ca8008227

1NIS-mf --

Sub-Aerial Tailings Deposition

R.B. Knight,[1] J.P. Haile[2]

SYNOPSIS

The sub-aerial technique involves the systematic deposition of tailings in thin layers and allowing each layer to settle, drain and partially air dry prior to covering with a further layer. Underdrainage produces densities in excess of those achieved by sub-aequous deposition and any air-drying serves to preconsolidate each layer with a resulting further increase in density. The low permeability of the tailings surface resulting from this deposition technique results in high runoff coefficients and, by decanting the runoff component of direct precipitation, a net evaporation condition can be achieved even in high rainfall areas. An underdrainage system prevents the build-up of excess pore-pressures within the tailings mass and at decommissioning the tailings are fully consolidated and drained thereby eliminating the possibility of any long term seepage. This paper presents a general description of these design concepts, and details of two projects where the concepts have been applied.

INTRODUCTION

Construction of tailings dams in North America has traditionally centred on the concept of water retaining type structures with essentially sub-aequous deposition of the tailings. The design of such conventional tailings ponds is normally concerned with control of the phreatic surface in structural zones of the embankments, and with reducing seepage rates through the embankment and seals by the use of low permeability materials. This often results in little or no regard being paid to deposition of the tailings, which can result in additional concerns with regard to liquefaction of the saturated tailings mass, consolidation of the finer fractions, and on-going long term seepage from the facility into the surrounding groundwater regime.

The sub-aerial technique of tailings deposition, which implies beneath air as opposed to beneath water, can serve to alleviate all difficulties associated with the containment of large volumes of water within the tailings facility. The provision of underdrainage beneath the tailings mass removes all excess free-draining water from the tailings during the operational phase of the

(1) President, Knight and Piesold Ltd, Consulting Engineers, Vancouver, B.C., Canada
(2) Director, Knight and Piesold Ltd., Consulting Engineers, Vancouver, B.C., Canada

facility, and can serve to reduce hydraulic gradients, and hence the seepage rate, across low permeability seals. Tailings facilities using these techniques are designed as solids retaining structures with the objective of achieving substantial liquid solid separation during deposition. The resulting drained, unsaturated tailings mass has considerable structural integrity and allows significant economies to be realised in embankment construction. In cases where storage of excess water is required for recycling as process makeup. or for treatment prior to discharge, a separate water storage reservoir may be required.

The sub-aerial technique has been developed over a number of years in Britain, Central Africa and Australia for the construction of high-density low permeability structurally stable tailings deposits. Applications of the deposition technique have been used in the construction of tailings dams above potential caving grounds, for the construction of low permeability core zones in hydraulic fill dams and for control of seepage into underground mine workings.

THE SUB-AERIAL TECHNIQUE

In the sub-aerial technique the tailings slurry is discharged onto a section of gently sloping beach of previously deposited tailings by means of distribution spray bars located along the upper edge of the beach. After it leaves the spray bars the slurry flows gently over the sloping beach and forms a uniformly thick layer. The slope of the beach and the thickness of the layer formed are functions of the characteristics of the slurry, typically the slope is between 1 and 0.5 percent and the thickness of the layer ranges from 100 to 150 mm.

Once the section of beach has been covered with the slurry, the discharge is moved to another section of beach and the newly deposited layer is left to settle, bleed and drain. During this process the coarser fractions settle towards the bottom of the layer and the finer fractions concentrate at the surface. The liquid released to the surface by the bleeding flows over the sloping surface to the bottom end of the beach and collects in the supernatant pond or is removed by a decant system. Because of the relatively flat slope of the beach the flowing liquid does not generate enough velocity to disturb the solid particles and the supernatant liquid is generally relatively clear and free of suspended solids. In some cases the scrubbing action of the slow, laminar flow over the relatively rough surface helps to remove suspended solids from the liquids. Drainage of liquid from the newly placed layer also occurs during deposition and continues while settling and bleeding is taking place. The liquid drawn from the bottom of the layer is absorbed by the air voids in the partially saturated layer beneath. The amount of liquid drained from the newly placed layer is a function of the specific capacity of the tailings solids and the degree of partial saturation in the tailings layers beneath. The time required for settlement, drainage and bleeding to be completed is a function of the solids content of the slurry and the physical characteristics of the tailings solids, and can vary from several hours up to several days.

