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Maximum Control Water Level (CWL) Jatibarang Dam to Avoid The Possibility of Overtopping Due to Flood 100 Years

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Abstract. The study of the maximum water level control of the Jatibarang reservoir is aimed to avoid the possibility of overtopping due to flooding after 100 years return period. Therefore, it is necessary to take into account the changes in land use, which were once plants turned into settlements. Changes in land use result in an increase in the drainage coefficient which results in an increase in surface runoff that the flood discharge in the river becomes even greater. Jatibarang Dam in Semarang at the time of planning was still designed to use flood discharge return period of Q 50 years. On the other hand, the water structure has included a hazard level classification, so flood safety standards should have been used return period of the Q 100 years. The aims of this study are (1) to analyze the maximum CWL value in the main spillway of the Jatibarang dam based on the analysis of flooding due to Q 100 years; and (2) comparing the maximum CWL value of the main overflow dam Jatibarang results of planning using Q 50 years with the maximum CWL value of the main overflow dam due to flood discharge Q 100 years. This present study is a survey study. Data collection methods were observation and documentation. The observation method was used to determine the coordinates of the dam spillway, which was then used to make a Jatibarang dam spillway watershed map and directly observe the Jatibarang dam spillway construction. The documentation method was used to collect rainfall data. The inflow flood hydrograph for a 100 year return period is 1838.84 m^3/s, while the outflow is 227.57 m^3/s. Therefore, the Jatibarang reservoir can accommodate or store flood discharge of 1611.27 m^3/s. The maximum elevation of the Jatibarang dam spillway is +155.3. The flood routing results show that the highest elevation is +154.05 at ten time. Comparison between the highest elevation of Q 100 years flood routing results which is equal to +154.05 is lower when compared to the maximum elevation of the Jatibarang dam spillway which is equal to +155.3; so that the main spillway elevation is still able to overcome of Q 100 years. Therefore, the Jatibarang dam spillway is still safe against the highest elevation of flood Q 100 years.

Keywords: maximum control water level; Jatibarang dam; overtopping due to flood 100 years

INTRODUCTION

Jatibarang Dam is located in Semarang City, Central Java. The coordinates of the Jatibarang reservoir are 7 ° 02′12 ″ S 110 ° 21′01 ″ E. Jatibarang Dam is located in four villages, consisted of Kedungpane, Jatibarang, Kandri and Jantirejo. In addition, in two districts, Mijen and Gunungpati, Jatibarang Dam was inaugurated by Minister of Public Works Djoko Kirmanto on Monday, 5 May 2014 which coincided with the XXII World Water Day. The dam, which was built at a cost of 655 billion IDR by the Japan International Cooperation Agency (JICA), also functions as a 1.5 kW Micro Hydro Power Plant (PLTMH) kW [1].

The study of the maximum CWL of the Jatibarang reservoir is to avoid the possibility of overtopping due to 100 years of flooding which must be conducted given the existence of changes in land use that was originally from plants turned into settlements with large areas that are not controlled. The change of land use results in an increase in the drainage coefficient which results in an increase in surface runoff so that the flood discharge in the river becomes even greater. In addition, the Jatibarang dam in Semarang at the time of planning was still designed using Q 50 years; even though it is classified as a medium hazard level and a small dam category, so flood safety standards or Q 100 years should be used [2].

The explanation above explains that it is necessary to increase awareness of the possibility of 100 years of flood discharge. The vigilance is manifested in the form of evaluation of overflow performance against 100 year flood discharge which exceeds the planned flood discharge. Increased vigilance that can be done by the dam manager is by maintaining the water level of the reservoir CWL that during a 100-year flood discharge, the reservoir can still reduce the flooding and the danger of overtopping can be avoided or at least can reduce the potential frequency of occurrence.

