Contraction Coefficient (Cc) Characteristic for Flow Under Sluice Gate using Trapezoid Baffle Block and Sill

by Sunik Sunik

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SUNIK SUNIK

Lecturer, Widya Karya Catholic University, Indonesia

ABSTRACT

Laboratory experiment was development to know contraction coefficient (Cc) characteristic for the flow under sluice gate while it operated with variation discharge and open gate using trapezoid baffle block withsill. Prototype model as horizontal channel used sluice gate installed on it made from fiberglass. Dimension of horizontal fiberglass channel: length (L) = 9 m, width (B) = 50 cm; sluice gate dimension, height (h) = 80 cm, thick (t) = 1 cm, width (b) = 50 cm. Variation of discharge (Q) and open gate (a = 1,2,3,4 cm) make the flow rise the contraction coefficient (Cc). Models of baffle block as trapezoid (Bb = 2.8 cm) installed as three row, specified location 25 cm after sluice gate using end sill (code T4-A, 10 running; code T4-B, 10 running; T4-C, 10 running; T4-D, 10 running). The height of flow (h) and velocity (v) were measured during each running test then Froude number and contraction coefficient (Cc) were analyzed. The result showed that trapezoid baffle block model T4-A (28 cm x 28 cm x 28 cm) (Fr = 0.12 - 0.50) gives the better performance modelling of Cc in term of the initial Froude number with R^2 = 0.9186, Ls_1, Ls_2 = 32 mm, L_2 = 100 cm. It was concluded that using three rows configuration of trapezoid baffle block with T4-A model gave better model than T4-B, T4-C, T4-D.

Keywords : *Trapezoid baffle block, sill, Froude number, contraction coefficient*.

1. INTRODUCTION

Sluice gate as one of infrastructure in hydraulic network while the gate operated, the flow under sluice gate will raise contraction coefficient (Cc). Placement sluice gates in channel to control and rises water level have been used as a hydraulic structure commonly. The discharge through a sluice gate is affected by the upstream flow depth for free flow (Henderson, 1966). To reach the stable condition and reduce the energy cause by hydraulic jump that occur, usually added structure will be placed in front of the gate. Adding structure usually use baffle block (Chaudry, 2008) that placed in front of the gate with certain distance will reduction velocity and energy when a hydraulic jump occurs and or using sill (Raju, et al, 1980) that placed atthe lower end of channel (tailwater/downstream depth) will increasing the water level at the downstream end ofthe channel.

Many experiment have been made to research free flow through the sluice gate to get some characteristics of contraction and discharge coefficient, done by some researcher as Abdulaziz (1997), Betts (1978), Belaud (1943), Dabral (2014), Fangmeier et.al (1967), Habibzadeh (2011), Isaacs (1977), Jung-Fu Yen (2001), Lauria (2020), Masliyah, et. al (1985) Mohammed, et.al (2013), Montes (1997), Nago (1978), Noutsopoulos, et.al (1978), Oskuyi, et.al (2011), Rajaratnam, et.al (1967), Rajaratnam (1977), Roth, et.al (1999), Sadeghfaam (2012), Shayan (2014), Sunik (2001, 2019, 2020), Swami (1990), Yen, et. al (2001) had been investigated about contraction coefficient and coefficient discharge for flow under sluice gate.

Contraction coefficient (Cc) define as the ratio of water depth at vena contracta, y_2 to gate opening defined as contraction coefficient (Cc). In this research, flow behavior under sluice gate is simulated, contraction coefficient (Cc) was analyze.

Henderson (1966) derived equation to compute Cd for free flow as $\eta = (Cc.\ b)/y_1$, $Cc = y_2/b$.

Scope of the Research

This research focuses to analyze equation modelling of Cc with one models of trapezoid baffle block (T4-A, T4- B,T4-C,T4-D) that located in front of sluice gate in three rows using prototype model channel test.

Objectives

The main objectives of this research are:

1. Analyze Froude number (Fr) that rise while sluice gate operating with different open gate (a) and discharge (Q),
2. Analyze contraction coefficient (Cc) that rise while trapezoid baffle block combined in front of the gate,
3. Analyze equation each model and compare which one more better than the other to use.

