Tailings2021 | 7th International Conference on Tailings Management

Filtered Tailings Storage Facility Design: A Sustainable Alternative to Modern Mining

Édgar Quiroz
Stantec, Peru

ABSTRACT

Filtered tailings are becoming an increasingly common consideration for tailings management at many mine sites. Several publications indicate that the use of filtered dry stack tailings storage facilities rather than surface paste facilities is a worldwide trend; however, few guidelines exist regarding filtered tailings.

This paper presents a real case study for the design of two filtered tailings storage facilities (TSF)s. The TSF, which depositaries 225 m and 210 high and capable of containing 3.60 Mm^3 of tailings, is in an area of extremely high seismicity in southern Peru.

This study details the geotechnical characterization for two different types of filtered tailings and includes determination of their contractive and dilative behavior through laboratory testing. It also includes verification of liquefaction, as well as slope stability analysis using the limit equilibrium method and seepage analysis, considering instrumentation and monitoring of moisture content.

The design criteria and experience gained during the 14-year operation of this TSF is discussed, introducing the drying factor concept for the design of this type of tailings facility.

INTRODUCTION

This paper presents a real case study on the design of the expansion of two filtered tailings storage facilities in a highly seismic area.

The purpose of this publication is to provide technical information on the design of filtered tailings facilities that helps support the development of sustainable mining projects.

Pahuaypite 1 and 2 are the TSF's where the disposal of filtered tailings material was considered. The project is located within the Cerro Lindo mine site in the District of Chavin, Province of Chincha and Department of Ica in Peru. Minerals such as copper, lead, silver, and zinc are exploited at the mine, with an estimated production of 21,000 tonnes per day (tpd) of ore and 9,700 tonnes per day (tpd) of tailings material, which requires to be stored in the Pahuaypite 1 and 2 tailings facilities.

Table 1 shows the largest filtered tailings mines in the world, Cerro Lindo mine ranks sixth among the ten largest mines in the world with filtered tailings deposits, with a production of 9.7 ktpd.

Table 1 Top ten mine with fileted tailings on the world

Mina	Location	Mineral	Capacity (ktpd)
Karara	Australia	Fe	35
Goro	Nueva Caledonia	Ni	20.4
La Coipa	Chile	Cu	18
Mantos Blancos	Chile	Cu	12
Vaal Reefs	Sudafrica	U	10
Cerro Lindo	*Peru*	*Zn-Pb*	*9.7*
Alunorte	Brasil	Al	8
Pinos Altos	Mexico	Au, Ag	6.5
Kwinanna	Australia	Bauxita	6
El Sauzal	Mexico	Au	5.3

METHODOLOGY

Design Considerations

The design of filtered tailings is influenced by climatic variables, since these are factors conditioning the water cycle, during both rainy seasons and periods of droughts or glaciation. For the Construction - Pahuaypite 1 and 2 TSF Expansion Modification project, the following conditions were present:

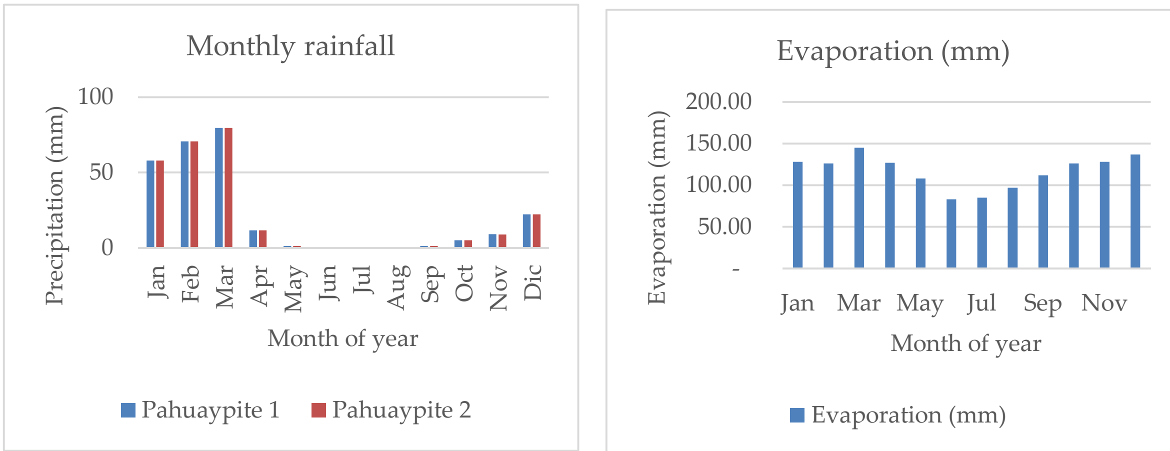


Figure 1 Hydrological Parameters averaged over a period of last 10 years

Drying Factor

The relationship between evaporation and annual rainfall at the project site needs to be identified to determine the degree of saturation to which the filtered tailings may be exposed and the preventive measures that will be required for the final design. To this end, the area where the two TSF's are located will be evaluated.

$$F_S = \frac{E \qquad (m\ )}{P_1 \qquad (m\ )} \tag{1}$$

Cerro Lindo: 1402 / 259 = 5.4 (w_a-w_o ≈ 3.5% to 7% for 4 to 10 days)

Drying Rate

It is important to define the tailings disposal method as either filtered or cycloned tailings. This will depend largely on the properties of the tailings, particularly the amount of decant water, the permeability and suction pressure that develop during the drying process, as well as the climate conditions during the evaporation and precipitation processes. The drying rate needs to be defined so that the moisture content at the filter outlet can be modified until the optimal compaction moisture is achieved (see Figure 2).

