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Geotechnical and Seismic Design Considerations in the Re-utilization of a Tailings Storage Facility in the Philippines

Gian Paulo D. Reyes, Roy Anthony C. Luna, Ramon D. Quebral, Patrick Adrian Y. Selda, Marielle Gwen G. Martinez, Desz Justinne N. Ocampo
AMH Philippines, Inc., gian.reyes@amhphil.com

ABSTRACT: The Philippines is known as one of the most mineralized countries in the world. It has the third largest deposits of gold, fourth for copper, and fifth for nickel. When the government lifted the ban on open pit mining recently, the production of precious minerals has once again peaked which warranted the construction of new tailings storage facilities (TSFs), as well as expansion of existing ones. However, in some cases, the construction of a new TSF may not feasible due to constraints in budget, timeline, and constructability. One specific mine site in the southern region of the country is planning to re-utilize an existing TSF by optimizing its storage capacity. This paper presents the geotechnical and seismic design considerations for the re-utilization of the TSF in accordance with the latest international guidelines and in conformance with the strict guidelines of the Philippine Department of Natural Resources - Mines and Geosciences Bureau (DENR-MGB). The methodology to re-use the TSF by reducing water content of existing tailings is discussed. Moreover, the challenges in designing structures in a region that is endangered by several geohazards, both seismic and climate related, such as the Philippines are presented. Discussions focus on the probabilistic seismic hazard analysis (PSHA) to quantify the overall seismic hazard of the area and obtain design accelerations, and limit-equilibrium methods to assess the stability and performance of the dams during static and earthquake events. A case study is presented.

KEYWORDS: Tailings storage facility, Reutilization, Seismic hazard analysis.

1 INTRODUCTION

After the ban for open pit mining was lifted by the Philippine government a few years ago, small- and large-scale mine sites across the country immediately resumed operations to recover loss time and recoup profit. One particular nickel-producing mine site in the southern region plans to increase its mineral production capacity by constructing a new tailing storage facility (TSFs), as well as re-utilize an existing TSF, which will be the primary focus of this paper.

In compliance with regulations from the Philippine Department of Environment and Natural Resources – Mines and Geosciences Bureau (DENR-MGB), once a TSF reaches its maximum storage capacity, the impounded land mass composed of waste materials must be repurposed or reprocessed into a low-impact, environmentally-sustainable area. In the case of the aforementioned nickel mine, an unconventional approach is being explored to further increase the capacity of an already full TSF prior to its decommissioning and rehabilitation. This unique scenario was driven by constraints related to construction time, restricted dam footprint, as well as the need to sustain ongoing productions.

The proposed re-utilization scheme will inherently involve modifications to the original design – which was prepared several years ago and may no longer align with the current regulatory requirements. As such, the updated TSF embankment design must undergo further scrutiny and validation before the mine is permitted by the local agencies to operate anew. In the absence of local codes, the dam design adopts the latest internationally accepted guidelines such as the International Commission on Large Dams (ICOLD), Australian National Committee on Large Dams (ANCOLD), and Global Industry Standard on Tailings Management System (GISTM). Moreover, with the country accounting for 3.2% of the world’s seismicity, while also experiencing more than twenty (20) typhoons every year, the DENR-MGB enforces strict design criteria when it comes to critical, high-risk structures such as TSF dams.

This paper discusses the details of the proposed re-utilization scheme, as well as the geotechnical engineering and seismic hazard assessments of the existing TSF embankment. A site-specific design approach is discussed which is specifically tailored to resist against the unique hazards present in the country due to its geographical location. Seismic design criteria are developed by performing Probabilistic Seismic Hazard Analysis (PSHA) and embankment stability is evaluated through Limit-Equilibrium Method (LEM) – both of which are part of the environmental audit requirements.

2 TSF RE-UTILIZATION SCHEME

During the closure of the first and oldest TSF at the nickel mine site, monitoring observations indicated that the tailings surface level receded by approximately two (2) meters following a six (6)-month period without tailings discharge. Desiccation-induced cracking was also observed with fissures ranging from 0.8 to 1.0 meter in width due to water loss from the tailings pond through drainage and evaporation (Figure 1). However, this TSF was immediately rehabilitated through plantation, hence the regenerated space was not utilized for further tailings storage. Consequently, it provided valuable information and reinforced the idea that re-utilizing completely filled up TSFs, especially the existing ones, is feasible.