2. EXPERIMENTAL WORK

These experimental was development from earlier research (Sunik, 2001, 2019, 2020). Configuration about experiment laboratory explain below as seen in Figure 1. The channel after the sluice gate separated into 12 section for measurement. Running measurement for water depth (y)and velocity (v) each running implemented in 12 section. The prototype model as horizontal channel made from fiberglass (used for trial running flow, with dimension as width (B) = 50 cm, length (L) = 9 m). Sluice gate placed on it with dimension, width (b) = 50 cm, thick (t) = 1 cm, height (h) = 80 cm, using added device (trapezoid baffle block and sill) as energy dissipator, present in Figure 1.

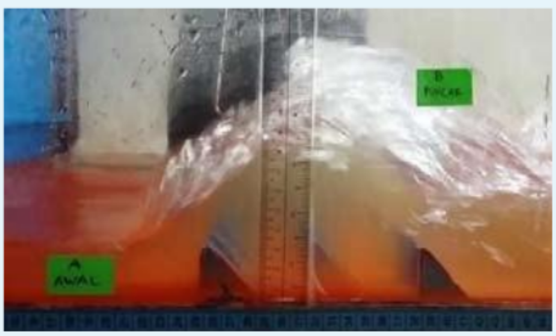

Fig. 1 : Trapezoid baffle block configuration in front of sluice gate

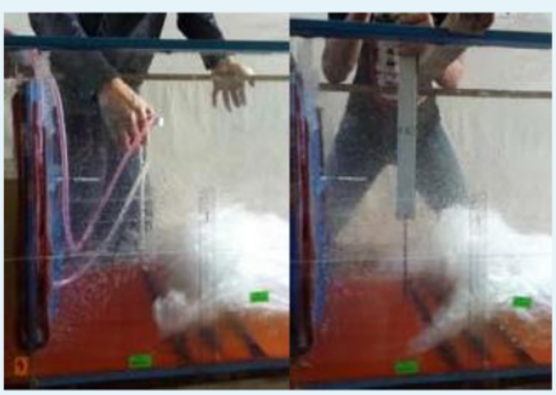

Fig. 2 : Water depth and velocity measurement for 12 section

Table 1 : Configuration dimension of trapezoid baffle block

No	Model Baffle Block	Type	Run	(b_b) mm	(l_b) mm	(h_b) mm
1	T4	T4-A	11	28	28	28
		T4-B	11	28	28	28
		T4-C	11	28	28	28
		T4-D	11	28	28	28

Table 2 : Configuration dimension of sill for the channel

No	Model Baffle Block	Type	Sill type	(hs) (cm)
1	T4	T4-A	s_1,s_2, s_3,s_4	1,5; 2; 2.7; 3,6
		T4-B	s_1,s_2, s_4	1,5; 2; 3,6
		T4-C	s_1,s_2, s_3,s_4	1,5; 2; 2.7; 3,6
		T4-D	s_1,s_2, s_3,s_4	1,5; 2; 2.7

Configuration dimension of trapezoid (T4-A, T4-B, T4-C, T4-D) baffle block type, width (b_b) = 28 mm, length (l_b) = 28 mm and height (h_b) = 28 mm. Sill placed in downstream channel with dimension width (b_{s1}) = 50 cm, thick (t_s)= 1 cm, height (h_{s1}, h_{s2}, h_{s3}, h_{s4} = 1.5 cm, 2 cm, 2.7 cm, 3.6 cm). Variation of open gate (a) = 1 cm, 2 cm, 3 cm, 4 cm.

Four set of experiments test with a total of 44 run, using trapezoid baffle block in cross sectional (three rows, each baffle block made from fiberglass) mixing with configuration of sill that placed in downstream present in Table 1 and Table 2. Simulation of flow for each run was trial till configuration of hydraulic jump was perform in stabilized to the desire location of 25 cm downstream from the sluice gate present in Figure 2. Measurement for depth (y) and velocity (v) of each flow 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). One section consist of nine measured consist of left, middle and right part that each part measure in above, middle and bottom of depth flow. The Froude number (Fr) affected by value of velocity and the depth.

