A HYDRAULIC CUT-OFF THROUGH UNCONSOLIDATED MINE DUMP MATERIAL

by

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Abstract

The paper describes the design, construction and performance of a 300,000 s.f. plastic concrete cut-off wall installed at the BHP-Utah Island Copper Mine at Port Hardy, British Columbia. The barrier was necessary to prevent water from a nearby sea inlet flowing through mine dump and fluvio-glacial materials forming an embankment protecting an 800' deep open pit mine. Conventional cable suspended grabs were used to excavate the wall, about 4,000' long, and as deep as 110'. The glacial till proved so dense that predrilling with large diameter augers had to be undertaken. The trench was excavated in a series of contiguous panels, up to 29' long, and backfilled with a plastic concrete mix. Concrete mix design was critical, as it had to be of low permeability, but high plasticity, as the region is one of high seismicity. Additional construction difficulties arose from loss of bentonite slurry during trench excavation, into the very open structured mine dump material. After completion, the effectiveness of the wall was proved by a closely monitored pumpdown test. This project confirms that such cut-offs constructed by the slurry trench method can provide economic and effective solutions in even the most unfavorable man made and natural ground conditions.

1. INTRODUCTION

Copper and other metal ores are mined from an 800' deep open pit at the Island Copper Mine, near Port Hardy, British Columbia, (Photograph 1). The mine wished to extract ore from the pit's south side, closest to a marine inlet, in an operation called the "Southwall Push Back" (Figure 1). This operation entails the removal of a ridge of the naturally impermeable andesitic bedrock, and the upper part of the wall will therefore be formed by waste, mine dump material. Highly permeable, this dump consists of angular shot debris and boulders of maximum volume 150 c.f. and dimension 7'. It was necessary to therefore

