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OF HYDRAULICS ENGINEERS

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FOREWORDS

The International Seminar with special focus on "**Advancement of Water Resources Management in a Global Challenge**" has been held successfully from 22nd to 24th November 2019 in Kupang, attended by experts and professionals from several countries including Indonesian as the host. The discussions of the Seminar covered the entire aspects of securing Water Resources and Risk Reduction, Managing Water Resources, and Capacity Building.

The overall presentations and discussions during the seminar concluded that the outputs will undoubtedly contribute to remarkable concepts, strategies, lessons learned, and sharing of experiences on the advancement of water resources management in a global challenge. Based on this fact, I believe that the proceedings of this seminar will be valuable document for implementation.

I would like to thank the organizing committee, peers and writers, seniors and all members of HATHI for enormous supports to the seminar. May God bless you all.

Kupang, November 2019

Dr. Ir. Imam Santoso, M.Sc., PU-SDA
Chairman of HATHI

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Sub Theme 1

SECURING WATER RESOURCES AND RISK REDUCTION

Water conservation, water related disaster mitigation and risk reduction, climate change adaptation and impact mitigation, advancement of early warning system technology and environmental protection.

RESEARCH PAPER

FLOOD CONTROL AT SAMPEAN BARU DAM AND GATE SIMULATIONS

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Abstract

The problem of flooding that often occurs requires serious management for its control. Dams are multipurpose functions, one of them being functioning as flood control. The Sampean Baru Dam located in Bondowoso Regency, East Java, functions as flood control and irrigation. The purpose of this research is to create a flood control scheme by simulating the operations of the seven gates of the dam. The utilized methods were flood forecasting (Synthetic Unit Hydrograph Nakayasu) and reservoir routing (continuity equation). The types of the gates are one tilting gate (located in the middle as the number 4 gate) and six radial gates (gates number 1, 2, 3, 5, 6, and 7). The results showed that the most optimal operation of the gate was the sequence of opening gates starting with gate 4, then gate 2 together with gate 6, then gate 1 together with gate 7, and if the water elevation was still high, then gate 3 was opened together with gate 5. The results of reservoir routing showed that the dam is still in a safe condition because the gates could route the peak flood discharge to the downstream areas, and thus the dam is safe from overtopping.

Keywords: flood control, Sampean Baru Dam, gate operation.

INTRODUCTION

Floods are occurrences where the flow of water inundates the land surface. Floods may also occur due to the inability of a channel to contain a high amount of flowing water. The resulting effects of floods are interruptions of activities of people, economic losses, difficulties of accessing clean water, appearances of illnesses, and losses of life. To regard the issue of flooding, it becomes important to institute flood control as a method of early warning for floods. Flood control is a method that is performed to prevent or reduce flooding. One of the methods of flood control is through the construction of dams that are designed to hold back flooding. Dams that possess the function of flood control must always be able to maintain the dam height at a certain level so that room is available when overflow occurs.

In gated dams, the height of the contained water may be maintained by regulating the dam height and the overflow of water. In this study, the Sampean Baru dam is a gated dam that uses gates to regulate the water height. These gates may be opened and closed according to needs. The Sampean Baru dam has 7 gates, composed of 6 radial gates and 1 tilting gate. The aim of this research is to simulate the opening of gates to maximize flood control. The simulation of opening these gates consists of the method of opening and closing dam gates to maintain water level in consideration of the runoff discharge.

