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Improvement of geotechnical and environmental conditions of mine taillings facilities by pre-fabricated vertical drains and jet grouting

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ABSTRACT

Ground Improvement provides solutions for a variety of geotechnical and environmental issues faced by operators of mine tailings facilities. Typical challenges include: excess fluid waste that does not decant water naturally due to fines content, dam instability and excessive settlement, leaking beneath dams, and the inability of operators to cap existing tailings facilities. Another concern may be the inability to place solid material and vegetation on top of the pond during the reclamation phase. There are a variety of proven ground improvement techniques that can be utilized to solve each of the issues above. This paper will present two case histories describing the use of ground improvement (wick drains and jet grouting) to improve tailings facilities.

1 INTRODUCTION

Several mine tailings failures have caught the attention of the general news media in recent years. Media coverage has attacked mine failures from the most recent Gold King Mine in Colorado, to the Mount Polley failure in British Columbia, to the Duke Energy collapse in North Carolina. There have also be significant mine failure in central and south America in recent years. Because of the remote nature of the sites and the media coverage in the respective countries, these incidents have not resulted in major news coverage in in the US and Canada. However these failures had environmental impact similar to, or greater than the failures in North America. Why is our industry being plagued by these mine failures? Are we currently seeing additional failures than in previous decades? Are we hearing about the failures in North America, and the failures in more remote locations are simply not being reported on? All of the referenced failures and many others resulted from stored tailings impoundments.

Depending on the operations of a given mine, water may be used in the mining process. The water can be used to move fine mine tailings, or even with the addition of various leachates may be used to extract the mined mineral from the tailings. Water has historically been a critical resource in many mining operations. Often times the mining operations that rely on water also prevent the water from being released from the fines or minerals that the water was used to carry. Because of the industrial process the water often cannot decant on its own. This results in an excess buildup of pore water pressure within the tailings. The pore water pressures cannot be relieved easily because of the nature of the fines. Generally in mining operations the fines will be all sub 200 size, silt like particles with relatively low permeability. The pore water pressures, combined with the low permeability of the material result in the tailings maintaining a fluid like or semi fluid state for a number of years or even decades. Until the pore water pressure can be relieved, the potential exists for the material to flow off the mine property into watersheds and other sensitive environments, posing a risk to the general public. Tailings dams are designed to prevent the movement of this material. However the dams may fail for a number of reasons, allowing movement of the fines.

The fluid nature of the tailings in many mining facilities may require substantial structures to hold back the tailings. If the owner of the tailings dam no longer wishes to upkeep the dam, or if a regulatory body requires that the dam no longer function as a dam, what steps can the owner of the facility take to reduce the risk of a breach of the dam? There are essentially two treatment options for the fines in a majority of the industrial facilities in North America. Either removal of the material from the tailings pond or treatment in place. The disadvantage of removing the material from the impoundment is the sheer cost and scale of such an operation. The impoundment may have been constructed over years or decades and may impound millions of cubic meters of material. Because of the incredible task of removal of the material, in situ treatment of the fines may prove to be a more economical and feasible solution.

Once an owner of the facility determines that treatment of the material must be completed they must decide between in situ and ex situ treatment, Ex situ treatment typically consists of removing the material from the pond and then stabilizing the tailings with pozzolanic materials such as lime, cement, or slag.

One technique the authors have employed is the use of drains (commonly known as wick drains, prefabricated vertical drains, or band drains) to reduce the moisture content of the tailings. The drainage of the tailings results in removal of pore water from the tailings and therefore consolidation of the material. The authors would like to highlight one particular project at an abandoned gravel quarry in an urban environment. Wick drains were placed in the tailings. Surcharge was then placed on top of the tailings pond. The surcharge material resulted in removal of excess water from the tailings. The wick drains reduced the seepage path of the pore water pressure, which reduced the time required for the consolidation to occur. The goal of the project was to increase the shear strength in the tailings to the point where the once semi fluid material could be excavated with conventional equipment. The excavation and removal of the inadequate and abandoned tailings dam was required by the regulatory agency. Through draining of the tailings allowed for the tailings to become self-supporting for the required excavation and subsequent redevelopment.

