DESIGN AND OPERATION OF THE MYRA FALLS TAILINGS DISPOSAL FACILITY

By
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ABSTRACT

Westmin's Myra Falls operations are located at the south end of Buttle Lake on Vancouver Island in steep, mountainous terrain. Initial mining activity at the site was combined with sub-aqueous disposal of the tailings in Buttle Lake and the proposed expansion of activities in the late 1970's coincided with growing concern over increasing metal levels in Buttle Lake. This required the introduction of on-land disposal of the tailings. Subsequent investigations showed that the source of the metals in Buttle Lake was bacteriological leaching of the waste dump from the Lynx open pit at the mine site.

The design of the tailings disposal system is based on the severe restrictions on available space, the tailings characteristics and the site characteristics. The resulting design is a drained, sub-aerial system which allows upstream construction and maximum utilization of the available storage area, as well as providing partial blanketing of the waste dump. The valley alluvium underlying the facility contains a system of groundwater drains to create a hydraulic confinement beneath the tailings and to intercept all existing acid mine drainage from the waste dump. Groundwater from the drains and water decanted from the tailings surface are pumped to a series of treatment ponds for lime addition and polishing prior to discharge into Myra Creek. The system became fully operational in 1985, and the first two upstream raises on the tailings beach have since been constructed. Metal levels in Buttle Lake have returned to background levels since commissioning of the groundwater drainage systems.

This paper describes the design and operating performance to date of the tailings disposal system. Design aspects include geotechnical testwork on the tailings, seismic stability evaluation, design of the groundwater drains and pumpstations, geotechnical instrumentation, which is currently being upgraded to include automatic data logging, and reclamation requirements. A discussion of operations includes tailings deposition, instrumentation results, sampling programs for material characteristics and acid generation, and construction of embankment raises.

INTRODUCTION

The location of the Westmin Resources Limited, Myra Falls operations is shown on Figure 1.

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Figure 1. General Project Location.

Mining operations at Myra Falls started in the late 1960's with open pit and underground mines at a nominal 1000 tpd of ore. Processing involved crushing, grinding and flotation to produce various flotation concentrates of predominantly zinc, lead and copper with gold and silver values. The flotation tailings were cycloned to separate out the coarse fraction for underground backfill with the fine fraction discharged through a gravity pipeline to Buttle Lake and discharged at depth in the lake.

Discovery of the new HW orebody in 1979 led to immediate plans to expand the mill capacity to 3000 tpd. This coincided with growing concern over increasing metal levels in Buttle Lake, which is the drinking water source for the town of Campbell River. Permitting of the expansion therefore required on land disposal of the tailings although subsequent investigations showed that the source of the metals in Buttle Lake was bacteriological leaching of the waste dump from the Lynx open pit. The resulting design of the tailings disposal facility included measures for intercepting the acid drainage from the dump for treatment prior to discharge.

SITE CHARACTERISTICS

The mine site is located in the heart of the Vancouver Island mountain ranges, in the steep sided hanging valley of Myra Creek. The general elevation of the valley floor is at 310 metres above mean sea level, and on either side mountains rise steeply to over

1800 metres. Myra Creek flows from west to east within the valley and discharges over Myra Falls immediately upstream from the entry point into Buttle Lake. Upstream of the falls the valley floor broadens into a narrow alluvial plain for a distance of approximately 3 km and the mine is located at the upstream end of this plain.

Hydrometeorological conditions at the mine site are typical for the west coast of British Columbia with high rainfall, predominantly in the period October through April. Mean annual precipitation and mean annual potential evaporation for the site are 2921 mm and 548 mm respectively. Mean daily temperatures fall below zero for relatively short periods in December through February and rise to over 20°C in July.

The mine is located in a relatively active seismic zone and is close to the epicentre of the Magnitude 7.3 Campbell River earthquake that occurred in 1946. Seismic design criteria for the site were calculated by the Pacific Geoscience Centre using extreme value methods and the then (1982) recently introduced Cornell method. The resulting ground motions for the site are given in Table 1.

Table 1. Predicted Ground Motions for Myra Falls, Vancouver Island.

		Extreme Value Method		Cornell Method	
Probability of exceedence in one year	Equivalent return period (yrs.)	Modified Mercalli Intensity	Peak Acceleration (g)	Peak Acceleration (g)	Peak Velocity (cm/s)
.333	3	IV	.01		
.100	10	V	.02		
.033	30	VI	.05		
.020	50	VII	.08		
.010	100	VIII	.16	.178	13.0
.005	200	IX	.30	.289	22.9
.002105	475			.513	45.1

Overburden materials within the narrow alluvial plain of the Myra creek valley consist predominantly of dense alluvial sands and gravels to depths of up to 60 metres. The valley provides the only practical location for a tailings storage facility in the vicinity of the mine.

TAILINGS FACILITY DESIGN

The tailings disposal facility is located on the north side of Myra Creek opposite the new HW shaft and down valley from the mill site. Myra Creek was diverted over a metre length to the south side of the valley to maximize the area available for the tailings facility. The tailings facility abuts the toe of the acid generating waste dump at the west end. A general arrangement of the tailings facility and other surface facilities is shown on Figure 2.

