On the use of waste rock inclusions to improve the performance of tailings impoundments

Sur l'utilisation d'inclusions de roches stériles pour améliorer la performance des parcs à résidus miniers

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ABSTRACT: A novel co-disposal method, consisting of the placement of waste rock in tandem with tailings, improves the environmental and geotechnical performance of surface impoundments. The waste rock is used to create linear inclusions within the tailings. These inclusions, being more permeable and more rigid than the tailings, improve the performance in several ways, such as facilitating consolidation of the tailings and augmenting the physical stability of the impoundment. The benefits of this new concept are being evaluated by means of in situ and laboratory testing, analytical and numerical methods and monitoring at a tailings impoundment where it is being implemented.

RÉSUMÉ : Une méthode de co-disposition, qui consiste à placer des roches stériles en tandem avec des résidus miniers, améliore la performance environnementale et géotechnique des parcs à résidus. Les stériles sont alors utilisés pour créer des inclusions linéaires dans les résidus. Ces inclusions, plus perméables et plus rigides que les résidus, améliorent la réponse de plusieurs façons, en facilitant par exemple la consolidation des résidus et en augmentant la stabilité physique du parc. Les avantages de ce nouveau concept, présenté ici, sont évalués au moyen d'essais in situ et en laboratoire, de méthodes analytiques et numériques, et par le surveillance d'un parc à résidus où il est mis en œuvre.

KEYWORDS: waste rock, tailings, inclusions, co-disposal, consolidation, stability, liquefaction, seismicity.

1 INTRODUCTION

Mining and mineral extraction produce two primary forms of solid waste: waste rock excavated to reach ore of economic value and tailings composed of particles of crushed rock from the milling process.

Generally, waste rock and tailings are stored on the surface separately, the waste rock in piles and the tailings in impoundments. The generation of acid mine drainage (AMD), the leaching of heavy metals, the presence of contaminants remaining after ore processing, and the physical stability of the structures formed by these wastes are critical and costly considerations during operations and after the closure of mining facilities.

Aubertin et al. (2002a) proposed a co-deposition method that creates inclusions of permeable, rigid waste rock in deposits of relatively impermeable, soft tailings. The use of such inclusions can result in significant improvement in the environmental and geotechnical performance of the disposal facitlity. This paper describes the concept and the expected improvements in the response of the impoundment based on in situ and laboratory testing, analytical and numerical studies, and observations at a site where it is currently in use.

2 MINE WASTES

2.1 *Tailings*

Tailings are typically produced as slurry composed of rock particles and process water. The particles range in size from colloids (less than 0.001 mm) to fine sands (> 0.075 mm) with the silty fraction dominating. The behavior of tailings is determined by the grain size distribution, water content and plasticity. Tailings from hard rocks mines tend to be non-plastic and are the subject of this research. Typically, the grain size distribution of such tailings lies within the range shown on Figure 1.

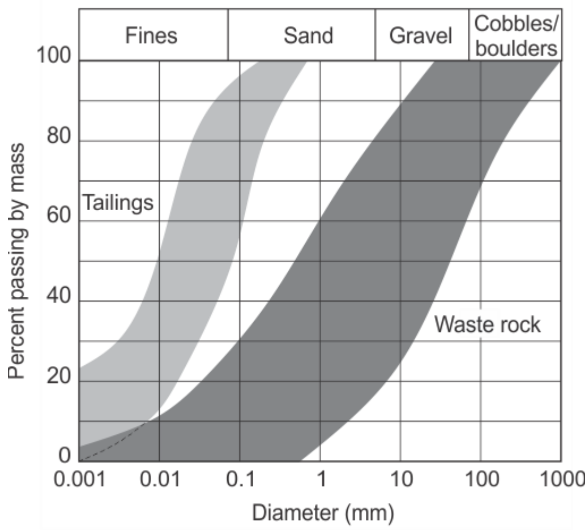

Figure 1. General range of grain size distributions for tailings and waste rock from hard rock mines (adapted from Gamache-Rochette 2004 and Bussière 2007).

