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Analysis of the impact of dam slope modifications on the sensitivity to rapid drawdown, earthquakes, and changes in water level at the Jragung Dam in Semarang Regency

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ABSTRACT

Urugan-type dams are the most common type of dam to work on in Indonesia, with a material composition that is easy to obtain and relatively more economical. Based on the results of slope stability, a sensitivity analysis will be carried out based on changes in slope slope to post-construction conditions, during reservoir operation water level and rapid drawdown conditions. In this study, we will analyze the changes in the value of safety factors that occur on the slope of the body of the Jragung Dam due to rapid drawdown events and seismicities (OBE and MDE) using the help of seepage analysis calculation software and slope stability. There are three models used, namely Model 1 using geometry according to DED (slope of upstream slope 1: 3.0 and slope of downstream slope 1: 2.5), Model 2 of using modification of field construction geometry (slope of upstream slope 1: 2.5 and slope of downstream slope 1: 2.5), Model 3 of using modification of field construction geometry (slope of upstream slope 1: 2.5 and slope of downstream slope 1: 2,25). From the three models, the initial stage will be processed to find the phreatic line on the dam body when drawdown and the next stage to find the value of the dam slope safety factor. After the overall analysis was carried out both in terms of seepage analysis and stability analysis of the three simulation models, for the construction in the field on the Jragung dam, the 3rd Model can be used, namely the proposed geometric modification with an upstream slope of 1: 2.5 and a downstream slope of 1: 2.25, and material parameters according to the availability specifications at the work site. Regarding the stability of the slope, it is noted that at the time of the MDE earthquake load of 10,000 years, when the rapid-drawdown conditions y/h = 0.5h and y/h = 0.75h there is a possibility that the Jragung dam will be damaged, but not collapsed.

Introduction

Urugan-type dams are the most common type of dam to work on in Indonesia, with a material composition that is easy to obtain and relatively more economical than concrete-type dams (Wicaksono, 2023). However, behind the advantages of this type of dam, some things need to be considered in the design and construction process, for example, related to the stability of the slope of the dam body.

The Jragung Dam is located in Candirejo Village, Pringapus District, Semarang Regency. Geographically, it is located at coordinates 6°52'19.41"S and 111°15'30.20" E located in the Jragung Watershed (Jragung Watershed Area 94.00 km^2). The geographical location of the Jragung watershed is in the northern part of Central Java which crosses 4 districts, starting from the widest Demak Regency, Semarang Regency, Grobogan Regency, and Semarang City (PT. Indra Karya, 2019).

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The history of earthquakes around the location of the Jragung dam in the period 1600 – 2018, recorded at more than 4.00 magnitude; obtained from the USGS website. One of them occurred on Saturday, October 23, 2021, in the early morning at 00:32 WIB, the Salatiga, Banyubiru, Bawen, and Ambarawa City areas in Central Java were shaken by a tectonic earthquake. The results of BMKG's analysis show that this earthquake has a magnitude of M = 3.00 to M = 3.30. The epicentre is located at coordinates 7,296 LS and 110,385 BT, precisely on land at a distance of 13.00 km northwest of Salatiga city with a hypocenter depth of 6.00 km. Refer to Figure 1.7 which explains the seismicity map of Central Java province and its surroundings related to the relationship between earthquake depth and magnitude. By paying attention to the location of the epicentre and the depth of the hypocenter, the earthquake that occurred on October 23, 2021, was a type of shallow earthquake due to activity in the active fault segment of Merapi-Merbabu (PT. Rayakonsult KSO, 2021).