Relation between contraction coefficient (Cc) and Froude number (Fr) was analyze using regression method (Nawari, 2007) to know influence of Fr against to Cc. Determination coefficient value that showed the variable against to the response (Sembiring, 1995) as:

$$R^2 = 1 - (\Sigma\ JKG / \Sigma JKT) \quad ...(1)$$

where:

Σ JKG = sum of error square

Σ JKT = total sum of squares

3. RESULT

3.1 Contraction Coefficient (Cc)

Correlation result between Froude number and contraction coefficient model T4-A, T4-B, T4-C, T4-D show in Figure 3; value of Cc present in Table 3, Table 4, Table 5 and Table 6.

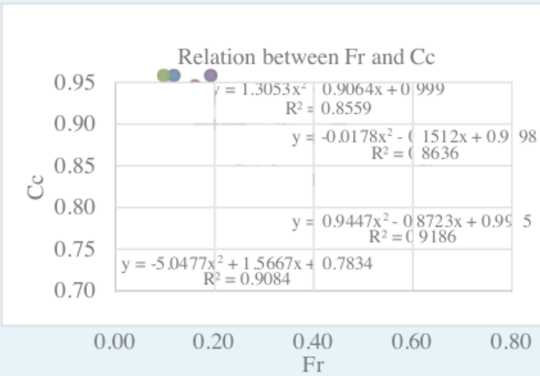

Fig. 3 : Contraction coefficient (Cc) for trapezoid baffle block model T4-A, T4-B, T4-C, T4-C, T4-D

Table 3 : Value of Contraction Coefficient (Cc) for T4-A model

No	Run	Type	Q (l/s)	a (cm)	sill (cm)	Fr	Cc
1	167	T4-A	23.20	3	1.5	0.27	0.83
2	168	T4-A	20.71	4	1.5	0.12	0.93
3	169	T4-A	14.65	3	1.5	0.14	0.88
4	171	T4-A	18.32	4	1.5	0.13	0.90
5	172	T4-A	17.74	3	2	0.25	0.87
6	173	T4-A	22.26	3	2	0.17	0.87
7	174	T4-A	24.80	4	2.7	0.25	0.83
8	175	T4-A	24.80	3	3.6	0.50	0.80
9	176	T4-A	24.80	3	2.7	0.42	0.80
10	177	T4-A	29.13	4	3.6	0.40	0.80

Table 4 : Value of Contraction Coefficient (Cc) for T4-B model

No	Run	Type	Q (l/s)	a (cm)	sill (cm)	Fr	Cc
1	126	T4-B	8.40	1	2	0.71	0.80
2	127	T4-B	13.05	2	2	0.33	0.85
3	125	T4-B	16.88	3	2	0.09	0.90
4	128	T4-B	20.71	4	2	0.14	0.90
5	150	T4-B	26.11	4	3.6	0.29	0.88
6	151	T4-B	21.64	3	3.6	0.45	0.87
7	154	T4-B	20.11	4	2	0.16	0.91
8	155	T4-B	16.88	3	2	0.23	0.87
9	156	T4-B	14.65	3	1.5	0.17	0.90
10	157	T4-B	18.03	4	1.5	0.12	0.90

Table 5 : Value of Contraction Coefficient (Cc) for T4-C model

No	Run	Type	Q (l/s)	a (cm)	sill (cm)	Fr	Cc
1	146	T4-C	19.81	4	2	0.10	0.93
2	158	T4-C	17.74	4	1.5	0.12	0.90
3	159	T4-C	20.71	4	2	0.17	0.89
4	160	T4-C	16.88	3	2	0.19	0.87
5	161	T4-C	14.65	3	1.5	0.13	0.90
6	162	T4-C	26.44	4	3.6	0.24	0.85
7	163	T4-C	23.68	3	2.7	0.32	0.83
8	164	T4-C	23.68	4	2.7	0.20	0.90
9	165	T4-C	23.20	4	3.6	0.24	0.85
10	166	T4-C	23.20	3	3.6	0.40	0.85

