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MODELING OF SEQUENT DEPTH RATIO FOR HYDRAULIC JUMP UNDER SLUICE GATE USING BAFFLE BLOCK AND SILL

*Sunik[1], Rispiningtati [2] Very Dermawan[3] Widandi Soetopo[4] Lily Montarcih Limantara[5]

[1]Faculty of Engineering, Department of Civil Engineering, Widya Karya Catholic University, Indonesia;
[2,3,4,5] Faculty of Engineering, Department of Water Resources Engineering, Brawijaya University, Indonesia

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ABSTRACT: The sequent depth ratio as one variable of hydraulic jump characteristics under sluice gate were studied experimentally using different configurations simulation of baffle block and sill. Experimental research used fiberglass prototype model as horizontal channel, width (B) = 50 cm, length (L) = 9 m and using sluice gate installed on it, width (b) = 50 cm, thick (t) = 1 cm, height (h) = 80 cm. Two models combination of baffle block as cubic (code K, 43 running) and trapezoidal (code T, 72 running) with different dimension installed as three row, specified location 25 cm after sluice gate. During each running test with variation open gate (a = 1,2,3,4 cm), variation type of baffle block (K1, K2, K3; T1, T2, T3, T4), the sequent depth, velocity distribution and Froude number were measured and analyzed. The result showed that the modeling of sequent depth ratio in term of the initial Froude number gives the better performance for cubic baffle block (K3, sill 2 cm and 2.7 cm, Fr = 0.16 - 0.39) with $R^2 = 0.9945$ and trapezoidal baffle block (T4, sill 3.6 cm, Fr = 0.26 – 0.52) with $R^2 = 0.9973$. It concluded that using three rows configuration of baffle block (cubic and trapezoidal baffle block) with value of blockage ratio as 50% was appropriate with USBR standard that value blockage ratio "η" do not exceed 0.5 (depend on the width of the block (Wb), spacing between adjacent blocks (S) and the number of baffle blocks).

Keywords: Baffle block, Hydraulic Jump, Froude Number, Blockage Ratio, Sequent Depth.

1. INTRODUCTION

Sluice gate as one of infrastructure component that usually installation in a channel while operated with certain open gate will raise a hydraulic jump. Hydraulic jump always became flow phenomenon that occurs under the gate. The hydraulic jump was a transition condition from the supercritical flow that will be converted to subcritical flow [1]. To reduce the hydraulic jump conditions or to reach the stable condition usually, it used the additional structure as baffle block that placed in front of the gate with a certain distance to stabilize the jump [9] or using sill [1] that placed at the lower end of the channel (tailwater/downstream depth). Baffle block has an impact on velocity and energy reduction when a hydraulic jump occurs. Sill has an impact on increasing the water level at the downstream end of the channel and causing backwater [14]. Transferring kinetic energy into potential energy occurs while the rapid change in flow considerable by energy dissipation and turbulence [2]. The depth before the jump was called the initial depth (y_1) and after the jump was called the sequent depth (y_2).

Sequent depth ratio (y_2/y_1) was one of hydraulic jump characteristic beside other as length of jump ratio (L_j/y_1), roller length ratio (L_r/y_1) and energy dissipation ratio ($\Delta E/E_1$). Belanger [3]-[7] presented the sequent depth ratio (y_2/y_1) and can be written as:

$$\frac{y_2}{y_1} = \frac{1}{2} \times (\sqrt{1+8F_1^2} - 1) \tag{1}$$

where: y_1 and y_2 refer to upstream and downstream of flow, Fr_1=upstream Froude number, g= gravitational acceleration (m/s^2). Horizontal bed slope will reduced sequent depth ratio [10], [11], [13].

The cubic baffle block generally stated as an effective device while trapezoidal baffle block usually more preferable with respect to width, height, position, and spacing on the channel [8].. United States Department of the Interior Bureau of Reclamation (USBR) recommended that function of block height to determine dimensions and shape of baffle block base on the width and upper longitudinal dimension [8] and it will rise blockage ratio [12]. Blockage ratio present as:

$$\eta = \sum Wb/\sum(Wb+S) \tag{2}$$

where S = clear spacing between the adjacent blocks, Wb = width of the block.

This research aims to analyze modeling of sequential depth ratio between trapezoidal and cubic baffle block that located in front of sluice gate in a channel using prototype model channel test.

