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Flow Failure of TSF Brunita in 1972, SE Spain

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Abstract

The aim of this study is to analyse the influence of the drainage system on the mechanism that might have caused the flow failure of the Brunita tailings storage facility (TSF Brunita) in southeast (SE) of Spain. The TSF Brunita failed on October 20, 1972. The forensic analysis used geological, geotechnical and hydrogeological criteria to determine the causes of the flow failure. With this information the conceptual hydromechanical model was developed. The 2D stability analyses were carried out with GeoStudio software (version 2012) in two phases: (1) steady state seepage analysis to establish the reference conditions before the heavy rainfall and (2) transient seepage analysis considering the additional water from the rainfall. For both cases, factors of safety and failure surfaces were calculated using limit equilibrium methods and stress-strain analysis was performed to estimate displacements and deformations in unstable areas under changing saturation conditions. The working hypothesis was to consider that the TSF failed due to a deficient drainage system. In order to verify this, two scenarios were considered: I) insufficient drainage system and II) sufficient and efficient drainage system modelled as a drain with saturated permeability of 0.001 m/s. The results confirmed the failure hypothesis. Heavy rainfall (119 L/m² in one week) led to a drastic reduction of the shear strength and stability of the TSF Brunita.

Keywords: Tailings storage facility (TSF), flow failure, numerical simulations, seepage, piping

Introduction

Rain can cause slopes to collapse, which is hard to predict and can be very damaging. Heavy rain can suddenly make slopes collapse, putting lives at risk. Rainfall is a key factor in how often slopes fail. Continuous rain weakens the soil because it increases water pressure or reduces suction. Once a slide begins, it's almost impossible to stop. Moreover, if the drainage system can't remove the water, a disaster is likely to happen. On October 20, 1972, the TSF Brunita, located in the Cartagena-La Unión mining district in SE Spain, failed (Fig. 1) taking life of the cementary/church janitor José Antonio Saura Gómez. This failure has been documented in various research studies, newspaper articles, and personal testimonies. A detailed account of the events between October 17 and 20, 1972, is available in MIN (1972). Martínez-Pagán *et al.* (2011) conducted a geophysical study and geochemical characterization of four metals (Pb, Zn, Cu, Cd), along with hydrogeological characterization in two boreholes. Rodriguez *et al.* (2011) provided a description of the failure of TSFs in the mining area, including the TSF Brunita case study, and analysed the physical-mechanical properties of the tailings. Moreno-Perales

(2016) performed stability calculations using the limit equilibrium method but did not account for precipitation. An environmental characterization and description of the spatio-temporal evolution of TSF Brunita can be found in Martín-Crespo *et al.* (2018). Despite extensive research on TSF Brunita, none of the available studies have confirmed the flow failure process through numerical simulation under different boundary conditions. Hence, the objective of this work is to analyse the failure mechanisms of the tailings facility using available geological, geotechnical, and hydrogeological information, to define the conceptual model of hydromechanical operation (Rodriguez (2006)), and to perform numerical simulations of seepage, stresses, deformations, and equilibrium conditions including (i) working and (ii) failed drainage system.

Hypotheses of Flow failure of TSF Brunita

Based on the information consulted and field mapping (Fig. 1), it is hypothesized that the flow failure of the TSF Brunita was due to a poor drainage system. The Brunita's drainage system consisted of rigid, ceramic, and perforated pipes (2 m length and 20 cm inner diameter) installed at the bottom of the valley. Pipes were joined together with the cement as the deposit grew. Moreover, pipes were not protected against the entry of fines. The failure of the drainage system facilitated the development of piping around the pipes (Fig. 1d). To validate this hypothesis, two cases of TSF stability analyses were considered: I) a deficient drainage system, and II) an efficient and sufficient drainage system.

