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EFFECT OF THE END-SILL TO THE STREAM PATTERN IN STILLING-BASIN

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ABSTRACT

The stilling basin is a structure that useful to reduce the water energy of super-critic-flow that spill on downhill of the weir to be the sub-critic-flow on the behind the end-sill. The end-sill structure is located at the end of the stilling basin. The hydraulic jump that formed in stilling basin, its length can be reduced by adding the end-sill high. 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 the downstream depth plus high of the end-sill and upstream depth of the hydraulic jump.

Keywords: Hydraulic, Weir, Jump, Length, Channel

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1. INTRODUCTION

The stilling basin is a structure which has a function as energy reducer in the downstream of a weir. One of the parts of the stilling basin is the end-sill (Figure 1). The end-sill useful to inhibit the super-critic- flow from the crest of the weir which falling down to the stilling-basin, so that change to be the sub-critic-flow behind the end-sill structure. Therefore the end-sill also use as an energy damper in stilling-basin. Since the flow in the stilling basin change from the super-critic to the sub-critic-flow caused by end-sill, then stream pattern in stilling basin also altered. In other word the hydraulic jump is generated in the stilling basin (Figure 1).

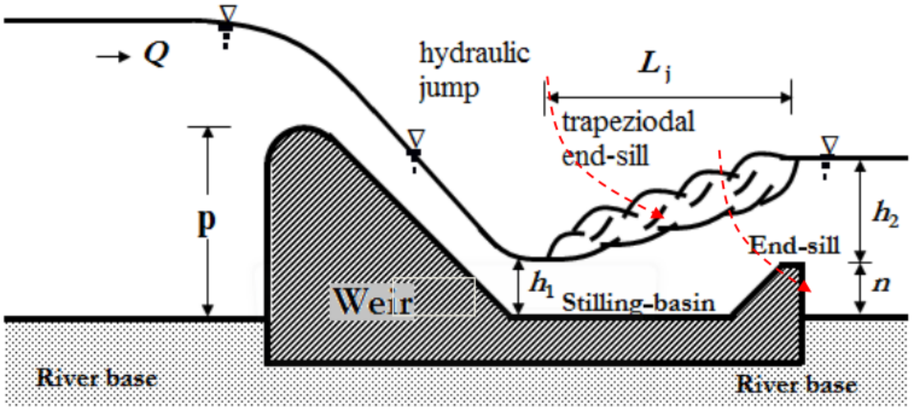

Figure 1 Hydraulic jump on stilling basin

where h_1 is upstream depth, h_2 is the downstream depth over the end-sill, L_j is the length of hydraulic jump, p is the crest high of the weir, n is the high of the end-sill, and Q is stream discharge.

The high of the end-sill can be adjusted up and down to compel the hydraulic jump always close to the downstream foot of the weir. If the hydraulic jump close to the weir, then the hydraulic jump length can be contracted. Hence the stilling-basin length also can be shorter, and the cost to build the stilling-basin structure to be cheaper. The pattern of the flow (the hydraulic jump) in the stilling-basin can be seen in Figure 1. Based on the above background in this research will be studied effect of the end-sill high to the parameter of hydraulic jump i.e. upstream and downstream depth and length of hydraulic jump.

In the irrigation standard of Indonesia (2010) it was found the formula to compute the hydraulic jump length (L_j) was,

$$L_j = 5(n + h_2) \quad (1)$$

The Equation (1) is valid for the rectangular end-sill (Figure 2).

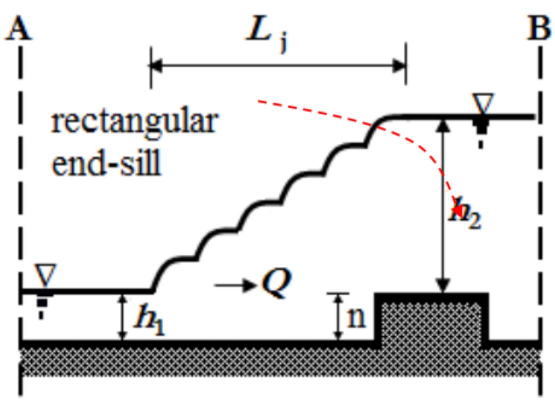

Figure 2 Stilling basin with rectangular end-sill

According to Equation (1) so in this paper the hydraulic jump length is developed based on trapezoidal end-sill Figure 1).

