Paste 2026 – AB Fourie, M Horta, M Oliveira & S Wilson (eds)

doi:10.36487/ACG_repo/2655_63

Monitoring of the surface disposal of an iron ore tailings slurry

André de Oliveira Faria [a,*], Guilherme Henrique da Silva Pinto [a], Mauro Pio dos Santos Júnior [a], Tadeu Marçal Miranda [b], Vanessa Luiza Thums [b]

[a] *Pimenta de Ávila, Brazil*

[b] *Vale, Brazil*

Abstract

The operation phase is one of the most important stages of a dam's life cycle, during which the continuous monitoring of the tailings characteristics is of the utmost importance. The control of the solids content and the water balance can allow for expansion of the tailings facility over the life of mine, as well as the maintenance of a beach width that provides the reduction of the pore pressure in the embankment, resulting in the possibility to increase the Factor of Safety. Also, the monitoring of the tailings particle size distribution helps to evaluate impacts on tailings facility operation due to changes in the orebody and the beneficiation process.

This paper presents a case study of the monitoring of an iron ore tailings surface disposal and its characteristics over time. Characterisation of the iron ore tailings slurry is presented in terms of particle size distribution curves, Atterberg limits, specific gravity of soil solids, and mineralogy. The surface disposal control is monitored in terms of reservoir filling comparing the surfaces obtained by topobathymetric surveys over time, using a colour map to help visualisation. The consolidated solids contents are evaluated measuring the mass of solids discharged in the reservoir and the consumed volume. A comparison with the initial solids content (disposal) is also presented.

The results indicated that the tailings evaluated herein present a high fines content with low plasticity and a significant presence of iron. The surface disposal control showed the accumulation of tailings near the embankment, resulting in a beach formation, since the material was initially disposed at the dam crest. The disposed solids content increased over time with changes promoted in the ore processing.

Keywords: *tailings disposal control, geotechnical characterisation, solids contents evaluation*

1 Introduction

Requirement 2.2 of the *Global Industry Standard on Tailings Management* (International Council on Mining and Metals et al. 2020) indicates that the physical and chemical properties of the tailings shall be characterised and updated regularly to account for variability in ore properties and processing. Requirement 3.2 indicates that the operator shall periodically review and refine the tailings technologies design and management strategies to minimise risk and improve environmental outcomes. Based on this, the first step to achieve these requirements is to develop a robust monitoring plan of the tailings surface deposition, since the physical characteristics and behaviour of the tailings can be influenced by the method of deposition at the tailings storage facility (TSF).

One of the major challenges in the management of TSFs is the monitoring of the volume occupied by tailings, allowing enough volume for the containment of water within the reservoir, and the maintenance of a prescribed beach width. In this context, the integration of topographic and bathymetric surveys (named in

[*] Corresponding author. Email address: andre.oliveira@pimentadeavila.com.br

the present study as topobathymetric surveys) can be used to inform tailings management strategies for safer operation (SME 2022a).

This study aims to advance the understanding of the monitoring of the surface disposal of an iron ore TSF. The source of the material and its characterisation are presented, followed by the presentation of the parameters: slurry-deposited solids content, consolidated solids content, and comparison of surfaces obtained by topobathymetric surveys. It is worth mentioning that some authors have studied different forms to perform the bathymetry using satellite information (Navarro et al. 2019; Stringari et al. 2024), but the objective of the present paper is to evaluate the results provided by conventional measurements obtained using a boat (boat-based bathymetric surveys).

2 Material characterisation

The tailings evaluated in this study is the fine product of the iron ore filtered process at a mine in the state of Minas Gerais, Brazil, which is hydraulically disposed in a slurry condition into the dam. The geotechnical characterisation of the tailings was composed of particle size distribution curve, specific gravity of soil solids (ρ_s), liquid limit (LL), and plastic limit (PL). Also, the chemical characterisation was evaluated.

The particle size distribution curves (ASTM International 2014) obtained from 76 disturbed samples collected in the reservoir are presented in Figure 1. The average tailings composition is 4.8% sand, 75% silt-sized particles, and 20.2% clay. Also, the classification based on the International Commission on Large Dams' Bulletin 181 (ICOLD 2021) indicated the majority composition of hard rock tailings (HRT) and altered rock tailings, with some regions with fine tailings (FT), as shown in Figure 2.

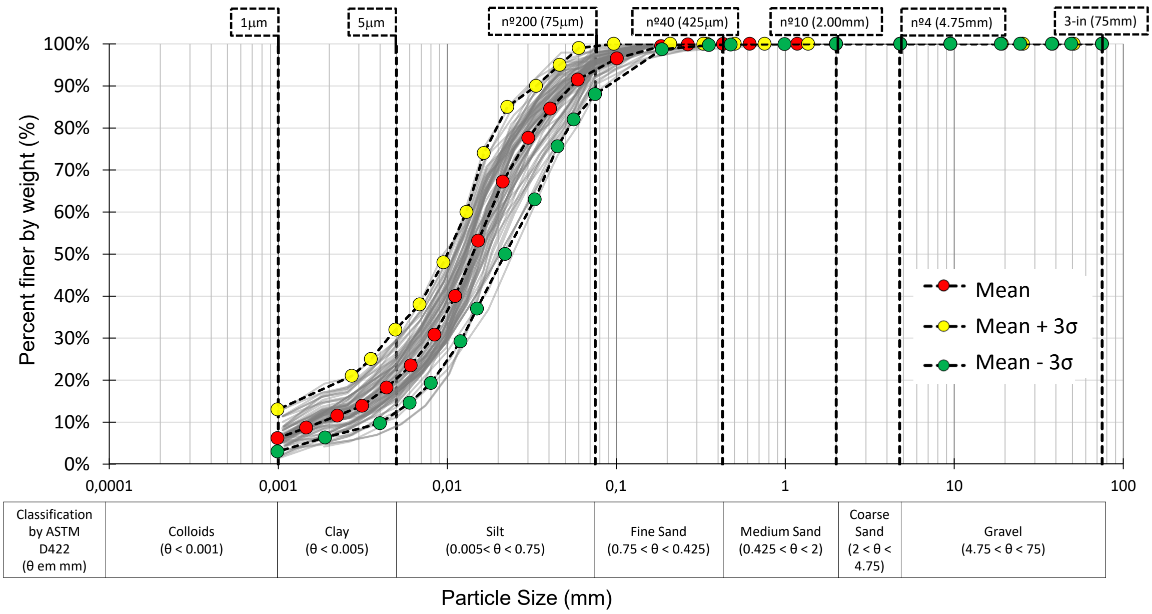


Figure 1 Particle size distribution curves (ASTM International 2014)

