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Construction Of A Cut-Off-Wall For Existing Tailings In Warm Permafrost In Alaska

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SUMMARY: Diaphragm walls are mainly known as underground structural elements commonly used for retention systems and permanent foundation walls or elements. They can of course also be used as deep groundwater barriers. This paper will describe the construction method and sequence of activities required for the construction of diaphragm type cut-off-walls using a trench cutter system. It also describes the main equipment which is needed to execute these works. By way of example, the paper will focus on the installation of a cut-off wall which has been designed along the Back Dam of the existing tailings impoundment at Red Dog Mine, Alaska. Upon completion the cut-off wall was about 1,525 m long and up to 45 m deep. The tailings impoundment is situated in an area of warm permafrost and high potential seismic activity, and as such the design had to account for thawing of the permafrost and the potential for seismic loading. Design incorporated an assessment of rock jointing to define the final depth of the wall along the alignment, and required the use of plastic concrete backfill to address the concerns associated with potential cracking of the wall due to settlement and seismic activity. About 371 m² of cut-off wall was constructed in 2007 to evaluate the performance of the cutter heads, the slurry transport systems, and the mix design. Cut-off wall construction continued in earnest in 2008 and 2009 operating with two 12-hour shifts from May to October. Approximately 13,750 m² of wall was completed in 2008 and13,935 m² in 2009. The wall was completed in 2010.

KEYWORDS: Cut-Off-Wall, Tailings, Cutter.

1 INTRODUCTION

In 2002 Teck Alaska Inc. (TAK) commissioned Golder Associates Inc. (Golder) to design a Back Dam to minimize the potential for seepage at the southern end of the tailings impoundment at Red Dog Mine, Alaska. The Back Dam was to be designed for an elevation of 292.6 m with a planned closure elevation of 300.5 m and was to include provisions to reduce long-term seepage through the native materials and weathered bedrock.

The initial design concept included construction of a cofferdam with installation of a geomembrane liner on the upstream face of the Overburden Stockpile that would be keyed into silty native soil of relatively low permeability. A geotechnical investigation completed by Golder in 2004 found ice-rich and organic materials as well as highly fractured bedrock near the liner key-in elevations, effectively rendering this concept unacceptable.

During revision of the Back Dam design and to address the concerns of regulatory bodies, TAK requested that Golder revise the design and incorporate a cut-off through the proposed Back Dam embankment, and extending to low permeability frozen bedrock to reduce the risk of seepage through the native materials and weathered bedrock. Several cut-off wall options were evaluated including sheet pile installation, slurry trench installation, extension of the geomembrane liner into a trench, and a cut-off wall constructed using deep soil mixing processes; specifically the Bauer Cutter Soil Mixing System (CSM).

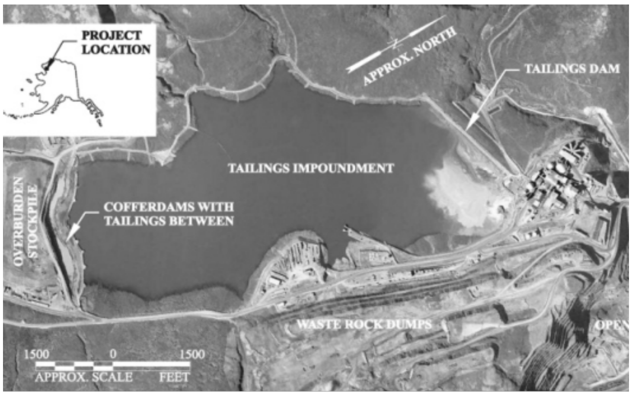

Figure 1. Back Dam Location

Subsequent discussions with the regulators indicated that completion of a cut-off to the frozen bedrock alone would not satisfy requirements and that the design should consider the effects of some thawing of the permafrost with possible seepage through the thawed bedrock. Additional geotechnical investigations along the southern cofferdam in 2005/06 to determine the depth to unweathered, low permeability bedrock, determined the required toe elevation of the wall, assuming thawed conditions. This indicated variable depths along the alignment, with the deepest section extending to about 51.8 m below the proposed dam crest elevation of 292.6 m.