Several prior researches have been conducted on the subject of flood control. Liu *et al*. (2019) conducted a research using the MIKE 21 software; they found that the volume of flooding by up to half using the model produced by the software compared to without its use. Adeyemo & Stretch (2018) applied evolutionary algorithms in their analysis, and they found that the model was proven to be able to resolve the operational model of complex reservoirs with a quick rate of convergence. Bencheikh, Tahiri, Chiron, Archimede, & Martignac (2017) used hydraulic software combined with several flow networks; they found that the results could decrease the peak of flooding at the upstream part and reduce the impact of flooding. Sordo-Ward, Gabriel-Martin, Bianucci, & Garrote (2017) used the K method in the operations of gates for flood control, and they found the optimal K value that could reduce the maximum peak of flooding. Uysal, Akkol, Topcu, Sensoy, & Schwanenberg (2016) applied the HEC-ResSim of USACE and the RTC-Tools package; the results were that each method has their own advantages and disadvantages, and thus their implementations require careful considerations. Finally, Rifai, Dermawan, & Sisinggih (2016) and Nugroho (2015) simulated gate openings based on the volume of the discharge entering the dam, and the results were that gate openings depended on the height of the water present in the dam. Continuing the successes of prior research, the aim of this research is to simulate gate openings for the efforts of flood prevention using a method that are simple, easily implemented, and applicative.

METHODOLOGY

Flood routing is a technique to determine the value of the flood hydrograph for the river or dam by utilizing data of the flood discharge from the upstream and downstream parts (inflow and outflow). Changes in the inflow and outflow of a dam comprise flood inflow (I) due to flood discharge and outflow (O) due to overflow. If $I > O$, the dam containment increases and the water surface elevation increases. Conversely, if $I < O$, the dam containment decreases and the water surface elevation decreases.

For flood routing, the following continuity equation applies:

$$I - O = \Delta S / \Delta t \quad (1)$$

where: ΔS = change in water containment (S) of the dam

The following is the continuity equation for period $\Delta t = t_2 - t_1$ (United States Department of The Interiors Bureau of Reclamation, 1987):

$$\left(\frac{I_1+I_2}{2}\right).\Delta t - \left(\frac{O_1+O_2}{2}\right).\Delta t = S_2 - S_1 \quad (2)$$

I_1 and I_2 are obtained from the inflow hydrograph of the dam. S_1 is the containment of the dam in the routing period, measured from the top of the spillway structure. O_1 is the outflow discharge at the beginning of the routing period.

For the Sampean Baru dam, its outflow facility is a spillway structure, which uses the following discharge formula (United States Department of The Interior Bureau of Reclamation, 1987):

$$Q = C \cdot B \cdot H^{3/2} \tag{3}$$

where:

Q = discharge passing through the spillway (m^3/s)
C = overflow coefficient
B = effective width of the spillway peak (m)
H = height of water pressure above the peak

The following is the formula for overflow discharge of the spillway through the gates (United States Department of The Interior Bureau of Reclamation, 1987):

$$Q = C_d . B \cdot a \cdot \sqrt{2gh_i} \tag{4}$$

where:

Cd = discharge coefficient ≅ 0.611
B = effective width/total gate width (m)
a = height of the gate opening (m)
h_i = upstream water height (m)
g = gravitation (m/s^2)

The following is the formula for discharge through the tilting gate (United States Department of The Interior Bureau of Reclamation, 1987):

$$Q = \mu \cdot b \cdot d \cdot \sqrt{g \cdot d} \tag{5}$$

where:

μ = discharge coefficient (depending on elevation)
b = width of the tilting gate (9.5 m)
d = (2/3) h
h = elevation – Y coefficient, Y (depending on gate opening (...°))
g = gravitational acceleration (m/s^2)

The following is the formula for discharge through the radial gate (United States Department of The Interior Bureau of Reclamation, 1987):

$$Q = \frac{2}{3} \cdot \sqrt{2 \cdot g} \cdot b \cdot c \cdot \left(h_1^{2/3} - h_2^{2/3}\right) \tag{6}$$

where:

g = gravitational acceleration (m/s^2)
b = width of each radial gate (m)
C = opening of the radial gate, adjusted with elevation and gate opening)
= gate opening / (elevation – base elevation of the gate)
h_1 = elevation – base elevation of the gate (m)
h_2 = elevation – (base elevation of the gate + gate opening) (m)

RESULTS AND DISCUSSION

Hydrological Analysis

Calculation of planned rainfall utilized the Nakayasu Method. The following are the obtained results for planned rainfall for various return periods:

Return period of 2 years	=	693 m^3/s
Return period of 5 years	=	825 $m^3/$ s
Return period of 10 years	=	940 m^3/s
Return period of 25 years	=	1,113 m^3/s
Return period of 50 years	=	1,265 m^3/s
Return period of 100 years	=	1,437 m^3/s
Return period of 200 years	=	1,631 m^3/s
Return period of 1000 years	=	2,193 m^3/s
Return period of Prob. Max. Flood	=	2,366 m^3/s

Containment Capacity of the Dam

Calculation of the dam capacity is necessary in order to find out the volume of the containment that can be stored when a flood occurs (Figure 1). Based on the data of the containment for the Sampean Baru dam, the calculation of the capacity can be stated in the form of the following equation:

$$Y = 86.12\, X^{0.029}$$

where:
X = Capacity (m^3)
Y = Elevation (m)

Flood Routing for the Dam

In order to find out the changes in the inflow and outflow of the dam, it becomes required to perform flood routing through the dam using the continuity equation (Equation 2).

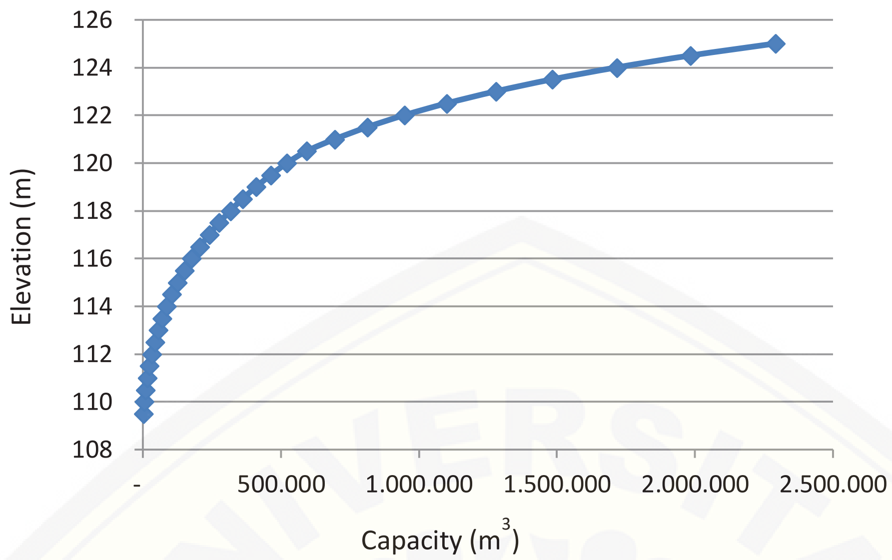

Figure 1. Curved reservoir capacity

Calculation of the C value of the spillway is affected by the factors of the height of the spillway, height of water above the spillway, amount of energy, and height of the water surface upstream of the spillway.

1. From calculation of the discharge coefficient value
   C = C1 x C2 x C3 = 3.92 x 0.92 x 0.92 = 3.3
2. From the data of peak width
   B = width of spillway gate x number of gates = 9.5 x 7 = 66.5 m
   $Q = 219.45 \times H^{3/2}$

Calculation of Gate Overflow Discharge

For the purpose of flood control, it is required to calculate the discharge to be released through the spillway. In this study, the spillway utilizes gates to regulate the overflow discharge. There are two types of gates on the Sampean Baru dam, which are 1 tilting gate in the middle of the dam and 6 radial gates on the left and right sides of the tilting gate, divided into two sets of 3 gates.

Based on the technical data for the operations of the dam gates, the following are calculations of overflow discharge for each gate.

1. Tilting Gate
   Discharge through the tilting gate uses Equation (5).
   For the tilting gate, the gate opening is measured in units of degrees.
   The utilized gate openings are openings that measure 61°, 60°, 54°, 51°, 45°, 41°, 35°, 31°, 27°, and 0°.
   These conditions of gate openings allow the calculation of overflow discharge through the tilting gate.