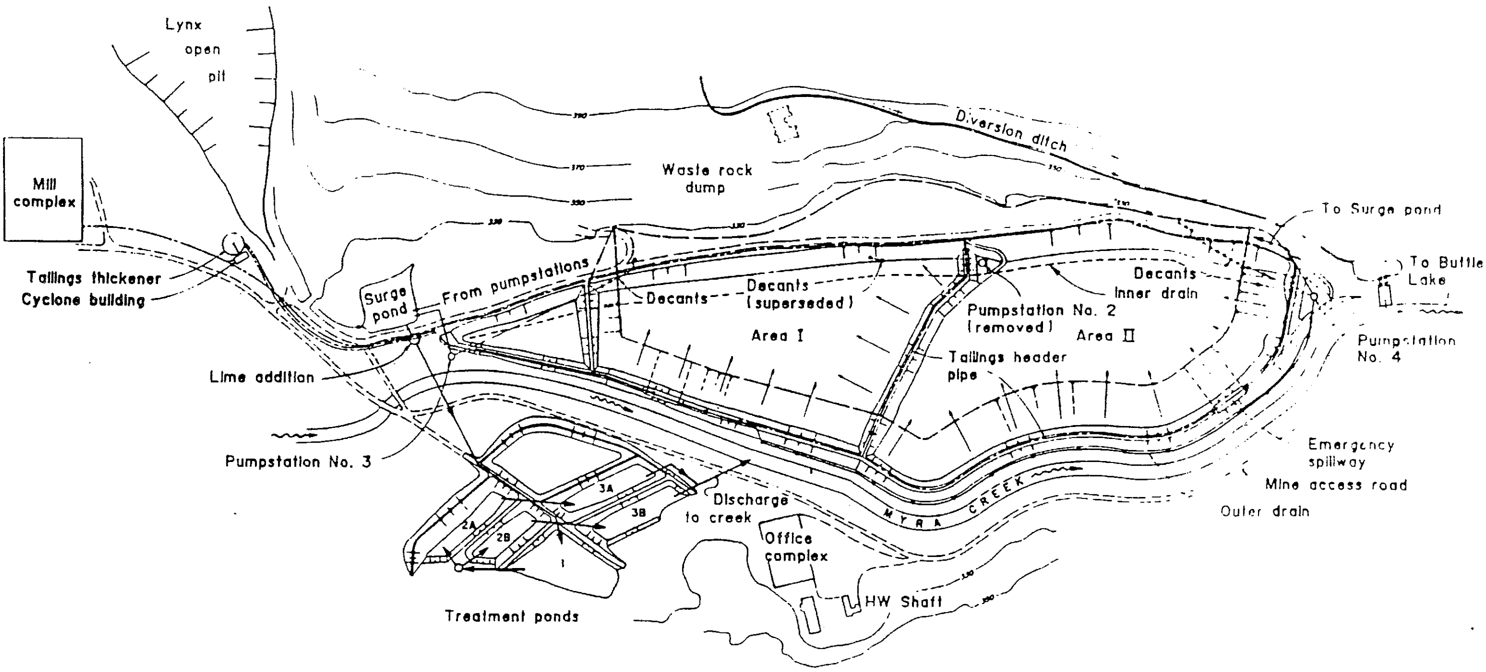

Figure 2. General Arrangement of Tailings Disposal Facility.

A typical cross-section through the facility showing the principal components of the starter embankment, inner drain, outer drain and decants is shown on Figure 3.

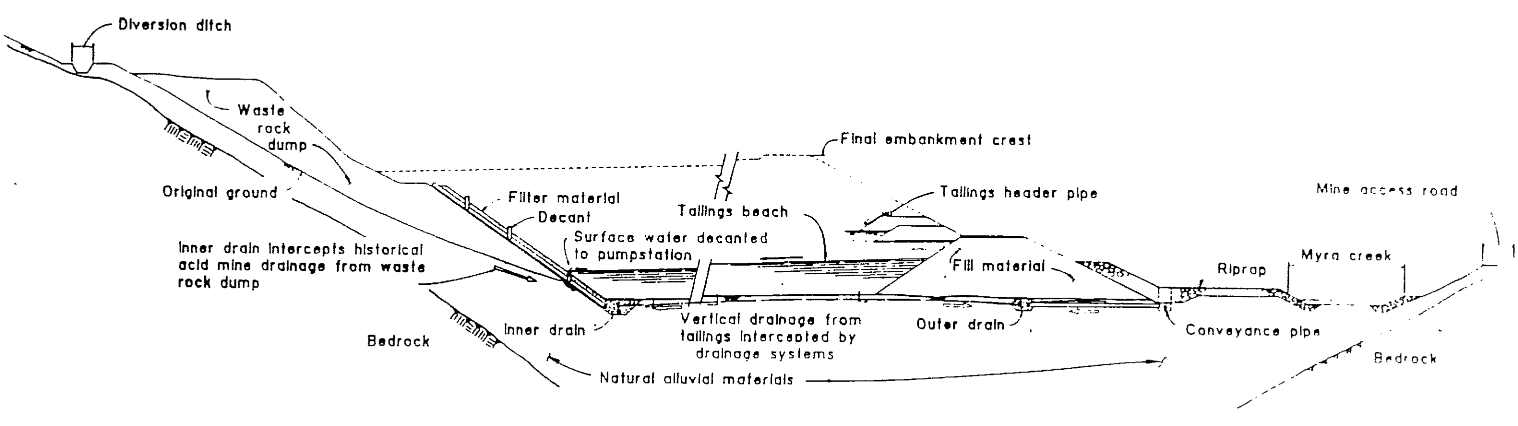

Figure 3. Typical Cross-Section Through Tailings Facility.

