International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Geotechnical Stability Performance of Batubesi Dam A Review of Seismicity Impact on Structural Dam Safety

Wiyatno Haryanto[1], Anom Prasetio[2], Agung Mulyo[3], Zufialdi Zakaria[4]

[1]Post Graduate Student at Universitas Padjadjaran, Faculty of Geological Engineering,
Jl. Dipatiukur No. 35, Bandung 40132, Indonesia

[2]Post Graduate Student at Institut Teknologi Sepuluh Nopember, Faculty of Physics Engineering,
Jl. Arif Rahman Hakim Kampus ITS Sukolilo Program Pascasarjana ITS, Surabaya, Indonesia

[3]Senior Lecturer at Universitas Padjadjaran, Faculty of Geological Engineering, Jl. Dipatiukur No. 35, Bandung 40132, Indonesia

[4]Senior Lecturer at Universitas Padjadjaran, Faculty of Geological Engineering, Jl. Dipatiukur No. 35, Bandung 40132, Indonesia

Abstract*:* *This journal is intended to evaluate geotechnical stability performance of Batubesi Dam, a technical review of the structural safety on a concrete facing rockfill dam (CFRD) in terms of geotechnical stability of downstream slope face under different seismicity models in several determined conditions. Batubesi Dam is a hydroelectric power plant located in an operation area of PT Vale Indonesia Tbk at Sorowako, East Luwu Regency, in South Sulawesi Province, Indonesia, constructed to elevated water level of the dam reservoir to generating electric power. In the present journal, effects of seismic loading and the reservoir in two different water levels (e.g. normal water level and probable maximum flood level) are exercised to understand behavior of the dam structure against external forces. A limit equilibrium method is introduced to determine factor of safety (FoS) of respective condition; meanwhile seismicity models are obtained from previous study, references, and standards. Geotechnical models of the dam structure and its ground profiles are referring to detailed engineering design and previous geotechnical investigation related to the study area. The dam structure is modeled in effective stress condition in free-drain concept in which the porewater pressures are represented by presence of piezometric surface (phreatic lines) that confirmed by in-place geotechnical monitoring and surveillance data. In certain conditions, some safety factors of the dam are not complying with the minimum requirement (standards and/or references); further additional analysis by means of finite element method should be performed to obtain stress deformation, stress-strain relationship behavior, and potential displacement (level of damage) of the dam.*

Keywords: Geotechnical stability, seismic loads, peak ground acceleration (PGA), limit equilibrium method, factor of safety (FoS), finite element, stress deformation.

1. Introduction

Batubesi Dam is located on Sorowako area within coordinate position: –2º42'41" latitude and 121º18'34" longitudes as part of central Sulawesi island, constitutes a region with very active seismotectonic intensity. The dam has been functioned as hydroelectric power plant owned and operated exclusively by PT Vale Indonesia Tbk (formerly PT International Nickel Indonesia Tbk called as INCO Limited) since 1978s to generate electric power with capacity about 3x65 MW for nickel ore processing plant.

Seismotectonic setting of Sorowako as site of interest is very active as proven by frequent earthquake occurrences and high magnitudes controlled by several active faults such as Matano, Lawanopo, Walanea, and Palu–Koro fault system. It has directly influenced the seismic hazard and calculation of seismic design parameters for engineering purposes that represented by peak ground acceleration (PGA) parameters.

Several standards and/or references had been published by national government and professional to determine PGA parameters for earthquake resistant building structures at Sorowako site-specific area such as:

- Bureau of National Standardization (1989) published SNI 03-1726-1989 and Kertapati, et al. (1999) published Ground Motion Hazard Map of Indonesia with PGA values between 0.10 – 0.15g, [1], [2],
- Wangsadinata, et al. (2002) published Seismic Resistant Design Standard for Building Structure and Bureau of National Standardization (2003) published SNI 03-1726-2003 as revision of SNI 03-1726 (1989), with PGA values between 0.15 – 0.20g [3], [4],
- Irsyam, et al. (2010) and Bureau of National Standardization (2012) published SNI 1726:2012 to revise SNI 03-1726 (2003) based on updated seismic data with PGA values equal to or more than 0.60g [5], [6], and
- Cipta, et al. (2016) published "A Probabilistic Seismic Hazard Assessment for Sulawesi" with PGA values between 0.35 – 0.40g [7].

The standards and/or references above provide different results about geotechnical stability performance of Batubesi Dam that represented by safety factor values. Furthermore, the compliance of engineering design with the standards and/or references is expectedly to be recognized by geotechnical modeling and simulation of safety factor dealing with the seismic loads.

Figure 1: Aerial photograph of Batubesi Dam

2. Geological and Seismotectonic Setting

Ahmad (2005) declared the elements of lithologic and major structures of Sulawesi comprises: West and North Sulawesi Volcano–Plutonic Arc which is controlled by North Sulawesi thrust-fault and strike-slips of Palu–Koro fault system, Lawanopo, and Lamasi faults; Central Sulawesi Metamorphic Belt controlled by strike-slips of Matano, Lawanopo, and Poso faults; East Sulawesi Ophiolite Belt which is controlled by strike-slips of Matano and Lawanopo faults; and Banggai-Sula & Tukang Besi Continental Fragments controlled by thrust of Batui, Sula, and Sula-Sorong faults [8] as shown in the following Figure 2.