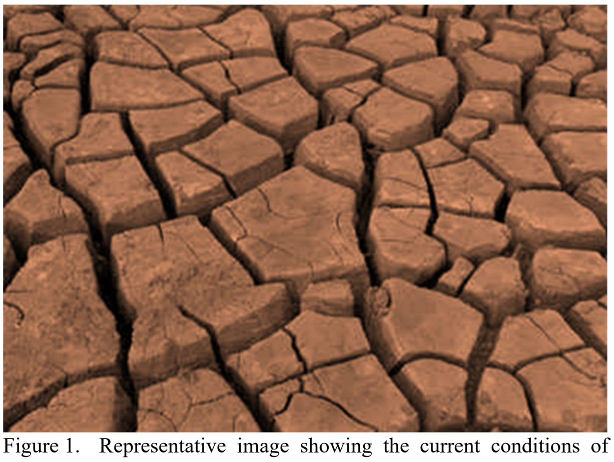


Figure 1. Representative image showing the current conditions of tailings materials – with visible cracks (not actual site photo)

As of February 2024, further assessment of the current TSF revealed a reduction in tailings volume, resulting in an estimated 3 million cubic meters of available storage space. This void space corresponds to approximately 8 to 10% of the facility's total designed storage capacity. Therefore, a re-utilization scheme was proposed for the existing TSF to increase its operational capacity prior to closure. This approach aims to optimize the available storage volume by allowing the moisture content of the deposited tailings to reduce and subsequently infilling the voids and fissures that may develop upon desiccation of the newly deposited solids, rather than expanding the TSF's physical footprint.

As illustrated in Figure 2, the storage optimization process is divided into four (4) sequential stages, which are implemented cyclically until the maximum allowable tailings' elevation within the existing TSF is achieved.

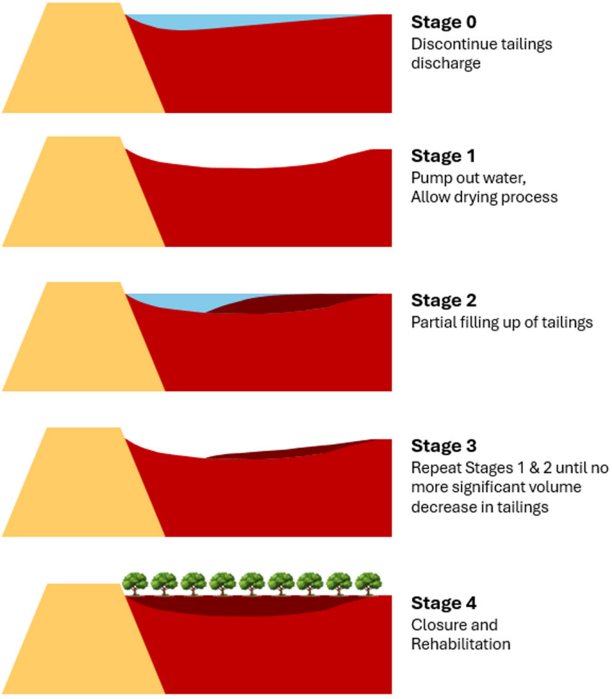


Figure 2. Schematics of TSF Re-utilization

The first stage involves initiating the drying process by ceasing tailings discharge and extracting the supernatant water through pumping. For this particular TSF, the dam crest elevation is 80 meters above sea level (MASL), with the emergency spillway located at 78 MASL. The operational maximum tailings elevation (MTL) is limited to 79.5 MASL, thereby maintaining a 0.5-meter freeboard as a safety allowance. Tailings deposition will continue until the 79.5 MASL elevation is reached, after which will be suspended, and the facility will undergo dewatering through mechanical pumping and natural evaporation. As illustrated in Figure 3, the remaining neutralized tailings will be diverted to other designated TSFs to prevent any disruption to ongoing operations during this process.

The second stage commences following surface settlement and the formation of desiccation cracks, typically occurring approximately six (6) months after the initial dewatering phase. These cracks, along with the settled surface, are then backfilled with fresh, solid tailings to minimize void spaces and improve in-situ compaction.

