Stability of Existing Banyukuwung Dam in Recent Hydrology and Geotechnical Conditions

Pitojo Tri Juwono[1], Runi Asmaranto[1*], Ari Murdhianti[2]

[1]Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Malang, 65145, Indonesia
[2]Associate Expert water resources and dam, PT. Triando Konsultama, Malang, 65145, Indonesia

runi_asmaranto@ub.ac.id

Abstract. Banyukuwung Dam is located in the villages of Sukorejo and Sudo, Sumber District, Rembang Regency, Central Java Province. This dam was built in 1995-1997 to serve the needs of 7750 ha of irrigation water and 35 l/s of raw water needs. Dam type is homogeneous reservoir, has a height of 19.40 m above the riverbed and 25.40 m above the foundation excavation. The length of the dam peak is 181.00 m and the width is 5.00 m while the reservoir volume under normal water conditions is 1.64 million m3. Along with seasonal changes and extreme hydrological behavior and based on an investigation of current geotechnical conditions, stability analysis is needed based on these two conditions. It is very important to plan operational and maintenance activities related to the dam maintenance program. So that it is expected to be useful for the relevant agencies in making operational decisions. The purpose of this study was to determine the stability of the existing Banyukuwung dam based on the latest hydrological and geotechnical behavior. The results are expected to provide recommendations in the management, operation and maintenance of the dam manager

Keywords: Banyukuwung reservoir, dam stability, hydrogeotechnical

1. Introduction

Water Resources are very important for humans because they are basic human needs. From all of the water on the surface of the earth, only 2.5% is in the form of fresh water. With this very limited amount, then needs the presence of protection on the existence of water resources and their optimal use. In the context of the maximum utilization of water sources, needed the development effort and good water management namely by building reservoirs to store water.

Banyukuwung Dam is located in Sumber District, Rembang Regency, it was built in 1995 [2]. In general, the Dam is to collect water that is used to meet various needs including irrigation, raw water, flood control, tourism and others. Analysis of the existing Banyukuwung dam stabilization needs to be done considering the age of the building which is old and there are some symptoms of damage due to hydraulic behavior, so that the preservation of building functions will be maintained [1][2][3].

2. Material and Methods

2.1. Study Location

The Study Location is Banyukuwung Dam which is located at the coordinate 06°46'51" S and 111°19'18,9" E in Banyukuwung, Sukorejo and Sudo Village, Sumber Subdistrict, Rembang Regency, Central Java Province.

Rembang Regency

Sukorejo Village

Banyukuwung dam

Figure 1. Location of Study

Banyukuwung Dam was built to provide 35 l/s raw water estimated to be able to meet the water needs of ± 20,000 residents in Rembang Regency, especially Kaliori District; and to provide irrigation supplies of around 775 ha through the Pentil Weir [2].

2.2. Primary and secondary data collection

Data needed in the processing of this study, among others [2][5];
1. Rainfall Data from Banyukuwung station for 1973-2017
2. Map of the Indonesian Earthquake 2017
3. Geotechnical investigation data of the foundation and body of Dam
4. Cross section of Banyukuwung dam body
5. Instrumentation measurement of standpipe Piezometer

2.3. Study Stage

The steps of this study are arranged systematically so that facilitate the completion of this analysis. The steps of the study that conducted are as follows [5][6];
1. Primary and secondary data collection
2. Determine the regional rainfall
3. Test the skewness of rainfall data
4. Frequency analysis test
5. Goodness of fit test
6. Maximum annual daily rainfall
7. Analysis of design flood discharge with the latest hydrological conditions
8. *Flood Routing*
9. Analysis of seepage in the body of the dam using the latest geotechnical data
10. Analysis of dam body stability using Bishop modified methods uses the latest soil sampling data

2.4. Geotechnical Survey and Investigation

A geotechnical investigation survey was conducted to find out the latest geotechnical parameters which include [5][11]