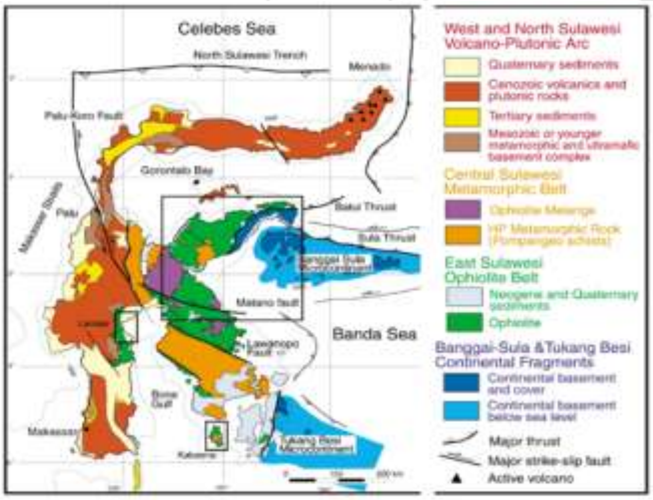

Figure 2: Lithologic and Major Structure of Sulawesi [8]

Simanjuntak, et al. (1991) had mapped Sorowako and vicinity area in terms of regional geological setting as written in the report of Geological Map of Malili Quadrangle, Sulawesi is located in East Sulawesi Ophiolite Belt that consists of Ultrabasic Complex rocks (MTosu) and Larona Formation (Tpls) with some pelagic sedimentary and mélange from Wasuponda Mélange Formation (MTmw) [9]. Some sedimentary rocks of Late Cretaceous period on the research location are characterized by intercalation of calcilutite and radiolarian chert on the bottom layer and some large parts of calcilutite on the top. The deep marine sediments had been mapped as Upper Matano Formation (Kml) and Matano Formation [10]. The calcilutite contains fossils of *Globotruncana* and *Heterohelix* (Late Cretaceous with thickness about 500 meters).

The depositional sequence of sedimentary rock in Cretaceous period is conformable overlying above Masiku Formation (KJml) or Lower Matano Formation (Kml). The Masiku Formation (KJml) consists of calcilutite intercalated with radiolarian chert and inserted by wacke and shale as same with bedded chert, nodules in calcilutite beds. The depositional sequences in Jurassic–Cretaceous period had been strongly deformed and faulted hence the thickness of the origin rocks is unknown; but Sukamto and Simandjuntak (1981) suggests the thickness is at least hundreds meters in which the lithologic contact of bottom layer are commonly thrusted [10]. The sequences are dominantly consists of bedded limestone intercalated with calcarenite conformable overlying Matano Formation (Kml). The depositional sequences mapped as Larea Formation on the eastern part of Sorowako had been deposited in Paleogene period in an open and shallow marine environment; the rocks appear in 150 meter thickness.

The sediment pelagic (Simandjuntak, 1980; Sukamto and Simandjuntak, 1981) comprises intercalating of carbonate material, radiolarian chert, and red shale as deposited at least in Jurassic–Late Cretaceous period [10]. In the middle of mélange rocks outcrops, there are ophiolite blocks, pelagic sedimentary rocks, and metamorphic as encountered in scaly clay as matrix. The sedimentary rocks in the Late Pliocene until Pliocene epoch are characterized by a fluvial depositional environment within a closed area as similar with Larona Formation (Tpls). The rocks consist of coarsen to fine material from the old parent rocks enable to be settling in the basin like graben. In some regions, the same grain-size had been deposited in a shallow marine environment.

The ultramafic rocks are dominantly located in the southeast arm of Sulawesi, meanwhile the mafic rocks are dominantly spread to the northern part that mainly laying along the northern shore of the southeast arm. The sequences of ophiolite are completely encountered on the east arm consists of mafic and ultramafic rocks, pillow lava, and pelagic sedimentary rocks that dominated by deep marine limestone and inserted with bedded chert. Based on the geochemical data, the East Sulawesi Ophiolite Belt is predicted from a mid-oceanic ridge process.

The stratigraphic sequences of local rock formations such as: Ultrabasic Complex (MTosu), Wasuponda Mélange Formation (MTmw), Matano Formation (Kml), and Larona Formation (Tpls). The Ultrabasic Complex is dominated by periodotite rocks consists of harzburgite, lherzolite, wehrlite, websterite, pyroxenite, serpentinite, dunite, diabase, locally as mafic rocks of gabbro and basal member of East Sulawesi Ophiolite Belt. The age of the rock cannot be confirmed, but it is estimated same with the ophiolite of the eastern arm of Sulawesi as Cretaceous–Early Tertiary period [9].

Wasuponda Mélange Formation (MTmw) comprises lower mélange complex, consists of boulders of mafic rocks, serpentinite, picric, chert, limestone, schist, amphibole, and eclogyte with several sizes embedded in scaly clay matrix

(Simandjuntak, et al., 1991). The formation had been formed by surficial expression of west-dipping subduction zone in Cretaceous period [9].

Simandjuntak, et al. (1991) described Matano Formation (Kml) consist of sedimentary rocks (Mesozoic era) as product of thrust-fault above ultrabasic [9]. Ahmad (2005) declared the Upper Matano Formation is represented by a strong crystalized limestone at the western part of ultrabasic body, calcilutite, marl, and shale inserted by chert and greywacke [8]. Toward the eastern part, marly-shale, bedded limestone, red chert and red shale of Lower Matano Formation are encountered. In the smaller scale, the assembled rocks such as massive limestone, phyletic, mylonitized serpentine, and occasional xenolith from garnetiferous schists are encountered. In between of Lower Matano Formation and lower part of thrust-faulted peridotite there is a thin zone of highly mylonitized serpentinite [9].

Larona Formation (Tpls) consists of sandstone, conglomerate, and claystone intercalated with tuff, constitutes surficial sediment that deposited in Late Tertiary (Pliocene) period overlies unconformity above peridotite rock member of Ultrabasic Complex (MTosu) from East Sulawesi Ophiolite Belt [9].

Some controlling geological structures in Sorowako site-specific area are commonly having strike-slip features that mostly called as sinistral (left) faults including Palu–Koro fault system, Walanae, Poso, Matano and Lawanopo faults in which the shallow crustal movements are still active until now; for example, Palu–Koro fault system according to Hall and Wilson (2000, after Tjia, 1973) [13] has tectonic movements are more than 750 m [11], meanwhile Silver, et al. (1983) considered the movement not more than 250 km [12], and Ahmad (1977) had estimated the sinistral strike-slip about 20–25 km [8]. The tectonic movements had triggered seismic events with epicenters scattered along the fault zones as plotted in the map [7] as shown in the following Figure 3.

