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Design and operational experience of the Cerro Lindo filtered tailings deposit

J.L. Lara *Golder Associates Peru S.A., Peru*

E. León *Compañía Minera Milpo S.A.A., Peru*

Abstract

Filtered tailings (FT) provides an alternative to surface tailings deposition that is being applied more frequently in areas in which availability of space and water is limited. FT can be applied in areas in which topographic, geotechnical and geodynamic conditions as well as seismic, climatic and rheological conditions of the tailings allow their implementation. Cerro Lindo Project (CLP) is located 200 km south of Lima-Peru in an area of limited rainfall and high seismic activity. The tailings deposit is located in a quebrada (ravine) with a moderate to high gradient, of the order of 20–25%, in a small basin less than 1 km^2 in area. The project started operation in 2007 and currently processes 7,000 tpd to obtain polymetallic minerals (lead, zinc and copper); CLP produces tailings that are deposited on the surface and in underground mining. For surface deposition of tailings, the tailings are filtered by belt filters until 85% solids content is reached. Then the tailings are transported by trucks to the deposition area where they are placed in different zones in a cyclical manner to allow drying until the proper moisture content is achieved to allow compaction in layers. The deposited tailings are high in pyrite, with high specific gravity and of sandy silt particle size.

This article shows design concepts and operational expertise gained over the past three years in the deposit management of filtered tailings of Cerro Lindo Mine. This is considered a unique and successful world class operation in the implementation of tailings dewatering, and in the application of friendly technologies with small impact on the environment and an operation that uses the water from the tailings dewatering process and also seawater for the operation of the mine.

1 Introduction

The Cerro Lindo Project, property of Compañía Minera Milpo S.A. (Milpo), processes currently 7,000 tpd for obtaining polymetallic minerals zinc, lead and copper, using the method of sub-level stoping exploitation. Concentrates produced, in the order of 10% of the processed mineral, are transported through trucks to Lima-Peru city for its commercialisation. From the generated tailings, 55% is used for paste filling of the underground mining works, and 45% is deposited on the surface as filtered tailings.

CLP has two (2) operative areas, the mining and the water and energy supply areas. The mining area is located 60 km from the adjacent coast to the Quebrada Topara, in which there is the concentrator plant, tailings deposit facility, underground mining works, tailings filtration plants and camps. The area of water and energy supply located along the coast is composed of seawater desalination plant, water pumping stations and one high tension power line, as well as electrical sub-stations.

CLP was developed from its design phase up to its operational phase in 18 months, and is considered a successful mining project of technological innovation in the application of filtered tailings technologies for its deposition on surface and application of paste fills for the underground mining. It is also considered an environmentally friendly project, since it does not use the limited natural water of the project area, but uses desalinated seawater, impacting a much reduced area for the tailings deposition.

The CLP initiated its operations in July, 2007.

2 Site location and site characteristics

CLP is located in the province of Chincha, department of Ica, 200 km south of the Lima-Peru city, and it can be accessed along a 40 km asphalt surfaced road from Panamericana Sur (Figure 1).

