Mine Closure 2026 – AB Fourie, G Boggs, J Heyes & M Tibbett (eds)

doi:10.36487/ACG_repo/2615_143

Applying the material point method to dam break assessment of a closed tailings storage facility

Kobi Song [a,*], Marcelo Llano-Serna [a], Seyedmohammadjavad Seyedan [b]

[a] *Geosyntec Consultants, Australia*

[b] *Geosyntec Consultants, Finland*

Abstract

Tailings dam failures pose a significant hazard to downstream communities and the environment. Effective risk management of dam failures requires accurate assessment. Conventional approaches include widely used empirical, depth-averaged models, as well as simplified continuum-based numerical methods. These conventional approaches are computationally efficient but often rely on significant simplifications, may overestimate runout extent, which is not necessarily conservative and fail to capture realistic flow behaviour.

This study applies the material point method (MPM) and a volume balance-based empirical approach to evaluate potential sunny-day dam breach consequences of a closed tailings storage facility (TSF). Both approaches are intended to represent the same clear-weather failure consequence scenario. The empirical approach provides a simplified estimate of runout based on volume balance assumptions and is not formulated to explicitly represent material strength degradation, pore pressure effects, or progressive deformation mechanisms. In contrast, the MPM simulation incorporates soils shear strength and large-deformation soil–water interaction, thereby providing a more realistic representation of tailings run-out behaviour. The analysis is limited to clear-weather conditions and does not consider additional run-out associated with rainfall or flooding-induced entrainment.

The results of the study show that MPM provides realistic predictions of post-failure deposition patterns while maintaining reliability. These findings highlight the value of MPM as a robust and strong tool for assessing the residual risk of closed TSFs and for bridging the gap between simplified industry tools and real tailings flow behaviour.

Keywords: *tailings storage facility, dam break assessment, MPM*

1 Introduction

Tailings storage facilities (TSFs) represent a critical challenge for mine closure, where long-term stability and risk reduction must be achieved with limited ongoing intervention. Historical failures have demonstrated that TSF breaches can result in severe environmental, social, and economic consequences, reinforcing the need for risk-based closure strategies that explicitly account for both the likelihood and consequences of failure.

Tailings dam breach analysis (TDBA) is central to this process, informing consequence assessments and closure design decisions. However, many conventional approaches – largely derived from water dam practice – do not adequately represent the complex mechanical behaviour of tailings. In particular, simplified fluid assumptions can mischaracterise flow behaviour, leading to uncertainty in predicted inundation extents and impact severity (Llano et al. 2025). Such limitations are especially critical in closure settings, where residual risks must be understood over long timeframes.

[*] Corresponding author. Email address: kobi.song@redearthengineering.com.au

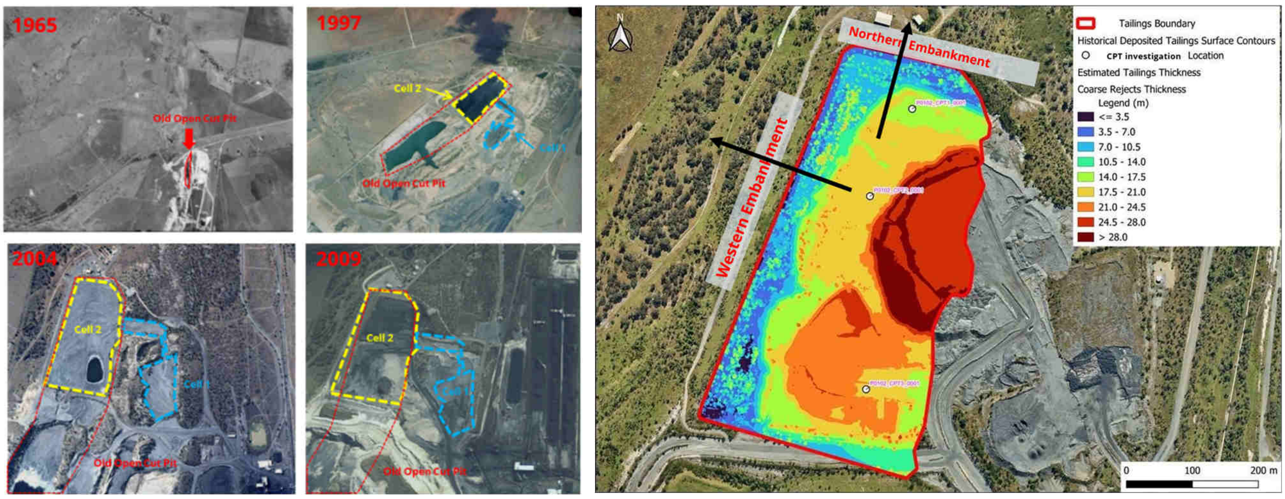
Recent guidance has placed increased emphasis on the identification of credible failure modes, defined as physically plausible mechanisms consistent with site conditions and material response. In this context, the material point method (MPM) provides an advanced numerical approach capable of simulating large deformations and phase transitions associated with tailings failure.