After the bleeding has ceased the surface of the layer is left exposed and additional moisture is removed by evaporation. Large negative pore pressures are induced by evaporation and drainage which cause further consolidation of the solid particles. The amount of consolidation that can be attained by drying shrinkage is governed by the charcteristics of the solids, and, in general, finer materials shrink more than coarser materials. It has also been established that the solids content of the slurry at the time of placing influences the final density that can be attained, particularly if the material is relatively fine grained. Ideally each layer of tailings is left exposed for sufficient time to allow the maximum shrinkage to occur, and this will typically mean a reduction in the moisture content of the tailings to below full saturation. Typical examples of the effects of drainage and air drying on the unit weights achieved are shown on Figure 1.

An important characteristic resulting from the sub-aerial technique is the particle segregation which occurs within each layer during settling. This produces an anisotropic condition in which the vertical coefficient of permeability can be up to two orders of magnitude less than the horizontal coefficient of permeability. This condition reduces the infiltration of precipitation into the deposit and helps maintain the partially saturated conditions. The vertical coefficient of permeability is dependent on factors such as fineness of the material, clay content, and the solids content of the slurry at the time of deposition. Actual values for materials tested in the field range from 10^{-7} m/s to 10^{-9} m/s. The low permeability results in a high runoff coefficient in the order of 0.85 to 0.98, and, except under extremely high and prolonged precipitation conditions, a major portion of infiltration is subsequently removed by evaporation.

The deposition technique results in a drained, consolidated deposit of laminated tailings which provides strict control of seepage during operation, and, since the tailings are fully drained and consolidated at all times, allows for relatively simple decommissioning and the elimination of long term environmental concerns.

The concepts have been applied to over 40 tailings storage facilities during the past 25 years in Britain, Central Africa and Australia to store a wide variety of mine tailings. In all cases, in addition to the environmental benefits, the relatively small additional operating costs have been more than offset by improved utilization of the storage facility. More recently the technique has been included in the design of several storage facilities in Canada and considerable research has been carried out to determine the applicability under northern climatic conditions. This work has shown that the potential benefits can still be realised providing the deposition technique is supplemented with a comprehensive underdrainage system to compensate for the adverse weather conditions.

KEY LAKE PROJECT

The Key Lake project is a major uranium mine and mill complex under development in northern Saskatchewan, Canada, and due for start-up in July 1983. The project site is located approximately 240 km north of La Ronge on the southern boundary of the Athabasca Sandstone Formation. The area is typified by undulating hills and drumlins, and numerous small lake-filled depressions. Vegetation is generally stunted spruce and jackpine typical of