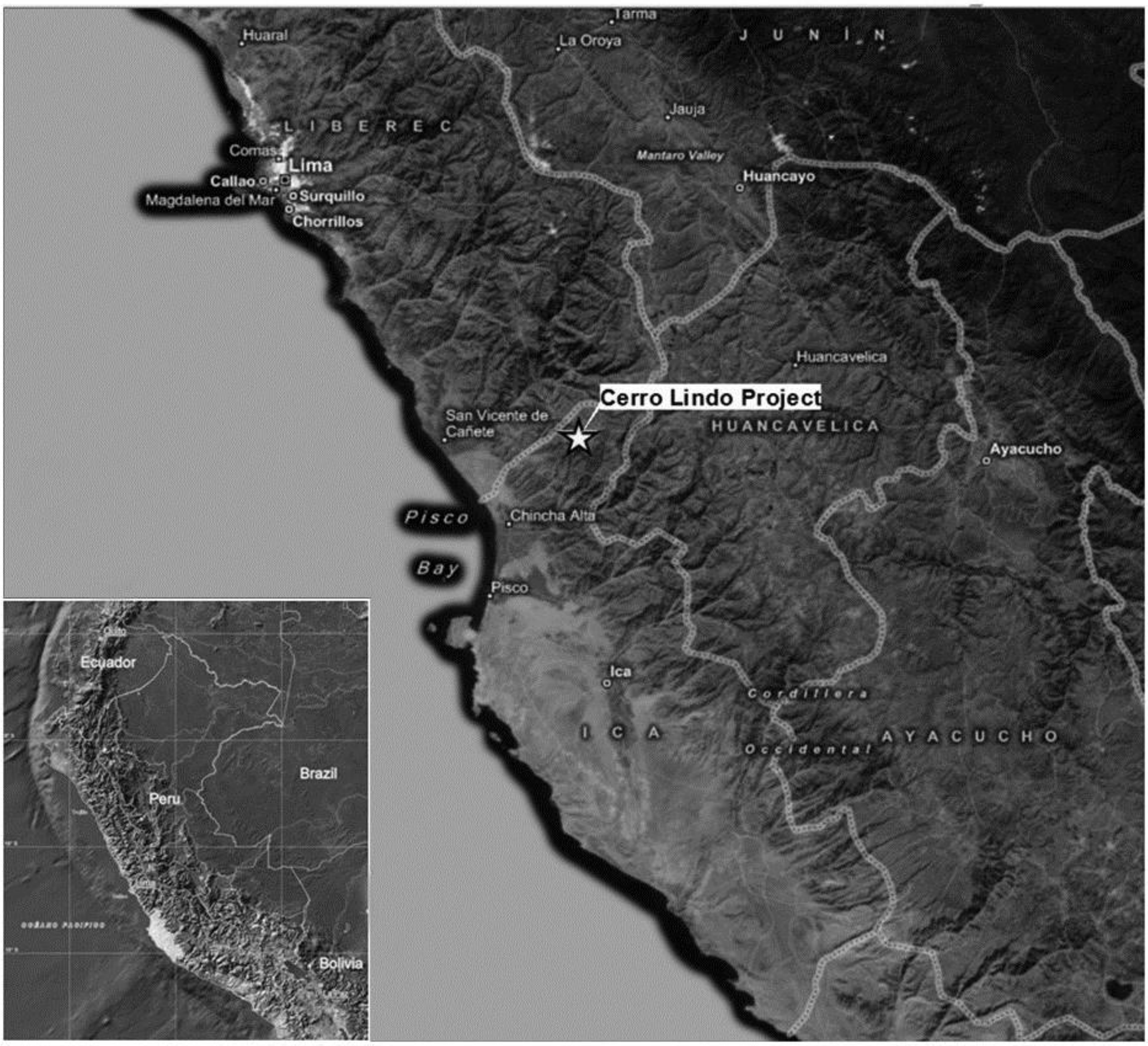

Figure 1 Location of the CLP area, Peru

The project area is located in the occidental Andes at an average elevation of 2,000 masl. The yearly average precipitation and evaporation are 200 and 1,500 mm, respectively. The zone is of arid climate, with average yearly temperatures of 19°C and with some rain concentrated in the months of December to March, for the rest of the year precipitation is rare and sporadic (Golder, 2006a).

The project area is located in a high seismicity area, less than 100 km from the Peru-Chile trench. Earthquakes in the area are expected up to a magnitude of Mw = 9.0 (for the maximum credible earthquake) with maximum accelerations at a basal rock level of 0.45 g (Golder, 2006b). In 2007 a significant seismic event of magnitude Mw = 8.0 occurred, considered as a maximum operation earthquake for the project area, with a return period of 500 years (Figure 2). The Cerro Lindo tailings storage facility (TSF) experienced good behaviour during and after this earthquake without damage.