1. Piezometer measurement
2. Investigation of undisturbed sampling at :
   a. physical properties of landfill and foundation
   b. mechanical properties of soil embankments and foundations
   c. Permeability of embankments and foundation. Investigation of land in the field was carried out by PT Supraharmonia in collaboration with the dam manager. The location of undisturbed sampling points is as follows:
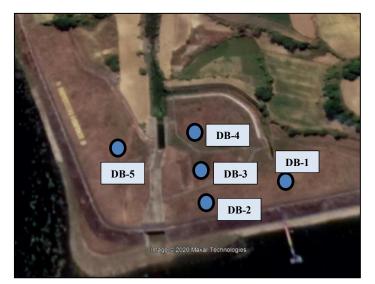

Figure 2. Drilling Bor location of soil properties investigation

Table. 1. Coordinate of drilling bore and depth

Location	X	Y	Depth (m)
DB-1	535460.61	9250423.01	15 m
DB -2	535403.03	9250413.43	15 m
DB -3	535398.74	9250439.85	10 m
DB -4	535396.65	9250459.20	10 m
DB -5	535327.03	9250448.97	10 m

 5 (five) drilling point locations (2 @ 15 m and 3 @ 10 m accompanied by a standard penetration test) have been carried out accompanied by fairly undisturbed samples in several depths of soil.
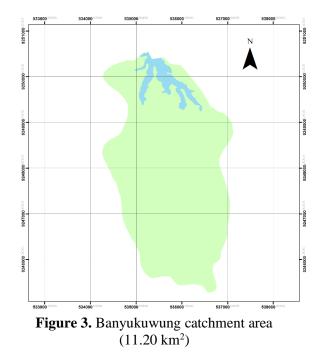
2.5. Hydrological Analysis

Hydrological analysis is done by comparing the analysis of rainfall and flood plans based on the results of analysis of studies in 1999, 2015 and present conditions. Hydrological calculations use basic rain data at Sulang and Sumber rain stations. Flood tracing is conducted to determine the modification of flood flow, to find out the maximum outflow discharge and maximum water level above the overflow threshold.

Frequency analysis can be applied to river discharge or rain data using annual maximum data, the largest data that occurs during one year, measured over several years. There are several forms of continuous (theoretical) distribution functions, which are often used in frequency analysis for hydrology such as the Normal distribution, Normal Log, Gumbel, Pearson, Pearson Log, etc [8][15].

Table 2. Soil data of drilling bore from laboratory test

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Borehole No.	DB-1		DB-2				DB-3			DB-4			DB-5		
Sample depth, m	2 – 2.5	8 – 8.5	12-12.5	0.5-1	6-6.5	14-14.5	2-2.5	4-4.5	8-8.5	2-2.5	4-4.5	6-6.5	0.5-1	4-4.5	8-8.5
Specific gravity, Gs	2.53	2.52	2.52	2.61	2.69	2.71	2.68	2.65	2.69	2.66	2.69	2.7	2.54	2.64	2.7
Liquid Limit (LL)	52	55	45	85	40	31	38	42	39	37	39	38	53	35	31
Plastic Limit (LL)	17	21	19	33	28	24	30	34	30	30	30	27	20	27	24
Shrinkage Limit (SL)	10	11	11	12	19	19	24	23	24	15	12	10	8	13	11
Indeks Plasticity (IP)	35	34	26	52	12	7	8	8	9	7	0	11	33	8	7
Liquidity Indeks (LI)	0.83	0.68	0.65	0.54	0.58	0.14	0.5	0.25	0.11	0.29	0.11	0.18	0.85	1.63	0.14
Wet Density, gr/cm^3	1.62	1.6	1.65	1.54	1.76	1.89	1.88	1.84	1.92	1.90	1.92	1.95	1.61	1.77	1.88
Dry Density, gr/cm^3	1.11	1.11	1.21	0.96	1.3	1.51	1.4	1.35	1.47	1.44	1.47	1.51	1.09	1.34	1.5
Natural water content, %	46	44	36	61	35	25	34	36	31	32	31	29	48	32	25
Porosity	0.56	0.56	0.52	0.63	0.52	0.44	0.48	0.49	0.46	0.46	0.46	0.44	0.57	1.49	0.44
Void Rasio	1.26	1.27	1.08	1.73	1.06	0.79	0.91	0.96	0.84	0.85	0.84	0.79	1.33	0.87	0.8
USCS Classification	CH	CH	CL	CH	ML	ML	ML	ML	ML	ML	ML	ML	CH	ML	ML

