DEVELOPMENT OF FIBERGLASS WATER GATE OPERATION MODEL

Ahmad Tusi[1], B.I.Setiawan[2], M. Amron[3], Hanhan A.S[4]

Abstract

Proper gate opening depends on the gate type, desired discharge, water level upstream and downstream of the gate, etc. thus, the determination of gate opening is a complicated work. A Fiberglass water gate operation model was formulated in this study to help engineers and farmers especially for operating the complicated irrigation canal regulators. The fiberglass gate with an half round shape in the bottom has contraction coefcient (C_c) = 0.951, and a value of dischage coeficient (C_d) can be determined by $C_d = C_c . \left(\frac{h_1 - w}{h_1 + k_0 . w} \right)^{k_1}$ *;* with k_0 = 15 and k_1=0.062 or by nomogram for free flow condition. In Operation level, it will help farmers to know how much water that enters to their farm and manage their water with better. The gate has width 50 cm and diameter of round shape of 20 cm.

Keywords: Fiberglass, water gate, discharge coeficient, fibre-concrete, operation

Summary and Conclusion

One important problem in the actual operation of canal system is determination of the gate opening in order to control the desired discharge to the desired area. However, most of the existing water gates in Indonesia was made of iron or/and wood. Both materials are relatively easy to rusted, damaged or decayed and also attractive to be stolen, and then they affected to delivery performance ration in irrigation canal. The objective of this research are (1) to develop the fiberglass gate operation model and make a curve or equation for determination of gate opening; (2) to test the accuracy and reliability of the gate operational.

The fiberglass gate was designed having two functions, i.e. water regulator and measurement. It has three different parts of functions, namely: (1) handle, door handle for the function to raise and lower the door, (2) leaves of the gate, serves to restrain the flow of water, and (3) an half round shape, serves to increase the value of discharge coefficient (C_d) approaches the value 1. This round shape is made with knock down system with a diameter of 20 cm. Testing models of fiberglass gate was conducted in the lab. Hydraulics, Irrigation Agency, Bekasi and field tests performed on a single building at B. CMK 23 in Cimanuk Irrigation Area, Garut. Hydraulic testing and calibration of water flow which occurred under the gate (undershot) is taken to the gate with a width of 50 cm effective.

[1] Graduate Student, Dept. Civil and Environmental Engineering, Bogor Agricultural University (IPB)
- Lecturer, Dept. Agricultural Engineering, the University of Lampung (email : atusi@unila.ac.id)
[2] Prof., Dept. Civil and Environmental Engineering, Bogor Agricultural University (IPB)
[3] Director General of Water Resources, Ministry of Public Works Republic of Indonesia
[4] Staff of Experimental Station for Irrigation, Center for Water Resources Research and Development, Research and Development Agency, Ministry of Public Works Republic of Indonesia.

The gate mounted in a channel with a channel 60 cm high and 50 cm wide channel. Weir found at the bottom of the gate with a height of 10 cm from the bottom of the channel.

Data collection was performed at three different locations, namely upstream, near/right gate, and downstream from the gate. The parameters that were used a high-water flow and an opening of the gate at these locations. Measurement using a ruler with 1 mm accuration level. Opening the gate was conducted from 1-11 cm, with flow conditions in free flow. Determination of flow and flow rate using the formula developed by Swamee (1992) and discharge calculation using the classical equation. As a comparison (calibrator) analysis using the formula, then mounted Standard Suppressed Rectangular Weir tool (Rehbock).

Predicted flow rate under the fiberglass gate with Swamee method is quite good, with values nearing discharge data calibrator. This is evidenced by the performance index value of these fiberglass gate, that is, calculating the Root Mean Square Error (RMSE) is about 5.68 l/s and Mean Absolute Percentage Error (MAPE) about 5.441 percent. According to Clemmens *et al.* (2003), the value of measurement error in the discharge of the general condition of free flow of $\pm$ 5 percent, whereas for Submerged flow conditions is more than 50 percent. Therefore, the results of calibration and testing of fiberglass gate with a width of 50 cm for free flow conditions are acceptable and reasonable.

The fiberglass gate with an half round shape in the bottom has contraction coefcient (C_c) = 0.951, and a value of dischage coeficient (C_d) can be determined by $C_d = C_c \cdot \left(\frac{h_1 - w}{h_1 + k_0 . w} \right)^{k_1}$; with k_0 = 15 and k_1=0.062 or by nomogram for free flow condition. In Operation level, it will help farmers to know how much water that enters to their farm and manage their water with better. The gate has width 50 cm and diameter of round shape of 20 cm.