[3] has conducted research using (1) rainfall data that has been used for 10 years from 2008 to 2017; (2) the rainfall data used is the maximum daily rainfall data at the Simongan, Gunung Pati and Mijen rain stations; (3) rainfall data used to further analyze the rainfall plan PMP; (4) the planned flood discharge used to analyze the Jatibarang dam spillway is the PMF flood discharge. The findings of this study are that the Jatibarang reservoir is able to accommodate flood discharge at Probable Maximum Flood (PMF) of 1,025,090 m^3/s. Furthermore, the maximum outflow rate in Jatibarang Dam is 365.505 m^3/s which will be a flood discharge downstream of the Kali Garang river. The meeting time between the inflow and outflow discharge is at the 8^{th} hour [3].

At the Jatibarang dam in Semarang, the main spillway is already equipped with an emergency spillway. The function of an emergency spillway is to avoid overtopping if there is a flood with Q over 50 years. The study of how the main and emergency spillway response to flood discharge or Q 100 years has never been done, especially on very long rain data (> 25 years), therefore research on the above needs to be done and written in journal form.

Design flood is the amount of flood discharge determined as a basis for determining the capacity and dimensions of hydraulic buildings (including buildings in rivers), so that damage that can be caused directly or indirectly by floods may not occur as long as the amount of flooding is not exceeded [4]. The magnitude of the design flood is expressed in the reservoir flood discharge with a certain return period. For example, if a design flood is determined with a birthday of T years, it can be interpreted that the probability of an equal or exceeding flood discharge event and the design flood discharge each year is an average of l/T.

FIGURE 1. Reservoir and spillway at the Jatibarang Dam in Semarang

The choice of the magnitude of the return period of flood design for each type of water building does not have definitive criteria. The return period must be able to produce a satisfying design [4]; in the sense that the hydraulic building that is built must still be able to function properly at a minimum for a specified time, both structural and functional. Decision making in return period flood design must at least be based on the results of economic analysis (benefit cost analysis) as one of the non-technical considerations. Design flood are generally determined based on the following considerations: (1) size and type of project, (2) availability of data, (3) interests of protected areas, (4) risk of failure that can be caused, and (5) sometimes political policy. Table 1 presents the criteria for the selection of the design flood re-election as an overflow capacity control based on the hazard level classification.

TABLE 1. Criteria for selection return period of flood design as overflow capacity control based on hazard level classification

No.	Danger level classification	Dam category	Flood safety standards
1.	Low	Small Moderate Big	50 years – 100 years 100 years – 50% PMF 50% PMF – 100 % PMF
2.	Significant	Small Moderate Big	100 years – 50% PMF 50% PMF – 100 % PMF PMF
3.	High	Small Moderate Big	50% PMF – 100 % PMF PMF PMF

Source: [2]

Location:
PMF : Probable Maximum Flood

The aims of this study are (1) to analyze the maximum CWL value in the main spillway of the Jatibarang dam based on the analysis of flooding due to Q 100 years; and (2) comparing the maximum CWL value of the main overflow dam Jatibarang results of planning using Q 50 years with the maximum CWL value of the main overflow dam due to flood discharge Q 100 years.

METHODOLOGY

This type of study was a survey. Data collection methods used were observation and documentation. The observation method was used to determine the coordinates of the dam spillway, which was then used to make a Jatibarang dam spillway watershed map and directly observe the Jatibarang dam spillway construction. The documentation method was used to collect rainfall data. Rainfall data obtained from the results of previous studies conducted by [5].

The steps of this research included (1) collecting daily rainfall data which in this study used documentation data that has been processed by [5]; (2) testing the consistency of rainfall data; (3) conducting rainfall frequency data analysis; (4) testing the normality of rainfall data; (5) analyzing the value of design rainfall; (6) determining the design flood discharge using the Nakayasu Synthetic Unit Hydrograph; (7) determining the design discharge value of the Q 100 years flood; (8) analyzing flood routing; (9) making inflow and outflow curves due to floods in the Q 100 years design on the dam spillway; (10) determining the CWL value on the dam spillway; and (11) comparing the existing CWL value with the CWL value due to flood discharge Q 100 years.