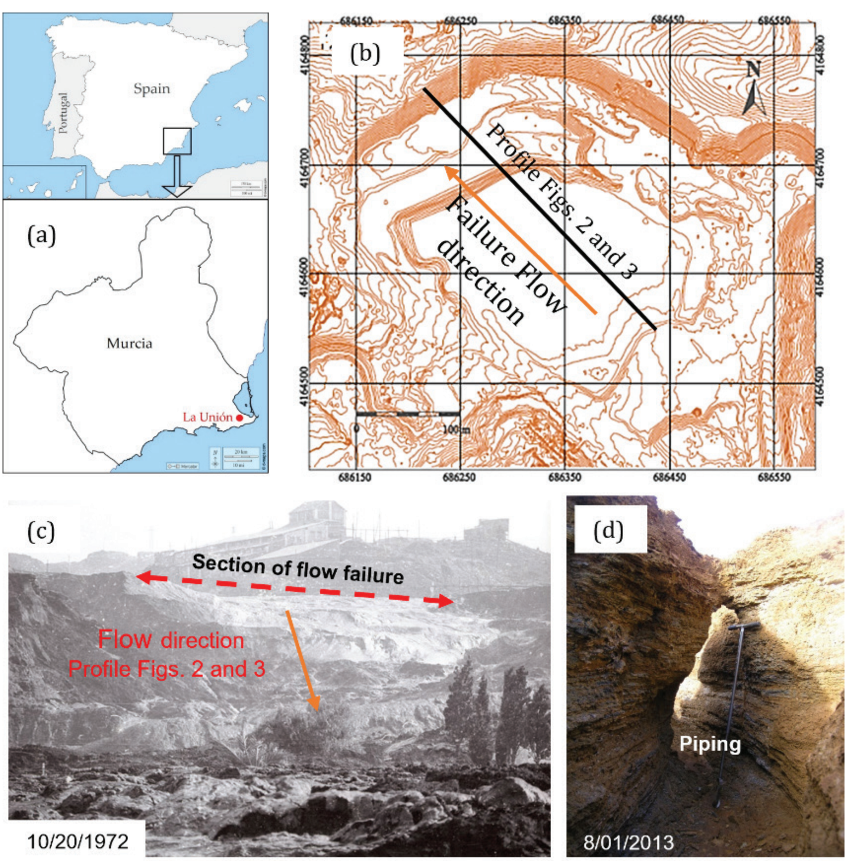

Figure 1 TSF Brunita, a) localization, b) topography of the TSF before the breach including the profile used in calculations, c) area affected by a flow failure and d) piping in TSF Brunita 50 years post-failure.

Materials

The properties of the materials that make up the tailings, the dam and the foundation were defined based on the analysis and interpretation of the information obtained from field and laboratory research and the results of various studies (Martínez-Pagán *et al*. 2011, Rodríguez *et al*. 2011, Moreno-Perales, 2016, Martín-Crespo *et al*. 2018, HORYSU, 2023 and GEOZONE, 2023). The geological, geotechnical, and hydrogeological characteristics of the tailings and the foundation materials of the TSF Brunita, used for the development of this work, are listed in Tab. 1.

Numerical model

Two-dimensional (2D) simulations were conducted using the finite element programs 'SEEP/W' and 'SIGMA/W' to model groundwater flow and stress-strain behavior, respectively. The mesh consists of 7063 elements (combination of quadrilaterals and triangles) and 7422 nodes as shown in Appendix 1 Fig. 1. Material was modelled as a linear elastic perfectly plastic Mohr-Coulomb. The program 'SLOPE/W' was used to calculate the factors of safety (FoS) using the limit equilibrium methods of Bishop (Bishop and Morgenstern 1960) and Morgenstern-Price (Morgenstern and Price 1967). The conceptual model was developed from available data, including the interpretation of aerial photographs and digital terrain models before and after the failure, as well as geotechnical and hydraulic parameters of the materials. This provided relevant information on the geometry and spatial distribution of tailings in the TSF Brunita, as shown in Figs. 2a and 3a. The main elements of the TSF were defined as a tailings basin, lagoon, a bedrock foundation, and dams/embankments. The basin was modeled with two types of tailings: a shallow layer of low plasticity silts and a deep layer of silty sands. The dams/embankments were composed of silty sand material. The maximum water level in the lagoon was fixed at 28.41 m. The drainage system was modelled as a layer of material with high permeability, having saturated permeability of 0.001 m/s. The vertical part extended to the maximum level of the lagoon's water table (28.41 m), and the horizontal part was extended through all deposit length, both with a width of 0.65 m. The deformability, shear strength, and hydraulic properties of each material are provided in Tab. 1.

