EFFECT OF THE SPILLWAY ELEVATION ON FLOOD ATTENUATION IN THE BENDO DAM

Submitted in partial fulfillment of the requirements for Bachelor of Engineering in Civil Engineering at Muhammadiyah University of Surakarta

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APPROVAL SHEET

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Abstrak

Bendungan Bendo merupakan bendungan multi fungsi yang digunakan sebagai wadah untuk pengendalian banjir, irigasi, air baku, serta untuk wisata. Dalam penelitian ini bermaksud untuk mengetahui keamanan dari rencana bendungan awal dan pengaruh peninggian elevasi bangunan pelimpah terhadap redaman banjir di Bendungan Bendo dengan debit rencana. Dalam penelitian ini akan dilakukan perhitungan menyeluruh mengenai debit banjir maksimum serta tinggi jagaan yang aman dan membandingkan jumlah inflow dan outflow di ketinggian yang berbeda. Analisis ini menggunakan perhitungan hidrograf satuan sintetik nakayasu sebagai perhitungan debit rencana serta metode newton raphson sebagai perhitungan routing banjir. Lokasi dalam analisis ini diambil di Bendungan Bendo Ponorogo. Data yang diperlukan dalam perhitungan ini adalah data curah hujan dari tahun 1996 hingga 2016 di daerah Ponorogo juga peta bumi daerah Ponorogo dari internet. Dalam analisis ini, akan dihitung pengarunnya redaman banjir tiap kenaikan elevasi bangunan pelimpah 2 m, dimulai dari ketinggian 214.6 m sampai ke puncak bendungan yaitu 224 m. Hasil penelitian ini, tinggi spillway yang digunakan di Bendungan Bendo 218,6 m aman untuk dibangun. Selain itu, pengaruh dari peninggian elevasi bangunan pelimpah yaitu redaman banjirnya meningkat. Pada kala ulang 1000 tahun, nilai terendah adalah 27,863% pada elevasi 214.6 m dan terus meningkat menjadi 29,543% pada elevasi 216.6 m, 30,982% pada elevasi 218.6 m dan maksimum 32,490% pada elevasi 220.6 m. Kemudian, pada PMF, nilai terendah adalah 24,949% pada elevasi 214.6 m dan terus meningkat menjadi 26,390% pada elevasi 220.6 m, 27,908% pada elevasi 218.6 m dan maksimum adalah 29,492% pada elevasi 220.6 m.

Kata Kunci : elevasi, penelusuran banjir, redaman banjir.

Abstract

Bendo dam is a multi-purpose dam which used as a flood control, irrigation, raw water, also tour place. Moreover, in this study intends to know the safety of initial dam planning and determine the effect of the spillway elevation on flood attenuation in the Bendo Dam with discharge planned. In this research is fully calculated the maximum flood discharge also the safe freeboard and compare the amount of inflow and outflow in different elevation. This analysis used unit hydrograph synthetic nakayasu as a design discharge calculation and newton raphson method as a flood routing calculation. The location in this analysis is taken at Bendo Dam Ponorogo. The data needed in this calculation was rainfall data from 1996 until 2016 in Ponorogo area also earth map in Ponorogo area from internet. In this analysis, will be calculated effect of flood attenuation with the increasing of spillway 2 m, starting from 214.6 m until peak dam are 224 m. The result of this analysis, spillway elevation are used in Bendo Dam 218.6 m was

safe to build. Then, the effect of spillway elevation is increase while the elevation increase also. In return period 1000 years the lowest value was 27.863% at elevation 214.6 m and keep increasing into 29.543% at elevation 216.6 m, 30.982% at elevation 218.6 m and maximum was 32.490% at elevation 220.6 m. Then, at PMF discharge, the lowest value was 24.949% at elevation 214.6 m and keep increasing into 26.390% at elevation 216.6 m, 27.908% at elevation 218.6 m and maximum was 29.492% at elevation 220.6 m.

Keyword : elevation, flood routing, flood attenuation.

1. INTRODUCTION

Water has a very important function for life. All activities, especially human activities such as industry, irrigation, daily life, and others are required water. Therefore, some effort need to be made to regulate and increase the efficiency of water flowing on the ground. One of a lot of way increasing water utilization can be done by making flood control or good irrigation systems. Some places needed facilities that can accommodate excess water, among of them are build a dam.

One of the dams being built is the Bendo dam, located in Kali Keyang River or also known as the Ngindeng River in Bendo, Ngindeng, Sawoo, Ponorogo. Bendo dam is one of the efforts to develop the Ponorogo regency area that is related to the development of water resources, in order to meet various needs of the community, such as providers of irrigation water, domestic, industrial raw water and flood control.

Given the importance of the function of the Bendo Dam, the safety of dam must be calculated accurately. In order to keep the structural safety against earthquake hazards, overtopping and breaching. This study intends to determine the safety of elevation and the effect of the spillway elevation on flood attenuation in the Bendo dam with design discharge.

For further objectives, this research can be used as additional literacy in flood routing analysis and the effect of spillway elevation on flood attenuation in the Bendo dam also others dam construction.