Following this investigation it was obvious that use of the Bauer CSM system would no longer be practical due to the required depth of the wall, and more importantly, the extent of the required penetration into hard rock. As an alternate, the Bauer Trench Cutter system was proposed. The Trench Cutter system has a proven track record of construction of deep cut-off walls extending deep into hard rock conditions

2 SITE CHARACTERISTICS

The Red Dog Mine is located approximately 144 km north of Kotzebue, Alaska at about 68 degrees latitude. The proposed Back Dam is located at the north end of the overburden Stockpile, as shown in Figure 1.

The climate at the Red Dog Mine is characterized by long, cold winters and moderately warm, windy and somewhat rainy summers. The average annual temperature is -4°C with an air freezing index (AFI) of 2628°C-days and an air thawing index (ATI) of 1055°C-days. Total precipitation is generally between 25 to 33 cm per year and the average annual snowfall is 120 cm.

Subsurface conditions were characterized near the proposed cut-off wall location from the data acquired during the geotechnical investigations completed in 2004 through 2006. These included 15 boreholes near the north face of the Overburden Stockpile and 26 boreholes along the southern cofferdam and near the abutments. The locations of these boreholes are shown in Figure 2 with subsurface profiles shown in Figure 3.

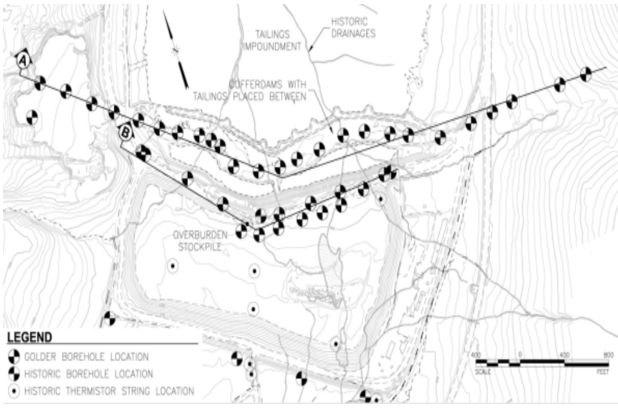

Figure 2. Borehole Locations

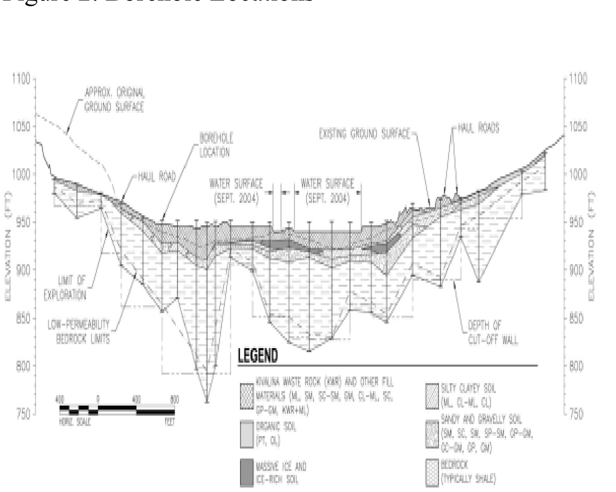

Figure 3. Section A through Cofferdam

These investigations also included test pits, thermistor string readings, packer tests, and laboratory testing. The significant findings of the investigations are summarized as follows.

Fill materials were encountered on the haul roads, cofferdam, and Overburden Stockpile. The waste rock fill materials at the haul road and cofferdam generally had a composition of silty gravelly soil with occasional cobbles and boulders. Fill materials at the Overburden Stockpile mainly consist of Kivalina shale that had been stripped from the mining area.

The native soils are colluvial and alluvial materials comprised of organic soil, ice and ice-rich soil, silty clayey soil and sandy gravelly soil.