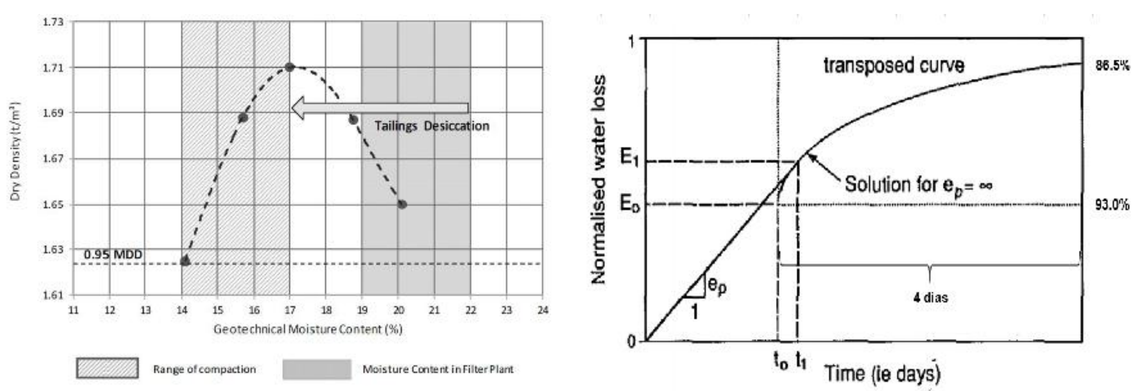
In Swarbrick and Fell (1992) the results of a research program to develop a method for predicting desiccation rates are described. Based on laboratory and field drying experiments, it was shown that the desiccation occurs as follows:

Tailings settle until the rate of water release equals the potential evaporation.

- Stage 1 drying, which occurs at a linear rate with time, generally at the same rate as from a free-water surface. However, it is not equivalent when the dry stack.
- Stage 2 drying, which occurs at a decreasing speed. This decreasing rate has been shown to satisfy the following equation:

$$E_{C1} = b\sqrt{t} \tag{2}$$

Figure 2 (a) shows the change in the humidity variation range of the filtered tailings considering the dry density, this change must be achieved in order to carry out the compaction of the filtered tailings to obtain a minimum design density that guarantees stability. physical reservoir, this range varies from 19 to 22% to 14 and 17%, in addition to that, it must also be considered that it must have consistency to be able to withstand the transit of compaction equipment and avoid their sinking. Figure 2 (b) shows the typical drying curve, which shows the variation (%) of the water loss as a function of time in days elapsed, this curve is specific for each type of tailings, but the trend is the same.



(a) (b)

Figure 2 Tailings **D**esiccation

For this study, to obtain an optimal compaction moisture content w_o, it was necessary to consider drying periods varying from 4 to 10 days depending on the season and the condition of the type of ore generating the tailings. Table 2 shows the values of *bs* for different periods and deposition conditions.

Table 2 Variation of *bs* to Determine E of the Filtered Tailings

Parameter	Dry Season		Wet Season	
	Optimal	**Extreme**	**Optimal**	**Extreme**

w_a	13.5%	16.0%	13.5%	16.0%
w_o	7.0%	9.0%	7.0%	9.0%
E_o	86.5%	84.0%	86.5%	84.0%
E_f	93.0%	91.0%	93.0%	91.0%
$t_f - t_o$	4	6	7	10
b_s	0.033	0.029	0.025	0.022

It defines the drying cycle of the filtered tailings, which guarantees the reduction of the maximum compaction humidity, with which the degree of compaction can be obtained so that the deposit is stable against the assumed design conditions, in such a way as to guarantee the physical and hydrological stability of the deposit.

Design Criteria

The principles for selecting the design criteria are described in Table 3.

Table 3 Pahuaypite 1 and 2 TSF Design Criteria

Description	Value	Comments
1.0 Pahuaypite 1 and 2 TSF's		
1.1 General		
Baseline topography	m	Topographic survey
Type of material contained in the facility	Filtered tailings	N.A.
Geochemical characterization of the material to be deposited	Acid generating	Based on PGA [1] studies
1.2 Consequence of Failure Classification		
Risk due to failure	High	Based on the Canadian Association of Dams Guidelines (CDA, 2014).
Risk due to failure	High	Based on the Global Tailings Management Standard for the Mining Industry (2020).
1.3 Seismicity and Physical Stability		

[1] PGA Peak Ground Acceleration.

Description	Value	Comments
Earthquake (OBE)[2] return period	100 years	In accordance with standard ER-1110-2-1806 of the U.S. Army Corps of Engineers. Hynes, 1984 and the "Guía Ambiental para Estabilidad de Depósitos de Desechos de Mina" (***Environmental Guide****line on* ***Stability of Mine Waste*** *Facilities*)", MEM 1997.
Magnitude of the seismic event (DSHA)[3]	Mw = 9.5	Seismic Hazard Study for the Cerro Lindo Mine 2020.
Seismic Acceleration (Operating and Design)	0.23g and 0.46g	The Design Seismic Acceleration (Matrix of critical Drifts MCD) is defined based on the deterministic Maximum Credible Earthquake (MCE), following the recommendations of ICOLD bulletin 72, 2010.
Seismic Coefficient	0.5 PGA	According to the "Guía Ambiental para Estabilidad de Taludes de Depósito de Desechos Sólidos de Mina", MEM 1997.
Minimum Factor of Safety (FOS)[4] for static conditions - Short term	≥1.3 (OBE)	According to the "Guía Ambiental para Estabilidad de Taludes de Depósito de Desechos Sólidos de Mina", MEM 1997, and the Canadian Dam Association Guidelines (CDA, 2007).
Minimum Factor of Safety (FOS) for pseudo-static conditions pseudo static - Short term	≥1.2 (OBE)	
Minimum Factor of Safety (FOS) for static conditions - Long term	≥1.5	According to the Canadian Dam Association Guideline (CDA, 2007)
Minimum Factor of Safety (FOS) for pseudo-static conditions - Long term	≥1.0	According to the "Guía Ambiental para Estabilidad de Taludes de Depósito de Desechos Sólidos de Mina", MEM 1997. And, according to the Canadian Dam Association Guideline (CDA, 2007).
Displacement analysis	≤ 1.0 m	Maximum allowable vertical settlement of the dam crest caused by an earthquake.