The inner drain is located along the north side of the valley remote from Myra Creek and serves as the primary collection point for existing acid mine drainage from the waste rock dump. The drain consists of three graded filter materials, ranging from a coarse sand to single size drain rock and perforated corrugated polyethylene pipes, which are connected at intervals to an unperforated HDPE conveyance pipe. The entire drain is duplicated vertically with the additional upper system adding a redundancy to ensure long-term operation.

The outer drain is located along the south side of the facility parallel to the realigned Myra Creek, and serves as a hydraulic barrier to seepage from the tailings facility into the creek. The drain consists of twin perforated corrugated polyethylene pipes set approximately 1 metre below creek bed level. These drain pipes are connected at access chambers to an unregulated conveyance pipe at each 0.5 metre elevation drop, with the provision at the connection to control the head in the drain. The head in the drain can therefore be adjusted to maintain a hydraulic gradient and hence flow direction from the creek to the drain while minimizing the inflow from the creek. A schematic arrangement of the access chambers is shown on Figure 4.

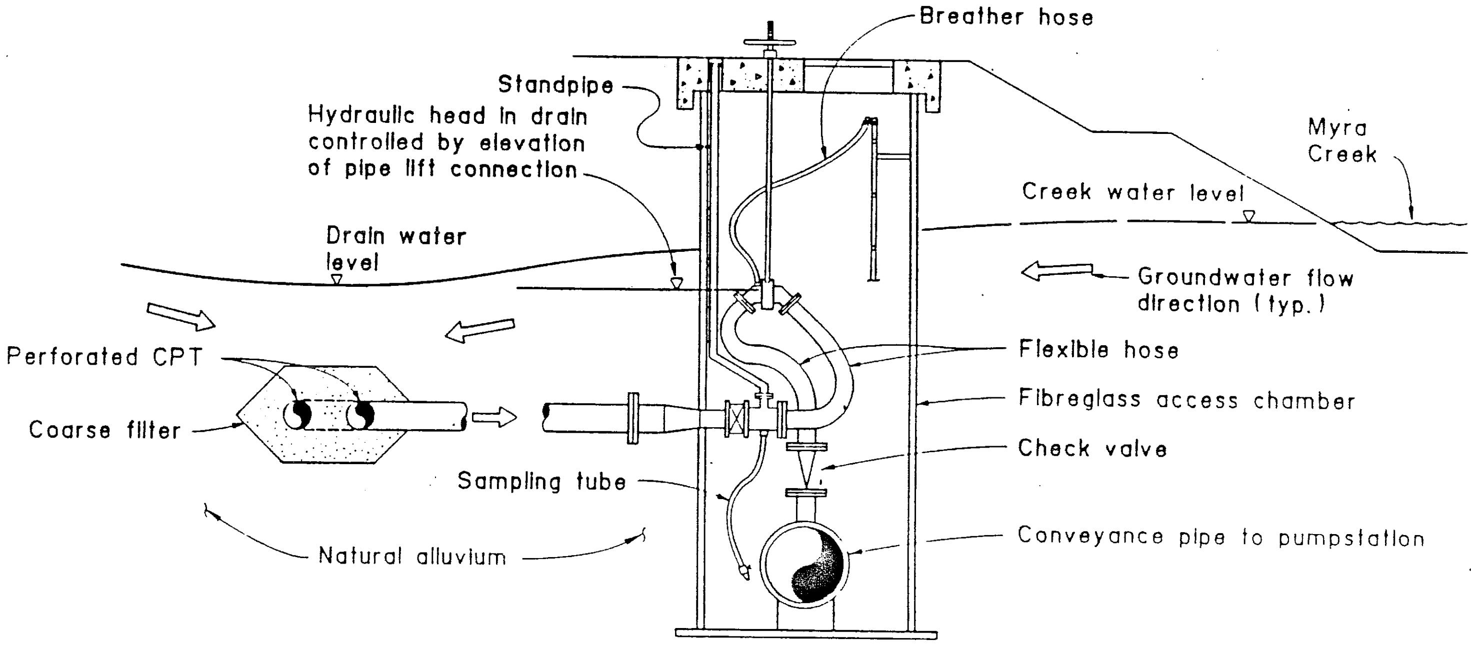

Figure 4. Schematic Arrangement of Access Chambers on Outer Drain.

The outer drain includes provision for direct discharge back into Myra Creek at various locations along its length should water quality criteria permit.

Decants are provided at the east and west ends of the facility and consist of multiple standpipes to which concentric rings of HDPE pipe are added in 300 mm increments. Operation of the decants is required to minimize the amount of surface ponding and provides rapid shedding of large storm events. The decant inlets are connected via HDPE conveyance pipes to pumpstations at each end of the facility, with the provision to divert decant flows directly to Myra Creek should water quality criteria permit.