Keywords: Fiberglass, water gate, discharge coeficient, fibre-concrete, operation

INTRODUCTION

To perform their function efficiently, irrigation canal must be managed appropriately; that is, the control structures need to be operated in such a way that the canals execute their functions adequately. In most cases, this requirement can be translated into a water level control problem.

In Indonesia with total national irrigation area about 7.4 million ha (KEPMEN PU No. 390/KPTS/M/2007), water level control in canal usually use water level and discharge regulator. The control of water distribution in manually operated canal networks in entirely left to the staffs. Many canal systems may have more than 100 water level and discharge regulator. Operating one regulator (water gate) will effect both upstream and downstream water level condition, particularly when the gates are operated under submerged condition. One important problem in the actual operation of canal system is determination of the gate opening in order to control the desired discharge to the desired area. However, most of the existing water gates in Indonesia was made of iron or/and wood. Both materials are relatively easy to rusted, damaged or decayed and also attractive to be stolen. It was proved with actual condition of the divison structure condition at Cimanuk Irrigation Area (CIA). There are almost 60 percent the gates condition in damage condition because of corrotion and stolen. This case not only in CIA but also in others irrigation area in Indonesia (www.wawasandigital.com,23/07/2009;www.kompas.com,08/02/2009;www.newspaper.pikiranrakyat.com,22/06/2009). The damaged gate on a division structure will effect to performance of water delivery in canal. Based on calculation of delivery performance ratio (Bos, 2005) in CIA shows an exesive water about 45.8 percent , 33.3 percent inadequate supply, and other was adequate supply.

Proper gate opening depends on the gate type, desired discharge, water level upstream and downstream of the gate, etc. thus, the determination of gate opening is a complicated work. Any irrigation projects that do not give attention to this issue, may have problems on water delivery and distribution. It will directly effect the irrigation and water delivery performance of the poject and also the irrigation efficiency.

Calculating the discharge under a sluice gate is not a trivial matter. In theory, the sluice flow rate formula can be accurately obtained if the contraction coefficient is known (Henderson, 1966). Unfortunately, the contraction coefficient varies with : the amount of gate opening, shape of the gate lip, upstream water depth, gate type and so forth (Lin *et al*., 2002). Thus, it is very difficult to know its true value for all operating condition in practice. That is way there are other approach that combine some theoretical and some practical knowledge in order to simplify the operational of the gate. The objective of this research are (1) to develop the fiberglass gate operation model and make a curve or equation for determination of gate opening; (2) to test the accuracy and reliability of the gate operational.

MATERIALS AND METHODS

Fiberglass Water Gates Model

Design Mix of Fiberglass

The thickness of the sample planned 12 mm. Composition of water gate made of fiberglass are made using glass fiber material (coarse and fine) with a type of woven rovings (WR) and chopped Strand Mat (CSM) with a weight of 450 and 300 gr/m^2. The number of layers of WR and CSM are 7 and 4. Glass fiber placement arranged symmetrically with the bond angle is 90˚ for WR and CSM with a random pattern, so that the door has the power evenly distributed in all parts of the door.

The composition of the mixture of polymer for manufacturing of fiberglass are: two kinds of resin, polyester resin type orthopthaltyc (157 Yukalac BQTN EX-Series) and isopthaltyc polyester resin (PERDIC) is commonly used to manufacture components of a boat with a ratio of 40: 60 , catalyst, cobalt (accelarator), erosil (filler) and a color pigment.

Testing Samples

Tests were carried out using JIS (Japan Industrial Standard), i.e. tensile, flexural test using a JIS standard (JIS A 1106 to 1964, Reaffirmed 1968) with the Universal Testing Machine (UTM) equipped with a capacity of one ton and the proving ring to measure deflection that had happen every millimeter. Calculation of flexural strength using the following formula:

$$\sigma_b = \frac{P\,L}{b\,d^2}\,x1000 \qquad /1/$$

where, σ_b (flexural strength, kg/cm2), P (maximum pressure from machine, tons), L (distance of span, cm), b (width of sample, cm), d (sample thickness, cm).

Dimension of Sample was 650 mm x 150 mm x 12 mm with two replication. The mold of sample was made with multiplex. Then create a composition of resin mixture (polymer) to the mold casting process that has been created. Prior to the foundry, glass and mirrors give PVA to make it easier when you remove the sample from the mold after completion.

Fiberglas Water Gate Design

The gate was designed having two functions, i.e. water regulator and measurement. It has three different parts of functions, namely: (1) handle, door handle for the function to raise and lower the door, (2) leaves of the gate, serves to restrain the flow of water, and (3) an half round shape, serves to increase the value of discharge coefficient (C_d) approaches the value 1. This round shape is made with knock down system with a diameter of 20 cm. This gate can be driven manually or with mechanical systems. Here is a picture of fiberglass gate.