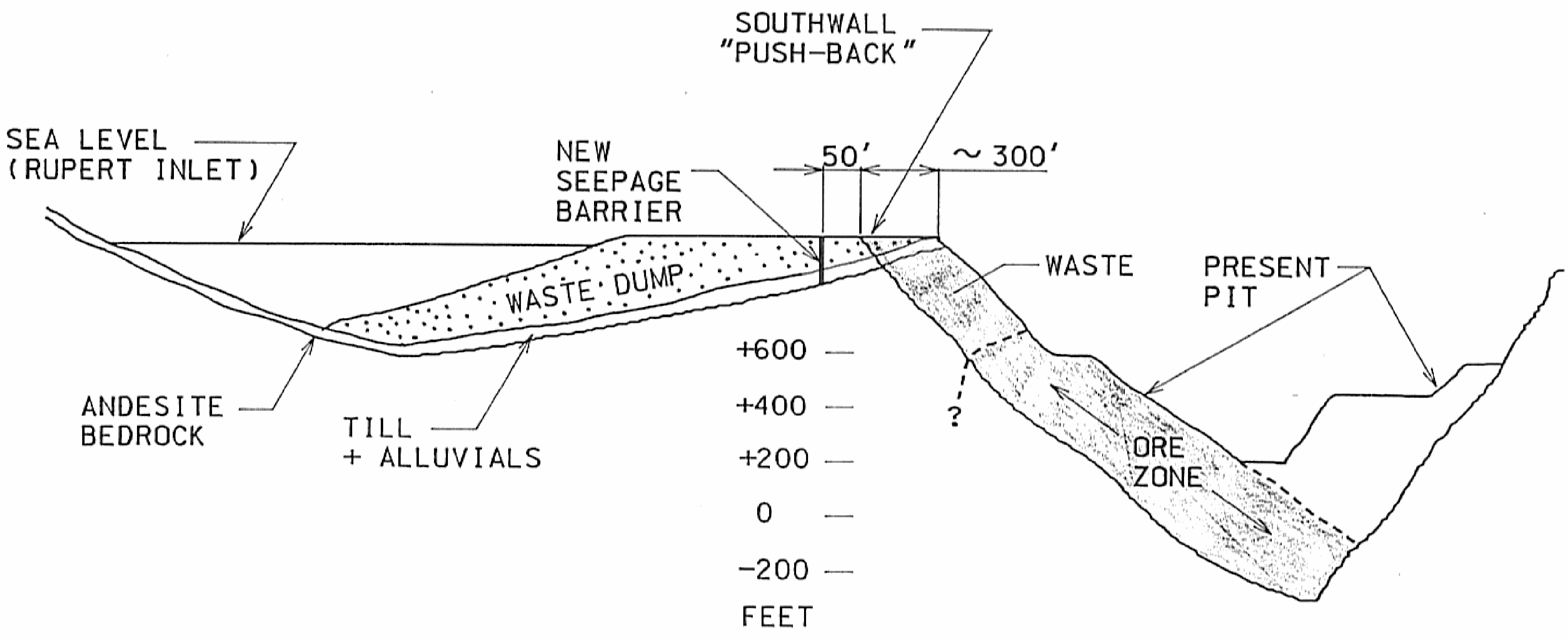


FIGURE 1 SIMPLIFIED CROSS-SECTION
SOUTH WALL "PUSHBACK"
AND CUTOFF BARRIER

construct a hydraulic barrier through these materials, and some underlying natural sediments, to prevent direct flow from the inlet into the pit, after the "push back".

The Mine and its consultants selected a plastic concrete diaphragm wall as the most appropriate form of cut-off, and competitive bidding led to the award of the work to a Joint Venture of ICOS Corporation of America and Nicholson Construction Company.

This short paper describes aspects of the design and construction of the wall, while these considerations, plus an analysis of the wall's performance, as indicated by the instrumentation and pump down tests, are carried in greater detail in a later paper (1).

2. DESIGN

2.1. Geotechnical Parameters

The range of geological conditions encountered is indicated in Figure 2. The cut-off was taken down to rock head (at the shallow extremities), or a minimum of 8' into the tough impermeable glacial till horizon (including a minimum of 3' into clay). The cut-off is about 4,000' long, being roughly and slightly crescent-shaped in plan. At the deepest point it was about 110' deep and averaged 75'. The actual excavated area was 299,049 s.f. Major geotechnical properties of the materials excavated are noted in Table 1. Throughout the construction, the piezometric level in the dump material was 4-10' below the surface, with small daily variations due to the inlet tidal action.

MATERIAL (From surface down)	Approx. Area Excavated (s.f.)	Representative Range of Permeability (cm/s)	γ * (pcf)	C * (pcf)	ϕ * (°)
Dumped Material (crushed, blasted, unsorted, andesitic bedrock)	187,000	Highly variable 10^{0} - 10^{-2}	130	0	30-34
Beach Deposits	58,000	10^{-1} - 10^{-4}	120-132	0	35-37
Fluvial Deposits	9,500	10^{-2} - 10^{-4}	125-132	0	37
Till	31,049	10^{-4} - 10^{-7}	135	1000	40
Glacial Outwash	13,500	10^{-2} - 10^{-8}	135	0	40
TOTAL	299,049				