The main equations used in this study include (1), (2), (3), (4) and (5) as presented below. Analysis of the 100 year Q design flood discharge used the Nakayasu Synthetic Unit Hydrograph which is the same as presented below [6].

$$Q_P = \frac{AR_O}{3{,}6(0{,}3t_P + T_{0,3})} \tag{1}$$

Where:

Q_P : Flood discharge peak (m^3/s)

A : catchment area of Cacaban reservoir (km^2)

R_O : Rain unit (mm)

T_P : time lag from the beginning of the rain to the peak of the flood (hour)

$T_{0,3}$: The time required by the discharge to descend from the peak discharge to 0.3 times the peak discharge (hours)

Flood routing reservoirs are carried out in a hydrologic routing based on the continuity equation [7], as for the equations as presented below.

$$I - Q = \frac{dS}{dt} \quad (2)$$

Where:

I	:	The discharge goes into the reservoir (m^3/s)
Q	:	The discharge goes through the spillway (m^3/s)
dS	:	Storage dimension (m^3)
dt	:	Flood routing period (s)

When the d_t routing period is changed to Δt. I_1 and I_2, could be known from the hydrograph discharge into the reservoir, while S represents the storage of the reservoir at the beginning of the routing period measured from the reference line of expenditure facilities (spillway weir or axis tunnel outlet), the flood routing equation according to [7] is represented by the formula (2).

$$\frac{I_1 + I_2}{2} + \left(\frac{S_1}{\Delta t} - \frac{Q_1}{2}\right) = \frac{S_2}{\Delta t} + \frac{Q_2}{2} \quad (3)$$

if, $\frac{S_1}{\Delta t} - \frac{Q_1}{2} = \psi_1$, and $\frac{S_2}{\Delta t} - \frac{Q_2}{2} = \varphi_2$

Thus equation (2) can be written as below

$$\frac{I_1 + I_2}{2} + \psi_1 = \varphi_2, \quad (4)$$

Where:

I_1	:	Incoming discharge whose position in the calculation table is above the discharge to be found (m^3/s)
I_2	:	Incoming discharge to be found (m^3/s)
ψ_1	:	Conditions at the start of routing
φ_2	:	Conditions at the end of routing
Δt	:	Flood routing period (seconds, hours or days)
S	:	Large storage reservoir (m^3)

Q was the outflow at the beginning of the routing period, which if its expenditure is spillway, then the equation as presented below [8].

$$Q = CBH^{3/2}, \quad (5)$$

Where:

C	:	Discharge coefficient for spillway (1,7-2,2 $m^{1/2}/s$)
B	:	Spillway weir width (m)
H	:	High energy above the spillway weir (m)

At normal water level elevation at +148.9 m the reservoir volume is 17.7 million m^3 and at the elevation of dead storage at EL +151.8 m of reservoir volume is 2.7 million m^3, while dead storage is 6.8 million m^3, in other words the effective volume of the reservoir is 10.8 million m^3.

TABLE 2. Comparison between elevation, inundation area and volume in the Jatibarang Dam

Elevation	Area (m^2)	Volume (m^3)	Cumulative volume (m^3)	Elevation	Area (m^2)	Volume (m^3)	Cumulative volume (m^3)
92	571	571	571	128	376931	753862	2733813
94	2293	4587	5158	132	485709	1942835	4676648
96	4327	8653	13811	134	528755	1057509	5734157
98	7065	14130	27941	136	577208	1154417	6888574
102	13650	54601	82542	138	624082	1248164	8136738
104	18052	36103	118645	142	723234	2892935	11029673

106	22818	45636	164281	144	775947	1551894	12581567
108	28014	56028	220309	146	832498	1664996	14246563
112	36439	145756	366065	148	887042	1774084	16020647
114	39544	79089	445154	150	950952	1901904	17922551
116	42665	85330	530484	152	1014862	2029724	19952275
118	46549	93098	623582	154	1075145	2150290	22102565
122	94485	377939	1001521	156	1150014	2300028	24402593
124	191141	382281	1383802	158	1206497	2412993	26815586
126	298074	596149	1979951				