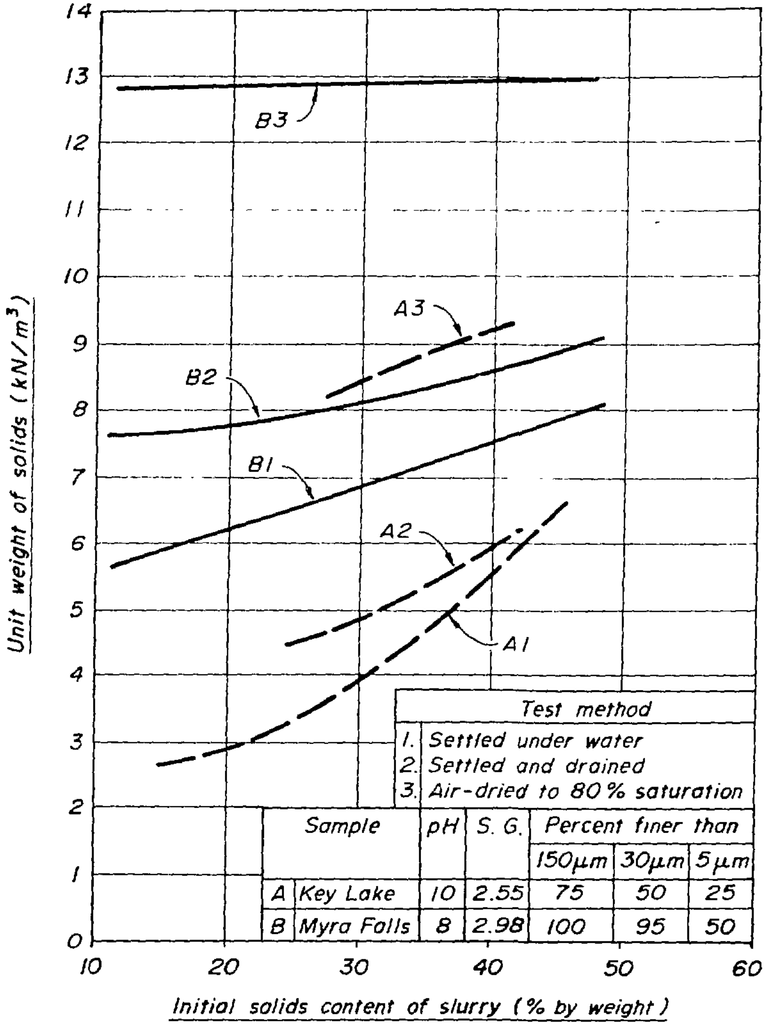

Figure 1 · Relationships between unit weight of solids and initial solids content of slurry for different methods of deposition.

sub-artic regions. Mean annual precipitation and mean annual potential evaporation for the site are 460 mm and 508 mm respectively.

The uranium at Key Lake is contained in two orebodies located at the sandstone basement contact beneath extensive deposits of outwash sands with thicknesses of up to 100 metres. The orebodies have an average grade of approximately 2.5 percent U_3O_8, and are also associated with high percentages of Nickel and Arsenic. Processing of the ore will be by pressure leaching to remove the uranium and other heavy metals with subsequent recombination and neutralisation of the leach residues and stripped raffinate solution. The resulting tailings product has an average composition of 70 percent leach residues and 30 percent gypsum and metal hydroxide precipitates. Principal environmental concerns originate from the radium content of the tailings, which is extremely high at over 6000 pCi/g, and the nickel and arsenic precipitates.

The physical characteristics of the tailings have been studied in laboratory and bench scale model tests carried out in conjunction with process research work for the project. The tailings material is comprised of approximately 35 percent fine sand, 65 percent silt and amorphous precipitates, and can be classified as a sandy silt of low plasticity. The tailings material parameters are summarised in Table I. Settling and drainage characteristics of the material are heavily influenced by the gypsum, resulting in extremely low subaqueous densities as illustrated by the test results plotted on Figure 1. Vertical drainage results in a small increase in density but this is offset by the addition of any excess lime. Air drying of the tailings material to maximum consolidation results in an increase in density of approximately 100 percent to produce a low permeability competent material. The results of consolidated undrained triaxial tests on undisturbed samples extracted from the model tests are included in Table I. Although the tailings material shows high strength characteristics, its inclusion in structural components of the tailings storage facility is precluded by regulations governing the storage of uranium mine tailings.

The tailings storage facility for the Key Lake project is located approximately 1.5 km west of the mill site on a broad ridge with a slope of approximately 2% towards the north-east. The general stratigraphy over the entire area consists of medium dense to very dense sandy till overlying sandstone at an average depth of 8 metres, which in turn overlies the crystalline basement of granitic gneisses. The thickness of sandstone varies from zero to approximately 20 metres. The till overburden material has an average gradation of 30 percent gravel, cobble and boulders, 65 percent sand, and 5 percent silt and clay, and forms the principal structural material in the construction of the tailings facility. Large quantities of clean outwash sands were also available from the open pit stripping operations and this material has been used to the maximum practicable extent.

Table I
Material parameters for Key Lake tailings

Tailings composition: 70% leach residues, 30% gypsum and metal hydroxides		
Solids contents at deposition: 30 - 35% by weight		
Temperature at deposition: 40°C		
pH at deposition: 10		
Average production rate of tailings solids: 1032 tonnes per day		
Average unit weight of solids used in design: 8.5 kN/m^3		
Consolidated undrained triaxial test results:		
c'	=	0
ϕ'	=	45°
c_v	=	4.4 to 36.6 m^2/yr
k (vertical)	=	7 x 10^{-8}m/s

The principal environmental requirements of the design of the tailings storage facility are as follows:

(i) Permanent, secure and total confinement of all solid waste materials.

