Kembangan Dam Safety Risk Index Sragen Regency

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Abstract

In dam management, in addition to the safety factors of the structure and condition of the dam and the emergency action plan that needs to be prepared, other elements that need to be considered are the operation, maintenance, monitoring and observation activities of the dam. In extreme circumstances, mistakes in dam operations can be fatal. The dam can fail and cause a massive flood that can damage facilities and infrastructure, and even loss of life downstream of the dam. Risk assessment is a way to identify risks that may occur under various conditions, so that the necessary follow-up can be done if the risk is unacceptable. In this study, a risk assessment was conducted to obtain a safety value for the Kembangan Dam located in Karangmalang District, Sragen Regency, Center Java Province. The method used in this research is to use the risk index method. The risk index method assessment parameters are obtained from the initial importance factor of the dam (I_{dam}), the calculation of the total risk index of the dam (IR_{tot}), and the safety value of the dam (N_{aman}). The results showed that the Kembangan dam had an initial importance factor (I_{dam}) of 356.25, a total risk index (IR_{tot}) of 66.618, and a dam safety value (N_{aman}) of 81.3. Thus, it can be concluded that the safety level of the Kembangan dam is included in the Kembangan clause.

Keywords: Dam Safety, Risk Assessment, Risk Index, Dam Safety Score.

A. INTRODUCTION

Apart from providing huge benefits for humans, the construction of dams also has huge potential dangers, where if the dam breaks it can cause huge disasters in downstream areas (Miki Riando et al., 2023).

The concept of dam safety as referred to in paragraph (3), consists of 3 (three) pillars, namely: a. structural safety in the form of safety against structural failure, safety against hydraulic failure, and safety against seepage failure; b. operation, maintenance and monitoring; and c. emergency preparedness (Ministry of PUPR, 2015).

In dams that have been built or are operating, one of the objectives of carrying out a risk assessment is to determine the priority or ranking of repair or rehabilitation work needed to improve safety based on the risks that exist in the dam (Paramudawati et al., 2020). Risk assessments can be used to determine dam priorities based on the risks they present.

The safety and operational performance of dams can be improved by carrying out maintenance, repair and rehabilitation activities, especially for dams that have been in operation for a long time. An improvement priority system needs to be implemented to streamline costs (Cristina Dwi Y et al., 2016).

The Risk Index is a method used to create a priority scale for maintenance, repair and evaluation of embankments which have limitations in instrumentation, conditions when built and performance history (Otani, 2014). The aim of this research is to carry out a security risk assessment at the dam Development based on risk index method. The results of the risk assessment are then classified as dam safety to determine the follow-up steps that need to be taken regarding this condition.

B. METHODS

The data used in this research was obtained from the results of a major inspection of the Kembangan Dam in 2020. A major inspection is a series of surveys, inspections and testing of the feasibility of a Dam so that it can continue to operate in the future. This major inspection is included in *the Dam Operational and Safety Project Phase-II (DOISP-II)* program activities within the Bengawan Solo River Basin Center.

1. Risk Index Method

In this research, the method used to determine the level of dam safety is the risk index method. This method requires several parameters to analyze the dam and the results are in the form of a weight/value (*score*) which is then sorted based on the priority rank (*priority rank*) of the level of risk (Ishbaev et al., 2014).

These parameters are taken from data from large dams and based on a weight table (*score*) that has been developed by Andersen et al. (2001), and modified in this paper for Indonesia. According to (Lamtio Purba et al., 2023), to obtain the values of these parameters, 6 approach procedures are used as follows:

a. Determining the Total Vulnerability Factor

According to (Ishbaev et al., 2014), the total vulnerability factor is defined as the dam's ability to withstand damage caused by nature or the sensitivity of the dam to natural disasters. The total vulnerability factor V can be calculated using the following equation (Andersen et al., 2001):

$$V = \frac{I_1+I_2+I_3+I_4}{4} x \frac{E_1+E_2}{2} x \frac{D_1+D_2}{2} \quad (1)$$

with I_1, I_2, I_3, I_4 = intrinsic factors influencing dam height, dam type, foundation type and reservoir capacity. E_1, E_2 = external factors (dam age and seismicity). D_1, D_2 = spillway capacity adequacy factor and dam stability factor.