The shale bedrock underlying the colluvial and alluvial materials is typically highly to completely weathered near the contact surface becoming fresher with depth. The rock is generally fractured with a rock quality designation (RQD) of less than 20%. Rock strengths vary from weak (R2) to very strong (R5) with estimated uniaxial compressive strengths (UCS) up to 150 MPa. The majority of bedrock encountered during the investigations, about 75%, had a UCS that was less than 50 MPa.

3 Design Considerations

3.1 Cut-off Wall Panel Target Depths

The depth to low permeability bedrock, which was defined as rock having a permeability of $1x10^{-6}$ cm/sec or lower, was established during the 2005/06 geotechnical investigation.

Since the rock was frozen, conventional packer tests were impractical. Permeability of the bedrock was therefore typically determined using visual methods. The visual criterion for apparent low permeability was defined as “one or less tight fractures per foot for a minimum length of three feet”.

Based on this criterion, the depth to apparent low permeability bedrock was identified and projected as shown in Figure 3. The cut-off wall panels were designed to be keyed 0.9 m into the apparent low permeability bedrock. (Anderson & Wilson, 2010)

3.2 Additional Investigation and Re-design

The original geotechnical investigation programs were completed from the cofferdam or the overburden stockpile and so were not on the actual alignment of the proposed cut-off wall.

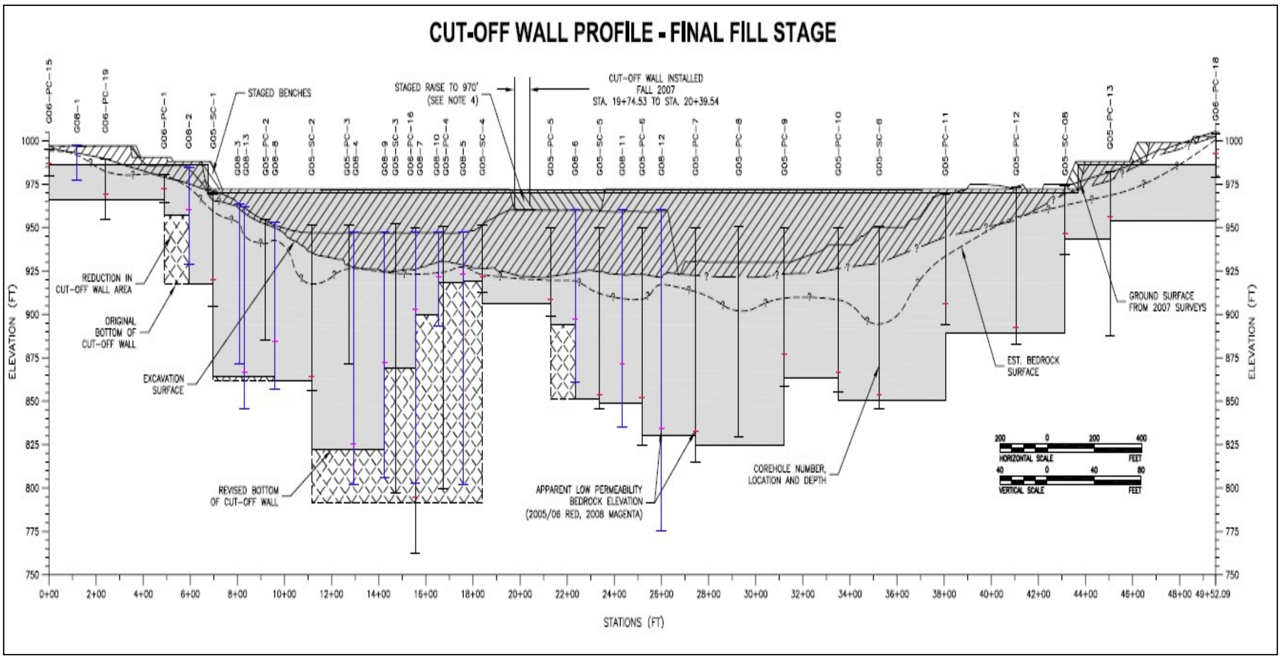

Figure 4. Revised Panel Depth

The data from these investigations had been used to formulate the original design which had formed the basis of the agency approvals to proceed with the construction.