[2] OBE (operating basis earthquake) with 50% probability of being exceeded during its lifespan; this corresponds to a 100-year return period for a project with a 70-year lifespan.

[3] DSHA Deterministic Seismic Hazard Analysis.
[4] FOS Factor Of Safety

For close condition according to local regulations it should be considered the Maximum Horizontal Earthquake Acceleration (MHEA) and the seismic coefficient that will be used to evaluate the pseudo-static stability of the deposit. This will be based on a seismic risk assessment, using a return period of at least 500 years or longer for high-risk structures.

Operating Parameters

The operating parameters are shown in table 4. For a throughput of 9,700 tonnes per day (tpd), a ratio of 0.82 to 1.13 Ha / 1000 tonnes is required, considering a layer thickness of 0.30 m for a moisture content of 7 to 9% and a drying time varying from 5 to 9 days depending on the season.

Table 4 Operating Parameters

Parameter	Quantity	Unit
Throughput volume	9,700.00	tpd
Layer thickness	0.30	m
% compaction moisture	7 - 9	%
Drying time	5 - 9	days
Required area in dry season	8.00	Ha
Required area in wet season	11.00	Ha
Drying area in dry season	0.82	Ha/k tonnes
Drying area in wet season	1.13	Ha/k tonnes

Conditions Analyzed

The analysis considered the most critical condition represented by the highest and steepest sections at the base for both Pahuaypite 1 (see Figure 3) and Pahuaypite 2 (see Figure 4) considering existing and projected (proyectados in spanish) build-ups, as shown in the figures.