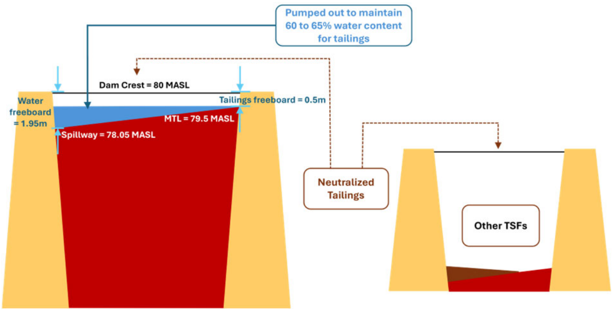


Figure 3. Dewatering Process of the TSF

Stages one and two are repeated over a duration of approximately two (2) to three (3) years, or until the reduction in tailings volume becomes negligible. This iterative method enhances water removal efficiency and promotes the infilling of available pore spaces with newly deposited materials.

Lastly, the final stage focuses on the rehabilitation and closure of the impounded tailings area, with the objective of converting the landmass into an environmentally sustainable landscape in accordance with applicable regulatory standards and industry best practices for mine closure and reclamation. As part of the provisional approval granted by the local mining authority, continuous monitoring and assessment of the TSF shall be conducted throughout the duration of the re-utilization.

3 SEISMIC HAZARD ANALYSIS

Seismic hazard analysis (SHA) is the process of quantifying the overall seismic hazard of an area in terms of acceleration. The probabilistic approach (PSHA) in performing SHA quantifies seismic hazard at different levels of risk depending on the recurrence interval or return period of the design ground motion. PSHA also considers multiple seismic sources simultaneously and accounts for uncertainties related to distance, time, recurrence, and size (magnitude). In performing SHA, empirically formulated attenuation models are utilized to determine the expected surface acceleration by estimating how seismic waves propagate and travel from source to site. Attenuation models are commonly referred to as Ground Motion Prediction Equations (GMPE), and these equations were formulated using globally acquired earthquake information (e.g. epicenter location, depth, and magnitude). The New Generation Attenuation West2 (NGA-West2) GMPE's developed by the Pacific Earthquake Engineering Research (PEER) Center were used for fault systems, and the BC Hydro GMPE (Abrahamson et al., 2016, 2018) was used for subduction zone sources.

Seismic velocity logging (SVL) was conducted to obtain in-situ seismic wave velocities (Vs). The test points were located adjacent to the TSF, a few meters from the TSF footprint, in order to collect data from the in-situ foundation layers. The gathered shear wave values will also be utilized in the design of new TSF embankment nearby. Test results reveal that the site characterization corresponds to a site class S_c with V_{s30} values ranging from 416.70 m/s to 468.92 m/s, with an average of 446.96 m/s. This corresponds to a "Very Dense Soil" as per the National Structural Code of the Philippines (NSCP) 2015. These observations were observed to be consistent with the findings from the previously conducted geotechnical investigations.

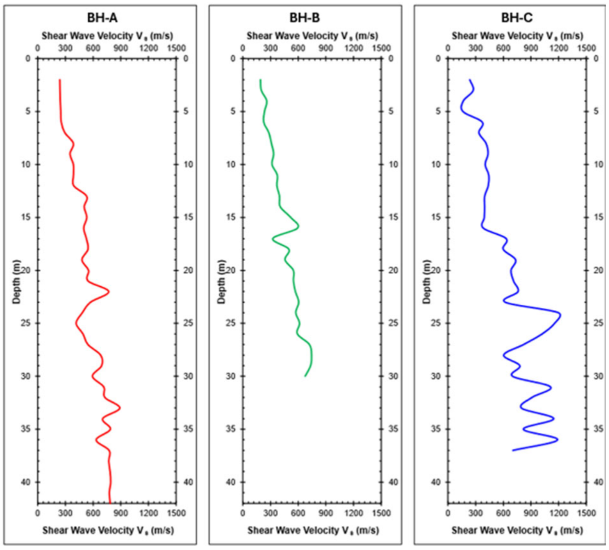


Figure 4. Shear wave velocity profiles of 3 foundation boreholes

By performing probabilistic seismic hazard analysis, the Safety Evaluation Earthquake (SEE, 10,000-yr return period) and Operating Basis Earthquake (OBE, 475-yr return period) response spectra are derived in accordance with ANCOLD provisions.