* Values used in FE Analyses

Table 1. Typical material properties

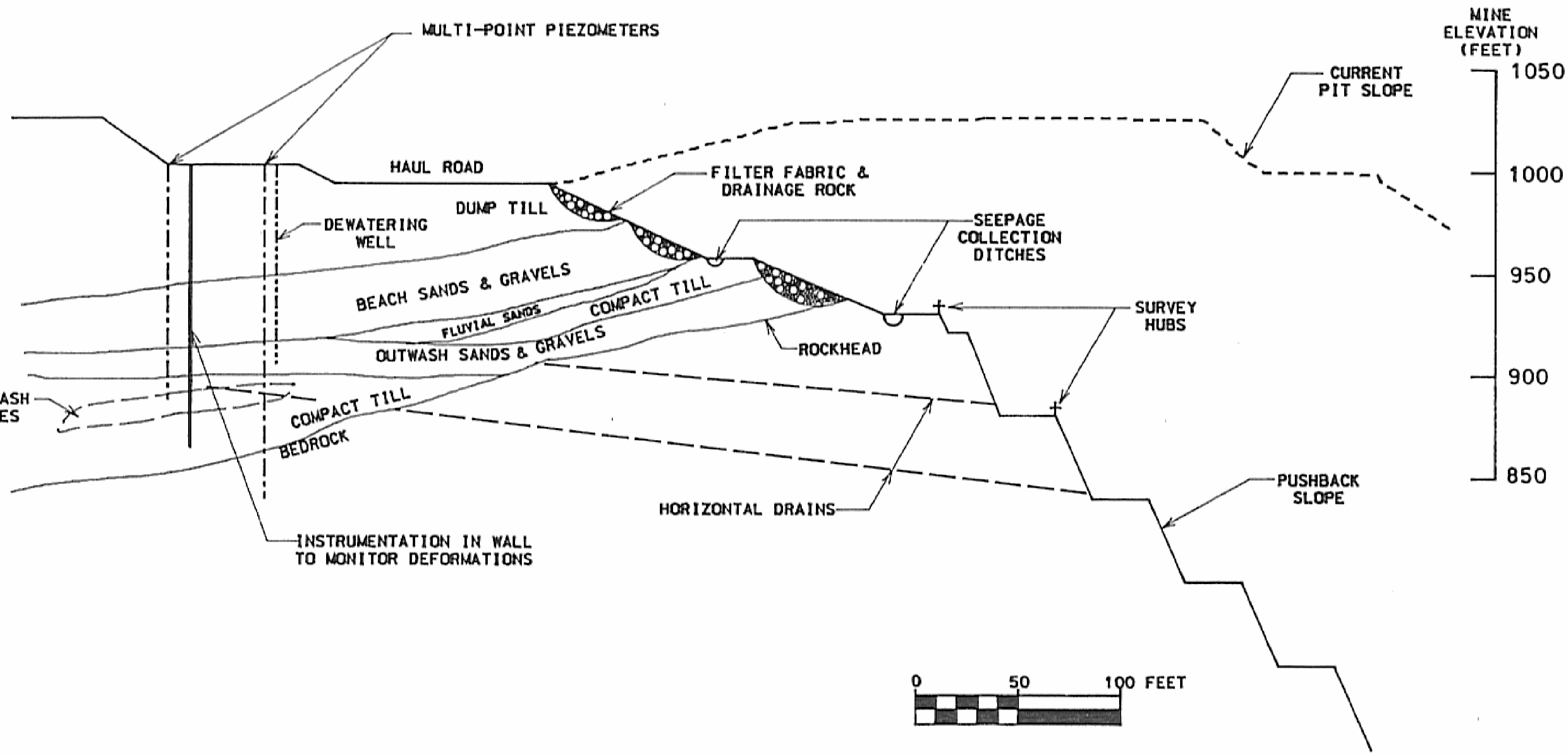


FIGURE 2 TYPICAL ARRANGEMENT OF STRATA, AND CONTROL INSTRUMENTATION.

2.2. Wall Parameters

As shown in Figure 2, the cut-off is located within 50' of the new pit backwall, and at worst will be subjected to about 120' of differential water head. The purpose of the wall is to reduce seepage flows to a level such that excessive pit pumpage would not be necessary, and to forestall instability or erosion of the rock and soil slopes. A target wall permeability of 10^{-7} cm/s was set, translating into a maximum permissible seepage through the wall of 25 imp. gpm for any 100' section, and an average of less than 5 imp. gpm per 100' over the entire length.

In addition, the wall had to be able to accommodate the lateral and shear displacements anticipated as the slope is cut and additional drainage is installed. Finally, it also had to be able to resist deformations due to consolidation or shear under dynamic loadings caused by vehicular traffic or seismic events. In this context, the projected 1 in 200 year event would produce peak horizontal accelerations of 0.21 g. In the recent past, events as high as 5.2 M had been recorded as close as 50 miles away. It was assumed that liquefaction of the natural and dumped materials would not occur, due to their granulometry and high density.

The cut-off's backfill mix was therefore designed to provide the optimum balance between deformability and erosion resistance. On the one hand, it had to be able to match the compressibility of the surrounding soil mass, as closely as possible, to minimize cracking under sustained deformation. On the other, it had to be highly resistant to erosion under the turbulent seepage conditions anticipated. Analyses favored a backfill material having about 200 psi unconfined compressive strength, an E value of 70,000 psi and a maximum jet erosion loss of around 0.5% weight in 15 days.

