

Dam-break: effect of water content in tailings vs run-out distance

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ABSTRACT

In current regulatory frameworks, dam breach and tailings run-out modelling of tailing storage facilities is a requirement and a matter of increasing interest within the regulatory agencies and practitioners. Increased levels of densification of impounded tailing materials by means of alternative tailing deposition technologies, by means of installation of wick drains, or by loading the surface of the impoundment with waste rock, all generate a change in the interstitial pressure of the tailing column that may lead to densification and an increase of the rheology of the settled tailings. In the case of run-out analyses, we present a sensitivity analysis of the effect of the degree of consolidation at the time of a dam breach on the run-out distance potential. The results show a decrease of up to 16% in the maximum area reached by the outflow due to the increase in the degree of consolidation. The incorporation of the relative effect of densification methods and the resulting change in rheology represents a progress in understanding the critical elements that drive the potential for downstream impact of a dam breach event.

INTRODUCTION

Tailings run-out distance refers to the distance that an outflow volume of tailings and water may travel as a consequence of a breach of the confining dam of the tailings storage facility (TSF). In Chile, these studies are mandatory for TSFs under Sernageomin regulation DS N°248. To date there is no specific methodology or official guidelines on the procedure to determine the tailings run-out distance. Several authors have proposed empirical and geometric methods to evaluate tailings outflow, such as those proposed by Rico *et al.* (2008) and Lucia *et al.* (1981). Martin *et al.* (2015) presents a practical guide to assessing dam break outflow modelling by comparing the key parameters that affect and control the run-out distance. According to the Canadian Dam Association (2013), three modes of failure are recognized: overtopping; collapse; and contaminated seepage. This study considers only failure by collapse.

The outflow hydrograph, geometry of the dam breach and rheological properties of the tailings are among the key variables that control the run out distance. This study evaluates the effects on the run out distance as a result of improving the tailings rheology by consolidation with wick drains. The incorporation of wick drains allows the reduction of water content, increasing the solids content by volume (Sotil *et al.*, 2018). The wick drains are complemented with consolidation load to reduce the consolidation time. Adams *et al.* (2017) demonstrated the effectiveness of applying a consolidation load accelerated with wick drains to densify, dewater, and reduce the flowability of tailings through an instrumented test program installed at a mine site in central British Columbia, Canada. The objective of this study is to evaluate the potential reduction of the inundation area that may result from improved tailings consolidation.

The studied TSF is a conventional tailings facility with 3 embankment dams and a total storage volume of 338.6 Mm³ (Figure 1). The analyses were carried out for the larger dam. The dam is raised using the downstream raise method, with an upstream slope of 2.5H:1V and a downstream slope of 2H:1V. The height of the dam is 64 m and the volume of the embankment is 3.8 Mm³.

The results of the inundation area are compared before and after the incorporation of improved consolidation methods of the tailings by means of wick drains. The methodology includes an estimation of the outflow volume and hydrograph for both tailings states, with and without wick drains. Numerical modelling was completed using the Flo-2D software.

A summary of the geometry and main elevations of the dam are those indicated in Table 1. Figures 1 and 2 show the general location of the TSF and a typical embankment section (Dam 2).

