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Research Paper

Risk Factor Classification Effect on Sematok Dam Slopes Stability

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ABSTRACT

The Semantok Dam was built with extreme classified risk factors. These conditions require a more detailed review of its stability with the imposition of Operationing Basic Earthquake (OBE) at the 200-year return period, as well as the imposition of Maximum Design Earthquake (MDE) at the 10000-year return period. This study aimed to determine the response of the dam due to the earthquake load in addition to the influence of pore pressure values under rapid drawdown conditions. Results of analysis using load Maximum Design Earthquake (MDE) of 0.6 g show a significant effect on the slope stability of the dam. In these conditions, there is a failure in maintaining the dam slope stability. Further examination for permanent deformation due to the influence of the earthquake load still meets the required criteria.

1. Introduction

National Strategic Projects Semantok Dam expected to provide a positive benefit to Nganjuk Regency society. Semantok dam built in the village Sambikerep, District Rejoso, Nganjuk, East Java Province, is based on the Semantok River flow with an area of 54,032 km^2 watershed. The main dam body, which has a length of 3,005 meters and a height of 31 meters, can accommodate a total water capacity of 32,094,000 m^3 with an adequate storage capacity of 18,303,260 m^3. Based on the projected storage capacity can meet the needs of raw water at 312 liters / second and meet the irrigation needs of the agricultural land area of 1,825 Ha.

Referring to the Analisis Dinamik Bendungan Urugan (2008) guidelines, the storage capacity of 32,094,000 m3 classified as having a high risk that could endanger residential areas around the downstream if the dam experiences structural failure. The potential failure of the dam structure caused due to earthquakes, floods, or due to their stored water (Dwi Y, Cristina, et al. 2016).

Potential dam failure structures due to earthquakes have a significant risk of impact. The greater acceleration of the earthquake tends to have an impact on the declining safety of the dam's slope stability (Goro, Garub Lambang, 2007). Nevertheless, it exacerbated by the results of screening on dams in Indonesia, the majority of which failed due to earthquake loads during the 10,000 year return period (Tanjung, Mahdi Ibrahim., et al., 2017). Another potential that can cause structural failure due to the collected water is the condition of rapid drawdown or rapid surface water level decline, which causes the

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equilibrium of the dam slope to become unbalanced (Ma'ruf, M. Farid, 2013). This condition starts from the downstream slope, which previously underwater pressure suddenly loses water pressure as a pore water balance. It is very dangerous because of the decrease in pore water in the body of the dam cannot go down as fast as the water level decrease (Alonso and Pounyol, 2009).

To avoid the failure of the dam's body structure, further analysis is needed so that the safety factor of the dam's slope fulfilled. Based on these problems, a study conducted to analyze the stability of the main dam body slopes of the Semantok Dam to the condition of rapid drawdown and earthquake loading using a source map and the Indonesian earthquake hazard.

2. Parameter and Design: Bendungan Semantok

The Semantok Dam is designed to have a typical dam body design with soil fill type and upright core zone, which can be seen in Figure 1.

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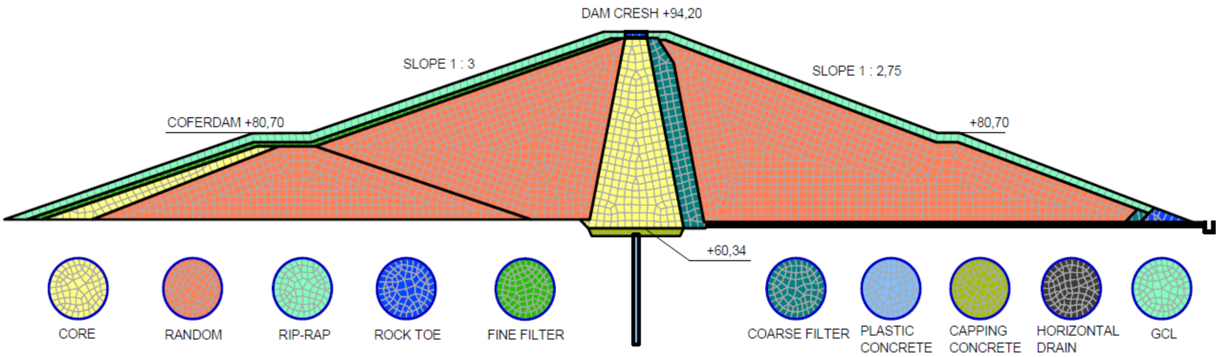


Fig. 1. The typical body design of Semantok Dam

The design of the dam has a slope of 1: 3 upstream, and 1: 2.75 for downstream, the top of the dam body is at +94,20, the cofferdam peak is at +80,70, and the bottom of the foundation is at +60,34.

The dam also equipped with a drainage system on the downstream side, namely vertical drainage using rough filters and horizontal drainage using finger drain. The use of drainage systems on downstream slopes intended to improve slope stability in rapid drawdown conditions (Moharrami, 2013). Its purpose can release excess pore water pressure when rapid drawdown occurs.

To meet the material needs of the dam's body, materials from the borrow and quarry areas are used. Results of the dam body filler material parameters as well as the foundation obtained from laboratory and field test results shown in **Table 1.**

Table 1. Dam material parameters.