2. RESEARCH METHOD

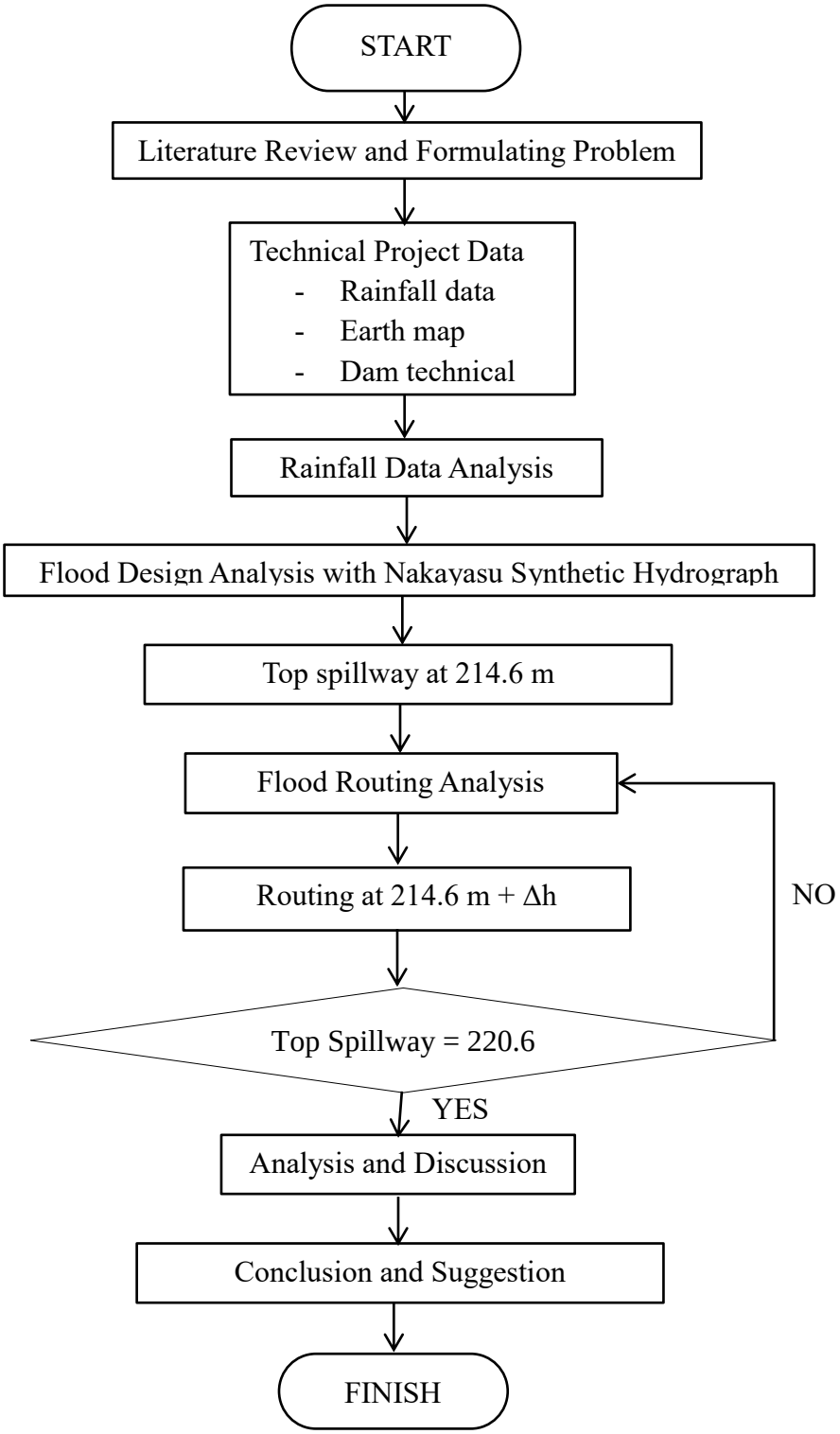

Figure 1. Research Flowchart

3. RESULT AND DISCUSSION

3.1 Research Location

This research is taken at Bendo Dam Ponorogo. Bendo is the name of that village which located in Sawoo, Ponorogo. This dam is passed by Kali Keyang river or called by Ngindeng river. In determining watershed, looking at the main river from upstream which passing the dam that was Kali Keyang river and all tributary from Kali Keyang river. After all part of tributary has been determined, the watershed can be made by area around of tributary. Total area of the watershed are 137.72 km^2.

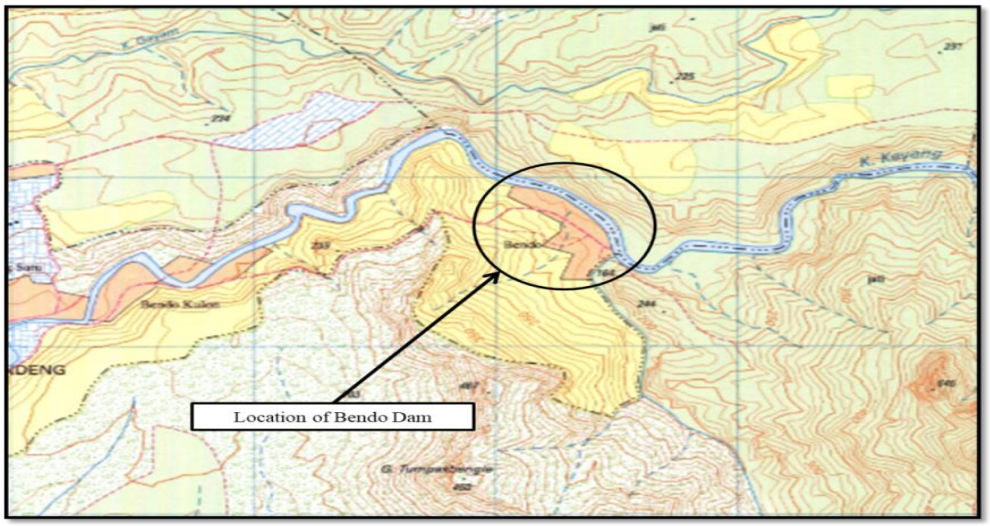

Figure 2. Location of Bendo Dam

3.2 Station Used

Ponorogo regency has around 20 rain stations. In determining which station used, looking at the station near by the location of Bendo dam. There were 6 stations that pinned on my research are Sawoo station, Sooko station, Pudak station, Talun station, Kesugihan station and Kori station. By plotting polygon thiessen on watershed, the result station that will be used are 4 stations and calculated the area of each station, as follows:

1. Pudak station has an area 14.83 km^2
2. Sawoo station has an area 43.99 km^2
3. Sooko station has an area 78.70 km^2
4. Talun station has an area 0.20 km^2

3.3 Consistency Analysis of Rain Data

Consistency test used RAPS method which done by calculating the cumulative value of the deviation. This test show the consistency of 4 station used. The calculation can be seen at table below.