Table 6 : Value of Contraction Coefficient (Cc) for T4-D model

No	Run	Type	Q (l/s)	a (cm)	sill (cm)	Fr	Cc
1	132	T4-D	21.02	4	2	0.14	0.90
2	133	T4-D	17.16	3	2	0.15	0.90
3	134	T4-D	23.68	4	2.7	0.19	0.93
4	135	T4-D	19.81	3	2.7	0.26	0.83
5	137	T4-D	18.76	4	2.7	0.11	0.90
6	140	T4-D	23.20	4	1.5	0.18	0.90
7	152	T4-D	21.64	3	2.7	0.30	0.80
8	153	T4-D	23.52	4	2.7	0.15	0.90
9	145	T4-D	14.65	3	2	0.17	0.90
10	147	T4-D	16.59	3	2	0.17	0.90

3.2 Froude Number (Fr)

Correlation result between Froude number (Fr) and contraction coefficient (Cc) using regression method show as:

No	Type	Equation	R^2
1	T4-A	y = 0.9447 x2 - 0.8723 x + 0.9995	0.9186
2	T4-B	y = - 0.0178 x2 - 0.1512 x + 0.9198	0.8636
3	T4-C	y = 1.3053 x2 - 0.9064 x + 0.9990	0.8559
4	T4-D	y = - 5.0477 x2 + 1.5667 x + 0.7834	0.9084

4. DISCUSSION

4.1 Contraction Coefficient (Cc)

In all type combination of trapezoid baffle block with sill, the value of Cc was below 1 (range value 0.80 – 0.93) while benchmark usually for free flow was based on the conformal mapping method $(\pi/(\pi+2)) \approx 0.611$ (in Belaud, 2009), it means the series dan rows of baffle block that installed affected the Cc value going to increased. Value Cc reach 0.93 while open gate was 4 cm combination with sill 1.5 cm

with smallest value for Fr as 0.12 (sub critic). The Cc value will decrease while height of sill was rises (2.7 cm and 3.6 cm). Based on R^2 value, the better performance showed by trapezoid baffle block type T4-A with open gate 3 cm and 4 cm with Fr = 0.12 - 0.50, the equation present as:

$$y = 0.9447x^2 - 0.8723x + 0.9995, R^2 \text{ value} = 0.9186$$

The value R^2 close to 1 for determination coefficient. It means that a strong relation between value Fr to contraction coefficient had present (value of Cc influenced by Fr, while Fr depend on velocity (v) and depth of water (y)). Adding device i.e sill at the channel influenced velocity of flow, affected to Cc value.

4.2 Froude Number (Fr)

In type T4-A model, range of Fr value was 0.12 – 0.50 (sub critic); T4-B model, range of Fr value was 0.09 – 0.71 (sub critic); T4-C model, range of Fr value was 0.10 – 0.40 (sub critic); T4-D model, range of Fr value was 0.11 – 0.30 (sub critic). While open gate being increase, Fr value tend to decrease and Cc value tend to increase. The velocity value affected the Fr value. While the velocity flow held by baffle block, it will decrease so the Fr value became decrease too.

5. CONCLUSION

Installing trapezoid baffle block in front of the sluice gate paired with sill at the end of the channel with matched composition (configuration dimension of block, width of the block, number of baffle block and spacing between block) will gave better performance of Cc (value < 1). It concluded that trapezoid baffle block model T4-A (2.8 cm) combine with four model of sill (1.5 cm, 2 cm, 2.7 cm and 3.6 cm) gave better performance for Cc and Fr value (determination coefficient $R^2 = 0.9186$) than model T4-B, T4-C and T4-D.

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Charge of Secretary, Central Board of Irrigation & Power being handed over to Dr. G.P. Patel by Shri V.K. Kanjlia, the out going Secretary of the Board, on 29th May 2020

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