Table 1. Intrinsic Factors Influence Dam Height (I_1 = Dam Height)

Dam Height		Weight
m	ft	
< 2.7	< 9	1
2.7 - 12.2	9 - 40	3
12.2 - 30.5	40 - 100	6
> 30.5	> 100	10

Source: Andersen et al. (2001)

Table 2. Intrinsic Factors Influence Dam Type (I_2 = Dam Type)

Dam Type	Description	Weight
Stone Fill	Consisting mainly of cobble rock or larger particles	4
Landfill	Consists of gravel, sand, and/or silt and clay-sized particles	10

Source: Andersen et al. (2001)

Table 3. Intrinsic Factors Influence Foundation Type (I_3 = Foundation Type)

Foundation Type	Weight
Rock	1
Moraines	5
Alluvium	10

Source: Andersen et al. (2001)

Table 4. Intrinsic Factors Influence Reservoir Capacity (I_4 = Reservoir Capacity)

Reservoir Capacity			Weight
ha. m	acre-ft	Million m3	
< 6.17	< 50	< 0.0617	1
6.17 – 123	50 - 999	0.0617 - 1.2335	3
123 – 6170	1000 - 50000	1.2335 - 61.674	6
> 6170	> 50000	> 61,674	10

Source: Andersen et al. (2001)

Table 5. External Factors Age of Dam (E_1 = Age of Dam)

Dam Age (year)	Weight
0 – 9	10
10 – 29	8
30 – 59	5
60 – 99	2
> 100	1

Source: Andersen et al. (2001)

Table 6. External Factors of Seismicity (E_2 = Seismicity)

Mercalli Modification Intensity	Weight
≤ V	1
VI	2
VII	6
VIII	8
IX	10

Source: Andersen et al. (2001)

Table 7. Overflow Capacity Adequacy Factor (D_1 = Overflow Capacity)

Condition	Weight
Condition is known	
The spillway capacity is less than half the required capacity	10

The spillway capacity is greater than half the required capacity	5
Spillway capacity is greater than required	1
Estimated Condition	
Spillway capacity is less than required	5
Spillway capacity is more than required	2

Source: Andersen et al. (2001)

Table 8. Dam Stability Factors (D_2 = Dam Stability)

Condition	Weight
Condition is known	
The Safety Factor (SF) against mass movement is smaller than necessary	10
The Safety Factor (SF) against mass movement is greater than necessary	1
Estimated Condition	
The Safety Factor (SF) against mass movement is smaller than necessary	7
The Safety Factor (SF) against mass movement is greater than necessary	2

Source: Andersen et al. (2001)

b. Determining Initial Interest Factors

The initial importance *of the dam* is the result of multiplying the weight of the total vulnerability factor (vulnerability) with the weight of the disaster factor (Hazard). The dam importance level factor (Importance of dam = I_{dam}) is calculated using the following equation (2) (Andersen et al. 2001):

$$I_{dam} = V \times H \quad (2)$$

with V = total vulnerability factor and H = disaster factor.

The potential hazard of a dam is determined according to the specific type of damage that could occur downstream due to a dam failure (FEMA, 2004). Determination of dam hazard classification (H) can be seen in Table 9.

Table 9. Dam Hazard Classification (H)

Hazard Classification	Description	Weight
High/ High	If there is a potential loss of life due to a dam collapse	10
Medium/Medium	It does not have the potential to cause loss of life but has the possibility of significant economic loss, environmental damage, and/or disruption of public facilities.	5
Low/Small	Has no potential to cause casualties and causes small economic and/or environmental losses.	1

Source: FEMA, (2004)

c. Determining Relative Importance Factors

According to (Andersen et al., 2001), the relative importance factor can be calculated using equation 3.

$$RI_j = P\left[C_j \mathrm{I} M_i\right] x\, P[M_i \mathrm{I} F] x I_{dam} \quad (3)$$

with RI_j = relative importance factor of the jth condition, P [Cj|Mi] = conditional probability of the ith failure variety, and P [Mi|F] = conditional probability of the jth physical condition.

