

Tailings Impoundment Closure Enhancement

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ABSTRACT

Many tailings impoundments provide long-term storage for saturated, semi-fluid fine grained materials. Closure of these tailings impoundments represents an ongoing priority and a potential challenge for owners and professionals due to the potentially fluid nature of the impounded tailings in the event of a hypothetical dam breach.

One solution is to cap and shape the impoundment surface using waste rock or other materials to promote surface runoff, minimize dusting, and densify the underlying tailings through consolidation. Poor surface trafficability can hinder capping operations, and the cap itself may not fully mitigate the potential for deeper saturated tailings to fluidize and flow in the event of a dam breach.

This paper provides an overview of a case study for the decommissioning of the Nye Tailings Impoundment at the Stillwater Mine. Additional details on the site investigations and tailings characterization work that has been completed to support decommission of the impoundment are included in Adams et al (2018) that was presented at the 2018 Canadian Dam Association (CDA) conference. The closure plan includes capping the loose saturated tailings with waste rock along with a cover of surface soils to reclaim the impoundment and create a stable landform. Initial staged construction of the closure cap will be accomplished using a geotextile to improve trafficability during placement of the initial rockfill capping layer.

A potential opportunity to enhance the closure of the impoundment can be achieved through the progressive development of a large waste rock storage area over the capped tailings surface. This closure enhancement would provide significant storage capacity for waste rock and reduce additional site disturbance during ongoing mine operations. As an added benefit, the waste rock load would promote consolidation, densification, and dewatering of the underlying tailings, further reducing the potential for the impounded tailings to fluidize and flow in the event of a hypothetical dam breach. This integrated waste management strategy for the Stillwater Mine will provide operational benefits for ongoing waste rock management while concurrently developing a stable reclaimed post closure landform to enhance the reclamation objectives for the mine site.

INTRODUCTION

Tailings impoundments store fine grained materials that remain from mining operations after the economic minerals have been extracted from the ore during processing. The stored tailings often comprise fine-grained sand, silt, and clay sized rock fragments mixed with water which facilitates slurry transport and deposition into the tailings impoundment. The settled tailings deposit may consist of soft, saturated, semi-fluid tailings in a lined impoundment. Storage of soft, saturated tailings is associated with increased physical risks because of the potential mobility of the material. These risks must be managed throughout the life of the mine and at closure.

Modern tailings impoundments are commonly closed in phases (CDA, 2014). The active closure phase begins once the impoundment reaches the ultimate capacity or the mine ceases production, and typically involves the construction of a closure cap to form a stable landform and minimize dusting. The capped tailings impoundment can then be reclaimed to other desirable land uses such as recreational or natural areas. The impoundment is closely monitored for a number of years during the active closure phase and will transition to passive closure once the long term physical and chemical stability of the impoundment has been demonstrated.

Demonstrating long term stability during closure for time periods ranging from decades to centuries is challenging given the complexity and uncertainty associated with future performance predictions. During the closure period, there is the potential for changes in the local environment, land use, meteoric conditions, topography, geology and state of practice. Increasing the density and reducing the flowability of the settled tailings within a tailings impoundment can reduce the consequence of a hypothetical dam breach and de-risk the tailings impoundment following closure.

This paper presents a case history for the tailings characterization, closure design, and proposed closure enhancement for the Nye Tailings Impoundment at the Stillwater Mine. The closure design involves the construction of a closure cap to stabilize the tailings surface and limit dusting. The closure cap will be constructed in stages to allow time for consolidation and strength gain while providing the mine with operational flexibility and capital cost distribution.

There is an opportunity to enhance the closure of the Nye Tailings Impoundment by placing additional waste rock over the capped tailings. Placement and storage of waste rock at the closed tailings impoundment will cause additional consolidation, dewatering, and densification of the underlying tailings. This will further stabilize and de-risk the closed tailings impoundment by reducing the potential for the tailings to flow in the event of a hypothetical dam breach event. Additional storage capacity for waste rock within areas that are already affected by the mine operations will reduce the need for additional disturbance and reduce the overall environmental impact of the ongoing mining operations. These improvements will lead to a reduction in the risks associated with the project, in both the operations and closure phases.