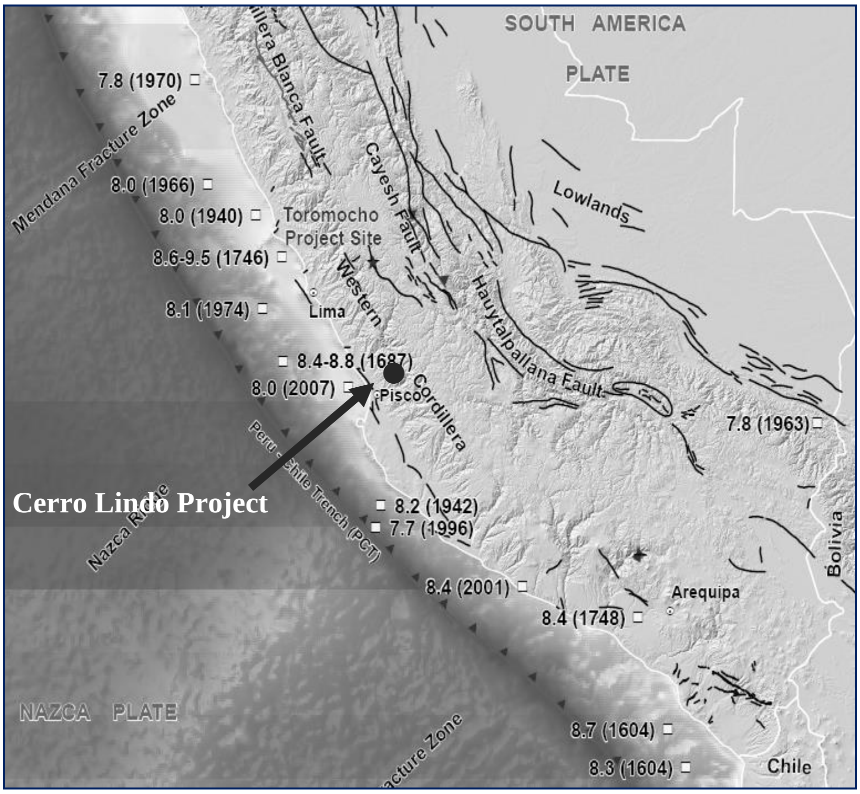

Figure 2 Seismic tectonic frame of the CLP area

The tailings deposit of CLP is located in the Quebrada Pahuaypite, which has an approximate watershed area of 0.45 km^2, quebrada presenting a very low external geodynamical activity (landslides). The average gradient of the bottom of the Quebrada Pahuaypite is 20–25%, and the valley side slopes are also variable between 25 and up to 45%. The Quebrada Pahuaypite has a few lateral quebradas, all of them are short and with evidence of shallow torrential fluvio deposits, less than 2.5 m.

Geologically, the area is composed by volcanic granodiorite rock that is surficially weathered, with improving geomechanical quality with depth; at 25 m depth, sound rock occurs. The soil cover is generally less than 3 m thick and consists mainly of moderately compact silty clayey gravel colluviums.

From a hydrogeological point of view, the quebrada does not have water flow at all times of the year and there is no evidence of water seepage. The groundwater level is more than 40 m deep in the area of the tailings deposit (Golder, 2006c).

3 TSF design

The tailings deposit of the CLP was designed taking into account the following conditions and requirements of the project:

- The tailings have high acid generating potential.
- Minimise the impact area for the tailings deposition.
- Minimise the discharge of water in contact with tailings and/or transport of sediments, downstream of the tailings deposit area.
- Minimise the water management in the tailings deposit.
- Maximise the recovery of process water.
- Highly seismic area with little precipitation.
- Start of operation in June, 2007.

Based on these requirements, the study was developed from the site selection and evaluation of the best alternative of tailings deposition, up to the preparation of construction documents, in the period from January to October, 2006.

The project developed was a filtered tailings deposit compacted in layers using a very small deposition area (Quebrada Pahuaypite) compared to a conventional slurry tailings deposit, of low geodynamical activity, without the presence of surface water flows and close to the process plant. The filtered tailings deposition was selected among other alternatives of tailings deposition, such as pulp and thickened tailings.