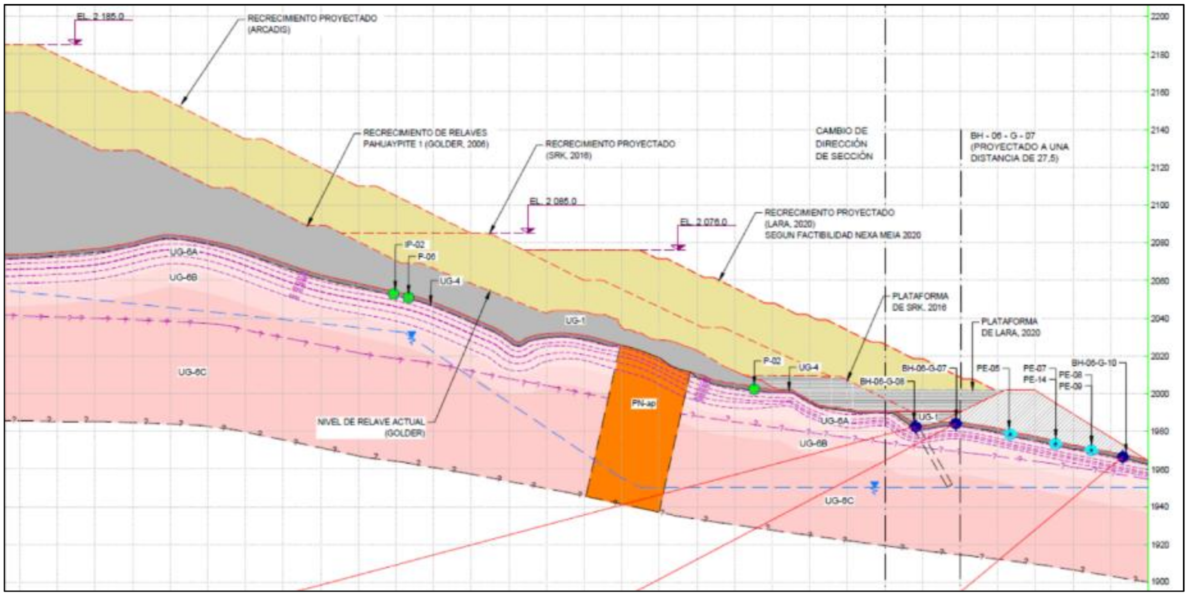


Figure 3 Critical Section of Pahuaypite 1

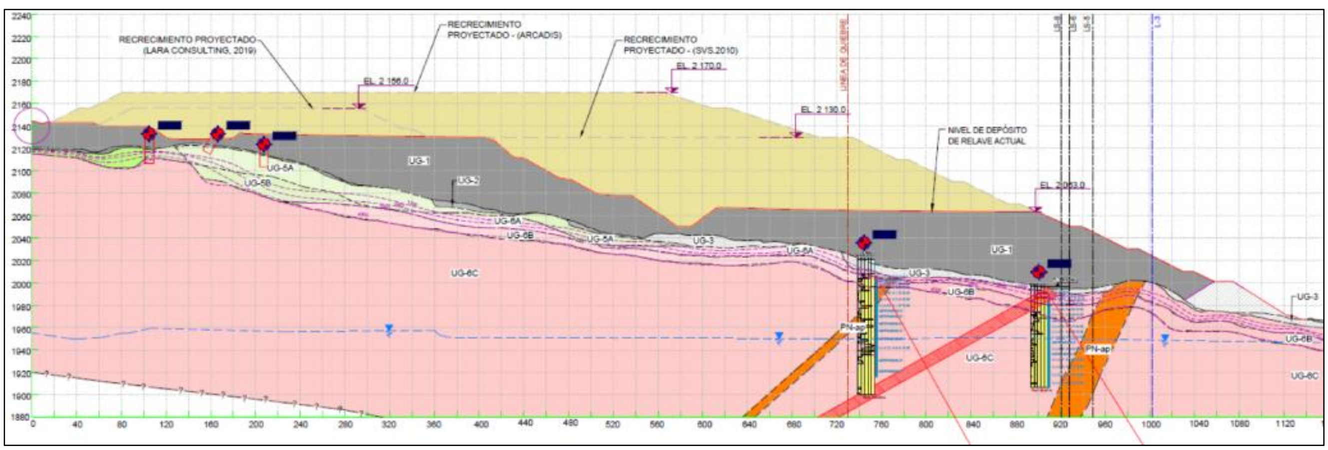


Figure 4 Critical Section of Pahuaypite 2

Tailings Characteristics

Geotechnical Characterization of Tailings

UG-1 (filtered tailings): Filtered tailings were defined as geotechnical unit 1 and are classified as low-plasticity silt (ML) and silty sand (SM). According to tests conducted in 2020, the tailings mostly consist of 51% sand and 42% silt and 7% clay, with no gravel present. The average specific gravity of the tailing's material is 4.12, which indicates that it has a high content of metallic sulfide minerals, a dry density of 2,660 g / cm^3, and natural moisture content of 6%. The Proctor tests determined a maximum dry density of 3.13 g / cm³ and an optimal moisture content of 7%. It shows low to no plasticity and a moisture content varying from 5 to 10%. The geometric average value of hydraulic conductivity of tailings is estimated to be equal to 6.2724 x 10-5 cm/s according to Table 5.

Figure 5 shows the hydraulic conductivity trend for filtered tailings, based on the tests conducted in the GEOT-01 and GEOT-02 drillholes located around the Pahuaypite 2 TSF. Pahuaypite 1 and 2 have similar characteristics.

Table 5 Physical Properties of Filtered Tailings

Sample / Material	SUCS	Gs	MDS (g/cm³)	OCH (%)	γ_d (g/cm³)	w %	K (cm/s)
B-1 / Tailings Pahuaypite 1	ML	4.17	-	-	2.340	10.0	6.3×10^{-4}
			-	-	2.280	10.0	6.3×10^{-4}
			-	-	2.410	10.0	-
TP_CL10-110 (M-1 / 1,10-1,40) / Pahuaypite 1 tailing	SM	4.43	-	-	3.290	4.8	2.0×10^{-6}
Mixed (M-1, M-2, M-3, M-4, M-5) / Pahuaypite 2 tailings	ML	4.34	3.01	6.6	2.830	7.2	1.95×10^{-5}
Pahuaypite I ratio	-	-	3.05	6.28	2.970	6.2	-
Pahuaypite II ratio	-	-	3.06	6.38	2.970	6.4	-
CDR-LC-02 M-01	SM	4.17	3.12	6.6	-	5.2	-
CDR-LC-06 M-01	SM	4.17	3.13	6.9	-	5.8	-
TP-ALC-20-01 to 04 / Pahuaypite 1 tailings	ML-SM	4.20	-	-	2.609	5.8	-
TP-ALC-20-05 to 08 / Pahuaypite 2 tailings	ML-SM	4.04	-	-	2.712	5.9	-

Where: Gs = solids density, MDS = maximum dry density, OCH = optimal moisture content, γ_d = dry density (final), k = permeability, SUCS Sistema Unificado De Clasificacion De Suelos (in Spanish).

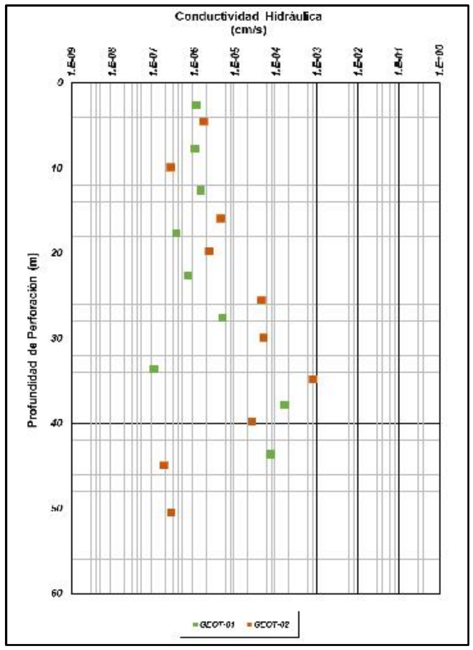


Figure 5 Hydraulic Conductivity Values vs Depth in the Pahuaypite 2 Tailings.

To determine tailings strength in the compacted state, CU (consolidated undrained) and recently CD (consolidated drained) triaxial tests were conducted. The results of the triaxial tests considered for this study are shown in Table 6.

Table 6 Triaxial Properties of Compacted Filtered Tailings

Study	Material / Location	Sample	SUCS	γd (g/cm3)	w %	CU Triaxial		CD Triaxial	
						c' (kPa)	**Φ' (°)**	**c (KPa)**	**Φ (°)**
Cerro Lindo	Tailings / Pahuaypite 1	B-1	ML	2.340	10.0	0	32.1	-	-
		B-1	ML	2.280	10.0	0	30.6	-	-
		B-1	ML	2.410	10.0	0	29.9	-	-
	Tailings / Pahuaypite 1	TP-ALC-20-01	ML	2.658	3.1	0	26	0	29
		TP-ALC-20-02	ML	2.365	10.7	0	31	17	31
		TP-ALC-20-03	SM	3.160	3.5	0	32	0	31
		TP-ALC-20-04	SM	2.251	5.9	47	31	7	33
		TP-ALC-20-05	SM	2.416	2.5	0	31	0	30

Study	Material / Location	Sample	SUCS	γd (g/cm3)	w %	CU Triaxial		CD Triaxial	
						c' (kPa)	Φ' (°)	c (KPa)	Φ (°)
	Tailings / Pahuaypite 2	TP-ALC-20-06	SM	3.043	6.7	-	-	-	-
		TP-ALC-20-07	ML	2.715	7.0	-	-	-	-
		TP-ALC-20-08	ML	2.672	7.2	-	-	-	-

Data:
c': Cohesion in terms of effective stress Φ': Angle of friction in terms of effective stress
c: Cohesion in terms total stress Φ: Angle of friction in terms of effective stress

Figure 6 shows the stress path at the p-q base obtained from the results of the triaxial tests conducted. In addition, it shows the Critical State Line (CSL) and the M value to estimate the critical state angle (φ_{cs}) to be equal to 29.9°.