Table 1. Consistency Test

Station	$Q_{counted}$	$R_{counted}$	$Q_{critical}$	$R_{critical}$	Note
Pudak	3.3061	4.0771	5.5999	6.5852	Consistent
Sawoo	2.8009	4.9269	5.5999	6.5852	Consistent
Sooko	3.3015	3.8654	5.5999	6.5852	Consistent
Talun	5.3828	5.3828	5.5999	6.5852	Consistent

3.4 Average Rainfall Analysis

Calculation of planning rainfall used rain data from all stations chosen by year of 1996 until 2016. The maximum average rainfall calculated by polygon thiessen method that a method which put the thiessen coefficient into each rain station.

Table 2. Maximum Average Rainfall

Maximum Rainfall (mm/hr)
94.32
86.00
74.67
73.44
71.24
69.01
68.69
66.55
65.17
63.83
63.07
62.74
62.17
61.95
61.60
61.52
61.46
60.47

59.41
58.80
58.78

3.5 Rainfall Distribution Analysis

In frequency distribution calculation, there are several analysis can be used. To determine which method can be applied, it will be chosen after testing the level of suitability.

Table 3. Distribution Type

No.	Distribution	Terms	Result	Note
1	Normal	Cs = 0	0.0048	Suitable
		Ck = 3	6.8125	Not
2	Log Normal	Cs/Cv = 3	0.0351	Not
3	EJ Gumbel	Cs = 1.1396	0.0048	Not
		Ck = 5.4002	6.8125	Not
4	Log Pearson Type III	Exepting above		Suitable

Based on the table above, calculation of frequency distribution used log pearson type III distribution analysis. Because the result of all coefficient is not suitable with the terms of each distribution except for log pearson type III.

Table 4. Rainfall Distribution

Return Period Distribution Frequency			
Return Period	k	Log Xt	Xt (mm)
2	-0.254	1.808	64.327
5	0.675	1,858	72.170
10	1.329	1,894	78.259
25	2.163	1.938	86.775
50	2.78	1.972	93.666
100	3.388	2.004	100.991
200	3.99	2.037	108.808
1000	5.39	2.112	129.409

The suitability of normal distribution above needed a further testing to find out whether the data used is correct. There were 2 test chi square and smirnov-kolmogorov test.

Table 5. Result of Suitability Distribution

No	Parameter Test	Value	Critical value	Result
1	Chi Square	0.428	7.815	Accepted
2	Smirnov-Kolmogorov	0.051	0.2986	Accepted

3.6 Rainfall Intensity

This analysis calculated with mononobe equation. This puddle on dam was assumption on 5 hours. It was counted on return period 1000 years because this dam include into big dam. To find the value of ABM (Alternating Block Method) with plotting the value of Ri in order to get the data from the lower going to bigger and back into lower again.

Table 6. Result of Effective Rainfall

Hour	Rainfall Intensity	Ri	ABM	Effective Rainfall
1	75.6786	75.6786	9.2763	1.5118
2	47.6745	19.6705	13.7984	6.0338
3	36.3825	13.7984	75.6786	67.9141
4	30.0331	10.9849	19.6705	11.9059
5	25.8817	9.2763	10.9849	3.2203

3.7 Flood Design Analysis

This analysis used a HSS Nakayasu. It shown a variation of discharge by time. Then, the unit hydrograph was a directly overflowed which caused by an effective rainfall volume that divided at time and place. The data should be known as follows:

Area of watershed (A) = 137.72 km^2

Length of river (L) = 42.93 km

It calculated the planned rainfall in 1000 years.

It calculated in 0.02 hour.