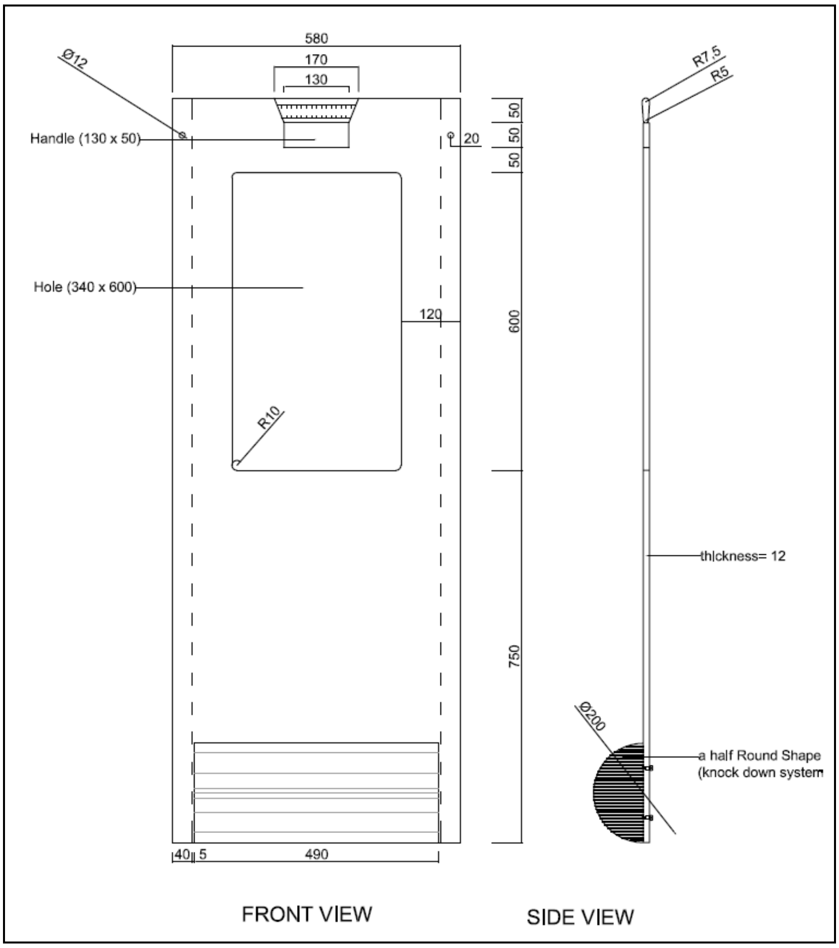

Figure 1. Fiberglass Water Gate Model

Theoretical Background of Steady State Gate Operation Model

It is very important to remark the existence of two particular working flow conditions when dealing with sluice gate : (1) the free flow condition, and (2) the submerged flow condition. Both conditions are sketched in figure 2.

To determine whether the jump will be free or submerged is another problem. In this respect, there are several formulas that have been obtained theoretically or empirically by many researchers. Because this topic is out of the scope of this work, the following simple condition presented in Swamee (1992) was used when needed to distinguish both working flow conditions :

Free flow : $h_1 \geq 0.81 h_3 \left(\frac{h_3}{l} \right)^{0.72}$ /2/

Submerged flow : $h_3 < h_1 < 0.81 h_3 \left(\frac{h_3}{l} \right)^{0.72}$ /3/

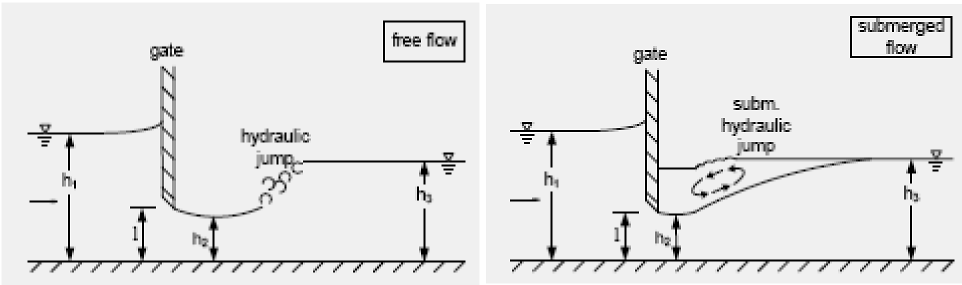

Figure 2. Sketch of Free Flow and Submerged Flow

Classical Theoretical Formulation

The most common flow rate expression makes use of the conservation energy, mass, and momentum in the sluice gate – hydraulic jump flow. This procedure yields the following equation :

$$Q = C_d \; l \; b \sqrt{2 g h_1} \qquad /4/$$

In equation 2, 3, and 4, *l* is the gate opening, *b* is the gate width, h_1 is the upstream water level and h_3 is the downstream water level. In this context, the discharge coefficient C_d is given by two equations (one for each flow condition), functions of the contraction C_c, b, h_1 and, for the submerged condition, the downstream water level h_3 :

