

# **The Drained Stacking of Granular Tailings: A Disposal Method for a Low Degree of Saturation of the Tailings Mass**

Joaquim Pimenta de Ávila, Consulting Engineer, *Pimenta de Ávila Consultoria Ltda.*

## **Abstract**

The method of tailings disposal, has a strong influence on the characteristics of the tailings mass within the reservoir and on the behaviour of the tailings dam. The presence, and the amount of the water in the voids of the tailings, is an important factor that governs several aspects of the performance and the safety of tailings dams.

A tailings mass with a low degree of saturation presents a lower risk of liquefaction of the tailings mass and achieves higher densities, in response to the loads applied by the reservoir filling.

This paper describes a method of disposal of tailings composed of silt and a fine sand fraction, with provisions to drain the water from the voids of the tailings. The starter dam is a construction controlled pervious dam with a drainage system provided within the tailings deposition area, in order that the tailings mass achieves a low degree of saturation. Two examples are presented of tailings disposal systems using this method, with stack structures achieving up to 195.0 meters height.

## **Introduction**

The construction of a sand stack by hydraulic slurry placement by the upstream method of dam construction offers a disposal method that is low cost and efficient. The ability to build such stacks is dependent on the permeability/drainage characteristics of the tailings, and a dam and impoundment design that achieves a degree of drainage during both operations and post closure that ensures that stability is maintained at all times. This paper provides examples of such designs (as described in item “examples of application”).

The reduction of the water content of the tailing mass is an important tool to achieve better characteristics of the system that consists of both the tailings and the dam. The presence and the amount of water in the voids of the tailings is an important factor that influences the stability of the dam and several aspects of the tailings deposit performance, such as the overall tailings density, the hazard potential and the whole system’s risk.

A tailings mass with a low degree of saturation present lower risk of liquefaction of the tailings mass and to achieve higher densities, as a response to the loads applied by the reservoir filling. So, several advantages are obtained from a tailings mass with low degree of saturation, in comparison with the characteristics of tailings with full saturation.

This paper presents a discussion of several aspects of a disposal method of tailings composed of silt and a fine sand fraction, with provision to drain the water from the voids of the tailings. The starter dam construction is a controlled pervious dam with a drainage system provided within the tailings deposition area, in order that the tailing mass achieves a low degree of saturation. Two examples are presented of tailings disposal systems using this method with stack structures achieving up to 195 meters in height. The resulting system, composed of the tailings deposit and the dam, presents several advantages in terms of safety, density of the tailings and closure conditions. Also presented are the design basis and the monitoring results of the performance of these structures.

## **Application of the Drained Stacking Method for Tailings Disposal Description of the Method**

The tailing disposal method presented in this paper includes a “pervious dam” as the starter dike, instead of a seepage barrier structure to retain both the tailings and the water. In addition to the pervious starter dike there is an internal bottom drainage system connected to the starter dike that provides a way to drain a substantial part of the water from the voids of the tailings.

The main objectives of this method of disposal are:

- To obtain a non saturated embankment, with improved stability;
- To obtain greater tailings density, aiming to increase the reservoir capacity;
- To achieve a lower hazard potential in a case of a failure;
- To improve the closure conditions with less cost for the environmental rehabilitation;
- To achieve safer conditions for the application of the upstream method of construction, with a low risk of liquefaction and failure.