The measurement result of updated GPS device [11] shown that the slip-rates about 4 cm/year in Palu–Koro fault is consistent with the estimated palaeomagnetic for rotation during the last 4–5 Ma. The seismic sources data which is contributing the seismicity setting at Sorowako site-specific is explained in Table 1.

Kertapati, et al. (1999) had developed the Earthquake Hazard Map of Indonesia [2] as refer to calculation of the peak ground acceleration (PGA) of certain return period and type of bedrock by means of probabilistic seismic hazard analysis (PSHA) with considering the occurrence of earthquake in the source zone or along the fault focused on the earthquake events with return period of 475 years (or probability of exceedance, POE 10% in 50 years) is shown in Figure 4. Based on the map, the peak ground acceleration (PGA) of Sorowako site-specific is in between of 0.15–0.20g.

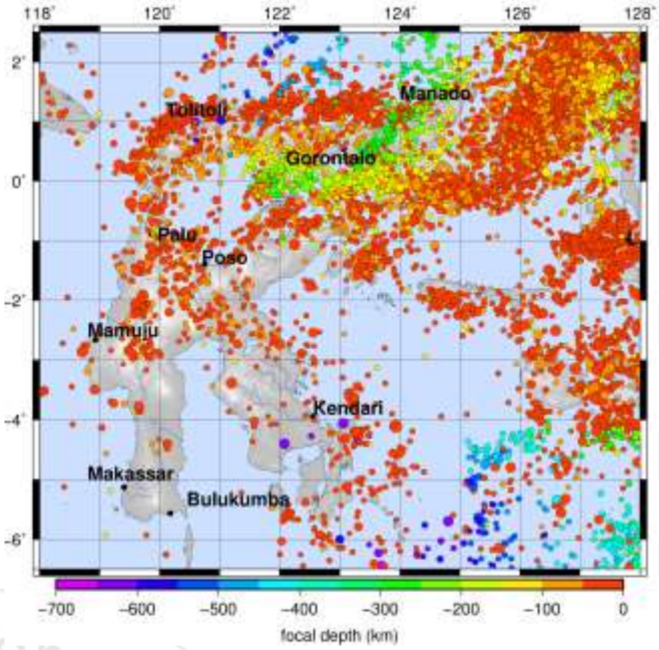

Figure 3: Distribution of Sulawesi Earthquake Epicenter [7]

Table 1: Earthquake Sources at Sorowako Site [12]

No.	*Fault Name*	*Slip-Rate*		*Fault Mechanism*	M_{max}
		mm/year	*Weight*		
1	Palu–Koro	30 35 44	0.25 0.5 0.25	Strike–Slip	7.9
2	Poso	2	1	Strike–Slip	6.5
3	Matano	37 44	0.5 0.5	Strike–Slip	7.3
4	Lawanopo	25	1	Strike–Slip	6.8
5	Walanae	2	1	Strike–Slip	6.6
6	Batui Thrust	2	1	Reverse–Slip	7.3
7	Tolo Thrust	9 10	0.5 0.5	Reverse–Slip	7.5

In 2003, Bureau of National Standardization has published SNI 03-1726-2003 to replace SNI 03-1726-1989 [1], [4] and forth being used as standard for engineering purpose of building structures. It comprises zone of earthquake hazards in Indonesia and response spectra acceleration of design earthquake for the peak ground acceleration (PGA) at bedrock with return period of 500 years that dividing Indonesia into six zones of earthquake hazards. Sorowako in the map is categorized into Zone 3 and 4 with the PGA value at bedrock in between 0.15–0.20g as shown in the following Figure 5.

In 2012, Bureau of National Standardization has published SNI 03-1726:2012 [6] to revise SNI 03-1726-2003 [4] by considering updated earthquake catalogue and additional information of active faults since 1900 until 2009 and relocated earthquake data until 2005. Some seismic sources were used in modeling such as fault sources, subduction sources, and gridded seismicity (background sources). The wholes fault and subduction sources were modeled using 3D modeling by considering tomographic for geometry and GPS for slip-rates, meanwhile the background sources and inter-slab subduction using smoothed gridded seismicity model. The attenuation function used in the modeling is the next generation attenuation (NGA) in which the attenuation arranged using worldwide global data [12].

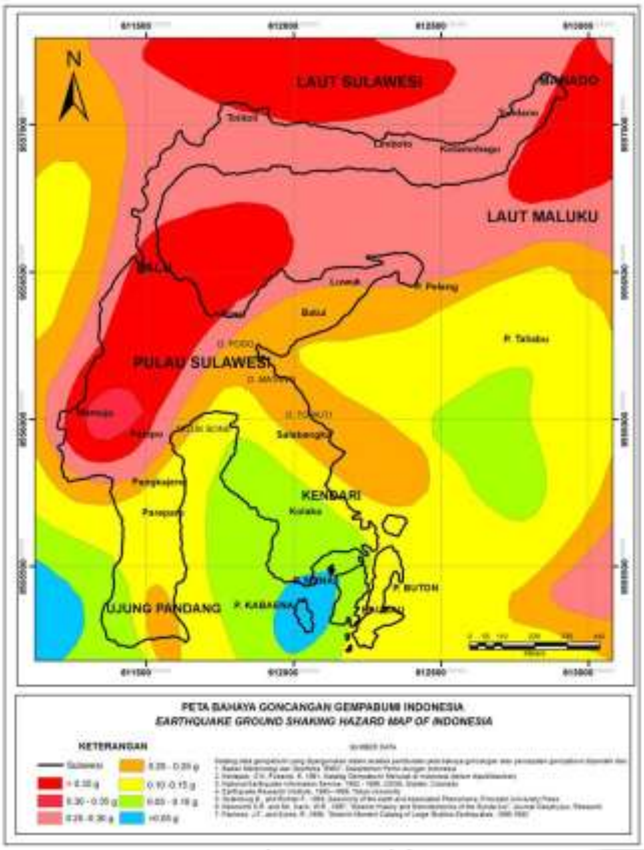

Figure 4: Earthquake Hazard Map of Sulawesi [2]