Free Flow : $$C_d = \frac{C_c}{\sqrt{1+\eta}} \qquad /5/$$

Submerged Flow : $$C_d = C_c \frac{\left[\xi - \sqrt{\xi^2 - \left(\frac{1}{\eta^2} - 1\right)^2 \left(1 - \frac{1}{\lambda^2}\right)}\right]^{1/2}}{\frac{1}{\eta} - \eta} \qquad /6/$$

Where $\eta = C_c b / h_1$, $\xi = (1/\eta - 1)^2 + 2(\lambda - 1)$ and $\lambda = h_1/h_3$

Empirical Discharge Calculation Method

Swamee (1992), they obtained discharge coefficient equations for equation 4, perfoming non linier regression on Henry's nomogram (figure 3). For both hydraulic conditions they obtained :

Free Flow : $$C_d = 0.611 \left(\frac{h_1 - l}{h_1 + k_0 l}\right)^{k_1} \qquad /7/$$

Submerged Flow : $$C_d = 0.611 \left(\frac{h_1 - l}{h_1 + k_0 l}\right)^{k_1} \left(k_2 \left(\frac{k_3 h_3 \left(\frac{h_3}{l}\right)^{k_4} - h_1}{h_1 - h_3}\right) + 1\right)^{-k_6} \qquad /8/$$

Where k_0, k_1, …., k6 are constants with the following values : $k_0 = 15$, $k_1 = 0.072$, $k_2 = 0.32$, $k_3 = 0.81$, $k_4 = 0.72$, $k_5 = 0.7$ and $k_6 = 1$.

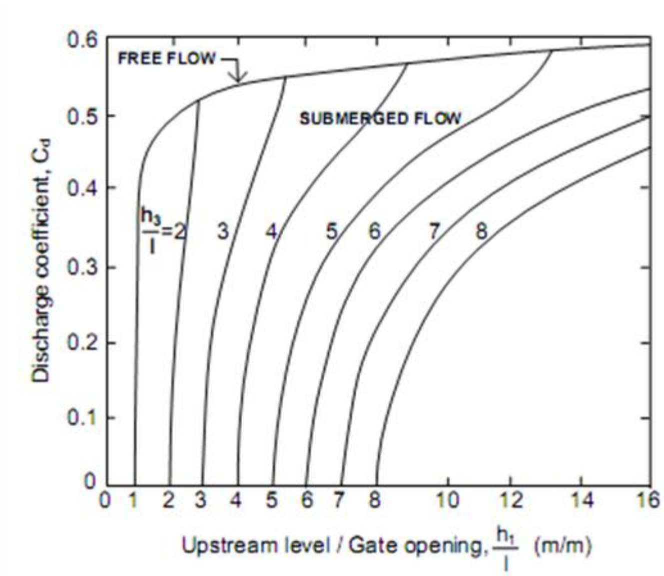

Figure 3. Henry's Nomogram

Model Calibration and Verification

Testing models of fiberglass gate made in the lab. Hydraulics, Irrigation Agency, Bekasi and field tests performed on a single building at B. CMK 23 in Cimanuk Irrigation Area, Garut. Hydraulic testing and calibration of water flow which occurred under the door (undershot) is taken to the gate with a width of 50 cm effective door. The door mounted in a channel with a channel 60 cm high and 50 cm wide channel. Weir found at the bottom of the door with a height of 10 cm from the bottom of the channel (Figure 4).