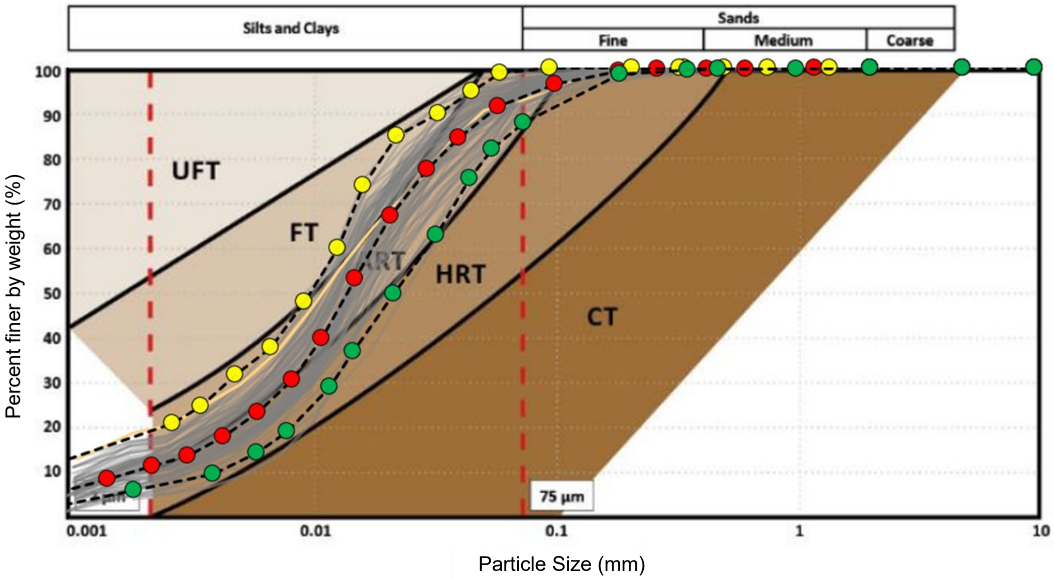
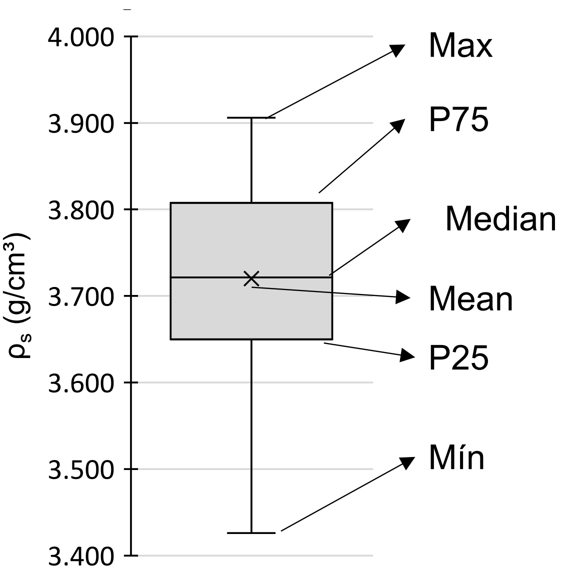


Figure 2 Tailings particle size classification according to ICOLD Bulletin 181 (ICOLD 2021)

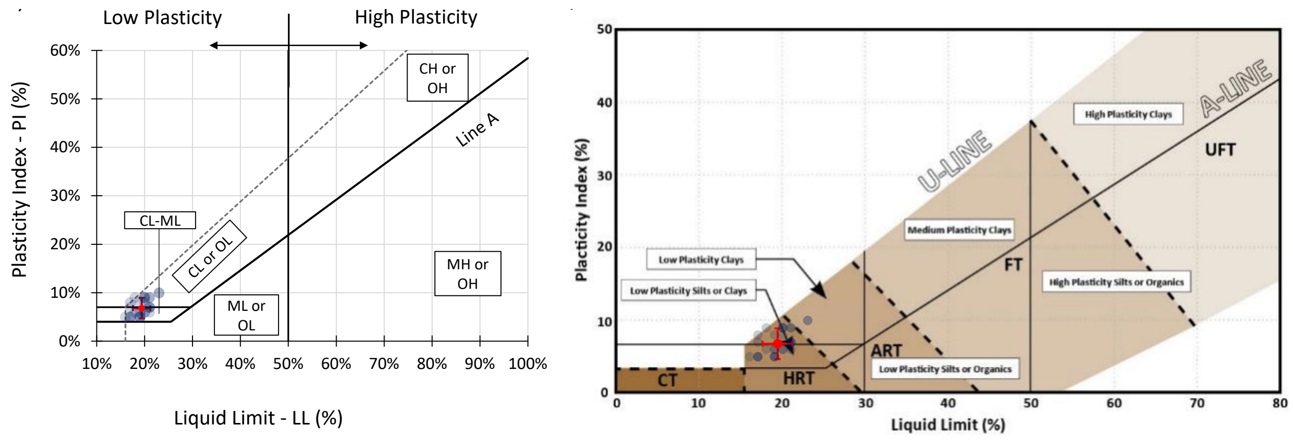
In terms of ρ_s, Figure 3 indicates the average of 3.691 g/cm^3 and the associated statistical parameters obtained from the data available. Additionally, the Atterberg limits were evaluated according to ABNT NBR 6459 (Associação Brasileira de Normas Técnicas 2016a) and ABNT NBR 7180 (Associação Brasileira de Normas Técnicas 2016b). The average LL was 20%, the PL was 12% and the plasticity index was 8%, indicating low plasticity (Figure 4).



Parameter	ρ_s (g/cm³)
Max	3.906
P75	3.801
Median	3.708
Mean	3.691
P25	3.628
Min	3.426
Std dev.	0.132
C.V.	3.59%
n	75

Figure 3 Characterisation in terms of specific gravity of soil solids (ρ_s)

The Atterberg limits were also evaluated according to ICOLD Bulletin 181 (ICOLD 2021), indicating the classification of HRT since many points were plotted in the region of low plasticity silts or clays (Figure 4). Also, the classification based on the United Soil Classification System (ASTM International 2025) indicated the majority of CL-ML (sand silty clay), with some points plotted in the region of CL (sand lean clay).

