Formation of Fine Iron Ore Tailings Deposits

L.M.K. Lima, W.L. Oliveira Filho

Abstract. Deposit formation back analysis of a two-year iron ore slime impoundment managed by the sub-aerial method is performed using two complementary approaches. The first one tries to identify the deposit stratigraphy and its formation history. This is made possible through sorted document review (reports, design documents, personal communication, photos, etc.) and by means of an extensive geotechnical investigation program, including laboratory and field testing. The second approach, considered more quantitative, deals with modeling the sub-aerial deposition method, using a numerical solution for events such as large strain consolidation and desiccation of fine, soft tailings, following filling and waiting periods, according to that disposal technique. For modeling, the computer program CONDES is used with constitutive functions of available material, also using actual slime management data. The numerical model rendered a final deposit height of 8.16 m, very close to the actual height measured in the field, providing the model validation. The analyses suggest that the desiccation process inherent to the sub-aerial method had a minimal effect or did not even occur during the impoundment operation. Other potential disposal schemes were also evaluated and comparisons were made. The study has shown the ability to understand the formation of fine iron ore mining tailing deposits, and how to make use of this tool in projects.

Keywords: fine tailings deposit, back analysis, sub-aerial method, tailings disposal, field investigation, numerical modeling.

1. Introduction

Mining industry is booming these days and in consequence an increasing amount of mine tailings has been generated, requiring increasing containment areas for disposal, since tailings are usually discarded as fluid pulp. Tailings placement depends on its grading. Coarse material is usually disposed close to the containment structure where it can be used as construction material for raising of dikes and dams, and also to function as their foundation. On the other hand, fine tailings are disposed upstream the impoundment, forming a decantation lake and generating a soft, compressible, low density deposit with poor bearing capacity.

Although man-made, fine tailing deposits present a similar behavior to the natural stratus of soft soils, showing, for example, high compressibility and low hydraulic conductivity. This fact potentially allows that the general knowledge of soft soil engineering properties and performance, accumulated over the years by geotechnical engineers, could be used to understand how fine tailings deposits work.

According to Massad (2003), soft soils are sedimentary soils with low shear strength (SPT indices not higher than 4). The clay fraction makes these soils cohesive and very compressible. The behavior of these soils depends, among other things, on the water content, the stress state and mineral characteristics. Additionally, the clay fraction also plays an important role in the characteristics and properties of soft soils, such as compressibility, permeability and shear strength.

The engineering properties of fine tailings are important for settlement analyses and bearing capacity calculations of the deposits. In dredging materials and in soft mine tailings (slimes), large deformations are expected, requiring more sophisticated analyses, such as the ones that use large strain consolidation theories. On the other hand, slope stability analyses are usually performed in terms of total stresses or undrained conditions.

In this paper, different strategies to study the formation of fine iron ore tailings deposits aiming at storage planning and as a foundation substrate for surface rehabilitation (closure) and temporary structures are discussed.

2. Background

2.1. Physical processes and disposal methods

Tailings are commonly produced as fluid pulp, which is transported through channels or pipes and disposed in confined areas (Vick, 1983). During disposal, fine tailings may experience several physical processes: sedimentation, consolidation, desiccation, and desaturation. Sedimentation is relatively fast, and volume change depends on the initial solid content of the pulp. In the consolidation and desiccation phases, significant but deferred settlements of the deposited material may occur. The desiccation phase is divided in two distinct steps: one-dimensional desiccation and three-dimensional desiccation. In the three-dimensional phase, crack opening and propagation occur. Finally, if tailings still lose water, without volume change, the material starts to desaturate. Figure 1 shows the sequence of

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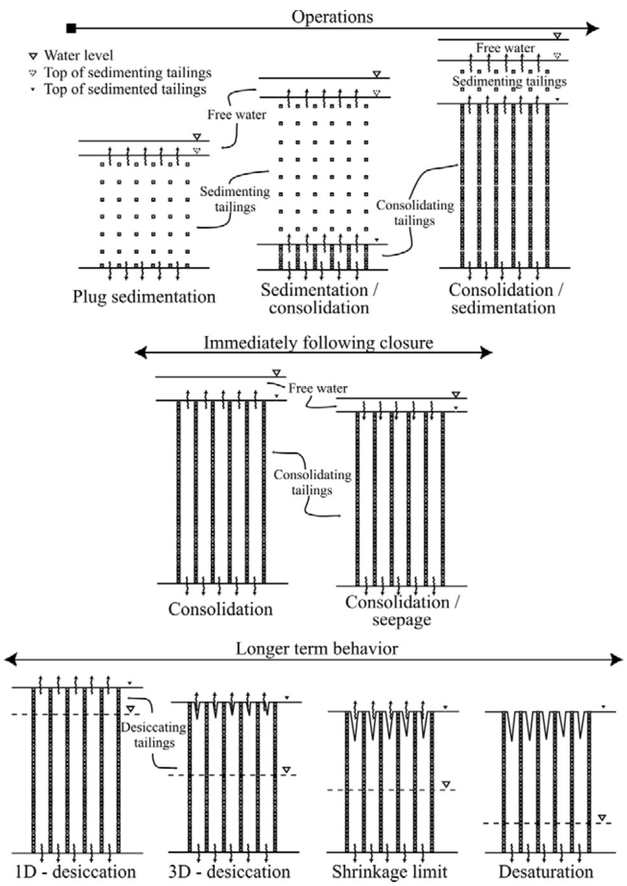

Figure 1 - Physical processes experienced by tailings during and after operational impoundment life-time. (Oliveira-Filho & van Zyl, 2006a).