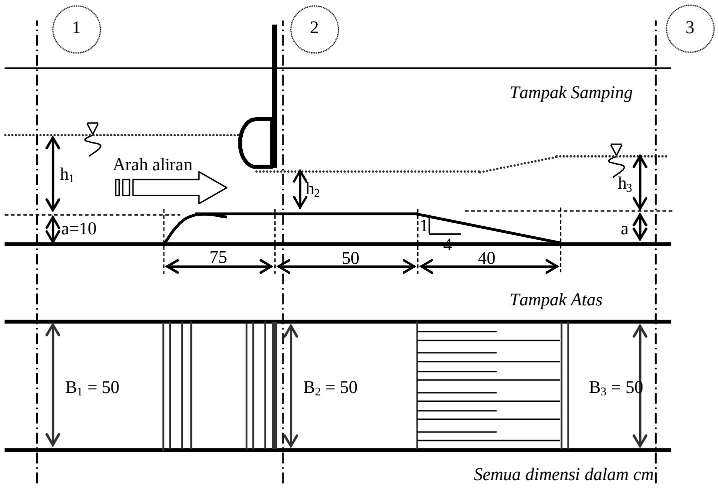

Figure 4. Model Structure Used in Experiment

Data collection was performed at three different locations, namely upstream, near/right door, and downstream from the gate. The parameters that were used a high-water flow and an opening of the gate at these locations. Measurement using a ruler with 1 mm accuration level. Opening the gate was conducted from 1-11 cm, with flow conditions in free flow.

Determination of flow using the formula developed by Swamee (1992) as in equations 2 and 3. .

Calculation of flow rate from the door were analyzed using equations 7 and 8 with a discharge calculation using the classical equation (Equation 4). As a comparison (calibrator) analysis using the formula, then mounted Standard Suppressed Rectangular Weir tool (Rehbock) rectangular with a width of 36 cm. This tool is installed in the lower reaches of the gate, while the water level observations at the downstream performed at a distance of 100 cm from the Rehbock. Here is the equation of these tools:

$$Q = \tfrac{2}{3}\mu \ L \ H\sqrt{2gH} \quad \text{..........(9)}$$

where:

Q = discharge m^3/sec
L = width threshold, m
H = elevation difference between the threshold of the water surface, m
μ = coefficient of discharge

Discharge coefficient measuring instrument is computed using the formula:

$$\mu = 0{,}615\left(1+\frac{1}{H+1{,}6}\right)\left[1+0{,}5\left(\frac{H}{H+D}\right)^2\right] \text{.....(10)}$$

where:

D = distance from the sill to the bottom of the approach channel, mm
H = elevation difference between the threshold of the water surface, mm

Then, optimization of C_d value was performed using the add-in Solver in Microsoft Excel spread sheet programs to minimize the difference between the discharge gate and discharge prediction based on a calibrator. To view the discharge measurement accuracy of fiberglass gate, then used the performance index value, namely in the form of calculation Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) as in Table 1.

Table 1. Fomula Performance Index Calculation

Index	Formula
MAPE	$\frac{100}{N}\sum_{i=1}^{N}\left\lvert\frac{Y_i - \tilde{Y}_i}{Y_i}\right\rvert$
RMSE	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Y_i - \tilde{Y}_i\right)^2}$

RESULTS AND DISCUSSIONS

Fiberglass Water Gates Mechanical Properties

Flexural strength testing was performed on samples of fiberglass 650 mm x 150 mm x 12 mm. During the test, the sample did not have cracked or broken. This indicates that the nature of fiberglass elatis enough. This is evidenced by not changing the form of samples tested. Thus, this material is safe enough in case of impact (shock blows) at the entrance of water, because of its elasticity.

The result of the analysis of the thickness of the gate with 50 cm wide, and modulus of elasticity of fiberglass (E_f) in the amount of 40 500 kg/cm^2 and the maximum water pressure of 62.5 kgf or 125 kgf /m. So there is the maximum moment of 3.9 kg.m. If the maximum allowable deflection only 5 mm, it will get the value of moment of inertia (I) for 5 cm^4. Thus, because of the gate form is is square, then used the equation $\boldsymbol{I = b.\ h^3/12}$. Then obtained value of 9.3 mm thick gate or 10 mm. .

So with such a thick gate that was planned for 12 mm can be used to span the channel 50 cm because it is quite safe.

Table 2. Flexural Strength Fiberglass

Deflection (mm)	P maks (t.f)			Flexural Strength (kg/cm^2)
	1	2	Average	
0	0.000	0.000	0.000	0.000
1	0.027	0.030	0.028	59.250
2	0.035	0.038	0.036	75.750
3	0.041	0.045	0.043	90.000
4	0.049	0.054	0.051	106.875
5	0.057	0.062	0.059	123.750
6	0.064	0.070	0.067	139.500
7	0.071	0.078	0.075	155.250
8	0.079	0.086	0.083	172.125
9	0.087	0.094	0.091	188.625
10	*0.095*	*0.103*	*0.099*	*206.250*

Calibration of Water Gate Design

In Table 3 shows that the predicted flow rate under the fiberglass gate with Swamee method is quite good, with values nearing discharge data calibrator. This is evidenced by the performance index value of these fiberglass gate, that is, calculating the Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) .