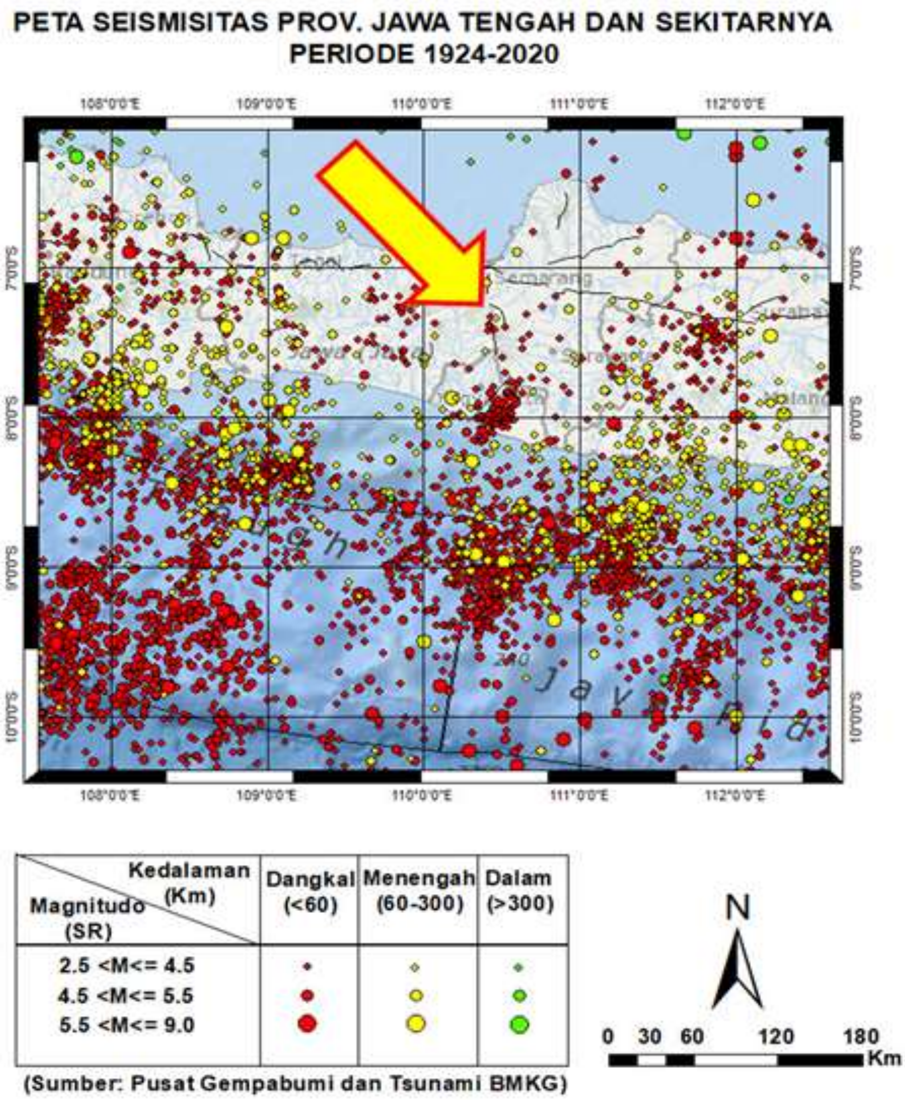

Figure 1 Seismizity Map of Prov. Central Java and its surroundings Per. 1924-2020 (PT. Rayakonsult KSO, 2021)

There are 5 active faults adjacent to the location of the Jragung Dam including, the Semarang fault, the Rawapening fault, the Merapi-Merbabu fault, the Pati fault, and the Opak fault as shown in Figure 1.8. Based on the image shown in Figure 1.9, we can see that the distance of the Jragung dam to the Merapi-Merbabu active fault is as far as 29.60 km (PT. Rayakonsult KSO, 2021).

Based on several lists of dam slope stability cases around the world, most construction failures are caused by rapid drawdown, which is a condition when the water level of a dam drops suddenly (Putra, Najib, & Hidayatillah, 2017). As is known, the rapid drawdown of the water level can reduce the safety condition of the slope in saturated conditions because the water pressure outside the dam body is reduced while the inner pore water pressure does not support the stability of the dam body itself (Nainggolan, 2023).

For the case study of the Campolattaro dam investigated by (Sica, Pagano, & Rotili, 2019), the occurrence of an earthquake can reduce the safety of the upstream slope during the rapid descent phase at y/h=0.50 when the speed > 1.00 m/day. The slower the descent time, the more stable the dam will be (the SF value is higher). In contrast, sudden changes in the water level on the slopes, without allowing time for drainage downstream, result in unsafe conditions (Pramulandani, 2020). It can be seen in Table 1.13 that the safe emptying of the reservoir y/h=1.00 due to the earthquake was identified within 1.00 m/day.

From the formulation of the problem above, several goals will be made to solve the problem. The objectives of the preparation of this research include the following:

1. To determine the effect of seepage of the Jragung dam body (initial design and modification proposal) during the water level condition of reservoir operation and rapid receding operation (simulation of rapid drawdown conditions).
2. Determine the safety factors of the slope of the Jragung dam body (initial design and modification proposal) at the time of simulation of the conditions of completion of construction
3. Determine the safety factors of the slope of the Jragung dam body (initial design and modification proposal) during the simulation of the water level conditions of reservoir operation.
4. Determine the safety factors of the slope of the Jragung dam body (initial design and modification proposal) during the simulation of rapid drawdown conditions.
5. To determine the relationship between the sensitivity of the slope of the dam body to the variation of the operating water level, the speed of drawdown, when an earthquake occurs, and the difference in slope slope.

Research Methods

A preliminary survey is carried out to find out the current condition of the project location to be researched and identify problems in the field so that they can take steps to find solutions to the problems that occur. A preliminary survey was also carried out to collect technical data on the Jragung dam so that accurate data could be used in analyzing slope stability.

The intended literature study is to collect materials that will be used as a reference in conducting research. The study materials that will be used in this study include the following:

1. References regarding slope stability calculations, seepage analysis and rapid drawdown analysis on the dam body.
2. References on the operation of slope stability aids & seepage analysis.
3. References to the effect of earthquake loads on slope stability.
4. References to sensitivity analysis that affects dams.
5. Regulations in force in Indonesia are related to dam structures.