Based on a review of this data, and in particular the dip angle of the joints within the rock, it was considered likely that additional investigations along the final alignment may yield reduced excavation depths as a result of encountering low permeability rock at shallower depth. TAK agreed to complete additional investigations and commissioned a drilling program that was carried out in late 2007 along the 2008 alignment construction zone and late 2008 along the 2009 and 2010 alignment construction zones. As suspected this investigation did indeed indicate low permeability rock at shallower depths directly on the cut-off alignment as shown in Figure 4.

These findings allowed development of a revised configuration for the wall and removed the need for a lower stepped bench along what was previously the deepest portion of the cut-off wall. The revised configuration streamlined the embankment construction and effectively reduced the cut-off wall surface area by approximately 6,500 m² with consequent savings in the order of \$3M.

3.3 Thermal considerations

The upper portion of the cut-off wall was expected to be susceptible to degradation from freeze-thaw cycles; therefore, once each section of wall was completed, an insulated section was installed over the top of the wall to prevent frost penetration into the top of the cut-off wall.

After the cut-off wall has been constructed, it is expected that the permafrost will aggrade into the fill embankment as it did into the Overburden Stockpile.

4 EQUIPMENT

4.1 Trench Cutter

The trench cutter itself, as shown in Figure 5, is a reverse circulation excavation tool. It consists of a heavy steel frame (1) with two drive gears (2) attached to its lower end. These rotate in opposite directions about the horizontal axes. Cutter wheels (3) are mounted onto the drive gears.

As they rotate, the soil beneath the cutter is continuously removed, broken up, mixed with the bentonite slurry in the trench and moved towards the opening of the suction box (4). The slurry charged with soil or rock particles is pumped by a centrifugal pump (5) which is located right above the cutter wheels via the mud hose (6) through a ring main of pipes to a de-sanding plant where it is cleaned and returned into the trench.