Figure 3. Banyukuwung catchment area (11.20 km^2)

2.6. Design Flood Discharge

Design Flood Discharge is a flood discharge used to plan the safety level of danger with the largest probability number. To analyze the design flood discharge can be done using the hydrograph method which is conducted using the assist of a synthetic unit hydrograph model and non-hydrographic methods carried out with the help of frequency analysis techniques.

In this study conducted the comparison of Nakayasu Synthetic Unit Hydrograph method [17], Gamma I Synthetic Unit Hydrograph [16] and HSS ITB Synthetic Unit Hydrograph method [6][8]

2.7. Flood Routing

To obtain the flood water level on the dam body it is necessary to conduct flood routing to determine the outflow discharge of the flood storage in the reservoir [11][17].

The width threshold type spillway is used with elevation and volume as follows [4][12];

$$Q = Cd \times B \times H^{3/2} \quad ....(1)$$

With:
Cd = Discharge coefficient
B = Diversion width (m)
H = Water Level above the Spillway (m)

In many cases, to build a fill type dam it is expected to be able to calculate the stability of the talud in order to check the safety of the natural talud, the cut talud, and the fill talud obtained. [1][2]. To determine the condition of the stability of the dam slope, used the modified Bishop Method. Bishop introduced a more thorough solution than a simple slice method. In this method, the effect of the forces on the edge of each slice is taken into account, as follows [3][4][5][14].

$$Tr = N_r \ tan(\varphi_d) + c_d \ \Delta L_n = N_r \left(\frac{tan\,\varphi}{F_s}\right) + \frac{c\ \Delta L_n}{F_s} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$Nr = \frac{W_n + \Delta T - \frac{c\ \Delta L_n}{F_s}\ sin\ \alpha_n}{cos\ \alpha_n + \frac{tan\ \varphi\ sin\ \alpha_n}{F_s}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

$$Fs = \frac{\sum_{n=1}^{n=p}(cb_n + W_n\ tan\,\varphi)\frac{1}{m_{\alpha\ (n)}}}{\sum_{n=1}^{n=p} W_n\ sin\ \alpha_n} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4)$$

2.8. Stability against Seepage

Seepage through dam bodies, foundations, abutment, or hills around the reservoir must be controlled, so that excessive uplift force may not occur.

The safety of soil fill type dam can be calculated based on the following formula [5];
$$Fs = \frac{I_c}{I_e} \geq 4 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (5)$$

3. *Result* and Discussion

3. 1. Rain storm and Design Flood

Based on the results of frequency analysis based on rainfall data at Banyukuwung Station, obtained rainfall design and design flood as follows:

Table 3. Recapitulation of the calculation results of Rain storm – Design Flood - Return period (Tr)

Tr	Rain storm R (mm)				Design flood Q (m³/s)			
	1999	2015	2016	2019	1999	2015	2016	2019
10	140.77	98.08	108.91	99.57	140.77	98.08	108.91	99.57
100	216.07	114.64	127.75	124.68	216.07	114.64	127.75	124.68
1000	308.18	126.75	141.53	140.71	308.18	126.75	141.53	140.71
PMP	700	315.53	317	260.60	700	315.53	317	260.60

Based on the above analysis, it can be seen that there was a decrease in design flood discharge when compared to the data ranges of the previous year (2015 and 2016). While the difference is significant in 1999, because the catchment area of the reservoir studied was different. Table 4 shows the results of the calculation of the rainfall and flood design with return periode each T = 50, 100 and 1000 years. Moreover, it is also compared with condition of 0.5 PMF (probable maximum flood) and PMF.