Results

In the geotechnical-structural stability analysis, pore pressures, phreatic surfaces, hydraulic gradients, seepage rates, factors of safety (FoS), potential failure surfaces, and horizontal displacements, were determined under different saturation conditions (Figs. 2 and 3). The analysis considered two hypotheses: I) an insufficient drainage system, and II) a sufficient and efficient drainage system. The analysis considering the maximum level of the lagoon (and working drains) before heavy rains was used as the base simulation. This base simulation allowed to obtain the initial pore pressures (Appendix 1 Fig. 2). The calculated safety factor was around 3. Subsequently, seepage analysis was performed considering the water input from rainfall to calculate changes in water tables and safety factors over time. The effect of

Table 1 *Geotechnical and hydraulic parameters: solid specific gravity (G_s), porosity (n), saturated unit weight (γ_{sat}), dry unit weight (γ_{dry}), cohesion (c), friction angle (ϕ), Young's modulus (E), Poisson's ratio (v), saturated hydraulic conductivity – horizontal (k_h^{sat}) and vertical (k_v^{sat}).*

Material	G_s kN/m³	n %	γ_{sat} kN/m³	γ_{dry} kN/m³	c kPa	φ °	E kPa	v –	k_v^{sat} m/s	k_h^{sat} m/s
Low plasticity silts (tailings)	28.9	42	18.5	16.84	15.14	28.25	1000	0.31	6.59×10^{-9}	6.59×10^{-10}
Silty sands (tailings)	28.9	40	19.1	17.38	38	29.25	3500	0.31	6.99×10^{-7}	6.99×10^{-8}
Silty sands (dam)	28.7	33	21.0	19.11	49	31	4000	0.31	8.31×10^{-5}	8.31×10^{-6}
Graphite schist and Quartzites (Foundation)		12	22.0	20.02	150	40	100000	0.28	1.15×10^{-11}	1.15×10^{-12}

rainfall was modeled by performing transient seepage analysis, accounting for the increase in water table height produced by 119 L/m² (119 mm) of rainfall in one week. This rainfall was recorded at the Algar (Murcia) weather station, located 4 km from the TSF Brunita and was equivalent to an infiltration rate of 1.97×10^{-7} m/s.

Hypothesis I: an insufficient drainage system

The results of the numerical simulation (Fig. 2) confirmed that the hypothesis regarding the insufficiency of the drainage system as the main cause of the failure was correct. The simulation indicated that the drainage system in place at the time of the rainfall was inadequate to evacuate the water stored within the facility. Fig. 2b shows a distribution of pore water pressure resulting from the saturation of the tailings from heavy rain, with the flooded surfaces of dams 1 and 2. The loss of stability is confirmed by the drop in the safety factor of the TSF (Figs. 2c and d). As shown in Fig. 2d, the factor of safety (FoS) reached 1 (limit equilibrium) 48 hours after the onset of rainfall, which aligns with the first landslide experienced by the TSF Brunita as described by MIN (1972). The slipped zone shows displacements of the mass of embankment 1 of 0.18 m (Fig. 2e),