The abandoned quarry site required ground improvement to stabilize the tailings to allow for re-sale of the valuable property. The mine operator had already taken the reserves of marketable stone from the quarry. Without treatment of the fines, the mine operator did not have the ability to return this land to the market and use the revenue for other purposes. This particular project had more of an economic incentive to complete the remediation than many traditional mine sites would have, however the lessons learned from the ground improvement are still applicable to traditional mine tailings recovery sites.

The material in the pond was generated from washing of gravel. The material washed out of the gravel was essentially a silt particle. The silt was washed from the gravel to meet DOT and building standards for course aggregate. Silt particles do not settle out of water easily and have a very low friction angle particularly when saturated. In place shear strengths were low enough that special care was taken to not capsize the wick drain installation equipment during installation.

The material was nearly all sub 200 particle size silt like particles. The permeability of this material prevents drainage of the pore water pressures in a timely manner. The removal of the water from the tailings then increased the internal friction angle of the material, resulting in an increase in shear strength.

The wick drains were installed on either a 2.2 meter spacing, or a 3.8 meter spacing, depending on the target consolidation level and the time available for consolidation. Wick drains were installed to a depth as great as 34 meter. The owner had targeted a 6 month consolidation window to reach 80-90 percent consolidation. The water that surfaced from the wick drains was channelled out of the work area using horizontal strip drains. The drains were installed prior to installation of the 9.5 meter of fill. Because of the rheology of the fines the specialist contractor needed to install the wick material with a smooth wall mandrel without vibration. There were concerns that installation with other types of equipment would result in liquefaction of the material, and possible clogging of the wick drain filter material. The wick drains terminated in the native materials lying below the mature fines.

Once the tailings had increased their shear strength to allow traditional excavation, Heavy construction equipment could be utilized to remove the abandoned and insufficient tailings dam. Figure 1 highlights the area with tighter wick drain spacing, which will be excavated and removed. Figure 2 demonstrate the volume of soil to be removed from the pond.

The wick drain installation allowed for the project goals to be met – removal of the abandoned mine with conventional equipment. After the removal of this material and replacement with engineered fill, the site was deemed satisfactory for traditional construction to proceed.

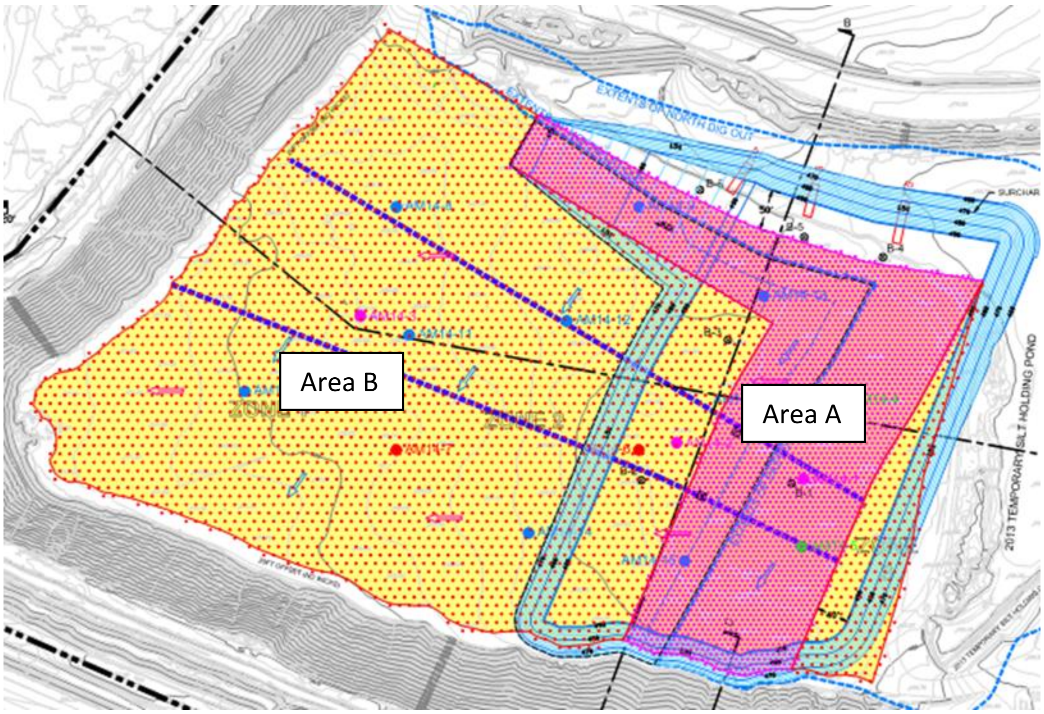

Figure 1. Plan view showing wick drain installation locations. Area A has wick drains on a 2.2 meter spacing, and is the area of the dam removal. Area B has wick drains on a 3.8 meter spacing.