PROJECT OVERVIEW

The Stillwater Mine is an underground platinum and palladium mine located approximately 5 miles southwest of Nye, Montana (MT), United States. The mine site layout, including the Nye Tailings Impoundment and the East Waste Dump, is illustrated on Figure 1.



Figure 1 The Nye Tailings Impoundment (looking East)

The coarse (sand) fraction of the tailings was historically pumped underground for cemented paste backfill to support the underground mining operations, while the finer tailings slimes were deposited into the Nye Tailings Impoundment located adjacent to the Stillwater River.

The Nye Tailings Impoundment was commissioned in 1987 and operated as the primary tailings impoundment until 2001. Tailings have only been intermittently deposited to the Nye Tailings Impoundment since another Tailings Impoundment was commissioned in 2002. The Nye Tailings Impoundment is near capacity and is currently utilized for operational management of water and tailings. The supernatant pond generally covers the northern half of the tailings impoundment, though the volume and surface area vary with meteoric conditions and the mine operations

The Nye Tailings Impoundment contains predominately fine grained tailings consisting of fine sands, silts, and clay sized rock fragments. Site investigations in 2016 and 2018 included geotechnical drilling and sampling, Cone Penetration Testing (CPT), and the installation of vibrating wire piezometers to characterize the tailings on the exposed tailings beach and below the supernatant pond to support the closure design. Key laboratory testing included Index, Direct Simple Shear (DSS), Constant Rate of Strain (CRS) consolidation, Cyclic Direct Simple Shear (CDSS) and Rheology testing.

The tailings in the Nye Tailings Impoundment are generally coarser at the south end of the impoundment and finer towards the north end of the impoundment. Sensitive fines were observed in the northern and north eastern areas of the impoundment while sandy silt and clayey silt was

observed in the southern and south western areas of the impoundment. A generalized stratigraphic cross section trending south to north through the impoundment is illustrated on Figure 2.

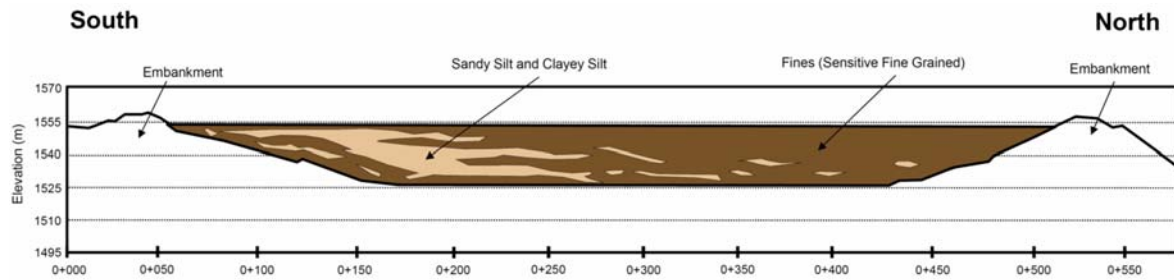


Figure 2 Typical South-North Stratigraphic Section through the Nye Tailings Impoundment

The phreatic surface within the tailings was observed at surface and the tailings are fully saturated and hydrostatic, consistent with normally consolidated tailings contained within a fully lined tailings impoundment.

CLOSURE PLAN

The closure plan for the Nye Tailings Impoundment has been developed to provide for long term public safety and to protect air, surface water, and groundwater resources at the site and on adjacent lands. The permitted closure plan includes construction of a closure cap over the tailings surface. The closure cap will include the following components:

- Placement of a geomembrane protection layer to maintain the integrity of the exposed geomembrane along the upstream slope of the embankment.
- Reduction and ultimate removal of the supernatant pond.
- Placement of a closure cap to stabilize the tailings surface. The closure cap will consist of a 1.2 m thick waste rock cap placed over a geotextile to improve trafficability.
- Installation of a sump and overflow spillway within the closure cap for surface water management during mine operations.

Placing the closure cap over soft, saturated tailings may present challenging construction conditions. The closure cap will be constructed over 4 or more years to allow time for removal of the supernatant pond and corresponding consolidation and strengthening of the tailings surface. The stability of the tailings will be closely monitored during and following construction of the closure cap. Monitoring will include piezometers to measure the pore pressures in the tailings, and survey monuments and inclinometers to confirm the stability of the embankments. The closure process will be complete once the closure cap is constructed and the monitoring data suggests that the impoundment is stable.