Pumpstation No. 4 at the east end of the facility services as the collection point for the inner and outer drains and the eastern decant. The pumpstation consists of a 4 metre diameter fibreglass wet well with 4 vertical turbine pumps giving a total pumping capacity of 500 L/s. The combined inflows are pumped to the Myra treatment ponds for lime addition and settling prior to discharge to Myra Creek. Pumpstation No. 3 is located at the west end of the facility to pump water from the western decant to the treatment ponds.

As a result of the initial low pH of the groundwater at the site all buried pipework and structures for the facility are constructed of HDPE or fibreglass with all pipe fittings of plastic or stainless steel. The tailings facility was constructed in various stages over the years 1982 to 1985 which resulted in two initial areas of development, Area I and Area II.

The original design parameters on which the tailings facility was designed are summarized in Table 2.

Table 2. Original Design Parameters for Tailings Disposal Facility.

Ore production rate:	2722 tonnes/day (3000 tons/day)
Cyclone split:	60 percent fine tailings
Fine tailings production:	1387 tonnes/day
Surface area of facility:	20 hectares
Rate of rise of tailings:	1.2 metres/yr.

The tailings slurry from the mill flows by gravity to a cyclone building, where it is separated by hydrocyclones into coarse and fine fractions. The coarse fraction is pumped to a temporary storage basin at the west end of the tailings facility and is ultimately used for underground backfill. The fine fraction is thickened and pumped to the tailings facility for discharge along the outer embankment using sub-aerial deposition (Knight and Haile, 1983). Reduced backfill requirements in the underground mines has led to provisions for periodic discharge of unthickened bulk tailings.

TAILINGS CHARACTERISTICS AND SEISMIC DESIGN

The physical characteristics of the tailings materials were defined in a series of bench scale laboratory tests carried out on samples from the existing mill and a pilot plant for the new HW mine tailings. In addition, a small scale sub-aerial deposition scheme was operated for several months using a stream off the tailings pipeline from the existing mill. This enabled undisturbed samples of consolidated and air-dried tailings to be recovered and tested.

Results of the tailings testwork are summarized on Table 3 which gives the design parameters for the different materials. The particle size distribution curves are shown on Figure 5.

Table 3. Tailings Material Characteristics.

Parameter	Myra-Lynx Fine Fraction	HW Fine Fraction
Specific gravity of solids	2.95	3.95
Liquid Limit	45	23
Plasticity Index	8	N/P
Dry Density (t/m^3)		
(i) after full drainage	0.8	1.7
(ii) after air drying	1.2	2.0
Coefficient of Vertical Permeability (cm/s)		
(i) after full drainage	2.5×10^{-5}	3.5×10^{-5}
(ii) after consolidation to average in-situ stress	1×10^{-6}	3×10^{-6}
Coefficient of Consolidation (m^2/yr)	14-153	78-147
Shear Strength		
(i) ϕ' (deg) remolded	27.2	30.0
(ii) ϕ (deg) undisturbed	32.8	34.5
(iii) c' (kPa)	0	0
(iv) $c_{u/p'}$ (strain = 2%)	0.35	0.32

The shear strength of the tailings materials was determined in consolidated, undrained triaxial tests on undisturbed samples from the pilot operations. All materials exhibited a dilatant stress strain response with continuous strain hardening to strains in excess of 8 percent.

The design of the tailings disposal facility is greatly influenced by seismic considerations. Myra Falls is located in an area of high seismicity with a potential for strong ground motions, as indicated in Table 1. The design therefore required a detailed assessment of whether liquefaction of the tailings would occur as well the potential consequences. Mitigative design measures were built into the design to ensure acceptable stability against earthquake loading. The cyclic resistance of the tailings materials was determined in a series of cyclic triaxial tests carried out on re-constituted samples of Myra-Lynx fine tailings and undisturbed samples of the HW fine tailings. Results of these tests are shown on Figure 6, which gives the relationship between cyclic stress ratio and number of cycles to liquefaction, and are generally in-line with results reported for typical tailings materials by Ishihara et al (1980).