Table 4. The results of the calculation of rainfall and flood design in various T (return periode) Mononobe (1hr)

T	Rainfall design	Inflow of design flood		Outflow of design flood								Note
		Nakayasu	Snyder	Nakayasu	Elevation	Hd	Freeboard	Snyder	Elevation	Hd	Freeboard	
(year)	(mm)	(m³/s)	(m³/s)	(m³/s)	(m)	(m)	(m)	(m³/s)	(m)	(m)	(m)	
50	118.51	111.08	59.66	63.89	53.22	1.72	0.78	47.12	52.89	1.39	1.11	
100	124.68	116.85	62.75	67.32	53.28	1.78	0.72	49.74	52.94	1.44	1.06	
1000	140.71	131.85	70.79	76.29	53.44	1.94	0.56	56.55	53.07	1.57	0.93	
0.5 PMF	130.30	121.98	65.44	70.34	53.44	1.84	0.66	51.98	52.98	1.48	1.02	
PMF	260.60	243.97	130.89	144.95	54.47	2.97	-0.47	109.11	53.97	2.47	0.03	overtopping
PMF750	750.00	701.67	376.22	433.15	58.27	6.77	-4.27	331.91	56.9	5.40	-2.90	overtopping
PMF Emergency spillway	260.60	243.97	130.89	133.98	53.25	1.75	0.75	81.49	52.76	1.26	1.24	
PMF 750Emergency spillway	750.0	701.67	376.22	398.34	56.13	3.63	-1.13	288.73	54.43	2.93	-0.43	overtopping

PSA-07

T	Rainfall design	Inflow of design flood		Outflow of design flood								Note
		Nakayasu	Snyder	Nakayasu	Elevation	Hd	Freeboard	Snyder	Elevation	Hd	Freeboard	
(year)	(mm)	(m³/s)	(m³/s)	(m³/s)	(m)	(m)	(m)	(m³/s)	(m)	(m)	(m)	
50	59.18	94.45	67.66	26.24	52.45	0.95	1.55	53.36	53.01	1.51	0.99	
100	62.27	99.39	71.24	27.89	52.49	0.99	1.51	56.48	53.07	1.57	0.93	
1000	70.31	112.23	80.55	32.28	52.59	1.09	1.41	64.61	53.22	1.72	0.78	
0.5 PMF	65.21	104.13	75.10	29.39	52.52	1.02	1.48	59.90	53.14	1.64	0.86	
PMF	130.43	208.26	150.20	68.87	53.33	1.83	0.67	127.14	54.24	2.74	-0.24	overtopping
PMF 750	375.84	600.51	436.56	217.62	55.67	4.17	-1.67	353.39	57.63	6.13	-3.63	overtopping
PMF Emergency spillway	130.43	208.26	150.20	35.98	52.23	0.73	1.77	81.63	52.76	1.26	1.24	
PMF 750 Emergency spillway	375.84	600.51	436.56	144.64	53.35	1.85	0.65	330.51	54.70	3.20	-0.70	overtopping

ITB 1 and ITB 2 (R = mononobe 6 hour)

T	Rainfall design	Inflow of design flood		Outflow of design flood								Note
		Nakayasu	Snyder	Nakayasu	Elevation	Hd	Freeboard	Snyder	Elevation	Hd	Freeboard	
(year)	(mm)	(m³/s)	(m³/s)	(m³/s)	(m)	(m)	(m)	(m³/s)	(m)	(m)	(m)	
50	118.51	58.29	75.50	21.10	52.31	0.81	1.69	21.36	52.32	0.82	1.68	
100	124.68	61.31	79.42	22.39	52.35	0.85	1.65	22.62	52.36	0.85	1.64	
1000	140.71	69.16	89.60	25.73	52.43	0.93	1.57	25.89	52.44	0.94	1.56	
0.5 PMF	130.30	63.94	82.86	23.28	52.37	0.87	1.63	23.60	52.38	0.88	1.62	
PMF	260.60	127.87	165.72	52.67	53.02	1.52	0.98	52.66	53.03	1.53	0.97	
PMF750	750.0	367.55	476.48	182.60	55.12	3.62	-1.12	188.89	55.26	3.76	-1.26	overtopping
PMF Emergency spillway	750.0	367.55	476.48	75.96	52.70	1.20	1.30	81.78	52.76	1.26	1.24	