Study of the flow parameter in the upstream of the end-sill has been conducted by Forster and Skrinde (1950) with thin end-sill and rectangular end-sill. The result of the study can be seen in Figure 3 and 4.

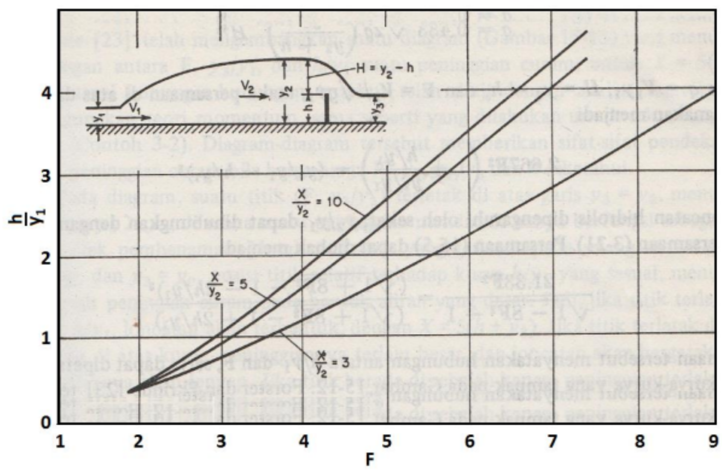

Figure 3 Study result of Forster and Skrinde (1950) with thin end-sill

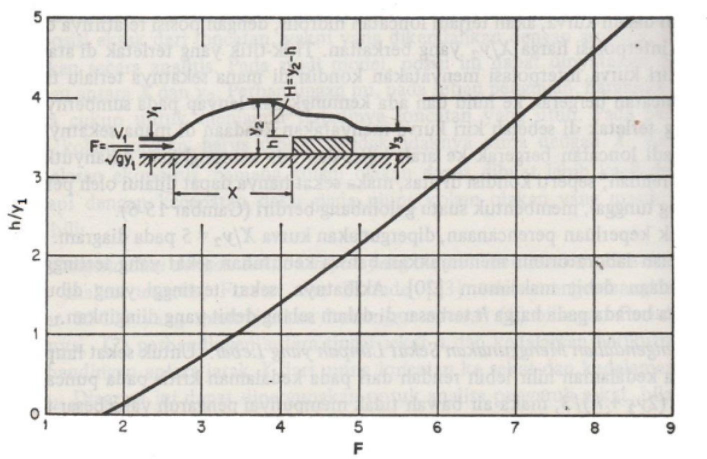

Figure 4 Study Result of Forster and Skrinde (1950) with rectangular end-sill

In the experiment result (Figure 3 and 4), Forster and Skrinde show the correlation between the ratio of h/y_1 and Froud number (F) on x/y_2 equal to 3, 5, and 10, where h is end-sill high, y_1 and y_2 are upstream and downstream depth in front of end-sill respectively and x is length of hydraulic jump.

The Indonesian Standard of Irrigation has brought off the experiment which almost similar to Forster and Skrinde with result can be seen in Figure 5.