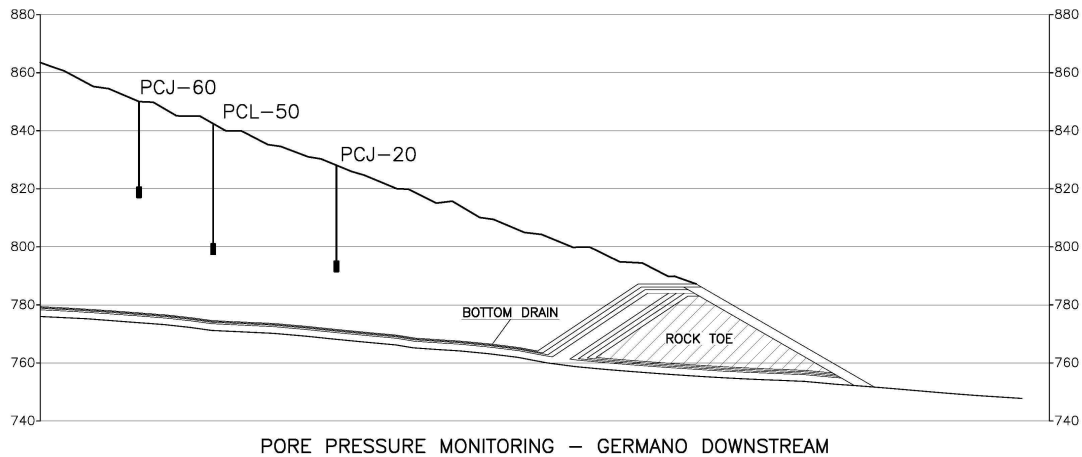
In addition, to these characteristics, this method of disposal is being observed as having lower cost per ton of tailings placed. In Brazil, the method has been inspired by experience gained from the drained disposal of sandy tailings, applied for moderate heights since 1980. More recently tailings embankment with heights up to 195 meters, with the possibility to exceed the 200 meters are under construction. Examples are the two structures of Samarco Mineração S.A. at Germano Mine presented herein: Germano Dam buttress and Germano Pit closure rehabilitation structure. The design, construction and monitoring results of these projects are presented in the following paragraphs.

Rainfall, slurry density and the rate of construction are important considerations. At the Germano mine the annual rainfall is 1,500mm the tailings slurry is around 55% at the discharge at the placement and the final density is between 80% and 90% by weight solids and the maximum rate of rise during construction was 2.5 meters per month.

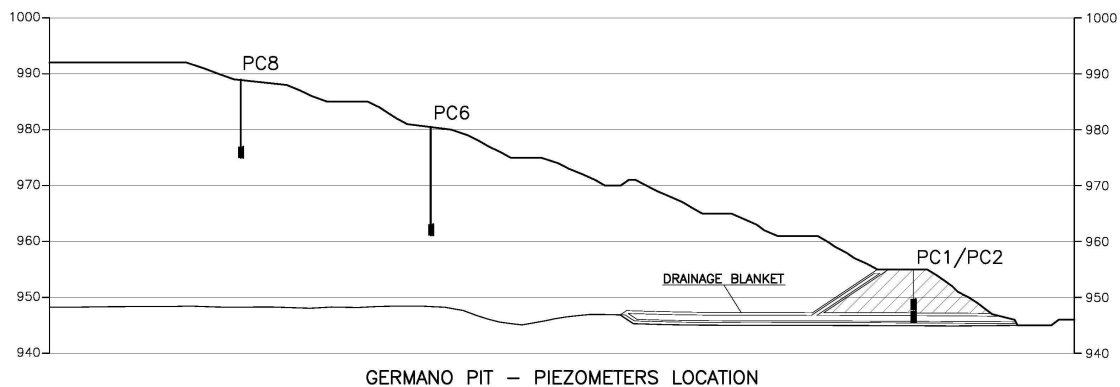
## **Examples of Application**

The following two figures present the typical sections of the starter dikes and the tailings disposal structures. The first figure, Fig. 1, presents the current stage of the Germano buttress structure, with the rock-fill starter dike founded at elevation 745.0. The transition between the rock-fill starter dike and the tailings is a multiple layered transition with sand, fine ore and coarse stone layers to meet filter criteria from the rock size to the tailings size. At the contact with the rock foundation, there is a bottom drain to provide an outlet for the flow of the Germano creek existent in the valley, as well for the water from the drainage of the placed tailings, both from the Germano main dam reservoir and the new Germano Buttress tailings reservoir. With such drainage provisions the water from the tailings drains to the bottom drain and there is not a pond on the surface of the tailings.

The current elevation of the tailings top in the buttress is about 880.0 meters. The Germano buttress is placed against the downstream slope of the Germano main dam, to provide safe stability conditions for the dam's closure. The crest elevation of the main dam is at 886.0 meters. It is scheduled to be constructed to elevation 940.0 meters for the top of the tailings, exceeding the required buttress height of Germano buttress, and achieving a toe to crest height of 195.0 meters. In the same figure are the locations of some of the current installed piezometers.



The second figure, Fig. 2, presents the Germano Pit rehabilitation structure, at its current elevation, around 992.0 meters.