Source: [9]

RESULTS AND DISCUSSION

Rainfall Design With Return Periods Of 25, 50, And 100 Years

Design rainfall analysis was used to determine the maximum rainfall with a certain return period to be used in the design discharge calculation. The return periods selected in this study were 25, 50, and 100 years. The method used for the calculation of rainfall is statistics or methods of distribution of average daily rainfall average in the catchment area. The distribution to determine the design rainfall used in this study is Log Pearson Type III. Below was presented the results of rainfall calculations for return periods of 25, 50, and 100, years, as presented in Table 3.

TABLE 3. High precipitation for return periods of 20, 50, 100, and 125 years use of Log Pearson Type III distribution

Log Pearson Type III			
T (year)	**k**	**Log X_T (mm)**	**X_T (mm)**
25	1.9794	2.39025	245.613
50	4.3864	2.45375	284.283
100	7.2104	2.51432	326.826

Source : The calculation results

Where:

X : Observational variation values
x_T : The expected X variant value occurs in the return period t year
T : The return period for t years (20, 50, 100, and 125 years)
k : The value of k can be obtained from the table which is a function of the return period and the coefficient of variation [10]

This study uses the Log Pearson Type III distribution, because this distribution is free from the requirements of descriptive statistical values, no matter how big the descriptive statistical value is always acceptable, while for other distributions it must meet certain values. The requirements that must be met by the design rainfall distribution equation other than Pearson Log type III are usually difficult to fulfill because the required amount of rainfall data is greater than or equal to 30 years.

Table 3 shows that the design rainfall in the repeat period: 25 years is 245.613 mm; 50 years is 284.283 mm; and the 100 years is 326.826 mm. Rainfall (R24/daily) of 245.613 mm; 284.283; and 326.826 mm are included in the category of heavy to very heavy.

Hydrograph Flood Design on Return Periods Of 25, 50, 100 Years

The calculation of the design flood discharge of the Jatibarang reservoir is determined based on the calculation of the design rainfall that is commonly used hydrological approach. The calculation of the design flood discharge is used of the Nakayasu Synthetic Unit Hydrograph (HSS). The Nakayasu Synthetic Unit Hydrograph (HSS) equation is formulated as presented in the equation (1).

TABLE 4. Hydrograph flood design 100 years

t_n Time	U_n	Hydrograph ordinate due to flooding					Q_{Flood} (m^3/s)	Q_{base} (m^3/s)	$Q = Q_{Flood} + Q_{base}$
		121.352	31.542	22.126	17.614	14.875			
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	1.89
1	0.60	72.90	0.00	0.00	0.00	0.00	72.90	1.89	74.79
2	3.17	384.74	100.00	0.00	0.00	0.00	484.75	1.89	486.64
3	10.50	1273.67	331.05	232.23	0.00	0.00	1836.95	1.89	1838.84
4	7.19	872.30	226.73	159.05	126.62	0.00	1384.69	1.89	1386.58
5	4.92	597.42	155.28	108.93	86.72	73.23	1021.57	1.89	1023.46
6	3.22	390.25	101.44	71.15	56.65	47.84	667.32	1.89	669.21
7	2.50	303.22	78.81	55.29	44.01	37.17	518.49	1.89	520.38
8	1.94	235.59	61.24	42.96	34.20	28.88	402.86	1.89	404.75
9	1.51	183.05	47.58	33.38	26.57	22.44	313.01	1.89	314.90
10	1.17	142.22	36.97	25.93	20.64	17.43	243.20	1.89	245.09
11	0.90	109.49	28.46	19.96	15.89	13.42	187.23	1.89	189.12
12	0.75	90.61	23.55	16.52	13.15	11.11	154.95	1.89	156.84
13	0.62	74.99	19.49	13.67	10.88	9.19	128.23	1.89	130.12
14	0.51	62.06	16.13	11.31	9.01	7.61	106.12	1.89	108.01
15	0.42	51.36	13.35	9.36	7.45	6.30	87.82	1.89	89.71
16	0.35	42.50	11.05	7.75	6.17	5.21	72.68	1.89	74.57
17	0.29	35.17	9.14	6.41	5.11	4.31	60.15	1.89	62.04
18	0.24	29.11	7.57	5.31	4.23	3.57	49.77	1.89	51.66
19	0.20	24.09	6.26	4.39	3.50	2.95	41.19	1.89	43.08
20	0.16	19.94	5.18	3.63	2.89	2.44	34.09	1.89	35.98
21	0.14	16.50	4.29	3.01	2.39	2.02	28.21	1.89	30.10
22	0.11	13.65	3.55	2.49	1.98	1.67	23.35	1.89	25.24
23	0.09	11.30	2.94	2.06	1.64	1.38	19.32	1.89	21.21
24	0.08	9.35	2.43	1.70	1.36	1.15	15.99	1.89	17.88