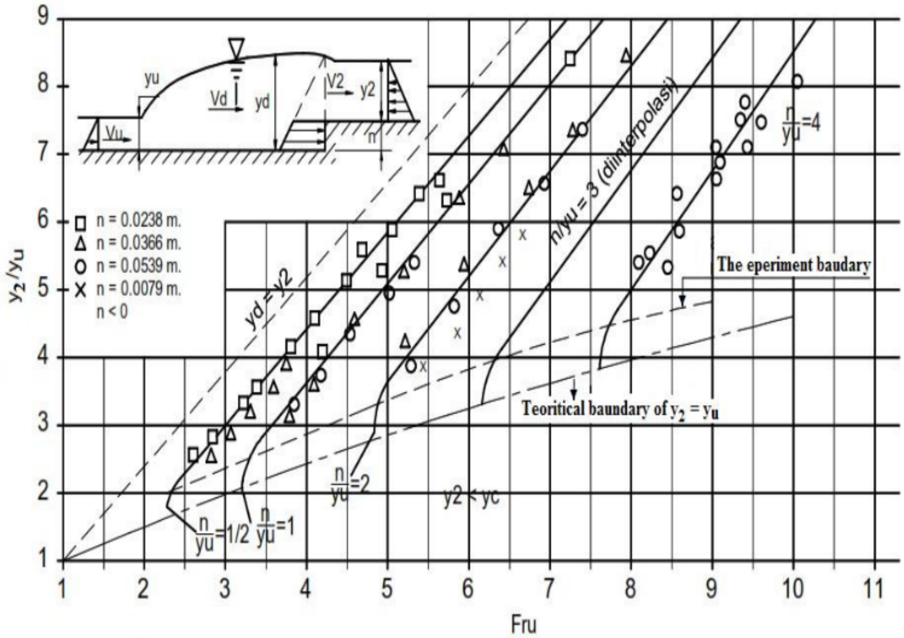

Figure 5 The experiment result from Indonesian Standard of Irrigation (2010) Book No. 04 with rectangular end-sill

The result in Figure 5 describe the correlation between the ratio of y_2/y_u and Froud number (Fu) on n/y_2 equal to ½, 1, 2, 3, and 4, where n is end-sill high, y_u and y_2 are upstream and over end-sill depth respectively of hydraulic jump.

Study of hydraulic jump has been done by Chanson and Montes (1995). They performed 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.

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 shows 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 feature of the undular jump flow is the presence of lateral shockwave superposed over the free-surface undulations.

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.

In this paper it is studied effect of end-sill to the stream pattern (hydraulic jump) in stilling-basin according to the hydraulic jump length equation development. Based on Equation (1) is developed two equations such as below.

$$L_j = C_j\,(n + h_2) \qquad (2)$$

where C_j is a function of h_2/h_1. In Equation (2) it is included the influence of h_1 on C_j.

$$L_j = C_j\,(n + h_2 - h_1) \qquad (3)$$

where C_j are a single value and a function of h_2/h_1. In Equation (3) it is included the influence of h_1 on C_j and in variable of $n + h_2 - h_1$.

3. METHODS

Experiments were performed in 10-m uniform rectangular section channel flume (Figure 3) in the Hydraulic Laboratory of Islamic University of Indonesia.

Figure 3 Flume in Hydraulic Laboratory of Islamic University of Indonesia

The channel width is 0.10 m and the sidewall height is approximately 0.40 m. The weir and end-sill model that was utilized in the study can be seen in Figure 4. The three model of the end-sill was made (Figure 4) with high 2, 2.5, and 3 cm for model-1, model-2, and model 3 respectively. The water discharge was measured typically using a bend, installed in below of the end of the channel flume (Figure 5).