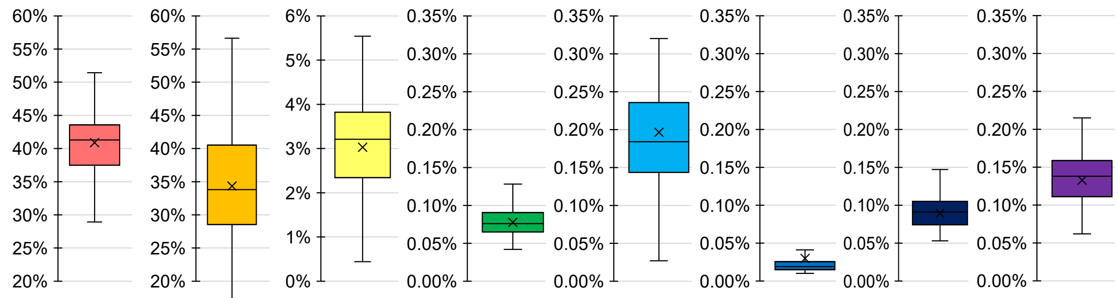


(a) (b)

Figure 4 Atterberg limits: (a) Plasticity chart according to ASTM D2487 (ASTM International 2025); (b) Classification based on ICOLD Bulletin 181 (ICOLD 2021)

Chemical characteristics of the tailings are largely influenced by the characteristics of the ore and the processing effort to remove the desired mineral. Gomes (2011) evaluated the chemical characterisation of iron ore tailings presented in the BI Dam and found the average composition of 48.08% Fe, 20.58% SiO_2, 3.16% Al_2O_3 and low concentrations for the other minerals present.

In terms of the chemical characterisation, the tailings evaluated in the present paper indicated the majority composition of Fe, SiO_2 (quartz) and Al_2O_3 (Figure 5), as expected according to studies available in the literature.



Parameters	Fe	SiO_2	Al_2O_3	P	Mn	CaO	MgO	TiO_2
Legend								
Max	66.38%	68.98%	5.54%	0.13%	0.81%	0.82%	0.15%	0.22%
P75	43.59%	40.51%	3.82%	0.09%	0.24%	0.03%	0.11%	0.16%
Mean	40.90%	34.34%	3.03%	0.08%	0.20%	0.03%	0.09%	0.13%
Median	41.28%	33.80%	3.21%	0.08%	0.18%	0.02%	0.09%	0.14%
P25	37.48%	28.55%	2.34%	0.07%	0.14%	0.02%	0.07%	0.11%
Min	20.61%	1.42%	0.44%	0.01%	0.03%	0.01%	0.01%	0.03%
Std dev.	7.13%	11.48%	1.15%	0.02%	0.11%	0.09%	0.03%	0.04%
C.V.	17.44%	33.43%	38.12%	28.56%	56.68%	258.73%	29.01%	27.63%
n	89	89	61	89	89	89	89	89

Figure 5 Chemical characterisation

3 Methodology

The monitoring of the surface disposal of the iron ore tailings was evaluated according to the slurry-deposited solids content, consolidated solids content, and comparison of surfaces obtained by topobathymetric surveys.

The deposited solids content was measured by the nuclear densimeter before being disposed in the reservoir, while the consolidated solids content was calculated using the relation between the mass of solids disposed and the occupied volume between topobathymetric surveys. Figure 6 shows the steps used to define the consolidated solids content (CSC).

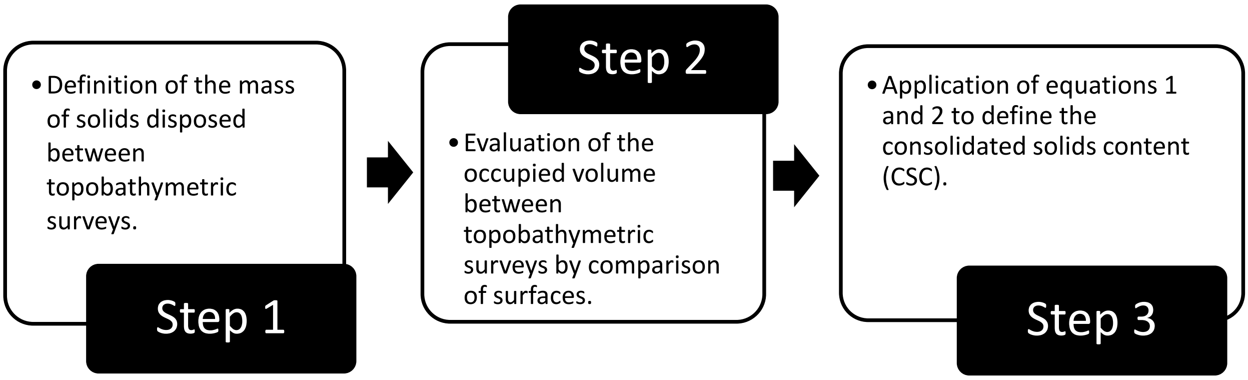


Figure 6 Methodology used to define the CSC

$$\text{Mass of Solids} = \rho * \text{Volume} * \text{CSC} \quad (1)$$

$$\rho = \frac{G_s}{\text{CSC}+\text{Gs} - \text{CSC}*\text{Gs}} \quad (2)$$

Where the mass of solids indicated in step 1 is provided by the ore plant, based on the tailings measured daily before the disposal. CSC is the consolidated solids content, and ρ is the consolidated tailings density.

The comparison of surfaces obtained by topobathymetric surveys can be used to calculate the CSC and to evaluate the reservoir occupation using a colour map. To illustrate the comparison of surfaces, Figure 7 shows a schematic example of the relation between 2 surfaces evaluated and the tailings condition (occupied and/or consolidated).