The starter dike has a rock drain on the dike's upstream slope and a drainage blanket at the foundation, extending 80.0 meters upstream of the starter dike. This drainage provision makes the water from the tailings to drain into the foundation and the pond that forms on the back of the tailings beach have only temporary duration at the time of precipitation. While the current elevation of the tailings embankment is at elevation 992.0 meters, the scheduled final elevation is at 1,100 meters, resulting in a toe to crest height of 155.0 meters.

For both structures, Germano buttress and Germano Pit, the raising of tailings surface is made by discharging the tailings from the crest. The impoundment beach edge containment at the crest is provided by a raise dike of 5.0 meters high constructed along the crest. After the discharged tailings have achieved an elevation close to the dike's crest, the discharge is stopped to construct a new dike, by the upstream method. This construction is performed a few days after shut down of the discharge (usually a week) when the drainage of the water from the voids of the tailings to the bottom drain has been effective.

The following photos, illustrates some of the details of the disposal process and results, using the Germano buttress embankment and Germano Pit for illustration. Photo 1, shows the drained surface of the tailings on Germano buttress dam, a few days after shut down the discharge. At the back of the photo is seen the downstream slope of the Germano main dam that is being buttressed.



**Photo 1- View of the tailings surface after a few days of stopping the discharge.**



**Photo 2- View of the tailings surface being excavated to obtain material to raise the structure.**

It can be observed in the photos 1 and 2 that good support is offered by the surface of the tailings for traffic of the equipment that will excavate the tailings to be used as the fill material for the raise dike.



**Photo 3- View of the final slope surface of the Germano buttress that is progressively prepared for closure.**



**Photo 4- View of a conveyor belt structure resting upon the final slope surface of stacked tailings.**

The photo 3 shows the final slope of the Germano buttress, which is being progressively closed with the construction of the surface drainage and re-vegetation. The photo 4 shows a view of a structure that was constructed over the stacked tailings embankment: a conveyor belt structure that links a pit mine site to the processing plant.

The good performance of this structure, for more than seven years now, provides a measure of the behavior of the stacked tailings embankment. The pore pressure monitoring of the embankment shows zero pore pressure within the placed tailings as presented further in this paper.

The photo 5 gives an overview of the system with the Germano main dam, Germano buttress (In the date of this photo, was still without the conveyor belt structure). At the back of the photo, closer to the

mountains it is possible to see the slope of the Germano Pit, that is shown in detail in the photos 6 and 7.

The performance of the drained stack as shown by the monitoring results indicates the safety requirements for stabilization of Germano main dam have been adequately achieved.



**Photo 5- View of the Germano buttress at an early stage of construction.**

The photo no. 6 shows the foundation preparation for the Germano Pit rehabilitation, with the drainage blanket and the starter dike under construction.

The photos no. 7 and 8, shows the Germano pit at it is at present.



**Photo 6- View of the Germano Pit drainage blanket in construction.**



**Photo 7- Upstream view of the Germano pit stacking.**

### **Design Aspects of the Drained Stacking for Germano Buttress and Germano Pit**

The geotechnical characteristics of the tailings, mainly gradation and permeability, have an important role with respect to the drainage capacity of the tailings mass to eliminate water from the tailings voids and to achieve a lower degree of saturation.

The design of the tailings disposal, using the drained stacking method was based on a detailed investigation of the tailings geotechnical characteristics.

The program for the tailings characterization, included the following stages:

- Laboratory characterization tests, including gradation, chemical analysis, max. and min. density tests, permeability tests, shear strength tests to investigate the strength, pore pressure response to undrained shear, liquefaction potential.

- Field test, with a test fill, constructed by discharging the tailings using the process that would be used in the prototype. This test fill was used to perform “in situ” density tests, to investigate the possible segregation and to collect samples for additional laboratory tests. Five tests stages were performed during the period of the discharge tests, each one in a different layer of tailings placement. A total of 45 samples were taken to give good representativeness of the tests results.



**Photo 8 – View of the Germano pit stacking from the crest downstream**

## **Geotechnical Characteristics of the Tailings**

### **Gradation**

The tailings have sandy silt characteristics, with roughly 60-70% passing in no.200 sieve and almost zero smaller than 2.0 micra.

### **“In situ” density**

The “in-situ” density tests were performed in several campaigns after each layer of tailings was discharged. The tests were made at depths intervals of 0.5 meters from the surface to 2.0 meters.