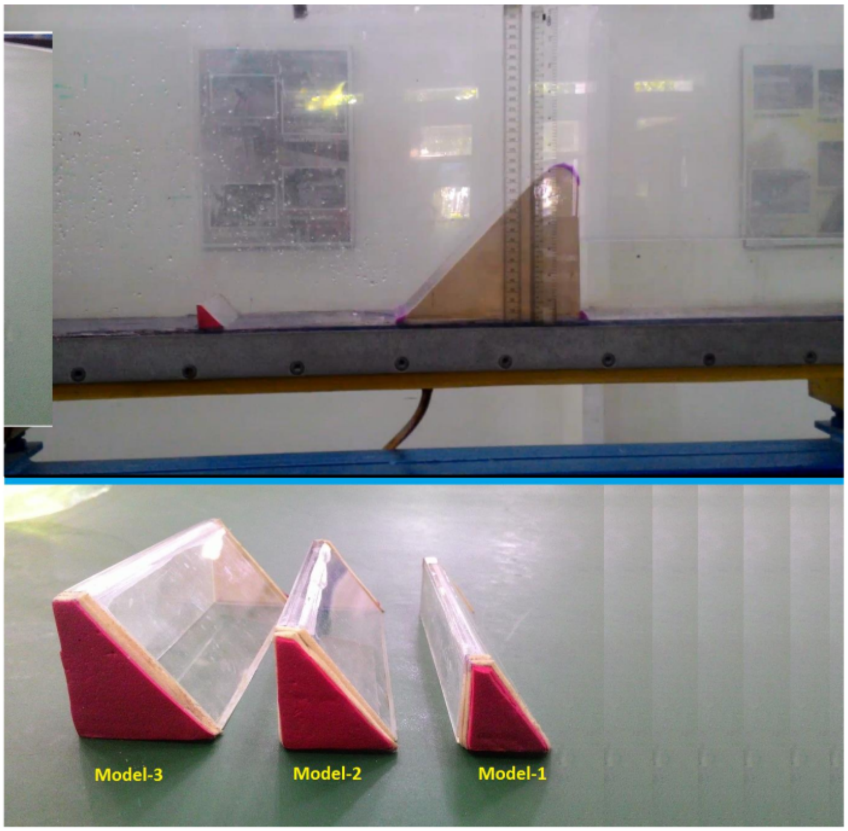

Figure 4 End sill model for study

Figure 5 Bend for discharge measurement

During the experiments, the location of the hydraulic jump always nearly close to the down-stream foot of the weir which was controlled by the end-sill.

4. MEASUREMENT OF DISCHARGE AND HYDRAULIC JUMP PARAMETERS

The four quantitative measured discharges were gauged by the bend for each of the end-sill model. The result of discharge measurement is in Table 1.

Table 1 Result of discharge measurement

n	Q	n	Q	n	Q
(cm)	(ltr/s)	(cm)	(ltr/s)	(cm)	(ltr/s)
2	0.5170	2.5	0.4645	3	0.4675
	0.6958		0.7165		0.7845
	1.1170		1.0307		1.0124
	1.3694		1.3509		1.3703

The parameters of the hydraulic jump which 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 2, 3, and 4. Table 2 is correlation of hydraulic jump depth and length.

Table 2 Result of hydraulic jump parameter measurement

n (cm)	Depth		Length of Hydraulic Jump L_j (cm)
	Upstream h_1 (cm)	Downstream h_2 (cm)	
2.0	0.30	2.50	15.00
	0.50	3.10	17.00
	0.70	4.00	20.00
	0.90	4.50	21.00
2.5	0.30	2.40	14.00
	0.50	3.20	17.00
	0.70	3.90	21.00
	0.90	4.60	24.00
3.0	0.30	2.40	12.00
	0.50	3.00	16.00
	0.65	3.60	20.00
	0.90	4.70	25.00

According to Equation (1) and (2), so based on the Table 2 can be computed the hydraulic jump coefficient i.e. $C_j = L_j/(n+h_2)$. The results are in Table 3.

Table 3 Correlations of h_1, h_2, $n+h_2$, L_j, h_2/h_1, and C_j

n (cm)	h_1 (cm)	h_2 (cm)	$n+h_2$ (cm)	L_j (cm)	h_2/h_1	C_j
2	0.30	2.50	4.50	15	8.3333	3.3333
	0.50	3.10	5.10	17	6.2000	3.3333
	0.70	4.00	6.00	20	5.7143	3.3333
	0.90	4.50	6.50	21	5.0000	3.2308
2.5	0.30	2.40	4.90	14	8.0000	2.8571
	0.50	3.20	5.70	17	6.4000	2.9825
	0.70	3.90	6.40	21	5.5714	3.2813

	0.90	4.60	7.10	24	5.1111	3.3803
3	0.30	2.40	5.40	12	8.0000	2.2222
	0.50	3.00	6.00	16	6.0000	2.6667
	0.65	3.60	6.60	20	5.5385	3.0303
	0.90	4.70	7.70	25	5.2222	3.2468

The average value of the C_j is 3.0748 ≈ 3.0. The C_j = 3.0 of the trapezoidal end-sill different from the rectangular end-sill Equation (1) the C_j is 5.0.