ITB 1 and ITB 2 (PSA 007 = 12 hour)

T	Rainfall design	Inflow of design flood		Outflow of design flood								Note
		Nakayasu	Snyder	Nakayasu	Elevation	Hd	Freeboard	Snyder	Elevation	Hd	Freeboard	
(year)	(mm)	(m³/s)	(m³/s)	(m³/s)	(m)	(m)	(m)	(m³/s)	(m)	(m)	(m)	
50	59.18	58.83	65.01	24.31	52.39	0.89	1.61	23.21	52.37	0.87	1.63	
100	62.27	61.92	68.42	25.85	52.43	0.93	1.57	24.64	52.40	0.90	1.60	
1000	70.31	69.94	77.27	29.88	52.53	1.03	1.47	28.49	52.50	1.0	1.50	
0.5 PMF	65.21	64.97	71.74	27.25	52.47	0.97	1.53	25.99	52.44	0.94	1.56	
PMF	130.43	129.93	143.48	62.31	53.20	1.70	0.80	59.55	53.15	1.65	0.85	
PMF 750	375.84	375.21	414.13	219.55	55.60	4.10	-1.6	210.47	55.51	4.01	-1.51	overtopping
PMF Emergency spillway	375.84	375.21	414.13	78.74	52.73	1.23	1.27	81.89	52.76	1.26	1.24	

Noted: Elevation of spillway = 51.5 m; Elevation of dam = 54.0 m

Based on the results of the flood discharge analysis above it can be seen that the condition of the Dam is safe against flood discharge of 0.5x Q_{PMF} and below. However, it is not safe against Q_{PMF} discharge, overtopping will occur, and the watch height is less than the required minimum of 0.75 m. However, if an emergency spillway is utilized, the condition is still safe from Q_{PMF} flooding. Based on field conditions, the emergency spillway is tending to solidify because it is used as a traffic access for residents in the fields/rice fields.

3. 2. *Reservoir Capacity*

Based on the results of the latest bathymetry measurements, it is known that the reservoir volume at Normally Water Level (NWL) is 1,764,897 m^3. While based on the results of a previous study in 1999 from PT.Indrakarya [2] the volume of reservoir was 2,293,800 m^3, this shows that there was a reduction in sediment by 0.529 million m^3, within a period of 19 years or sediment deposition of 27.84 m^3/ year. The curved graph of the Banyukuwung Reservoir Capacity results of the latest bathymetry measurements are as follows Figure 4.
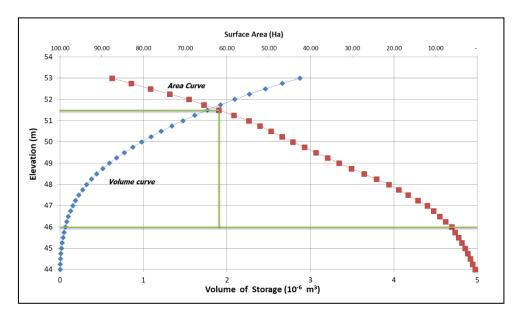