No	Description	γ_{sat}	Saturation	Elasticity Modulus	Poisson's Rasio	Friction Ratio	Cohesion	K
		kN/m^3	Sr (%)	kN/m^2	(μ)	φ (°)	kPa	m/dt
1	Core material	16,48	51	20000	0,4	25	5	1,0 x 10^{-7}
2	Filter	17,35	36	75000	0,35	30	-	5,0 x 10^{-5}
3	Transition (rough filter)	18	36	100000	0,35	32	-	6,0 x 10^{-5}
4	Random soil	16,4	48	60000	0,37	27	18	6,0 x 10^{-6}
5	Rip-rap	22	30	150000	0,33	40	-	1,0 x 10^{-2}
6	Rock Toe	22	33	150000	0,33	40	-	1,0 x 10^{-2}
7	Finger drain	22	30	100000	0,35	32	-	1,0 x 10^{-2}
8	Plastic concrete	20	45	207908	0,3	-	-	1,0 x 10^{-10}
9	Concrete capping	23	50	12000000	0,15	-	-	1,0 x 10^{-10}
10	GCL	23	50	20000	0,15	25	5	1,0 x 10^{-11}
11	Sand clay foundation	17,35	-	58254	0,35	16	4	3,7 x 10^{-5}

No	Description	γ_{sat} kN/m³	Saturation Sr (%)	Elasticity Modulus kN/m²	Poisson's Rasio (μ)	Friction Ratio φ (°)	Cohesion kPa	K m/dt
12	Sandstone foundation	18,5	-	165692	0,3	41	-	$5,0 \times 10^{-5}$
13	Gravel sand foundation	16,4	-	75000	0,35	41	-	$1,4 \times 10^{-4}$
14	Sand foundation	16,48	-	75000	0,35	41	-	$1,7 \times 10^{-4}$
15	Silt stone foundation	19	-	60000	0,37	42	4	$4,8 \times 10^{-7}$

3. Classification of risk factors dam

The level of risk at the dam is considered based on dam capacity, dam height, evacuation requirements, and downstream damage (Dynamic Analysis of Urugan Dam, 2008). All risk factors formulated in the following equation:

$$FR_{tot} = FR_k + FR_t + FR_e + FR_h \quad [1]$$

The value of the total risk factor (FRtot) obtained by adding up the risk factor value of the reservoir capacity (FRk), high dam risk factors (FRt), evacuation needs risk factors (FRe), and downstream damage factor (FRh) that obtained from **Table 2**. The results of total risk factors will be classified according to **Table 3**. Based on these results, it will be used as a parameter for loading due to the earthquake shown in **Table 4**.

Table 2. Dam safety risk criteria

Risk Factor	Rating				
	Extreme	High		Moderate	Low
Capacity (10^6 m³) (FR_k)	> 100 (6)	100 - 1,25 (4)		1,00 - 0,125 (2)	< 0,125 (0)
High (m) (FR_t)	> 45 (6)	45 - 30 (4)		30 - 25 (2)	< 15 (0)
Evacuation Needs (number of people) (FR_e)	> 1000 (12)	1000 - 100 (8)		100 - 1 (4)	0 (0)
Downstream damage rate (FR_h)	**Very High** (12)	**High** (10)	**Rather high** (8)	**Moderat** (4)	**None** (0)

Source: Analisis Dinamis Bendungan Urugan, 2008

Table 3. Dam safety risk criteria

Total Risk Factor	Risk Class
(0 - 6)	I (Low)
(7 - 18)	II (Moderate)
(19 - 30)	III (High)
(31 - 36)	IV (Extreme)

Source: Analisis Dinamis Bendungan Urugan, 2008

Table 4. Earthquake load criteria

Risk class with useful life	Requirements without damage		Requirements allowed damage without collapse	
	T (year)	Analysis Method	T (year)	Analysis Method
IV	100 - 200	Earthquake coefficient	10000	Earthquake or dynamic coefficient
III	50 - 100	Earthquake coefficient	5000	Earthquake or dynamic coefficient
II	50 - 100	Earthquake coefficient	3000	Earthquake or dynamic coefficient
I	50 - 100	Earthquake coefficient	1000	Earthquake or dynamic coefficient

Source: Analisis Dinamis Bendungan Urugan, 2008

4. Slope Stability

Slope stability analysis is a step in determining the slope safety factor against sliding expressed in comparison in the following equation.

$$FK = \frac{S}{\tau} \quad [2]$$

Slopes are stated in safe condition if the shear strength (S) is higher than the shear stress (τ).

SNI 8064:2016, as well as the Pedoman Analisis Dinamis Bendungan Urugan 2008, used in determining the slope stability of the dam. The conditions for using the minimum safety factor shown in **Table 5.**

Table 5. Minimum safety factor requirements

Kondisi	Minimum Safety Factor		
	Without earthquake	**OBE earthquake**	**MDE earthquake**
Lasting Flow	1,5	1,2	1
Rapid Drawdown	1,3	-	-
Rapid Drawdown with 50% earthquake coefficient	-	1,1	-

5. Research methods

5.1 Earthquake loading

Earthquake loading carried out by modifying the earthquake acceleration value on bedrock (SB) obtained from the results of the 2017 earthquake source and hazard map in Indonesia. The use of earthquake loads takes into account Operationing Basic Earthquake (OBE) and Maximum Design Earthquake (MDE), which based on the return period described in the results of the earthquake load criteria in **Table 4**.