According to (Indrawan et al., 2013), the parameter values P [Cj|Mi] and P [Mi|F] are difficult to obtain due to limited data on dam failures in Indonesia. The steps taken to get around the required data were to use previous research from the experience of USCOLD 1998, United States.

d. Determining Inspection Conditions

A visual inspection was carried out to describe the current physical condition of the dam in the field. There are 9 (nine) checklists that need to be identified according to the physical conditions in the field. Each of the nine physical conditions is given a weight/score in the form of a condition function (CF_j). The CF_j weight scale ranges from 0 (failure) to 10 (ideal).

e. Calculation of Total Risk Index

The total risk index is the sum of all risk index values for all forms of potential failure. The risk index value is obtained by combining the inspection condition weight (CFj) with the relative importance factor. The total risk index can be calculated using Equations 4 and 5 (Andersen et al., 2001).

$$IR_j = RI_j x \frac{(10 - CF_j)}{10} \tag{4}$$

$$IR_{tot} = \sum RI_j \tag{5}$$

with IR_j = risk index of the jth physical condition, RI_j = relative importance factor of the jth physical condition, CF_j = physical condition resulting from field inspection, and IRtot is the total risk index.

f. Dam Safety Value

According to (Soetjiono, 2018), to determine the safety level of a dam can be done by determining the dam's safety value (N_{safe}). The dam safety value is then used to determine the necessary follow-up actions regarding the dam's safety conditions. Calculation of dam safety values is carried out using equation (6), while the classification of dam safety levels is presented in table 10.

$$N_{aman} = \frac{[(I_{dam} - IR_{tot})]}{I_{dam}} x100 \tag{6}$$

with N_{safe} = dam safety value, I_{dam} = initial importance factor, and IR_{tot} = total risk index.

Table 10. Classification of Dam Safety Conditions

No	Security Value	Criteria			Action required
	N_{safe}	Classification	Ordinary Load Conditions (Notmal)	Exceptional Load Conditions	
1	>75	Satisfying	Safe	Safe against design floods and design earthquakes	T here is no follow-up required
2	65 – 75	Enough	Safe	Possibly less safe against design floods and design earthquakes	It is necessary to confirm whether the reservoir can operate normally or not

3	55 – 64	Less satisfactory	Safe	Not safe, there is a possibility of deterioration in the quality of the material	Needs further research and investigation. Increased caution during surgery
4	<55	Not Good/Unsatisfactory	Not safe	Not safe	Needs immediate treatment; Cessation or limitation of operations

Source: Ishbaev et al. (2014)

C. RESULTS AND DISCUSSION

1. Kembangan Dam Inspection Results

a. Main Dam

Based on the results of the inspection, it was found that the top of the dam uses an asphalt layer which is in a damaged condition. This damage is caused by the old asphalt reinforcement layer. Recommendations for this damage are immediately made to repair the asphalt layer and create drainage at the peak.

Figure 1. Condition of the Dam Top

On the slopes of the dam, there are *fishbones* that are in poor condition and many of them are no longer there, which results in uncontrolled rainwater flow and disrupts the safety of the dam. On the slopes, the rip-rap is scattered and much of it is missing. The recommendation for this damage is to immediately tidy up *the fishbone* and rip-rap structures and clean up the surrounding vegetation.

Figure 2. Condition of Dam Slopes

In the dam inundation area, sedimentation and wild plants were found because the inlet channel carried a lot of sediment and the useful life of the reservoir was quite long. This results in the effective reservoir capacity being reduced. The recommendation for this damage is to immediately dredge the reservoir sediment.

Figure 3. Condition of Inundation Area

b. Spillway Buildings and Stilling Pools

From the results of the inspection, it was found that the inspection ladder on the launch wall was cracked and peeling and wild plants such as grass and moss were growing on the spillway building. Recommendations for this damage are immediate repairs and maintenance so as not to disrupt the stability of the dam. In the stilling pool , there doesn't seem to be a problem.

Figure 5. Condition of the Spillway Building

Figure 6. Condition of the Stilling Valve

2. **Dam Instrumentation**

Dam instrumentation is any type of equipment installed in the body and foundation of a dam or in other places which is primarily intended to monitor the behavior of the dam on an ongoing basis. Monitoring of dam instrumentation is carried out by checking, inspecting and recording the performance and behavior of the dam and its accessory buildings or certain other objects by means of direct measurements, observations and readings, with the aim of obtaining dam behavior as early as possible, so as to avoid the occurrence of damage that is dangerous to the dam. surrounding environment.

a. Seepage Measuring Equipment

At the Kembangan Dam, to measure seepage that occurs in the dam body, one uses a *toe drain channel* that ends at the V-Notch. Based on the results of the inspection, the condition of the V-notch is full of sediment and weeds or wild plants and is disturbed by the flow of water from residents' drainage which enters the V-Notch channel. This means that the flow through the v-notch cannot be used as a guide to the quantity of seepage that occurs in the Kembangan dam body. Therefore, improvements are needed to the Toe Drain channel so that the V-Notch function can be utilized properly.