Related to Equation (3), from the Table 2 can be calculated the hydraulic jump coefficient i.e. $C_j = L_j/(n+h_2-h_1)$, as in Table 4.

Table 4 Correlations of h_1, h_2, $n+h_2-h_1$, L_j, h_2/h_1, and C_j

n (cm)	h_1 (cm)	h_2 (cm)	$n+h_2-h_1$ (cm)	L_j (cm)	h_2/h_1	C_j
2	0.30	2.50	4.20	15.00	8.3333	3.5714
	0.50	3.10	4.60	17.00	6.2000	3.6957
	0.70	4.00	5.30	20.00	5.7143	3.7736
	0.90	4.50	5.60	21.00	5.0000	3.7500
2.5	0.30	2.40	4.60	14.00	8.0000	3.0435
	0.50	3.20	5.20	17.00	6.4000	3.2692
	0.70	3.90	5.70	21.00	5.5714	3.6842
	0.90	4.60	6.20	24.00	5.1111	3.8710
3	0.30	2.40	5.10	12.00	8.0000	2.3529
	0.50	3.00	5.50	16.00	6.0000	2.9091
	0.65	3.60	5.95	20.00	5.5385	3.3613
	0.90	4.70	6.80	25.00	5.2222	3.6765

The mean value of the C_j from Table 4 is 3.4132. The C_j = 3.4132 different from the C_j of Equation (1) i.e. 5.0.

5. DATA ANALYSIS AND RESULTS

The equations which developed in this study are such as in Equation (2) and (3). The hydraulic jump coefficients (C_j) of the two equations are taken in form of a single value and a function of h_2/h_1 ratio. The form of C_j which will be used can be seen as in Equation (4).

$$C_j = a\,(h_2/h_1)^b \quad (4)$$

Results of analysis to determine the hydraulic jump length functions in Equation (2) and (3) are as the following equation.

Equation (2) in form of Equation (5)

$$L_j = 3.0(n + h_2) \quad (5)$$

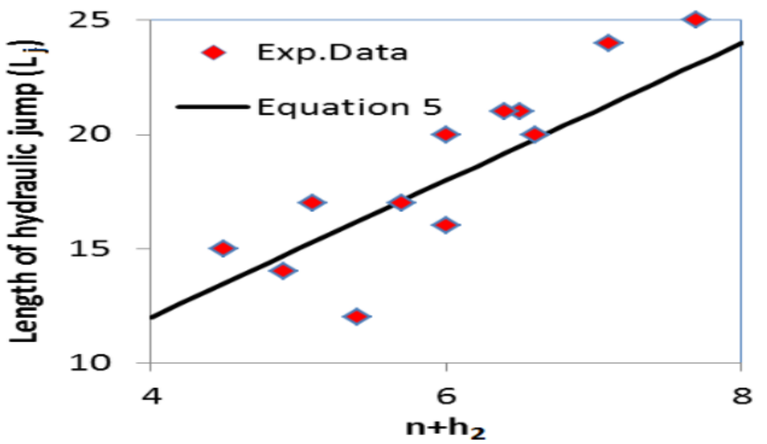

Figure 6 Relation of L_j and $n+h_2$ of Equation (5) with correlation coefficient 0.875