Modification of the earthquake coefficient is adjusted by the Japanese method "Seismic Design Guidelines for Fill Dam". This function takes into account the design earthquake coefficient based on the function of the depth of the dam. These adjustments described in the following equation:

$$PGA_M = F_{PGA} \times S_B \quad [3]$$

$$K_h = PGA_M / g \quad [4]$$

$$K_o = \alpha_2 \times K_h \quad [5]$$

annotation:

PGA_M = Earthquake acceleration corrected
F_{PGA} = Amplification factor for PGA
S_B = Base earthquake acceleration value
g = Earth's gravity acceleration
K_h = Seismic coefficient corrected each reset period T
α_2 = Structural influence factor (backfill dam = 0.5)
K_o = Earthquake coefficient corrected at ground level

In its application, the earthquake coefficient at each depth from the peak of the dam symbolized Y has different coefficients. The application of stability analysis uses depth, namely: Y = 0.25H; 0.5H; 0.75H, and 1.0H, where H is the height of the dam. Earthquake coefficients at different Y depth can be searched using the following equation:

at $0 < Y/H \leq 0{,}4$

$$K = K_O \times (2{,}5 - 1{,}85 \times (Y/H)) \quad [6]$$

at $0{,}4 < Y/H \leq 1{,}0$

$$K = K_O \times (2 - 0{,}60 \times (Y/H)) \quad [7]$$

annotation:

K = Earthquake coefficient at each depth
K_o = Earthquake coefficient corrected at ground level
Y = Depth of the point of view from the top of the dam.
H = Dam height

5.2 Permanent Deformation

In 1978, Makdisi and Seed introduced a simplified method for calculating deformation estimates on the embankment using average earthquake acceleration. From this method, it can be predicted the amount of permanent deformation on the embankment with a parameter comparison of the maximum earthquake acceleration acting at the center of the slip plane (Kmax) with earthquake acceleration resulting in a slope stability safety factor equal to 1 (Ky).

Its application does not have permanent deformation if Ky> Kmax. On the contrary, permanent deformation occurs if Ky <Kmax.

Swaisgood has developed further studies for comparison in 2003. Permanent deformation at the peak of the dam can be estimated based on the results of his record of 69 events of peak dam decrease due to earthquake loads around the world. Based on the notes, then an estimated percentage of deformation at the top of the dam is made:

$$\%SETTLEMENT = e^{(6{,}07\,PGA + 0{,}57\,Ms + 8{,}0)} \quad [8]$$

Where PGA is earthquake acceleration, and Ms is earthquake magnitude. This analysis used an earthquake of magnitude 6.5; 7; and 8.25.

5.3 Geostudio Modeling

The use of the finite element method using Geostudio 2012 software was utilized for this study. Before the slope stability analysis carried out, an analysis of the pore pressure conditions carried out on the dam due to a variety of water level storage conditions using the Geostudio feature, SEEP/W. Analysis on SEEP/W includes several dam conditions including Normal Water Level (NWL) conditions at elevation +90.14; High Water Level (HWL) at 93.31 elevations; rapid drawdown from High Water Level (HWL) at 93.31 elevations to Normal Water Level (NWL) at +90.14 elevations within ten days; and rapid drawdown from Normal Water Level (NWL) at +90.14 elevations to Low Water Level (LWL) at +80.64 elevations using the material parameters presented in **Table 1.** From these results, a combined analysis then performed using the SLOPE/W feature with pore pressure from the results of the SEEP/W modeling. Analysis using SLOPE/W then using loading conditions without an earthquake, OBE earthquake, and MDE earthquake.

6. Results

Analisis Dinamis Bendungan Urugan (2008), states that a soil type dam with a large reservoir volume must consider the safety factor for dam stability. The safety factor is not permitted damage due to Operation Basic Earthquake (OBE), but it is permitted damage without collapse due to Maximum Design Earthquake (MDE). These requirements will be used as material for evaluating dam behavior in this study.

6.1 Risk dam classification

Based on the 2017 Semantok Dam design certification report, the dam has a construction height of 31 meters, can accommodate water with a capacity of 32,094,000 m3, with a high level of downstream damage, as well as residential evacuation areas around the downstream dam of more than 1000 people. Thus, it can be seen the weight of each risk factor refers to the guidelines shown in **Table 2**. Then, FRtot can be calculated from these results using equation 1 as shown in **Table 5**

Table 5. Analysis of Semantok Dam risk classification

Risk factor	Description	Weight
FR_k	32.094.000 m^3	6
FR_t	31 m	4
FR_e	> 1000 people	12
FR_h	High	12
$\boldsymbol{FR_{tot}}$		**34**

From the sum of FRtot with a value of 34, based on table 3, Semantok Dam is classified as having an extreme risk class. Thus, referring to the guidelines listed in table 4, the earthquake loading analysis method is carried out with a 100-200 year return period on Operationing Basic Earthquake (OBE) and a 10,000 year return period on the Maximum Design Earthquake (MDE).