In the initial phase of the study, a site selection and best alternative evaluation of tailings deposition were carried out. Deposition of conventional tailings, thickened and filtered tailings were evaluated, as well as different sites for the tailings deposition in a radius of 10 km around the process plant. The project area has a very uneven topography and high slopes, therefore the available areas for the tailing deposition is very limited and generally requires high tailings dams. Once the site selection evaluation and the tailings deposition alternative were completed, it was decided that the best technical-economical alternative of the tailings deposit was filtered tailings in the Quebrada Pahuaypite for the following reasons:

- The Quebrada Pahuaypite has a small watershed area of 0.45 km^2. It is the smallest watershed of the evaluated sites.
- The impacted area for the tailings deposition was the minimal among the evaluated alternatives. This meant a lower environmental impact and lower social resistance.
- The water management of the tailings deposit had the least risk among the evaluated alternatives, having the minimum seepage risk of the tailings deposition area.
- The deposition of the filtered tailings allows a progressive closure of the tailings deposit.
- The Quebrada Pahuaypite is adjacent to the process plant, which made the mining operation more flexible.
- The capital cost was the minimum among the evaluated disposition alternatives, basically because of the minimal volume of the dam required. The operation cost was the highest of the evaluated deposition alternatives; however, the total cost was the lowest of the evaluated alternatives.

The filtered tailings to be deposited in the Quebrada Pahuaypite required the compaction in layers of the tailings, due to the elevated site topography and the high seismic activity of the site. Likewise, the topographic conditions and the narrowness of the quebrada made it advantageous for the tailings transport to be by means of trucks instead of conveyors. An additional advantage of compacting tailings in layers was that it created a medium of low permeability, diminishing the risks of infiltration of rain water, and inhibiting the entrance of oxygen, thus minimising the generation of acid drainage.

3.1 Operational data

The most relevant operational data were:

- Ore reserves: 33.6 Mt.
- Operation days per year: 360 days.
- Ore production: 5,000 tpd.
- Relation tailing/ore: 0.9.
- Percentage of tailings for surface disposition: 45%.
- Content of tailings solids of thickener feed: 30%.
- Content of tailings solids of thickener underflow: 78%.
- Content of tailings solids at the filter plant output: 88%.
- Specific gravity of the tailings: 4.2.

- Useful life of the mine: 19 years.
- Tailings production: 4,438 tpd.
- Total volume of tailings to be deposited on surface: 4.93 Mm^3.

3.2 TSF description

The Pahuaypite tailings deposition operation consists of a tailings filter plant, a filtered tailings deposition area, and a dam collecting filtrations and sediments, Pahuaypite Dam (Figure 3).

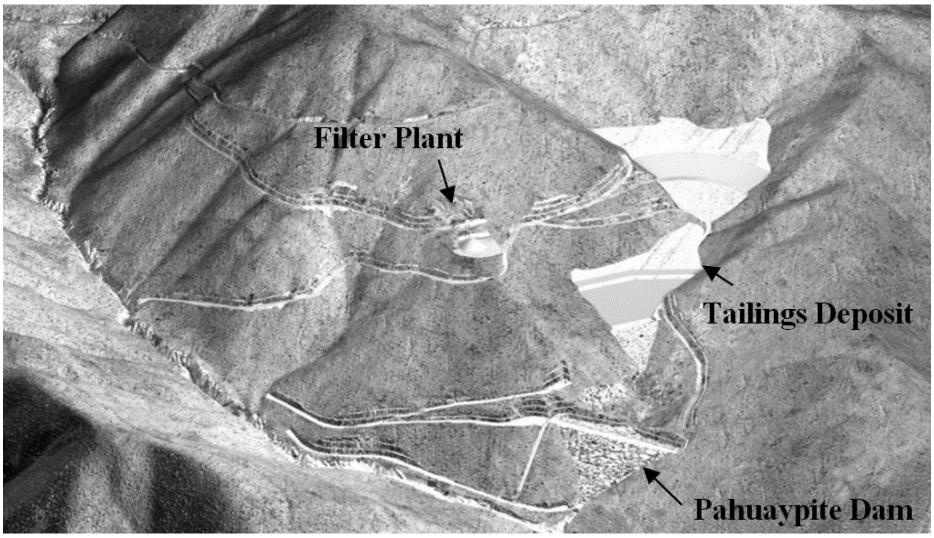

Figure 3 View of the Cerro Lindo tailings deposit: year 1 of operation (2008)