(ii) Control and collection of all contaminated liquid wastes for treatment prior to release to the environment.

(iii) Permanent arrangements to monitor all aspects of the performance of the tailings facility.

(iv) Minimizing of the radiological impact of the tailings with respect to leaching and groundwater dispersion of radioactive elements, radon emanation, direct beta and gamma radation, and wind dispersion of radioactive dust from the tailings surface.

Early testing on the tailings material indicated that direct radiation and radon emanation from the tailings could be controlled within acceptable limits and that the tailings surface would be sufficiently cohesive to withstand erosion up to the maximum anticipated wind speeds at the site. Furthermore, the combined impact of these sources was found to be insignificant compared to the potential adverse effects of ongoing seepage from the facility.

The principal design objectives of the facility are therefore to achieve a system whereby seepage discharge to the environment will be reduced to negligible proportions during operation, and to ensure that at decommissioning the tailings will be fully drained and consolidated such that immediate construction of a surface seal will eliminate any long term seepage. In order to achieve these objectives, the design integrates a deposition strategy based on the sub-aerial technique with a comprehensive underdrainage system. The bottom of the entire facility is covered by a graded underseal with a filter blanket and perforated drainage system overlying the seal. The underdrainage system serves to intercept all seepage from the base of the tailings, and by removing any build-up of head within the filter blanket significantly reduces seepage across the seal.

The tailings will be deposited in thin layers from spray bars along the western end of the facility and will flow towards the main embankment to produce an exposed tailings beach with a slope of approximately 1 in 100. Precipitation and supernatant water will flow down the beach towards the main embankment. The main embankment incorporates a pervious upstream zone which will continuously decant precipitation and supernatant water by gravity into a system of collection pipes leaching through the embankment. Continuous decanting through the pervious zone will eliminate surface ponding and contribute to the fully drained condition of the tailings. Surface water and seepage from the underdrainage system are collected in a central sump and pumped to water storage reservoirs adjacent to the mill site prior to treatment. A schematic arrangement of the tailings facility is shown on Figure 2.

Construction of the facility was substantially completed during the summer of 1982 with final completion in 1983 prior to start-up of the mill. The underseal beneath the facility, and seals within the main embankment, were constructed by in-situ modification of the till material with bentonite, moisture conditioning and compacting. An average bentonite addition of 3 percent by weight over a depth of 200 mm has achieved a coefficient of permeability consistently lower than the design objective of 1.0×10^{-9}m/s.

The tailings will be delivered to the tailings storage facility at a temperature of approximately 40°C and, on the basis of climatic records, it is anticipated that it will be possible to deposit the tailings by means of the sub-aerial technique for at least 8 months of each year. During extreme winter temperatures the spray bars will be disconnected and the tailings will be deposited by open ended discharge to form a single thicker layer covering half of the facility. During the ensuing spring and summer this layer will be left exposed to thaw, settle, drain and consolidate prior to covering with additional layers of tailings. The location of the winter discharge layer will be alternated from side to side on a yearly basis in order to distribute the thicker layers evenly throughout the tailings mass. This strategy will eliminate the possibility of any large long term differential settlement from occuring and will prevent lenses of frozen material from becoming trapped within the tailings.

Unique features of the design are that at full storage capacity and at any time during deposition no excess pore pressures exist within the tailings mass, and the tailings have been drained and consolidated to densities over and above those that could be achieved by physical loading and dewatering of conventionally placed sub-aqeous tailings. Settlements during construction of the final seal will be immediate and will be a function of the compressibility of the consolidated tailings only.

WESTERN MINES, MYRA FALLS

The Western Mines Division of Westmin Resources Limited is an operating base metal mine located at Myra Falls on Vancouver Island, British Columbia, Canada. Existing milling operations are at a rate of 1000 tons of ore per day with a planned expansion to 3000 tons per day. Previous practise has been to