Figure 7 shows the stress path at the p'-q base for samples TP-ALC-01 and TP-ALC-02 (tailings classified as ML according to SUCS) under CIU and CID conditions, from which it can be observed that the TP-ALC-01 sample under CU conditions has a contracting behavior; and the M value of the CSL is equal to 1.2. The internal friction angle at critical state (φ_{cs}) is equal to 30°. The same figure shows that the TP-ALC-02 samples under CIU conditions exhibit a dilative behavior and the M value of the CSL is equal to 1.5. The internal friction angle at critical state (φ_{cs}) is equal to 37°.

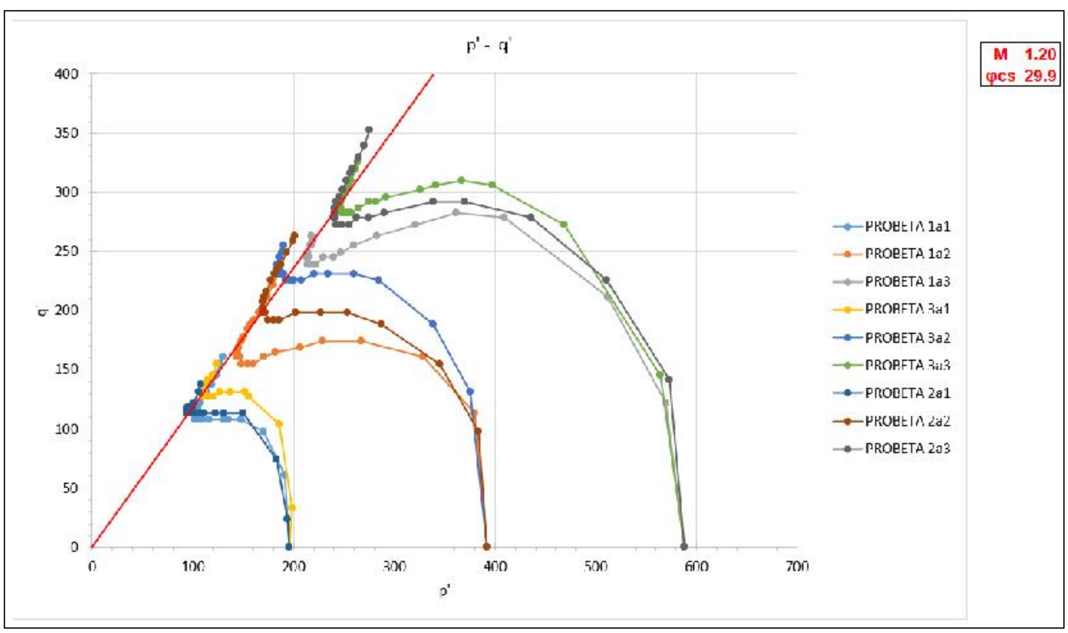


Figure 6 p'-q' Stress Path (CIU Triaxial Test)

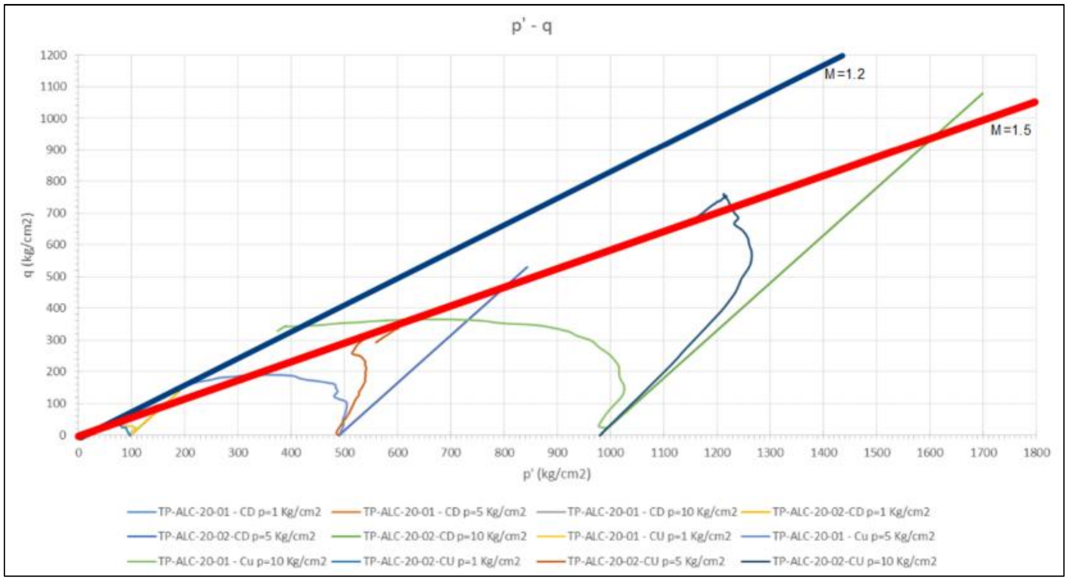


Figure 7 Cambridge p'-q Space Stress Path for Samples TP-ALC-01 and TP-ALC-02 under CU and CD conditions