3.3 Tailings filter plant

The tailings filter plant is located on the right slope of the tailings deposit less than 500 m from the deposition area (Figure 3). Tailings generated in the process plant (relation tailings/ore = 0.90) are sent to a 30 m diameter high compression thickener (HCT) (elevation 2,120 masl), where tailings enter with a solids content of 30% and come out with a solids content of 76–78%. These thickened tailings are sent through centrifugal pumps to the tailings filter plant (elevation 2,097 masl), a distance of 0.8 km (Figure 4).

Figure 4 View of the filter tailings plant

The filter tailings plant consists of a Delkor type belt filter (Figure 5). At the exit of this plant, tailings come out with a solid content of 88%. Tailings are piled at the discharge of the plant in a mound with slopes of 1.3H:1V (Figure 4) from where they are loaded to 15 m^3 capacity trucks to be sent to the tailings deposit.

Figure 5 View of the belt filter

3.4 Deposit of filtered tailings

The filtered tailings deposit is composed of two desiccation platforms, of approximately 2,250 and 14,050 m^2 each, located at elevations 2,028 and 2,082 masl, respectively. In these platforms, filtered tailings are discharged, spread by sectors to obtain desiccation and to allow further compacting (Figure 6).

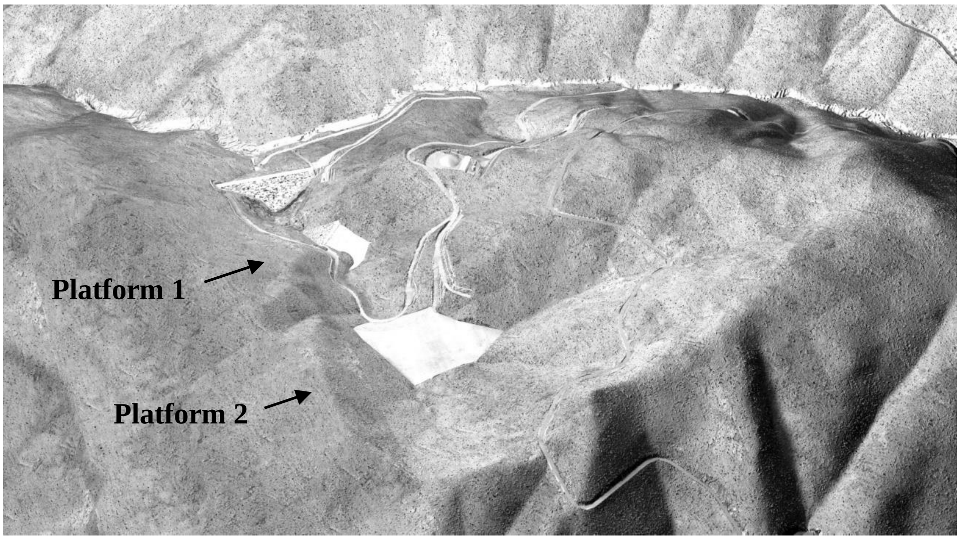

Figure 6 View of the desiccation platforms of filtered tailings

The tailings deposit has been designed to store 14 Mt of tailings and is built as a large fill which will have an overall slope of 2.8H:1V. The tailings storage construction has benches with a minimum width of 10 m each and 20 m high (Figure 7).