Figure 7. V-notch Shape of the Dam

b. Deformation Measuring Instrument

Based on the inspection results, there were 28 sliding stakes/ *settlement plates* (SP), of which SP 1 and SP 14 were missing and SP 5 was broken. Based on information from officers in the field, they do not yet have the initial coordinates for placing the sliding stakes. The treatment for this finding is to immediately reinstall the lost and damaged sliding stakes. Furthermore, the measurement results are documented and used as a guideline, then it is hoped that periodic checks will also be carried out on the position of the existing sliding stakes, at least by the Dam Management Unit or Kembangan dam operations and maintenance officers.

c. Pore Pressure Measuring Instrument

Based on the results of inspections in the field, it can be concluded that the Kembangan Dam has 35 piezometers with the location and condition of each piezometer, from which several conclusions can be drawn regarding the existing condition of the piezometers that have been installed in the field:

1). The condition of the graph line being flat indicates that it has reached the tip elevation or lower end of the piezometer.

2). The condition of the graph line that is above the Water Level line indicates that there is a problem with the piezometer. Therefore, it is necessary to maintain piezometers, including by flushing piezometers that are indicated to have problems.

Figure 8. ***Piezometer*** **Reading Graph 1**

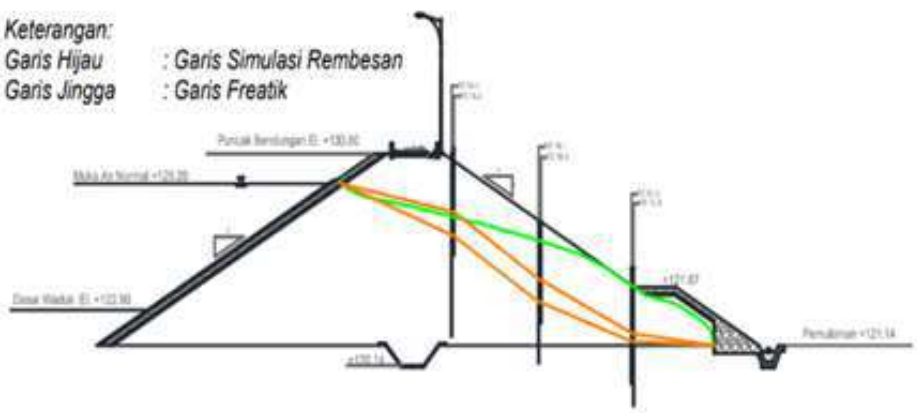

Figure 9. Freaktic Piezometer Line for Normal Water Level Conditions

3. Seepage and Dam Piping

Referring to the limits that apply in Japan (*Japanese Institute of Irrigation and Drainage*), the amount of leakage through the foundation and body of the dam cannot be more than 1% of the average river discharge entering the reservoir. (Anonymous, 2005).

The results of the pore water pressure and v-notch readings were then carried out for seepage analysis using SEEP/W Geostudio software by PT. Intimulya Multikencana, under conditions of flood water level FWL +130.38 and normal water level NWL 129.20, the seepage capacity for reservoir water level elevation FWL and NWL $Q_{baseflow}$ is 1.24 X 10-3 m3 /s, $Q_{baseflow}$ 1% 1, 24 X 10-5 m3 /s, and $Q_{seepage}$ 5.15

In piping, after drilling data was obtained, it was found that the specific gravity of soil in a saturated state (γsat) was 1.758 tons/m3 and the specific gravity of water (γwater) was 1 ton/m3 at flood water level conditions FWL +130.38 and normal water level NWL 129 .20 is obtained from the average vertical hydraulic gradient in each condition, then the safety factor for vertical piping FS piping is obtained $_{which}$ is greater than the safety factor number permitted by the FS_{permit}, then from these two conditions at the time of the flood water level (FWL) and the normal NWL water level does not occur piping

4. Slope Stability

Analysis of slope stability against landslides uses the Bishop method from the SLOPE/W Geostudio 2012 program with three simulation conditions, namely:

a. Empty condition
b. Conditions when the water level is normal (NWL)
c. Conditions at flood water level (FWL)
d. Conditions when the water level experiences a sudden drop (*Rapid Drawdown* +) on the upstream slope of the dam body

The earthquake load for slope stability analysis for each earthquake is:

a. OBE earthquakes use PGA = 0.126
b. MDE earthquakes use PGA = 0.385

The results of the analysis for slope stability against landslides using the SLOPE/W Geostudio program with various simulations are shown in Table 11, Table 12 and Table 13.