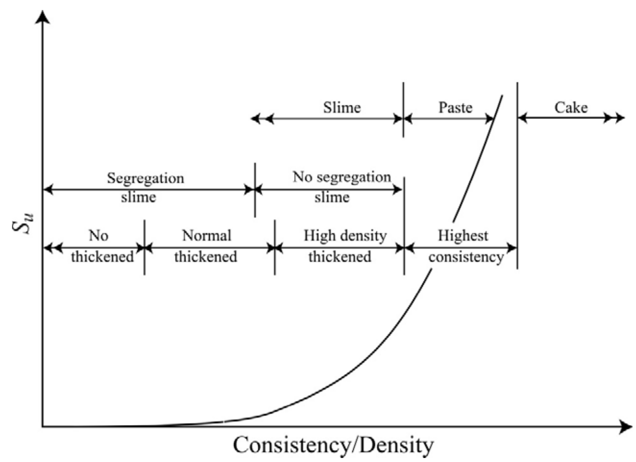

Figure 2 - Shear strength slime versus consistency (ICOLD, 2002).

these phenomena. Almeida (2004) and also Oliveira-Filho & van Zyl (2006a) present a detailed description of all these physical processes.

Alternatively, other tailings disposal schemes have been devised for fine tailings, leading to initial solid content higher than when disposed in the conventional way (Norman & Raforth, 1998; Ulrich *et al.*, 2000). The alternative methods, from lower to higher initial density at the time of disposal, are: sub-aerial disposal, thickened tailings (TTD), and paste. A common characteristic of these alternative methods is their intermittent character of disposal with alternating cycles of filling and waiting periods (no disposal). Figure 2 shows the initial gain in shear strength resulted from the different disposal techniques.

Development of alternative methods of tailings disposal has been mainly related to the search of tailings facilities with: reduced risk and liability, easier permitting in difficult regulatory environments, improved water recovery, faster area rehabilitation, and expanded storage of higher volumes in smaller areas. However, the alternative methods have a relatively higher cost when compared to the conventional methods. Table 1 compares the alternative methods according to important design features.

As it can be seen in Table 1, one or other option will be more cost-effective depending on which aspects are considered more relevant in a particular project.

2.2. Modeling

Fine tailings deposit materials are constituted of silts and/or clays. Depending on their grading, the deposit behavior is a function of these material engineering properties, such as compressibility, hydraulic conductivity and

Table 1 - Comparison of the alternative fine tailings disposal methods.

	Sub-aerial	TTD	Paste
Final density	Intermediate – High	Intermediate – High	High
Segregation	High – Intermediate	Low	None
Superficial water	High – Some	Some – None	None
Rehabilitation	After some time	Almost immediate	Immediate
Permeability	High – Low	Low	Very low
Application	On the surface	On the surface	On the surface and underground
Water consumption	High – Intermediate	Intermediate	Low
Cost	Intermediate – High	High	High

shear strength. Additionally, the disposal method could impair certain degree of heterogeneity to the tailings deposit which may also affect its behavior. Thus, modeling deposit formation is a task that requires caution, experience and clear hypotheses, and scope.

To model discharge of interstitial water in tailing impoundments, Oliveira-Filho & van Zyl (2006a, 2006b) use the computer code CONDES (Yao *et al.*, 2002; Almeida *et al.*, 2005), which models large strain consolidation and desiccation processes. These are two of the main physical processes experienced by tailings upon deposition, regardless the disposal scheme (conventional or alternative). For consolidation analyses, using CONDES, compressibility and permeability relations are expressed, respectively, by

$$e = A(\sigma' + Z)^B \tag{1}$$

$$k = Ce^D \tag{2}$$

where e is the void ratio, k is the saturated hydraulic conductivity, A, B, C, D and Z the model parameters.

Regarding desiccation analyses, additional material functions have to be provided to CONDES, including compressibility and permeability relations, similar to Eqs. 1 and 2, and other functions related to cracking initiation and propagation, and cracking geometry (Abu-Hejleh & Znidarcic, 1996).

CONDES is also used by Oliveira-Filho & Lima (2006) to model the construction of homogeneous, clayey deposits built using the sub-aerial method. In the proposed sub-aerial disposal scheme, cycles of filling and waiting are simulated, modeling physical processes such as consolidation and desiccation. In their analyses, Oliveira-Filho & Lima (2006) do not consider cracking formation, because this is a secondary factor if the focus is on volume change. In addition, one-dimensional desiccation is treated as an extension of the consolidation analyses, using the same compressibility and permeability relations. The main results of the sub-aerial simulation of a two-layer deposit are shown in Figs. 3 and 4. In Fig. 3, physical processes of volume reduction due to self-weight consolidation, as well as desiccation are presented. The former has two steps (filling and waiting stages) and the latter starts at a certain instant of the waiting period. In Fig. 4, the void ratio decrease at the top of the layer due to desiccation can be noted.

Using the same disposal scheme model, Oliveira-Filho & Lima (2006) expand the analyses, repeating the scheme eight times (eight complete cycles of filling and waiting stages or layers). Figure 5 shows the final void ratio profile for each complete cycle or layer.

As it can be seen in Fig. 5, desiccation on every intermediate layer is still noticeable (see void ratio reduction at the top of the layer), but decreasingly less effective. The consequence of this trend is that a lower overall volume reduction is achieved by the disposal scheme. To obtain a better performance in a tailings management, such as the sub-aerial, Oliveira-Filho & Lima (2006) suggest that the waiting cycle should be gradually increased.

2.3. Back analysis

Man-made fine tailings deposit characteristics and behavior depend on a series of factors, including disposal technique, filling history, material properties, climate, and foundation conditions. All these aspects yield changes in the slime initial consistency, according to the physical phenomena of consolidation and desiccation. The slime consistency modifications often lead to a gradual densification and strength development in the deposit. These changes can be monitored during deposit formation (operational life) (Konrad & Acad., 1997; Silva, 2003). Or, when the deposit

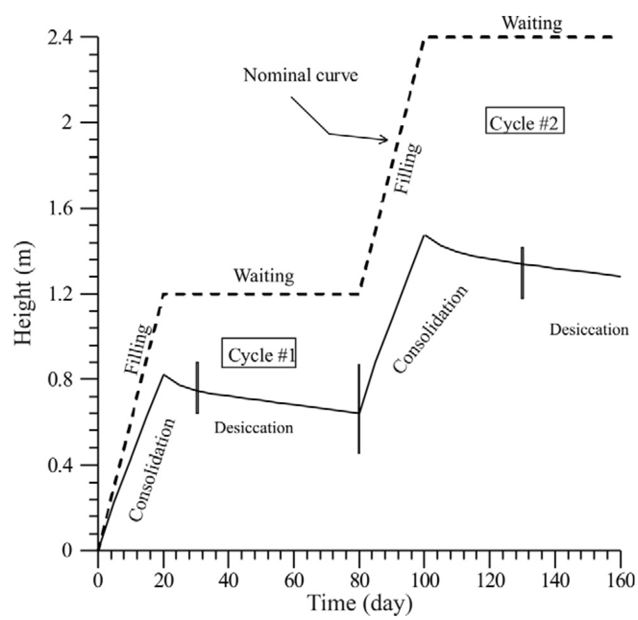

Figure 3 - Sequence of two sub-aerial modeling scheme cycles (nominal and simulation heights), where vertical bars delimit physical processes (Adapted from Oliveira-Filho & Lima, 2006).