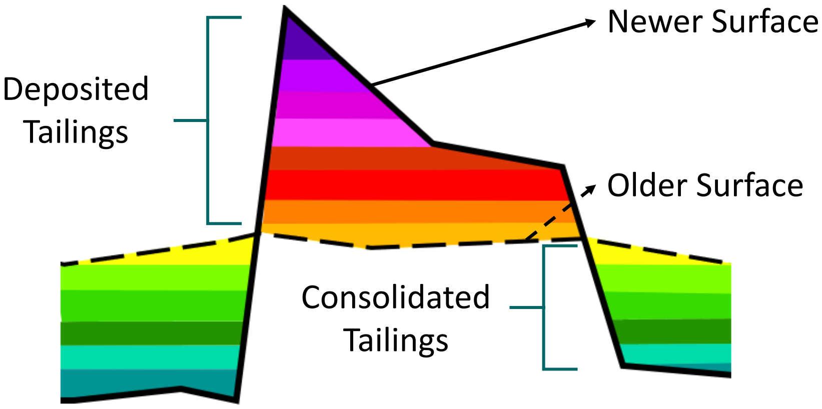
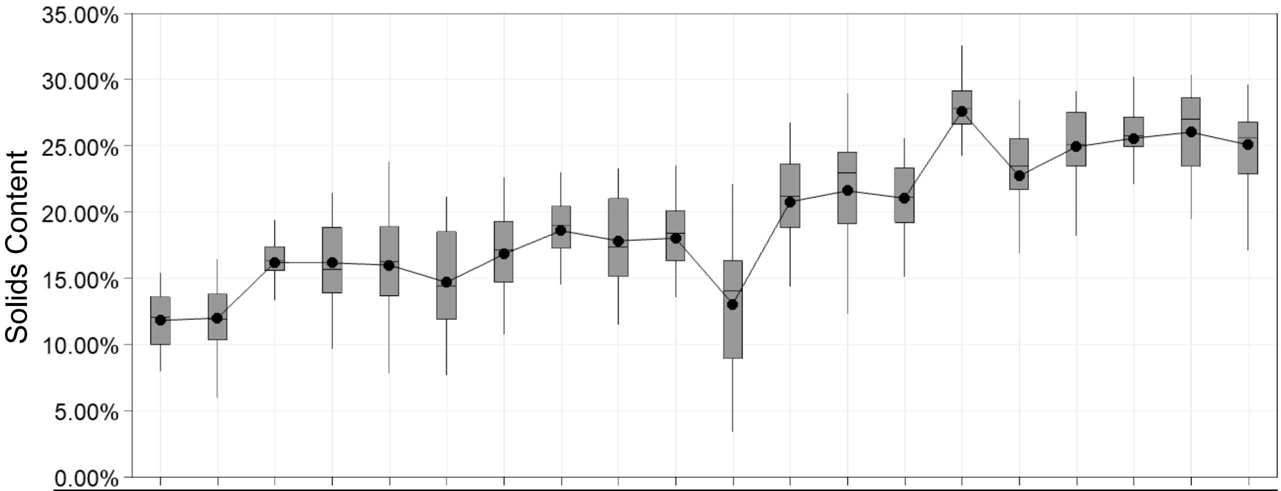


Figure 7 Schematic to illustrate the comparison between a newer surface and an older surface

4 Performance evaluation results

4.1 Solids content

The solids content of the disposed tailings was measured monthly from January 2024 to August 2025, and the values are indicated in Figure 8. As can be seen, the values vary from 11.9% to 27.6%, increasing from December 2024 onwards. This increase is associated with the calibration of the tailings production plant to reduce water inside the dam reservoir, increasing the disposed tailings solids content. Also, 3 months indicated values below 14%, which can be explained by some tests performed by the plant.



Parameter	jan/24	feb/24	mar/24	apr/24	may/24	jun/24	jul/24	aug/24	sep/24	oct/24	nov/24	dec/24	jan/25	feb/25	mar/25	apr/25	may/25	jun/25	jul/25	aug/25
Max	15.5%	16.4%	19.5%	21.5%	23.8%	21.2%	22.6%	23.0%	23.3%	23.5%	22.1%	26.8%	29.0%	25.6%	32.6%	28.5%	29.2%	30.2%	30.3%	29.6%
P75	13.6%	13.8%	17.4%	18.9%	18.9%	18.5%	19.3%	20.4%	21.0%	20.1%	16.4%	23.6%	24.5%	23.4%	29.2%	25.5%	27.6%	27.2%	28.6%	26.8%
Mean	12.2%	12.2%	16.4%	15.8%	16.3%	14.5%	17.3%	19.1%	17.8%	18.5%	14.5%	21.5%	23.0%	21.4%	28.0%	23.6%	25.3%	25.8%	27.1%	25.7%
Median	11.9%	12.0%	16.2%	16.2%	16.0%	14.7%	16.8%	18.6%	17.8%	18.1%	13.1%	20.8%	21.6%	21.1%	27.6%	22.7%	24.9%	25.6%	25.9%	25.1%
P25	10.0%	10.4%	15.6%	13.9%	13.7%	11.9%	14.7%	17.3%	15.1%	16.3%	9.0%	18.8%	19.1%	19.2%	26.6%	21.7%	23.5%	25.0%	23.2%	22.9%
Min	8.0%	6.0%	10.2%	9.7%	5.7%	7.7%	10.8%	9.3%	11.5%	9.9%	3.4%	10.5%	12.4%	12.6%	19.0%	5.9%	15.6%	12.4%	19.5%	17.1%
Std dev.	2.2%	2.5%	1.9%	3.2%	4.2%	3.8%	3.2%	2.7%	3.2%	3.0%	5.3%	3.7%	4.2%	3.3%	3.0%	4.3%	3.3%	3.2%	3.2%	2.9%
C.V.	18.2%	20.7%	11.7%	19.8%	26.0%	25.6%	19.2%	14.8%	17.8%	16.9%	40.4%	18.0%	19.5%	15.8%	10.8%	19.1%	13.2%	12.6%	12.2%	11.5%
n	31	29	31	30	31	30	31	31	29	29	10	31	29	23	31	30	30	30	25	31

Figure 8 Solids content of the disposed tailings

The CSC was calculated monthly according to the methodology indicated in Section 3, and the results are presented in Table 1. As can be seen, the values vary from 55.63–85.00%, with an average of 74.94%. The consolidated tailings density varied from 1.68–2.63 t/m^3, with an average of 2.23 t/m^3.

The first 2 rows (IDs 1 and 2) indicated the lowest values since, during this time, the solids content of the disposed tailings was the lowest recorded (Figure 8). Also, the highest values obtained in IDs 6 and 7 are associated with inconsistencies in the topobathymetric surveys. As can be noted in Table 1, it was not possible to perform the calculations in some months, due to a lack of surveys.

Table 1 Consolidated solids content calculated with monthly topobathymetric surveys

ID	Base survey	Comparison survey	Solids content	ρ (t/m^3)
1	January 2024	February 2024	66.21%	1.93
2	February 2024	March 2024	55.63%	1.68
3	March 2024	April 2024	80.06%	2.40
4	April 2024	May 2024	70.97%	2.07
5	May 2024	June 2024	78,20%	2.33
6	August 2024	September 2024	83.21%	2.54
7	September 2024	October 2024	85.00%	2.63
8	May 2025	June 2025	78.70%	2.35
9	June 2025	July 2025	75.70%	2.23
10	July 2025	August 2025	75.70%	2.23
–	**–**	**Mean value**	**74.94%**	**2.23**

As indicated in Table 1, the monthly evaluation of the solids content can be influenced by some inconsistencies in the topobathymetric surveys. To avoid this, the cumulative evaluation (using a more extended period), was performed to increase the accuracy of the assessment. Table 2 illustrates the CSC calculated using a timeframe of at least 6 months between the base and comparison surveys.