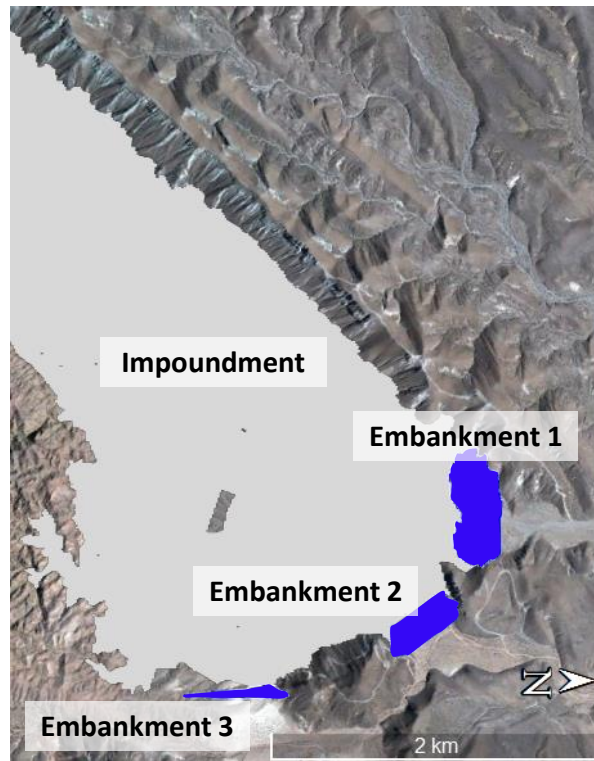


Figure 1 General layout

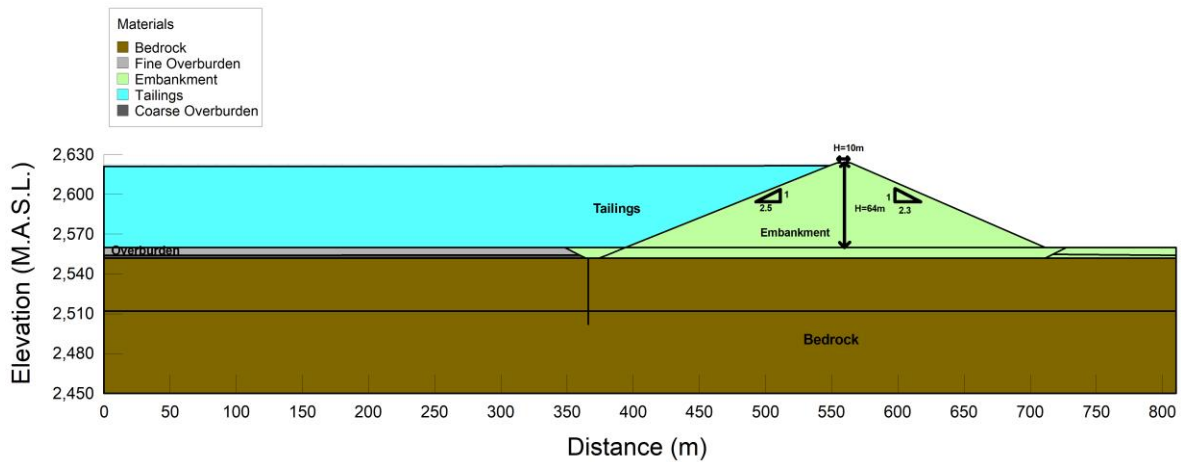


Figure 2 Embankment typical section

THEORY AND METHODOLOGY

The methodology implemented for dam break analyses is currently an ongoing matter of debate within the engineering community, therefore conservative criteria and parameters have been utilized. It is noted that the aim of this research is not on the discussion of the methodology for the dam break analysis, but rather quantifying the affected area of the outflow material. The tailings properties used in the analysis are shown in Table 1.

Table 1 Tailings properties

Frictional angle, drained (ϕ)	Dry unit weight ($\frac{t}{m^3}$)	Cohesion ($\frac{t}{m^2}$)	$\frac{S_u}{\sigma_{vLiquefaction}}$
26	1.6	0	0.06

The outflow volume was estimated using Equation 1 to obtain the friction angle (ϕ). The outflow volume therefore is function this friction angle and tailings elevation, the latter is intended to reduce as it will be explain in the next sections. Has been analysed static liquefaction failure with the tailings residual strength ratio. Figure 1 illustrates the equivalent friction angle derived from the residual strength ratio utilized in the model (Blight, 2010).

$$\phi = \tan\left(\frac{S_u}{\sigma_v}\right)^{-1} \tag{1}$$

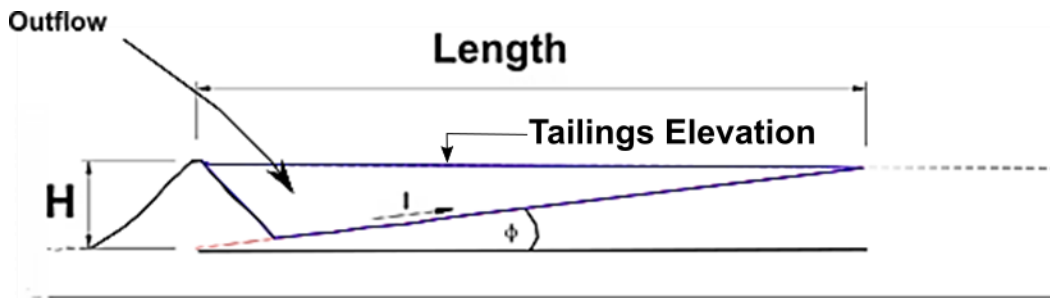


Figure 1 Angle friction on Dam

Piping failure was simulated by means of Bossbreach software, which solves Equation 2 in order to calculate the outflow as an output hydrograph. The analysis considers the total embankment failure and the outflow volume passes through the complete width of the embankment.

$$g_b = A[2g(H - H_p)/1 + fL/D]^{0.5} \tag{2}$$

where: g_b : flow through the pipe; G = gravity acceleration; A : cross-sectional area of the pipe channel; $H - H_p$ = hydrostatic head on the pipe; L : length of the pipe channel; D = width of the pipe; f = Darcy friction factor.