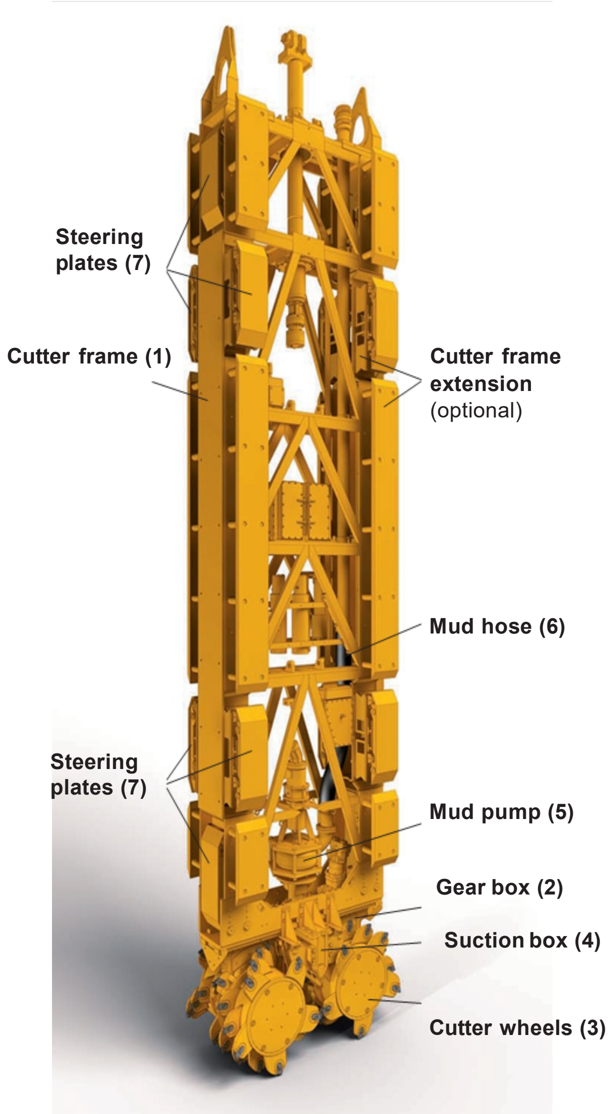

Figure 5. BAUER trench cutter

The torque of the cutter wheels in combination with the weight of the cutter is typically adequate to cut in hard soil and even soft rock and to overcut the concrete of adjacent panels. The pump will pass gravel and small cobbles (up to 80 mm diameter), and the configuration of the cutter teeth and wheels is often sufficient to break cobbles. Depending on the soil type, different types of teeth can be deployed, ranging from aggressive teeth for cutting fine-grained soil to percussive teeth for crushing boulders. Changing the wheels also allows the system to be used for rock applications, with documented experience for rock strengths of up to 250 MPa.

The verticality of the trench cutter and thus the trench alignment are generally measured on two axis by means of two independent inclinometers, the "X"-axis, normal to the trench alignment and the perpendicular "Y"-axis. Data provided by these inclinometers is processed by the on-board computer and displayed on-line. In this way the operator can monitor continuously and, if necessary, correct the verticality of the cutter. Adjustment of verticality in the two directions is carried out by a system of steering plates (7). Throughout the excavation process the rig's operator is prompted by the machine's software that calculates its status and indicates the most appropriate action to take.

All information can be downloaded on a "Panel report" that can be printed after completion of each panel and used for QA/QC purposes. (Gerressen & Schöpf, 2010)

5 CONSTRUCTION PROCESS

The working sequence for the construction of a diaphragm or cut-off wall is relatively straightforward, and comprises the following key steps:

5.1 Site Preparation

Due to the nature of the equipment used in the construction process, construction requires the provision of a generally level platform of about 18 m in total width, with about 12 m of space on the equipment side of the trench and about 6 m on the opposite side to accommodate concreting operations and the like.

The platform should be sufficiently robust to support a 165 ton crane. Where the ground surface slopes along the alignment, benches should be constructed to keep the crane level.

5.2 Guide wall Construction

For the cutter to operate properly Guide Walls need to be constructed prior to the diaphragm wall cutting to provide:

- Guidance to ensure the correct alignment of the pre-excavation.
- Stability to the upper portion of the trench
- Protection against instability of the uppermost portion of the cut as a result of washing and fluctuating levels of bentonite slurry during excavation.

5.3 Pre-excavation

For the cutter to operate properly the circulation of bentonite must be established before the machine starts to excavate the trench. The cutter's mud pump is located just above the cutting wheels. In order to prime this pump it needs to be fully submersed in the bentonite fluid hence pre-excavation of the trench to in the order of approx. 3 m depth is necessary prior to positioning the cutter.

5.4 Excavation

Following preparation of the site and construction of the guide walls, excavation of the diaphragm or cut-off wall can begin using the trench cutter.

Excavation relies on the rotation of the cutter wheels about a horizontal axis combined with the weight of the cutter frame to loosen the soil or rock and place it in suspension in the working slurry. This slurry is then continuously pumped to the desanding plant to remove the excavated soil from the trench, with fresh slurry added to maintain operating levels. Rate of progress is a function of the relative density of the soil, or hardness and jointing of the rock, the type of teeth used on the cutter, and the weight or crowd force applied from the cutter frame.

required and the feasibility of completing such backfilling operations in a single shift. Panel layout and sequencing is predetermined such that closing or secondary panels will cut sufficiently far into primary panels to ensure an intimate and watertight joint between panels (see Figure 6).