MAPE value on discharge of the above predictions of 5.441 percent with an error of measurement of 5.68 l / s. According to Clemmens *et al.* (2003), the value of measurement error in the discharge of the general condition of free flow of $\pm$ 5 percent, whereas for Submerged flow conditions is more than 50 percent. Therefore, the results of calibration and testing of fiberglass gate with a width of 50 cm for free flow conditions are acceptable and reasonable.

To facilitate operations at the field level and also automate the irrigation gate purposes, it needs to be made to the relationship between a upstream water level (h1) and opening the door (l) with the discharge coefficient (C_d). In Figure 5 shows that the curve produced from the experiment for fiberglass gate having the characteristic of contraction coefficient (C_c), k_0, and k_1 are 0.951, 15, and 0.062 with a C_d value will approach a constant value in 0.951. This parameter is obtained by comparing the value of observation in the field with the prediction using Solver add ins. In Ms. Excel.

Table 3. Calibration of Fiberglass Water Gate

DATA			CALIBRATOR			FIBERGLASS GATE		PERFORMANCE INDICATOR		
l (cm)	Depth of Water h1 (m)	Depth of Water h3 (m)	H (m)	m	Q (l/s)	Cd	Q (l/det)	MAPE (%)	RMSE (l/s)	Flow Condition
1.0	0.097	0.025	0.042	0.657	6.011	0.891	6.143	0.022	0.018	Free Flow
1.0	0.087	0.015	0.043	0.657	6.233	0.886	5.789	0.077	0.197	Free Flow
1.0	0.099	0.027	0.042	0.657	6.011	0.891	6.212	0.032	0.040	Free Flow
1.5	0.048	0.025	0.042	0.656	5.901	0.833	6.063	0.027	0.026	Free Flow
1.5	0.052	0.025	0.043	0.657	6.121	0.838	6.350	0.036	0.052	Free Flow
1.5	0.044	0.027	0.042	0.657	6.011	0.827	5.764	0.043	0.061	Free Flow
2.0	0.032	0.025	0.043	0.657	6.121	0.773	6.121	0.000	0.000	Free Flow
2.0	0.032	0.024	0.043	0.657	6.233	0.773	6.121	0.018	0.012	Free Flow
5.0	0.120	0.080	0.120	0.712	31.269	0.812	31.154	0.004	0.013	Free Flow
7.0	0.220	0.125	0.180	0.746	60.610	0.832	60.489	0.002	0.015	Free Flow
7.0	0.215	0.130	0.180	0.746	60.610	0.830	59.686	0.015	0.854	Free Flow
7.0	0.210	0.125	0.180	0.746	60.610	0.829	58.873	0.030	3.017	Free Flow
9.0	0.175	0.140	0.180	0.746	60.610	0.794	66.185	0.084	31.078	Free Flow
9.0	0.175	0.145	0.180	0.746	60.610	0.794	66.185	0.084	31.078	Free Flow
11.0	0.165	0.145	0.180	0.746	60.610	0.764	75.614	0.198	225.116	Free Flow
11.0	0.165	0.145	0.180	0.746	60.610	0.764	75.614	0.198	225.116	Free Flow
Total Error								5.441	5.683	