Figure 4. Reservoir capacity of Banyukuwung Dam on 2018

3. 3. *Dam Stability Analysis*
3.3.1.*Geotechnical properties*

Banyukuwung Dam is a type of landfill with material in the form of grayish yellow clay to blackish gray with N values between 9/30 cm to 16/30 cm. Whereas in bedrock N values range from 45/30 cm to above 60 / 30cm. Permeability test shows that the pile material is waterproof, with k values ranging from 10^{-5} to 10^{-8} cm/s. In bedrock k values range from 10^{-6} to 10^{-9} cm/sec. The results of laboratory analysis of soil mechanics show that the embankment has a specific gravity of 2.3 to 2.7 with a content weight of 1.51 - 2.07 gr/cc. Atterberg limit shows LL value of 60.8% - 69.9%, PL value = 17.6% - 25.8%, and PI value = 40.4% - 44.1%, so it is included in the ML group (Silt- Low Plasticity). Consolidated Undrained (CU) triaxial test results the value of C '= 0.14 - 0.19 kg/cm^2 and ϕ = 30° - 31°. While the Unconsolidated Undrained (UU) triaxial results of C = 0.16 - 0.26 kg/cm^2 and ϕ = 22° - 29° while the consolidation parameters, C_c = 0.2498 - 0.3019. The area around the pool has hilly morphology with lithology of clay, silt, silty clay and clayey silt which is mostly agricultural land.

3.3.2.Seepage Analysis of dams

The amount of seepage that comes out of the Dam body is calculated by finite element in the form of Flux, namely the discharge (Q) of the seepage that passes through the dam core [7]. The seepage analysis analyzed was at the Flood Water Level (FWL El. +52.5 m), Normal Water Level (NWL El. +51.5 m), and Lowest Water Level (LWL El. +42 m) shown if Figure 3 – 5.
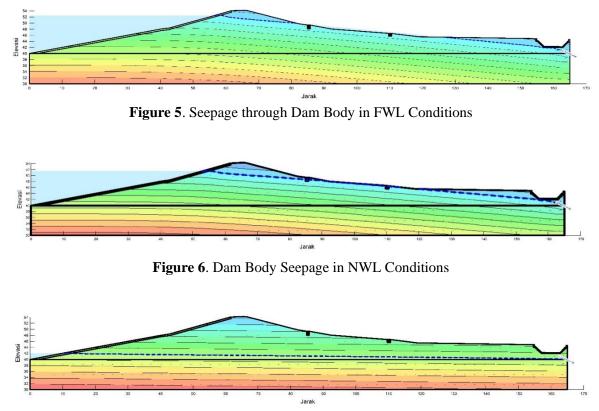

Figure 5. Seepage through Dam Body in FWL Conditions

Figure 6. Dam Body Seepage in NWL Conditions

Figure 7. Dam Body Seepage in LWL Conditions

The results of seepage analysis on water level conditions are presented as follows:

FWL +52.5 m = 9.36 x 10^{-9} m³/s/m

NWL +51.5 m = 8.56 x 10^{-9} m³/s/m

LWL +42 m = 1.11 x 10^{-9} m³/s/m

Average = 6.34 x 10^{-9} m³/s/m x 352 m = 2.23 x 10^{-6} m³/s

Average seepage capacity (2.23 x10^{-6} m³/s) <1% of the average Q of river inflow (1.69.10^{-4} m³/s). Therefore, it can be seen the seepage capacity that occurs in the foundation and body of the Banyukuwung Dam still meets the requirements specified:

- Q average river inflow = 0.016905 m³/s

- 1% of the average river Q = 1.69.10^{-4} m³/s.

3.3.3. Slope Stability Analysis

Dam slope stability was analyzed using the Bishop Modification method produced as shown in Figure 8, for Optimum Base Eartquake (OBE) conditions with 100 years earthquake return period. The calculation results are then tabulated as follows.
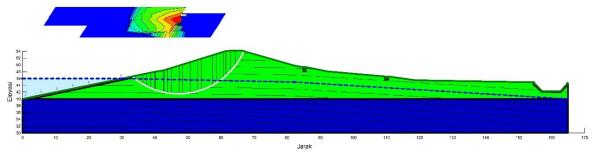
Figure 8. Analysis of the dam slope stability with OBE earthquake load
(Return periode T = 100 years)

Table 5. Safety factor of OBE condition – water level (Upstream,Us/Downstream,Ds)