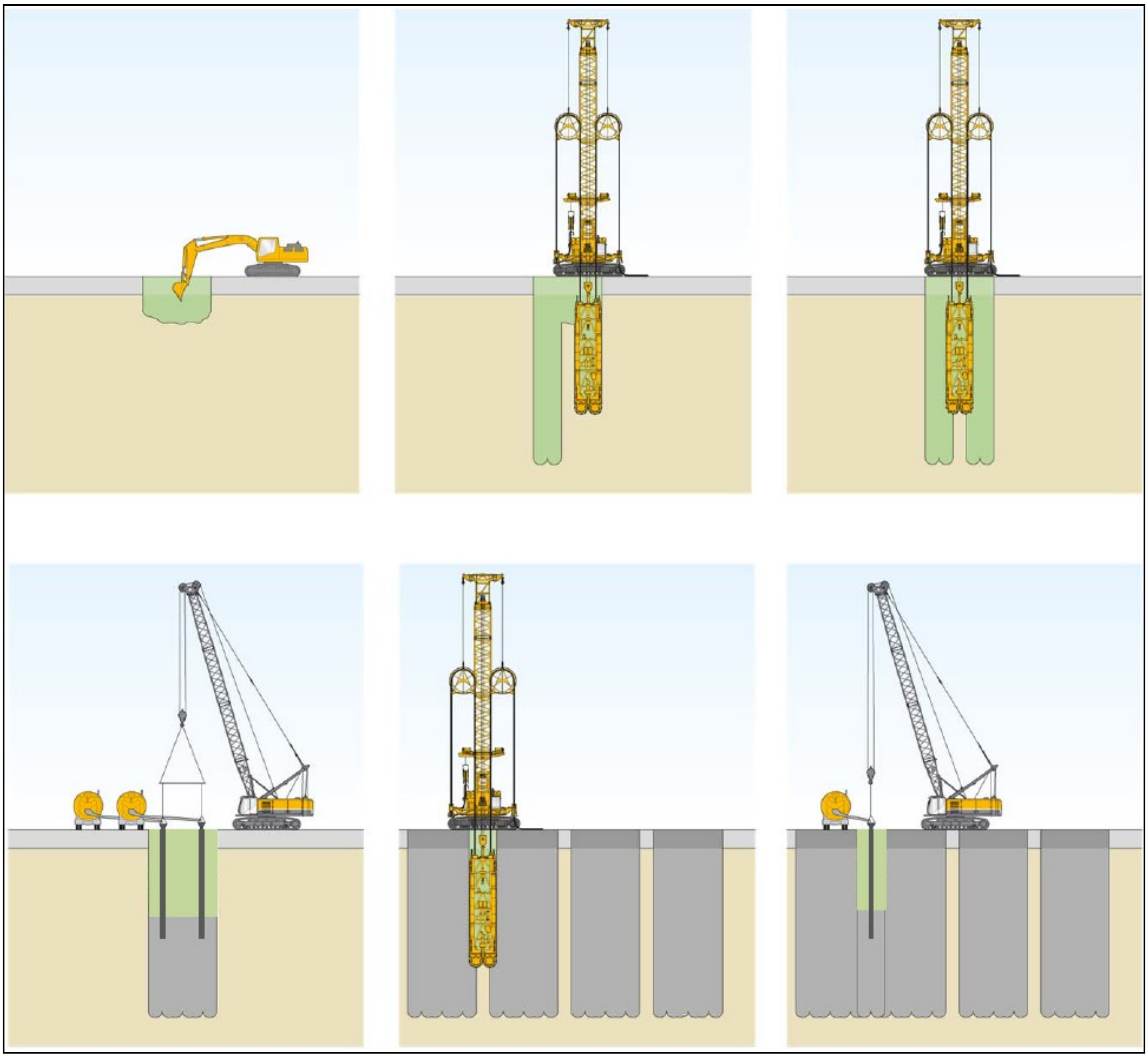
Figure 6. Construction Sequence General

Diaphragm or cut-off wall construction involves the trench being excavated in discontinuous sections or "panels" under a head of bentonite slurry. Typically primary single or multiple bite panels are excavated and constructed first, followed by the excavation and construction of intermediate secondary or closing panels. The sizes of panels are often determined by the quantity of concrete backfill

5.5 Desanding

As indicated above, the excavation process relies on the placement of excavated soil and rock into suspension in the bentonite slurry. This slurry is processed through a desanding plant to remove the solids and return the clean bentonite to the trench.