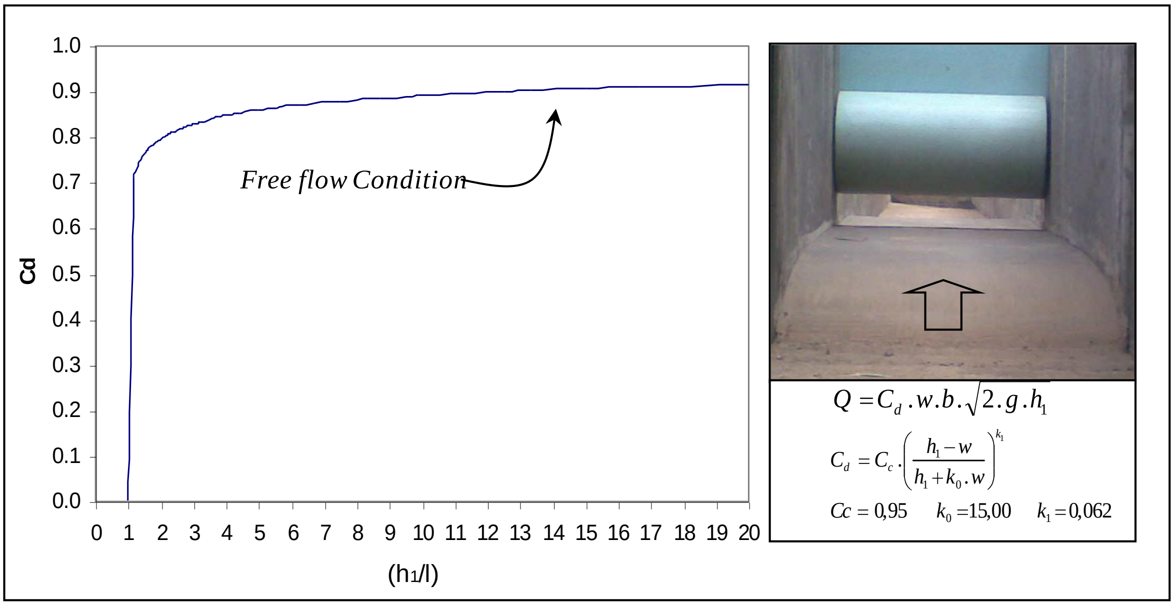

Figure 5. Fiberglass Water Gate Specifications

Fiberglass gate with an half round shape in the bottom could increase the value of C_d that is almost approaching the value of 1 with a value of C_c = 0.951. While, Henry's nomogram (1950) in Toepfer (2007), Rajaratnam and Subramanya (1967) and Swamee (1992) has a value C_d approaching the constant value in the value of 0.611 and a C_c value of 0.611 (see Figure 6). This is different due to type of door, both door materials, shape design that used a different door. This is in accordance with the opinion expressed by Lin *et al.* (2002), which states that the value of C_c will vary depending on the magnitude of opening the door, the door leaf shape is used, the depth of water in the upstream and the type of flow.

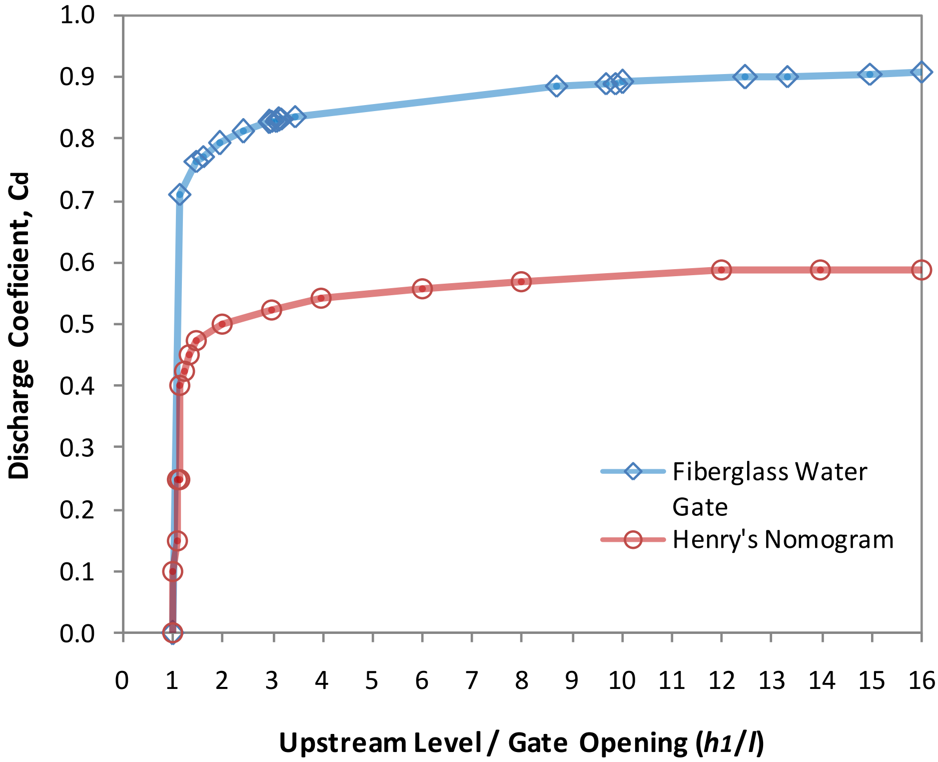

Figure 6. Discharge Coeficient of Fiberglass Water Gate

Changes in the form of lower lip of the gate square as used in Henry's nomogram to form a circle with a diameter of 20 cm could increase the discharge coefficient value approaching 1. Thus, the fiberglass water gate has a high accuracy of measurement / prediction with a better discharge. And then, in operation in the field can be used for setting and measurement of water in the channel. To prove the reliability of this door then conducted field tests in CIA, Garut, at one of the buildings (B. CMK 23). The gate is still in the stage of the process of observation.