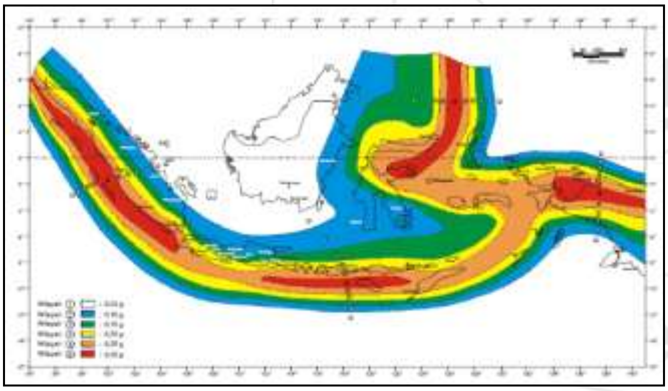

Figure 5: Earthquake Hazard Map of Indonesia [4]

Furthermore, Irsyam et al. (2010) published the Earthquake Hazard Map of Indonesia 2010 contains some modeling of peak ground acceleration (PGA) and response spectra acceleration (SA) at bedrock (S_B) with various probability of exceedance (POE) and return period as summarized in the following Table 2 [12].

Referring to the SNI 1726:2012 [6] as formerly proposed by Irsyam, et al. (2010) [5], the map of peak ground acceleration (PGA) of risk-targeted maximum considered earthquake (MCE) is shown in the following Figure 6.

Table 2: PGA and SA at Sorowako Site-Specific

POE	*Life Service (Years)*	*Acceleration*			*Return Period (Years)*
		PGA	*Response Spectra*		
		0 Second	*0.2 Sec*	*1.0 Sec*	
–	–	0.4–0.5g	–	–	50
–	–	> 0.5g	–	–	200
10%	50	> 0.6g	> 1.2g	> 0.6g	475
	100	> 1.0g	> 2.0g	> 1.0g	975
2%	50	1.0–1.2g	2.0–2.5g	1.0–1.2g	2,475
DSHA Faults		0.6–0.7g	1.5–2.0g	0.4–0.5g	150%
DSHA Subduction		< 0.05g	< 0.05g	< 0.05g	Median

The PGA value of Sorowako area based on the risk-targeted maximum considered earthquake (MCE) is 0.6g or about three times of the previous PGA value (read: SNI 03-1726-2003). The map is shown in the following Figure 6 below.

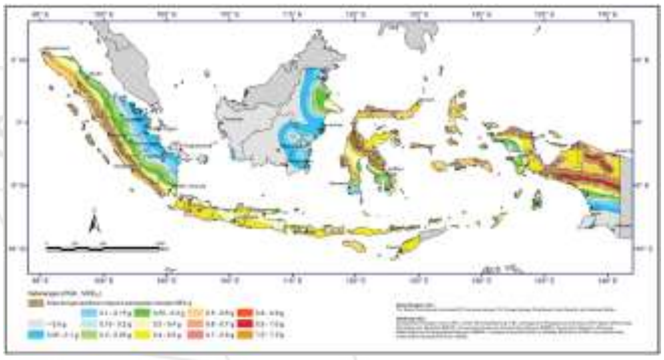

Figure 6: PGA of risk-targeted MCE [6]

Cipta, et al. (2016) had separately assessed seismic hazard for Sulawesi by means of probabilistic approach (PSHA) with return period of 500 years [7] in which Sorowako has peak ground acceleration (PGA) value is about 0.35–0.40g.

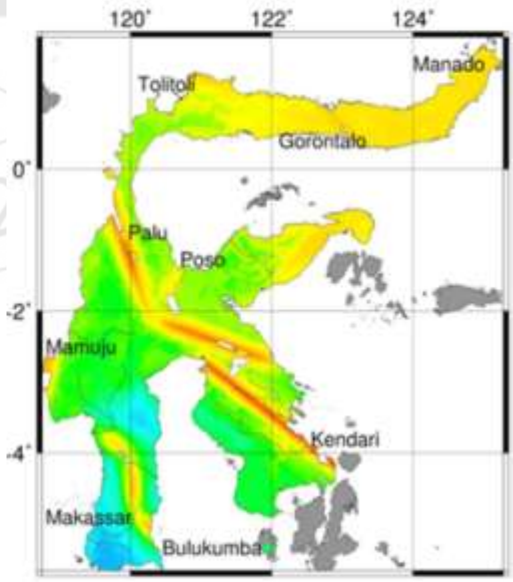

Figure 7: PGA with return period of 500 years [7]

Summary of differently peak ground acceleration (PGA) parameters refer to several standards and/or references is stipulated in the following Table 3 below.

Table 3: Summary of PGA at Sorowako Site-Specific

No.	*Standard or Reference*	*PGA*	*Remark*
1	SNI 03-1726 (1989) [1] & Kertapati, et al. (1999) [2]	0.10–0.15g	PSHA, DSHA
2	Wangsadinata, et al. (2002) [3] & SNI 03-1726 (2003) [4]	0.15–0.20 g	PSHA, DSHA
3	Irsyam, et al. (2010) [5] & SNI 1726 (2012) [6]	0.60g	PSHA, DSHA
4	Cipta, et al. (2016) [7]	0.35–0.40 g	PSHA

3. Methodology

To evaluate geotechnical stability performance of the dam, modeling and simulation by means of limit equilibrium approach is conducted to obtain safety factor of respective conditions based on geotechnical modelling and simulation by inputting seismic loads in pseudostatic condition. The safety factor is defined as a result of resisting forces divided driving forces, meanwhile the seismic loads itself are represented by value of peak ground acceleration (PGA) as referring to the previous study.

A critical condition is considered to be achieved in effective stress (drain) condition on maximum high water level of the dam reservoir induced porewater pressure from piezometric surface (phreatic line).