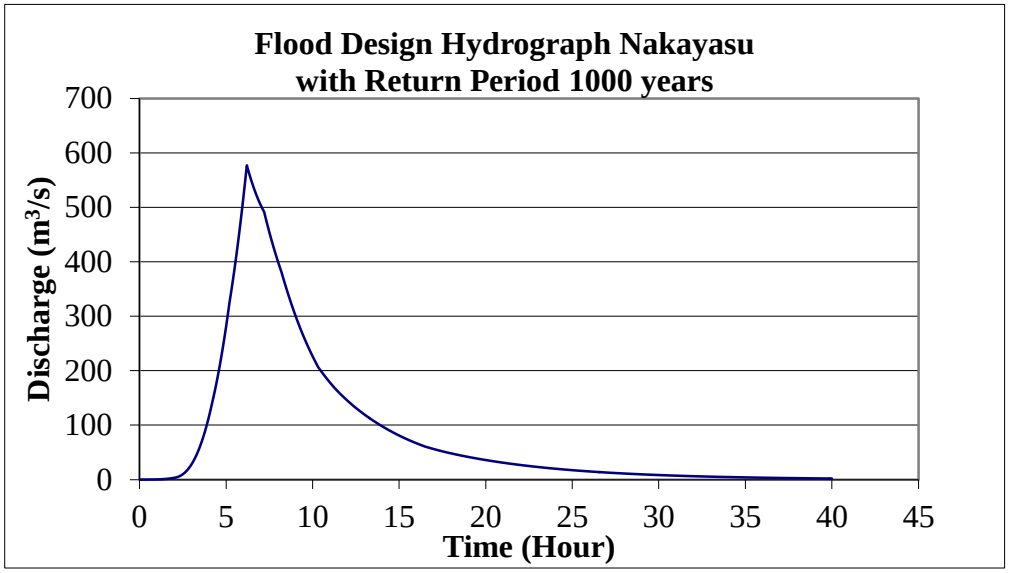

Figure 3. Graph of Hydrograph Nakayasu

3.8 Flood Routing Analysis

In determining the total storage should calculate the capacity of dam by looking at the area and also the elevation of dam. This analysis will show with the graph which correlate between elevation and the volume.

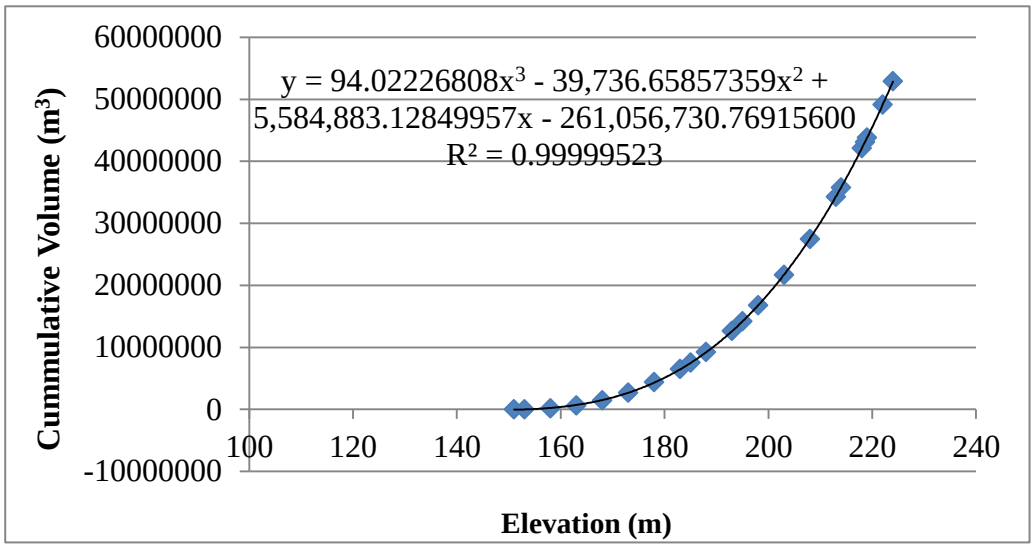

Figure 4. Graphic Relationship between Elevation and Volume

From the graph above, it conclude that the capacity or volume of dam has an equation as :

$S = 94.02226808\ h^3 - 39{,}736.65857359\ h^2 + 5{,}584{,}883.12849957\ h - 261{,}056{,}730.76915600$

Then, to calculate the flood routing in dam it used Newton Raphson method. This method needed the data of discharge by calculation of hydrograph nakayasu before in return period of 1000 years as inflow. Also the PMF discharge to give the appropriate result of safety in dam. Then the equation above as a storage of dam. For the outflow itself, calculate the discharge as used side type for spillway. This analysis will make a differentiation of spillway elevation. Based on the analysis from consultant in the Bendo dam project, the appropriate height of spillway elevation is 218.6 m. Then, to know the effect of changes in spillway elevation of damping flood, this routing will increase the elevation in 2 m height above as 220.6 m. Also to minimize the overtopping, it decrease the elevation in 2 m height below as 216.6 m and 214.6 m both return period 1000 years and PMF discharge. The graph of flood routing shown at figure below:

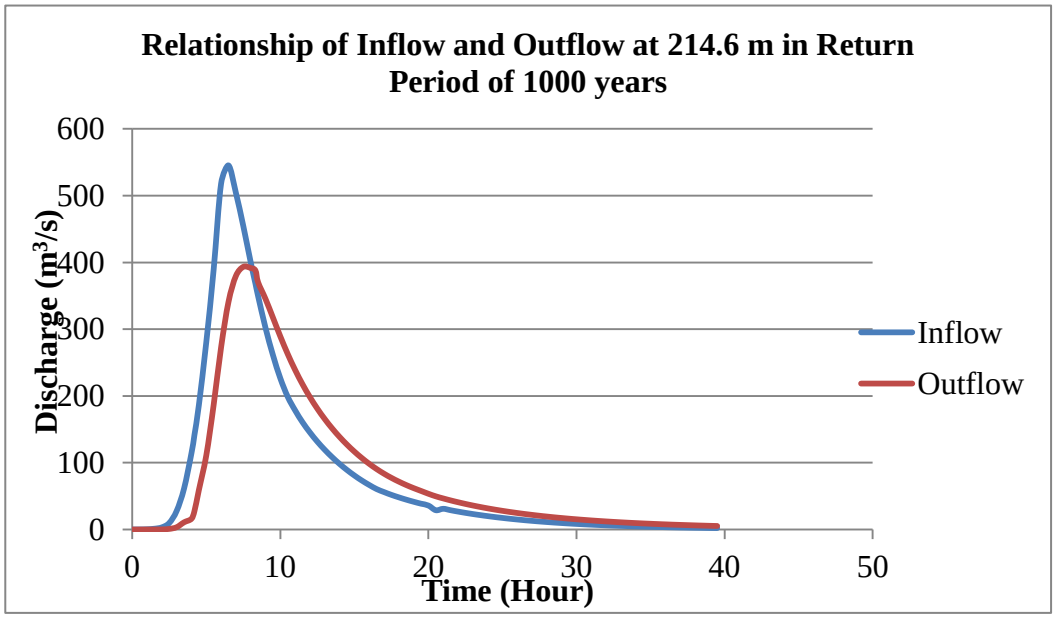

Figure 5. Graph of Inflow and Outflow at Elevation of 214.6 m in Return Period of 1000 years