Source : The calculation results

Where:

Q_{Flood} : Discharge due to rain and base flow (m^3/s)

Q_{base} : Base flow (m^3/s)

U_n : Unit hydrograph value, time n

t_n : Time

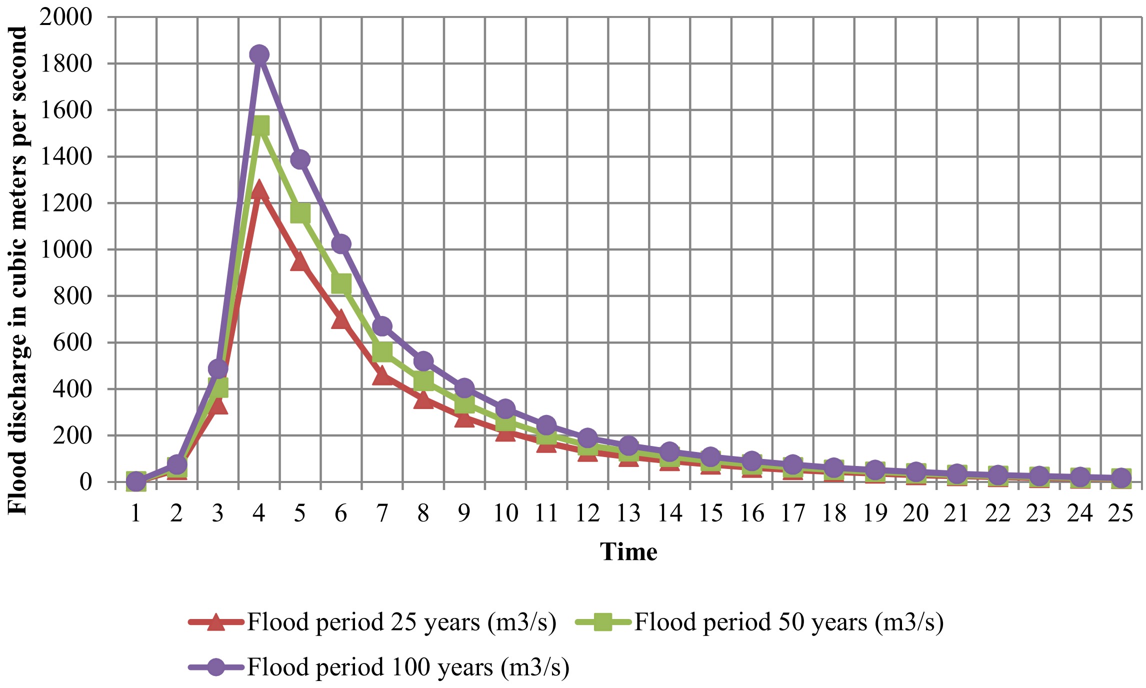

FIGURE 2. Hydrograph flood design of 25, 50, and 100 years

Flood Routing 100 Years

The 100 years return period flood routing is conducted through several stages: (1) arranging Table 5 on the relationship between Water Reservoir elevation, storage and debit (ψ); (2) determining the regression equation between the Water Reservoir elevation with Storage and the Water Reservoir elevation with the discharge (ψ); (3) compiling Table 5; and (4) create a flood routing chart through a spillway (inflow and outflow discharge chart).