After obtaining the hydrograph, the results were entered as input to the Flo-2D model to evaluate the affected area from the outflow. This program performs finite difference modeling in a three-dimensional space and it is possible to determine flow characteristics such as height, velocity and time of arrival of the flow at different control points downstream of the reservoir

Yield stress and dynamic viscosity vs solid concentration are required for the software that characterise the tailings transportation on the area downstream of the embankment. The Figure 2 (a)-(b) shows the equations for the rheological behaviour. Four samples were tested with a rotational viscometer and correspond to conventional copper tailings.

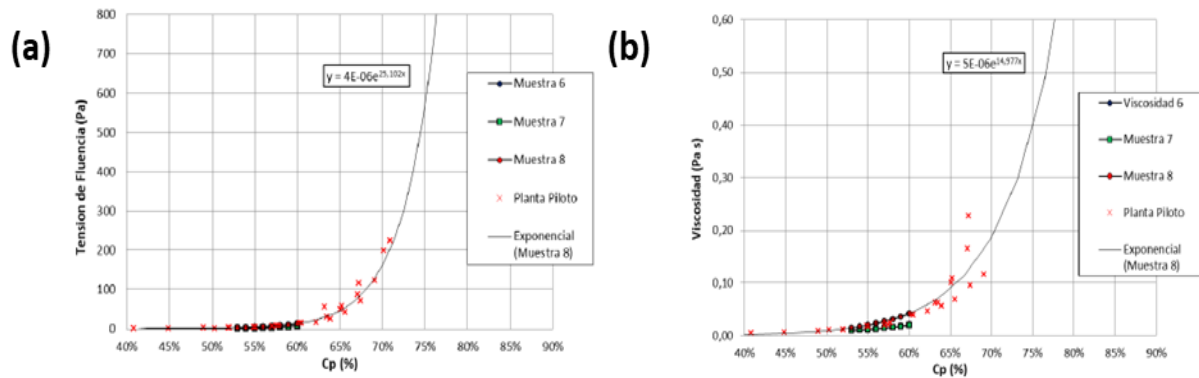


Figure 2 Rheology of tailings utilized in the model (a) Yield stress, (b) Dynamic viscosity.

The aim of the outflow modelling was to evaluate the effect of accelerated or improved tailings consolidation by means of wick drain installation within the impounded tailings during the deposition phase. The purpose of the installation of wick drains is to increase the density of the tailings materials by accelerating the rate of seepage outflow from saturated tailings. The increased density is expected to result in an increase of the rheology of the tailing materials.

Wick drain installation within the impounded tailings was considered up to 20 m depth and 1 m spacing between wick drains. The tailings consolidation was modelled as shown in Figure 3 (a), corresponding to the ultimate configuration of the TSF with the highest column of tailings. A loading pressure of 10 kPa was applied over the ultimate elevation of the tailings column, for a duration of approximately one half year. The wick drains were modelled with a total depth below the surface of 20 meters, as shown in Figure 3 (b); the final excess pore water pressures after the installation of the wick drains are also shown in Figure 3 (b). Figure 3 (c) shows the increase of settlement due to the installation of wick drains, converging to about 2 meters within one half year.