4. Engineering Design and Dam Criteria

Batubesi Dam is a concrete facing rockfill dam (CRFD) structure, constructed to elevate water head of the reservoir for feeding the hydroelectric power plant. The dam had been equipped with an intake canal and concrete canal made of segmental-U concretes along 6.969 km length from the reservoir to a head pond (penstock forebay) with maximum capacity 153 m^3/s. Further, the water is passing three penstocks with respective capacity 51 m^3/s and elevation head about 143.88 m from Francis turbines position. The dam structure is having reservoir volume about 10 million m^3 with total length of the dam body about 550 m, 32.3 m height, and the top dam elevation on +322 m amsl.

The excessive water level on the dam reservoir will be spilled out by the main spillway and expected being retained on the spill point of El. +319.3 m amsl with maximum flow debit 3x171 m^3/sec. Three emergency spillways (as fuse plugs) segments had been constructed such as: 1x20 m length on El. +321.0 m amsl and 2x20 m length on El. +321.4 m amsl using selected collapsible fill material means the fuse plugs will be collapsed by design in case of the water level of the reservoir exceeding the normal level. The table below describes technical data of the dam based on design and result of the last two major inspections:

Table 4: Technical Data Sheet of Batubesi Dam

No.	*Description*	*By Design*	*Dam Safety Major Inspection*	
			2009	*2013*
1.	Elevation of Parapet (m amsl)	+322.30	+322.30	+322.30
2.	Elevation of Top Fuse Plug (m amsl)	+321.00	+321.00	+321.00
3.	Elevation of PMF Water Level (m amsl)	+324.10	+320.12	+320.30
4.	Elevation of 1000 Years Flood (m amsl)	+320.80	–	–
5.	Elevation of Normal Water Level (m amsl)	+318.00 to +319.60	–	–
6.	Freeboard (m)	1.50	2.39	2.48

Detailed engineering design, as-built drawings, material data sheets, technical specification, and also previous geotechnical site investigation reports were collected to evaluate behavior of geotechnical stability performance of the dam. The following Figure 8 is detailed drawing of the dam cross section defining construction method, material specification, including its geometrical shapes.

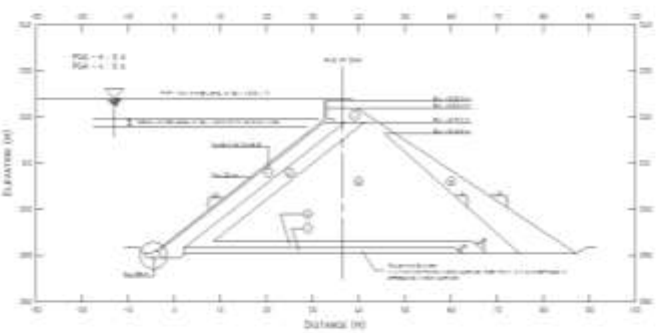

Figure 8: Cross Section of Batubesi Dam

The dam body was divided into several zones according to the typical of construction material, layering and its compaction methods as explained as follows:

- Zone 1: consists of iron cap with gradation 100% passing US standard's sieve dia. 3", 80 – 100% passing sieve dia. 1", 40 – 80% passing sieve No. 4, 10 – 40% passing No. 16, and 0 – 20% passing sieve No. 200. Maximum layer thickness before compaction in confined areas is 10 cm, meanwhile in areas accessible to roller in foundation blanket 1.0 m, and in others areas 25 cm or as required to achieve degree of compaction as per specified by geotechnical engineer.
- Zone 2: consists of crushed rock alternative to Zone 1, minus dia. 3" in crusher run, 25 – 50% passing US standard's sieve No. 4, and 0 – 8% passing sieve No. 200. In confined areas, maximum layer thickness is 10 cm; the compaction methods by hand, operated vibrators and hand tools.
- Zone 3: consists of rockfill material up to 1.0 m size with no more fine particles than will fill voids between larger rock sizes. Maximum layer is 1.0 m and minimum 4 passes of SP-60 roller.
- Zone 4: consists of rockfill material up to 25 cm size, well graded from coarse to fine with rockfill maximum size 25 cm, well graded from course to fine with enough fines to fill the voids while maintaining rock to rock contact.
- Zone 5: consists of rockfill material oversize from Zones 3 and 4, or Zones 3 and 4 materials. No limitation with maximum layer thickness and compaction method.

Mechanical properties of Batubesi Dam materials are referring to original design that reconfirmed by geotechnical investigation results on the last major inspection are shown in the following table.

Table 5: Geotechnical Properties of Batubesi Dam Materials

No.	Material Type	Model	Geotechnical Properties		
			Unit Weight	Cohesion	Friction Angle
			γ (kN/m^3)	c (kPa)	φ (°)
1.	Concrete Face	Mohr & Coulomb	24	350	45
2.	Rockfill		24	0	45
3.	Sandstone		26	0	45
4.	Conglomerate		26	0	45
5.	Bedrock		26	200	45

For geotechnical engineering purposes in terms of the slope stability analysis of the dam, shear strength parameters of the soil or fill materials must be adapted with porewater pressure condition and presence of seepage water (piezometric surface) as discussed by Fell, et al. (2015 after modified Duncan, et al., 1987) [14] as follows:

Table 6: Shear Strength, Pore Pressure, and Unit Weights for Stability Analysis (after Duncan, 1992) [14]

	Condition		
	End of Construction	Rapid Drawdown and Staged Construction	Normal Operating (Steady Seepage)
Analysis procedure and shear strength for free draining zone: filters, rockfill, sand/ gravel in foundation	Effective shear strength analysis, using c' and φ'	Effective shear strength analysis, using c' and φ'	Effective shear strength analysis, using c' and φ'
Analysis procedure and shear strength for low permeability zones	Total stress analysis using S_u and φ[1] or effective stress analysis modeling partly saturated condition	Total stress analysis using S_u and φ[1] for the dam prior to drawdown or construction of second stage	Effective stress analysis using c', φ', unless soils are contractive[2] in which case use S_u measured in the dam
Internal porewater pressure	No internal porewater pressure (u) for total stress analysis; set u equal to zero in these zones. Porewater pressure deter-mined from laboratory tests for effective stress analysis	No internal porewater pressure (u) for total stress analysis; set u equal to zero in these zones. Porewater pressure from seepage analysis for effective stress analysis	Porewater pressure from seepage analysis and/or from piezometer reading for effective stress analysis
Reservoir water	Include (usually as a zone with c' = 0, φ' = 0, γ = 9.8 kN/m^3)	Include (usually as a zone with c' = 0, φ' = 0, γ = 9.8 kN/m^3)	Include (usually as a zone with c' = 0, φ' = 0, γ = 9.8 kN/m^3)
Unit weights[3]	Total	Total	Total