Equation (2) in form of Equation (6)

$$L_j = 5.7025\left(\frac{h_2}{h_1}\right)^{-0.3434}(n+h_2) \tag{6}$$

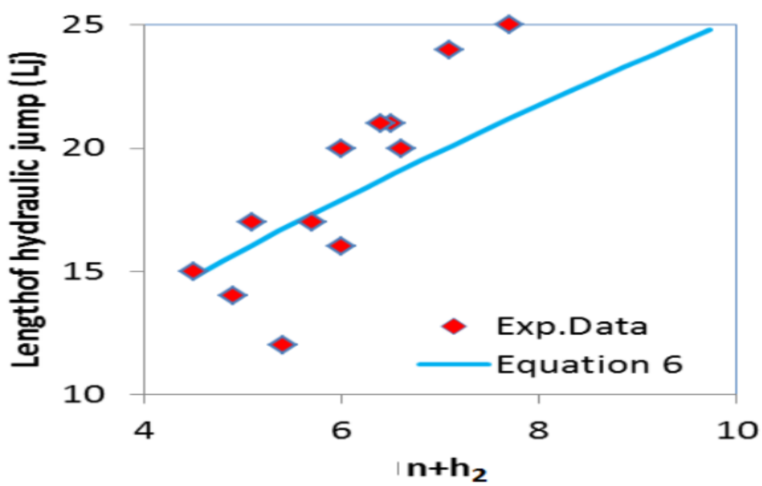

Figure 7 Relation of L_j and $n+h_2$ of Equation (6) with correlation coefficient 0.748

Equation (3) in form of Equation (7)

$$L_j = 3.4132(n + h_2 - h_1) \tag{7}$$

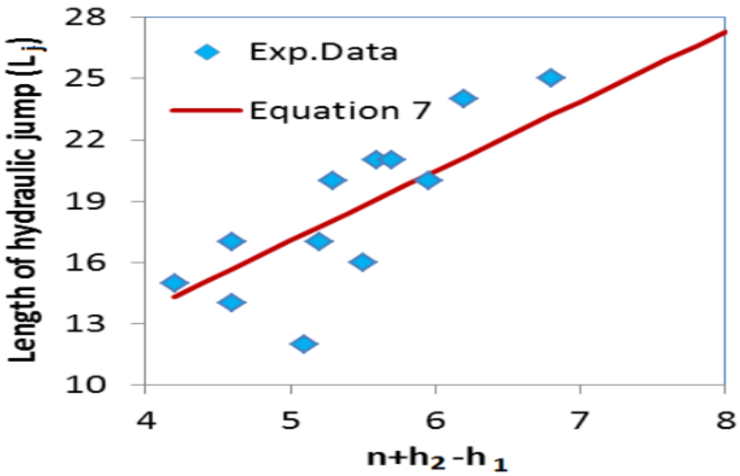

Figure 6 Relation of L_j and $n+h_2 - h_1$ of Equation (7) with correlation coefficient 0.768

Equation (3) in form of Equation (8)

$$L_j = 8.3107\left(\frac{h_2}{h_1}\right)^{-0.4944}\left(n + h_2 - h_1\right) \quad (8)$$

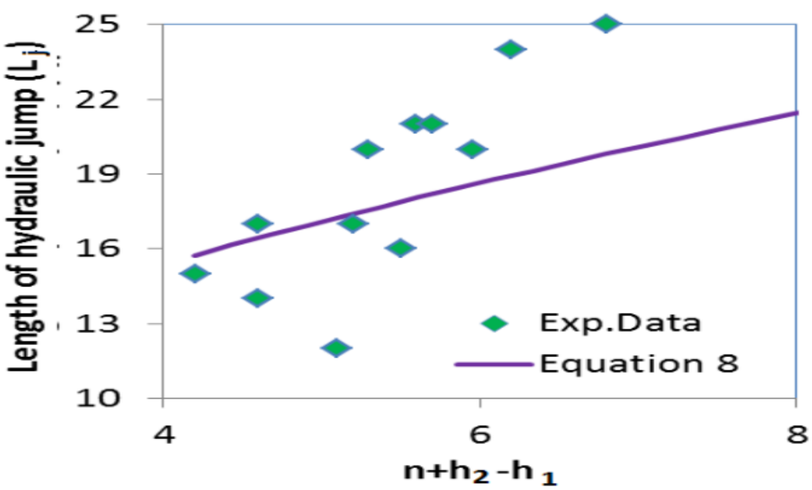

Figure 6 Relation of L_j and $n+h_2 - h_1$ of Equation (8) with correlation coefficient 0.663