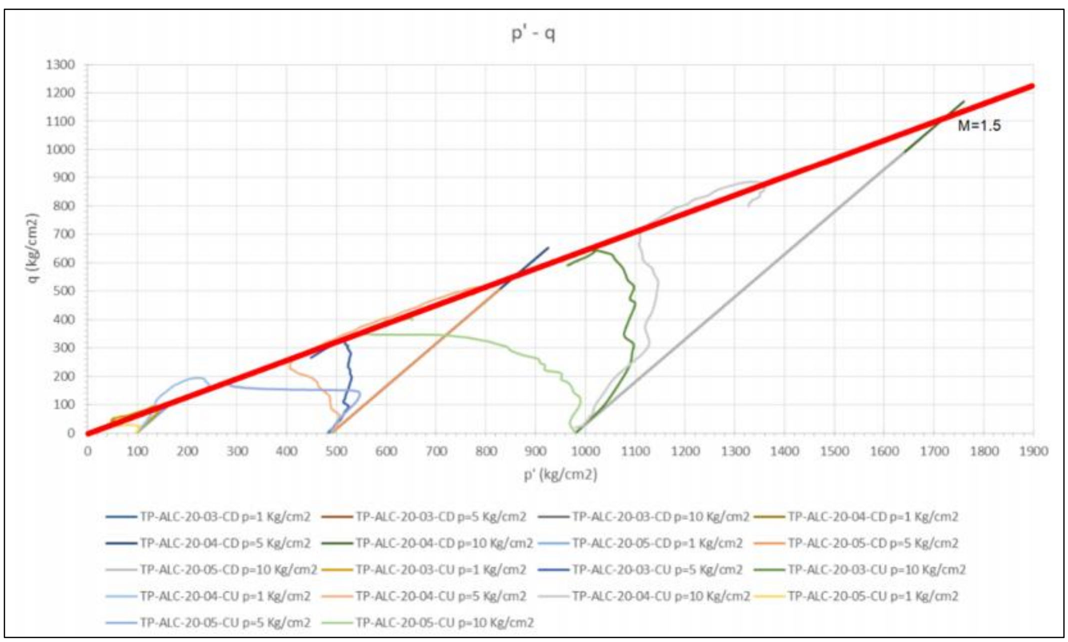


Figure 8 **Cambridge p'-q Space Stress Path for Samples TP-ALC-03, TP-ALC-04, and TP-ALC-05 under CU and CD conditions**

Figure 8 shows the stress path for samples TP-ALC-03, TP-ALC-04, and TP-ALC-05 (tailings classified as SM according to SUCS) under CIU and CID conditions. The samples exhibit a dilative and contractive behavior and the M value of the CSL is equal to 1.5. The internal friction angle at critical state (φcs) is equal to 37°.

For the physical stability analysis evaluation of the Pahuaypite 1 and 2 TSF slopes, an internal friction angle at critical state (φcs) equal to 30° and a contribution of cohesion equal to 5 KPa were considered.

Pahuaypite 1 TSF Stability

Geotechnical Configuration

The geotechnical model of the Pahuaypite 1 TSF is comprised of a total of seven geotechnical units: four soil units (UG-1 filtered tailings facility, compacted fill dam-embankment, mine waste rock platform and UG-4 residual facilities) and three bedrock units (UG-6A highly weathered granodiorite, UG-6A / UG-6B weathered granodiorite and UG-6C fresh granodiorite). Figure 9 shows the units that correspond to the Pahuaypite 1 TSF.