6.2 Loading earthquake

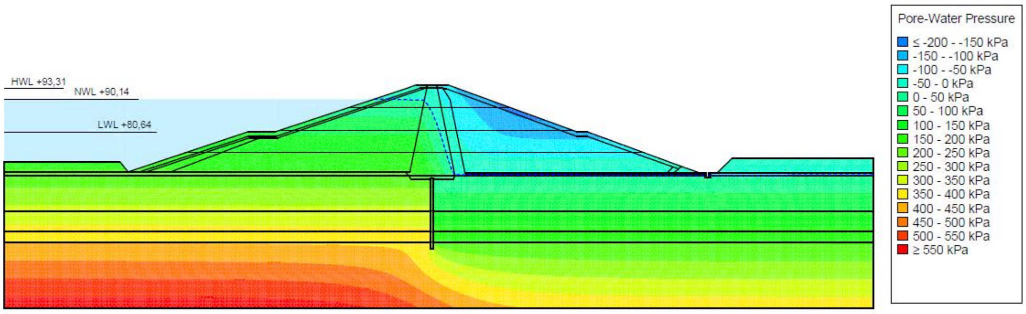
Based on the 2017 Indonesia Earthquake Source and Hazard Map, the location of the Semantok dam is at latitude -7.449485 and longitude 111.89051, has SB: 0.15 & FPGA: 1 in the 200-year return period, and has SB: 0.6 & FPGA: 1 in the return period of 200 years. By using equation 3, the PGAM value of the 200-year return period (OBE) can be calculated as 0.15 and in the 10000-year return period (MDE) of 0.60. Therefore, earthquake coefficients based on each depth can be known using equations 4,5,6, and 7, as shown in **table 6.**

Table 6. Earthquake coefficients of OBE and MDE

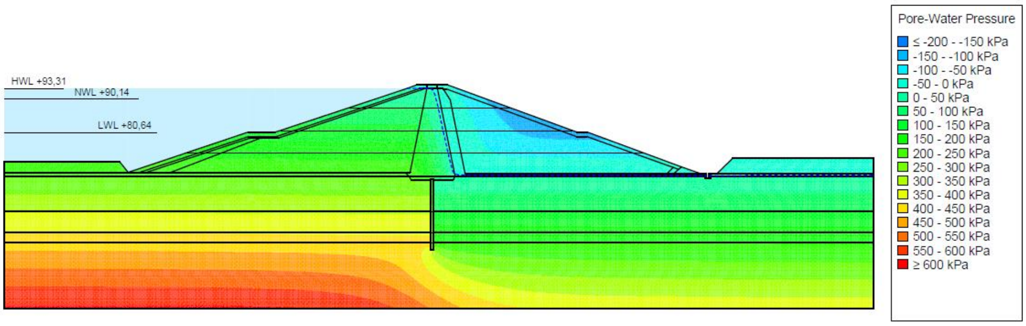
Earthquake load	K_h	K_o	K			
			Y/H			
			0,25	0,5	0,75	1
OBE	0,150	0,075	0,153	0,128	0,116	0,105
MDE	0,600	0,300	0,611	0,510	0,465	0,420

6.3 Analisis kestabilan lereng

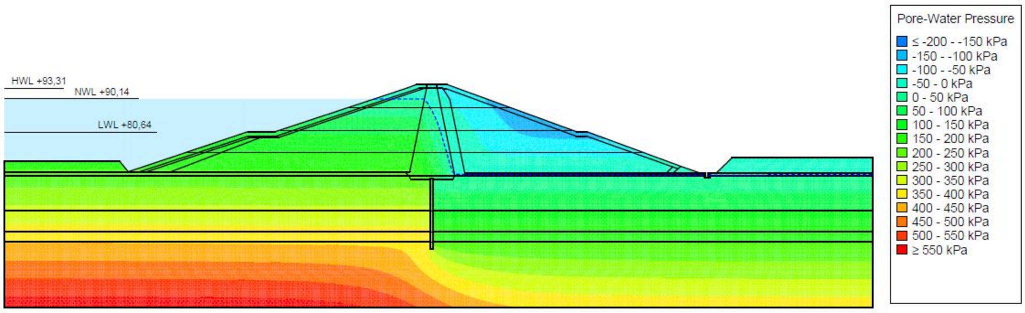
The condition of pore pressure in the operational period analyzed before the stability of the dam slope. Pore pressure during the operational period of the semantok dam from the results of the SEEP / W analysis is presented in **Figure 2**.



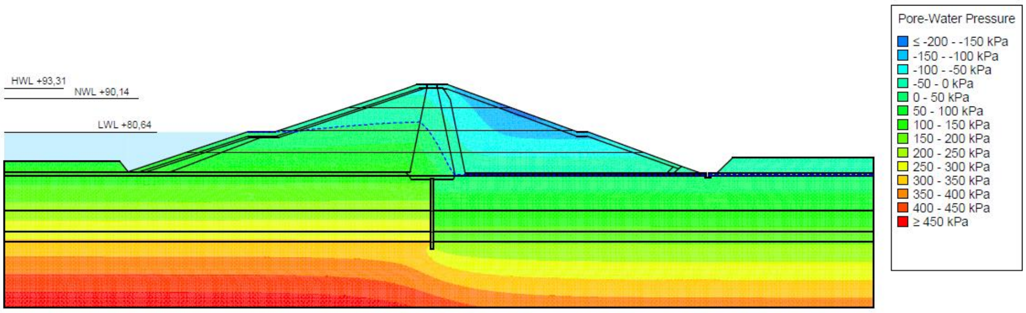
(a)



(b)



(c)



(d)

Fig. 2. (a) normal water level conditions, (b) flood water level conditions, (c) rapid drawdown conditions from floodwater levels to normal water level, (d) rapid drawdown conditions from normal water level to minimum water level.