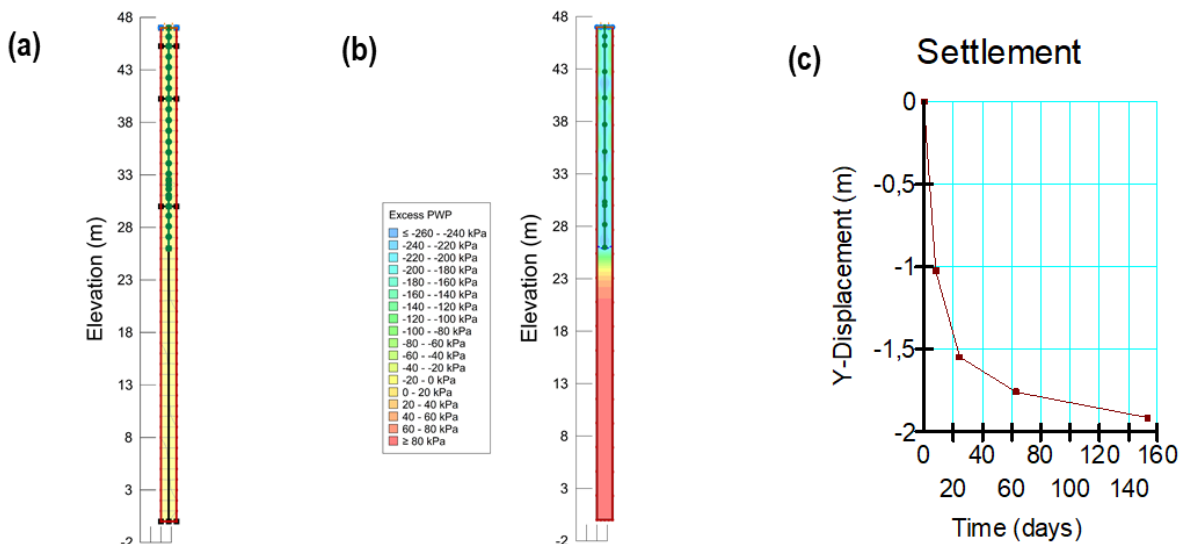


Figure 3 (a) tailings column (b) Excess water pressure (c) Total settlement Tailings

RESULTS AND DISCUSSION

This section presents the model results for the study case. Details for the hydrograph and parameters of the outflow volume are shown in Table 2. The results show an increase of the total consolidation as well as a reduction of the water content between the base case (no wick drains) and the accelerated consolidation case (with wick drains). The accelerated consolidation also increases the equivalent solids content by weight (C_p) from the reduction of the water content. The behaviour of the outflow hydrographs, shown in Figure 4, is similar between each case, but there is a difference in the maximum amplitude between the case base and the accelerated consolidation case.

Table 2 Hydrograph and characteristics parameters

Parameter	Base case	Consolidated Impoundment
Angle $\phi_{Liquefied}$ (*)	3.53°	3.53°
Outflow volume (m ³)(**)	32,219,857	27,854,071
C_p (%) (***)	60	63
Q peak (m ³ /s)	8,844	5,625

(*) Value obtained from eq. (1) and resistance $S_u/\sigma_{vLiquefaction} = 0.06$

(**)The outflow volume was estimated for Base case and Consolidated impoundment using eq. 1 to obtain the friction angle (ϕ), and decrease of the tailings height (volume reduction) due the densification process for the Consolidated impoundment.

(***) Assumed mean value Tailings C_p .