Notes:

1) S_u and φ_u describe undrained shear strength envelope, so the variation in undrained strength, with increase in total stress, can be modelled in the analysis.
2) Contractive soils include poorly compacted saturated clay fill, normally and lightly overconsolidated clays. Effective stress analyses which ignore porewater pressure generated on shearing overestimate the factor of safety.
3) For free draining zones use γ_{dry} or γ_{moist} for zones above water, γ_{sat} below. For low permeability zones, use γ_{sat} or γ_{moist}.

5. Geotechnical Stability Analysis Result

There are two scenarios of the dam reservoir water levels that modeled in this geotechnical slope stability analyses such as: (1) maximum flood level with El. +324.10 m amsl referred to as probable maximum flood (PMF) and (2) normal water level within operational level on El. +318.00 to +319.60 m amsl as higher level (NHWL) are determined in the analysis.

The first scenario (PMF at El. +324.10 m amsl): water level of the dam reservoir is exceeding parapet, then spilling and overtopping above the top dam and the downstream slope; it may resulting factor of safety (FoS) of the dam without seismic load (PGA = 0g) FoS = 1.10.

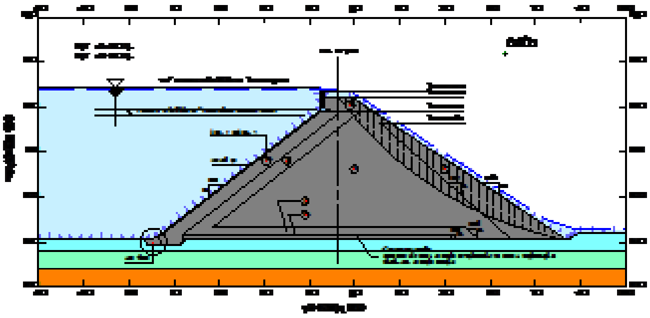

Figure 9: Slope Stability with PGA = 0 g, Maximum Water Level, El. +324.10 m amsl, FoS = 1.10

In case of probable maximum flood (PMF) occurs without presence of earthquake, safety factor (FoS) of the dam is 1.10; on the other hand when the probable maximum flood (PMF) coincidentally occurs together with the earthquake event simultaneously, by design the dam structure may not be collapsed since the emergency spillways (fuse plugs) working on the spill point at El. +321.00 m amsl to spilling out the excessive water level.

The second scenario (normal high water level, NHWL at El. +319.6 m amsl): water level of the reservoir is below the top dam and emergency spillway (fuse plug) as well. The water seepage relatively low controlled by concrete face; hence factor of safety (FoS) of the dam such as: 1.66 (PGA = 0g), 1.37 (PGA = 0.1g), and 1.17 (PGA = 0.2g), 0.96 (PGA = 0.3g), 0.91 (PGA = 0.4g), and 0.75 (PGA = 0.6g).

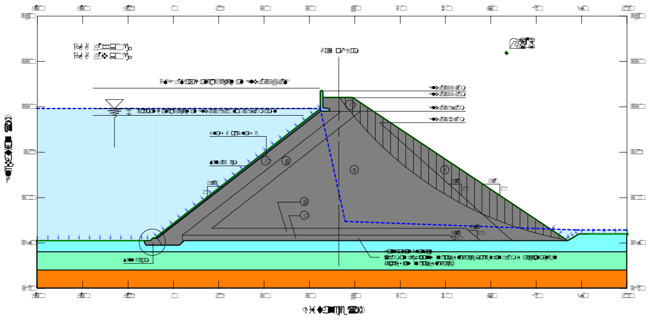

Figure 10(a): Slope Stability with PGA = 0.0 g, NHWL, El. +319.60 m amsl, FoS = 1.66

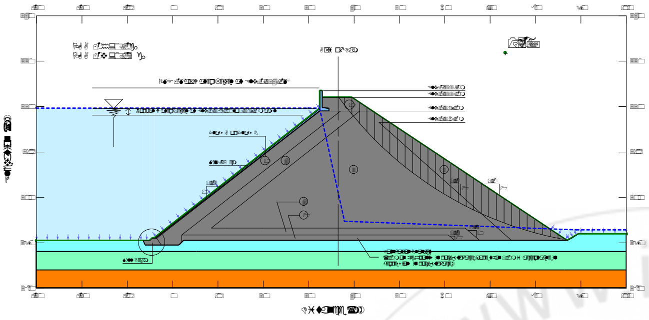

Figure 10 (b): Slope Stability with PGA = 0.1 g, NHWL, El. +319.60 m amsl, FoS = 1.37

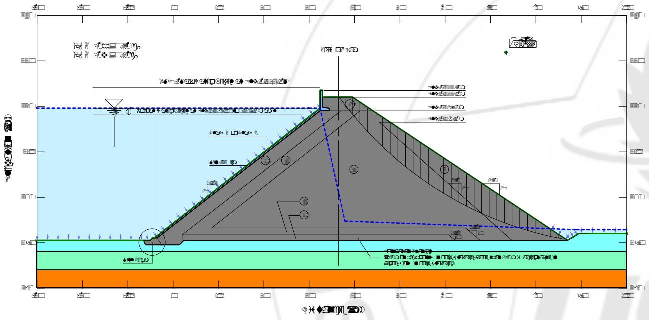

Figure 10(c): Slope Stability with PGA = 0.2 g, NHWL, El. +319.60 m amsl, FoS = 1.17