This paper examines the application of MPM to TDBA in a closure context and compared to the conventional approach to improve failure mode definition and enhance the reliability of consequence predictions to support risk-informed mine closure.

2 Case study background

Figure 1a shows the studied TSFs condition over time. The TSF was an open cut pit formed by mining operations in the 1960s. Tailings deposition began in 'Cell 1' in 1993, then flowed into 'Cell 2', ceasing in 1999. Zoned embankments were built on three sides of 'Cell 2' (northern, western, and southern) from 1996 to 1998 to increase storage capacity. A crust layer of tailing formed in both cells by 2004.

The facility was utilised to stockpile the mine-spoil-coarse-rejects material since 2009, and the existing coarse-rejects thickness varies across the facility. Figure 1b presents an interpreted heatmap of coarse-rejects thickness, with the maximum thickness of 28 metres.



(a) (b)

Figure 1 (a) The studied Tailings storage facilities (TSFs) condition over time; (b) The studied TSF current condition with the capping material's thickness

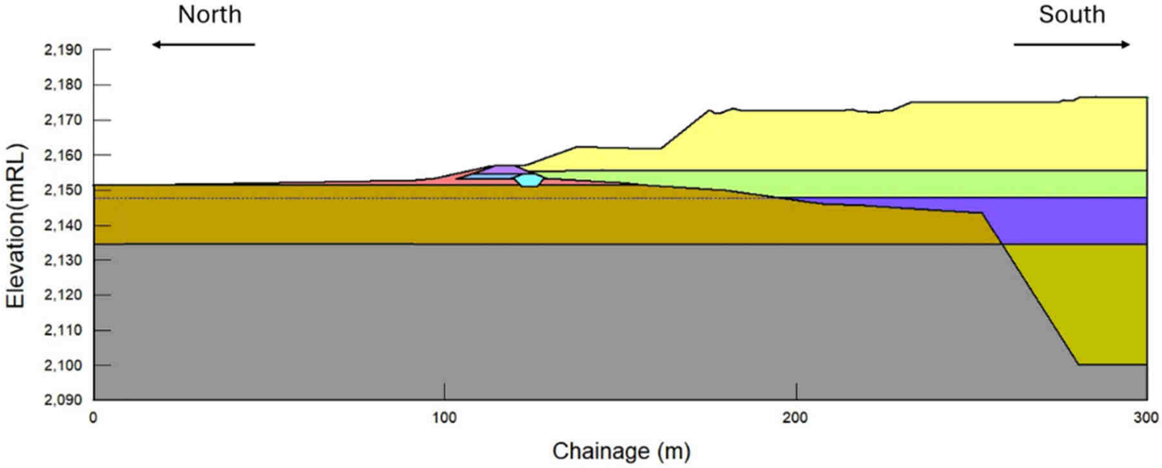
The existing capping geometry is not engineered and does not meet site rehabilitation criteria or free-drainage requirements. A dam break study has therefore been undertaken to assess potential failure consequences and inform the future landform reshaping design.