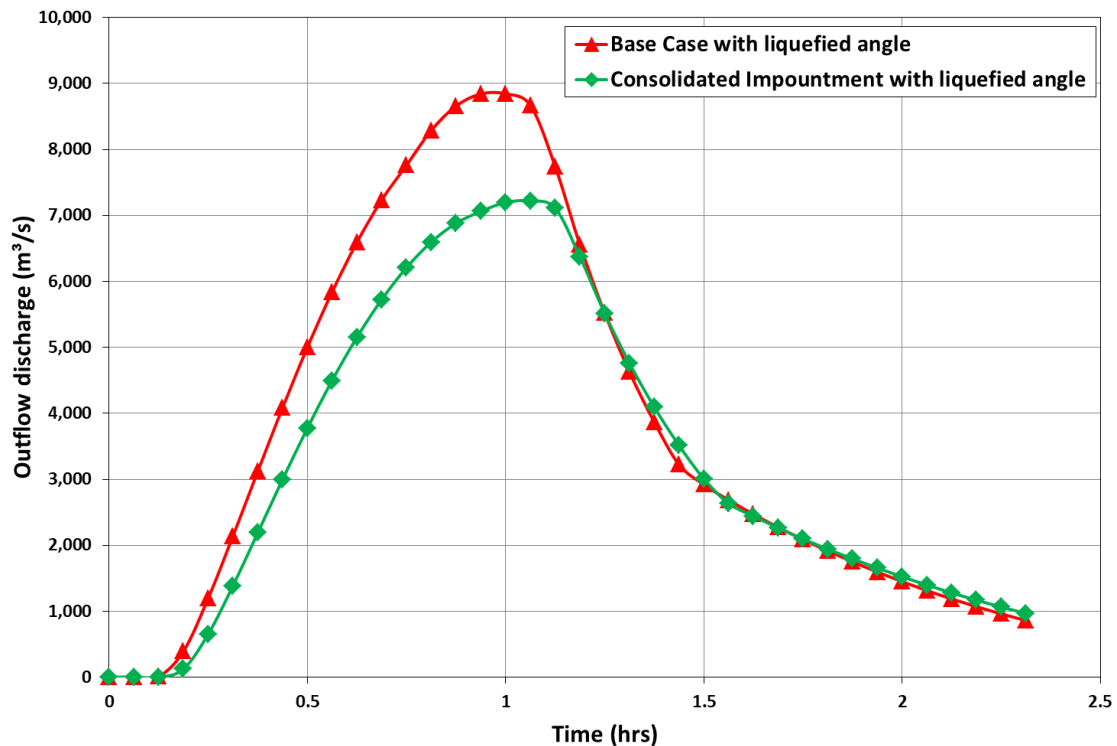


Figure 4 Outflow hydrographs

The results from the run-out model show that the outflow stream reaches high velocities along the initial reach of the downstream path, in accordance with the narrow landscape, and a decrease of the maximum velocity in the flatter landscape. The scenarios evaluated are constrained by the natural topography and the operating time of the wick drains, in this case one half year.

The deployment of wick drains in the impoundment of the TSF results in a higher degree of densification and a higher equivalent Cp value and the resulting flooded area decreases. Figure 5 shows the flooded areas from the outflow volume for the study cases and the maximum velocity of the slurry along the flow path. The flooded area associated to low velocities is reduced in the improved consolidation case (with wick drains). The results show a decrease of the flooded area by 16% as a result of the higher rheology from improved consolidation by wick drain installation.

Table 3 Summary results

Item	Flooded Area (m ²)	Run-out Distance (m)
Base Case	23,855,040	14,097
Consolidated Impoundment	20,113,139	12,941
Reduction	3,741,901	1,156
Reduction (%)	16%	8%

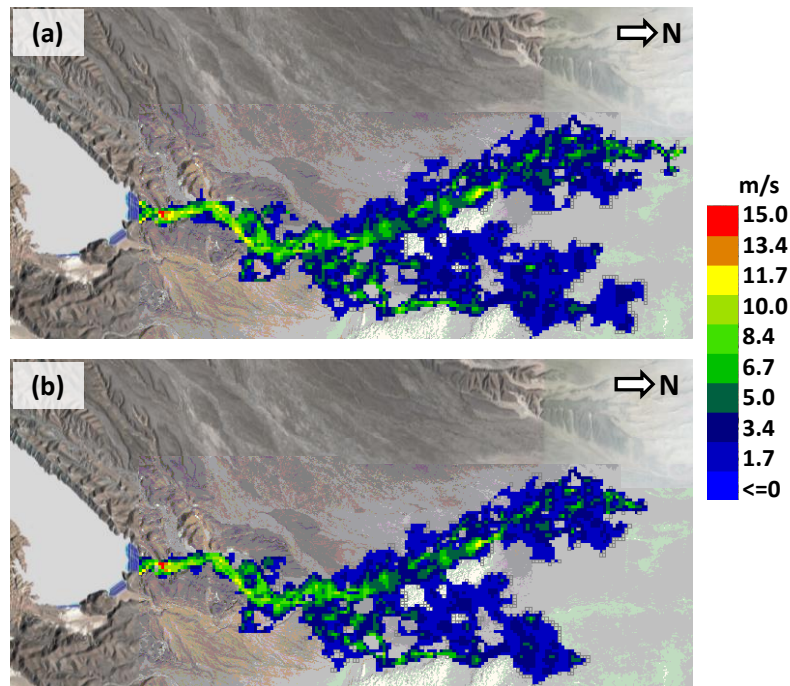


Figure 5 Flooded area and maximum velocity of the slurry along the flow path for liquefied angle. (a) Case Base; (b) Consolidated Impoundment Case

CONCLUSIONS

This research presents an evaluation of the effects of the installation of wick drains in the impoundment of a TSF on the increase of the degree of tailings consolidation and the resulting increase of the rheology and the reduction of the ability to flow downstream of the TSF under a hypothetical dam breach. The rise of 3% on the C_p parameter implies a densification of the tailings and a fall of 16% of the flooded area and under the dam-break analyses the run-out distance decrease 8%. Although the reduction of the run-out distance is not too notorious, the flooded area reduction is significant in the analyses. The wick drains were used in this study because of their ability to accelerate in a short time the dissipation of excess pore pressure.

The results shown are site-specific and serve as an example, and are therefore limited by the topography of the study area; consequently, the reduction of the flooded area presented in this study may vary from site to site. Another important aspect, within the limitations of the results presented in this study, is the operation time of the wick drains.

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