A laboratory testing program was conducted in advance of construction to find an appropriate mix design. The plastic concrete design actually used was (per cubic yard)

Coarse aggregate	1330 lb (crushed rock < 1/2")
Fine aggregate	1330 lb (fine sand, silt)
Cement (Type I)	239 lb
Bentonite	53 lb
Fresh water (including that in the aggregate)	667 lb

3. CONSTRUCTION

Overall, the wall comprised 225 panels, varying from 9 to 29' in length depending on construction sequence (i.e. Primary and Secondary), depth and excavating bucket size. Panel thicknesses of 32" (nominally) were reduced to 24" in the till. Highlights of the construction were as follows:

- Guide Walls

Reinforced concrete guide walls were considered necessary to ensure the correct plan alignment of the wall and verticality of the panels. It was originally foreseen to pre-excavate a trench, 6' to 8' wide by 4' deep, place a central blockout 3' wide and pour the concrete into the steel reinforcing cages placed on each side. However, it soon proved that the upper backfill materials tended to collapse readily into the trench during excavation, causing voids to appear along the outer side of each guide wall. This was clearly unacceptable.

In the revised scheme, a trench 6' wide by 10' deep was pre-excavated, and filled to a depth of about 4' from the surface with lean mix concrete (Photograph 2). Light vertical starter bars were then placed, to secure the reinforcing cages, followed by the erection of a double form work with an internal separation of 3'. After placing the concrete, the forms were stripped and backfill placed against the outer sides of the walls. This method therefore resolved the collapse problem and eliminated the need to excavate (by slurry wall method) the upper 10' of loose dumped rock.

- Excavation

A maximum of five excavating cranes were used, equipped with cable activated excavating buckets (grabs) giving "bites" from 24 to 32" wide and 9' to 13'6" long. Of the problems which were encountered during excavation, three in particular strongly affected the rate of progress: sudden major slurry losses into the dump material, the hardness of the dump material, and the extreme toughness of the till.

Regarding the slurry losses,which can lead to trench collapse in certain conditions, various remedies were taken, either sequentially or simultaneously. These included

- Increasing the viscosity of the bentonite slurry by either increasing the bentonite content or using "heavy" contaminated bentonite displaced during the concreting of other trenches, before desanding.

- Adding dry cement at the trench.

- Placing volumes of dry selected fill with a loader or bucket to dessicate the slurry at the critical elevation, so making it extremely viscous.

Although the smaller components of the dump material could be "grabbed" readily, the larger boulders needed to be broken up by dropping a heavy steel "chisel" before they could be excavated.

The extreme hardness of the till prevented the buckets from grabbing significant volumes in each pass. Therefore, systematic predrilling of 8' of till in problem panels was conducted at 4' centers with a 32" diameter crane mounted rock auger (Photograph 3). A total of 3,549 l.f. of such predrilling was conducted.

In typical slurry wall construction, alternate adjacent panels are designated Primary and Secondary and constructed in that order. However, in this case Primary panels were "scouted out" with as many as five or six other planned panel locations between. These intermediates were then completed progressively outwards from each Primary. The main reasons for this proceedure were as follows:

- Excavating conditions could be revealed sufficiently in advance of the main construction that the impact of particularly bad zones could be accommodated with minimum program consequences.

- This long site was naturally split into distinct work zones, making local operational control better, reducing congestion, and reducing the distances of crane travel.

- The method reduced the requirement for the supply and handling of the steel end stops, used as form-work for the free ends of panels during concreting (Photographs 4 and 5).

- This approach allowed the naturally weak panel concrete longer to gain significant strength prior to their edges being exposed to further excavation activities.

The Primaries were typically 13' long, and excavated to full depth by one machine without predrilling. Secondary panels were up to three "bites" long: this procedure aids the straightness, continuity and integrity of the final concrete element.

The Primaries encountered most of the major slurry losses, and had the highest concrete "overpours", as described below. However, these excesses did appear to reduce somewhat the gross porosity of the adjacent ground as the problems were not so severe when the Secondaries were constructed.

Panel verticality was checked every 30' by careful measurements on the position of the grab suspension cables relative to the guide walls. The specified tolerances were $\leq$ 1% on verticality, and an interpanel overlap (between Primary and Secondary) of at least 24".