Based on the SEEP / W analysis results, a slope stability parent analysis performed using the SLOPE / W feature. The first stage of slope stability analysis carried out without using earthquake load to determine the behavior of pore pressures on dam slope stability. The following analysis results are shown in **Table 7**.

Table 7. Safety factor without earthquake load

Condition	SF Requir.	Safety Factor	
		Upstream	**Downstream**
NWL lasting flow (+90.14)	1,5	2,729	2,143
HWL lasting flow (+93,31)	1,5	3,079	2,141
Rapid drawdown from Elv. +93,31 to Elv. +90,14	1,3	2,724	2,143
Rapid drawdown from Elv. +90,14 to Elv. +80,64	1,3	2,031	2,143

These results indicate the condition of rapid drawdown resulted in a decrease in the upstream slope of the safety factor. This condition occurs because of an increase in pore water pressure under rapid drawdown conditions rather than a water level condition that can be seen in Figure 2. However, these conditions are not alarming because the safety factor of the slope stability meets the permitted requirements.

The next step is the addition of OBE earthquake loads. In this condition, the dam slope is not allowed to experience damage. If the OBE earthquake load damages the slope, the dam slope design must be reviewed. The results of adding OBE earthquake load to the stability of the dam slope presented in **Table 8.**

Table 8. Safety factor with OBE earthquake

Condition	SF Requir.	Y/H	Safety Factor	
			Upstream	Downstream
MAN lasting flow (+90,14)	1,2	0,25	1,789	1,539
	1,2	0,50	1,566	1,632
	1,2	0,75	1,562	1,642
	1,2	1,00	1,524	1,590
MAB lasting flow (+93,31)	1,2	0,25	1,927	1,539
	1,2	0,50	1,715	1,632
	1,2	0,75	1,679	1,632
	1,2	1,00	1,609	1,581
Rapid drawdown from Elv. +93,31 to Elv. +90,14	1,1	0,25	1,786	1,539
	1,1	0,50	1,558	1,632
	1,1	0,75	1,558	1,642
	1,1	1,00	1,521	1,590
Rapid drawdown from Elv. +90.14 to Elv. +80,64	1,1	0,25	1,967	1,539
	1,1	0,50	1,763	1,632
	1,1	0,75	1,450	1,642
	1,1	1,00	1,361	1,590

The addition of OBE earthquake load to the slope stability resulted in a significant decrease in safety factors. The reduction in the number of safety factors is still within the permissible terms. Thus, the dam design geometry does not need to be reviewed.

The next step is to analyze with MDE earthquake load. At this stage, the dam is allowed to suffer damage, but may not collapse. The results of dam slope stability with MDE earthquake load can be seen in **Table 9**.

Table 9. Safety factor with MDE earthquake

Condition	SF Requir.	Y/H	Safety Factor	
			Upstream	Upstream
NWL lasting flow (+90.14)	1,0	0,25	0,775	0,672
	1,0	0,50	0,662	0,784
	1,0	0,75	0,627	0,849
	1,0	1,00	0,603	0,846
HWL lasting flow (+93,31)	1,0	0,25	0,697	0,672
	1,0	0,50	0,650	0,784
	1,0	0,75	0,627	0,804
	1,0	1,00	0,604	0,807
HWL lasting flow (+93,31)	1,0	0,25	0,769	0,672
	1,0	0,50	0,659	0,784
	1,0	0,75	0,626	0,849
	1,0	1,00	0,601	0,845
Rapid drawdown from Elv. +90.14 to Elv. +80,64	1,0	0,25	0,897	0,672
	1,0	0,50	0,862	0,784
	1,0	0,75	0,697	0,850
	1,0	1,00	0,634	0,846

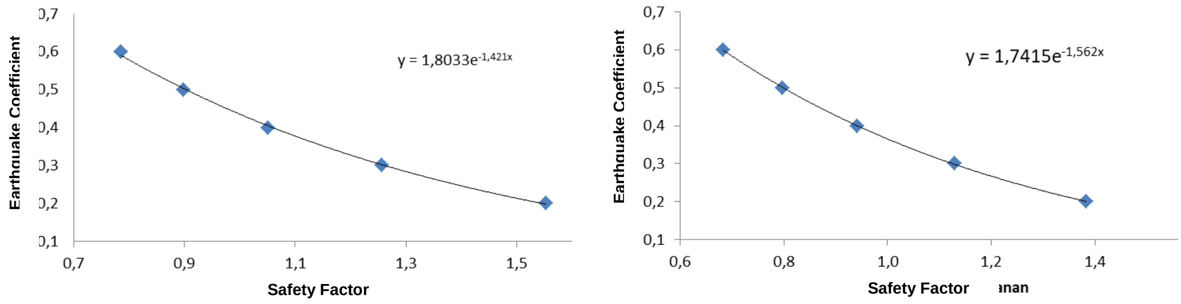
The addition of MDE earthquake loads resulting in dam slope stability both upstream and downstream sides of failure in maintaining stability. This condition is dangerous if the failure results in a collapse. In order to know that the dam slope did not collapse due to the MDE earthquake load, further analysis of permanent deformation was carried out.