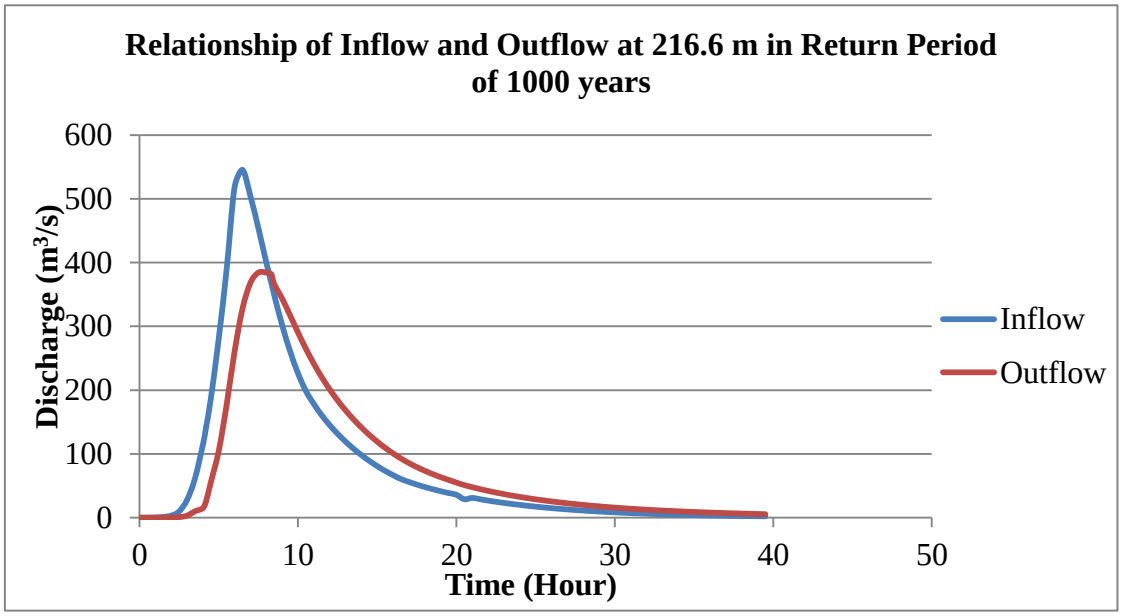

Figure 6. Graph of Inflow and Outflow at Elevation of 216.6 m in Return Period of 1000 years

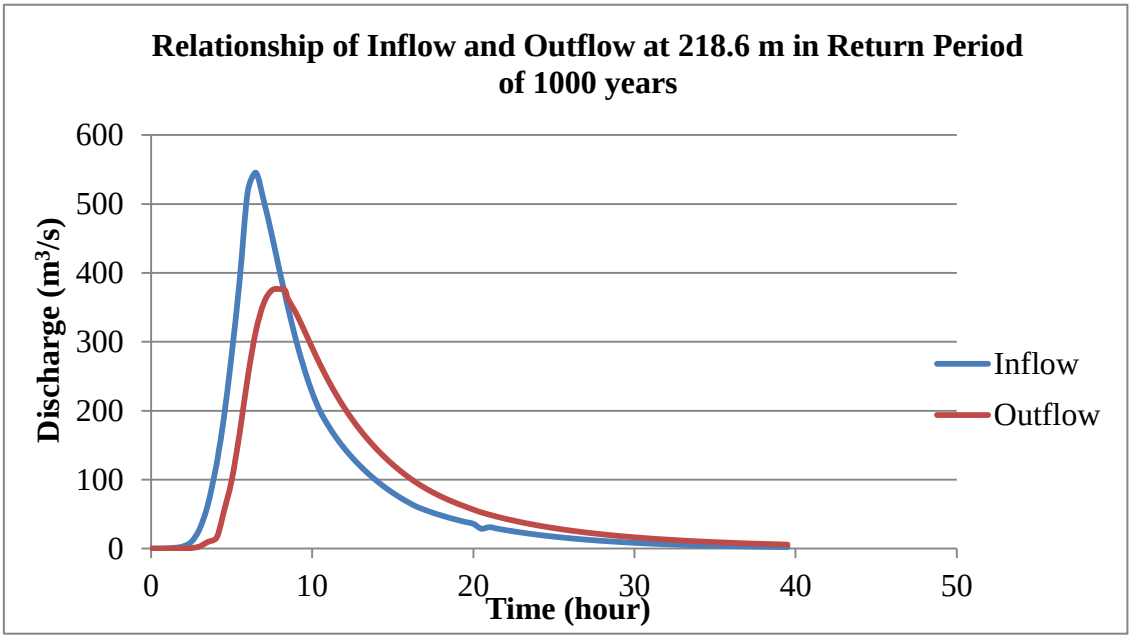

Figure 7. Graph of Inflow and Outflow at Elevation of 218.6 m in Return Period of 1000 years