Table 2 Consolidated solids content calculated with topobathymetric surveys – cumulative assessment

ID	Base survey	Comparison survey	Solids content	ρ (t/m³)
5.1	January 2024	June 2024	76.60%	2.27
6.1	January 2024	September 2024	73.09%	2.14
7.1	January 2024	October 2024	73.70%	2.16
8.1	January 2024	June 2025	77.91%	2.32
9.1	January 2024	July 2025	77.32%	2.29
10.1	January 2024	August 2025	77.27%	2.29
–	**–**	**Mean value**	**75.98%**	**2.24**

As indicated in Table 2, the cumulative approach provided a smaller range of values, as expected, with solids content ranging from 73.09–77.91% and tailings density from 2.14–2.32 t/m^3. The mean value of 75.98% obtained is in accordance with the typical final per cent solids content of 76% indicated by SME (2022b) for HRT, considering the unthickened condition of disposal.

In addition, a sample was collected in the reservoir (Figure 9) to evaluate the in situ condition, indicating the value of 77.60% and a tailings density of 2.31 t/m^3. In this context, the in situ results showed that the cumulative approach was a consistent method to evaluate the tailings conditions, since the values obtained were close to the field.

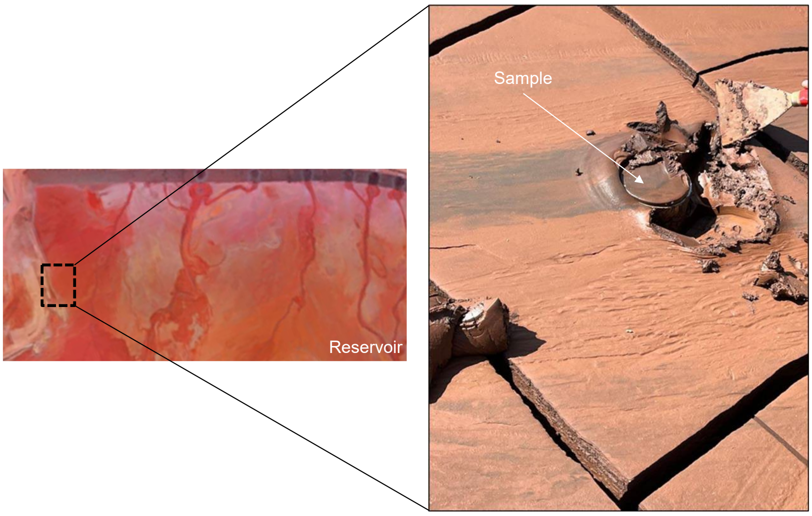


Figure 9 Sample collected in the reservoir

Figure 10 presents the fitting curve to evaluate, at the same time, the solids content and the water content considering the conditions of the deposited tailings, consolidated tailings using the cumulative topobathymetric surveys (Table 2), and the field condition assessed with sampling. For this, the curve to determine the water content and solids content as a function of the tailings density were plotted with the assumptions of degree of saturation of 100% (S = 100%) and ρ_s = 3.691 g/cm^3 (mean value in Figure 3).

As indicated in Figure 10, the square symbols in the curves represent the disposal condition (lowest values of solids content and highest values of water content), and the circles represent the consolidated conditions (with the black circle representing the field sample collected). Therefore, the difference between the disposed and consolidated condition indicates the reduction of water content over time, which shows the tailings consolidation. It can also be shown that the field sample indicated a good fit with the upper values of consolidated condition calculated with topobathymetric surveys indicated in Table 2.

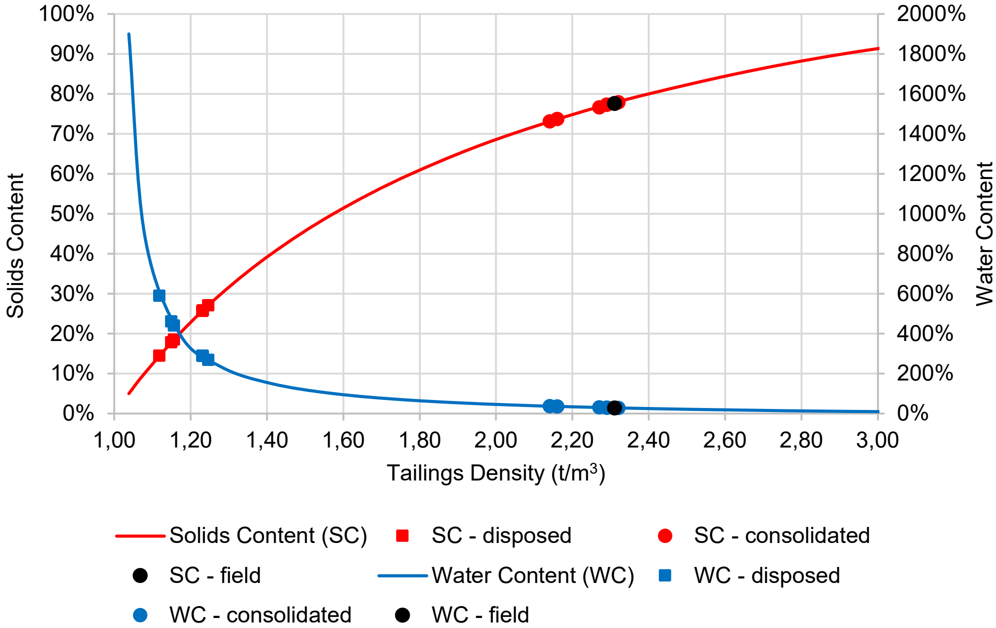


Figure 10 Water content, solids content and tailings density – deposited and consolidated condition

Figure 11 illustrates the tailings conditions in the field according to the solids content during the disposal and after the consolidation, with the solids content increasing over time. As can be seen, the deposited tailings look like a slurry condition, while the condition over time tends to increase in terms of solids content with the occurrence of surface shrinkage cracks.