Once completed, the closure cap will stabilize the upper layer of the tailings, create a trafficable surface, provide long term water management, and minimize dusting. The reclaimed impoundment embankments and the capped and closed tailings impoundment surface will form a stable landform.

CLOSURE ENHANCEMENT

Tailings Densification

The behaviour of settled tailings varies significantly with water content and density as illustrated by the Boger Slump rheological tests shown in Figure 3. As the water content of the tailings decreases from left to right, the density increases and the tailings become less flowable under static stresses.



Figure 3 Tailings Flowability

Figure 3 illustrates the effects of changing the moisture content and density of the settled tailings. A similar relationship has been noted between strength at a given moisture content, and the tailings grain size and clay content (i.e. Adams, et al, 2017a). Finer grained tailings with higher percentages of clay are more stable than coarser, sandy tailings at the same water content.

Many different ground improvement technologies are available and can be effectively applied to tailings impoundments to improve the performance of the settled tailings. A commonly used and effective ground improvement technology involves constructing a compressive load to induce consolidation in the underlying soil as illustrated on Figure 4.

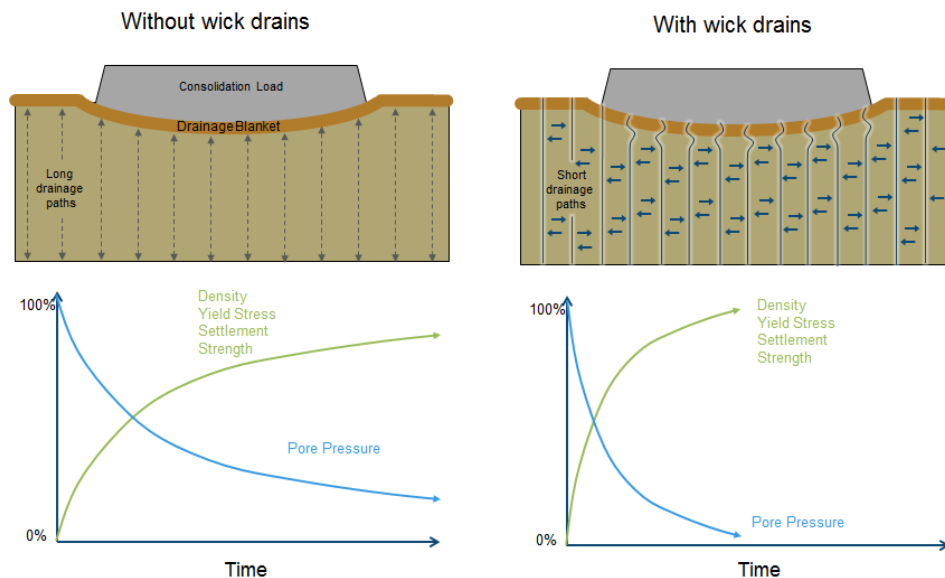


Figure 4 Schematic ground improvement technology consisting of a compressive load constructed over tailings amended with wick drains.

As the soil consolidates, the density will increase and the water content will decrease. This process may require long time periods to achieve the desired effect depending on the characteristics of the

soil. Wick drains can be installed to enhance the soil drainage and accelerate the consolidation process. Adams et al (2017b) 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.

The weight of the waste rock closure cap overtop of the Nye Tailings Impoundment will result in consolidation of the near surface tailings which will in turn increase the density and reduce the water content and flowability of the near surface tailings. This will create a stable landmass for the expected loading conditions. A portion of the settled tailings within the landmass may remain in a semi-fluid state and may have the potential to flow during a hypothetical dam breach event. Although the probability of a hypothetical dam breach is very low, additional tailings densification could be achieved by increasing the thickness of the waste rock overtop of the closed tailings impoundment. The additional tailings consolidation would increase the density and reduce the flowability of the settled tailings. This will further reduce the consequences of a hypothetical dam breach and will de-risk the tailings impoundment following closure.