Condition of dam	FS	Safety Factor				Note
		y/H = 0.25	y/H = 0.5	y/H = 0.75	y/H = 1	
Us-empty	1.1	2.46	2.53	2.57	2.60	safe
Ds-empty	1.1	2.64	2.73	2.78	2.81	safe
Us -LWL	1.1	2.16	2.22	2.25	2.28	safe
Ds-LWL	1.1	2.60	2.68	2.72	2.75	safe
Us-NWL	1.1	2.41	2.51	2.56	2.61	safe
Ds-NWL	1.1	2.00	2.07	2.10	2.14	safe
Us-FWL	1.1	2.62	2.75	2.81	2.88	safe
Ds-FWL	1.1	1.85	1.91	1.95	1.97	safe

Results of dam slope stability analysis with Maximum Design Earthquake (MDE) - T = 3000 yr with Earthquake Map of the 2010, as follows Table 6.

Table 6. Safety factor of MDE condition – water level (Upstream,Us/Downstream,Ds)

Condition of Dam	FS	Safety Factor				Note
		y/H = 0.25	y/H = 0.5	y/H = 0.75	y/H = 1	
Us-empty	1.1	1.33	1.46	1.53	1.61	safe
Ds-empty	1.1	1.31	1.46	1.54	1.62	safe
Us -LWL	1.1	1.18	1.29	1.34	1.41	safe
Ds-LWL	1.1	1.33	1.48	1.55	1.64	safe
Us-NWL	1.1	1.10	1.28	1.28	1.36	safe
Ds-NWL	1.1	0.98*	1.09	1.15	1.21	*Not Safe*
Us-FWL	1.1	1.11	1.24	1.31	1.40	safe
Ds-FWL	1.1	0.911*	1.01	1.07	1.13	*Not safe*

Based on the table above it can be seen that the NWL and FWL conditions, with a ratio of y/H = 0.25, the downstream slope conditions are less safe (critical) in the earthquake return period = 3000. Results of dam slope stability analysis with Maximum Design Earthquake (MDE) - T = 3000 yr with Map of the 2017 Earthquake, as follows Table 7.

Table 7. Safety factor of OBE condition – water level (Upstream,Us/Downstream,Ds)

Condition of Dam	FS	Safety Factor				Noted
		y/H = 0.25	y/H = 0.5	y/H = 0.75	y/H = 1	
Us-empty	1.1	1.46	1.60	1.66	1.74	safe
Ds-empty	1.1	1.46	1.61	1.69	1.77	safe
Us -LWL	1.1	1.29	1.40	1.46	1.52	safe
Ds-LWL	1.1	1.48	1.63	1.70	1.78	safe
Us-NWL	1.1	1.29	1.35	1.42	1.50	safe
Ds-NWL	1.1	1.10	1.21	1.27	1.33	safe
Us-FWL	1.1	1.24	1.39	1.46	1.55	safe
Ds-FWL	1.1	1.02*	1.12	1.17	1.23	*Not safe*

Based on the table above, it can be seen that in the FWL condition, with a ratio of y/H = 0.25, the downstream slope condition is less safe (critical) in the earthquake return period = 3000 yr

4. Conclusions

Based on the results of the analysis above on the stability conditions of the Banyukuwung Dam, it can be concluded as follows:

Under normal load conditions, the hydrological and flood hydraulic conditions are in the "sufficient" category, the seepage condition is safe and the review of the body structure aspects of the dam is "safe". Whereas in terms of dynamic (extraordinary) load conditions, the hydrological and flood hydraulic conditions of the category of "less", seepage conditions are safe, while the condition of the dam's body structure is "less safe". Consequently, the safety status of the dam is "ENOUGH", but there is a threat to the hydrological/hydraulics conditions at the QPMF discharge potentially overtopping. While the stability of the dam slope there is a threat to the Maximum Design Earthquake (MDE), T = 3000 year dynamic load conditions. However, if we look at the design criteria for the Banyukuwung Dam, it was originally designed according to the small pond criteria, so that the above conditions are quite understandable that if a safety review is carried out based on the criteria of a large dam, there are a number of parameters that need to be adjusted accordingly.