Data Collection

Data collection is carried out by collecting related technical data that will be used in the process of analyzing the slope stability of the dam body. The data needed in the analysis is a type of secondary data. Secondary data is data obtained indirectly in the form of records, survey results or research results from other agencies or parties.

Earthquake Load Coefficient Analysis

This section aims to classify the earthquake zones and calculate the earthquake coefficient that will be used in the area where the Jaragung dam construction project is located. The earthquake analysis method used for modelling the Jragung dam is classified into two, namely static earthquake analysis and modified earthquake analysis Operating Base Earthquake (OBE) – Maximum Design Earthquake (MDE). The earthquake coefficient obtained will later be applied as seismic input in software to help analyze the stability of the dam body's slope.

Seepage Analysis

Seepage analysis was used to determine the water level (phreatic line) in the body of the Jaragung dam. To help in modelling this phreatic line, the SEEP/W program is used. Through the SEEP/W software, the phreatic line on the dam body can be immediately known according to the material permeability coefficient.

Modelling during rapid drawdown in the SEEP/W software is carried out in a steady state condition and followed by a transient condition. In transient conditions, the phreatic line is reviewed that changes over time, therefore it is necessary to determine the calculation of the time. In transient conditions, the water level is reviewed in a period starting from the initial time, 30 days, 60 days, to 80 days.

Slope Stability Analysis

Slope stability analysis is used to determine the safety factor in the body of the Jaragung dam. For the calculation of the safety factor, the SLOPE/W auxiliary program will be used. So that the output of the SEEP/W that has been carried out is used as the pore water pressure value in the analysis settings of SLOPE/W.

In modelling the stability of the slope, in addition to normal conditions (steady state), the influence of static earthquake loads and modified earthquakes Operating Base Earthquake (OBE) at the 100-year reage – Maximum Design Earthquake (MDE) at the 10,000-year reage will also be modelled. In earthquakes, the modified earthquake coefficient applied uses a variation in earthquake depth y/h = 0.25; y/h = 0.5; y/h = 0.50; y/h = 1.00; where H is the height of the dam.

Results and Discussion

Analysis of the Sensitivity of the Influence of Water Level on the Value of Slope Stability Safety Factor in the Jragung Dam

The analysis of water level sensitivity due to the influence of elevation changes on the value of dam body safety factors (SF) is an effort to understand how changes in water level elevation can affect dam stability (Candra & Pratiwi, 2010). The purpose of this analysis is to determine how sensitive the value of the safety factor of the body of the

Jragung dam is to changes in water level elevation, which is an important factor in the management and operation of the dam (Juwono, Subagiyo, & Winarta, 2022).

In this analysis, it will be divided into two, namely the effect of water level change on the upstream slope side and water level change on the downstream slope side. The conditions used for this sensitivity analysis are only under normal conditions without the influence of earthquake loads and will be applied to 3 simulation models (Rohmawati, 2022).

Analysis of the Sensitivity of the Influence of Upstream Water Level on Safety Factor Value

To calculate the sensitivity value of the influence of water level on the safety factor based on the existing data, we can use the elevation change (water level) as the variable that affects (X) and the change in the Safety Factor (SF) as the variable that affects (Y). With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value. The preliminary data for the calculation of this sensitivity value can be seen in Table 1 and the comparison graph in Figure 2.

Table 1
Data on Comparison of Safety Factor Values According to Water Level Elevation Conditions (Upstream)

Water Level	Elevation	Safety Factor Upstream Normal Condition		
		Model 1	Model 2	Model 3
Empty	67.76	4.758	4.620	4.708
MAR	93.00	3.784	3.743	3.748
MAN	115.00	4.877	4.911	4.946
MAB	117.28	5.033	5.059	5.113
RDD	93.00	3.779	3.740	3.745

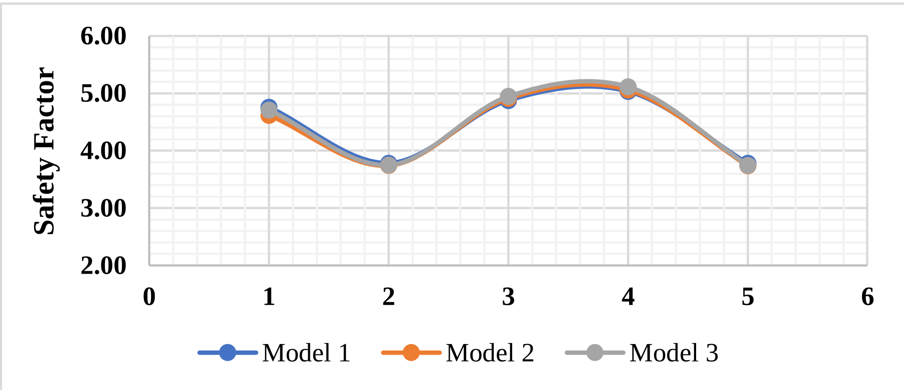

Figure 2 Comparison chart of safety factor values of water level elevation conditions (upstream)

The next step is to calculate the relative change in water level elevation (ΔX/X) followed by the calculation of the relative change in the safety factor (ΔSF/SF). Then with the equation 2-27 in Chapter 2, the value of Sn is calculated.