Future Waste Rock Storage

The proximity of the Nye Tailings Impoundment to the underground mine makes it an ideal location for future waste rock storage for the ongoing operations at Stillwater Mine. Re-purposing the closed Nye Tailings Impoundment as a Waste Rock Storage Area (WRSA) will achieve the following objectives:

- Reduces the overall disturbance area required to support ongoing mine operations
- Provides a new waste rock storage area located within a short haul distance from the shaft and underground portals
- Enhances the closure of the Nye Tailings Impoundment by further consolidating, densifying, and dewatering the tailings contained within the closed impoundment to further reduce the flowability of the settled tailings during a hypothetical dam breach event.

A conceptual section illustrating the potential waste rock storage arrangement overtop of the Nye Tailings Impoundment and on the adjacent valley slope is illustrated on Figure 5.

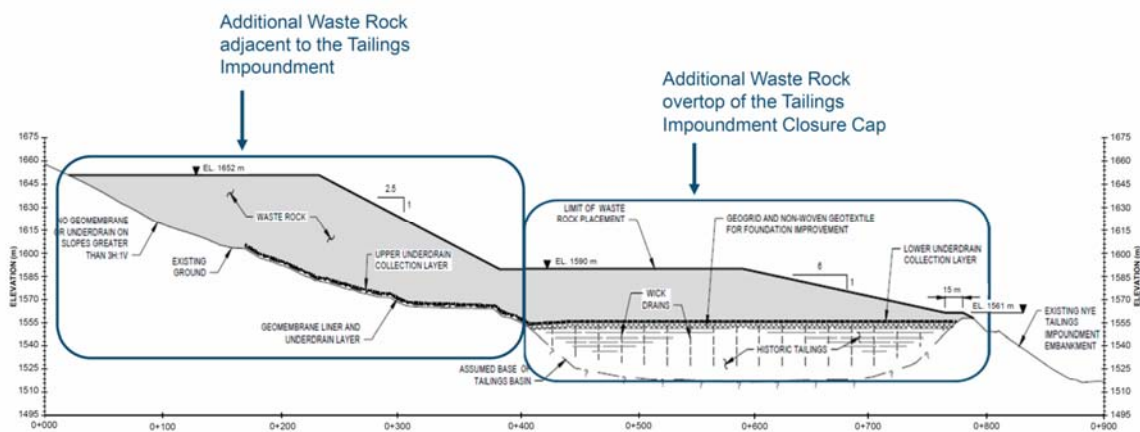


Figure 5 Conceptual Closure Enhancement – Waste Rock Storage Area

The total mass and placement geometry of waste rock that could potentially be stored over the closed Nye Tailings Impoundment will depend on the strength, deformability, and drainage characteristics of the tailings, the rate of waste rock placement, and the ability of the impoundment embankment to support the additional load. The waste rock placement schedule will need to allow time for pore pressures that develop in the underlying tailings to dissipate. Wick drains may be necessary to enhance drainage and accelerate pore pressure dissipation.

The potential response in the tailings as a result of the closure cap construction, and further placement of waste rock over the closed tailings impoundment is conceptually illustrated on Figure 6. Currently, the tailings at depth are consolidated under self weight and hydrostatic pore pressures and have a soft to firm consistency. Construction of the closure cap is expected to substantially increase the density and decrease the water content in the near surface tailings, but may have a much lesser impact on the deeper, denser tailings. The placement of additional waste rock over the capped tailings impoundment will result in additional loading over the entire tailings volume and will induce further consolidation, densification, and dewatering at depth. Reducing the water content of the tailings will result in an increase in yield strength and a reduction in the potential to flow.