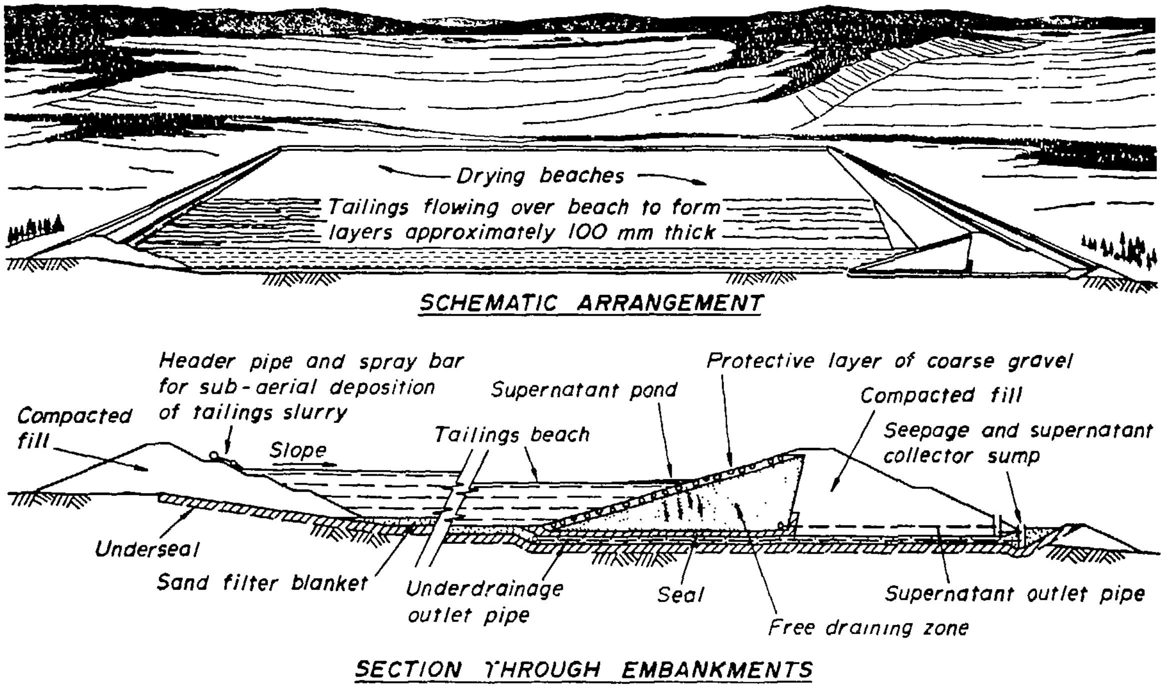

Figure 2 · Schematic Arrangement of Tailings Storage Facility for the Key Lake Project, Saskatchewan.

discharge the fine tailings fraction at depth into a nearby lake, but the expansion plans have required the permitting of alternative on-land disposal.

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. 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 occured in 1946. Mean annual precipitation and mean annual potential evaporation for the site are 2921 mm and 548 mm respectively.

Milling operations at the mine result in the removal of approximately 20% of the ore in concentrate form, with the remaining tailings being cycloned to remove the coarse fraction for mine backfill. Present cyclone separation achieves a split of approximately 50% between the fine and coarse tailings, resulting in a production rate of approximately 400 tons per day of fine tailings. The tailings storage facility is concerned with storage of this fine tailings fraction which, after mine expansion, will be produced at an increased production rate of up to 1200 tons per day.

Tailings material characterisation has been carried out in laboratory tests on samples of tailings to establish the material properties with regard to settling and drainage characteristics, shear strength parameters, permeability and consolidations characteristics, and resistance to cyclic loading. The material can be classified as a clayey silt of low plasticity, with typical particle size distribution and settling characteristics as shown on Figure 1. The tailings material parameters are summarized in Table II. Settling and drainage characteristics of the material show that a significant increase in density can be achieved by drainage alone and this can be further enhanced by air drying. Practical verification of the results of sub-aerial deposition of the tailings has been carried out in a pilot test area which has been in operation at the mine since mid 1981. Undrained shear strength testing on the tailings shows the material to be continuously strain hardening up to very large strains, and this is true for both reconstituted and undisturbed samples from the test area, and for post liquefaction monotonic loading in cyclic triaxial tests.

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, and has been previously used during early mining operations for a waste rock dump which is situated aginst the north side of the valley. The residual pyritic content at the rock dump, together with infiltration of precipitation have resulted over the years in extensive atmospheric leaching with resulting seepage of contaminated groundwater into the alluvial overburden materials on the valley floor, and eventual discharge into Myra Creek. With this situation, the design of the tailings storage facility has the added objective of controlling and ultimately eliminating existing contaminated groundwater discharges into the creek.