2. EXPERIMENTAL WORK

The experimental work for this research has been done in the Laboratory of River Engineering, Water Resource Department, Engineering Faculty, Brawijaya University, Malang, Jawa Timur, Indonesia.

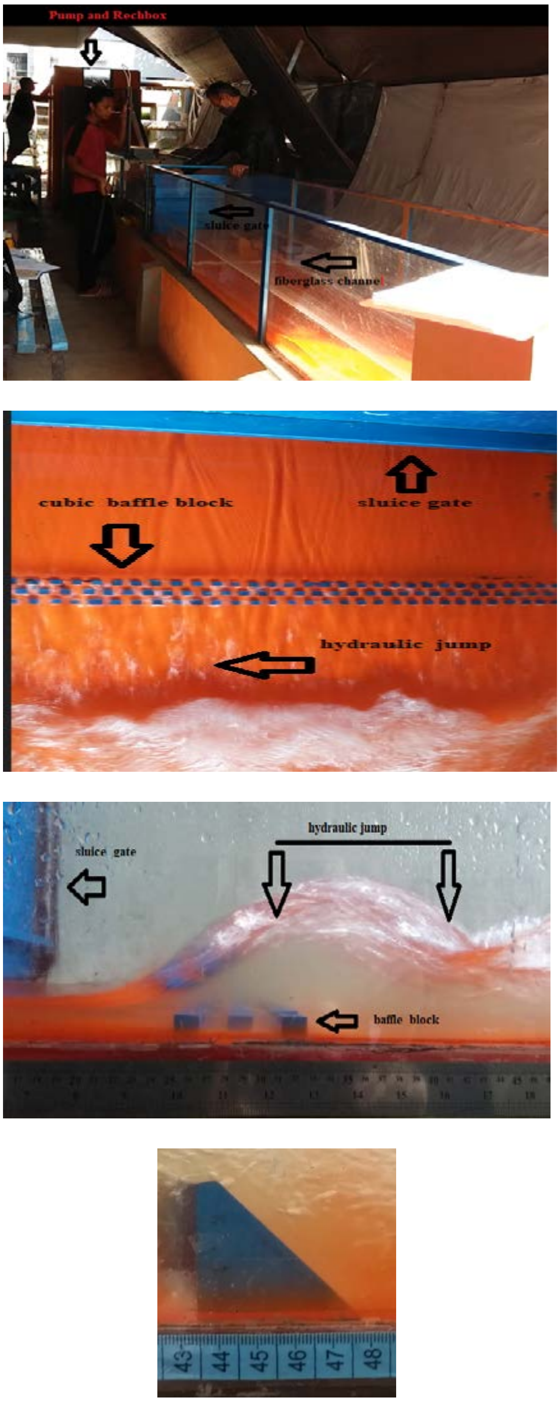

Fig 1. Model prototype, baffle block configuration and a sketch of hydraulic jump (source: primary data)

Table 1 Configuration dimension of cubic and trapezoidal baffle block

No	Model Baffle Block	Type	Run	(b_b) mm	(l_b) mm	(h_b) mm
1	K	K1	19	7	7	7
		K2	16	14	14	14
		K3	8	21	21	21
2	T	T1	12	7	7	7
		T2	12	14	14	14
		T3	8	21	21	21
		T4A	10	28	28	28
		T4B	10	28	28	28
		T4C	10	28	28	28
		T4D	10	28	28	28

Table 2 Configuration dimension of sill for the channel

No	Model Baffle Block	Type	Sill type	(hs) (cm)
1	K	K1	s_1,s_2,s_3	no sill; 2 and 2.7
		K2	s_2,s_3	2 and 2.7
		K3	s_2,s_4	2 and 2.7
2	T	T1	s_1,s_3	no sill; 2.7
		T2	s_1,s_2,s_3	no sill; 2 and 2.7
		T3	s_2,s_3	2 and 2.7
		T4A	s_4	1.5
		T4B	s_2	2
		T4C	s_3	2.7
		T4D	s_5	3.6

Source: primary data

The model prototype that used to running flow as horizontal channel made from fiberglass, width (B) = 50 cm, length (L) = 9 m, with sluice gate placed on it, width (b) = 50 cm, thick (t) = 1 cm, height (h) = 80 cm, using added device (baffle block and sill) as energy dissipator, present in Figure 1.