Data for calculations:

Height of opening	=	61°
Elevation	=	120.3 m
Y coefficient for 61° opening	=	119.7
μ for elev. 120.30	=	1.15
h	=	120.3 – 119.7 = 0.6 m
d	=	2/3 × h = 2/3 × 0.6 = 0.4 m
g	=	9.81 m/s^2

Therefore:

$Q = \mu \cdot b \cdot d \cdot \sqrt{g \cdot d}$ = 1.15 x 9.5 x 0.4 x (9.81 x 0.4)$^{1/2}$ = 8.7 m^3/s

2. Radial Gate

Discharge through the radial gate uses Equation (6). The radial gates of the Sampean Baru dam with gates of 5 m have openings from 0.25 m to 5.00 m. The following is the calculation of overflow discharge through the radial gates:

Gate opening	=	0.25 m
Base elevation of the gate	=	115.5 m
Elevation	=	120.3 m
Gravitational acceleration	=	9.81 m/s^2
Gate width	=	9.5 m
C	=	0.25 / (120.3 – 115.5) = 0.05 ~ 0.1
c	=	0.72 (based on the value of C)
h_1	=	120.3 – 115.5 = 4.8 m
h_2	=	120.3 – (115.5 + 0.25) = 4.55

Therefore:

$$Q = \frac{2}{3} \cdot \sqrt{2 \cdot g} \cdot b \cdot c \cdot \left(h_1^{2/3} - h_2^{2/3}\right) = 16.37 \text{ m}^3/\text{s}$$

The Method of Gate Operations

The following are the operations of the Sampean Baru dam gates, based on technical data:

1. The operation of the tilting gate is for water surface elevations ≤ +120.30.
2. The operation of the tilting gate to let through overflow discharge is limited; based on calculations of overflow discharge through the tilting gate, a flood water surface elevation of +123.00 and a maximum opening of 0° can only let through a discharge of 279.38 m^3/s.
3. Thus, a greater amount of overflow discharge is let through with the radial gates.
4. The operation of the radial gates is for water surface elevations greater than +120.30.
5. The stages of gate openings based on the technical data of gate operations are presented in Table 1.

Table 1. Stages of Gate Operations with Normal Water Surface Indicators

Stage of Gate Operation	WLH Indicator (cm)	Height of the Gate Opening (m) 1	2	3	4	5	6	7	Estimated Discharge (m^3/s)
1	<50				0*				111
2	>50		0.25		0*		0.25		146
		0.25	0.25		0*		0.25	0.25	178
		0.25	0.25	0.25	0*	0.25	0.25	0.25	211
	<50	Return to Normal Operating Position of Tilting Gate							
3	>50	0.25	0.5	0.25	0*	0.25	0.5	0.25	279
		0.5	0.5	0.25	0*	0.25	0.5	0.5	314
		0.5	0.5	0.5	0*	0.5	0.5	0.5	348
4	>50	0.5	1	0.5	0*	0.5	1	0.5	454
		1	1	0.5	0*	0.5	1	1	520
		1	1	1	0*	1	1	1	585
5	>50	1	1.5	1	0*	1	1.5	1	705
		1.5	1.5	1	0*	1	1.5	1.5	772
		1.5	1.5	1.5	0*	1.5	1.5	1.5	840
6	>50	1.5	2	1.5	0*	1.5	2	1.5	966
		2	2	1.5	0*	1.5	2	2	1,010
		2	2	2	0*	2	2	2	1,093
7	>50	2	2.5	2	0*	2	2.5	2	1,233
		2.5	2.5	2	0*	2	2.5	2.5	1,299
		2.5	2.5	2.5	0*	2.5	2.5	2.5	1,366
8	>50	2.5	3	2.5	0*	2.5	3	2.5	1,499
		3	3	2.5	0*	2.5	3	3	1,550
		3	3	3	0*	3	3	3	1,600
9	>50	3	3.5	3	0*	3	3.5	3	1,756
		3.5	3.5	3	0*	3	3.5	3.5	1,820
		3.5	3.5	3.5	0*	3.5	3.5	3.5	1,884
10	>50	3.5	4	3.5	0*	3.5	4	3.5	2,049
		4	4	3.5	0*	3.5	4	4	2,113
		4	4	4	0*	4	4	4	2,178
11	>50	4	4.5	4	0*	4	4.5	4	2,351
		4.5	4.5	4	0*	4	4.5	4.5	2,416
		4.5	4.5	4.5	0*	4.5	4.5	4.5	2,480
		4.5	5	4.5	0*	4.5	5	4.5	2,541
		5	5	4.5	0*	4.5	5	5	2,602
		5	5	5	0*	5	5	5	2,662