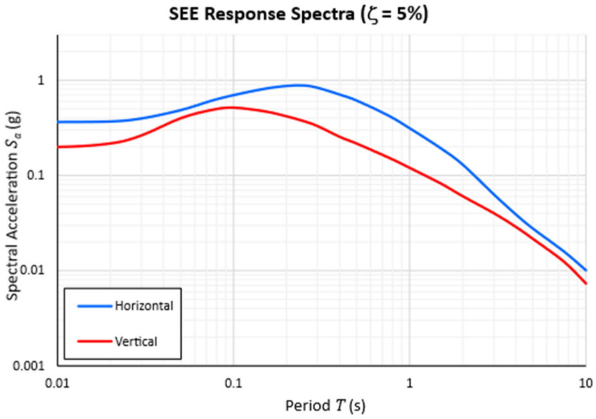


Figure 5. 5%-damped SEE (10,000-yr) response spectra

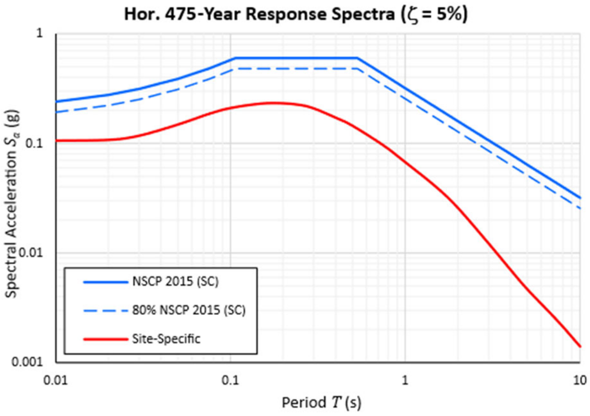


Figure 6. 5%-damped horizontal OBE (475-yr) response spectra

For the subsequent geotechnical stability analysis of the TSF embankment, the following seismic design parameters were derived based on the PSHA results. According to established studies and literature, namely Hynes-Griffin and Franklin (1984) and Kavazanjian et al. (1984 & 1997), a conservative approach in selecting the seismic coefficient is to assume $k_h = \frac{1}{2} PGA$.

Table 1. Seismic design parameters for stability analysis

Seismic Hazard level	Peak Ground Acceleration (PGA)	Horizontal Seismic Coefficient (k_h)
Operating Basis Earthquake (OBE); 475-yr	0.105g	0.053g
Safety Evaluation Earthquake (SEE), 10,000yr	0.363g	0.182g

4 FACTOR OF SAFETY

The minimum recommended factors of safety used in this study were adopted from several well-established and widely accepted references in the field of embankment stability analysis. These references provide Factor of Safety (FoS) thresholds for the slope stability of embankments under various loading conditions and at different stages of construction or operation. The agencies and the corresponding references used are as follows:

1. Department of the Army, U.S. Army Corps of Engineer (USACE) – Engineer Manual EM 1110-2-1902 Slope Stability, October 2003.
2. Australian National Committee on Large Dams (ANCOLD) – Guidelines on Tailings Dam Design, Construction and Operation, October 1999.
3. Japan National Committee on Large Dams (JCOLD) – Design Criteria for Dams, August 1978.

Based on these references, the following FoS values were applied in this study.

Static Condition:

- Factor of Safety for maximum storage pool (steady seepage); Long term: 1.5

Earthquake (Pseudo-static) Condition:

- Factor of Safety for Operating Basis Earthquake (OBE); Long term: 1.2
- Factor of Safety for Safety Evaluation Earthquake (SEE); Long term: 1.0 – 1.1

These FoS values are also in conformity with the provision of the Department of Environment and Natural Resources Memorandum Order (DMO) 1999-32, which states that dams made of earth and rock materials are to be designed and constructed with an FoS against failure of at least 1.2 under static conditions and at least 0.98 to 1.2 under maximum probable earthquake conditions.

5 EMBANKMENT STABILITY

5.1 *Methodology*

Rocscience Slide ®, a slope stability computer software, was utilized to facilitate calculations for determining the global stability of the dam embankment. This modeling software performs slope stability analysis procedure based on Limit Equilibrium Methods (LEM).

The stability analysis was analyzed in compliance with the references mentioned in Section 4, which requires analysis in both static and pseudo-static (earthquake) conditions. For both circular and non-circular failure surfaces, the Morgenstern-Price Method was used due to its rigorous and widely accepted approach in geotechnical engineering. The method enables detailed analysis of complex slope geometries and varying soil and rock profiles.