TABLE 5. The relationship between the elevation of the reservoir, the storage and discharge (ψ) on the Cacaban dam (Q 125 Years)

No	Elevation (m)	H (m)	Strorage (S) (m^3)	S/3600 (m^3/s)	Discharge (Q) (m^3/s)	Q/2 (m^3/s)	psi (m^3/s)	phi (m^3/s)
1	148.90	0	16876502.80	4687.92	0.00	0.00	4687.92	4687.92
2	149.22	0.32	17035667.09	4732.13	3.53	1.76	4730.36	4733.89
3	149.54	0.64	17194831.37	4776.34	9.98	4.99	4771.35	4781.33
4	149.86	0.96	17353995.66	4820.55	18.34	9.17	4811.38	4829.73
5	150.18	1.28	17513159.94	4864.77	28.24	14.12	4850.65	4878.89
6	150.50	1.6	17672324.23	4908.98	39.47	19.73	4889.25	4928.71
7	150.82	1.92	17831488.51	4953.19	51.88	25.94	4927.25	4979.13
8	151.14	2.24	17990652.80	4997.40	65.37	32.69	4964.72	5030.09
9	151.46	2.56	18149817.08	5041.62	79.87	39.94	5001.68	5081.55
10	151.78	2.88	18308981.37	5085.83	95.31	47.65	5038.17	5133.48
11	152.10	3.2	20059788.50	5572.16	111.62	55.81	5516.35	5627.98
12	152.42	3.52	20236678.19	5621.30	128.78	64.39	5556.91	5685.69
13	152.74	3.84	20413567.87	5670.44	146.73	73.37	5597.07	5743.80
14	153.06	4.16	20590457.56	5719.57	165.45	82.73	5636.85	5802.30
15	153.38	4.48	20767347.24	5768.71	184.91	92.45	5676.25	5861.16

16	153.70	4.8	20944236.93	5817.84	205.07	102.53	5715.31	5920.38
17	154.02	5.12	21121126.61	5866.98	225.91	112.96	5754.02	5979.94
18	154.34	5.44	21298016.30	5916.12	247.42	123.71	5792.41	6039.83
19	154.66	5.76	21474905.98	5965.25	269.57	134.78	5830.47	6100.04
20	154.98	6.08	21651795.67	6014.39	292.34	146.17	5868.22	6160.56
21	155.30	6.4	23597582.20	6554.88	315.72	157.86	6397.02	6712.74

Source : The calculation results

The relationship between storage volume (S) with elevation (h) of Water Reservoir elevation is obtained by regression equation $h = 1x10^{-6} S + 149.5$ (a); the correlation between Storage with elevation (h) is 0.939 (r = 0.939). The relationship between elevation (h) and psi (ψ) of Water Reservoir elevation is obtained by regression equation $\psi = 293.2h - 31052$ (b); the correlation between ψ and h is 0.928 (r = 0.928).

Hydrograph flood discharge inflow for a 100 years return period and outflow discharge is shown in Figure 4, where the outflow peak discharge of 227.57 m^3/s (spillway width is 15 m) is at elevation. EL. +154.05 m. Thus it can be said that the flood discharge for a 100 year return period does not result in overtopping because the elevation of the top of the dam is in EL. +155.3 m.