Two potential breach locations were assessed for the TSF based on consequence-driven criteria:

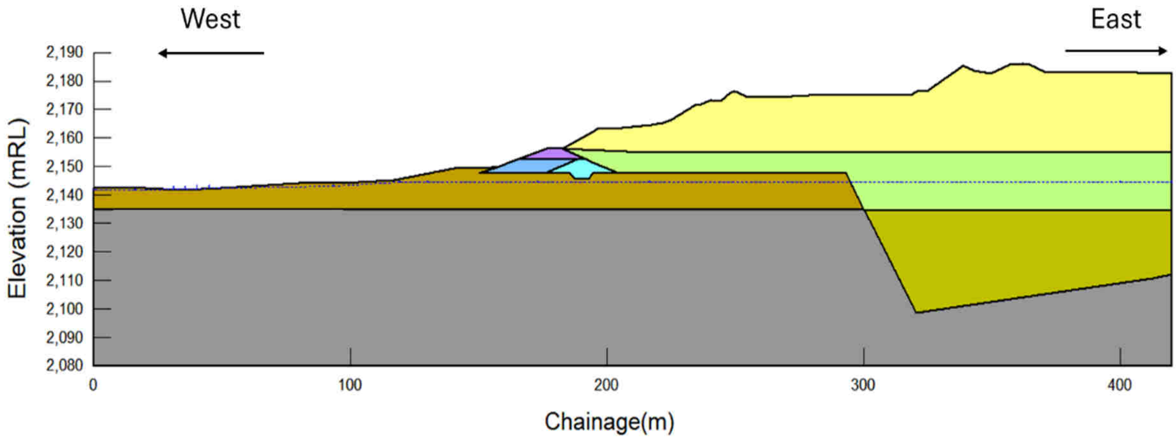
1. Northern embankment: selected due to the minimal separation distance between the facility and the site warehouse, representing the highest fatality risk. The existing cross-section is shown in Figure 2a.
2. Western embankment: selected based on the maximum elevation difference between the coarse particulate capping layer and the downstream terrain, representing the largest potential containments release. The corresponding cross-section is shown in Figure 2b.

The facility comprises a staged embankment constructed with three material zones. The embankment layout is presented in Figure 2c, with zoned material descriptions summarised as follows:

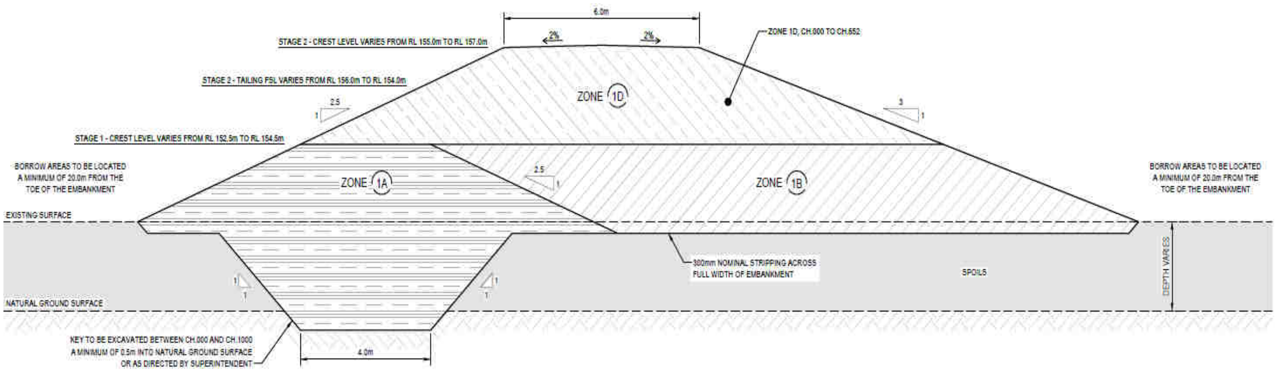
- Zone 1A: predominantly silty, clayey sands and gravels sourced from site borrow materials.
- Zone 1B: semi-pervious, compacted plant rejects derived from the CHPP.
- Zone 1C: low-permeability earthfill forming the core or sealing zone.