5.2 *Material Properties*

The geotechnical properties for the TSF embankment were assigned by grouping the materials into three (3) general zones: embankment, foundation, and tailings. The methodology for assigning properties varies based on how each material category occurs on-site. Foundation materials are naturally occurring, embankment materials are processed and placed according to their engineered purpose, and tailings occur as by-products resulting from processing operations.

The geotechnical properties of the embankment and foundation were primarily determined through field and laboratory testing. Laboratory testing included the determination of natural moisture content, particle size distribution, Atterberg limits, particle density, specific gravity, standard compaction characteristics, and shear strength through triaxial testing. The selection of geotechnical parameters also considered the specific requirements of each embankment zone, such as stability, permeability, compaction, and other performance criteria. In contrast, for the tailings material, representative shear strength parameters were adopted based on typical values and established correlations for cohesive soils, supported by field evidence of cohesive behavior observed in the tailings, as well as a few laboratory tests conducted for another TSF.

The embankment is located at the base of an existing siltation pond and is underlain by a sequence of silty to clayey alluvial soils of varying thickness, originating from the transport of weathered ultramafic rocks from upstream areas. Beneath the alluvial soils lie residual soils developed from the weathering of mudstone and claystone. The underlying bedrock consists primarily of siltstone and mudstone, interbedded with layers of indurated quartz sandstone.

Table 2. Material Properties for the TSF Dam

Material Zone	Material Type	Unit Weight, γ [kN/m^3]	Cohesion, c' [kPa]	Friction Angle, ϕ' [°]
Embankment	Core Zone	19.0	1.5	31
	Fine Filter Zone	20.0	0	35
	Coarse Filter Zone	19.0	0	35
	Rock Zone (First Stage)	18.0	5	36
	Rock Zone (Final Stage)	18.0	5	38
Foundation	Foundation Layer 1	18.0	5	35
	Lean Clay/Silt	15.0	5	25
	Clayey Sandy Silt	15.0	5	22
	Residual Claystone	16.0	10	25
	Coarse Drain Material	21.0	5	25
	Foundation Layer 2	30.0	50	45
Tailings	Slightly Consolidated Tailings	16.0	15	18
	Consolidated Tailings	18.0	50	25

In accordance with Makdisi and Seed (1978) and Kavazanjian et al. (1997), shear strength reduction should be applied to the embankment, foundation materials, and tailings deposits under earthquake loadings. During strong ground shaking (i.e., SEE), significant porewater pressure builds up within the soil matrix, reducing the soil's effective shear strength. In addition, ANCOLD Guidelines (2019) state that shear strength parameters may still be reduced even in the absence of liquefaction potential. Therefore, in this study, materials below the phreatic surface consider shear strength reduction under SEE loading, while those above are assumed unaffected. Table 2 presents the adopted shear strength reduction factors for pseudo-static conditions.

Table 3. Shear Strength Reduction Factors for Seismic Case

Material Zone	Material	Shear Strength Reduction Factor
Embankment	Core Zone	80%
	Fine Filter Zone	80%
	Coarse Filter Zone	80%
	Rock Zone (U/S)	80%
	Rock Zone (D/S)	95%
Foundation	Soil	90%
	Rock	-
Tailings	-	80%

5.3 *Load Cases*

The table below outlines the various load cases considered in the dam stability analysis, along with their respective minimum FoS. For both the analysis types, the load cases are categorized into upstream (U/S) and downstream (D/S) scenarios to account for the different sides of the dam. Additionally, two (2) seismic hazard levels, OBE and SEE, are considered, as initially outlined in Section 3.

Table 4. Design Load Cases

No.	Type of Analysis	Description	Min. FoS
1	Static	After Operation – U/S	1.5
2		After Operation – D/S	1.5
3	Pseudo-static	After Operation – U/S with OBE	1.2
4		After Operation – D/S with OBE	1.2
5		After Operation – U/S with SEE	1.0
6		After Operation – D/S with SEE	1.0

5.4 *Slope Model*

The slope cross-sections and material boundaries were derived from the as-built plans of the TSF embankment, which detailed the different stages of construction. In addition, the subsurface idealization of the residual soil and foundation layers was interpolated from the slope stability analysis models provided by the original designer. Furthermore, an average tailings elevation of 79.5 MASL, representing the maximum operational tailings level, was incorporated into the analysis to ensure a comprehensive assessment of the TSF embankment's stability conditions.