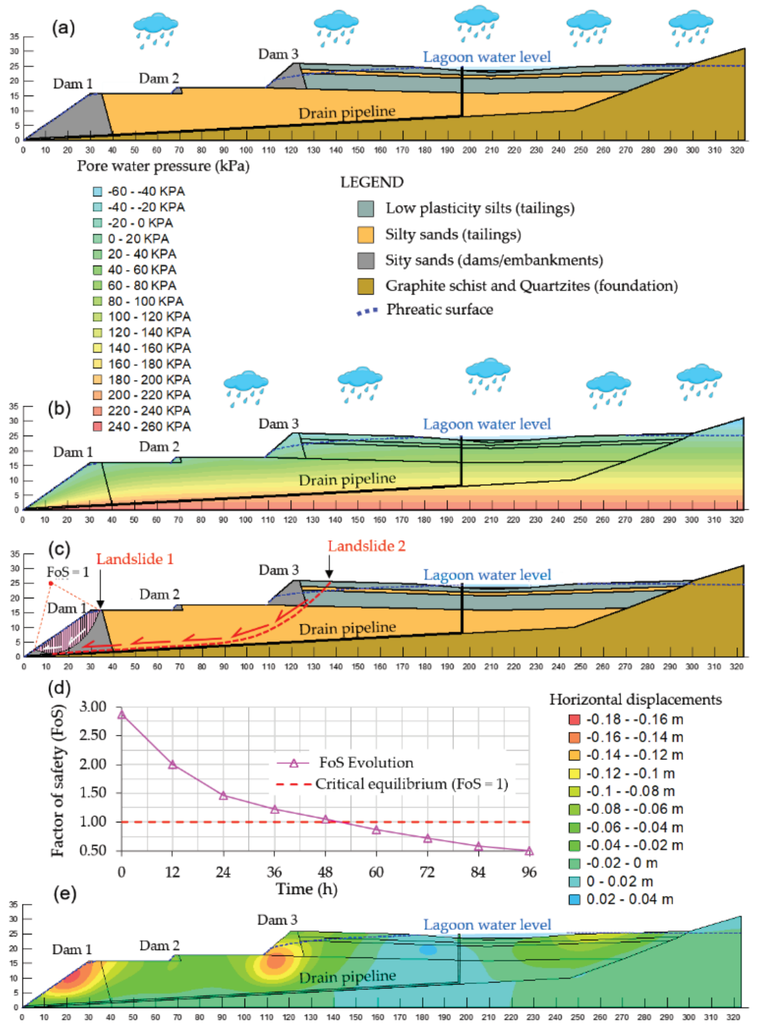

Figure 2 *Behaviour of the TSF Brunita with an insufficiently drainage system: (a) conceptual model, (b) pore water pressure resulting from tailings saturation (time = 48 h), (c) slip surface of TSF Brunita, (d) reduction of FoS of the dam 1 of TSF, (e) displacements computed in TSF (time = 48 h).*

while the displacements at the base of dike 3 are 0.12 m. The water flow through the dam 1 slope at the time of failure was 11.27 m^3/s (Appendix 1 Fig. 3).

Hypothesis II: a sufficient and efficient drainage system

In this case, a drain with a saturated hydraulic conductivity of 0.001 m/s was installed. When the drain is functioning, there is no increase in pore pressures (Fig. 3b). As shown, all three embankments remain in an unsaturated condition. If the drainage system can evacuate the volume of infiltrated water throughout the period of heavy rainfall, the factor of safety (FoS) remains higher than 2 (Fig. 3c). As seen in Fig. 3d, no large deformations occur in embankment 1. The largest deformations occur in embankment 3, which is consistent with the increased saturation of the tailings.

Conclusion

The numerical analysis of the TSF Brunita highlights the critical importance of a good drainage system for the stability of TSFs, especially during intense rainfall. The numerical simulation confirmed that the 1972 failure was due to fault drainage (did not

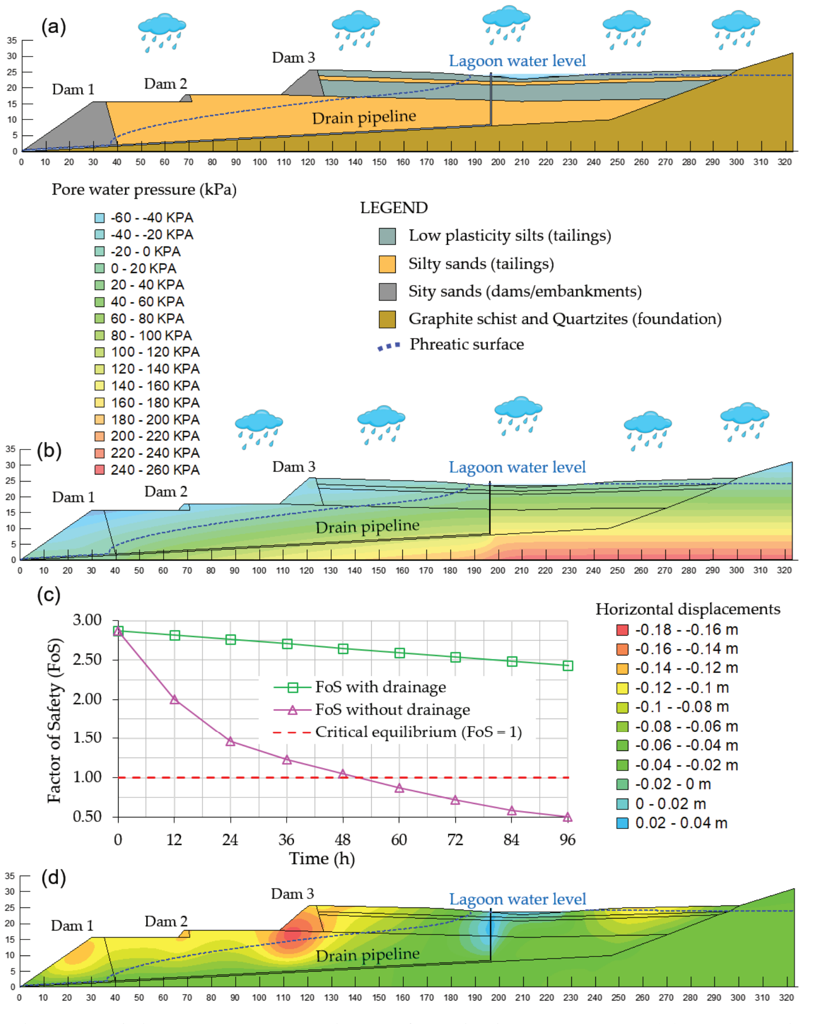

Figure 3 *Behaviour of the TSF Brunita with a sufficiently drainage system (a) conceptual model, (b) pore water pressure resulting from tailings saturation (time = 48 h), (c) comparison of the safety factor of tailings dam 1 for the case with and without drainage, (d) displacements computed in TSF (time = 48 h).*

comply with the regulations) that could not handle the water from the rains. Key points:

- Poor drainage: The rains increased the water pressure in the tailings, reducing their strength, causing slope instability and ultimately flow failure. Moreover, the drainage system consisting only of subsurface drains (that not comply with the drainage design regulations) was not sufficient to evacuate water from the deposit. The drains might have clogged/break at some point, causing seepage through the face of the tailings facility. Hence, the usage of only subsurface rigid drains should be discouraged from being used.
- Sufficient and efficient drainage: A good drainage system may keep the slopes unsaturated and provides a high safety factor, even during extreme rainfall. Although, the finite element method cannot predict piping around the drain, it is expected that piping that developed around the pipe was the cause of failure.
- Design and maintenance: It is essential to design and maintain adequate drainage system that should include more elements to evacuate water (impermeable membranes, drainage canals, tailings dewatering, etc.) to mitigate the risks of severe weather events, which are increasingly common due to climate change.

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References

Bishop AW, Morgenstern NR (1960) Stability coefficients for earth slopes. Géotechnique 10(4):129–150. doi:10.1680/geot.1960.10.4.129

GEOZONE, 2023. Estudio geofísico mediante tomografía eléctrica, polarización inducida y MASW para proyecto de remediación ambiental de residuos mineros y emplazamientos afectados por la minería en los TT. MM. de Cartagena – La Unión. Informe Técnico, GEOZONE ASESORES S.L. 2023, 115p.

HORYSU, 2023 Sondeos exploratorios con pruebas de penetración estándar y ensayos de laboratorio para estudio geológico y geotécnico en la cuenca del Mar Menor, La Unión, Murcia. LABORATORIOS HORYSU Inversiones de Murcia, S.L.

Martín-Crespo T, Gómez-Ortiz D, Martín-Velázquez S, Martínez-Pagán P, De Ignacio C, Lillo J, Faz A (2018) Geoenvironmental characterization of unstable abandoned mine tailings combining geophysical and geochemical methods (Cartagena-La Union district, Spain). Engineering Geology 232:135—146. doi:10.1016/j.enggeo.2017.11.018

Martínez-Pagán P, Faz A, Acosta JA, Carmona DM, Martínez-Martínez S (2011) A multidisciplinary study for mining landscape reclamation: A study case on two tailing ponds in the Region of Murcia (SE Spain). Physics and Chemistry of the Earth, Parts A/B/C 36(16):1331—1344. doi:10.1016/j.pce.2011.02.007

MIN (1972). Informe sobre accidente ocurrido en el dique de estériles del lavadero "Brunita", propiedad de la Empresa Eloy Celdrán Conesa, en término municipal de la Unión (Murcia). Ministerio de Industria.

Moreno-Perales A (2016) Stability calculation of the "Brunita" tailings dam, La Unión, Murcia, Spain. Master's Thesis Polytechnic University of Cartagena.

Morgenstern NR, Price VE (1967) A numerical method for solving the equations of stability of general slip surfaces. Computer Journal 9(4): 388–393. doi:10.1093/comjnl/9.4.388

Rodríguez R (2006) Hydrogeotechnical characterization of a metallurgical waste. Canadian Geotechnical Journal 43(10): 1042–1060. doi:10.1139/t06-061

Rodríguez R, García-García C, Zarroca M, Roqué C, Linares R, Oldecop L (2011) Características geológicas y geotécnicas de los lodos de flotación de la Sierra Minera de Cartagena-La Unión (SE España). Boletín Geológico y Minero 122 (2).

SEEP/W (2012). Seepage Modeling with SEEP/W. An Engineering Methodology. March 2012 Edition. GEO-SLOPE International Ltd. Alberta, Canada.

SLOPE/W (2012). Stability Modeling with SLOPE/W. An Engineering Methodology (July 2012 edition), GEO_SLOPE Internacional Ltd, Alberta, Canada, p. 246.

SIGMA/W (2013). Stress-Deformation Modeling with SIGMA/W. An Engineering Methodology (July 2013 edition), GEO_SLOPE Internacional Ltd, Alberta, Canada, p. 223.