comparison of experiment result and Sulistiono and Makrup

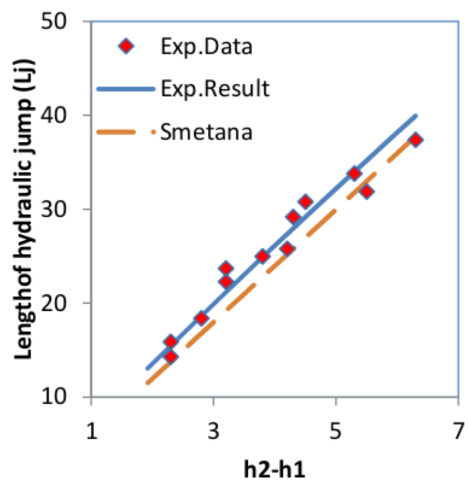

Figure 11 Comparison of experiment result and Smetana

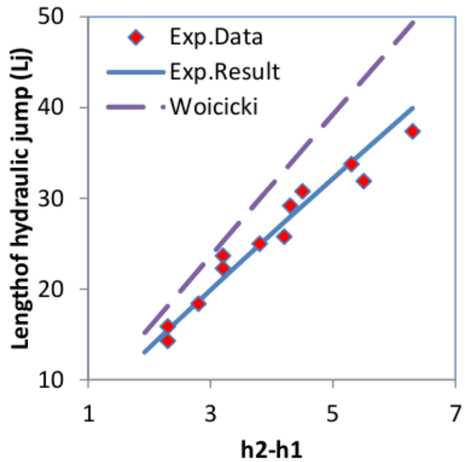

Figure 12 Comparison of experiment result and Woicicki

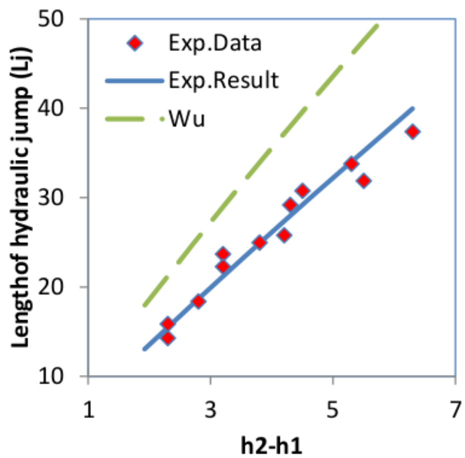

Figure 13 Comparison of experiment result and Wu

For the whole of the comparison results can be implied that the result of the study very close to the Sulistiono and Makrup result. The both lines of the result almost coincide, so the two results can be considered the same. The result of the study also exists between Ivanchenko, Woicicki, Wu results and Smetana had. Because the results of Ivanchenko, Woicicki, and Wu greater enough than result of the study (Equation 18) and Smetana result little bit smaller than the study. Therefore the study and Sulistiono and Makrup results can be utilized as a replacement for the all experts results as mention in references (Equation 1 to 7) to compute the hydraulic jump length.

7. CONCLUSION

Based on the above discussion can be known that the equation to calculate the hydraulic jump length has been found. The hydraulic jump length equation which was obtained has the best correlation to the experiment data. Therefore the hydraulic jump length equation result of the study can be utilized as a substitue for all equations of the hydraulic jump length before.

RECOMMENDATION

The research gives the satisfied result based on discussions and conclusions above. Although still needed such the other research to acquire the hydraulic jump length that more accurate.

ACKNOWLEDGMENT

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