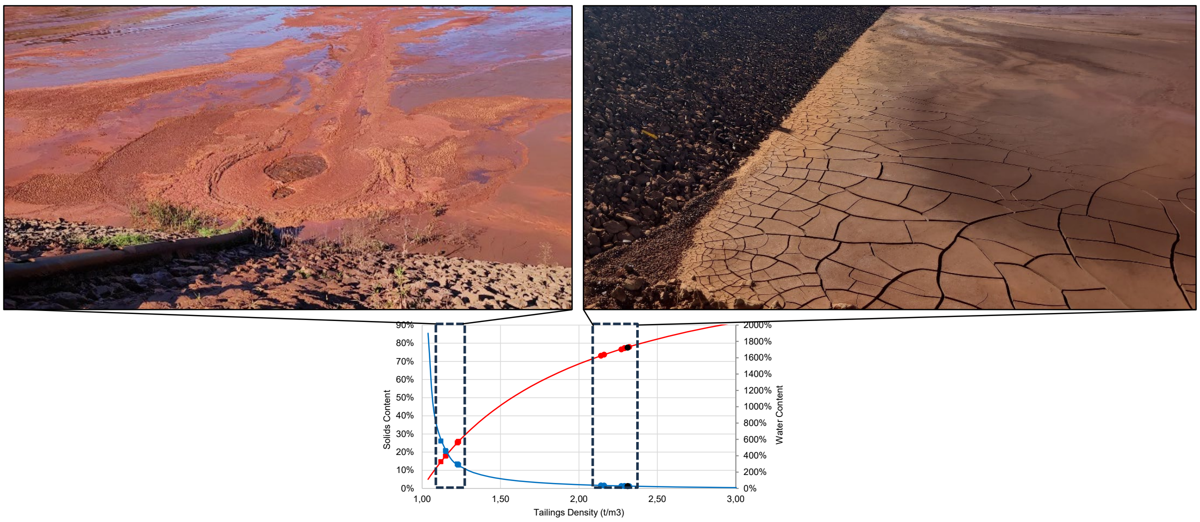


Figure 11 Tailings condition according to the solids and water content

4.2 Surfaces comparison

In addition to calculating the CSC, the comparison of surfaces obtained by topobathymetric surveys can also be used to evaluate the reservoir's occupation. To support this assessment, a colour map was elaborated using the concept indicated in Figure 7 (Chapter 3), which helps to identify the occupied and consolidated tailings, as indicated in Figure 12.

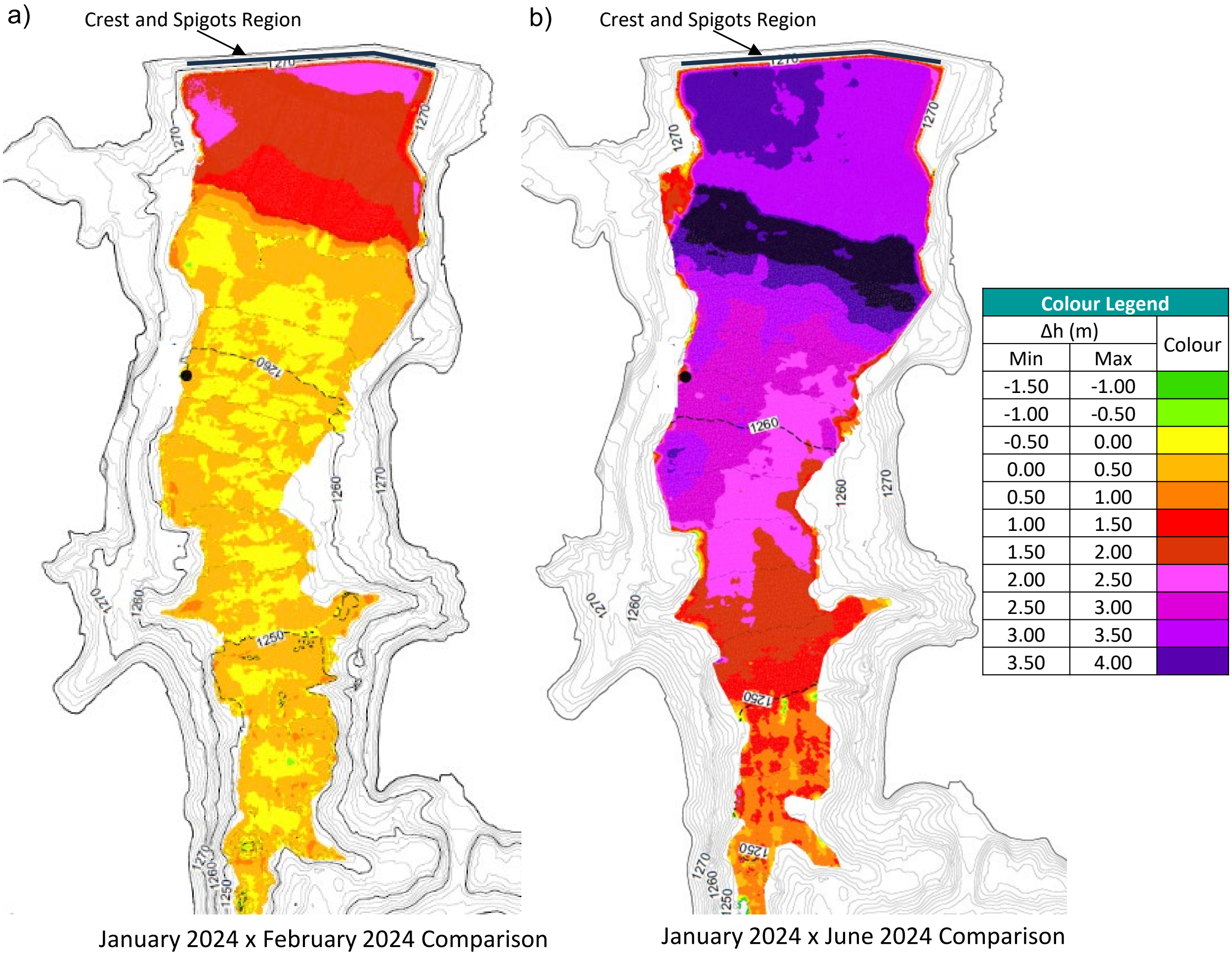


Figure 12 Survey comparison: (a) January 2024 and February 2024; (b) January 2024 and June 2024

As can be seen, Figure 12a illustrates the comparison between the condition in January 2024 (base survey) and February 2024 (comparison survey). Considering that during this time the tailings was disposed from the crest of the dam, most of the occupation occurred near the crest (pink and brown colours). In complement, Figure 12b illustrates the cumulative condition with the comparison between January 2024 (base survey) and June 2024 (comparison survey), indicating that most of the occupation occurred just upstream of the main occupied region in Figure 12a. This is associated with the fact that a comparison with such a small timeframe does not allow for the consolidation to occur near the embankment, and a larger timeframe gives more time to the tailings to spread out and occupy the reservoir.

With the advancement of the dam's operation and the objective of better occupying the reservoir, the location of the spigots has changed to a point in the crest near the right abutment and a point in the upstream region of the reservoir (the main point of the operation). Figure 13 indicates the location of the spigot points, as well as a comparison of 2 topobathymetric surveys.