Operations and Maintenance The Gate

Here is how the operation of fiberglass gate 50 cm wide with several alternatives for opening the door and water level conditions in the upstream gate (Table 4). One of the things that need to be observed in the water with a sliding door arrangement is in the condition of the water level upstream. Usually in field conditions, the water level in upstream already gives a chance remains high by regulating the water surface surveillance channel. So this will be easier to manage how large the gate must be opened? Given the water needs during the growth period of paddy rice was 1.5 l/sec/ha and tertiary area of 10 ha with water flowing in the channel efficiency by 70%, then the water needs to be provided in buildings is 21.4 l/sec. If the water level in the upstream was set up at 40 cm, then by opening the gate at 2 cm resulting the discharge coefficient values for 0.915 with a discharge of 25.6 l/sec. .

As for the operation and maintenance aspects of this gate is relatively easy because it has a fairly light weight, that is equal to 15 kg, making it easier for lifting and down the gate. While, maintaining the gate that need to be considered periodically are cleaning of garbage and mud sedimentation, giving the side door with the grease to facilitate the operation of the gate, for example, for six months minimum. .

So the gate is expected can help to know the flow rate that out from the gate, so hopefully the water supply can be given appropriately and opportunities a step towards automation would be easier and better. But unfortunately, in this study that only for free flow conditions. So this is the next challenge to create a nomogram or equation for Submerged flow.

CONCLUSION

a) The fiberglass gate with an half round shape in the bottom has contraction coefcient (C_c) = 0.951, and a value of dischage coeficient (C_d) can be determined by $C_d = C_c \cdot \left(\frac{h_1 - w}{h_1 + k_0 . w} \right)^{k_1}$; with k_0 = 15 and k_1=0.062 or by nomogram for free flow condition.
b) Predicted flow rate under the fiberglass gate with Swamee method is quite good, with values nearing discharge data calibrator. with Root Mean Square Error (RMSE) is about 5.681 l/s and Mean Absolute Percentage Error (MAPE) is about 5.441 percent.

ACKNOWLEDGEMENTS

We owe my deepest gratitude to Director General of Water Resources, Ministry of Republic Indonesia, DR. Mochammad Amron, MSc; Head of Water Resources Research and Development centre, Dr. Arie Setiadi Moerwanto, MSc; and Head of Experimental Station for Irrigation, Ir. Lolly M. Martief, MT; whose encouragement, guidance and support this research.

REFERENCES

A. J. Clemmens, T. S. Strelkoff, and J. A. Replogle. 2003. Calibration of submerged radial gates. Journal of Hydraulic Engineering, 129(9):680–687,

Anonim. 2009. Maraknya Pencurian Mur Baut Pintu Irigasi.www.wawasandigital.com. tanggal 23 Juli 2009. (akses date 1/09/2009)

Anonim. 2009. Ratusan Pintu Irigasi di Tangerang Tidak Befungsi. www.kompas.com. Tanggal 8 Pebruari 2009. (akses date 1/09/ 2009).

Anonim. 2009. Komponen Pintu Irigasi Banyak Hilang Dicuri. http://newspaper.pikiran-rakyat.com/prprint.php?. date 22 June 2009. (akses date 1/09/2009).

Bos, M.G., M.A. Burton and D.J. Molden. 2005. Irrigation And Drainage Performance Assessment : Practical Guidelines. CABI Publishing. London, UK.

JIS [Japanese Industrial Standard]. 1968. Method of Test for Flexural Strength of Concrete : JIS A 1106 – 1964; Reaffirmed 1968. Published by Japanese Standard Association. Japan

KEPMEN PU [Keputusan Mentri Pekerjaan Umum] No. 390/KPTS/M/2007. Tentang Penetapan Status Daerah Irigasi Yang Pengelolaannya Menjadi Wewenang dan Tanggung Jawab Pemerintah Provinsi, dan Pemerintah Kabupaten/Kota. Jakarta.

Lin, C.H., J. F. Yen, and C. T. Tsai. 2002. Influence of sluice gate contraction coefficient on distinguishing condition. Journal of Irrigation and Drainage Engineering, 128(4):249–252.

Rajaratnam, N., and K. Subramanya. 1967. Flow Equation for The Sluice Gate. Journal of Irrigation and Drainage Engineering. No. 93 (3), pages 167 – 186.

Swamee, P.K. 1992. Sluice-gate discharge equations. Journal of Irrigation and Drainage Engineering,118(1):56–60.

Toepfer, C.A.S. 2007. Instrumentation, Model Identification and Control of an Experimental Irrigation Canal. Disertation. Universitat Politecnica de Catalunya. Barcelona, Spain.