For most mines, tailings are deposited hydraulically in impoundments formed by retention dykes and consolidate under their own weight. The predominance of fine particles results in low consolidation rates and porewater pressure build up during filling. For practical reasons, such as waste water storage and to prevent acid generation, the water level in tailings impoundments is often kept near the surface. Such a mass of loose, saturated, cohesionless material is particularly susceptible to liquefaction. Numerous failures of tailings impoundments have been associated with seismically-induced liquefaction, while impoundment failure from other causes often results in static liquefaction (Aubertin et al. 2002a; James 2009; Azam and Li, 2010).

The release of tailings following the failure of an impoundment is the one of the most serious risks associated with mining and historically has caused numerous fatalities and enormous environmental damage (ICOLD 2001).

2.2 *Waste Rock*

Waste rock, the silt to boulder size particles of broken rock excavated to access ore, is a byproduct of mining. It may be chemically inert or reactive, depending on the mineral composition. In any event, it must be stored safely and indefinitely at a reasonable cost. The grain size distribution of waste rock generally falls in the range shown on Figure 1. The gradation of waste rock results in a permeable material with a relatively high stiffness and frictional strength. In geotechnical terms, waste rock can be considered as rockfill.

3 WASTE ROCK INCLUSIONS

The construction of a tailings impoundment with waste rock inclusions would proceed as follows: a) construction of the starter dyke; b) placement of a thin layer of waste rock on the bottom and sides of the impoundment; c) placement of waste rock along pre-designated routes within the impoundment (local heaps can also be placed – not shown here); d) hydraulic deposition of tailings. For each stage of raising of the dyke, the placement of additional waste rock on top of the existing inclusions is followed by tailings deposition.

The resulting configuration of the impoundment with inclusions is shown schematically on Fig 2.

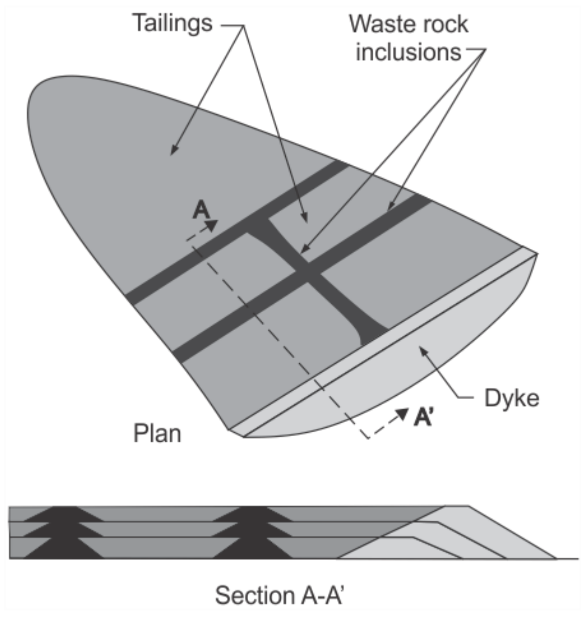

Figure 2. Schematic representation of a tailings impoundment with waste rock inclusions.

The basic premises of the method are that the waste rock being more permeable and stronger than the tailings would accelerate drainage and thus consolidation of the tailings, while providing some physical reinforcement of the tailings. This is somewhat similar to the use of gravel columns in deposits of soft clay or silt for consolidation and reinforcement (Adalier et al. 2003).

The expected benefits of waste rock inclusions include accelerated consolidation and compartmentalization of the tailings, increased stability of the impoundment, and secure placement of waste rock in the impoundment, additional waste management options, and additional closure options.

Two issues which must be addressed are the infiltration of the tailings into the waste rock and the ability of the tailings to support the successive stages of waste rock placement. These are discussed later in this paper.

Waste rock inclusions are currently being used at a gold mine in western Quebec to help manage the tailings and accelerate their consolidation. Figure 3 is photograph of an inclusion at the mine. Surveillance and in situ testing of the performance of these inclusions is ongoing.

Figure 3. A waste rock inclusion in a tailings impoundment at a mine in western Quebec.