The overall average, disregarding the zero meters depth samples (because of the large scattering) was:

- Specific gravity = 3.074
- Water content = 10.94 % by weight
- Max. Dry dens. = 2.11t/m<sup>3</sup>
- Min. Dry dens. = 1.60t/m<sup>3</sup>
- In situ Dry dens.= 1.83t/m<sup>3</sup>

The relative density of the tailings, were found to be close to 60% on average, while the scattering of the values includes values from 20% to 80%. So it was concluded that there were loose sand spots within the tailings mass.

### **Permeability**

There were seven values of the permeability varying between  $8.67 \times 10^{-5}$  cm/sec and  $1.8 \times 10^{-3}$  cm/sec.



## **Shear Strength**

The effective friction angle was consistently found to be close to  $42^\circ$ , when computed, from triaxial tests, to the point of the maximum effective principal stress ratio. However, for the samples with lower densities, at the deformations required to mobilize the full friction angle the pore pressure was high. In general, the loose samples showed values of the pore pressure parameter A, as high as 1.8 and for the denser samples there was practically no pore pressure.

These results indicate that with poor drainage conditions, the tailings will assume a loose packing and possess a high susceptibility to liquefaction. For good placement/drainage conditions, where the higher densities were obtained, the behavior may be adequate in terms of the risk of liquefaction.

Therefore, good drainage conditions are an essential requirement during placement, both for the beach maintenance and for the internal drainage requirements.

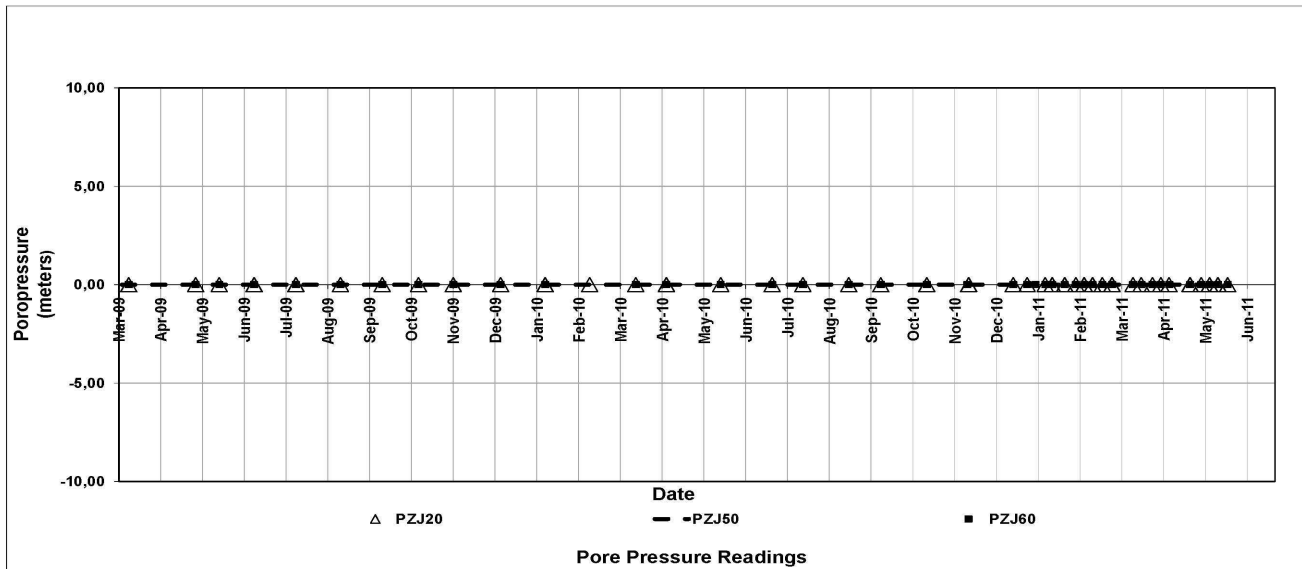
## **Design Aspects**

Based on the characteristics of the tailings, as well as on the pilot tests results, it was concluded that the internal drainage system shall be conservative and a bottom drain was included in the design with a drainage blanket for the Germano pit (Fig. 2 and Photo no. 6) and a bottom drain for the Germano Butress (Fig. 1).