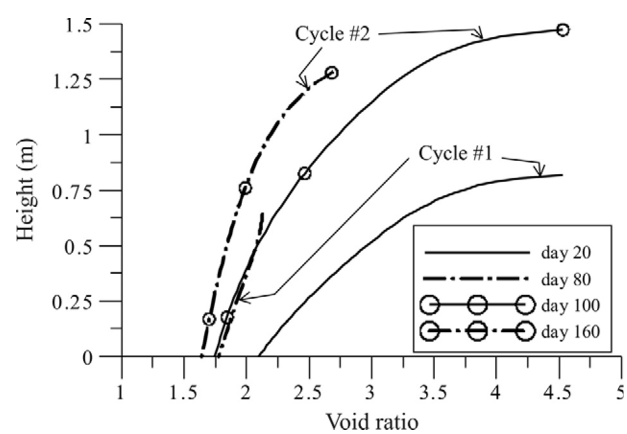

Figure 4 - Sub-aerial modeling results: void ratio profiles at the end of two subsequent filling or waiting cycles (Adapted from Oliveira-Filho & Lima, 2006).

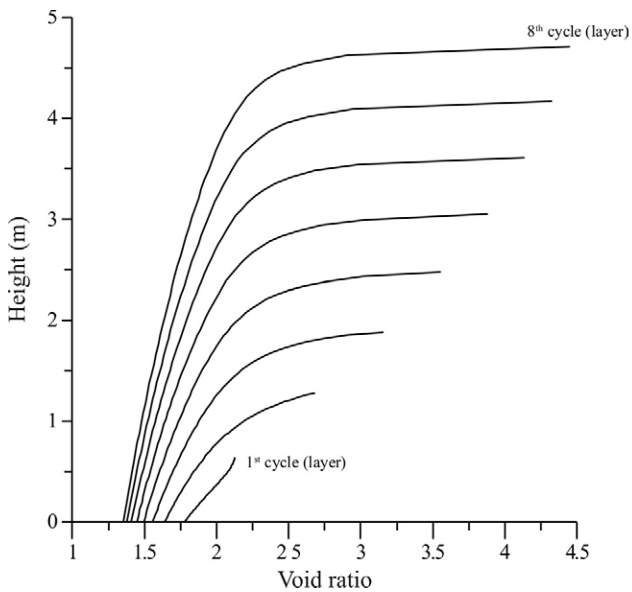

Figure 5 - Void ratio profile at the end of the waiting cycle for an eight-layer deposit (for clearness, filling cycles were omitted; adapted from Oliveira-Filho & Lima, 2006).

is already built, the changes can be assessed by means of a suitable model, combined with site investigations and laboratory tests, in an effort known as back analysis (Lima, 2006). In the first case, *i.e.*, during impoundment operations, monitoring of the slimes can be done by extensive instrumentation programs and sampling. In case of back analysis, experimental work that involves field and laboratory methods is required to determine the deposit stratigraphy and material geotechnical properties. This activity commonly involves geotechnical logging, sampling and also field and laboratory testing (Árabe, 1995; Schnaid, 2000; Oliveira, 2002; Massad, 2003; Spannenberg, 2003; Bedeschi, 2004; Albuquerque Filho, 2004; Mondelli, 2004; and Lima, 2006). Furthermore, in the case of back analysis, history and document researches regarding the deposit play an important role. These data provide information on discharge timeline, amount and kind of disposed material at the site. Certainly, validation of the back analyses should be sought by means of an objective function, which could include data such as actual deposit heights or/and void ratio profiles. With comprehensive information about the deposit, material properties and modeling, the deposit formation can be properly back analyzed. Moreover, the back analysis results could be used in a variety of projects, such as reclamation of closed disposal areas and construction of earthworks on these materials (Wels *et al.*, 1999).

3. Case Study

The previous section sets the basis of a case study presented as follows, where the back analysis of an iron ore slime deposit built by the sub-aerial method is examined. The case explores the engineering judgment to understand the result of a two-year impoundment operation, in order to safely design future temporary and permanent structures on that kind of support (deposit seen as a foundation). In addition, this study provides vital information for mass balance prognoses, supposing that the operation in that deposit would not change. The case study was addressed by developing a suitable model for deposit formation (as explained in item 2.2), combined with site investigations and laboratory tests, production history data, related document reviews, and information obtained from company's staff.

3.1. Deposit history

The slime deposit is located in the Germano dam impoundment that belongs to Samarco Mineração S.A., in the Quadrilátero Ferrífero (Iron Quadrangle), in Mariana, Minas Gerais. From the iron ore processing plant, two kinds of tailings were generated, a coarse (sandy) and a fine (slime).

The Germano tailings were disposed in a conventional way between 1976 and August/2003. Coarse tailings were disposed from the crest of the main dam, forming a beach. They also served as construction material (for raising dikes), after dewatering by gravitational drainage (upstream construction). On the other hand, the slimes were launched from the impoundment upstream, far from the dam crest, forming a sedimentation decant lake, without compromising the safety of the containment structure.

From September/2003, with the increasing of mineral production, and consequently of tailings, the company started a desiccation project for the slime tailings (Pimenta de Ávila Consultoria, 2001). This project aimed to create economic and environmental benefits, such as volume optimization and shortening of the reclamation period.