4 WASTE MANGEMENT AND CONSOLIDATION

Depending on the respective volumes of tailings and waste rock produced, using waste rock inclusions could allow much of the latter to be placed in the impoundment and eventually submerged, significantly reducing the potential for AMD and possibly eliminating the need for a separate disposal facility for the waste rock. In some instances the reactive waste rock could be used to form inclusions, which will remain submerged, while the nonreactive waste rock is stored conventionally in piles.

Tailings could be discharged from conduit on the top of the inclusions (as is done at the above mentioned mine), as well as on the crest of the dyke, allowing for a more even distribution of the tailings within the impoundment. In wide impoundments this would result in additional volume for storage and more flexible placement schemes.

The hydraulic conductivity of waste rock allows the inclusions to act as drains within the tailings, accelerating consolidation which leads to more rapid strength gain and liberates more water which may be reused at the site. Parametric numerical modeling of tailings consolidation with and without waste rock inclusions by Jaouhar (2012) and Bolduc (2012) indicates that waste rock inclusions can lead to a significant increase in the rate of consolidation, depending on the spacing of the inclusions, the thickness of the deposit, and the hydraulic conductivity of the tailings. The accelerated rate of consolidation is due to the reduced length of drainage paths within the tailings as shown on Figure 4.

There can be some infiltration of the tailings into the waste rock during placement and consolidation. The grain size distribution of the waste rock tends to be highly heterogeneous, in part due to segregation during transportation and placement. Based on field observations at the site where inclusions have been installed, many drainage pathways remain viable despite the infiltration of tailings. Laboratory testing of the effect of tailings infiltration on the flow through waste rock is currently underway.

With respect to the stability of the inclusions within the impoundment, the consolidation of the adjacent drained tailings provides adequate bearing capacity for the support of the successive levels of waste rock.

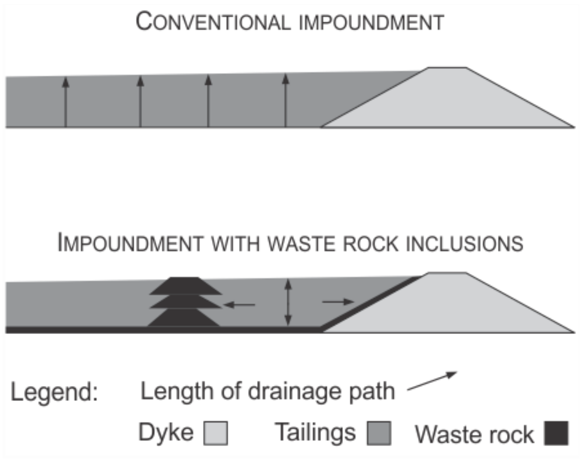

Figure 4. Schematic of the reduced drainage paths for consolidation with waste rock inclusions.

5 STATIC AND SEISMIC STABILITY

Most tailings impoundment failures are the result of, or lead to, the liquefaction and flow of tailings. The liquefaction resistance of tailings increases with consolidation. Therefore, accelerated consolidation provided by waste rock inclusions reduces the tendency for liquefaction of the tailings during operations, particularly when the water table can be lowered below the tailings surface (producing unsaturated conditions).

James (2009) conducted parametric dynamic numerical analysis of a 20-m-high, upstream-raised tailings impoundment, with and without waste rock inclusions. The dynamic loads were equivalent to the occurrence of earthquakes of moment magnitude 6.5 to 7.5 with epicentral distances of 30 km from the site. It was found that the presence of the inclusions significantly reduced the horizontal deformation of the impoundment, particularly at the dyke crest. In the case of the largest magnitude event (7.5), the simulations indicated that the inclusions prevented rupture of the impoundment. The horizontal displacement of the crest of the impoundments obtained from the calculations versus the earthquake magnitudes are shown on Figure 5. The improved performance of the impoundment with waste rock inclusions (WRI) is due to the reinforcing effect of the inclusions. Due to the relatively low permeability of the tailings, the inclusions did not reduce the development of excess porewater pressures during shaking, except in their immediate vicinity.