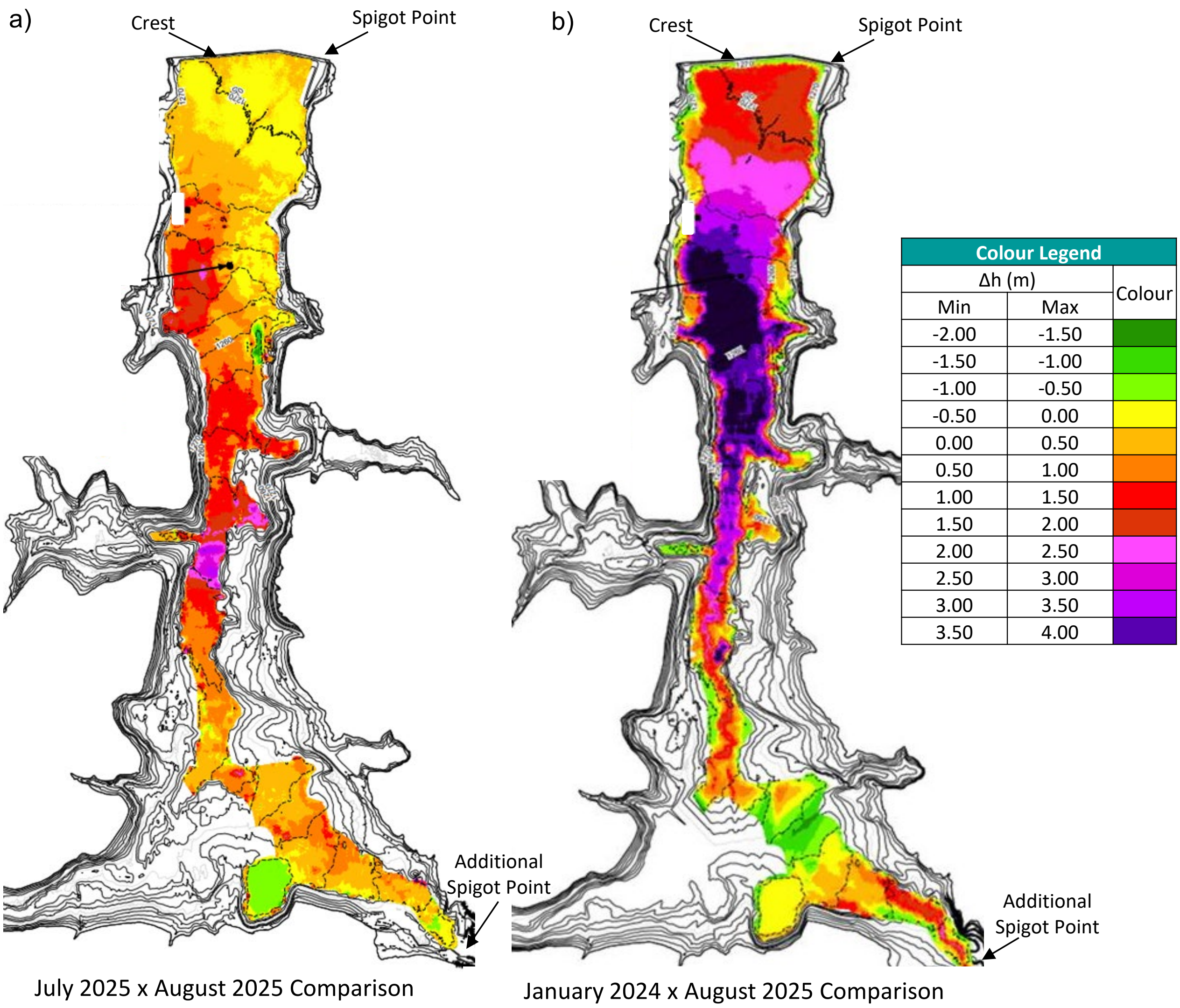


Figure 13 Survey comparison: (a) July 2025 and August 2025; (b) January 2024 and August 2025

Figure 13a illustrates the comparison between the condition in July 2025 (base survey) and August 2025 (comparison survey), indicating that the tailings consolidated near the crest (yellow colour), which is consistent with the operation plan, since during this period the tailings was mostly disposed in the upstream region of the reservoir. Considering that the central region of the reservoir has the lowest elevation, when compared with the location of the spigot points, most of the tailings accumulation occurred at the centre (red and purple colour). In addition, Figure 13b illustrates the cumulative evaluation with the comparison between the condition in January 2024 (base surface) and August 2025 (comparison surface), confirming that the central region of the reservoir is the most occupied over time. Furthermore, this comparison indicates that the right region near the crest is more occupied (brown colour) than the left (red colour) due to the tailings deposition near the right abutment (spigot point).

Another use for the topobathymetric surveys is the evaluation of the volume of the reservoir, comparing the surface of the tailings in each month to the survey taken prior to deposition. Considering that the first month of operation was August 2021, the topobathymetric surveys were used to calculate the consumed volume over time and this information was compared with the expected at the project stage (Figure 14).

Figure 14 shows that from August 2021 to August 2022 the disposed volume had a good adjustment with the planned volume, while in the following months the value of the disposed volume was lower than planned. This condition occurred due to some adjustments in the plant's operation. Considering the last recorded month (August 2025), the difference between the planned and disposed volume was approximately

2.07 Mm^3. It is important to mention that, in some months, the topobathymetric surveys were not performed due to operational adversities and, therefore, the monthly volume was not measured, as occurred between November 2024 and March 2025.