Table II
Material parameters for Myra Falls tailings

Tailings classification: Clayey silt of low plasticity (ML)
Specific Gravity: 2.98
Liquid Limit: 45
Plasticity Index: 9
Solids content at deposition: 45% by weight
pH at deposition: 8
Average production rate of fine tailings solids: 1200 tons per day
Average unit weight of solids used in design: 12 kN/m^3
Consolidated undrained triaxial test results:

c'	=	0
ϕ'	=	28^o
τ_f / σ'	=	0.4
c_v	=	14 to 154 m^2/yr
k(vertical)	=	1×10^{-8} m/s

The principal environmental requirements of the design of the tailings storage facility are as follows:

(i) Permanent, secure and total confinement of all solid wastes.

(ii) Control and collection of all contaminated liquid wastes from both the tailings and the existing waste rock dump for treatment prior to release to the environment.

(iii) Permanent arrangements to monitor all aspects of the performance of the tailings facility.

(iv) A tailings deposition system whereby the tailings will be transformed from a saturated fluid mass to a drained unsaturated stable condition in order to eliminate long term contaminated seepage, and to enhance seismic stability.

In order to achieve these objectives the design of the tailings storage facility makes use of the sub-aerial technique of tailings deposition, and utilises the pervious overburden materials on the valley floor, together with a drainage system, to provide underdrainage for the tailings and to control, collect and monitor groundwater from beneath the facility. Separate water treatment ponds have been constructed for treatment of contaminated water from the entire mine site.

The tailings storage facility is be located on the north side of the creek utilising the existing area between the creek and the waste rock dump. Provision will be made for future diversion of Myra Creek to allow an extension of the facility longitudinally down the valley. Initial construction will involve construction of a starter embankment adjacent to the creek with suitable rip-rap protection to contain flood flows within the existing creek bed. Surface stripping of the entire valley floor area between the starter embankment and the rock dump will be carried out to expose the sand and gravel overburden material which will provide the underdrainage. In conjunction with the starter embankment, an outer drainage pipe is located below the creek elevation with the ability to create a reverse hydraulic gradient from creek to drain, and to intercept and collect all groundwater flows from within the area of the starter embankment. This outer drainage pipe therefore provides a hydraulic barrier to migration of contaminated seepage from within the area, and, with a series of manholes and control gates, allows adjustment of drawdown to confine interception to selected sections of the pipe. Construction of the first stage of outer drainage pipe was carried out in June and July of 1982, and has been successful in intercepting approximately 80 percent of the previous zinc loading of the creek.

Tailings deposition will be carried out from the starter embankment towards the north side of the valley by systematic sub-aerial deposition of the tailings from spray bars. Surface runoff will be continuously decanted by a sloping filter layer against the rock dump, and will be collected by an inner drainage pipe. Both inner and outer drainage pipes are graded longitudinally down the valley and drain by gravity to a collector sump, from where the water is pumped to the treatment ponds. Overflow decants will be provided for major storm runoff, and surface runoff from above the facility is intercepted by a major diversion ditch on the hillside. A schematic arrangement of the tailings facility is shown on Figure 3.

Tailings deposition within the facility will result in a build-up of the tailings beach at a rate of approximately 1 metre per year, and when the level of the tailings approaches the crest of the starter embankment it will be necessary to provide additional freeboard. The drained nature of the tailings deposit and the strength characteristics of the tailings will allow this to be carried out by construction of additional 2 metre high confining bunds of free draining material on the previously deposited tailings. Construction of these bunds will be carried out during the summer months when the maximum benefit of air-drying of the tailings will also be realised. In this way the tailings facility will be gradually built up and will progressively cover the waste rock dump on the north side of the valley.

Seismic stability considerations have shown that, although there is a small possibility of an earthquake-induced loss of strength during the operating life of the mine, the strain-hardening nature of the material and post liquefaction undrained strengths are sufficient to limit potential displacements to acceptable values. Under the maximum design acceleration for a 475 year return period earthquake of 0.51 g, displacements would be in the order of 6 metres. The operating method of the tailings facility, which precludes surface ponding of water for any extended period, together with the construction of a surface seal and controlled surface drainage at decommissioning, remove the possibility of any adverse consequences of such displacements.