6.4 Permanent deformation

The requirement that must meet to ensure that there is no collapse due to MDE earthquake load is that permanent deformation must be less than half the height of the guard (U max <50% D). Permanent deformation is calculated by the method of Makdisi and Seed and also Swaisgood.

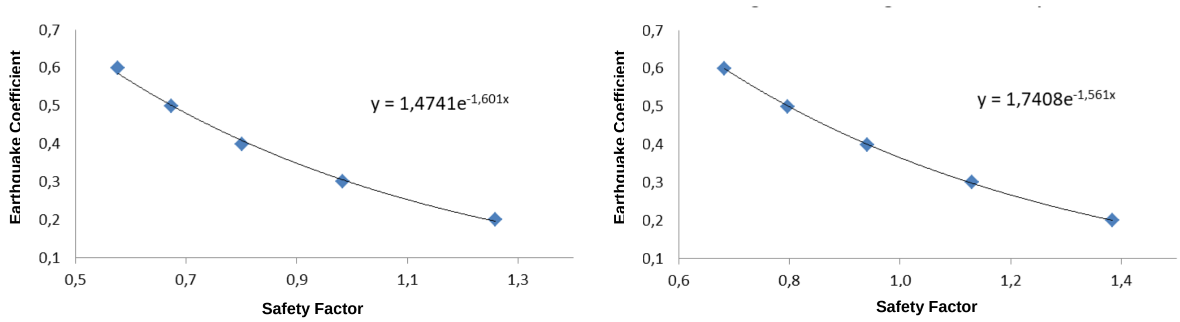
6.4.1 Dynamic analysis of the Makdisi and Seed methods

Parameters for calculating permanent deformations that must be met are the values of Ky and Kmax. The Ky parameter is sought by providing variations in the earthquake coefficient (Kh). The results of trial and error Ky values at Y / H 0.25; 0.5; 0.75; 1 on the upstream and downstream sides can be seen in **Figures 3,4,5 and 6**.



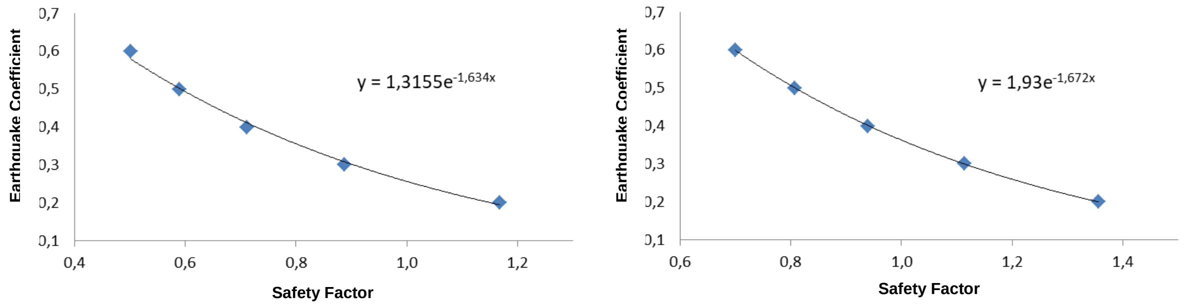
(**a**) (**b**)

Fig. 3. (a) Ky parameter at Y / H 0.25 upstream side, (b) Ky parameter at Y / H 0.25 downstream side.



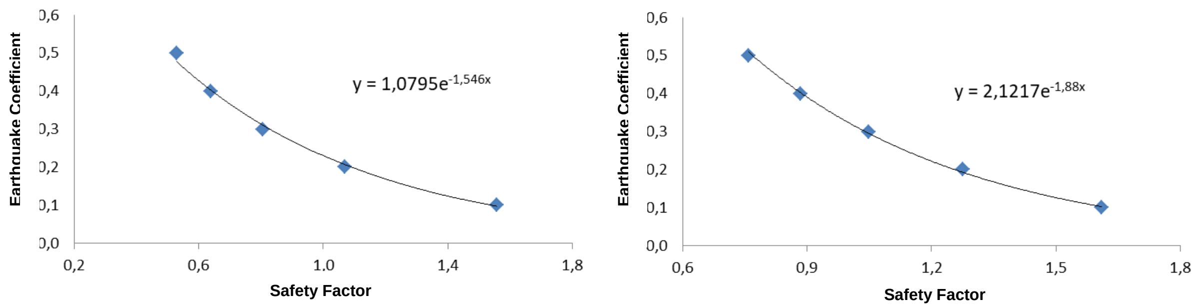
(**a**) (**b**)

Fig. 4. (a) Ky parameter at Y / H 0.5 upstream side, (b) Ky parameter at Y / H 0.5 downstream side.



(**a**) (**b**)

Fig. 5. (a) Ky parameter at Y / H 0.75 upstream side, (b) Ky parameter at Y / H 0.75 downstream side.



(**a**) (**b**)

Fig. 6. (a) Ky parameter at Y / H 1.0 upstream side, (b) Ky parameter at Y / H 1.0 downstream side.