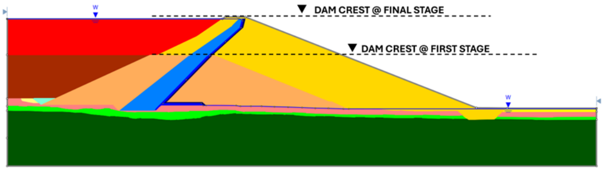


Figure 7. Combined slope section considered for analysis

5.5 *Results*

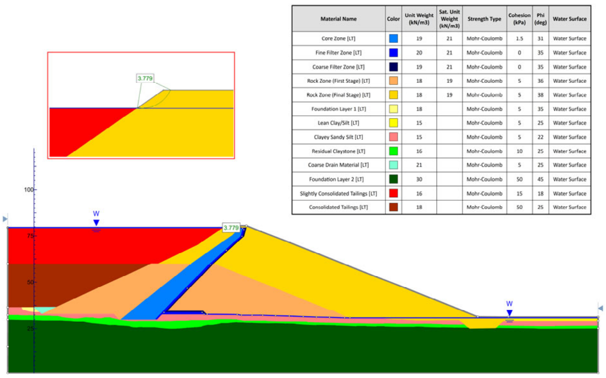
To determine the global minimum Factor of Safety (FoS), the "Auto Refine Search" function in Rocscience Slide ® was utilized. This approach considered approximately 38,000 potential slip surfaces, encompassing both circular and non-circular failure mechanisms. The analysis results indicated that the majority of the lowest FoS values were associated with non-circular failure surfaces, as determined using the Morgenstern-Price method.

Table 5 provides a summary of the stability analyses results, presenting both the required and critical FoS values for each load case.

Table 5. Summary of embankment stability analysis results

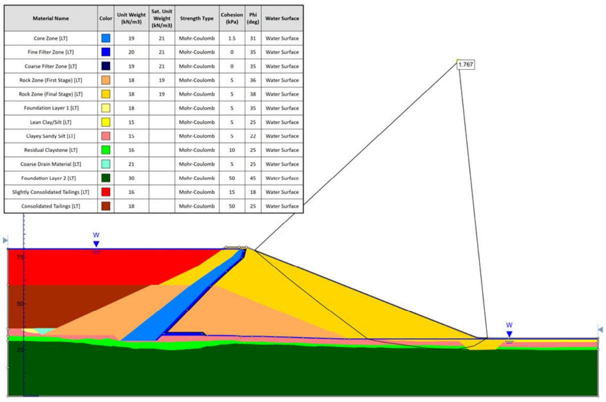
Type of Analysis	Description	Failure Type	Min. FoS	Calc. FoS
Static	After Operation – U/S	Circular	1.5	3.78
	After Operation – D/S	Non-Circular	1.5	1.77
Pseudo-static	After Operation – U/S with OBE	Non-Circular	1.2	3.72
	After Operation – D/S with OBE	Non-Circular	1.2	1.52
	After Operation – U/S with SEE	Non-Circular	1.0	1.05
	After Operation – D/S with SEE	Non-Circular	1.0	1.11

Based on the analysis results, non-circular failure surfaces in the upstream analysis predominantly occur within the slightly consolidated tailings, as shown in Figure 10. This phenomenon is attributed to the inherently loose, fine-grained composition of the tailings, which renders them weaker than the dam structure itself. The relatively lower degree of consolidation further exacerbates this weakness. Moreover, the upstream concern area is mainly composed of fresh tailings, which retain elevated pore water pressures. These high pore pressures significantly reduce the shear strength of the material, thereby increasing its susceptibility to failure.



Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Core Zone [LT]	🟦	19	21	Mohr-Coulomb	1.5	31	Water Surface
Fine Filter Zone [LT]	🟦	20	21	Mohr-Coulomb	0	35	Water Surface
Coarse Filter Zone [LT]	🟦	19	21	Mohr-Coulomb	0	35	Water Surface
Rock Zone (First Stage) [LT]	🟧	18	19	Mohr-Coulomb	5	36	Water Surface
Rock Zone (Final Stage) [LT]	🟨	18	19	Mohr-Coulomb	5	38	Water Surface
Foundation Layer 1 [LT]	🟨	18		Mohr-Coulomb	5	35	Water Surface
Lean Clay/Silt [LT]	🟨	15		Mohr-Coulomb	5	25	Water Surface
Clayey Sandy Silt [LT]	🟥	15		Mohr-Coulomb	5	22	Water Surface
Residual Claystone [LT]	🟩	16		Mohr-Coulomb	10	25	Water Surface
Coarse Drain Material [LT]	🟩	21		Mohr-Coulomb	5	25	Water Surface
Foundation Layer 2 [LT]	🟩	30		Mohr-Coulomb	50	45	Water Surface
Slightly Consolidated Tailings [LT]	🟥	16		Mohr-Coulomb	15	18	Water Surface
Consolidated Tailings [LT]	🟫	18		Mohr-Coulomb	50	25	Water Surface