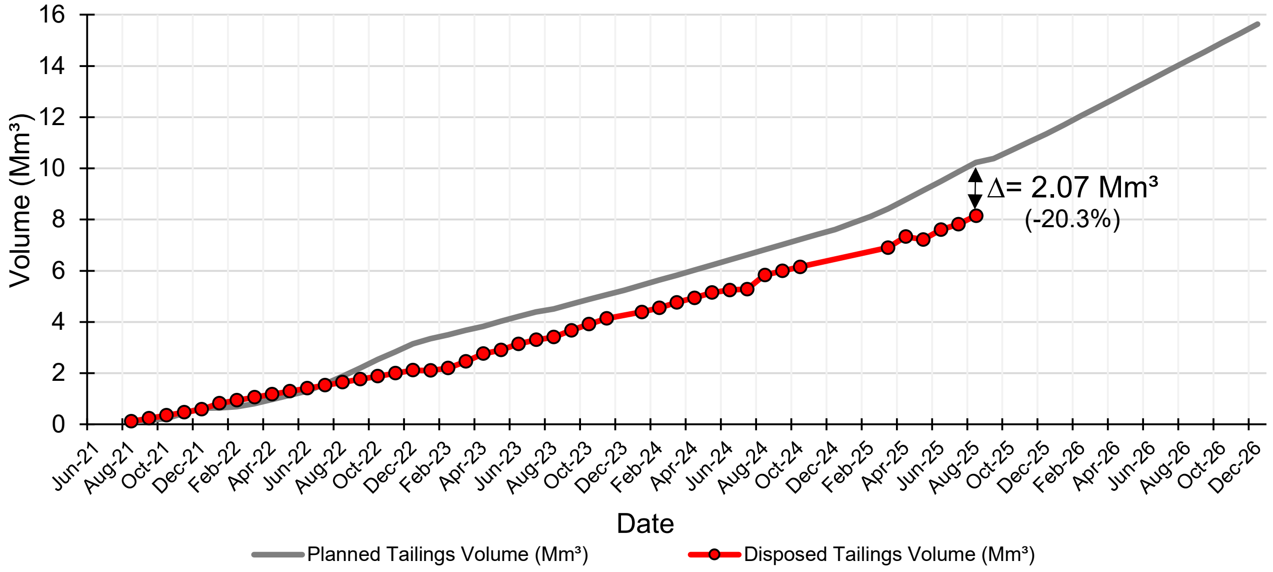


Figure 14 Reservoir filling evaluation

5 Conclusion

The main objective of this paper was to present the results of the monitoring of the surface disposal of an iron ore tailings facility. The tailings is the fine product of iron ore at a mine located in the state of Minas Gerais, Brazil, which is hydraulically deposited in the dam reservoir (slurry condition).

The geotechnical characterisation of the tailings was presented in terms of index properties and chemical characteristics. The particle size distribution indicated 4.8% sand, 75.0% silt-sized particles, and 20.2% clay, and the chemical evaluation resulted in most of the composition of Fe and SiO_2 (quartz), as expected.

The monitoring of the surface of the tailings used topobathymetric surveys with the objective of calculating the CSC, evaluating the surface of the tailings, and monitoring the occupation of the reservoir.

The deposited solids content of the tailings varied from 11.9–27.6%, since the values presented variations associated with different calibrations of the tailings production plant. The CSC was measured with the monthly topobathymetric surveys and with the cumulative evaluation using the comparison of at least 6 months of topobathymetric surveys. The first approach indicated that the solids content varied from 55.63–85.00%, while the second one resulted in the range of 73.09–77.91%. The difference in the range of the values occurred because the monthly evaluation can be influenced by some inconsistencies in the topobathymetric surveys, while the cumulative evaluation tends to increase the accuracy of this assessment.

A sample was collected in the reservoir to evaluate the in situ solids content, indicating the value of 77.60%, which showed that the cumulative approach was a good form to evaluate the tailings conditions, since the values obtained were close to the field.

The surface comparison was used to understand the occupation of the reservoir. The monthly comparison indicated that the occupation could vary depending on the spigotted region. When the tailings were being deposited from the crest, the occupation tended to occur mainly at this region (near the upstream slope of the embankment), whereas the occupation was predominantly in the centre of the reservoir when one of the spigots were relocated upstream.

In terms of the cumulative surface comparison, the results confirmed that the central region of the reservoir is the most occupied over time, since it has the lowest elevation when compared with the location of the spigot points. Furthermore, regions near the spigot points were also well occupied, as expected.

Another use for the surface comparison was the evaluation of the reservoir filling. The evaluation of the monthly topobathymetric survey over time indicated a good adjustment between the planned and disposed volume during the first year of the dam operation, while in the following months the tailings production was lower than planned. This condition occurred due to some adjustments in the plant's operation, and the last month recorded indicated that the difference between the planned and disposed volume was approximately 2.07 Mm^3.

Finally, the importance of monitoring the surface disposal of tailings should be recognised, since it can impact the performance and the life cycle of the dam. The daily control of the tailings dry mass, the monthly topobathymetric surveys, and the constant investigation of the tailings properties, especially the particle size distribution and the chemical characteristics, are important indicators to be considered during the operation of the dam.

Acknowledgement

The authors thank Pimenta de Ávila and Vale for providing the data and encouraging the scientific production of practical geotechnical applications.

References

Associação Brasileira de Normas Técnicas 2016a, *Soil - Liquid Limit Determination (ABNT NBR 6459)*, Rio de Janeiro.

Associação Brasileira de Normas Técnicas 2016b, *Soil - Plastic Limit Determination (ABNT NBR 7180)*, Rio de Janeiro.

ASTM International 2014, *Standard Test Method for Particle-Size Analysis of Soils (ASTM D422 - 63(2007))*, West Conshohocken.

ASTM International 2025, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (ASTM D2487-17e1)*, West Conshohocken.

Gomes, MA 2011, 'Technological characterization of iron ore tailing', *Revista Escola de Minas*, vol. 64, no. 2, pp. 233–236, https://doi.org/10.1590/S0370-44672011000200016

International Council on Mining and Metals, United Nations Environment Programme & Principles for Responsible Investment 2020, *Global Industry Standard on Tailings Management*, https://www.icmm.com/en-gb/our-principles/tailings/global-industry-standard-on-tailings-management

International Commission on Large Dams 2021, *Tailings Dam Design – Technology Update (Bulletin 181)*, Paris.

Navarro, L, Aravena, G, Engels, J & Turner, J 2019, 'Satellite bathymetry for the monitoring of supernatant water volumes within tailings storage facilities', in AJC Paterson, AB Fourie & D Reid (eds), *Paste 2019: Proceedings of the 22nd International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 205–217, https://doi.org/10.36487/ACG_rep/1910_13_Engels

SME 2022a, 'Part VI: case studies', in KF Morrison (ed.), *Tailings Management Handbook - A Life-Cycle Approach*, Society for Mining, Metallurgy & Exploration, Englewood, pp. 977–979.

SME 2022b, 'Overview of tailings management', in KF Morrison (ed.), *Tailings Management Handbook - A Life-Cycle Approach*, Society for Mining, Metallurgy & Exploration, Englewood, pp. 41–64.

Stringari, CE 2024, 'Measuring tailings storage facility bathymetry using Sentinel-2 and Landsat-8/9 multispectral imagery and machine learning', in J Engelbrecht & B Eaton (eds), *Canadian Symposium on Remote Sensing*, International Society for Photogrammetry and Remote Sensing, Halifax, pp. 63–69, https://doi.org/10.5194/isprs-archives-XLVIII-M-4-2024-63-2024