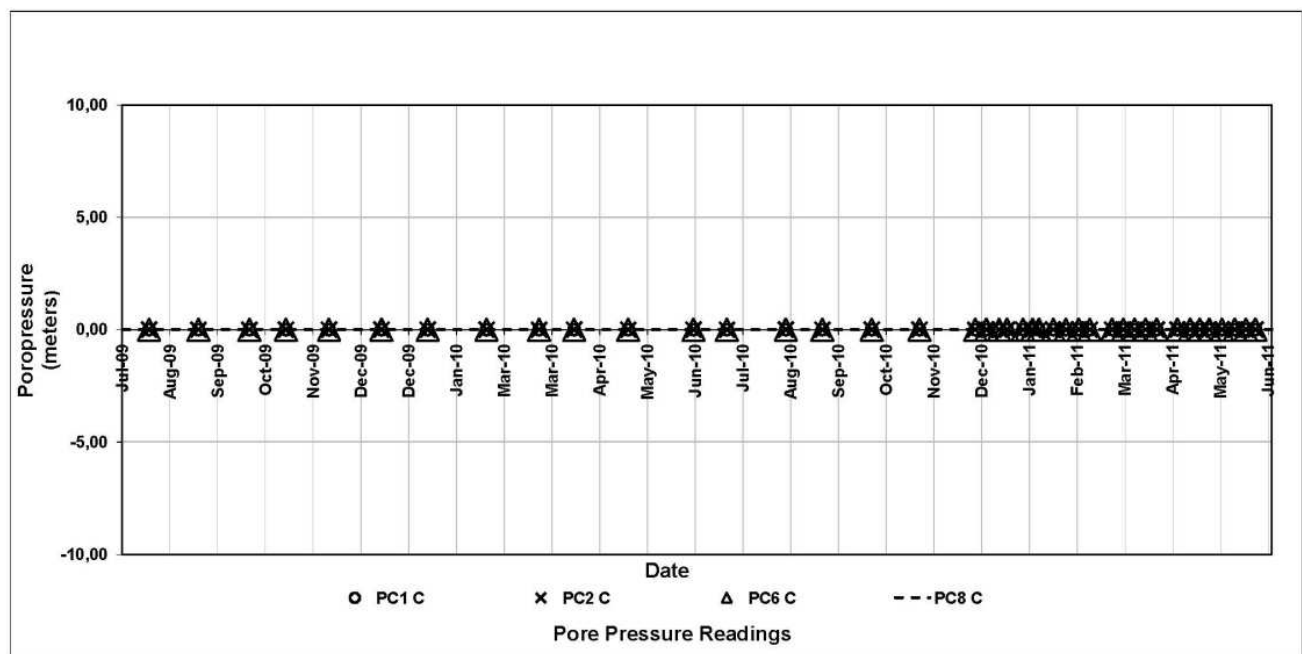
The stability analysis of the tailings embankment was performed using the effective strength and the pore pressure parameter A, varying between the values obtained for the dense and the loose condition. The factor of safety obtained was: FS ~ 1.9 for the lower pore pressure parameter, and FS ~ 1.2 for the worst condition of a saturated embankment and a loose state.

The pore pressure response of the tailings in the prototype was monitored with cell piezometers. The figures 1 and 2 show the positions of the piezometers. The graphs shown in figures 3 and 4 shows the pore pressures readings. While the graphs are presented for the period of the last two years, the results are the same for the previous years.

It may be observed that values of the readings are consistently zero. Considering that the cell piezometers could have performance problems, it was decided to check the pore pressures with stand pipe piezometers, installed in the tailings at corresponding positions. The results confirmed the zero values for the pore pressure. It was concluded that the conditions of drainage of the tailings embankments are adequate for both structures.



**Figure 3: Germano Buttress pore pressure readings (last two years)**



**Figure 4: Germano Pit pore pressures readings (last two years)**

## Conclusions

The experience from the two projects presented herein, shown that the drained disposal of the granular tailings can result in an embankment of non saturated sand, with very low or no pore pressure.

The low degree of saturation of the tailings mass means low or no risk of liquefaction.

This means that the risk of failure is low as is also the hazard potential.

This method of disposal can be applied safely for granular tailings with favorable permeability characteristics to achieve sand stacks to significant heights.

## **Acknowledgements**

The author wishes to acknowledge the project owner, Samarco Mineração S.A., for their permission to publish the information presented in this paper.

The consultant Dr. Andy Robertson, for his contributions to the design and for the preparation of this paper;

Also the designer of the projects: Pimenta de Ávila Consultoria, is fully acknowledged.

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