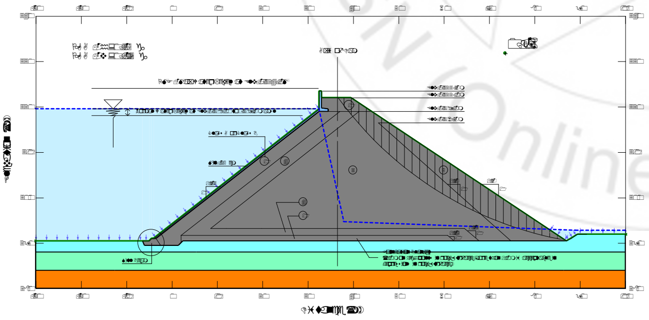

Figure 10(d): Slope Stability with PGA = 0.35 g, NHWL, El. +319.60 m amsl, FoS = 0.96

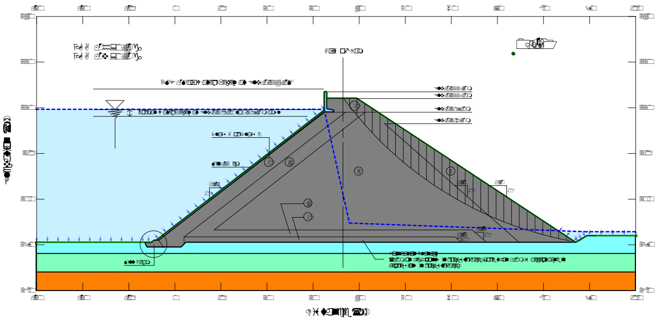

Figure 10(e): Slope Stability with PGA = 0.40 g, NHWL, El. +319.60 m amsl, FoS = 0.91

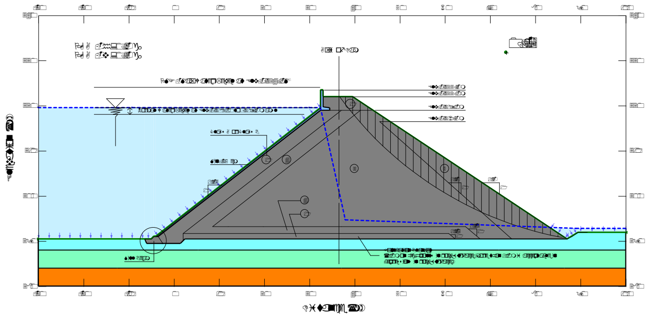

Figure 10(f): Slope Stability with PGA = 0.60 g, NHWL, El. +319.60 m amsl, FoS = 0.75

In normal high water level (NHWL) without presence of the earthquakes, it may provide safety factor of the dam about 1.66, meanwhile the presence of the earthquake with seismic load about 0.35g it may provide safety factor about 0.96 which is not complying with the minimum requirement.

The safety factor of Batubesi Dam based on the two different conditions i.e. water level of the reservoir and presence of the seismic loads and how its compliance with the standards and/or references is summarized in the following Table 7. Several safety factors are still complying with the standards and/or references of SNI 03-1726 (1989) [1], Kertapati, et al. (1999) [2], Wangsadinata, et al. (2002) [3], and SNI 03-1726 (2003) [4]; meanwhile the others are not complying with Irsyam, et al. (2010) [5], SNI 1726 (2012) [6], and Cipta, et al. (2016) [7].

Table 7: Safety factor (FoS) of Batubesi Dam Refer to

No.	*Standard or Reference*	*PGA (g)*	*Factor of Safety (FoS)*	
			PMF	*NHWL*
1.	Without Seismic Load	0.00	1.10	1.66
2.	SNI 03-1726 (1989) and Kertapati, et al. (1999)	0.10–0.15	n/a [1]	1.37–1.26
3.	Wangsadinata, et al. (2002) and SNI 03-1726 (2003)	0.15–0.20	n/a [1]	1.26–1.17
4.	Irsyam, et al. (2010) and SNI 1726 (2012)	> 0.60	n/a [1]	< 0.75 [2]
5.	Cipta, et al. (2016)	0.35–0.40	n/a [1]	0.96–0.91 [2]

Notes : [1] By design, this situation may not be happen since the emergency spillways (fuse plugs) working to spill out the excessive water level
[2] Further analyses should be conducted by means of finite element method in dynamic modes

6. Conclusion and Recommendation

Referring to the discussion as above mentioned, it can be concluded that the safety factors of Batubesi Dam with seismic loads (PGA) below 0.30g referring to SNI 03-1726 (1989) [1], Kertapati, et al. (1999) [2], Wangsadinata, et al. (2002) [3], and SNI 03-1726 (2003) [4] based on the limit equilibrium method are still complying with the minimum requirement (standards and/or references); meanwhile for seismic loads (PGA) more than 0.35g according to Irsyam, et al. (2010) [5], SNI 1726 (2012) [6], and Cipta, et al. (2016) [7], the safety factors of the dam are below design and need more review.

Additional technical review and discussions by means of finite element method to obtain stress deformation, stress-strain relationship behavior, and potential displacement (level of damage) should be conducted to evaluate status of the dam safety in the dynamic failures. Although the safety factor (FoS) on some conditions are less than 1.00 under seismic loading it doesn't mean the dam structure may collapsed. Further geotechnical stability of the dam structure should be reassessed using dynamic analysis model whether or not the deformation exceeding half of the freeboard; when it occurs, the dam structure assumed will be failed.

Retrofitting program as part of the dam structure remediation had been done by PT Vale Indonesia Tbk by means of constructing counterweight at the toe of downstream slope face in order to strengthen geotechnical stability of the dam to comply with the required factor of safety (FoS) against maximum considered earthquakes at Sorowako site-specific.

7. Acknowledgement

This journal is dedicated to management of PT Vale Indonesia Tbk such as: Mr. Lovro Paulic as Chief Operating Officer (COO),Mr. Andi Suntoro as Director of Maintenance & Utilities (M&U) Department, Mr. Roimon Barus as Chief of Mine Technical (KTT); Prof. Dr. Ir. Adjat Sudradjat, M.Sc., Dr. Ir. Dicky Muslim, M.Sc., and Dr. Ir. Sapari Rahadian, MT., as our respectful counterpart in scientific discussion, and all academic community of Universitas Padjadjaran (UNPAD) in Bandung, and all colleagues.