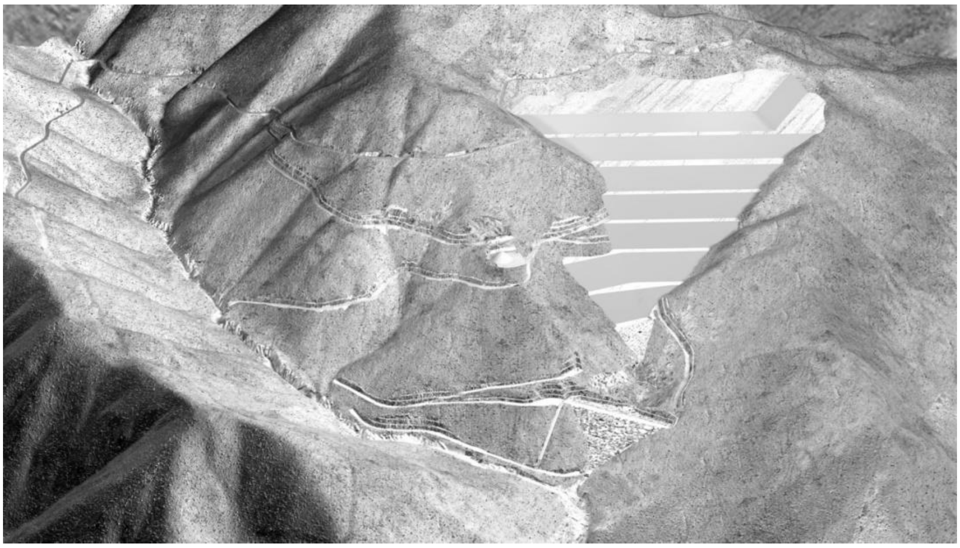

Figure 7 View of the tailings deposit – final operation stage

As part of the tailings deposit, a basal drainage system has been provided for seepage collection from the tailings deposit. The installation of inclinometers and underground water monitoring wells is also considered. They will be progressively installed in berms that will form the tailings deposit.

3.5 Pahuaypite Dam

Pahuaypite Dam is a zoned dam located with crest elevation at 2,004 masl. It has an 8 m crown width and upstream and downstream slopes of 1.6H:1V and 2H:1V respectively. The downstream slope is comprised of rockfill and upstream slope of silty, clayey and gravelly material. The upstream slope and inner part of the impoundment area of Pahuaypite Dam are lined with low permeability material and an HDPE 1.5 mm geomembrane (Figure 8).

Figure 8 View of Pahuaypite Dam

Pahuaypite Dam also has a seepage collection system at the downstream toe of the dam, and a geotechnical instrumentation system of vibrating wire piezometers for measuring the pore pressure. The dam has an emergency spillway with a capacity to discharge a probable maximum flood of 0.9 m^3/s (Figure 8).

4 TSF operation

4.1 Tailings characteristics

CLP tailings consist of Pyrite (65%), Barite (30%) and Silicate (5%). The specific gravity of the tailings varies from 4.0 to 4.2 (Milpo, 2009).

Filtered tailings are non-plastic clayey silty soils with fine content of 55–60%, with a mean value of 57% fines. The sand that forms part of the tailings is fine sand with a maximum particle size of 0.5 mm. The average liquid limit index is 12.

The maximum dry density is from 2.70–2.85 t/m^3, and the optimum moisture content is from 7–8.5%. For the range of dry density between 2.70 and 2.85 t/m^3 the permeability is in the range of 1×10^{-4} and 5×10^{-4} cm/s, thus, these tailing are considered to have from moderate to low permeability. The saturation level of these tailings is from 11–13% for the above mentioned range of consolidation.

The resistance and consolidation parameters were evaluated through triaxial and consolidation testing. Table 1 shows the summary based on the extensive laboratory investigation program (Golder, 2006d).

Table 1 Summary of tailings geotechnical parameters (Golder, 2006d)

γ_d	Shear Resistance					k	Consolidation	
	c´	c	ø´	ø	S_u/γ_{vo}´		Pc	Cc
t/m^3	kg/cm^2		°			cm/s	kg/cm^2	
2.7–2.8	0.0	0.1–0.4	30–32	9–14	0.10–0.14	10^{-5}–10^{-6}	1.80–1.85	0.077–0.130

Where:

γ_d = dry density.

c´ = cohesion in effective stress.

c = cohesion in total stress.