- Bentonite Slurry/Preconcreting Preparation

The standard slurry of 5-6% Wyoming Bentonite and fresh water was prepared in jet mixers, and held in temporary storage ponds (100 x 40 x 3') before being pumped to the excavation. Slurry displaced during subsequent concreting was not recirculated after desanding, but fed directly to adjacent trenches.

The properties of the hydrated slurry were as follows:

Marsh Cone	32-50 Seconds (typically 40)
Specific Gravity	64-78 lb/ft^3 (typically 65)
Filter Water	pH8-11
Pressure Filtration Test	< 20 ml at 100 psi in 30 minutes

Overall, the solid bentonite consumption averaged well over 20 lb/sf of wall, while some of the especially troublesome Primaries recorded far higher consumptions.

Several mobile desanders were used to "clean" and lighten the slurry sufficiently prior to concreting the panels, to a maximum sand content of 5%. These operated via 8" diameter steel pipes, suspended 1' off the base of the excavation. The lifting process was aided by the action of a 1" diameter compressed air line, exiting near the bottom of the steel line, and agitating loose soil and other debris. (Photograph 4)

The one (Secondary panel) or two (Primary panel) steel endstops were placed by crane at the extremities of each panel before desanding. About 3-6 hours after concreting, these endstops were lifted slightly to break the adhesive bond between the steel and concrete. They were fully extracted about six hours later.

- Concreting

The bentonite and water were supplied from the slurry plant, directly into the truck mixers. The other constituents were added at the central batching plant. The typical batch plant output was 75 yds^3/hour, and as many as six mixer-trucks were in simultaneous use.

The concrete was then tremied into each panel (Photograph 5) via a single 10" diameter steel pipe, careful records being made of the correlation between concrete volume placed and the depth of concrete measured. The tremie was lifted periodically, but care was taken to ensure the outlet was at least 20' below the slurry/concrete interface. Concrete placement rates ranged from

40-60 c.y./hour for panels each requiring from 120 to 275 c.y. of backfill. Slumps in the region of 8-9" were recorded as part of the intensive qa/qc program.

Overall, the overpour (i.e. volume of concrete actually placed compared to neat excavated trench volume) was over 40%, although the tremie records show that this overpour was exclusively in the dumped rock, occasionally being over 100%. A total volume of 44,000 c.y. of plastic concrete was placed.

4. MONITORING

During the work, which was generally conducted at a rate of 12 shifts per week, very detailed records were maintained of all aspects of the construction. This allowed possible abnormalities to be identified a priori: panels with suspected collapses during concreting or short interruptions during tremieing; unusual concrete takes; doubts about joint continuity, and so on. Particular attention could, therefore, be paid to these areas during the subsequent testing and long-term performance behavior, and possible remedial actions prepared in advance.

The hydraulic and structural performance of the wall is monitored by an extensive array of instrumentation (Figure 2). At approximately 300' distances along the wall, there are groups of piezometers, in the fill on both sides, and inclinometers and extensometers within the wall to measure deflection and vertical strain respectively. In addition, precise surveying of survey movements will be conducted during the wall push back to record surface deformations.

As an advance test of the hydraulic efficiency of the wall, pumpout wells were used to lower the piezometric surface on the downstream (pit) side. Data are still being analyzed, but it is clear that the wall is proving to be an exceptionally efficient cut-off, with a performance superior to design requirements. Details will be provided in later related publications.

5. FINAL REMARKS

The hydraulic cut-off at the Island Copper Mine posed searching problems for both the designers and the contractors. The designers were faced with arriving at a plastic concrete mix design which had to satisfy demands placed on permeability, permanence, and deformability. The contractors had to excavate both through hard, permeable dump rock, and very dense, resistance, glacial till. High consumptions of both bentonite slurry and concrete were recorded. However, preliminary test results show that the wall is capable of performing at least as well as anticipated, and that the planned mine expansion can well as anticipated, and that the planned mine expansion can proceed as foreseen.

Given the extreme difficulties faced by all parties on this project, this reflects a great deal of credit on all concerned.