Table *2*
Calculation of Sn Value of Simulation Model 1 Effect of Water Level Elevation (Upstream)

Water Level	Elevation (X)	Model 1 (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
Empty	67.76	4.758					
MAR	93.00	3.784	25.240	0.372	- 0.974	- 0.205	- 0.550
MAN	115.00	4.877	22.000	0.237	1.093	0.289	1.221
MAB	117.28	5.033	2.280	0.020	0.156	0.032	1.613
Average Sn in Simulation Model 1							**0.762**

Table *3*
Calculation of Sn Value of Simulation Model 2 Effect of Water Level Elevation (Upstream)

Water Level	Elevation (X)	Model 2 (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
Empty	67.76	4.620					
MAR	93.00	3.743	25.240	0.372	- 0.877	- 0.190	- 0.510
MAN	115.00	4.911	22.000	0.237	1.168	0.312	1.319
MAB	117.28	5.059	2.280	0.020	0.148	0.030	1.520
Average Sn in Simulation Model 2							**0.777**

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Calculation of Sn Value of Simulation Model 3 Effect of Water Level Elevation (Upstream)

Water Level	Elevation (X)	Model 3 (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
Empty	67.76	4.708					
MAR	93.00	3.748	25.240	0.372	- 0.960	- 0.204	- 0.547
MAN	115.00	4.946	22.000	0.237	1.198	0.320	1.351
MAB	117.28	5.113	2.280	0.020	0.167	0.034	1.703
Average Sn in Simulation Model 3							**0.836**

Table *5*
Calculation of Average Sn Value Influence of Water Level Elevation (Upstream)

Model	Sn Value
Simulation Model 1	0.762
Simulation Model 2	0.777
Simulation Model 3	0.836
Average Sn Value	**0.791**

From the three simulation models, the average Sn value will be taken due to the influence of the water level on the upstream slope, so that from Table 4.54 the average Sn value = 0.791 is obtained (Nugraha, Prayudha, Ibrahim, & Riyadi, 2017). The sensitivity value (Sn) between data points starting from the empty water level after construction to the flood water level is 0.791. This means that a 1% change in elevation leads to a change of about 0.791% in the Safety Factor value. The greater the absolute Sn value, indicating that the safety factor is very sensitive to changes in water level elevation (Kusnandar, 2019). The smaller the absolute Sn value, indicating that the safety factor is not too sensitive to changes in water level elevation. The negative Sn value indicates that the safety factor decreases when the water level elevation increases.

Sensitivity Analysis of the Influence of Downstream Water Level on Safety Factor Value

The same application applies to the downstream slope side, we can use the elevation change (water level) as the variable that affects (X) and the change in the Safety Factor (SF) as the variable that affects (Y). The preliminary data for the calculation of this sensitivity value can be seen in Table 6 and the comparison graph in Figure 3.

Table 6
Comparative Data on Safety Factor Values According to Water Level Elevation Conditions (Downstream)

Water Level	Elevation	Safety Factor Downstream Normal Condition		
		Model 1	Model 2	Model 3
Empty	67.76	5.228	5.405	5.859
MAR	93.00	3.653	3.822	3.791
MAN	115.00	3.606	3.725	3.707
MAB	117.28	3.475	3.778	3.685
RDD	93.00	3.654	3.824	3.787

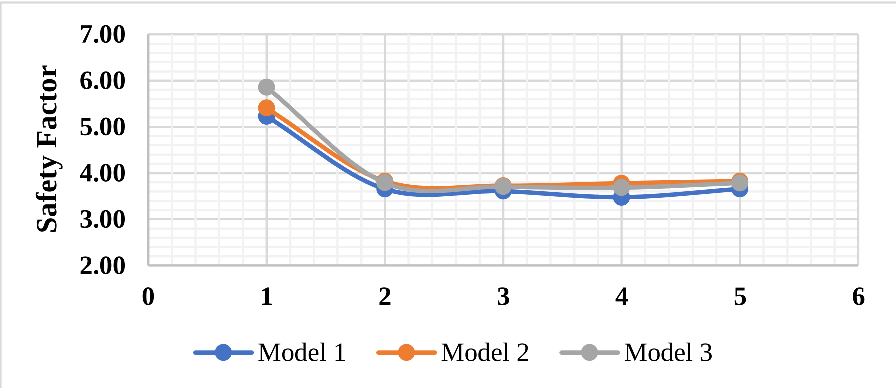

Figure 3 Comparison Chart of Safety Factor Values of Water Level Elevation Conditions (Downstream)

The next step is to calculate the relative change in water level elevation (ΔX/X) followed by the calculation of the relative change in the safety factor (ΔSF/SF). Then with the equation 2-27 in Chapter 2, the value of Sn is calculated. Details of the calculation will be presented in Table 7 to Table 10.