Based on these results, it can be seen Ky value based on the equation shown in the picture. Thus, the Ky values obtained at each depth condition are listed in **Table 10**.

Table 10. Ky value at Y / H 0.25; 0.5; 0.75; and 1.0

Condition	Ky	
	Upstream	Downstream
Y/H = 0,25	0,435	0,365
Y/H = 0,5	0,297	0,365

Condition	Ky	
	Upstream	Downstream
Y/H = 0,75	0,257	0,363
Y/H = 1	0,230	0,324

Afterward, the Kmax parameter is known based on the Y / H relationship with the earthquake acceleration shown in **Figure 3**.

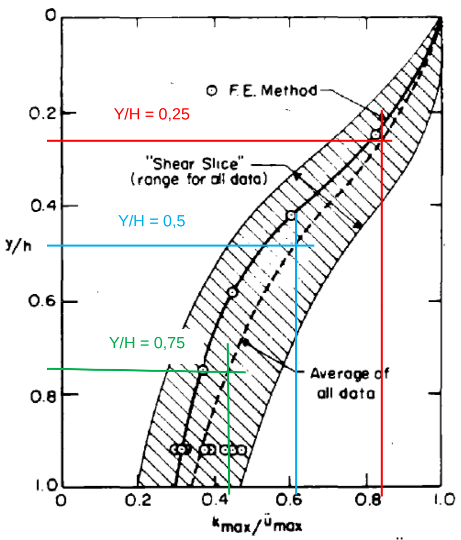


Fig. 3. Relationship value of Y / H vs Kmax / Ümax value
(Source: Makdisi and Seed, 1978)

Whereas, the earthquake acceleration value at the peak of the dam body (Ümax) is known based on the graph of the Bray and Rathje, 1998 methods presented in **Figure 4**.

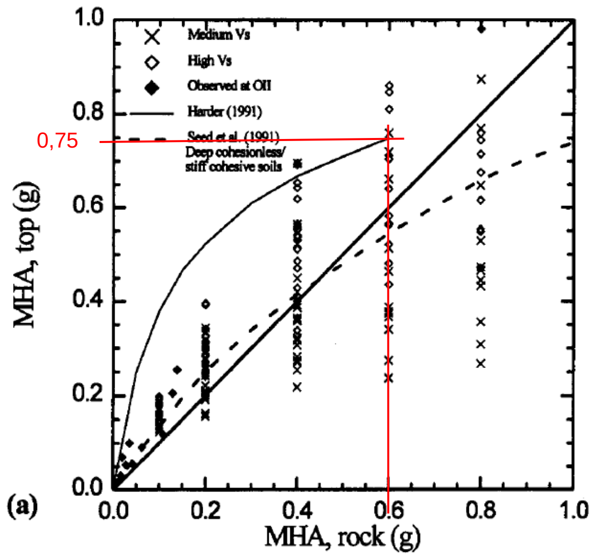


Fig. 4. The relationship between PGA_M vs $\ddot{U}_{max}$.
(Source: Bray dan Rathje, 1998)

The results of the Ky, Ümax, and Kmax parameters are used to find the magnitude of the total deformation value that occurs on the upstream and downstream slopes of the dam. Semantok Dam has a guard height of 406 cm, so that half of the guard height of 203 cm. The results of the calculation of upstream and downstream slope deformations with earthquake magnitudes Ms 6.5; 7.5; and 8.25 can be seen in **Table 10** and **Table 11**.

Table 10. Permanent deformation of upstream slope

Area	Ms	Y/H	*Ümax* (g)	Kmax / *Ümax*	Kmax (g)	Ky (g)	Ky/Kmax	U max (cm)
upstream	6,5	0,25	0,750	0,85	0,6375	0,435	0,68	7
		0,50	0,750	0,61	0,4575	0,297	0,65	8
		0,75	0,750	0,42	0,3150	0,257	0,81	2,5
	7,5	0,25	0,750	0,85	0,6375	0,435	0,68	8
		0,50	0,750	0,61	0,4575	0,297	0,65	9,5
		0,75	0,750	0,42	0,3150	0,257	0,81	2
	8,25	0,25	0,750	0,85	0,6375	0,435	0,68	25
		0,50	0,750	0,61	0,4575	0,297	0,65	45
		0,75	0,750	0,42	0,3150	0,257	0,81	6

Table 11. Permanent deformation of downstream slopes

Area	Ms	Y/H	*Ümax* (g)	Kmax / *Ümax*	Kmax (g)	Ky (g)	Ky/Kmax	U max (cm)
downstream	6,5	0,25	0,750	0,85	0,6375	0,365	0,57	9,5
		0,50	0,750	0,61	0,4575	0,365	0,80	2
		0,75	0,750	0,42	0,3150	0,363	1,15	-
	7,5	0,25	0,750	0,85	0,6375	0,365	0,57	25

Area	Ms	Y/H	*Ümax* (g)	Kmax / *Ümax*	Kmax (g)	Ky (g)	Ky/Kmax	U max (cm)
		0,50	0,750	0,61	0,4575	0,365	0,80	3
		0,75	0,750	0,42	0,3150	0,363	1,15	-
	8,25	0,25	0,750	0,85	0,6375	0,365	0,57	70
		0,50	0,750	0,61	0,4575	0,365	0,80	7
		0,75	0,750	0,42	0,3150	0,363	1,15	-

The total deformation value (U max) is known using the Ky / Kmax relationship graph with the displacement of the makdisi and seed method in **Figure 5**.