Table 11. Slope Stability Simulation Results for Empty Water Conditions

Condition	Analysis	Earthquake	Y/H	FK_{min}	Fk_{hit} Upstream	Note	Downstream	Note
LWL	Static			1.50	2,950	Safe	2,856	Safe
	Dynamic	OBE	0.25	1.20	1,853	Safe	1,802	Safe
			0.50	1.20	1,794	Safe	1,751	Safe
			0.75	1.20	1,848	Safe	1,798	Safe
			1.00	1.20	1,906	Safe	1,847	Safe
		MDE	0.25	1.00	1,027	Safe	1,024	Safe
			0.50	1.00	0.978	Not safe	0.975	Not safe

			0.75	1.00	1,023	Safe	1,020	Safe
			1.00	1.00	1,072	Safe	1,069	Safe

Source: PT. Intimulya Multikencana (2021)

Based on the results of slope stability calculations under empty water conditions, it was found that F_k at MDE earthquake loading was less than 1.00, so based on the guidelines a dynamic analysis had to be carried out using the Makdisi-Seed method and the results were that no deformation occurred.

Table 12. Slope Stability Simulation Results for Normal Water Conditions

Condition	Analysis	Earth-quake	Y/H	FK_{min}	Fk_{hit} Up-stream	Note	Down-stream	Note
N.W.L	Static			1.50	4,457	Safe	2,437	Safe
	Dynamic	OBE	0.25	1.20	2,171	Safe	1,560	Safe
			0.50	1.20	2,079	Safe	1,514	Safe
			0.75	1.20	2,163	Safe	1,556	Safe
			1.00	1.20	2,255	Safe	1,598	Safe
		MDE	0.25	1.00	1,039	Safe	0.891	Not safe
			0.50	1.00	0.983	Not safe	0.851	Not safe
			0.75	1.00	1,035	Safe	0.887	Not safe
			1.00	1.00	1,093	Safe	0.929	Not safe

Source: PT. Intimulya Multikencana (2020)

Based on the results of slope stability calculations under normal water conditions, it was found that Fk_{under} MDE earthquake loading was less than 1.00, so based on the guidelines a dynamic analysis had to be carried out using the Makdisi-Seed method and the results were that no deformation occurred.

Table 13. Slope Stability Simulation Results for Flood Water Conditions

	Analysis	Earth-quake	Y/H	FK_{min}	Fk_{hit} Up-stream	Note	Down-stream	Note
Condition	Static			1.50	5,084	Safe	2,381	Safe
	Dynamic	OBE	0.25	1.20	2,317	Safe	1,524	Safe
			0.50	1.20	2,212	Safe	1,479	Safe
			0.75	1.20	2,309	Safe	1,520	Safe
			1.00	1.20	2,413	Safe	1,564	Safe
		MDE	0.25	1.00	1,064	Safe	0.874	Not safe
			0.50	1.00	1,004	Safe	0.835	Not safe
			0.75	1.00	1,059	Safe	0.871	Not safe
			1.00	1.00	1,121	Safe	0.911	Not safe

Source: PT. Intimulya Multikencana (2020)

Based on the results of slope stability calculations under flood water conditions, it was found that F_k at MDE earthquake loading was less than 1.00, so based on the guidelines a dynamic analysis had to be carried out using the Makdisi-Seed method and the results were that no deformation occurred.

Table 17. Slope Stability Simulation Results for Rapidly Receding Water Level Conditions

Condition	Analysis	Earth-quake	Y/H	FK min	Fk count	
					Upstream	Information
Rapid Drawdown (RDD) for 1 day (Critical SF first 10 minutes)	Static			1.30	2,408	Safe
	Dy-namic	OBE	0.25	1.10	1,546	Safe
			0.50	1.10	1,498	Safe
			0.75	1.10	1,542	Safe
			1.00	1.10	1,588	Safe
		MDE	0.25	1.00	0.877	Not safe
			0.50	1.00	0.838	Not safe
			0.75	1.00	0.874	Not safe
			1.00	1.00	0.914	Not safe

Source: PT. Intimulya Multikencana (2020)

Based on the results of slope stability calculations for rapidly receding water levels, it was found that Fk_{at} MDE earthquake loading was less than 1.00, so based on the guidelines a dynamic analysis had to be carried out using the Makdisi-Seed method and the results were that no deformation occurred.