Table *7*
Calculation of Sn Value of Simulation Model 1 Effect of Water Level Elevation (Downstream)

Water Level	Elevation (X)	Model 1 (SF)	Δx	Δx/X	ΔSF	ΔSF/ SF	Sn
Empty	67.76	5.228					
MAR	93.00	3.653	25.240	0.372	- .1.575	- 0.301	- 0.809
MAN	115.00	3.606	22.000	0.237	- 0.047	- 0.013	- 0.054
MAB	117.28	3.475	2.280	0.020	- 0.131	- 0.036	- 1.832
Average Sn in Simulation Model 1							**- 0.899**

Table *8*
Calculation of Sn Value of Simulation Model 2 Effect of Water Level Elevation (Downstream)

Water Level	Elevation (X)	Model 2 (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
Empty	67.76	5.405					
MAR	93.00	3.822	25.240	0.372	- 1.583	- 0.293	- 0.786
MAN	115.00	3.752	22.000	0.237	- 0.097	- 0.025	- 0.107
MAB	117.28	3.778	2.280	0.020	0.053	0.014	0.718
Average Sn in Simulation Model 2							**- 0.059**

Table *9*
Calculation of Sn Value of Simulation Model 3 Effect of Water Level Elevation (Downstream)

Water Level	Elevation (X)	Model 3 (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
Empty	67.76	5.859					
MAR	93.00	3.791	25.240	0.372	-.2.068	- 0.353	- 0.948
MAN	115.00	3.707	22.000	0.237	- 0.084	- 0.022	- 0.094
MAB	117.28	3.685	2.280	0.020	- 0.022	- 0.006	- 0.299
Average Sn in Simulation Model 3							**- 0.447**

Table *10*
Calculation of the Average Sn Value of the Effect of Water Level Elevation (Upstream)

Model	Sn Value

Original Model	- 0.899
Alternative Model 1	- 0.059
Alternative Model 2	- 0.447
Average Sn Value	**- 0.468**

Sensitivity Analysis of the Effect of Rapid Drawdown Time Speed on Normal Conditions on Safety Factor Value

To calculate the sensitivity value of the effect of the speed of the rapid drawdown time on the safety factor based on the existing data, we can use the change in the rapid drawdown time as the variable that affects (X) and the change in the Safety Factor (SF) as the variable that affects (Y). With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value.

Sensitivity Analysis of the Effect of Rapid Drawdown Time Speed on the Downstream Side Conditions of Static Earthquake Effect on Safety Factor Value

The same application applies to the downstream slope side during earthquake conditions, we can use the change in the time of rapid ebb and flow as the variable that affects (X) and the change in the Safety Factor (SF) as the variable that affects (Y). With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value.

Sensitivity Analysis of the Effect of Earthquake Load on the Value of Slope Stability Safety Factor in the Jragung Dam

The next sensitivity analysis is the effect of earthquake load on the value of the slope stability safety factor at the Jragung dam, which is an evaluation process to understand how changes in earthquake load intensity affect slope stability. The earthquake load that occurs can significantly affect the stability of the slope, especially in conditions that are already critical. It can also be useful for identifying potential risks of slope failure caused by earthquake loads.

This analysis is only carried out on the upstream slope side and will be divided into two, namely: when the water level is normal and the water level is rapidly receding (rapid drawdown) with the influence of the 100-year OBE earthquake load and the 10,000-year MDE earthquake load and will be applied to 3 simulation models.

Sensitivity Analysis of Normal Water Level Conditions The Effect of OBE 100 Years and MDE 10,000 Years Earthquake on Safety Factor Values

To calculate the sensitivity value of normal water level conditions of the influence of OBE earthquake load of 100 years and MDE 10,000 years on the safety factor based on existing data, we can use the change in the earthquake coefficient as the influencing variable (X) and the change in the Safety Factor (SF) as the influencing variable (Y). In this analysis of the sensitivity of normal water level conditions, the earthquake coefficient used was 100%. With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value. The initial data for the calculation of this sensitivity value can be seen in Table 11 and the comparison graph in Figure 4.