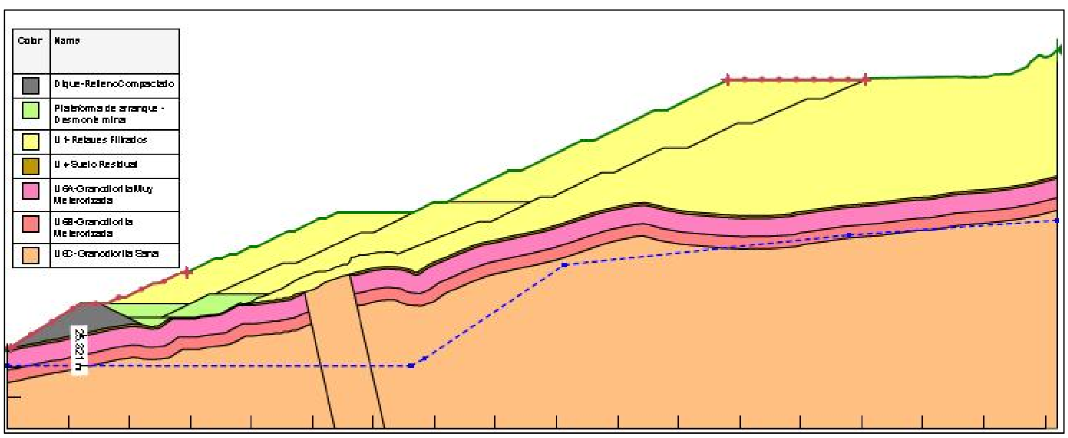


Figure 9 Geotechnical Model of the Pahuaypite 1 TSF

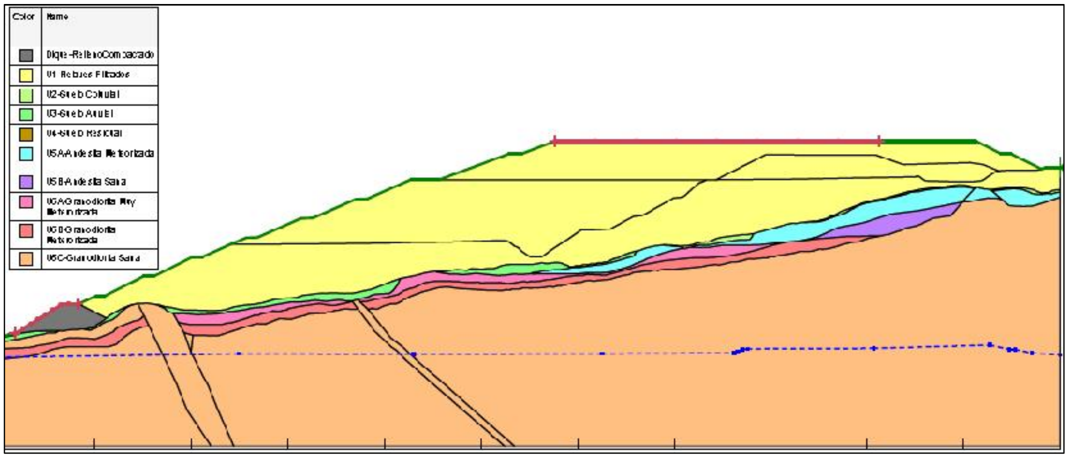


Figure 10 Geotechnical Model of the Pahuaypite 2 TSF

Geotechnical Properties of Materials

The materials that control the stability conditions in the Pahuaypite 1 TSF are the filtered tailings that will be placed and compacted, and the foundation materials. The strength parameters of the filtered tailings were defined considering those triaxial compression tests that achieve axial deformations greater than or equal to 30%. The shear strength parameters of bedrock units (UG-6A, UG-6B and UG-6C) were obtained according to the Hoek & Brown failure criteria. See which are these units on figure 9 and table 7.

Table 7 Summary of Geotechnical Parameters for the Pahuaypite 1 Units

Geotechnical Unit	Material	Unit Weight (kN/m³)	c (KPa)	Ø (°)	m_b	s	a
Unit 1	Filtered tailings	22.9	0	30	-	-	-
Dam-dike	Compacted backfill	20	0	37	-	-	-
Platform	Mine waste rock	20	0	35	-	-	-
Unit 4	Residual soil	21	10	35	-	-	-
Unit 6A	Highly weathered granodiorite	22	150	31	0.384	0.00003	0.524
Unit 6B	Weathered granodiorite	24	300	46	0.924	0.0003	0.508
Unit 6C	Fresh granodiorite	26	1520	58	2.350	0.0067	0.501

Note: m_b, s, a= rock mass strength parameters according to the failure criterion of Hoek Brown.

Water Table

According to the summary of monitoring readings from the five piezometers in the Pahuaypite 1 TSF area, the water table is present at a depth varying between 25 and 32 m, which corresponds to the foundation bedrock. Therefore, based on these results, the use of a water table in the geotechnical model was considered across the analysis section, which is present in the UG-6B and 6C geotechnical units.

Stability Analysis Results

Stability analyses of the Pahuaypite 1 filtered tailings facility were performed for static and pseudo-static conditions (occurrence of the design earthquake), 1.3 for the operation phase and 1.0 for the closure phase, considering the projected conditions of the TSF slopes, the influence of the water table, the maximum storage capacity and maximum load in the short and long term.

Table 8 Stability Analysis Results of the Pahuaypite 1 TSF

Structure	Phase	Cases of Analysis (Fault Type)	Static Safety Factor	Pseudo-static Safety Factor (k=0.115 and 0.23)
Pahuaypite 1 TSF	Operation	Global Analysis	1.8	1.3
	Closure	Global Analysis	1.8	1.0

Pahuaypite 2 TSF

Geotechnical Configuration

The geotechnical model for the Pahuaypite 2 TSF is comprised of a total of eleven geotechnical units: six soil units (UG-1 filtered tailings facility, UG-2 colluvial deposit, UG-3 alluvial deposit 2, embankment [compacted fill] and platform [mine waste rock]); and five bedrock units (UG-5A weathered andesite, UG-5B fresh andesite, UG-6A highly weathered granodiorite, UG-6A / UG-6B weathered granodiorite, and UG-6C fresh granodiorite).

Geotechnical Properties of Materials

The materials controlling the stability conditions in the Pahuaypite 2 TSF are the filtered tailings that will be placed and compacted, and the foundation materials. The shear strength parameters of the filtered tailings were defined considering those triaxial compression tests that achieve axial deformations greater than or equal to 30%, according to the failure criteria of Hoek & Brown. See which are these units on figure 10 and table 9.

Table 9 Summary of Geotechnical Parameters of the Pahuaypite 2 Units

Geotechnical Unit	Material	Unit Weight (kN/m3)	c (KPa)	Ø (°)	mb	s	a
Unit 1	Filtered tailings	22.9	0	30	-	-	-
Unit 2	Colluvial soil	20	0	37	-	-	-
Unit 3	Alluvial soil	22	20	35	-	-	-
Dike	Compacted backfill	22	0	37	-	-	-
Platform	Rockfill	22	0	38	-	-	-
Unit 4	Residual soil	21	10	35	-	-	-
Unit 5A	Highly weathered to weathered andesite	24	200	35	0.588	0.0001	0.514
Unit 5B	Fresh andesite	26	500	48	1.079	0.0007	0.504
Unit 6A	Highly weathered granodiorite	22	150	31	0.384	0.00003	0.524
Unit 6B	Weathered granodiorite	24	300	46	0.924	0.0003	0.508
Unit 6C	Fresh granodiorite	26	1520	58	2.350	0.0067	0.501

Note: m_b, s, a= rock mass strength parameters according to the failure criterion of Hoek Brown.

Water Table

The Pahuaypite 2 creek has a water table with a minimum depth of 20 m, which varies between 26 and 95 m and corresponds to the foundation bedrock present in geotechnical units UG-6A, 6B, and 6C.

Stability Analysis Results

Stability analyses of the Pahuaypite 2 filtered tailings facility were performed for static and pseudo-static conditions (occurrence of the design earthquake), considering the influence of the water table, the maximum storage capacity and maximum load in the short and long term, 1.3 for the operation phase and 1.0 for the closure phase. These analyses contain information on the most critical section of the facility, the material properties, and the location of the failure surface with the lowest factor of safety. See table 10 for results.

