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Catastrophic mass flows resulting from tailings impoundment failures

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ABSTRACT

Tailings dam failures have received significant attention in recent years due to the catastrophic downstream consequences, as evidenced by the 2019 Feijão disaster in Brazil and numerous precedents. This paper presents a timely review of tailings flows with the support of a comprehensive global database of 63 cases that have been remotely analyzed through a compilation of satellite imagery, digital elevation models and literature. The synthesis provides insight into the influence of impoundment conditions, preconditioning and trigger variables, failure mechanisms and the downstream environment on tailings flow behaviour. The database also sheds light on the limitations of data quality and availability in the public domain. Magnitude-frequency statistics indicate that tailings dam breaches that have produced catastrophic mass flows with total outflow volumes of $\geq 1 \text{ M m}^3$ have occurred at a mean recurrence interval of 2–3 years over the period 1965–2020. Weather hazards and impoundment drainage issues are identified as major causative variables. The occurrence of liquefaction and/or the incorporation of free water are sufficient conditions to trigger extremely rapid, highly mobile behaviour. Travel path confinement and steeper bed slopes enhance flow velocities (peak of 25–30 m/s) and kinetic energy, whereas flow mobility appears to be exacerbated along major rivers. Although general trends may be observed in empirical observations, such efforts are prone to substantial uncertainty due to the complexity and variability of site conditions (that are typically unaccounted for in broad statistical approaches) as well as poor data availability and/or quality for many of the selected cases. This highlights the importance of performing site-specific investigations through numerical models, laboratory tests and field observations to better predict post-breach behaviour (ideally within a probabilistic framework) when undertaking site assessments.

1. Introduction

1.1. Preamble

The production and safe storage of tailings is an integral waste management procedure of standard mining projects as well as some industrial and power plant operations. Tailings are fine-grained waste rocks that are conventionally discharged as slurries into long-term storage facilities (Vick, 1983; Blight, 2010; Kossoff et al., 2014; Jeffries and Been, 2016). Given that tailings disposal is necessary insofar as operations continue, tailings dams are perpetually evolving structures that are raised in stages over the span of several years to decades, with some impoundments being among the largest man-made structures in the world (Vick, 1983; ICOLD, 2001). When unfavourable conditions

persist in a storage facility (i.e. when a large volume of tailings are very wet, contractive and/or overlain by ponded water), a triggering mechanism may initiate a dam breach resulting in a mass movement of failed materials into the downstream environment (Dobry and Alvarez, 1967; Chandler and Tosatti, 1995; Blight, 2010; Morgenstern et al., 2015, 2016; Robertson et al., 2019).

Voluminous tailings flows are capable of catastrophic, highly mobile behaviour, with some events rendering considerable infrastructural damage, geomorphological impact, environmental contamination and socio-economic cost (Troncoso et al., 1993; Kossoff et al., 2014; Takahashi, 2014; Macías et al., 2015; Bowker and Chambers, 2015, 2017; Cuervo et al., 2017; de Lima et al., 2020). Some tailings flows have also led to mass casualties when travelling through inhabited areas, with a few examples including 1937 Los Cedros in Mexico (300+ deaths;

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