References

[1] Anonymous, "Indonesian National Standard, SNI 03-1726-1989 about Guideline of Earthquake Resistant Design for House and Buildings", Bureau of National Standardization, Jakarta, Indonesia, 1989.
[2] Kertapati, E.K., Setiawan, Y.B., Ipranta, "Earthquake Hazard Map of Indonesia", Geological Research and Development Center, Ministry of Mining and Energy, Bandung, Indonesia, 1999.
[3] Wangsadinata, et al. "Seismic Resistant Design Stan-dard for Building Structure", Ministry of Resettlement and Regional Infrastructure, Bandung, 2002.
[4] Anonymous, "Indonesian National Standard, SNI-03-1726-2003 about Procedure of Earthquake Resistant Design for Building Structures", Bureau of National Standardization, Jakarta, Indonesia, 2003.
[5] Irsyam, M., Sengara, W., Aldiamar, F., Widiyantoro, S., Triyoso, W., Hilman, D., Kertapati, E.K., Meilano, I., Asrurifak, M., Ridwan, M., Suhardjono, "Earthquake Hazard Map of Indonesia 2010 as Reference for Engineering and Design of Earthquake Resistant Infrastructures", Ministry of Public Work, Jakarta, Indonesia, 2010.
[6] Anonymous, "Indonesian National Standard, SNI 1726:2012 about Procedure of Earthquake Resistant Design for Building and Non-Building Structures, Bureau of National Standardization, Jakarta, Indonesia, 2012.
[7] Cipta, A., Robiana, R., Griffin, J.D., Horspool, N., Hidayati, S., Cummins, P., "A Probabilistic Seismic Hazard Assessment for Sulawesi, Indonesia, http://sp.lyellcollection.org, the Geological Society of London, Special Publication, 441, April 26, 2016 [Online]. Available: http://doi.org/10.1144/SP441.6 [Accessed: Sept. 4, 2017].
[8] Ahmad, W., "Geology along the Matano Fault Zone of East Sulawesi", Regional Conference on the Geology and Mineral Resources of South East Asia, Jakarta, Indonesia, 1977.
[9] Simandjuntak, T.O., Rusmana, E., Surono, Supandjono, J.B., "Geological Map of Quadrangle Malili, Sulawesi", Geological Research and Development Center, Bandung, Indonesia, 1991.
[10] Sukamto, R., and Simandjuntak, T.O., "Tectonic Relationship between Geologic Provinces of Western Sulawesi, Eastern Sulawesi, and Banggai-Sula in the Light of Sedimentological Aspects", Geological Research and Development Center, Bandung, Indonesia, 1981.
[11] Hall, R., and Wilson, M.E.J., "Neogene Sutures in Eastern Indonesia", Journal of Asian Earth Sciences 18, 781–808, 2000.
[12] Irsyam, M., Sengara, W., Aldiamar, F., Widiyantoro, S., Triyoso, W., Hilman, D., Kertapati, E.K., Meilano, I., Asrurifak, M., Ridwan, M., Suhardjono, "Summary of Revision Study on Earthquake Hazard Map of Indonesia 2010, Second Edition, Ministry of Public Work, Bandung, Indonesia, 2010.
[13] Tjia, H.D., "Active Faults in Indonesia", Geological Society Malaysia, Bulletin, 10, December 1978, Kualalumpur, Malaysia, 1978.
[14] Duncan, J.M., Buchignani, A.L., Wet, M.D., "An Engineering Manual for Slope Stability Studies". Virginia Tech Center for Geotechnical Practice and Research, Blacksburg, VA 24061, United States of America, 1987.

Author Profile

Wiyatno Haryanto received undergraduate degree in Geological Engineering from Universitas Padjadjaran (UNPAD) in 2002 and certified as Geotechnical Expert from Indonesian Society for Geotechnical Engineering (ISGE) – member of International So-ciety for Soil Mechanics and Geotechnical Engineering (ISSMGE). He involved in some prestigious projects for survey, investigation and design, feasibility study, geotechnical engineering, technical peer review, and slope management of infrastructure and mining sector. He has been working with PT Vale Indonesia Tbk for ten years dealing with mining operation, mine development, and strategic projects.

Anom Prasetio received undergraduate degree in Water Resources Engineering from Universitas Brawijaya (UNBRAW) in 1997. He is a Civil Engineer who has been specialized playing the role in civil engineering and dam safety management. He is certified as Dam Expert from Indonesian Committee National of Large Dam (INACOLD – KNIBB) as entitled with his accountability as Senior Dam Maintenance at PT Vale Indonesia Tbk, also managing some engineering projects related to civil works operation & maintenance in thermal and hydro implementation program. He has been working with PT Vale Indonesia Tbk for eleven years.

Agung Mulyo receive the undergraduate degree in Geology from Universitas Padjadjaran (UNPAD) in 1985, Master degree in Engineering Geology from Postgraduate Program of Geological Engineering – Institut Teknologi Bandung (ITB) in 2000, and Doctor degree in Geology from Faculty of Geological Engineering, Universitas Padjadjaran (UNPAD) in 2016. He is a senior lecturer in the Faculty of Geological Engineering, Universitas Padjadjaran (UNPAD), Bandung, Indonesia. He is interested for research work in geotechnics and engineering geology.

Zufialdi Zakaria received the undergraduate degree from De-partment of Geology, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran (UNPAD), Bandung in 1988; Master of Engineering degree on Engineering Geology from Postgraduate Program of Geological Engineering – Institut Teknologi Bandung (ITB) in 1999; Doctor degree in Geological Engineering from Faculty of Geological Engineering, Universitas Padjadjaran (UNPAD) in 2015. Now, he is a senior lecturer in Faculty of Geological Engineering, Universitas Padjadjaran (UNPAD). Interest research: geotechnics, Geomechanics, engineering geology, geological mapping, and terrain analysis.