TABLE 5. Flood routing analysis is through Spillway

Waktu (jam ke)	**Q_{banjir} (m^3/s)**	**(In+In+1)/2 (m^3/s)**	**Psi (m^3/s)**	**phi (m^3/s)**	**Outflow (m^3/s)**	**H (m)**	**Elevasi (m)**	**S**
0	1.89	0.95	4564.88	4565.83	0.00	0.00	148.90	0.00
1	74.79	37.39	4721.30	4758.69	10.31	0.65	149.55	269226.23
2	486.64	243.32	4804.26	5047.57	19.52	1.00	149.90	1983991.43
3	1838.84	919.42	5134.06	6053.48	71.58	2.38	151.28	8533528.21
4	1386.58	693.29	5385.23	6078.52	123.85	3.43	152.33	13267551.21
5	1023.46	511.73	5563.22	6074.95	166.27	4.17	153.07	16506148.60
6	669.21	334.61	5664.93	5999.53	192.31	4.60	153.50	18316747.98
7	520.38	260.19	5732.11	5992.30	210.20	4.88	153.78	19497803.92
8	404.75	202.37	5772.27	5974.64	221.14	5.05	153.95	20198181.98
9	314.90	157.45	5791.70	5949.15	226.50	5.13	154.03	20535726.29
10	245.09	122.55	5795.56	5918.11	227.57	5.15	154.05	20602657.16
11	189.12	94.56	5787.58	5882.14	225.36	5.11	154.01	20464237.61
12	156.84	78.42	5773.38	5851.80	221.44	5.05	153.95	20217553.75
13	130.12	65.06	5754.50	5819.56	216.27	4.97	153.87	19888782.25
14	108.01	54.00	5732.18	5786.18	210.22	4.88	153.78	19499024.59
15	89.71	44.86	5707.42	5752.28	203.56	4.78	153.68	19065202.03
16	74.57	37.28	5681.02	5718.31	196.55	4.67	153.57	18600811.97
17	62.04	31.02	5653.60	5684.62	189.35	4.55	153.45	18116560.56
18	51.66	25.83	5625.65	5651.49	182.11	4.43	153.33	17620887.32
19	43.08	21.54	5597.55	5619.09	174.92	4.32	153.22	17120397.50
20	35.98	17.99	5569.59	5587.58	167.86	4.20	153.10	16620216.70
21	30.10	15.05	5541.98	5557.03	160.99	4.08	152.98	16124280.46
22	25.24	12.62	5514.88	5527.50	154.34	3.97	152.87	15635570.11
23	21.21	10.61	5488.43	5499.03	147.94	3.86	152.76	15156304.31
24	17.88	8.94	5462.68	5471.62	141.80	3.75	152.65	14688094.27

Source : The calculation results

Hydrograph inflow floods for 100 years return period and outflow discharge is shown in Figure 4, where the peak inflow discharge is 1838.84 m^3/s which is reduced to 227.57 m^3/s (outflow), this is due to reservoir storage and spillway capacity. Therefore, the Jatibarang reservoir can accommodate or store flood discharge of 1611.27 m^3/s.