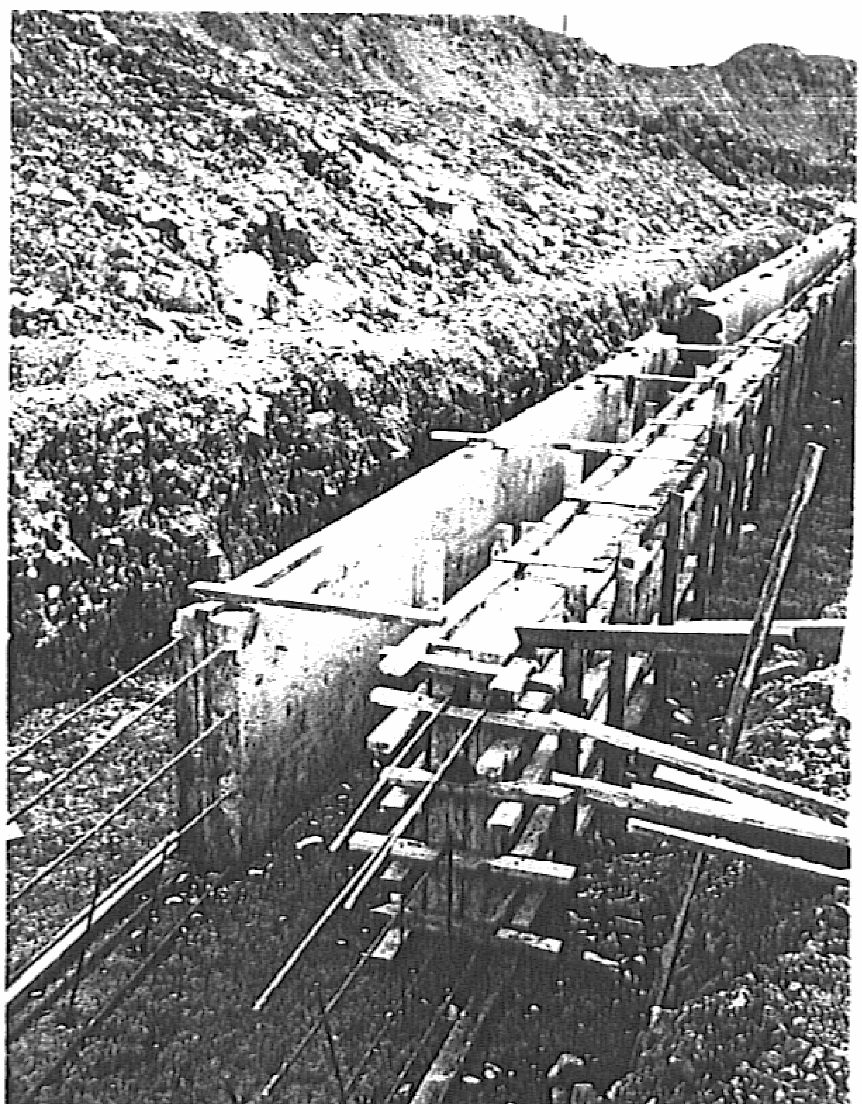
Reference

1. R.R. Davidson et al (1991). Case history study of Island Copper Mine Cut-off Wall. Being prepared for ASTM Intl' Symposium on Slurry Walls, Atlantic City, NJ, June 27-28

Acknowledgements

The owner of the project is BHP - Utah Mines Ltd. - Island Copper Mine. The rock mechanics consultant is Steffen, Robertson and Kirsten (Vancouver), and the wall consultant Woodward Clyde Consultants (Denver). The general contractor was a Joint Venture of ICOS Corporation of America (Englewood, NJ) and Nicholson Construction Co. (Bridgeville, PA). The authors acknowledge the full contribution of all parties, and appreciate the opportunity to present these details on their behalf, although the opinions expressed are those of the authors themselves.

Photograph 1. General view of the site, showing south wall of 800' open pit, the marine inlet, and the cut-off wall between.



Photograph 2. Casting of revised pattern guide walls, on lean mix concrete base placed in pre-excavation.

Photograph 3. Large diameter auger used to predrill through the till.

Photograph 4. Desanding of Secondary panel prior to concreting. End stop shown at far end of panel.

Photograph 5. Concreting of Primary panel with two end stops in place.