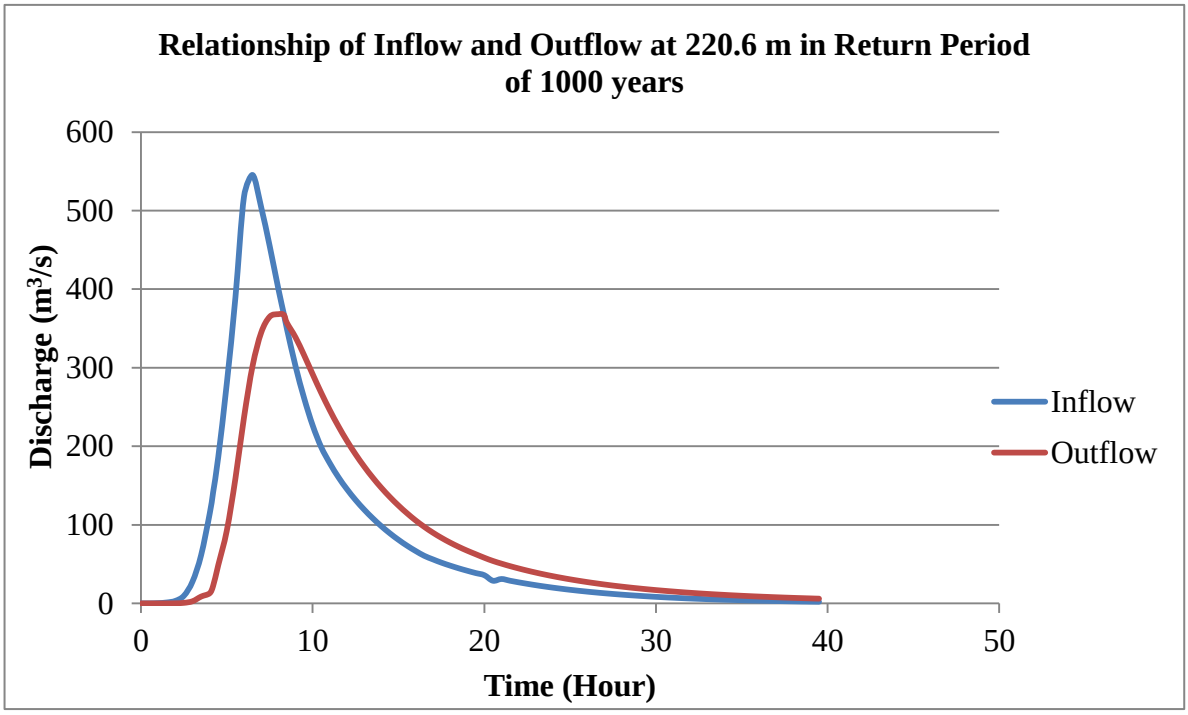

Figure 8. Graph of Inflow and Outflow at Elevation of 220.6 m in Return Period of 1000 years

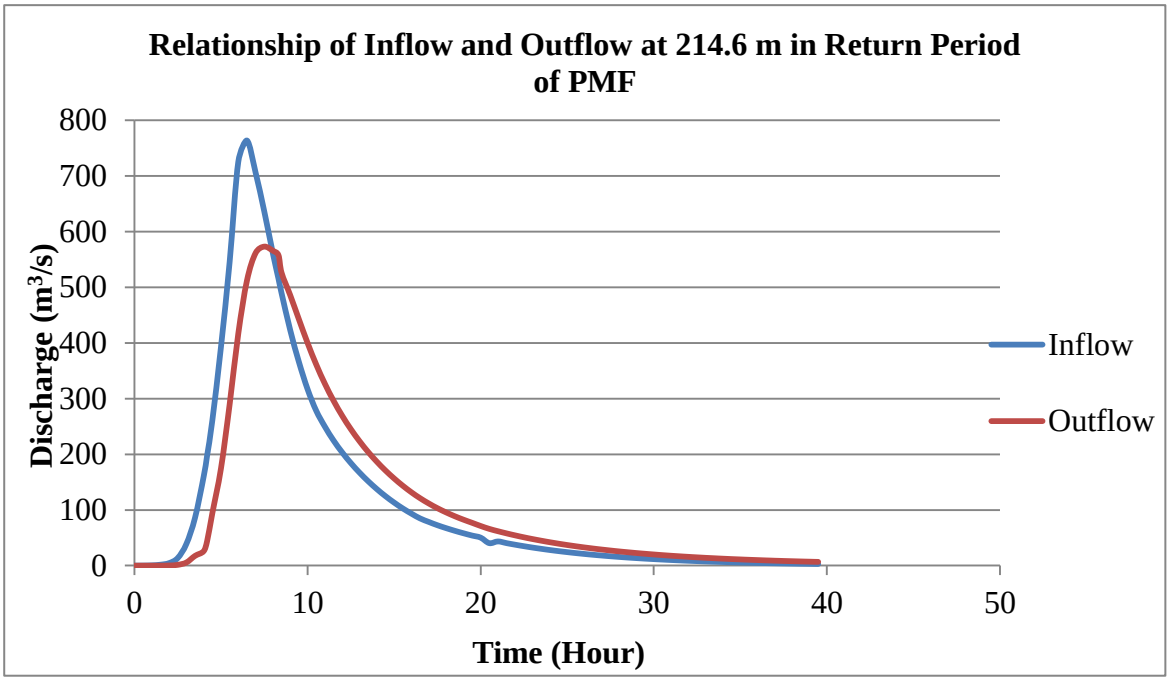

Figure 9. Graph of Inflow and Outflow at Elevation of 214.6 m in Return Period of PMF