Once the target depth has been reached circulation of the bentonite continues until as much of the solids from excavation as is practical, are removed. Despite this, some sand and fine grained particles can remain within the bentonite and possibly settle to the bottom of the trench. As a safeguard it is therefore recommended that, prior to concreting, bentonite in the trench be re-circulated through the desanding plant to remove any residual solids; alternatively it may be partly or completely replaced by fresh bentonite so that its characteristics satisfy the contract requirements.

5.6 Concreting

Concreting a fluid filled trench is carried out using a “Tremie pipe” that introduces fresh concrete to the bottom of the trench and allows it to rise upwards displacing the fluid in the trench. Concrete is typically supplied to the trench locations by concrete trucks at a rate sufficient to ensure a continuous pour of about 45 m3 per hour and prevent the first loads of concrete from gaining initial set prior to the pour being completed.

The number of tremie pipes and rate of delivery will be determined primarily based on the length and depth of the individual panel to be concreted.

6 CUT-OFF WALL CONSTRUCTION

As indicated previously, construction of the cut-off wall at Red Dog Mine commenced in 2007 with what amounted to a series of trials to determine the most effective configuration of equipment and procedures in preparation for the main construction seasons of 2008 and 2009.

Work on the wall was to be completed in parallel to the construction of the back dam itself and was to start close to the eastern end of the works since only the eastern end of the dam, and hence a working platform, was complete in 2007.

6.1 Guide Walls

Concrete precast guide walls were used at the Back Dam cut-off wall. L-shaped walls were precast at site and positioned up to 50 m in advance of the Trench Cutter operations.

Guide walls were typically stripped out about 3 weeks following completion of a section of wall allowing them to be re-used further along the alignment.

6.2 Cutter Wheels and Cutter Teeth

Use of the most appropriate cutting wheels and teeth is one of the main keys to optimized productivity. Trench cutters are typically fitted with one of three types of wheels and teeth: flat toot wheels; bullet tooth wheels; or round shank mount wheels.

The configuration of cutting wheel used for full scale production at Red Dog was the round shank mount (RSM) wheels (see Figure 7).

Figure 7. Bauer Cutter Heads Showing RSM Wheel Setup

These wheels can cut a variety of rock hardness ranging from R1 to R5 were ideally suited for the majority of rock conditions encountered along the Back Dam alignment.

They were not the optimum configuration for the cutting of the overburden soils, however the loss of productivity in this zone was far outweighed by the gain in productivity in the rock zones.

For construction through the 2008 season, ten types of RSM teeth were purchased in an effort to optimize tooth wear and cutting production. Since the teeth used were adapted to match the anticipated rock hardness on a day to day basis, the production variations among the teeth types were negligible through the 2008 and 2009 season staying relatively consistent at 0.45 teeth/m².

6.3 Productivity

The Back Dam cut-off wall included the construction of a total of 39,000 m² of wall over four construction seasons, with an average productivity per 12 hour shift of about 80 m² of wall.

While attempts were made to correlate productivity of excavation to rock strength, insufficient data on rock strength was available to make this possible. Furthermore it was apparent that different teeth configuration also appeared to play a significant role in overall productivity, and since tooth type was changed on a regular basis, it would not have been possible to isolate this aspect.

CONCLUSION

The trench cutter method is an ideal tool for both the construction of diaphragm walls and for the construction of deep cut-off walls.

Experience on the Red Dog project indicates that the trench cutter is very effective in the construction of deep cut-off walls extending through both overburden and rock and that it is worthy of consideration particularly for projects where grouting of weathered and/or fractured rock may be considered the only alternative.

Careful selection of the type of cutting wheel, as well as type of tooth, is important to generate optimal production, particularly when dealing with highly variable rock strengths. Management of the slurry mixing and delivery processes, as well as careful consideration of the handling properties of the mix design for the wall should also be given detailed consideration during planning of the project.

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