ø ´ = friction in effective stress.

ø = friction in total stress.

S_u/γ_{vo}´ = ratio of ultimate strength versus effective vertical stress.

k = permeability.

Pc = pre-consolidation load.

Cc = compressibility index.

4.2 Tailings disposal

Tailings generated in the process plant are discharged to the surface as filtered tailings and are used as paste fill to be used in underground mining works, 55% of the time tailings are discharged to be used as backfill for underground mining and 45% of the time they are discharged on surface.

Tailings are released from the process plant with 30% of solids and are conveyed to a 30 diameter HCT thickener. Underflow Tailings from the HCT reach 76–78% solids content and are sent to the filter plant. There are two filter plants, one for surface tailings deposition and other for underground mining. Both of them are located less than 500 m from the above mentioned facilities.

In the filter plant, tailings are dewatered with belt filters to reach a solids content between 83 and 85% for a proper mix design with cement which varies between 0 and 5% by weight depending on the stope to be filled in the underground mining (elevation 1,850 masl).

In the filter plant for surface deposition, the filtered tailings have a solids content (Cs) between 87 and 88%, which is equivalent to a moisture content (w%) between 14 and 15% (w% = 1/Cs^{-1}). These tailings at this moisture content can form stacks with slopes of 1.3H:1V. Tailings are handled with wheel loaders to trucks with a capacity of 25 t (Figure 9). Trucks discharge tailings into the tailings deposit by sectors to obtain the dewatering and compaction cycles.

To obtain tailings that achieve a minimum initial dry density, that is seismically stable, and not below 2.8 t/m^3, the tailings need to be first dewatered until reaching a moisture content in the range of 5–7% and then compacted to 95% standard proctor density. To reach a dry density for compaction, operation cycles from 3–5 days are applied depending on the period of the year. In summer (December to March), the wet season, cycles could last 5 days. For the rest of the year, cycles could last 3 days approximately. Operation cycles consist of the following activities: discharge, spreading, drying – compacting (Figures 10 and 11).

The layer thickness to form tailings is 30 cm, and after reaching a moisture from 5–7%, tailings are compacted through vibrating rollers of 10 t until reaching the required density, which is obtained generally with two cycles of roller passes (Figure 11).

Figure 9 Loading of the filtered tailings into trucks to be transported to the tailings deposit

Figure 10 View of the discharge and drying operation of tailings

Figure 11 View of the tailings compaction process

4.3 Monitoring of the tailings deposits

The tailing deposit considers the following monitoring program (Figure 12). Table 2 shows a summary of the mentioned controls:

- Thickness control of the compacted layer.
- Onsite moisture and density control of the compacted layer.
- Gradation and specific gravity control of the deposited tailings.
- Resistance and moisture control in depth through standard penetration tests (SPT) tests.
- Level and quality control of underground water under the tailings deposition area.
- Overall slope control of the tailings deposit.

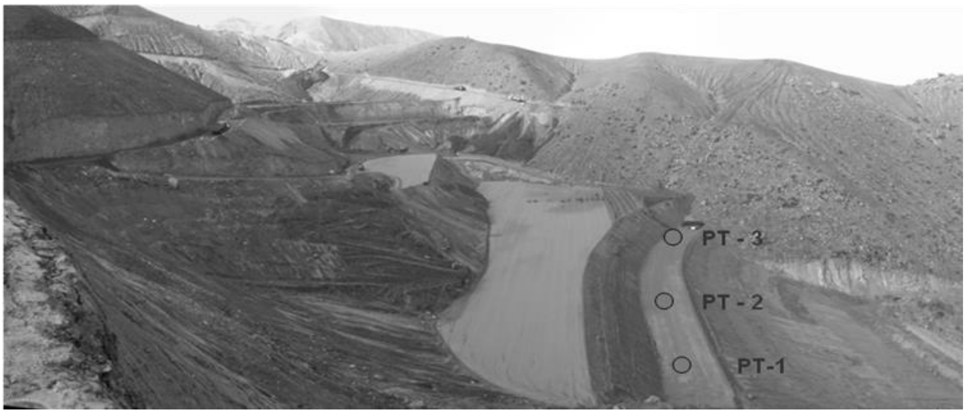

Figure 12 View of the installation points of casagrande type piezometers, SPT tests and moisture in depth