5. Total Vulnerability Factors and Initial Importance of the Kembangan Dam

The total vulnerability factor (V) is the dam's ability to withstand damage caused by nature or the dam's sensitivity to natural disasters. The Kembangan dam technical data is used as a basis for determining the total vulnerability factor, namely a combination of technical data between total vulnerability factors and disaster factors and can be seen in Table 14.

Table 14. Total Vulnerability Factors and Kembangan Dam Disaster Factors

Parameter	Mark	Weight
Dam Height (I1)	10m	3
Dam Type (I2)	UT	10
Foundation Type (I3)	Stone (BT)	3
Reservoir Capacity (I4)	0.82 million m3	3
Dam Age (E1)	70 years old	2
Seismicity (E2)	VIII MMI	8
Overflow (D1)	SC>R	2
Dam Stability (D2)	FK>R	1
Risk Class (H)	Tall	10

The total vulnerability factor value (V) is obtained as 35.625 by entering the weight of each parameter into equation (1). Next, by combining the V value with the disaster factor (H) of 10 according to Equation (2), you will get an $I_{dam\ value}$ of 356.25.

6. Kembangan Dam Inspection Conditions

The field physical condition checklist is weighted in 9 (nine) parameters obtained from analysis of the results of visual observations of major inspections and other related analyses. Inspections or reviews in the field (*on-site inspection*) are carried out to get data on the actual physical condition of the dam. The results of visual observations of the physical conditions of the field are presented in Table 20.

Table 15. Physical Conditions of the Kembangan Dam Inspection Field

No	Inspection Parameters	Weight
1	Obstruction on spillway (CF_1)	9
2	Guard Height (CF_2)	9
3	Barriers to the outlet channel at the bottom of the dam (CF_3)	9
4	Erosion of the spillway (CF_4)	8.5
5	Dam surface protection material (CF_5)	7
6	Reed erosion on the dam body (CF_6)	7
7	Reed erosion of dam foundations (CF_7)	7
8	Landslides on embankment dams (CF_8)	7.5
9	Landslides on dams and their foundations (CF_9)	7.5

7. Total Risk Index and Safety Value of Kembangan Dam

The total risk index is a value to determine whether the dam is functioning properly (Dept. Public Works 2000). By combining relative importance factors and physical inspection conditions (CFj), the total risk index value obtained using equations (3) to (5), is presented in Table 16.

Table 16. Assessment of Relative Importance Factors and Risk Index for Each Form of Failure

No	Forms of Failure	Prb. Failure	Prb. Physical condition	Relative Determinants Index	CFj weight	jth Risk Index
		P [Cj] [Mi]	P[Mi] [F]	RIj		IRj = Rij (10-CFj)/10
1	Overtopping	0.49	0.3	52,368	9	5,237
			0.1	17,456	9	1,746
			0.6	104,737	9	10,474
2	External Erosion	0.10	0.7	24,937	8.5	3,741
			0.3	10,687	7	3,206
3	Ersi Reed	0.32	0.7	79,800	7	23,940
			0.3	34,200	7	10,260
4	Slope Stability	0.09	0.5	16,031	7.5	4,008
			0.5	16,031	7.5	4,008
IR_{total}						**66.618**

To calculate the dam safety value ($_{safe}N$) equation (6) is used. With the I_{dam} and $IR_{tot\ values}$ known from previous calculations, a $_{safe}N$ value of 81.3 is obtained. Based on Table 10 of dam safety classification conditions, the Kembangan dam is in a satisfactory condition and is safe against design floods and design earthquakes and no follow-up is required.

D. CONCLUSION

Risk analysis of the Kembangan dam using the risk index method based on the inspection results of the 2020 Kembangan dam major inspection report has been carried out with the results of calculating the initial level of importance (I dam), total $_{risk}$ index (IR $_{tot}$), and dam safety value (N $_{safe}$). respectively 356.25, 66.618, and 81.3. Thus, the safety level of the Kembangan dam is in a satisfactory and safe condition against design floods and design earthquakes and no follow-up is required with a $_{safe\ N\ value}$ of more than 75. However, it is still recommended to continue to carry out routine and periodic safety monitoring of the Kembangan dam to avoid risks. which can happen at any time.

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