Table 11
Comparative Data on Safety Factor Values of Normal Water Level Conditions Affected by the 100-Year OBE Earthquake and the 10,000-Year MDE Earthquake

Conditions	Earthquake Coefficient	Safety Factor Upstream		
		Model 1	Model 2	Model 3
Normal Conditions	-	4.877	4.911	4.946

Static Earthquake Conditions	0.090	3.074	3.285	3.297
OBE Earthquake 100 Th 0.25 H	0.125	5.685	5.314	5.315
OBE Earthquake 100 Th 0.50 H	0.104	3.328	3.372	3.400
OBE Earthquake 100 Th 0.75 H	0.095	2.598	2.601	2.609
OBE Earthquake 100 Th 1.00 H	0.086	3.126	3.611	3.348
MDE Earthquake 10000 Th 0.25H	0.873	1.581	1.546	1.545
MDE Earthquake 10000 Th 0.50H	0.729	0.990	0.973	0.977
MDE Earthquake 10000 Th 0.75H	0.664	0.700	0.758	0.779
MDE Earthquake 10000 Th 1.00H	0.600	0.923	1.067	1.066

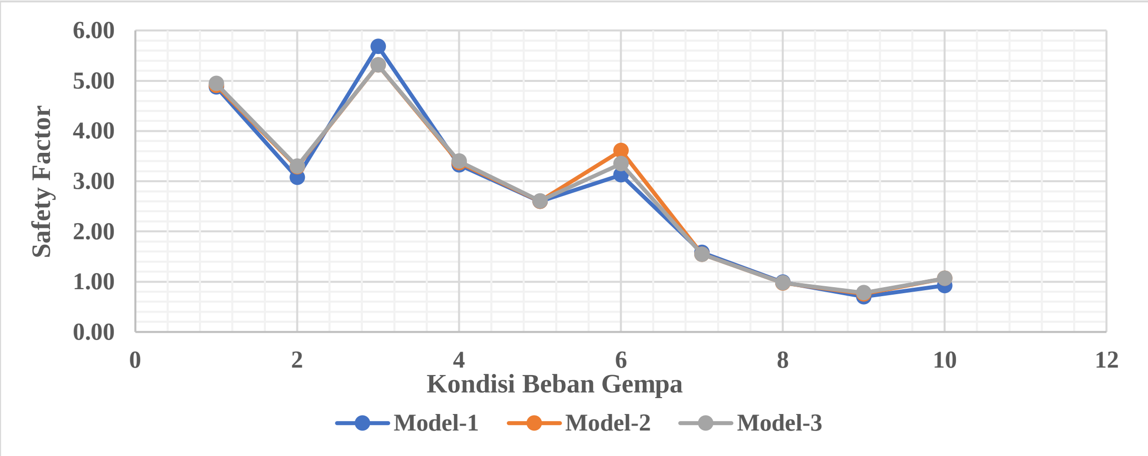

Figure *Error! No text of specified style in document.* **Chart of Safety Factor Values of Normal Water Level Conditions Affected by the 100-Year OBE Earthquake and the 10,000-Year MDE Earthquake**

Analysis of the Sensitivity of Rapid Drawdown Water Level Conditions The Effect of OBE 100 Years and MDE 10,000 Years Earthquake on Safety Factor Values

Furthermore, the same application also applies to calculations during rapid drawdown conditions, we can use changes in earthquake coefficients as variables that affect (X) and changes in Safety Factor (SF) as variables that affect (Y). In this analysis of the sensitivity of the rapidly receding surface condition, the earthquake coefficient used was 50%. With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value.

Sensitivity Analysis of the Effect of Slope Slope on the Value of Slope Stability Safety Factor in the Jragung Dam

The sensitivity analysis of the influence of slope slope on the value of slope stability safety factor at the Jragung dam is an evaluation process to understand how changes in slope slope affect slope stability. The slope of the slope is one of the important factors that affect stability, as small changes in slope can significantly affect the likelihood of landslides or other instability. The slope coefficient is based on the value of the planned slope angle on the Jragung dam.

In this analysis, the sensitivity calculation is carried out on the upstream slope side and the downstream slope side with the influence of operating water level conditions and fast low tide water level and will be applied to 3 simulation models. As a limitation for sensitivity analysis due to the influence of slope, this does not take into account the influence of earthquakes.

Sensitivity Analysis of the Effect of Slope of Upstream Side Slope on Safety Factor Value

To calculate the sensitivity value of the influence of slope on the safety factor based on existing data, we can use the change in the slope angle as the variable that affects (X) and the change in the Safety Factor (SF) as the variable that affects (Y). With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value. The initial data for the calculation of this sensitivity value can be seen in Table 12 and the comparison graph in Figure 5.