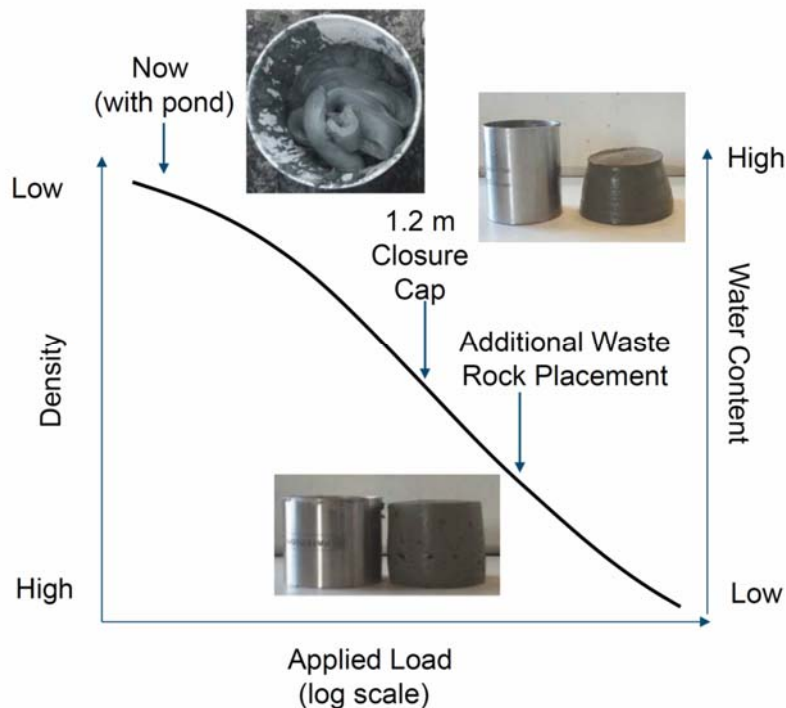


Figure 6 Tailings Rheology Continuum at Closure

It is important to note that the tailings will remain normally consolidated despite placement of additional waste rock. Over long periods of time the tailings may become slightly over consolidated due to ongoing creep (secondary compression). However, the tailings void ratio is expected to remain above the critical state line. As a result, there will still be potential for the tailings to contract and liquefy in response to a triggering event. Reducing the volume of water stored within the tailings mass will significantly reduce the potential for the tailings to flow.

The additional waste rock will be placed in stages and the observational approach will be implemented to carefully monitor the performance of the facility. The waste rock will be placed in a controlled manner and at a rate to allow time for pore pressure dissipation and strength gain, thus mitigating the potential for undrained failures. Instrumentation and monitoring including vibrating wire piezometers, settlement monuments, slope inclinometers, and regular surveying will be used to monitor the tailings response and embankment performance. The construction staging and waste rock placement rate will be adjusted as necessary to manage pore pressures within the tailings and to provide for a stable storage facility during ongoing mine operations and at closure. Consolidation and deformation within the underlying tailings mass will enhance the overall stability and lower the long-term consequences associated with a hypothetical dam breach event, effectively de-risking the tailings impoundment post closure.

SUMMARY

The Nye Tailings Impoundment is near capacity and is currently being used to provide operational flexibility for process water and tailings management at the Stillwater Mine. The closure plan for the Nye Tailings Impoundment includes construction of a closure cap to stabilize the tailings surface and provide long term water management.

There is potential to enhance the closure for the Nye Tailings Impoundment by storing additional waste rock over the capped tailings surface. This integrated waste management strategy will provide operational benefits for ongoing waste management while concurrently developing a stable reclaimed post closure landform to enhance the reclamation objectives for the mine site. The controlled placement of waste rock over the impounded tailings will promote further densification and dewatering in the tailings at depth, thus reducing the potential for the tailings to flow during a hypothetical dam breach event and de-risking the project.

This closure enhancement approach is not unique to the Nye Tailings Impoundment and may be applicable to other facilities. The following key aspects should be considered during the planning stages for similar projects:

- Tailings Characterization – A tailings characterization program is required to evaluate the type, strength, and deformability of the tailings. The tailings characterization program should include in situ CPT probes and the collection of representative samples for laboratory testing.
- Design – The design should evaluate both the stability and deformation of the tailings and overlying waste. The staging plan should be developed in conjunction with the mine plan to provide sufficient time to allow for consolidation and pore pressure dissipation in the impounded tailings.
- Monitoring – Monitoring is required to evaluate the field performance of the tailings under increasing effective strength. At minimum, vibrating wire piezometers should be installed to monitor pore pressures within the tailings and inclinometers should be installed to monitor the stability of any embankments. Regular surveying is recommended to monitor the rate of settlement of the tailings.

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