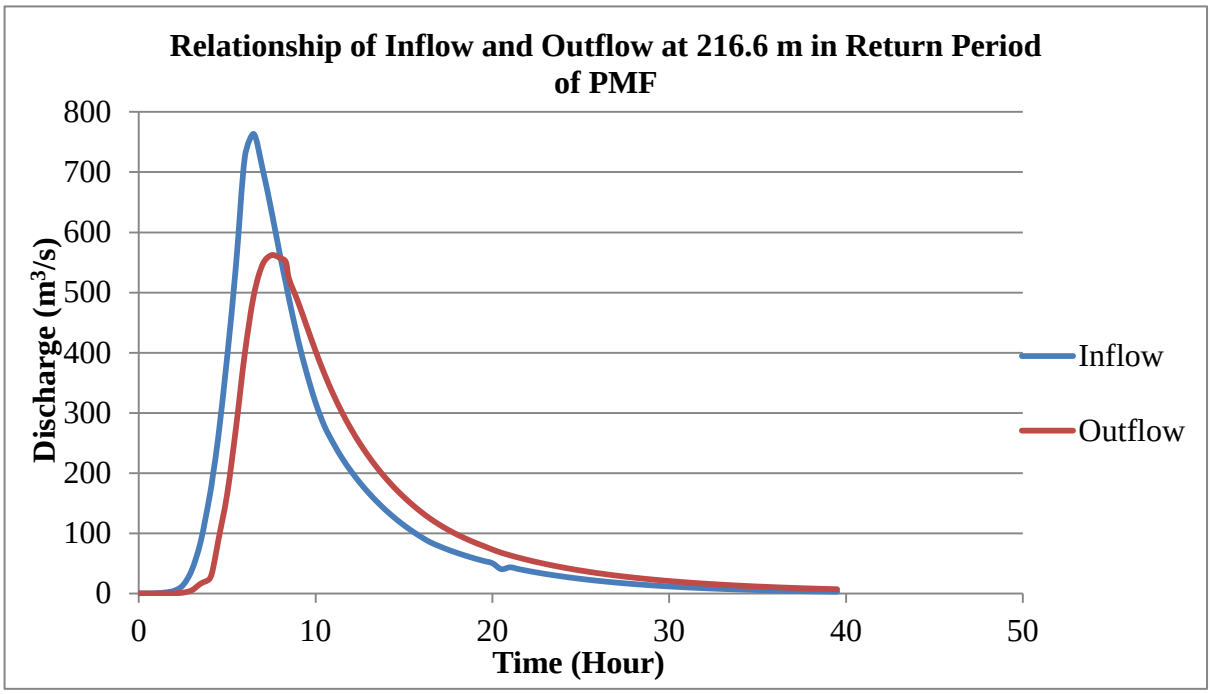

Figure 10. Graph of Inflow and Outflow at Elevation of 216.6 m in Return Period of PMF

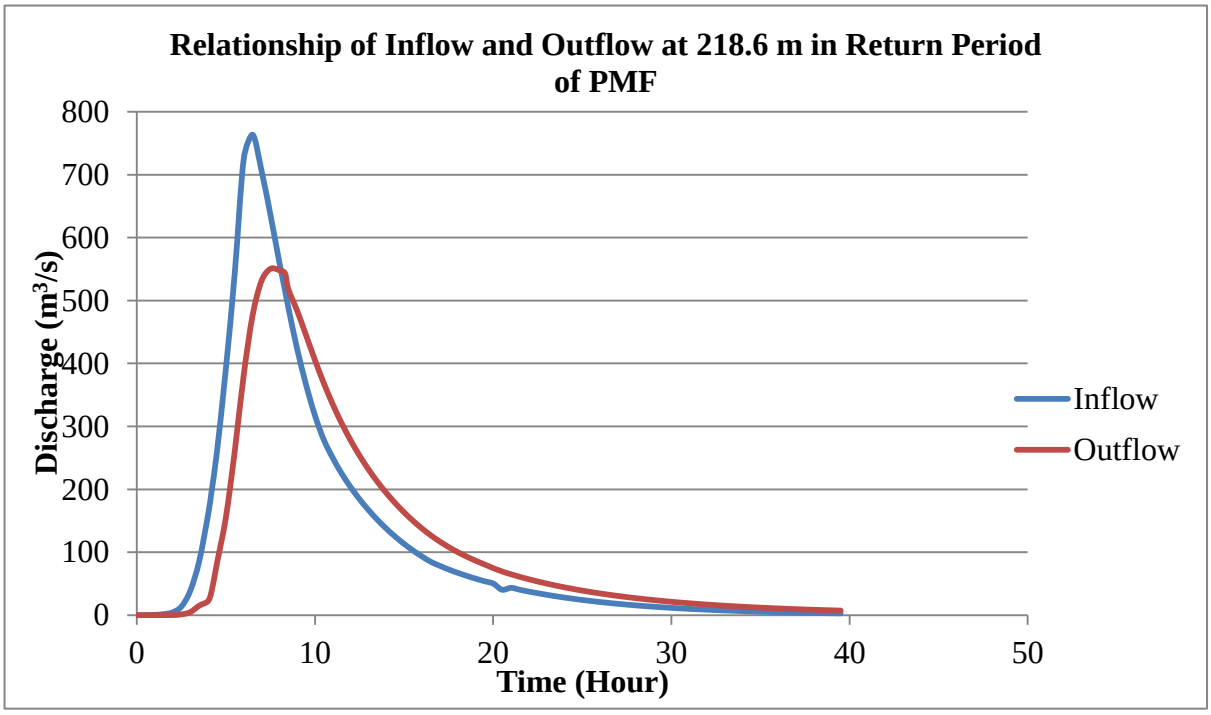

Figure 11. Graph of Inflow and Outflow at Elevation of 218.6 m in Return Period of PMF