The desiccation project devised a system of five closed ponding areas (pads or bays). The slimes generated by milling processes were discarded in the padding system through a sole spigot and one structure at a time. This procedure guaranteed an intermittent filling of the slime material in the padding system, allowing drainage and surface drying intervals (waiting stage). Among the padding areas, padding area #4, (Bay 4) shown in Fig. 6, was selected for this case study as the most representative of the sub-aerial method (more regular filling and waiting cycles).

Formation of the deposit in padding area #4, using the sub-aerial method, took place between October/2003 and September/2005. However, the filling and waiting periods started to be recorded only in April/2004 as shown in Fig. 7 (Samarco, 2005).

According to field records (Fig. 7), it is apparent that there were no regular intervals of the filling and waiting phases. For example, in December/2004 and July/2005, no slimes were disposed in the pad area #4, whereas in June/2004, slimes were disposed during the whole month. Throughout the total period, field records indicated 210 days of filling and 333 days of resting.

Figure 6 - Padding area #4 in Germano Impoundment.

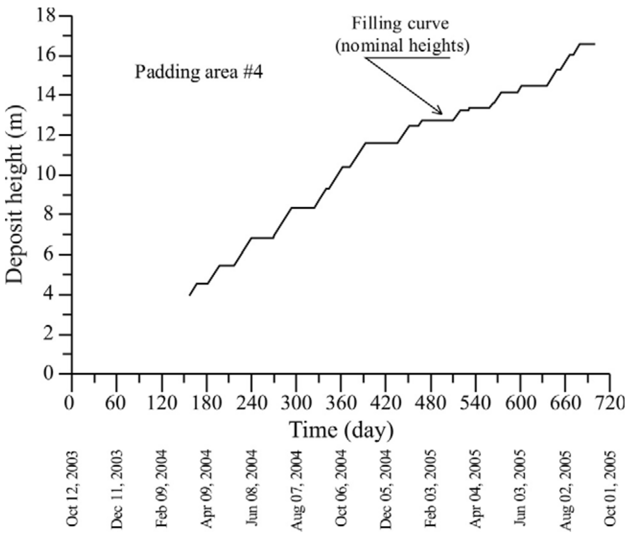

Figure 7 - Filling curve according to dredger records (April 2004 to September 2005).

3.2. Deposit stratigraphy

3.2.1. Investigation program

The investigation program for establishing the deposit stratigraphy consisted of field and laboratory activities. Field investigation took place in the vicinity of the padding area center (El. 905.00 m), and at the crest of the northeast containment wall (El. 907.50 m). Figure 6 shows the approximate investigation locations, represented by black dots.

Field exploration consisted of standard penetration tests (SPT), piezocone tests (CPTU) and undisturbed sampling, performed in phases, and in this order. Two SPT tests were performed for the preliminary evaluation of the deposit stratigraphy. In addition, two piezocone tests provided a better definition of the deposit stratigraphy and classification. Then, thirteen undisturbed samples collected from the deposit at different depths at the crest location allowed a texture calibration of piezocone results for that tailing management (Lima, 2006).

Laboratory tests were performed at the geotechnical laboratory of the Viçosa Federal University (Viçosa, 2006) with those thirteen undisturbed samples collected at the crest location (dike). This testing program was intended to obtain basic characterization of the material that underlies the dike. These characterization tests included construction material of the dike, dike material contaminated by the deposit material and, at depth, the deposit material itself.

3.2.2. SPT tests

SPT tests were performed by a local contractor, following the ABNT standards (Regulations: NBR 6484/2001 and NBR 7250/1982). Figure 8 shows the position of two SPT tests in a schematic cross section, one at the center of the impoundment and the other at the dike (crest).

The profile at the center of the impoundment presents low SPT indices (N_{SPT}) from surface down to 10 m depth (ranging from 0 to 4). These numbers indicate the existence of materials with low to medium shear strength. In general, clayey and silty soils with N_{SPT} lower than 5 are soft and compressible (Schnaid, 2000). Similar values are also typical of loose sands and sandy silts. These results can be extrapolated to the whole deposit layer assuming horizontal homogeneity of the deposited material. This hypothesis is possible since the material was disposed by hydraulic means, with relatively high solid content, and therefore with no possibility of segregation (Vick, 1983).

On the other hand, higher N_{SPT} values were observed in the first meters of the dike profile. These results can be explained by the presence of compacted sandy tailings used in the dike construction. The presence of this type of material at the site and the information that the end dump method was used for dike construction suggest that the dike stratigraphy consists of near surface material with high shear strength, probably the compacted sand tailings, then

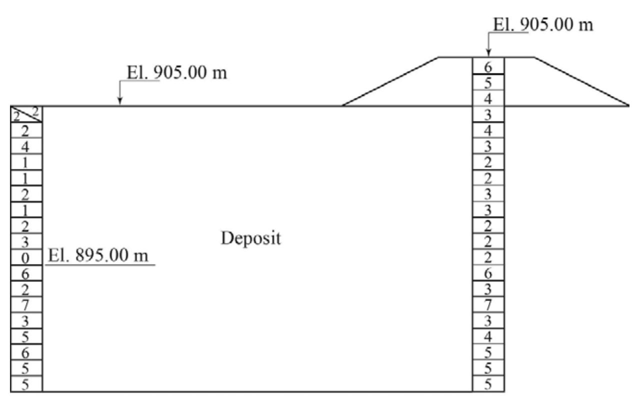

Figure 8 - Position of SPT tests in a schematic cross section, one at the central area and the other at the dike crest (numbers in boxes are N_{SPT}).

no-compacted sandy tailings that sunk displacing the deposit material and eventually mixing with it, and finally the deposit material.

In the two soundings, sampling was unsuccessful at several depths, mainly under the water table. Few samples collected through the SPT sampler allowed strata description as sandy or clayey silt material, deposited in thin layers (centimeter to decimeter thicknesses) as shown in Fig. 9.

Figure 9 - SPT sampler with material collected in the soundings: top – clayey silt, middle – clayey and sandy silt in sequence, bottom – sandy silt.