(a)



(b)



(c)

Figure 2 (a) Northern Embankment critical cross-sectional geometry; (b) Western embankment critical cross-sectional geometry; (c) Typical zoned embankment cross-sectional layout

3 Dam break study methods

3.1 Empirical method

The volume balance approach, as one of the empirical methods, could be used for simulating clear-weather dam failures. This type of dam breach analysis is based on geometric configuration and is typically designed for simulating a sunny-day tailings dam breach.

The volume balance approach is a geometry-driven method that does not model dynamic breach processes. The breach is defined by its location, elevation, and width, and a failure surface is then projected upstream as an inverted cone at a specified post-failure slope until it intersects the tailings surface (Figure 3).

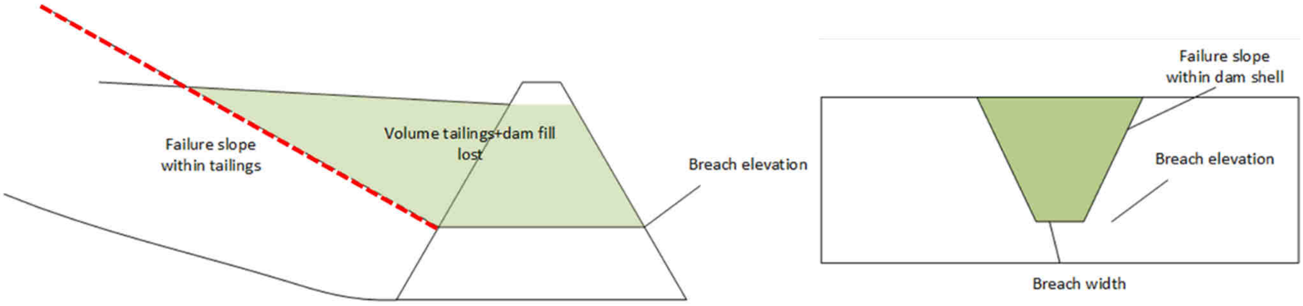


Figure 3 Muk3D Dam break modelling concept (MineBridge 2024)

The released volume is defined by mass balance between the backscarp and the downstream deposit. This volume is then projected onto the terrain using a post-failure surface to generate the flow footprint, enabling rapid estimation of extent and thickness.

3.2 Material point method

MPM is a continuum mechanics-based method proposed by Sulsky et al. (1994). An MPM model is composed of a background grid or and material points. Figure 4 shows the MPM concept and key elements for a structured mesh with square elements. MPM algorithm discretises objects using particles, which store all time-dependent information, and solves the momentum equations on a grid.

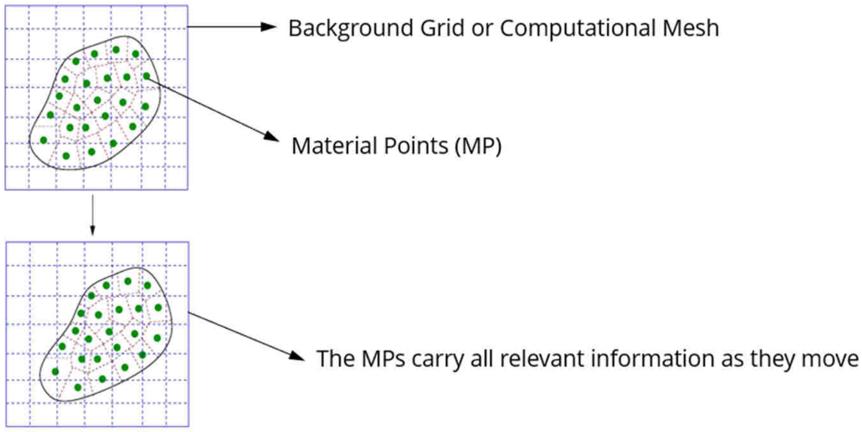


Figure 4 The material point method concept (www.imechanica.org)

For a large deformation process, such as that seen during a tailing dam failure, MPM has some important advantages. First, MPM can handle large deformation without dealing with mesh distortion. Mesh distortion is the problem preventing common numerical methods (for example, the finite element method) from capturing large deformations. Second, the continuum mechanics base of MPM allows it to model large deformations with reasonable computational cost. The continuum mechanics base of MPM enables it to use common and advanced soil constitutive models.