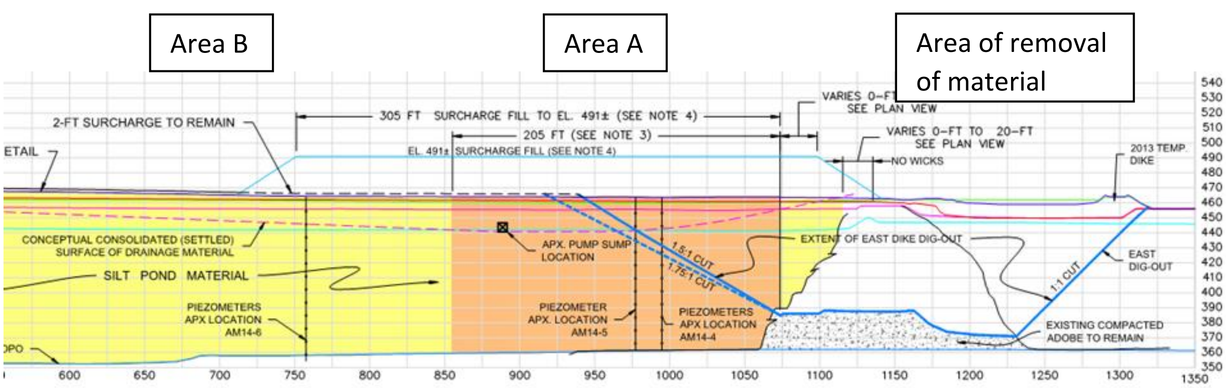

Figure 2. Shows the wick installation areas, A and B as well as the area of mass excavation in section.

2 CASE HISTORY TWO – JET GROUTING FOR REMEDIATION OF TAILINGS

2.1 Introduction

The subject mine tailings remediation project is located at a remote site at a high elevation in a seismically active region. The copper mine operated between 1938 and 1957. After sitting dormant for over 50 years, the 120 acre site is undergoing a multimillion dollar remediation. Because of the project's remote location all required personnel, equipment, materials, and supplies were required to loaded on a vessel and barged over 40 miles and then hauled 12 miles up a forest service road. Heavy winter snowfall limits the construction season to roughly 5 months beginning in early June and extending into October, conditions permitting. While onsite the remediation personnel were housed in the mining camp once used by the miners themselves.

During active mining operations, tailings were piled immediately adjacent to a creek at slopes up to 45 degrees. As part of the remediation effort, the three tailings piles are being re-graded to flatter slopes. During early investigations, liquefiable layers called "slimes" were encountered at the boundary between the tailings and the underlying alluvial deposits. The slime layer posed a significant seismic hazard for the stability of the tailings piles.

Jet Grouting was selected as the design solution to create in situ blocks of soil-cement to act as shear keys along the half mile long toe of two of the tailings piles. This solution improved the factor of safety to the global slope stability analysis during a seismic event to acceptable levels. The operation consisted of installing 119 blocks, each consisting of six 1.6 meter diameter Jet Grout Columns were constructed. Figure 4 shows a portion of the toe of the tailing pile and the jet grout shear keys.

Jet grouting is an erosional based grouting technique used to improve the geotechnical characteristics of soils. During the jet grouting process a drill still is extended to depth. Grout and water is then pumped through small diameter nozzles at a high velocity. This pumping action results in erosion of the soils as well as mixing of the native soils with the introduced grout.