6. DISCUSSION

Related to hydraulic jump length Equation (1), if the computation results of Equation (5) compared to the Equation (1) so the yield is Equation (1) greater than Equation (5), see Figure 7. The difference was occurred caused by the end-sill which utilized in Equation (1) was rectangular and in Equation (5) was trapezoidal. The difference in end-sill use lead to differences in hydraulic jump length coefficient. In this case, the hydraulic jump length coefficient of Equation (5) was found equal to 3, and for Equation (1) was known equal to 5.

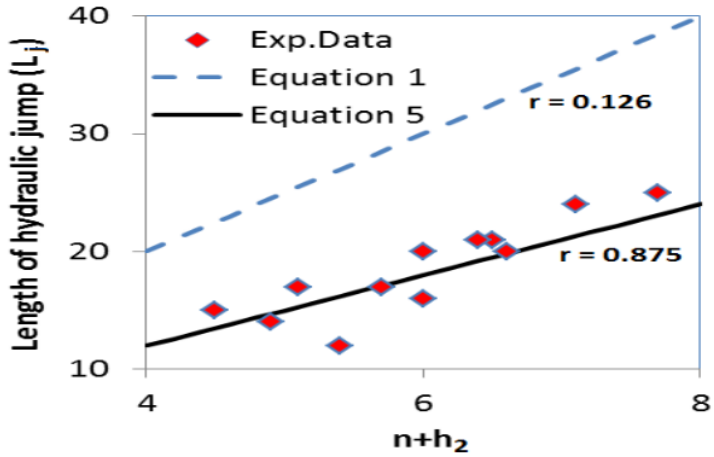

Figure 7 Difference of L_j between Equation (1) and (5)

As mention in the above paragraph that, the hydraulic jump length equations which studied are Equation (2) and (3). The results of the study are Equation (5), (6), (7), and (8). For the next discussion will be continued with compare between a hydraulic jump length equation study results to another. The comparison results can be seen visually in the next figures.

Comparison of Equation (5) to (6)

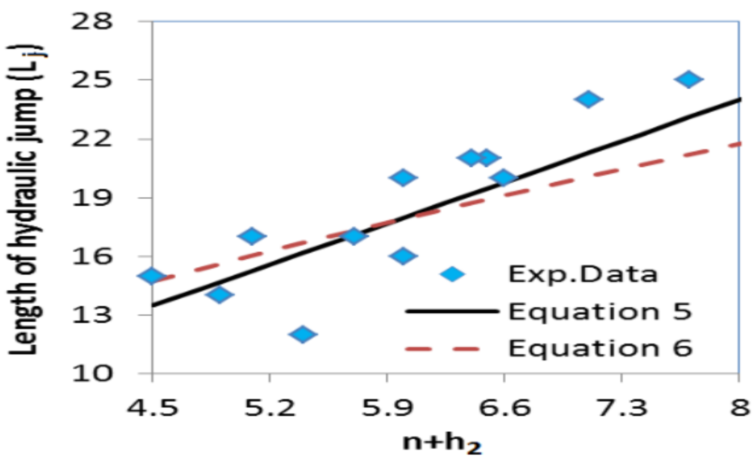

Figure 8 Comparison result of Equation (5) to (6) visually

Figure 8 shows that the Equation (5) closer to the experiment data compares to the Equation (6). From the result of the correlation analysis it was found the correlation coefficient of Equation (5) greater than Equation (6). So that the hydraulic jump length equation with $n+h_2$ variables which appropriate to use in practice is Equation (5).