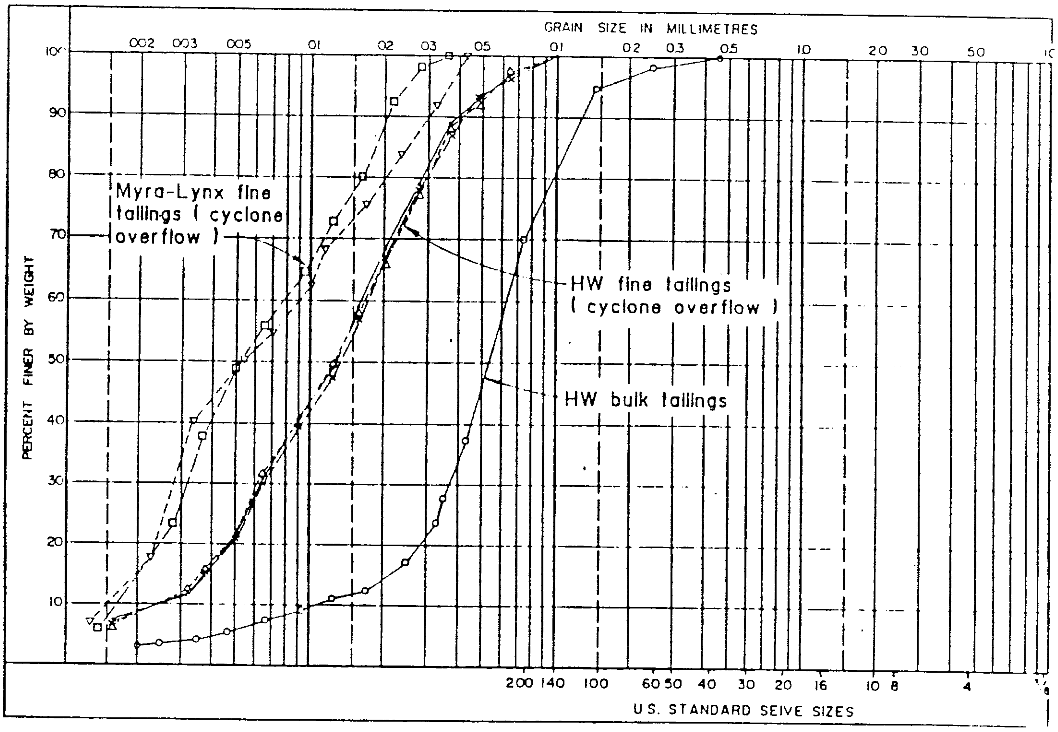

Figure 5. Particle Size Distribution for Tailings Materials.

The cyclic triaxial tests were also used to determine the post-liquefaction undrained strength of the tailings. In a total of 14 tests on normally consolidated samples, all samples exhibited a post-liquefaction continuous gain in strength, for strains of up to 13 percent as a result of dilation or strain hardening of the material. A comparison of pre- and post-liquefaction undrained stress-strain behaviour is shown for a typical sample on Figure 7.

An evaluation of potential liquefaction of the fine tailings using standard procedures established by Seed (1976) indicates that there is an approximately 20 percent chance of seismically induced stress ratios exceeding the cyclic resistance of the tailings over the operating life of the mine. However, this does not mean that a complete loss of strength and flow slide of the tailings would occur, as indicated by the post-liquefaction dilatant behaviour of the material. The fine nature of the tailings, and application of the Seed criteria (1981) for potentially liquefiable materials, indicates that undrained conditions will be sustained during and immediately after the earthquake loading. This allows post-liquefaction total stress stability analyses to be carried out and a calculation of potential displacements using procedures established by Newmark (1965) and Makdisi-Seed (1977). The results of these analyses are summarized in Table 4.

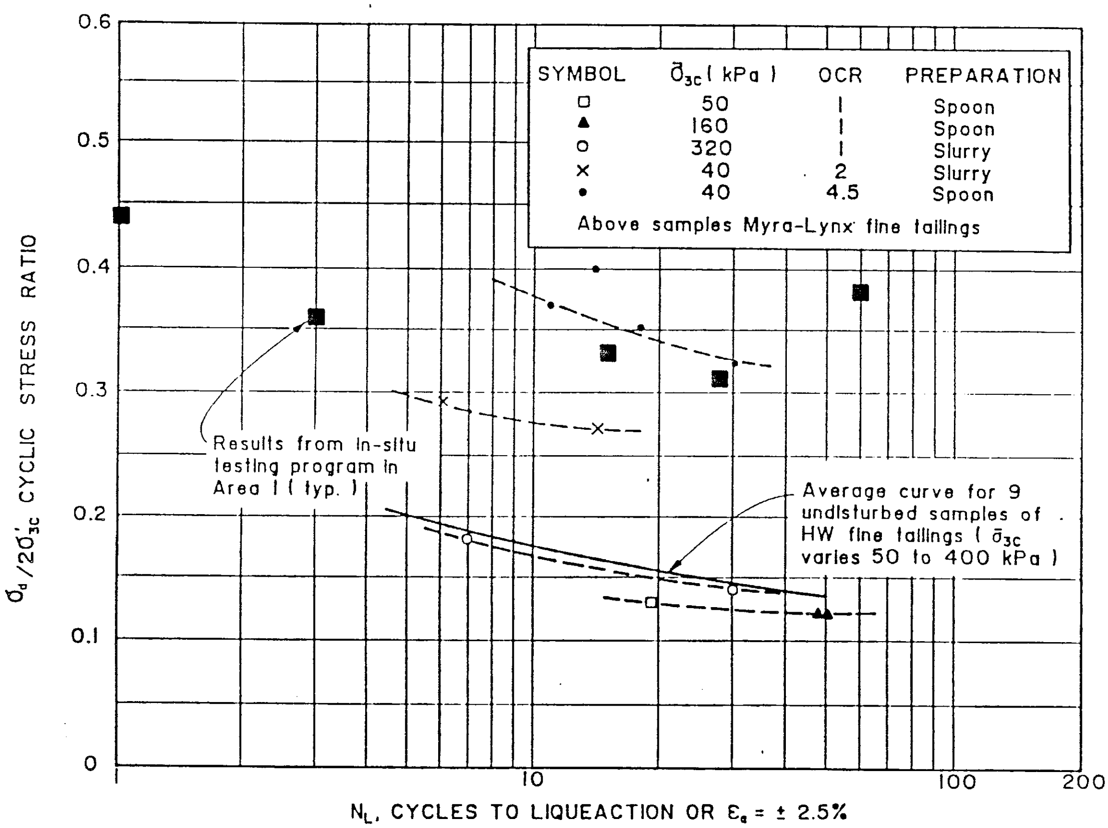

Figure 6. Results of Cyclic Triaxial Tests on Tailings Materials.