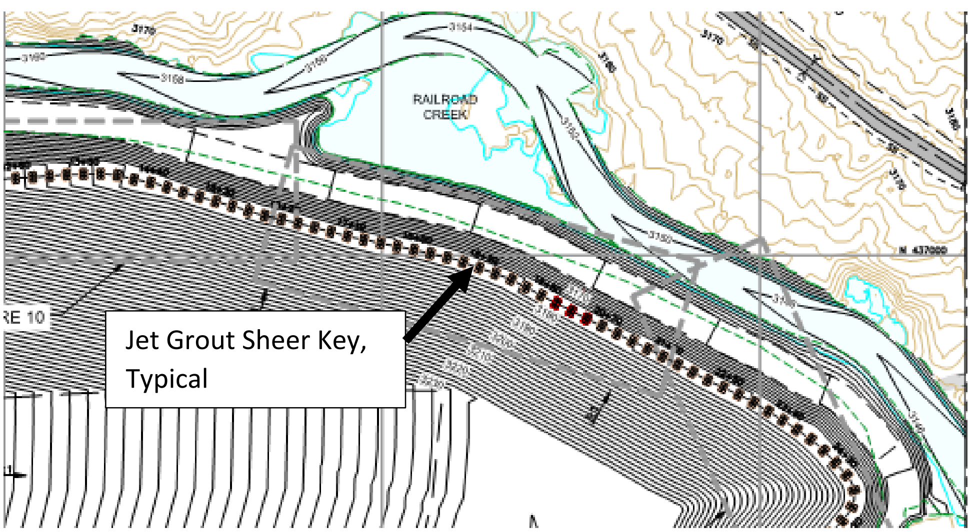

Figure 3. Jet grout shear keys along the toe of the tailings pile.

The specialty contractor worked with the owner to conduct a pre investigation program. As part of this pre investigation program, six soilcrete blocks were constructed to evaluate the effectiveness of jet grouting in the site soil conditions. Three independent combinations of jet grouting withdrawal and rotation rates were evaluated during the test program. The jet grout column installation within each block was sequenced using primary and secondary columns. Of the six test blocks, three were installed at a location where they could be sampled using a core drill and then later exhumed. This allowed for visual inspection of both the internal and external attributes of the blocks. The remaining three blocks were installed on the production bench, at the actual elevation of the production work. Because these blocks were constructed 50’ below grade visual inspection was not possible. Instead these locations were cored to test the effectiveness of the jet grouting in the tailings, slime, and alluvial material.

While the jet grout test locations were being complete, cone penetration tests (CPT’s) were conducted at the location of each proposed production jet grout blocks. Standard penetration tests (SPT’s) were completed at each 5th block to obtain samples of the insitu material. In total, data was collected from 157 CPT and 26 SPT locations. Analysis of the obtained geotechnical engineering data identified potentially liquefiable zones and provided engineering properties of the ‘slimes’. The efforts of the extensive pre-investigation program allowed production grouting to be completed at specific targeted depths as well as specific targeted treatment lengths.

Production Jet Grouting then began the following season incorporating the recommended parameters and lessons learned from the pre-investigation program. In production, the actual depth and length of treatment was “field fitted” in real time by correlating the drill rig response to the field investigation data. Data was collected in real-time using a proprietary data acquisition software and hardware package.

Quality control of the jet grouting consisted of taking unconfined compressive strength of wet-cast spoil samples and core samples. Coring was also conducted to verify column diameter and overlap.

Jet grouting has proven to be an effective means for increasing the factor of safety of the slimes during a seismic event. The extensive geotechnical investigation and pre-production analysis improved the effectiveness and efficiency of the jet-grouting program. Having an understanding of the subsurface conditions at each jet grout block allowed for the jet grouting parameters to be fine tuned for the actual subsurface conditions.

Figure 4. Jet grouting and spoils handling at the remote mountainous site. Jet grouting is being used to form shear keys in the slime layer at depth.

3 CONCLUSION

Ground improvement is an effective means for treatment of mine tailings. The paper presents two of the many possible solutions for treatment of tailings. Ground improvement programs can be tailored to actual site conditions.

Given the social and environmental oversite in today's world of mining, mine owners and operators cannot be too careful in evaluating the risk of movement of existing tailings. As mine tailings facilities are forgotten or decommissioned there are ways to improve the tailings that would prevent future discharge of the tailings off of the mine property. Improvement can be through mixing of binders into the material or by removal of the water from the cuttings. Each of these techniques can be accomplished in a variety of ways. Specialist contractors and consultants can be a valuable resource in determining the most cost effective means of treatment at a given facility.