3.2.3. *Piezocone tests*

The piezocone tests were performed, one at the center of the impoundment area and the other at the dike location. Piezocone testing followed MB 3406 (Soil – in situ Piezocone penetration) and ASTM 3441 (Standard test method for deep, quasi-static, cone and friction-cone penetration test of soil). Pore water pressure measurements were performed using a porous element made of bronze, positioned at the cone base (u_2 position).

The cone test results corresponding to the dike location served as basis for texture calibration of the material deposited at the padding area #4. Lima (2006) interpreted these CPTU results using well-known classification charts (Robertson & Campanella, 1983; Senneset *et al.*, 1989; Robertson, 1991). Lima (2006) compared these results with the basic characterization of the samples collected using Shelby samplers at the dike location. Then, Lima (2006) concluded that the better agreement was obtained using the classification by Senneset *et al.* (1989). This classification relates pore pressure coefficient, B_q, (Eq. 3) with corrected tip stress, q_T. In equation 3, u_2 represents the pore water pressure measured at the cone shoulder, u_0 the hydrostatic pressure and σ_{vo} the *in situ* total vertical stress.

$$B_q = \frac{u_2 = u_0}{q_T - \sigma_{V_0}} \tag{3}$$

CPTU results at the center of the impoundment are shown in Fig. 10. The profile shows, in general, a soil with low values of corrected tip stress (q_T) and excess of dynamic pore water pressure (u_2). The presence of excess of dynamic pore water pressure is normally related to deposits with mainly fine texture and low hydraulic conductivity (Schnaid, 2000). The existence of these strata within the deposit can also be identified through pore water pressure coefficient (B_q) also shown in Fig. 10.

The interpreted stratigraphy of the deposit according to Senneset *et al.* (1989) is presented in Fig. 11. The inter-

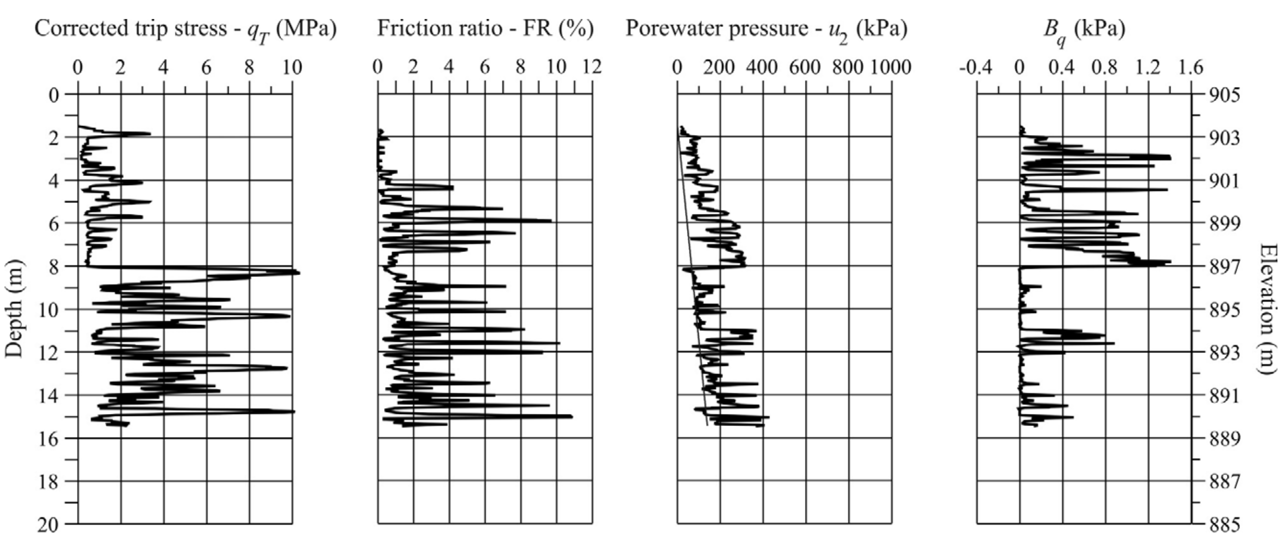

Figure 10 - Piezocone data.