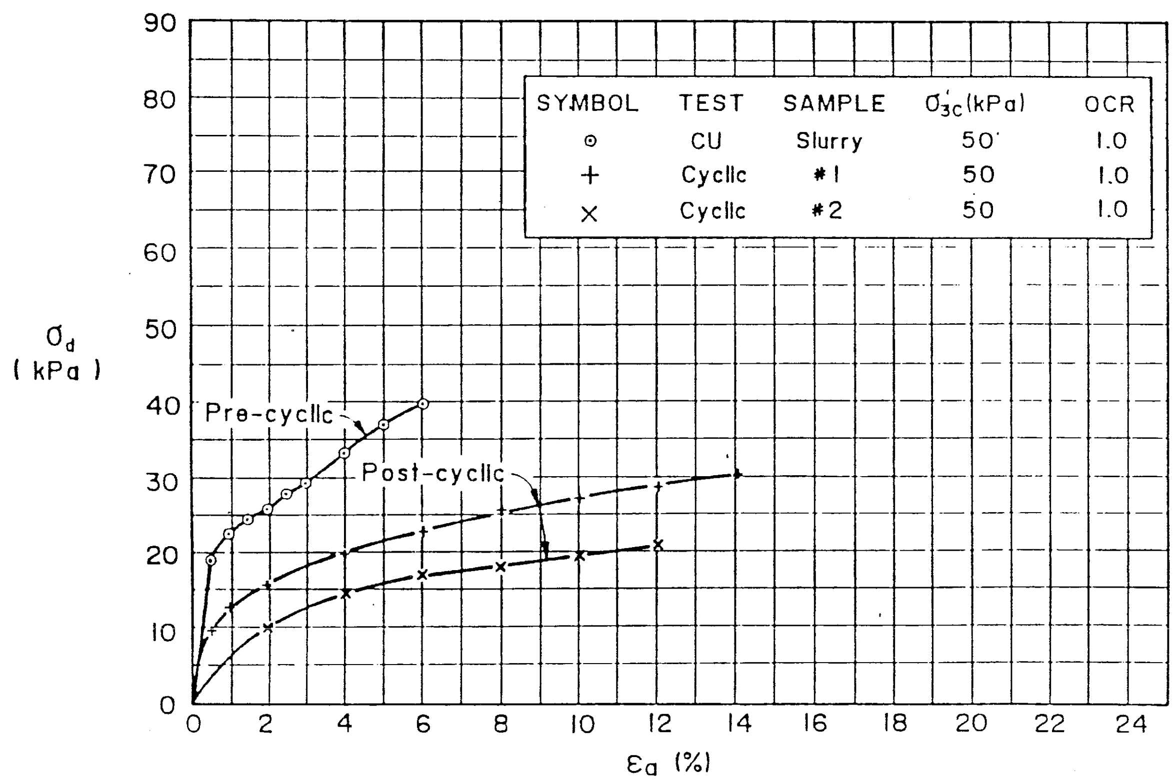

Figure 7. Typical Undrained Stress-Strain Behaviour of Fine Tailings Material.

The later addition of bulk tailings from the HW mine presented a new liquefaction concern. Segregation of this material on the beaches was considered likely to create lenses of more permeable material which could transmit water to the shear zone if saturated. To alleviate this, a series of vertical sand drains were installed in several rows along the inside of the confining embankment. This area represents the portion of the beach where segregation would be most prevalent and which forms the foundation for future embankment raises. The drains were extended into the foundation alluvium to ensure the coarse tailings remains fully drained.

Table 4. Summary of Stability Analyses for Ultimate Tailings Embankment.

Static Factor of Safety	
- effective stress analysis	2.56
- total stress analysis	1.46
Post-Liquefaction k critical*	0.16g
Potential Displacements for 475 yr. earthquake**	
- Newmark	4.0m
- Makdisi-Seed	0.3-1.75m

* k critical is horizontal acceleration required to reduce F.O.S. to unity for total stress analysis using post liquefaction undrained strengths.

** Includes a factor of 2 to allow for reduction in modulus after cyclic loading.

A significant aspect of the design is the instrumentation in the tailings and underlying alluvium to assess the actual pore-pressure conditions within the tailings. A schematic cross-section of piezometer installations is shown on Figure 8.

Piezometers consist of vibrating wire strain gauge and pneumatic types with de-airing capabilities. Initial results and upgrading of the system are discussed in the section on Operations.

The cyclic resistance of the foundation alluvium was investigated by drilling a series of boreholes and conducting SPT tests at frequent intervals. A total of 216 SPT tests were carried out in 14 boreholes, and the blow count values normalized to account for overburden pressure. The majority of values exceeded 50 indicating the material was generally very dense. Three areas were identified, however, as being potentially liquefiable under the 475 year acceleration for the site. These were:

(i) Localized surface material to a depth of 2.5 metres.

(ii) One deep isolated pocket within the facility.

(iii) Several isolated lenses of silty material at depth.