Configuration dimension of cubic (K) and trapezoidal (T) baffle block as type of K1, width (b_{b1}) = 7 mm, length (l_{b1}) = 7 mm and height (h_{b1}) = 7 mm; type of K2, width (b_{b2}) = 14 mm, length (l_{b2}) = 14 mm and height (h_{b2}) = 14 mm, type of K3, width (b_{b3}) = 21 mm, length (l_{b3}) = 21 mm and height (h_{b3}) = 21 mm; type of T1, width (b_{b4}) = 7 mm, length (l_{b4}) = 7 mm, height (h_{b4}) = 7 mm; type of T2, width (b_{b5}) = 14 mm, length (l_{b5}) = 14 mm, height (h_{b5}) = 14 mm; type of T3, width (b_{b6}) = 21 mm, length (l_{b6}) = 21 mm, height (h_{b6}) = 21 mm; type of T4A-T4B-T4C-T4D, width (b_{b7}) = 28 mm, length (l_{b7}) = 28 mm, height (h_{b7}) = 28 mm; Sill placed in downstream channel with dimension width (b_{s1}) = 50 cm, length (l_s)= 1 cm, height (h_{s1}, h_{s2}, h_{s3}, h_{s4}, h_{s5} = no sill, 2 cm, 2.7 cm, 1.5 cm and 3.6 cm. Variation of open gate (a) = 1 cm, 2 cm, 3 cm, 4 cm).

Ten sets of experiments test present in Table 1 was performed with a total of 115 runs, using cubic and trapezoidal in the cross-sectional shape of baffle blocks (three rows, each baffle block made from fiberglass) mixing with the configuration of sill that placed in downstream as present in Table 2. In each run present in Figure 2, simulation of flow was trial till configuration of the hydraulic jump was perform in stabilized to the desired location of 25 cm downstream from the sluice gate. The depth (y) measured was done in 12 section of flow (1-upstream, 2-under the gate, 3-before baffle block installation, 4-before the jump (the initial depth, y_1), 5-above the baffle block, 6-the end baffle block, 7-after the jump (sequent depth, y_2), 8-end of roller, 9-end of jump, 10-3/4 length before the sill, 11-1/2 length before the sill, 12-1/4 near the sill). Each section measured in left, middle and right part that each part measure in above, middle and bottom of height flow (one section consist of nine measured). The local velocity (v) for 12 section was measured in the same procedure. Value of velocity and the depth will rise the Froude number (Fr_1).

The relation between Froude number, Fr_1 and sequent depth y_2/y_1 was analyzed using regression method [15] to know the influence of Fr_1 against to y_2/y_1. Determination coefficient value was criteria that showed the variable against the response [16] as:

$$R^2 = 1 - (\Sigma\ JKG / \Sigma JKT) \tag{3}$$

where:
Σ JKG = sum of error square
Σ JKT = total sum of squares

Fig 2. Experiment test measurement in 12 section (source: primary data)

3. RESULTS

3.1 Blockage Ratio

This research result shows that the value of the blockage ratio for all type block was 50% present in Table 3.

Table 3 Blockage ratio value

Type Baffle	Wb (mm)	S (mm)	Number of Blocks	η %
K1	7	7	35	50
K2	14	14	17	50
K3	21	21	11	50
T1	7	7	35	50
T2	14	14	17	50
T3	21	21	11	50
T4	28	28	8	50

Source: primary data and analysis

3.2 Sequent Depth Ratio

Sequent depth analysis for cubic and trapezoidal baffle block (115 runs) show in Figure 3 – Figure 5.

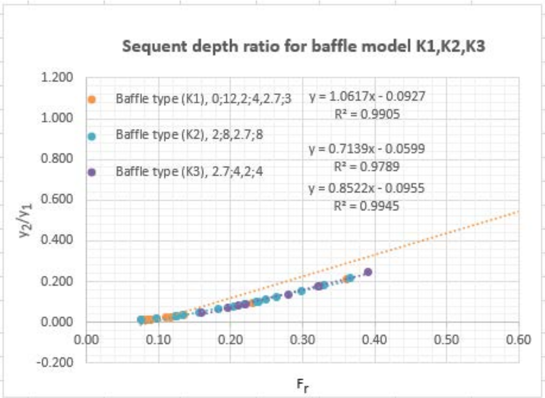

Fig.3 Sequent depth ratio for cubic baffle block model K1,K2,K3 (source: analysis data)