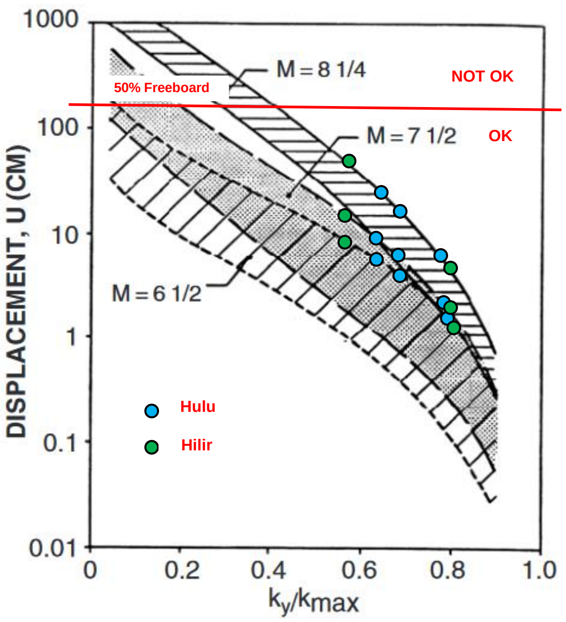


Fig. 5. Seismic displacement vs. Ky/Kmax and magnitude
(Source: Makdisi and Seed, 1978)

Based on the calculation results, the permanent deformation of the Makdisi and Seed method obtained U max = 70 cm <50% D = 203 cm. Therefore, the stability of Semantok Dam due to Maximum Design Earthquake (MDE) still meets the required safety requirements

6.4.2 Dynamic analysis of the Swaisgood method

The parameter used in determining the permanent deformation using this method is the PGAM (Peak Ground Acceleration) value obtained from the 2017 Indonesia earthquake source and hazard map. In the previous analysis, it is known that the PGAM value in the 10000-year return earthquake (MDE) was 0.6 g. Therefore, by using equation 8 the results are presented in **Table 12**.

Table 12. Permanent deformation of the Swaisgood method

Ms	*Settlement (%)*	*H (m)*	*Deformation (cm)*
6,5	0,5	31	16,13
7,5	0,9	31	28,53
8,25	1,4	31	44,00

Based on the results of the calculation above, the most significant permanent deformation value of 44 cm was obtained at an earthquake magnitude (Ms) of 8.25. With this result, the permanent deformation that occurred was still within the safe limit of half a guard height (50% D) of 203 cm.

Analysis of permanent deformation that occurred at Semantok Dam due to Maximum Design Earthquake (MDE) using different methods is produced different results. The analysis showed that the use of the Makdisi and Seed methods obtained permanent deformation values higher than the Swaisgood method. The largest permanent deformation is 70 cm.

These results are still smaller than the figure implied by half the height of the guard at 203 cm.

7. Discussion

The greater a dam built, the greater the risk of the safety factor that must be taken. Thus, a detailed analysis of the dam safety requirements is needed. One thing that needs to be considered is checking the stability of the dam slope.

Dam slope stability greatly influenced by the magnitude of pore water pressure and also earthquake loading. In normal conditions without loading, excess pore water pressure during rapid drawdown results in a decrease in the safety factor of the stability of the slope compared to the water level held in a calm state. The existence of earthquake loading on the slope also has a huge impact. The greater the coefficient of the earthquake given causes, the greater the number of slope stability security decreases.

Further attention needs to be given to the development of the risk of earthquakes in the Semantok Dam area. The more frequent occurrence of earthquakes with a large scale will cause the earthquake coefficient value in each return period is increasing. These conditions will further increase the risk of failure of the Semantok Dam slope stability.

8. Conclusion

Slope stability modeling simulations have been carried out due to the risk of rapid drawdown danger and also the earthquake loading at Semantok Dam using the help of Geostudio 2012 software. The modeling results show that the condition of rapid drawdown without earthquake loading, which causes excessive pore water pressure causes a decrease in the stability of the dam slope but within safe limits. Analysis with the addition of the Maximum Design Earthquake (MDE) earthquake load causes the failure of the slope to maintain its stability. However, based on an analysis of permanent deformation due to earthquake load, the dam is still within safe limits. Thus, the design of Semantok Dam meets the criteria for safety requirements for dam stability.

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Symbols and abbreviations

FR_{tot}	Total risk factor
FR_k	Rssk factors for reservoir capacity influence
FR_t	High risk factors for dams
FR_e	Risk factors for evacuation needs
FR_h	Risk factors for the influence of downstream damage
PGA_M	Earthquake acceleration corrected
F_{PGA}	Amplification factor for PGA
S_B	Base earthquake acceleration value
g	Earth's gravity acceleration
K_h	corrected earthquake coefficient for each return period T
K_o	Corrected earthquake coefficient at ground level
α_2	Structural influence factor
$Kmax$	Maximum earthquake acceleration acting at the center of the slip plane
Ky	Earthquake acceleration which results in a slope stability security factor equal to 1
$\ddot{U}_{max}$	The acceleration of the earthquake at the top of the dam
$U\ max$	Permanent deformation
D	Dam guard height