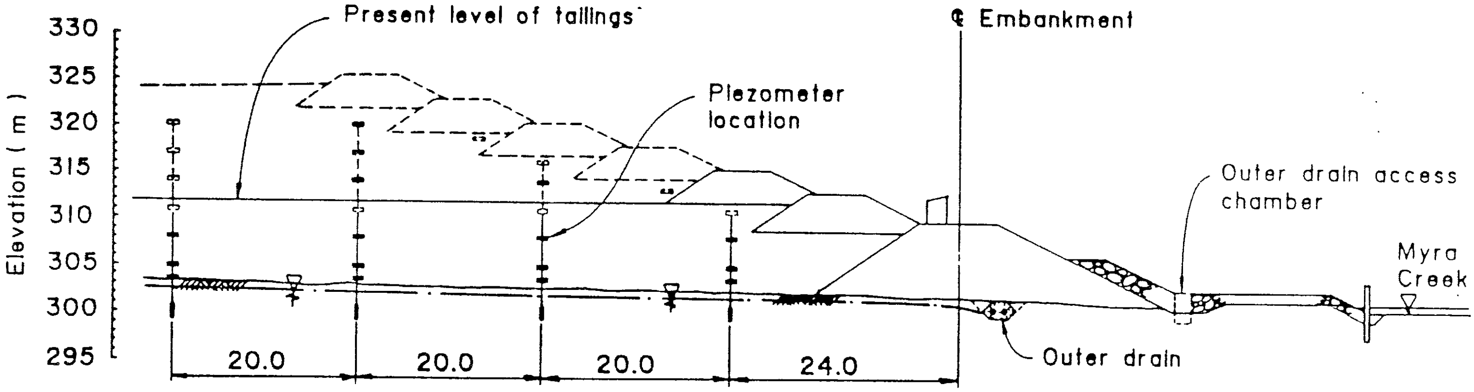

Figure 8. Schematic Cross-Section of Embankment Showing Piezometer Installations.

During construction of the facility the surface material was removed and used as fill in the confining embankment. The other areas were considered to be sufficiently isolated and confined to prevent any significant failure.

OPERATIONS

Initial deposition of tailings into Area I of the facility started in July, 1984 with the re-routing of Myra-Lynx tailings from Buttle Lake. Deposition of HW tailings started in March, 1985, after completion of the full facility.

The full storage capacity of Area I behind the starter embankment was used up by the summer of 1985. The Area I tailings beach was left exposed from this time until the summer of 1988 while the level of the tailings beach in Area II was allowed to catch up.

Daily throughput of the mill has been gradually increased to 4000 tonnes per day. Reduced requirements for underground backfill have also resulted in significant periods of time when the full bulk tailings stream has been discharged to the facility, generally adjacent to north edge of the facility and in one discrete location along the outer embankment. In addition, sludge from the treatment ponds has been co-mingled with the tailings on an intermittent basis. This has resulted in an average input to the tailings facility of approximately 2500 tonnes per day and a corresponding average rate of rise of 2.2 metres per year.

The high initial rate of rise of the tailings created difficulties in extending the vertical drains in the embankment section of the tailings. These were therefore capped and abandoned. On-going monitoring of pore pressures in the tailings will be used to establish the need for future installation of vertical drains from the surface of on-going embankment raises.

To date two geotechnical investigation programs have been undertaken on the tailings. In both cases test pitting and sampling was carried out to confirm the initial design assumptions and assess the impact of storing the bulk tailings and sludge materials. Geotechnical parameters determined from the investigations generally agreed with or exceeded the design assumptions. The results are summarized on Table 5.

Results of cyclic triaxial tests carried out on five undisturbed samples are plotted on Figure 6 for comparison with the initial test results. These data show the cyclic resistance ratio of the samples correspond to an apparent over-consolidation ratio of between 3 and 4. This is due in part to the fact that the samples were partially saturated at the natural moisture content and attempts to re-saturate the samples were not fully effective, and also the presence of lenses of the coarse tailings fraction. The stress strain characteristics for the pre- and post-liquefaction conditions confirmed the dilatant and continuously strain hardening behaviour of the material, with some softening after liquefaction.

Table 5. Tailings Material Parameters from Operational Testing.

Parameter	Myra-Lynx Fine Fraction	HW Fine Fraction	Combined Tailings
Specific gravity of solids	3.01-3.03	3.74-3.94	3.29-3.78
In-situ Dry Density (t/m^3)	1.27-1.76	1.85-2.10	1.6-1.9
Coefficient of vertical permeability (cm/s)	10^{5}-2 x 10^{-7}	10^{-5}-2 x 10^{-7}	10^{-5}-2 x 10^{-7}
Coefficient of consolidation (m^2/yr)	16-24	15-24	20-27
Shear Strength			
(i) ϕ' (deg)	35	37	36
(ii) c' (kPa)	0	0	0
(iii) $c_{u/p'}$ (strain = 2.0%)	.45	.55	.45

Surface sampling of the exposed tailings beach in Area I has been carried out by the Environmental Protection Service of Environment Canada over the last several years to test for the development of acid generating conditions in the tailings. Detailed results of this testing are beyond the scope of this paper but can be summarized as follows (Ferguson, 1989):

(i) extensive pH depression was found on the tailings beach surface in Area I, which has been left exposed for 3 years.

(ii) the depth of pH depression is highly dependant on the tailings gradation, with depths of up to 1 metre in coarse tailings, but no penetration through fine tailings laminations.

(iii) vertical shrinkage cracking results in pH depression at greater depths, but with the zone of depression limited to the sides of the cracks.