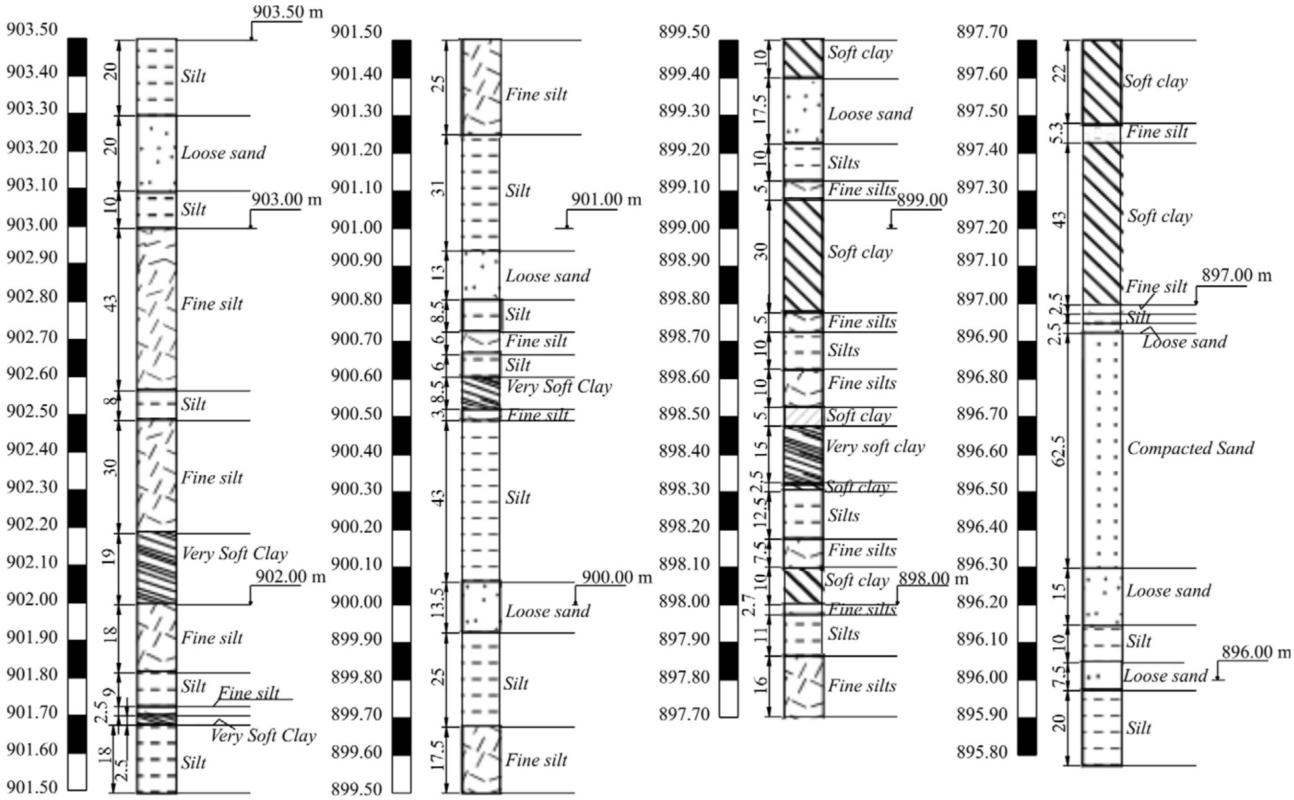

Figure 11 - Deposit stratigraphy interpreted from CPTU data according to Senneset *et al.* (1989).

preted deposit profile is heterogeneous, with uniform strata ranging from sand to soft clays, and layer thicknesses ranging from centimeters to decimeters. Below elevation 897 m there is a significant change in the stratigraphy, which may correspond to the top of the deposit soil foundation. According to the impoundment records, the deposit foundation also consisted of tailing material from previous tailing management in the Germano reservoir (see item 3.1). From this analysis it was concluded that the deposit depth at the center of the impoundment was approximately 8.0 m.

4. Discussion of the Deposit Formation

4.1. Qualitative model

As it appears in Fig. 11, material heterogeneity in the deposit is significant, showing that disposed materials were not only clayey silt slimes, as it was supposed in previous works (Pimenta de Avila Consultoria, 2001; Silva, 2003; Almeida, 2004). The texture sequence of the deposit materials reflects a typical pattern of hydraulic deposition and a particular mode of management. In that respect, the gradual change in the material texture ranging from sand to clay is apparent.

Regarding tailings management, data history indicate that the tailings deposit in padding area #4 originated from dredging operations on a decant pond also in the Germano impoundment. This decant pond served as residence for slimes (to increase solid content) before their relocation into the desiccation pads (item 3.1). Figure 12 shows a schematic diagram of the dredger operation, which typically started at slime level and continued in depth, finding different strata in a vertical profile. When moving the dredger, the operation was repeated, and a similar layering sequence was found. The dredged material was pumped

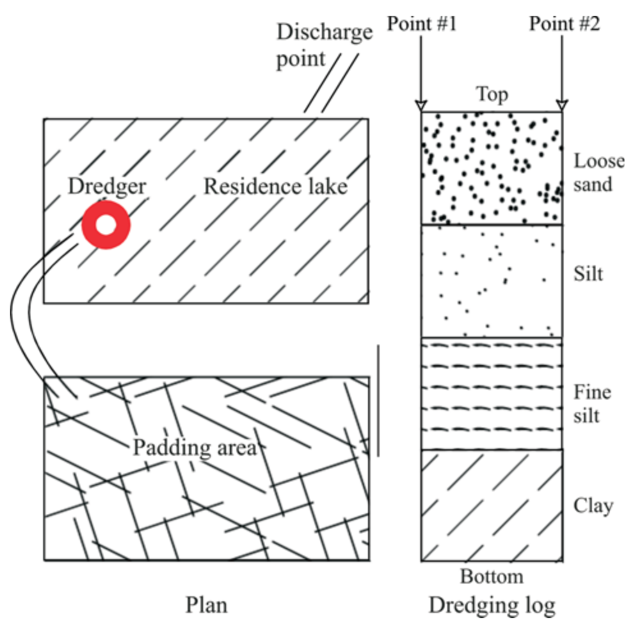

Figure 12 - Dredging operation scheme.

and disposed in the padding structures and the resultant profile had a reversed sequence of the one existing in the residence (decant) lake.

A good example of the above discussion is the profile shown in Fig. 11, between elevations 900.00 m and 899.00 m. In this profile the gradual change of material texture from sand to clay in two contiguous sequences is apparent.

4.2. Numerical model

4.2.1. Input and premises

Back analysis of the deposit formation was simulated using the CONDES software and the disposal scheme as explained in item 2.2 (modeling construction of homogeneous, clayey deposits built using the sub-aerial method) with all its premises and simplifications (*e.g.* no cracking formation). For numerical modeling purpose, it was decided not to use the actual filling curve (Fig. 7), but an averaged one with regular intervals of filling and waiting phases and the same final height of solids (H_s = 3.00 m) or total filling time (276 days). This modeling decision was made in order to simplify the model supposing that it should not affect the analysis. Thus, 23 time intervals of filling and waiting phases of 12 and 18 days, respectively, were adopted. The whole operation lasted 690 days. This last number was established according to the site records (Samarco, 2005) and personal inquiries with Samarco's staff (the extrapolation for the first days without records).

Concerning the deposit material, it was assumed to be homogenous at first approximation, despite this assumption was not supported by the deposit stratigraphy based on field investigations (Fig. 11). The reason for that is the inability of CONDES to model heterogeneous medium and also because similar constitutive relationships (especially compressibility) for all fine tailings which form that depositor an averaged response are expected. Thus, compressibility and permeability relationships for consolidation and desiccation analyses were the same as those obtained by Silva (2003) and Almeida (2004) and presented in Table 2. These authors performed experiments with slimes provided by Samarco, the former, a field test, and the latter, a series of hydraulic consolidation tests (HCT). Those experiments gave them confidence on the material properties. For this reason it is assumed that these material properties are adequate for the case study presented in this paper.