Table 2 Summary of the Geotechnical and Water quality control (Milpo, 2009)

Type of Control	Unit	Value	Control Frequency
Layer thickness	cm	30–35	Per compacted layer
Compacting moisture	%	5–7	Per compacted layer
In situ dry density	t/m^3	2.7–2.8	Per compacted layer
Gradation	-	ML	Monthly
Specific gravity	-	4.0–4.2	Monthly
Strength with depth	Nspt	20–40	Annually
Moisture with depth	%	6–8	Annually
Depth of underground water level	m	>40	Monthly
Overall slope of the tailings deposit	H:V	2.8:1	Annually

5 Co-deposition of filtered tailings and waste rock

As part of the tailings deposit operation, the co-deposition of filtered tailings and waste rock is considered. The waste rock has a good geomechanical quality and is potentially acid generating.

For the co-deposition of the waste rock and filtered tailings, a reduced area located at the back of the tailings deposit was selected. This procedure has been applied mainly discharging tailings that leave the filter plant having moisture contents exceeding 13%. Two objectives are achieved with this procedure: discharge saturated tailings in areas that do not represent a risk for the overall stability of the tailings deposit, accelerate the dewatering process of tailings when being discharged into the slope and allow a proper mixture of tailings and waste rock (Figure 13).

Figure 13 View of the co-deposition area of filtered tailings and waste rock

6 Discussion

Filtered tailings deposition is a widely used alternative of tailings deposition in the last decade, especially in areas where there are restrictions of water availability and space. In South America at least five successful operations are known, in La Coipa, Quebrada Blanca and El Peñon projects, all located in Chile, and Catalina Huanca and Cerro Lindo Projects located in Peru. Figure 14 shows the approximate location of these projects and Table 3 shows the summary of the characteristic of these tailings deposits.

Figure 14 Location of the filtered tailings deposits in South America (updated to 2007)

Table 3 Summary of the filtered tailings deposit characteristics under operation in South America (updated to 2007)

Project	Unit	Mantos Blancos	La Coipa	El Peñon	Cerro Lindo
Location		Chile	Chile	Chile	Peru
Production	tpd	12,000	18,000	2,600	5,000
Ore		Cu	Cu	Au	Zn-Pb-Cu
Transport		Conveyors	Conveyors	Truck	Truck
Type of Filter		Belt	Belt	Belt	Belt
Cs	%	82–83	79–82	82–83	87–88
Classification	SUCS	SM	ML	ML	ML
% fines	%	35–40	53–55	61–65	56–58
Gs		2.67–2.69	2.76–2.78	2.60–2.62	4.0–4.2
Compaction		No	No	No	Yes
Pma	mm	<50	<50	<50	200
Ema	mm	>2,000	>2,000	>2,000	1,500

Where:

Cs = solid content to the exit of the band filter.

Gs = specific gravity.

Pma = mean annual precipitation.

Ema = mean annual evaporation.

The biggest restriction to the use of filtered tailings is associated with the higher capital and operating cost in comparison with the conventional slurry tailings deposition. It also has restrictions when applied in areas of high to moderate precipitation and when compaction is required. Notwithstanding the foregoing, the application of filtered tailings deposition is becoming more popular due to the reduced water availability and deposition areas and because the technology of filtered tailings facilitates its application.

Generally, deposits of filtered tailings require containment dikes of smaller dimensions than those required for the conventional tailings deposition (slurry tailings), and even for thickened tailings. Therefore, the deposition of filtered tailings is not necessarily the highest total cost of the available alternatives, in many cases, such as CLP, which is the alternative of total lowest cost, and environmentally more friendly.

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