(iv) monitoring of normal operations in Area II revealed no evidence of pH depression on the tailings beach.

Routine operation of tailings deposition in Area I has now been resumed with continuous cycling of high pH tailings slurry over the surface. The testing program confirms the need to operate the facility without prolonged exposure of areas of the tailings surface, and the need for a properly engineered cover to the tailings surface at decommissioning.

Monitoring of pore pressures within the tailings facility has been carried out on an infrequent basis since start-up. Results from the most recent set of readings on one instrumentation plane are shown diagramatically on Figure 9, and show the phreatic surface depressed below the base of the tailings and negative or small positive pressures in the tailings mass.

Because of the extreme importance of close monitoring of the pore pressure regime, the instrumentation system is currently being upgraded with automatic data logging equipment. The system includes a seismic trigger with a set point of 0.04g that will initiate a higher frequency of readings in the event of major earthquake.

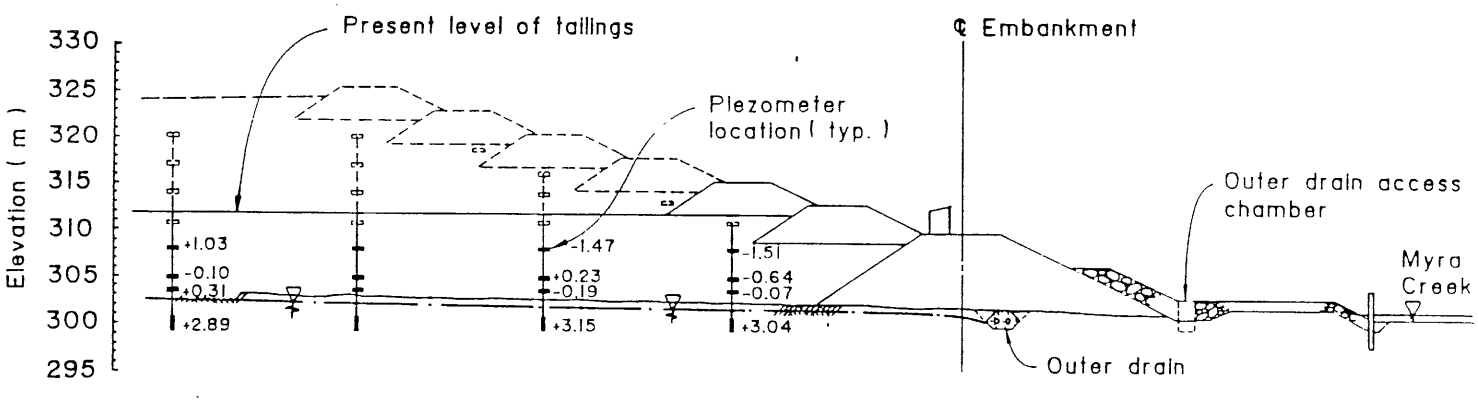

Figure 9. Typical Pore Pressure Readings in Tailings Facility (March, 1989).

SUMMARY

This paper describes the design and initial operations of the tailings disposal facility at Myra Falls, Vancouver Island. The facility is located in the alluvial filled, hanging valley of Myra Creek, in an area of high precipitation and high seismic actively.

The basic design of the facility is for a fully drained system with minimal surface ponding that allows for maximum utilization of the limited available space and upstream embankment construction on the tailings. The valley alluvium contains a system of drains that act as a hydraulic confinement beneath the facility and prevent the build-up of a phreatic surface into the tailings. The drains also serve to intercept acid mine drainage from an existing waste rock dump in the valley.

A seismic stability assessment of the proposed upstream embankment can be summarized as follows:

(i) The rate of tailings rise is sufficiently low to ensure full consolidation under two-way drainage during operations.

(ii) Comparison of the cyclic resistance of the tailings with extreme earthquake loadings indicate there is a possibility of liquefaction if saturated conditions exist.

(iii) The fine tailings, however, exhibits post-liquefaction strain hardening and is sufficiently impervious to ensure undrained conditions and post-earthquake factors of safety in excess of 1.0. Potential displacements are in the order of 2 to 4 metres under the 475 yr. earthquake.

(iv) The inclusion of lenses of coarse tailings in the embankment zone may provide lubrication to shear zones during earthquake loading, and the addition of a detailed network of vertical drains may be required to ensure such lenses are fully drained.

(v) On-going monitoring of the facility is provided by piezometers in the alluvium and tailings mass which are currently being upgraded with automatic data logging equipment and a seismic trigger. The criteria for successful operation is zero build-up of excess pore pressures throughout the structural zone of the tailings.

(vi) The facility is not used for water storage and by minimizing the volume of ponded water potential adverse impacts of embankments deformations are significantly reduced.

Operation of the tailings facility from 1984 has indicated performance to date in line with design expectations, and the first two embankment raises have been constructed. Sampling for acid-generation on the tailings surface has confirmed the need for continuous re-wetting of the surface with high pH slurry and the need for a properly engineered surface cover.

Since installation of the first groundwater drain in 1982 and commissioning of the facility in 1984, further contamination of Buttle Lake with acid mine drainage from the existing waste rock dump has been prevented and water quality in the lake has returned to background levels (Van Dyk (1986)).

ACKNOWLEDGEMENTS

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