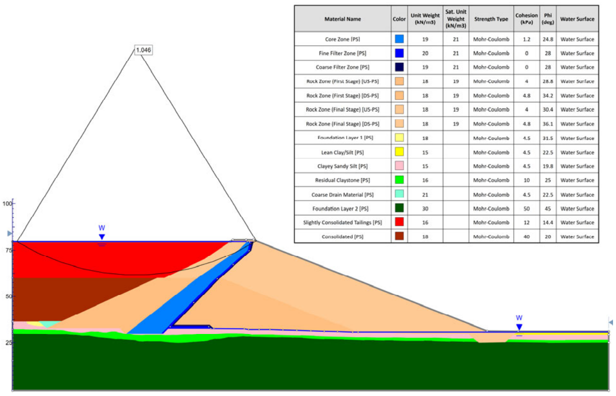
Figure 8. Slope stability analysis result for upstream under static condition (Source: Rocscience Slide®)



Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Core Zone [LT]	🟦	19	21	Mohr-Coulomb	1.5	31	Water Surface
Fine Filter Zone [LT]	🟦	20	21	Mohr-Coulomb	0	35	Water Surface
Coarse Filter Zone [LT]	🟦	19	21	Mohr-Coulomb	0	35	Water Surface
Rock Zone (First Stage) [LT]	🟧	18	19	Mohr-Coulomb	5	36	Water Surface
Rock Zone (Final Stage) [LT]	🟨	18	19	Mohr-Coulomb	5	38	Water Surface
Foundation Layer 1 [LT]	🟨	18		Mohr-Coulomb	5	35	Water Surface
Lean Clay/Silt [LT]	🟨	15		Mohr-Coulomb	5	25	Water Surface
Clayey Sandy Silt [LT]	🟥	15		Mohr-Coulomb	5	22	Water Surface
Residual Claystone [LT]	🟩	16		Mohr-Coulomb	10	25	Water Surface
Coarse Drain Material [LT]	🟩	21		Mohr-Coulomb	5	25	Water Surface
Foundation Layer 2 [LT]	🟩	30		Mohr-Coulomb	50	45	Water Surface
Slightly Consolidated Tailings [LT]	🟥	16		Mohr-Coulomb	15	18	Water Surface
Consolidated Tailings [LT]	🟫	18		Mohr-Coulomb	50	25	Water Surface

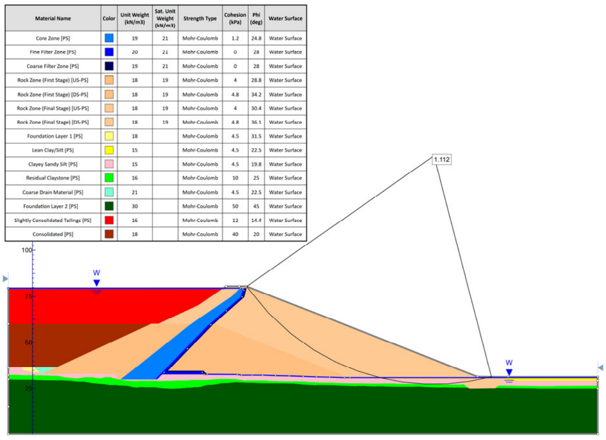
Figure 9. Slope stability analysis result for downstream under static condition (Source: Rocscience Slide®)

Furthermore, the shear strength reduction factors for the seismic case contributed to lower FoS, particularly in the downstream analysis (Figure 11). This reduction reflects the dynamic behavior and material degradation, or temporary weakening, of the soil layers under cyclic loading conditions. Such materials exhibit a decrease in strength and an increase in damping capacity at high-strain rates, causing them to behave more like a liquid under rapid loading.



Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Core Zone [PS]	🟦	19	21	Mohr-Coulomb	1.2	24.8	Water Surface
Fine Filter Zone [PS]	🟦	20	21	Mohr-Coulomb	0	28	Water Surface
Coarse Filter Zone [PS]	🟦	19	21	Mohr-Coulomb	0	28	Water Surface
Rock Zone (First Stage) [US-PS]	🟧	18	19	Mohr-Coulomb	4	28.8	Water Surface
Rock Zone (First Stage) [DS-PS]	🟧	18	19	Mohr-Coulomb	4.8	34.2	Water Surface
Rock Zone (Final Stage) [US-PS]	🟧	18	19	Mohr-Coulomb	4	30.4	Water Surface
Rock Zone (Final Stage) [DS-PS]	🟧	18	19	Mohr-Coulomb	4.8	36.1	Water Surface
Foundation Layer 1 [PS]	🟨	18		Mohr-Coulomb	4.5	31.5	Water Surface
Lean Clay/Silt [PS]	🟨	15		Mohr-Coulomb	4.5	22.5	Water Surface
Clayey Sandy Silt [PS]	🟥	15		Mohr-Coulomb	4.5	19.8	Water Surface
Residual Claystone [PS]	🟩	16		Mohr-Coulomb	10	25	Water Surface
Coarse Drain Material [PS]	🟩	21		Mohr-Coulomb	4.5	22.5	Water Surface
Foundation Layer 2 [PS]	🟩	30		Mohr-Coulomb	50	45	Water Surface
Slightly Consolidated Tailings [PS]	🟥	16		Mohr-Coulomb	12	14.4	Water Surface
Consolidated [PS]	🟫	18		Mohr-Coulomb	40	20	Water Surface

Figure 10. Slope stability analysis result for upstream under SEE seismic condition (Source: Rocscience Slide®)



Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Core Zone [PS]	🟦	19	21	Mohr-Coulomb	1.2	24.8	Water Surface
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Rock Zone (First Stage) [US-PS]	🟧	18	19	Mohr-Coulomb	4	28.8	Water Surface
Rock Zone (First Stage) [DS-PS]	🟧	18	19	Mohr-Coulomb	4.8	34.2	Water Surface
Rock Zone (Final Stage) [US-PS]	🟧	18	19	Mohr-Coulomb	4	30.4	Water Surface
Rock Zone (Final Stage) [DS-PS]	🟧	18	19	Mohr-Coulomb	4.8	36.1	Water Surface
Foundation Layer 1 [PS]	🟨	18		Mohr-Coulomb	4.5	31.5	Water Surface
Lean Clay/Silt [PS]	🟨	15		Mohr-Coulomb	4.5	22.5	Water Surface
Clayey Sandy Silt [PS]	🟥	15		Mohr-Coulomb	4.5	19.8	Water Surface
Residual Claystone [PS]	🟩	16		Mohr-Coulomb	10	25	Water Surface
Coarse Drain Material [PS]	🟩	21		Mohr-Coulomb	4.5	22.5	Water Surface
Foundation Layer 2 [PS]	🟩	30		Mohr-Coulomb	50	45	Water Surface
Slightly Consolidated Tailings [PS]	🟥	16		Mohr-Coulomb	12	14.4	Water Surface
Consolidated [PS]	🟫	18		Mohr-Coulomb	40	20	Water Surface

Figure 11. Slope stability analysis result for downstream under SEE seismic condition (Source: Rocscience Slide®)

Considering an average tailings level of 79.5 MASL, results show that FoS for both static and pseudo-static conditions yield adequate values (i.e., above the minimum requirement).

6 CONCLUSIONS

While the process of re-utilizing existing TSFs appears to be simple and straightforward, there are several key factors that need to be considered; each one having significant impact on the socio-economic aspects of mine sites. From an engineering perspective, TSF dams constructed decades ago must now be retrofitted or re-evaluated in accordance with the more stringent requirements of current codes and provisions. Legally, mine sites must secure re-approval from the local mining authority to continue operations even after exceeding the conditions outlined in the original permit. On a social aspect, potential opposition from adjacent communities and local government units must be carefully navigated. With all these things considered, re-utilizing TSFs that are already at their capacity limits can substantially enhance storage capacity within a shorter timeframe and at a much lower cost—without introducing additional risks to the mine site and its nearby communities.

Future monitoring works will be conducted throughout the duration of the re-utilization process. Subsequent geotechnical engineering assessments will be performed based on the data and results gathered from the monitoring activities.

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