Table 2 - Input data for analyses.

Input Data		
Constitutive properties	A (kPa^{-1})	2.5438
	B	-0.1920
	C (m/day)	9.45 x 10^{-5}
	D	4.2370
	Z (kPa)	0.0495
Unit weight of water (kN/m^3)		9.81
Specific gravity of solids		3.89
Minimum void ratio		1.05
Evaporation rate (m/day)		0.002

4.2.2. Analysis results

Modeling results are shown in Figs. 13 and 14 in terms of deposit height versus time and void ratio profile at different times, respectively. Figure 14 shows that the simulated final height of the deposit (H_f) reached 8.16 m after 690 days, which is very close to the measured height in the field (8,0 m, item 3.2.3). This fact can be used to validate the analyses.

Also in Fig. 13, the results show that settlements due to consolidation and desiccation during a cycle were gradually larger. On the contrary, the settlement rates show smaller values as time progresses. This demonstrates that as new layers are superposed, they cause additional settlements (consolidation) in the lower ones due to self-weight. On the other hand, the inferior layers become stiffer (lower void ratio), decreasing settlement rate as cycles succeed.

Focusing on the desiccation process, which is supposed to happen during the waiting period, the analyses show in Fig. 14 that this phenomenon occurs increasingly late as more layers are added to the deposit. Furthermore, in this case, its occurrence could be questioned from the 2nd cycle on, as there is no void ratio reduction on top of the profile during the waiting period, except in the first cycle.

The modeling procedure mentioned before was adequate to make an estimate of the deposit height close to the actual stratified system, despite it has been assumed a homogeneous profile (clayey silt material). This can be explained by probably similar compressibility relationships of the different textures found in the deposit profile. Another aspect that might have contributed to the quality of the back analysis modeling is the fact that flow process of consolidation dominates the whole period of the deposit formation (no desiccation). This validates the hypothesis of averaging the filling curve. Still regarding consolidation, the time to complete the self-weight consolidation of each layer was enough during the filling and waiting stages. It does not matter if the material was sandy or clayey silt.

4.2.3. Other considerations about slime management and design

The foregoing results of slime management (sub-aerial model and actual data) could be compared with other potential management strategies. In case of a conventional disposal scheme, *i.e.* continuous disposal during 276 days, and considering consolidation as the only physical process, using the same filling rate (0,06 m/day) and height of solids, CONDES analyses would result in a final deposit height of 8.20 m after 690 days as shown in Fig. 15. It is practically the same height measured in the field or the one

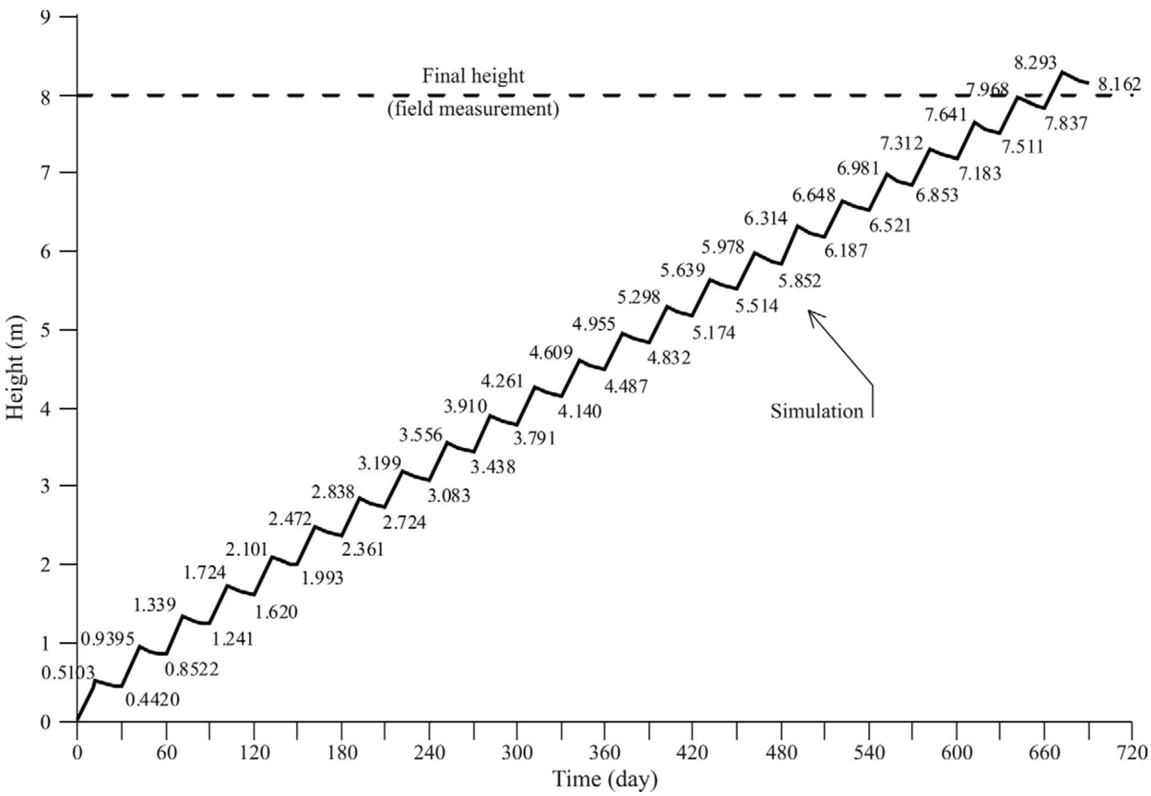

Figure 13 - Deposit height modeling (23 cycles).

obtained in the sub-aerial model analysis. The only drawback in the conventional disposal option would be the requirement of a higher containment structure during the filling operation, because the maximum deposit height would reach 10.22 m. One way to overcome this disadvantage would be to slow down the filling rate (*e.g.* a filling rate that would cover the whole period of 690 days (0.024 m/day). In this case, after 690 days, the deposit height would be 8.22 m, almost the same value obtained above. Figure 15 also shows deposit heights obtained following this second disposal scheme.