From Table 1, it can be seen that, with reference to the normal water surface position (+120.00) and consideration of the increase in water level height (WLH), the following are the stages of gate operations:

1. Stage 1. With a WLH increase indicator of < 50 cm or for discharge of < 111 m^3/s, gate operations utilize the tilting gate.
2. Stage 2. With a WLH increase to > 50 cm, the radial gate starts to be opened to an opening of 0.25 m for gates number 2 and 6. If the water level height still increases, gates number 1 and 7 are opened, and if the increase continues, gates number 3 and 5 are opened. If the WLH shows a decrease to < 50 cm, gate operations return to the initial position, using the tilting gate.

3. Stage 3. If the WLH increases again to > 50 cm, the radial gates are opened to 0.5 m for gates number 2 and 6, followed by gates 1 and 7 and gates 3 and 5.
4. Stage 4. If the WLH increases again to > 50 cm, the radial gates are opened to 1 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
5. Stage 5. If the WLH increases again to > 50 cm, the radial gates are opened to 1.5 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
6. Stage 6. If the WLH increases again to > 50 cm, the radial gates are opened to 2 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
7. Stage 7. If the WLH increases again to > 50 cm, the radial gates are opened to 2.5 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
8. Stage 8. If the WLH increases again to > 50 cm, the radial gates are opened to 3 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
9. Stage 9. If the WLH increases again to > 50 cm, the radial gates are opened to 3.5 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
10. Stage 10. If the WLH increases again to > 50 cm, the radial gates are opened to 4 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5.
11. Stage 11. If the WLH increases again to > 50 cm, the radial gates are opened to 4.5 m in the same order, being gates 2 and 6 first, followed by gates 1 and 7, and then gates 3 and 5. If at the estimated discharge of 2,480 m^3/s the water level has not decreased, the gates are opened to the maximum opening of 5 m, in the same order as the previous stages above.

Results of Gate Opening Simulations

Results of flood routing for the values of peak outflow discharge for various return periods and PMF (Probable Maximum Flood) and Results of gate opening simulations for each discharge are presented in Table 2.

Flood routing showed that the overflow gates could let through the entire peak outflow discharge.

Table 2. Results of Simulated Overflow Gate Openings to Let Through the Peak Outflow Discharge

No.	Return Period	Q of peak outflow (m^3/s)	Height of Opening (m)	Number of Gates Opened
1	Q 2 yr.	703	1.9	7
2	Q 5 yr.	831	2.2	7
3	Q 10 yr.	942	2.4	7
4	Q 25 yr.	1,110	2.7	7
5	Q 50 yr.	1,257	2.9	7
6	Q 100 yr.	1,423	3.2	7
7	Q 200 yr.	1,612	3.6	7
8	Q 1000 yr.	2,156	4.5	7
9	Q PMF	2,324	4.8	7

Results of simulation showed that if the Q PMF flood discharge were to occur, the Sampean Baru dam will still be able to contain the discharge, and the gates can let through the flood discharge with an opening of 4.8 m. Therefore, in this case, the dam will not experience overtopping.

CONCLUSION

The flood control strategy at the Sampean Baru Dam has been successfully carried out. The model used is to simulate flood control gates openings with total number seven (7) units. Gate openings relate to the amount of flood discharge that enters to the reservoir. With the gate opening simulation model as made above, it can pass the flood discharge with a return period of flood from Q2 years up to QPMF. Therefore, the dam will not experience overtopping

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