References

[1] IPCC., 2007 Intergovernmental Panel on Climate Change, IPCC Fourth Assessment Report: Climate Change

[2] Ammar Rouaiguia and Mohammed A. Dahim, 2013. Numerical Modeling of Slope Stability Analysis, International Journal of Engineering Science and Innovative Technology (IJESIT), ISSN: 2319-5967

[3] Torimtubun, Angelina Tutulenan, 2018. Analisa Banjir Akibat Keruntuhan Bendungan Banyukuwung dengan Menggunakan HEC-RAS. Undergraduate thesis, Universitas Brawijaya.

[4] Anonymous, 2004. Stability analysis of earth fill dams due to earthquake load. Guidelines of PdT-14-2004. Ministry Public Work and Transport.

[5] Anonymous, 2003. Guidelines Inspection/Evaluation Dam and the Guidelines for Common Criteria Dam Design, SK Dirjen SDA/KKB No.05 / KPTS / 2003. Dam Safety Commission.

[6] Asmaranto, R., Suryono, A., & Hidayat, M. 2019. Inspections of Hydro-Geotechnical on Ngancar Dam. Civil and Environmental Science Journal, 2(2), pp.117-127. doi:https://doi.org/10.21776/ub.civense.2019.00202.5

[7] Asmaranto, runi et.al. 2020. Safety evaluation of the existing Grawan Dam based on hydro-geotechnical behaviour conditions to ensure the availability of water resources, published under licence by IOP Publishing Ltd, IOP Conference Series: Earth and Environmental Science, Volume 437, The 3rd International Conference of Water Resources Development and Environmental Protection 12–13 October 2019, Malang https://iopscience.iop.org/article/10.1088/1755-1315/437/1/012006,

[8] E Fadaei Kermani and G. A Barani. 2012. Seepage Analysis through Earth Dam Based on Finite Difference Method, Journal of Basic and Applied Scientific Research ISSN 2090-4304 vol 2 (11) page 11621-11625

[9] Fahim Ashkar and Taha B. M. J. Ouarda, Approximate Confidence Intervals for Quantiles of Gamma and Generalized Gamma Distributions, Journal of Hydrologic Engineering, 10.1061/(ASCE)1084-0699(1998)3:1(43), 3, 1, (43-51), (1998).

[10] J.R. Swaisgood P.E. 2003. Embankment dam deformations caused by earthquakes. Colorado. USA

[11] Ms Abhilasha P.S and T.G Antony Balan. 2013. Numerical Analysis of Seepage in Embankment Dams, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 13-23

[12] PR. Bamane and Dr.S.S.Valunjkar. 2014. Dam Safety Instrumentation, American Journal of Engineering Research (AJER) e-ISSN: 2320-0847 p-ISSN: 2320-0936 page 58-62

[13] Sosrodarsono, Suyono & Takeda, Kensaku. 1989. Bendungan Type Urugan. Jakarta: Erlangga.

[14] Xiaoli Ding and Hui Qin. 1998. Geotechnical Instruments in Structural Monitoring, Journal of Geospatial Engineering, Vol. 2, No.2, pp.45-56

[15] Yu Zhao, Zi-Yhi Tong and Qing Lu. 2014. Slope Stability Analysis Using Slice-Wise Factor of Safety, Hindawi Publishing Corporation, Mathematical Problems in Engineering, Volume 2014, Article ID 712145, 6 pages.

[16] Virgiawan Eric A, etal. 2014. Analisa Keruntuhan Bendungan Gondang Dengan Menggunakan Program Zhong Xing HY21. Jurnal Teknik Pengairan

[17] Harto, Sri BR. 2009. Analisa Hidrologi. Yogyakarta: Biro Penerbit Keluarga Mahasiswa UGM

[18] Soemarto, C.D. Hidrologi teknik. 1995. Jakarta: Erlangga