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Combined Analysis of Self-Potential, Electrical Resistivity, Mineralogy, and Hydrochemistry for Mapping Flows in Tailings Dams

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Introduction.

The Self-Potential (SP) method, traditionally employed for detecting groundwater flow trends, contaminated sites, and mineral exploration of metal-bearing sulphide ore bodies, has been increasingly applied in geotechnical engineering, particularly in tailings dams in Brazil. Such applications were further motivated after the Fundão dam collapse in 2015. This expansion in use, driven by the critical need to map water flows, has revealed significant discrepancies between observed field behaviours and predicted geotechnical models, resulting in major challenges for data interpretation. Although published studies and company reports have attempted to analyse the complex SP patterns to infer the underlying flow paths, they often overlook the mineralogical composition of the dam's construction materials and the chemistry of the water percolating through the internal filters and the dam's structure. Preliminary observations from over a decade of investigating tailings dams suggest distinct SP patterns for tailings from different ore types, but some apparently similar patterns for dams constructed with comparable materials, that are discussed in the presented study.

Theory

The SP signal is a complex phenomenon resulting from the combination of three main sources: electrokinetic phenomena, which arise from fluid flow through a porous medium; electrochemical gradients, associated with differences in the pore-water ionic composition and fluid-mineral interactions; and redox potential gradients, related to oxidation-reduction reactions coupled by electronically conductive minerals. Tailings dams are geotechnical engineering structures constructed from various materials, including clayey soils, processed tailings—which can exhibit distinct mineralogical and chemical characteristics based on the original ore type and beneficiation process—and waste rock from mineral extraction. The variation in water head along the dam's slopes drives pore water flow, resulting in an intrinsic electrokinetic contribution to the observed SP signal. While ideal electrokinetic models predict a consistent negative-to-positive SP trend from crest to toe, field observations often show partial or even opposite patterns. Even minimal deviations from this ideal electrokinetic trend can indicate additional SP contributions from electrochemical or redox effects, influenced by material mineralogy and percolating water chemistry, which also affect electrical resistivity tomography (ERT) measurements.

Conclusions

We present a set of field studies in which the recognition of an SP signal of electrokinetic origin is identified and then used as a reference to determine contributions from other sources. Our main objective is to develop a methodology to isolate the electrokinetic component of SP through a correction derived from the dam's chemical and mineralogical properties. Subtracting this estimated electrokinetic component (which includes the topographic contribution) will allow us to identify and analyse residual anomalies in the SP profile. Such "residual" anomalies are essential for enhancing filter system performance assessments, detecting mid-slope flows that could potentially compromise structural stability or indicate a design flaw, and enabling the early identification of internal erosion (piping) processes, ultimately improving the monitoring and safety of tailings dams. These potentials are interpreted using ERT resistivity sections and 3D mosaics, along with information about dam construction materials and the properties of the percolating water.