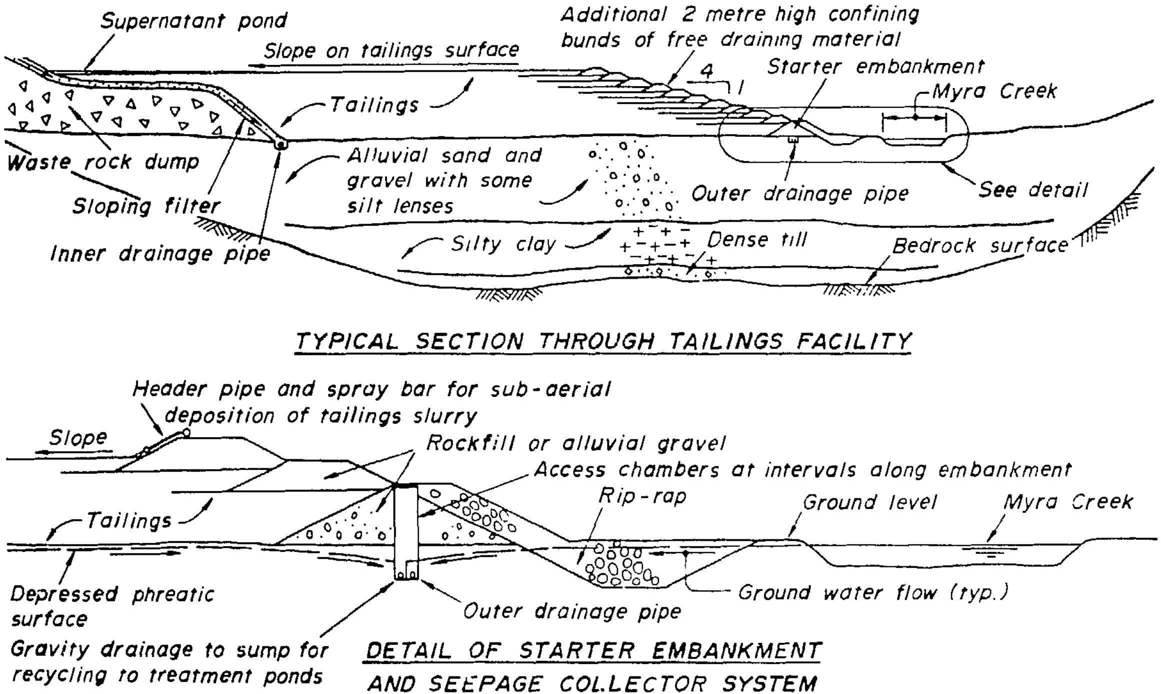

Figure 3 · Schematic Arrangement of Tailings Storage Facility for Western Mines, Myra Falls, B.C.

SUMMARY

Tailings deposition using the sub-aerial technique and underdrainage to achieve liquid solid separation during deposition of the tailings can lead to significant benefits in the construction of tailings storage facilities, and in the control of seepage. In practical terms this requires the removal of all excess water from the tailings facility by minimizing as far as possible any surface ponding, and by the provision of an extensive underdrainage system. Potential benefits resulting from the use of these concepts can be summarized as follows:

(i) Significantly greater unit weights are achieved in the stored tailings resulting in better utilization of the storage facility.

(ii) The drained nature of the tailings, and the removal of surface ponding adjacent to facility embankments, enables major portions of the structural elements of the facility to be constructed out of tailings material by so-called "upstream" construction, thereby effecting significant economies.

(iii) Due to the low-permeability laminated structure of the tailings deposit resulting from the deposition method, seepage from the tailings is eliminated during operation of the facility, providing sufficient operating area is available.

(iv) At decommissioning of the facility, the tailings are fully drained and consolidated allowing immediate construction of a surface seal and the elimination of any long-term seepage.

(v) The drained nature of the tailings increases the resistance to liquefaction under seismic loading, and the elimination of surface ponding reduces the possibility of adverse consquences that could result from liquefaction induced embankment deformations.