Table *12*
Comparative Data on Safety Factor Values Affected by Upstream Slope Slope

Slope	Angles	Safety Factor Upstream Normal Condition					Description
		Empty	MAR	MAN	MAB	RDD	
1: 3.00	18.000	4.758	3.784	4.877	5.033	3.779	Model 1
1: 2.50	22.000	4.620	3.743	4.911	5.059	3.740	Model 2
1: 2.50	22.000	4.708	3.748	4.946	5.113	3.745	Model 3

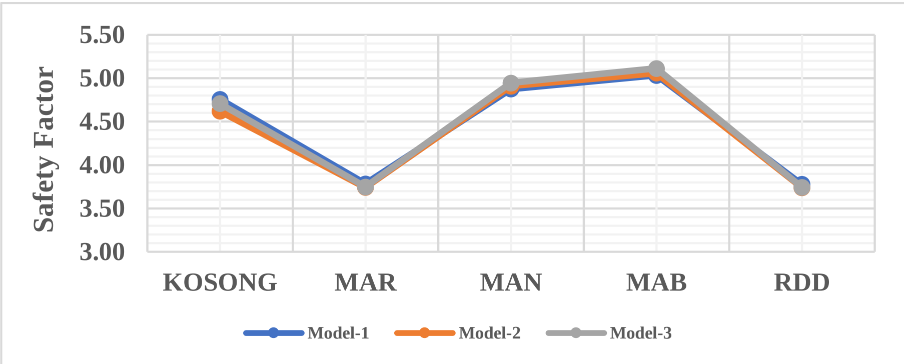

Figure *6*
Comparison Chart of Safety Factor Values Affected by Slope Upstream

Sensitivity Analysis of the Influence of Downstream Side Slope Slope on Safety Factor Value

The same application applies to the downstream slope side, we can use the change in the slope angle as the influencing variable (X) and the change in the Safety Factor (SF) as the influencing variable (Y). With equations 2-27 in the previous Chapter 2, we can calculate the sensitivity value. The preliminary data for the calculation of this sensitivity value can be seen in Table 13 and the comparison graph in Figure 7.

Table *13*
Comparative Data on Safety Factor Values Affected by Downstream Slope Slope

Slope	Angles	Safety Factor Downstream Normal Condition					Description
		Empty	MAR	MAN	MAB	RDD	
1: 2.50	22.000	5.228	3.653	3.606	3.475	3.654	Model 1
1: 2.50	22.000	5.405	3.822	3.725	3.778	3.824	Model 2
1: 2.25	24.000	5.859	3.791	3.707	3.685	3.787	Model 3

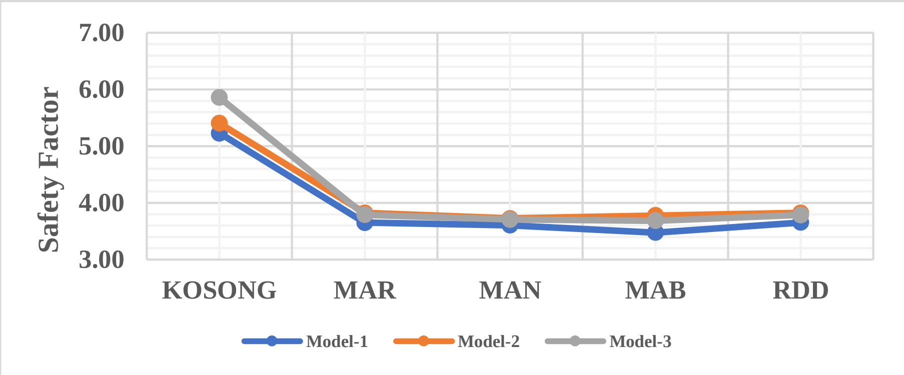

Figure *7*
Comparison Chart of Safety Factor Values Affected by Downstream Slope Slope

The next step is to calculate the relative change in the slope angle coefficient (ΔX/X) followed by the calculation of the relative change in the safety factor (ΔSF/SF). Then with the equation 2-27 in Chapter 2, the value of Sn is calculated. Details of the calculation will be presented in Tables 14 to 19.

Table *14*
Calculation of Sn Value in Post-Construction Conditions – Downstream Slope Side

Slope	Angles (X)	Empty (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
1: 2.50	22.000	5.228					
1: 2.50	22.000	5.405	2.000	0.091	0.177	0.034	0.372
1: 2.25	24.000	5.859	2.000	0.091	0.631	0.117	1.284
Sn Average on The Downstream Side Of Normal Post-Construction Conditions							**0.828**

Table 15
Calculation of Sn Value in MAR Condition – Downstream Slope Side

Slope	Angles (X)	MAR (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
1: 2.50	22.000	3.653					
1: 2.50	22.000	3.822	2.000	0.091	0.169	0.046	0.509
1: 2.25	24.000	3.791	2.000	0.091	0.138	0.036	0.397
Sn Average on The Downstream Side Normal Low Water Level Conditions							**0.453**

Table *16*
Calculation of Sn Value in MAN Conditions – Downstream Slope Side

Slope	Angles (X)	MAN (SF)	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
1: 2.50	22.000	3.606					
1: 2.50	22.000	3.725	2.000	0.091	0.119	0.033	0.363

1: 2.25	24.000	3.707	2.000	0.091	0.101	0.027	0.298
Sn Average on The Downstream Side Of The Normal Condition Normal Water Level							**0.331**