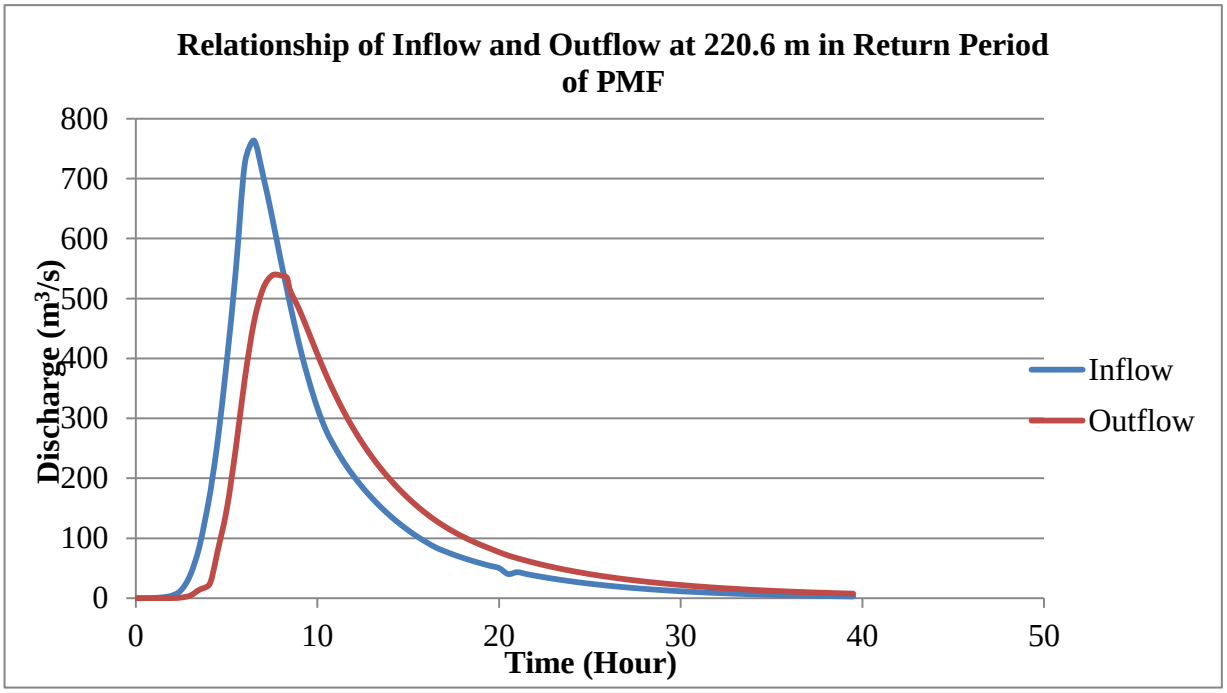

Figure 12. Graph of Inflow and Outflow at Elevation of 220.6 m in Return Period of PMF

Table 8. Result of Flood Routing

Return Period	Spillway Elevation (m)	Peak Dam Elevation (m)	Flood Water Level Elevation (m)		Freeboard Real (m)		Max. Outflow (m^3/s)	Max. Inflow (m^3/s)	Flood Attenuation
			Max	Min	Max	Min			
1000 years	214.600	224.000	216.5679	214.60	9.40	7.43	393.422	545.3847	27.863%
	216.600	224.000	218.5372	216.60	7.40	5.46	384.259	545.3847	29.543%
	218.600	224.000	220.5107	218.60	5.40	3.49	376.416	545.3847	30.982%
	220.600	224.000	222.4827	220.60	3.40	1.52	368.191	545.3847	32.490%
PMF	214.600	224.000	217.1303	214.60	9.40	6.87	573.0423	763.5386	24.949%
	216.600	224.000	219.0977	216.60	7.40	4.90	562.044	763.5386	26.390%
	218.600	224.000	221.0631	218.60	5.40	2.94	550.450	763.5386	27.908%
	220.600	224.000	223.0268	220.60	3.40	0.97	538.354	763.5386	29.492%

Based on table above, to know the safety and the effect of spillway elevation we can conclude that the minimal freeboard of JANCOLD (The Japanese National Committee on Large Dams) standard on earth fill dam type should has 3 m above of height dam in between 50 – 100 m.

Table 9. Freeboard Safety by JANCOLD

No.	Dam Height (m)	Concrete Dam	Earthfill Dam
1	< 50	1 m	2 m
2	50 - 100	2 m	3 m
3	100 <	2.5 m	3.5 m

Because of the height of spillway in dam construction was 71 m was safety in this calculation. Moreover, it will be more safety that can be lower than that. On the other hand, the damping flood of spillway will be increase while the elevation increase also, because the amount of outflow is decrease.

4. CLOSING

4.1 Conslusion

Based on the result of this analysis, can be conclude into several points as follows:

a. In discharge planning of 1000 years with newton raphson method in flood routing analysis, it conclude that the spillway elevation of Bendo dam 218.6 m was safety against overtopping.
b. The effect of spillway elevation on flood attenuation is increase while the elevation increase also. In return period 1000 years the lowest value was 27.863% at top elevation 214.6 m and increasing into 29.543% at top elevation 216.6 m, 30.982% at top elevation 218.6 m and maximum was 32.490% at top elevation 220.6 m. Then, at PMF discharge, the lowest value was 24.949% at top elevation 214.6 m and increasing into 26.390% at top elevation 216.6 m, 27.908% at top elevation 218.6 m and maximum was 29.492% at top elevation 220.6 m.

4.2 Suggestion

Based on the result on analysis, the suggestion as follows:

a. For further analysis, can be adding next year rain data.
b. In comparing the calculation of discharge plan can be adding with each return period.
c. For safety is better to get a data for freeboard calculation.

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