Table 10 Stability Analysis Results of the Pahuaypite 2 TSF

Structure	Phase	Analysis Case (Fault Type)	Static Safety Factor	Pseudo-static Safety Factor (k=0.115 and 0.23)
Pahuaypite 2 TSF	Operation	Global Analysis	1.8	1.3
	Closure	Global Analysis	1.8	1.0

Challenges to develop and operate a dry stack design

Reduce the high capital and operating costs associated with modern filtration technology that renders other tailings storage options more economic to develop.

Finding equipment that allows to have tailings filtering plants of greater capacity and at low cost.

Establish a surface contour management procedure to avoid accumulation and easy removal of water content, this procedure should cover all ranges of variation of the filtered tailings parameters, including the operating conditions of the filtration plant and concentrate processing.

Know the past and future seasonal fluctuations, considering climate change. An important consideration in the design of a dry stack facility. A dry stack installation in a high rainfall environment can create day to day management problems for accessibility of compaction and haulage equipment.

Dust control should be considered, especially in arid climates, this impact occurs because of tailings disposal due to the low moisture content of the material placed.

Know detailed geochemical characterization of the tailings, may not be practical for some ore types - oxidation of sulphides in the tailings can create high concentrations (but low volume) of seepage water.

RESULTS AND DISCUSSION

The site conditions need to be defined by the drying factor and desiccation rate; in this case of study the values of 5.4 for drying factor and range of 0.022 to 0.033 for desiccation rates was obtained, these numbers are dimensionless. The safety factors for physical stability were obtained: 1.8 for static condition and 1.3 for pseudo static condition during the operation phase, and 1.8 for static condition and 1.0 for pseudo static condition during the closure phase. These values meet the design criteria.

CONCLUSIONS

The use of filtered tailings will depend on the site conditions and the filter plant processing capacity. Filtered tailings require surfaces of considerable size to achieve the compaction conditions that guarantee the stability of the facilities. The use of filtered tailings is part of the good design practices for tailings facilities including designs that can adapt to tailings with different properties, obtain low saturation, and reduce the risks resulting from excess pore pressure and generation of tailings liquefaction, especially in seismic zones. Defining the range of moisture content is a key objective in the design of filtered tailings plants. The purpose of this research was to study and document the behavior of filtered tailings, considering arid climate conditions and high mineral production. This research also includes the use of field data and results obtained from one of the world's largest operations involving filtered tailings.

ACKNOWLEDGEMENTS

The author would like to thank Eduardo León (Nexa Resources Peru, Peru), Hugo Valqui (Consultant for Nexa Resources, Peru), Marcelo Llano (Technical Committee for GECAMIN) and the anonymous reviewers for their support in the development of this publication.

NOMENCLATURE

E cum	Accumulated evaporation after linear stage
t	Time after linear stage (days)
b	Sorptivity / absorption coefficient (mm days ^ -0.5)
F. Sec	Drying factor
wa	Moisture achievable by the selected equipment
wo	Degree of fineness of tailings defines optimal compaction moisture
Ky	Seismic creep coefficient
Ts	Sliding mass period
Mw	Magnitude moment
Vs	Shear wave velocity
P (D = 0)	Displacement probability equal to zero
PGA	Peak Ground Acceleration
Sa	Pseudo-acceleration
CIU	Triaxial Undrained Assay
CID	Drained Triaxial Test
kPa	Kilo Pascal

SUCS Unified Soil Classification System

REFERENCES

Davies, M.P, & Lupo, J. & Martin, T. & McRoberts, E. & Musse, M. & Ritchie, D. (2010) *Dewatered Tailings Practice – Trends and Observations. In proceedings of Tailings and Mine Waste '10*, Balkema, (viewed 06-05-2021https://www.researchgate.net/publication/32576393_Filtered_Dry_Stacked_Tailings-The_Fundamentals).

D Bray, J., & Macedo, J. & Travasarou, T. (2018) *Simplified Procedure for Estimating Seismic Slope Displacements for Subduction Zone Earthquakes*, 3(144), (viewed 06-05-2021https://doi.org/10.1061/(ASCE)GT.1943-5606.0001833).

Hynes-Griffin, M., Franklin A. (1984) *Rationalizing the seismic coefficient method.* U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miscellaneous Paper.

Hynes (1984) *ER-1110-2-1806.* US Army Corps of Engineers.

Klohn Crippen Berger (2017) *Best Practices for Tailings Dam Design*, (viewed 06-05-2021, https://www.klohn.com/blog/best-practices-for-tailings-dam-design/.

Klohn Crippen Berger (2020) *History of Tailings Dam Design*, Klohn Crippen Berger, https://www.klohn.com/blog/history-of-tailings-dam-design/.

Ministerio de Energía y Minas - Gobierno del Perú (2006) *Guía para la elaboración de planes de cierre de minas*, Dirección General de Asuntos Ambientales Mineros, page 20.

Srk consulting (2021) *Tailings Facility Design*, (viewed 06-05-2021, https://www.srk.com/en/projects/karar-iron-ore-mine-tailings).

Swarbrick, G., & Fell, R. (1992) *Modeling Desiccating Behavior of Mine Tailings*, Journ. Geotech. Eng., ASCE, v. 118, no. 4, (viewed 06-05-2021 https://doi.org/10.1061/(ASCE)0733-9410(1992)118:4(540)).

Seed, H.B. and Idriss, I.M. (1971). *Simplified procedure for evaluating soil liquefaction potential.* Journal of Soil Mechanics and Foundations Division 97(9), 1249-1273

TAILPRO Consulting (2021) *Tailings Info*, (viewed 06-05-2021, https://www.tailings.info/disposal/drystack.htm).