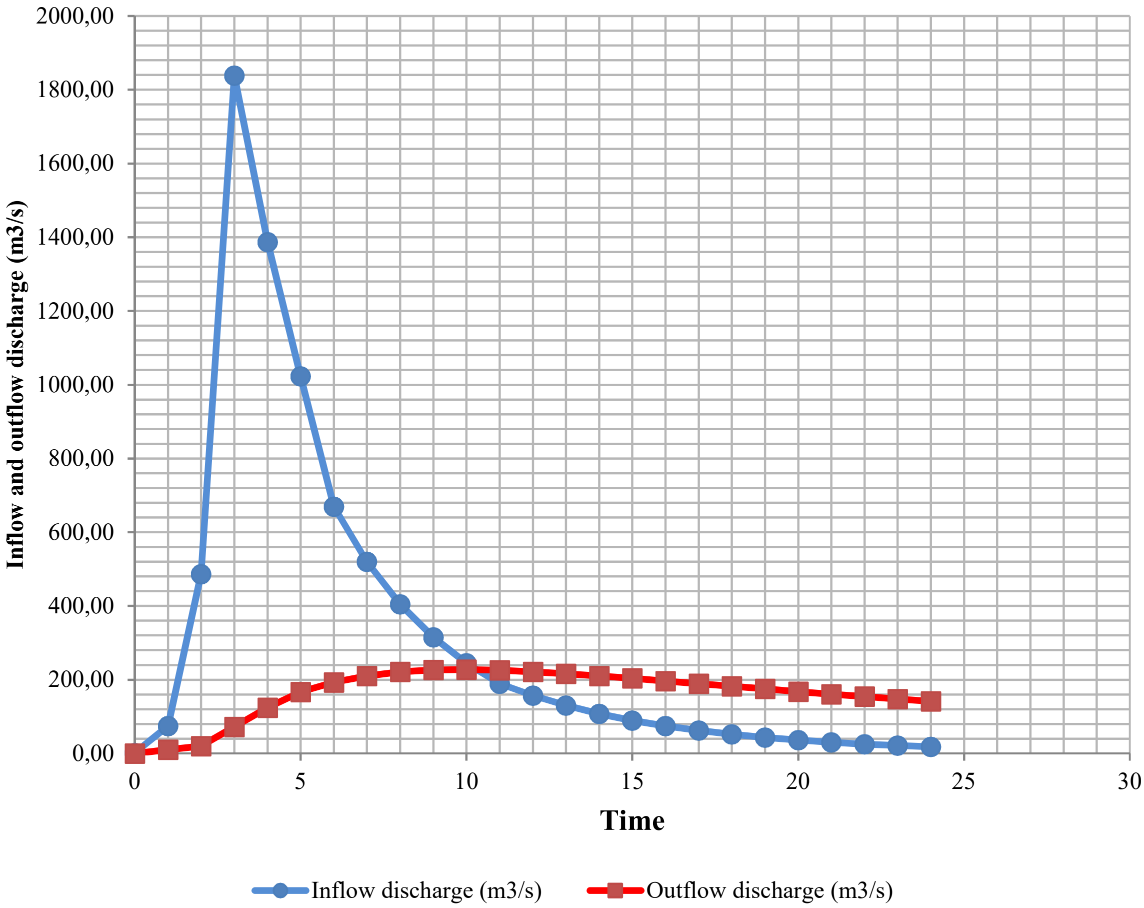

FIGURE 3. Flood routing graph through spillway (inflow and outflow discharge)

The maximum elevation of the Jatibarang dam spillway is +155.3. The flood routing results show that the highest elevation is +154.05 at ten time. Comparison between the highest elevation of Q 100 flood routing results which is equal to +154.05 is lower when compared to the maximum elevation of the Jatibarang dam spillway which is equal to +155.3; so that the main spillway elevation is still able to overcome Q 100 years. Thus the Jatibarang dam spillway is still safe against the highest elevation of flood Q 100 years.

The highest elevation of the Jatibarang dam is +157.00, while the highest elevation of the Q 100 year flood is +154.04, so the Jatibarang dam is also safe against to the phenomenon of overtopping. Security due to overtopping of the elevation of the Jatibarang dam is safer, because when the elevation of the flow on the spillway reaches +151.8, the emergency spillway starts flowing toward the chute spillway, so that flooding can be quickly suppressed. It can be said that the security of the peak of the Jatibarang dam is very safe against flooding with Q 100 years.

CONCLUSION

The inflow flood hydrograph for a 100 year return period is 1838.84 m3 / s, while the outflow is 227.57 m3 / s, thus the Jatibarang reservoir can accommodate or store flood discharge of 1611.27 m^3/s. The maximum elevation of the Jatibarang dam spillway is +155.3. The flood routing results show that the highest elevation is +154.05 at ten time. Comparison between the highest elevation of Q 100 years flood routing results which is equal to +154.05 is lower when compared to the maximum elevation of the Jatibarang dam spillway which is equal to +155.3; so that the main spillway elevation is still able to overcome of Q 100 years. Thus the Jatibarang dam spillway is still safe against the highest elevation of flood Q 100 years.

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