Table *17*
Calculation of Sn Value in MAB Conditions – Downstream Slope Side

Slope	Angles	MAB	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
	(X)	(SF)					
1: 2.50	22.000	3.475					
1: 2.50	22.000	3.778	2.000	0.091	0.303	0.087	0.959
1: 2.25	24.000	3.685	2.000	0.091	0.210	0.056	0.611
Sn Average at The Downstream Side Of The Normal Flood Level							**0.785**

Table *18*
Calculation of Sn Value in Rapid Drawdown Conditions – Downstream Slope Side

Slope	Angles	RDD	Δx	Δx/X	ΔSF	ΔSF/SF	Sn
	(X)	(SF)					
1: 2.50	22.000	3.654					
1: 2.50	22.000	3.824	2.000	0.091	0.170	0.047	0.512
1: 2.25	24.000	3.787	2.000	0.091	0.133	0.035	0.383
Sn Average on The Downstream Side Of Normal Rapid Low Tide Conditions							**0.447**

Table *19*
Calculation of the Average Sn Value of the Effect of the Slope of the Downstream Slope

Slope	Sn Value					Description
	Empty	MAR	MAN	MAB	RDD	
1: 3.00	-	-	-	-	-	Model 1
1: 2.50	0.372	0.509	0.363	0.959	0.512	Model 2
1: 2.50	1.284	0.397	0.298	0.611	0.383	Model 3
Average Sn Value					**0.569**	

From the three simulation models, the average Sn value will be taken due to the influence of slope on the downstream slope side, so from Table 4.109, the average Sn value = 0.569 on the influence of safety factor is obtained. This means that a 1% change in the amount of the angle of inclination coefficient causes a change of about 0.569% in the Safety Factor value. The greater the absolute Sn value, indicating that the safety factor is very sensitive to changes in the slope angle. The smaller the absolute Sn value, indicating that the safety factor is not too sensitive to changes in the slope angle. If the Sn value is negative, it indicates that the safety factor decreases along with the increase in the slope angle. Meanwhile, if the Sn value is positive, it will indicate that the safety factor increases along with the increase in the slope angle.

Conclusion

In Simulation Model 1, when the water level conditions are normal and the water level recedes rapidly (rapid drawdown), the filtration seepage that occurs in the dam core and the lower foundation is within the safe limit because it does not exceed 0.05% of the reservoir capacity. The filtration flow rate also remains below the critical speed, making it safe from piping hazards. The safety factor (FK) value for piping is 5,702, which is higher than the minimum requirement of 4,000, indicating that the dam is in safe condition. In Simulation Model 2, filtration seepage conditions also remain safe during the operation of the reservoir at normal water level and fast receding. The filtration flow rate that remains below the critical speed indicates that the dam is safe from piping hazards. The FK value for piping of 4,401 meets the minimum safety requirements. Simulation Model 3 shows that the filtration seepage condition remains within the safe limit at normal water level conditions and recedes rapidly. The filtration flow rate that remains below the critical speed also indicates that the dam is safe from piping hazards. The FK value for piping of 4.046 meets the minimum safety requirements. The slope stability analysis in Simulation Model 1 shows that the dam is stable under normal conditions, static earthquakes, and 100-year OBE earthquakes, with a safety factor (SF) higher than the minimum value. However, the dam was not safe in a 10,000-year MDE earthquake with an SF of 0.700 which was lower than the minimum value of 1,000. Nonetheless, the deformation still shows that the damage will not cause the dam to collapse The slope stability in Simulation Model 2 shows that the dam is stable under normal conditions, static earthquakes, and 100-year OBE earthquakes, with a safety factor higher than the minimum value. However, the dam was not safe at the 10,000-year MDE earthquake with an SF of 0.758 which was lower than the minimum value of 1,000. Nonetheless, the deformation shows that the damage will not cause the dam to collapse.

In Simulation Model 3, the slope stability shows that the dam is stable under normal conditions, static earthquakes, and 100-year OBE earthquakes, with a safety factor higher than the minimum value. However, the dam was not safe in a 10,000-year MDE earthquake with an SF of 0.779 which was lower than the minimum value of 1,000. Nonetheless, the deformation shows that the damage will not cause the dam to collapse. Sensitivity analysis shows that the safety factor against changes in water level elevation on the upstream side is quite large, but not too significant on the downstream side. Rapid drawdown time negatively affects the safety factor on the upstream side, but the effect is small. The earthquake load shows that the safety factor is very sensitive to changes in earthquake intensity, with a greater influence on OBE earthquakes than MDE earthquakes. The slope of the upstream slope does not affect the safety factor too much, while the slope of the downstream slope is quite sensitive to changes in the angle of inclination. Overall, the Jragung Dam was declared safe against piping hazards and stable under various simulated conditions. However, the 10,000-year MDE earthquake requires special attention because although the dam was damaged, it did not cause a complete collapse.

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