Comparison of Equation (7) to (8) visually

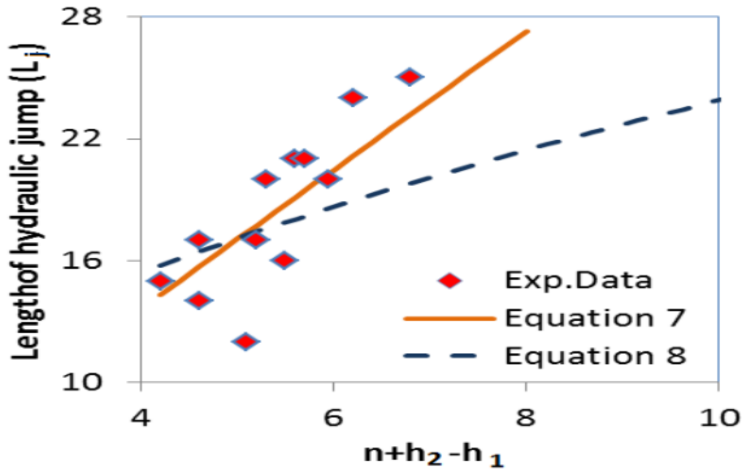

Figure 10 Comparison result of Equation (7) to (8) visually

Figure 10 gives that the Equation (7) nearer to the experiment data compares to the Equation (8). From the result of the correlation analysis it was found the correlation coefficient of Equation (7) bigger than Equation (8). So that the hydraulic jump length equation with $n+h_2 - h_1$ variables which appropriate to use in practice is Equation (7).

Comparison of Equation (5) to (7) visually

The Equations (5) and (7) has the different independent variable. The Equation (5) with $n+h_2$ and the Equation (7) has $n+h_2-h_1$. The two equations give the curve that nearly parallel. In general the L_j values of the Equation (7) are greater than Equation (5). To select the one of the two equations to be utilized in practice, it is recommended to choose based on value of the correlation coefficient (Figure 11).

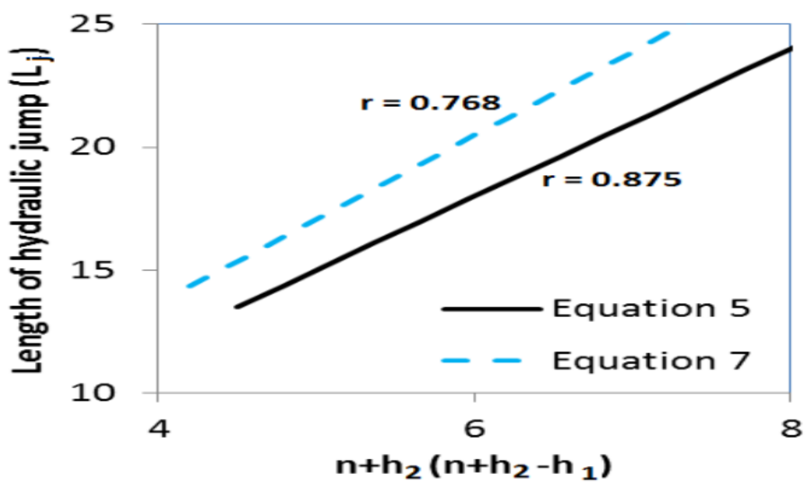

Figure 11 Comparison of Equation (5) and (7) visually

The all of comparison results show that the four equations which have been developed give L_j values that different between the one and another. In equations with independent variable n+h_2 (Figure 8) can be seen that the curves of the function crossing to each other but both closer to the experiment data. In equations with independent variable n+h_2-h_1 (Figure 9) show that the two curves crossing to each other but the one is closer to the experiment data and another not. The study give choice that the equation that appropriate to calculate the hydraulic jump length is Equation (5)

7. CONCLUSION

The above discussion gives a picture that the equation to calculate the hydraulic jump length as basis to design the stilling basin with end-sill has been found. The hydraulic jump length equation which was obtained has the good correlation to the experiment data. Therefore the hydraulic jump length equation result of the study can used in practical purpose.

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 equation to design the stilling basin with end-sill that more accurate.

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