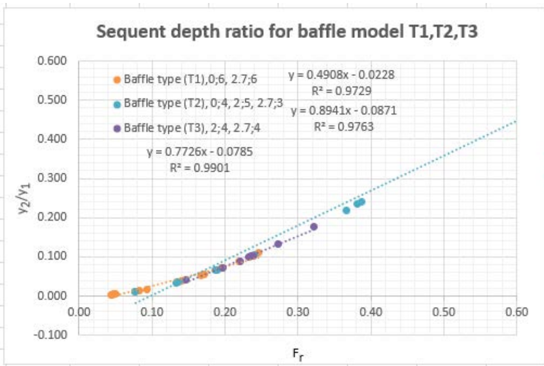

Fig.4 Sequent depth ratio for trapezoidal baffle block model T1,T2,T3 (source: analysis data)

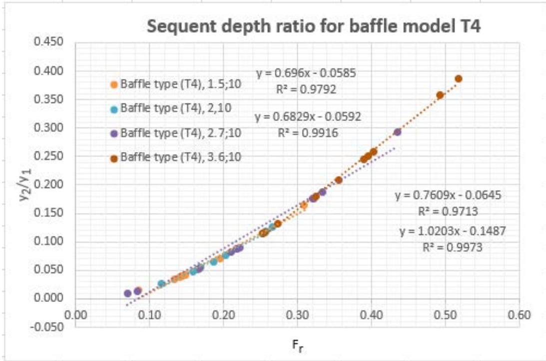

Fig.5 Sequent depth ratio for trapezoidal baffle block model T4 (source: analysis data)

4. DISCUSSION

4.1 Blockage Ratio

Blockage ratio value analysis depends on the width of the block (Wb) and spacing between adjacent blocks (S). Other, the value affected by a number of baffle blocks. USBR recommended that value blockage ratio "η" do not exceed 0.5 [12]. Value blockage ratio for this research (K1, K2, K3, T1, T2, T3, T4) was 50%. It can be concluded that the configuration of baffle block for this research comply the USBR standard for blockage ratio value.

4.2 Sequent Depth Ratio

Recapitulation of modeling sequent depth ratio equation (ten equation) and R^2 value can be seen in Table 4.

Table 4 Modelling of sequent depth ratio equation

No	Type Baffle	Equation	R^2
1	K1	y = 1.0617 x - 0.0927	0.9905
	K2	y = 0.7139 x - 0.0599	0.9789
	K3	y = 0.8522 x - 0.0955	0.9945
2	T1	y = 0.4908 x - 0.0228	0.9729
	T2	y = 0.8941 x - 0.0871	0.9763
	T3	y = 0.7726 x - 0.0785	0.9901
	T4A	y = 0.696 x - 0.0585	0.9792
	T4B	y = 0.6829 x - 0.0592	0.9916
	T4C	y = 0.7609 x - 0.0645	0.9713
	T4D	y = 1.0203 x - 0.1487	0.9973

Source: analysis data

Based on R^2 value, the better performance showed by cubic baffle block (type baffle of K3, used sill 2 cm and 2.7 cm, Fr = 0.16 - 0.39) and R^2 = 0.9945 show by trapezoidal baffle block (type baffle of T4, sill 3.6 cm, Fr = 0.26 – 0.52) with R^2 = 0.9973, so the equation represent as:

Cubic, $y_2/y_1 = 0.8522\ Fr_1 - 0.0955$

Trapezoidal, $y_2/y_1 = 1.0203\ Fr_1 - 0.1487$

All R^2 value range in 0.97 – 0.99 almost to 1 value for determination coefficient. It means that there is a strong relation between value Fr_1 to sequent depth ratio (value of Fr_1 affected the sequent depth ratio value, while Fr_1 depend on velocity (v) and depth of water (y_1))

5. CONCLUSION

The configuration of baffle block for research should be referred to comply the USBR standard for blockage ratio value while USBR standard that value blockage ratio "η" do not exceed 0.5 (depend on the width of the block (Wb), the spacing between adjacent blocks (S) and a number of baffle blocks).

Trapezoidal baffle block gave determination coefficient value (R^2 = 0.9973) better than cubic baffle block. It represents sequent depth ratio against to Froude number value that depends on to sill dimension and distance between the block.

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