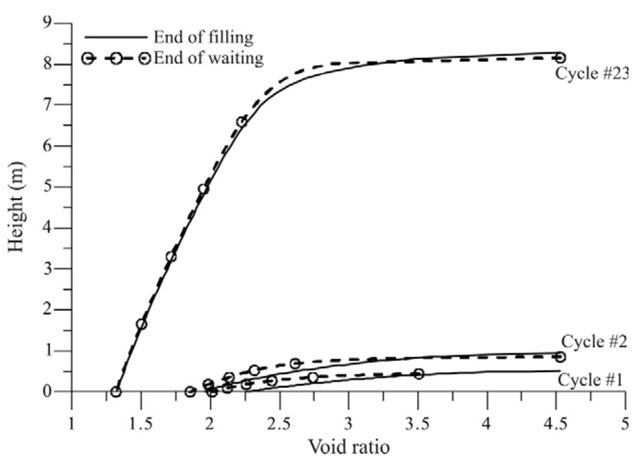

Figure 14 - Void ratio profile progress in the deposit (for clearness, cycles from 3rd through 22nd were omitted).

Another scheme would be to perform the sub-aerial disposal in such a way that thin layers were desiccated to their limit (shrinkage limit), before the placement of new fresh slimes. In this case, a simple model of one-dimensional shrinkage would result in a final deposit height of 6.15 m. For this evaluation, the following Eq. 4 is used,

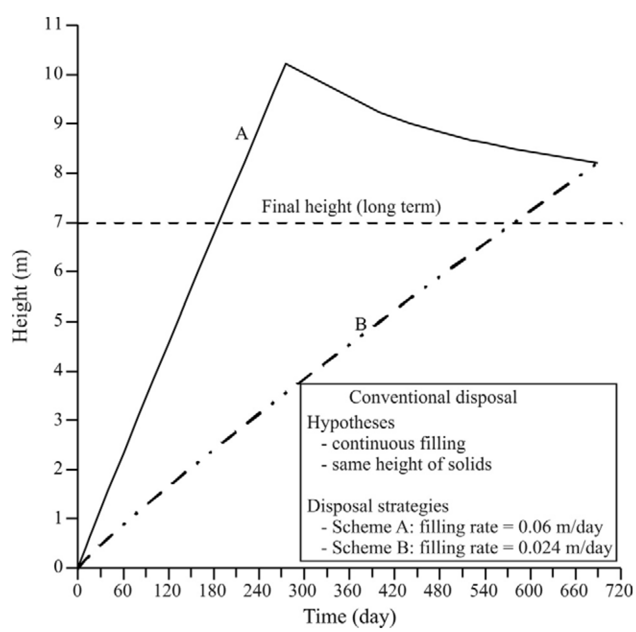

Figure 15 - Conventional disposal models.

where e_{min} corresponds to the void ratio at the shrinkage limit, H_s the height of solids and H_f the final height.

$$H_f = H_s (1 + e_{min}) \quad (4)$$

The final height obtained with this desiccation scheme would result in a deposit height even lower than the long term value of the conventional model (7.00 m) shown in Fig. 15. However, this scheme would probably require a period of time longer than the 690 days considered in this analysis (Oliveira-Filho & Lima, 2006).

4.2.4. Final discussion of the deposit modeling

Figure 16 shows a comparison of all results obtained by modeling and the actual deposit height. It is apparent that in the desiccation case, the slime management efficiency would be the maximum, although at a high cost of a longer waiting time (not shown). It is also interesting to note in this study, that the sub-aerial management scheme (actual or modeled with average cycles of filling and waiting) did not result in more efficiency as far as the storage capacity than the conventional disposal method (scheme A or B in Fig. 15).

5. Summary and Conclusions

The ability to understand formation of fine mining tailing deposits is demonstrated with a case study from experimental investigation and numerical analyses. A two-year iron ore slime impoundment built by the sub-aerial method is back analyzed. The analyses were based on a suitable model combined with site investigations and laboratory testing to determine deposit stratigraphy and material geotechnical properties. Field investigation data show that the slime deposit was not homogenous, but composed of stratified layers of tailings, ranging from loose sands to silty clays. Considering a deposit formed only by silt clay slimes, a numerical model was developed with the CONDES computer program (large strain consolidation and desiccation analysis software) using available material functions and slime management data. The analyses resulted in a deposit final height of 8.16 m, which is close to the actual height measured in the field. The result was used to validate the model. The analyses suggested that the desiccation process inherent to the sub-aerial method had a minimal effect or did not even occur. This fact indicates that sub-aerial strategy was not successful in this project and that the same results might have been achieved using a conventional disposal management. Other potential disposal schemes were also evaluated and comparisons made. It is suggested that this case study serve as a model for back analyses of other fine tailing deposits, in which consolidation and desiccation are the major processes involved. Finally, the role of proper site investigation to fulfill the study goal is recognized, especially with a series of piezocone tests to establish the deposit stratigraphy.

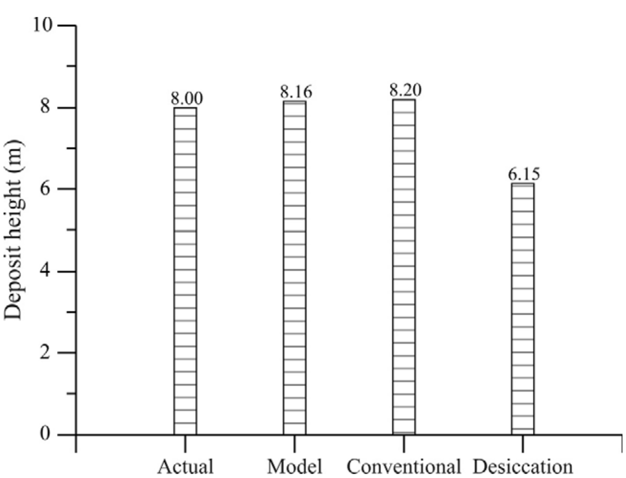

Figure 16 - Comparison of final deposit height according to different disposal strategies.

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