Tailings impoundments can also fail due to the dissipation of excess porewater pressure generated during and after earthquake shaking (Ishihara 1984). With inclusions, these excess porewater pressures can be dissipated without adversely affecting the stability of the impoundment (James 2009). The positive effect of inclusions on excess pore water pressure development and dissipation was also demonstrated using tests on a seismic simulator (Pépin et al. 2012).

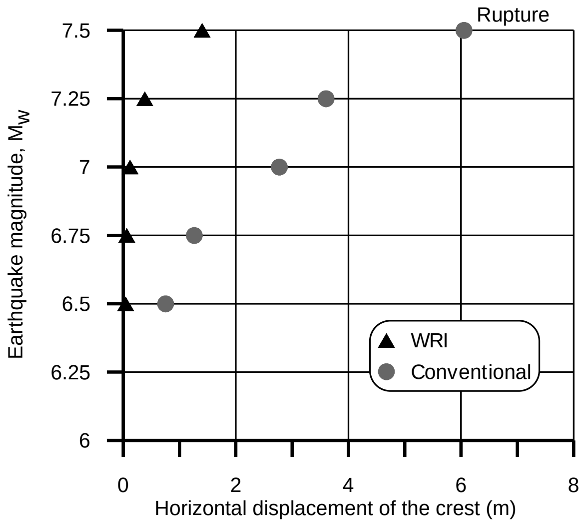

Figure 5. Horizontal displacements of the crest of a conventional and a reinforced (WRI) tailings impoundment as a function of earthquake magnitude (adapted from James 2009).

6 LIMITING THE CONSEQUENCES OF FAILURE

During the dynamic numerical analysis described above, it was found that the presence of waste rock inclusions significantly limited the extent of deformation within the impoundment during shaking. The simulation results also indicated that in the event of a rupture of the retention dyke, the quantity of tailings released, and thus the consequences of failure, would be significantly reduced by the presence of the inclusions. Waste rock inclusions can thus reduce the risks associated with tailings impoundment failure.

7 MINE CLOSURE ASPECTS

By accelerating consolidation and compartmentalizing the tailings, the use of waste rock inclusions can permit faster or staged closure of the tailings impoundment. For example, a cover for long-term prevention of AMD can readily be installed on the surface of consolidated tailings (Bussière 2007). Consolidation of the tailings during operations will result in less effluent from the impoundment following closure.

Additionally, waste rock in the tailings impoundment will not require any closure work in addition to what’s necessary for the tailings. If all of the waste rock can be placed in the impoundment (as can be the case for underground mines), there will be no waste rock piles to reclaim following closure.

8 ONGOING RESEARCH ACTIVITIES

The research activities described above are part of an integrated research program on the use of waste rock inclusions in tailings impoundments being conducted by the authors’ group. Other research activities completed or in progress on this subject are described below.

In situ testing consisting of piezocone testing and test pit excavation was completed in the tailings impoundment of another gold mine in Quebec to characterize the state of the tailings in situ (James 2009).

Conventional and dynamic testing of tailings was conducted on tailings samples to evaluate their static and dynamic properties and behavior. Dynamic testing included cyclic simple shear (James 2009) and cyclic triaxial tests (Poncelet 2012). Additional cyclic triaxial testing is in progress.

Parametric numerical modeling studies of the consolidation of tailings with and without waste rock inclusions were conducted to establish baseline parameters for the dimensioning of waste rock inclusions (Jaouhar 2012; Bolduc 2012).

Seismic table testing of tailings with and without inclusions was conducted to evaluate their behavior under a range of conditions, e.g. drained or undrained, flexible or rigid (Pépin et al. 2012).

The cyclic simple shear testing and shaking table testing were modeled numerically to verify and calibrate a constitutive numerical model used to simulate the dynamic behavior of tailings (James 2009).

Large-scale laboratory testing of the interaction between tailings and waste rock inclusions with respect to infiltration and drainage capacity and the potential for clogging is in progress.

An actual impoundment with WRI is being monitored to assess its response following tailings deposition.

9 CLOSURE

Waste rock inclusions can provide a number of environmental and geotechnical benefits and are a viable option in the sustainable development and operation of mining facilities. Ongoing work is underway to further validate the concept and the results presented here.

10 ACKNOWLEDGEMENTS

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