ENVIRONMENTAL GEOTECHNOLOGICAL CONSIDERATIONS IN THE DESIGN OF THE CANNON MINE TAILING IMPOUNDMENT

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ABSTRACT

Environmental geotechnology may be viewed as a planning tool, a philosophy of approach, or as the set or class of problems in geotechnical engineering that relates to environmental considerations. This paper explores these ideas by way of a description of the design and construction of the Cannon Mine Tailings Impoundment. The case history shows that each view of environmental geotechnology is valid in particular applications and, when used appropriately, environmental geotechnology facilitates planning, public acceptance, and sound construction of soil and rock structures that have considerable environmental significance.

INTRODUCTION

Tailings impoundments are argueably the largest geotechnical structures commonly constructed by man. They inevitably impact their environment and in the long term become new land forms. The design, construction, operation, and reclamation of an impoundment require a sensitive consideration of the interplay of geotechnical engineering and the environmental disciplines.

These basic considerations are the starting point for and an integral part of the philosophy of the design of the new tailings impoundment, currently being constructed for the Cannon Mine at Wenatchee, Washington.

This paper describes the environmental geotechnological issues involved in: the selection of the site of the impoundment; evaluation of seepage from the impoundment; assessment of the hydrogeochemistry of potential contamination from the impoundment; the social, visual, land use, and air quality aspects of the impoundment; and the reclamation plans for the impoundment.

GEOTECHNICAL ENGINEERING, THE ENVIRONMENT, AND TAILINGS IMPOUNDMENTS.

Sembenelli and Ueshita (1981) urge that environmental geotechnics be considered as a planning and decision tool, to be used before the construction of a facility to avoid geotechnical problems that might arise. In this role environmental geotechnology is an interdisciplinary activity.

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Morgenstern (1985), in proposing a classification of environmental geotechnology issues, starts with the assumption that the dominant concern of geotechnical engineering in matters of environmental concern has to do with the elimination or mitigation of environmental hazards. He divides such hazards into natural and man-made hazards. A tailings impoundment is a man-made hazard, and the subdivisions proposed by Morgenstern for man-made hazards are based on the distinction between problems associated with the flow of fluids and the movement of solids. In terms of Morgenstern's classifications tailings impoundments are structures of environmental geotechnological significance because they must store the tailings - that is prevent the movement of tailings to the environment - and because either or both water and contaminants may seep from the retention facility.

For the purpose of this paper, and because it reflects the basic view of the authors, a tailings impoundment is considered to be a geotechnical structure that is built into and becomes a permanent part of the environment and hence all aspects of its siting, design for stability and seepage control, construction, operation, and reclamation constitute an exercise in environmental geotechnology.

In this view environmental geotechnology is a window through which we see things as a part of a greater whole. It is an attitude of mind that permeates the processes of designing and constructing all geotechnical structures. It enables us to be sensitive to both human and technical considerations. It is more than a tool; it is a benign master that is at the heart of good geotechnical practice.

This attitude provides ample room for the Sembenelli approach of using environmental geotechnology beforehand as a planning tool; indeed it becomes a sina qua non for the planning of an impoundment. The attitude embraces a wider field than that allowed by Morgenstern's classification, but that may be necessary to bring together all the interdisciplinary issues of an impoundment.

THE PROJECT

The Cannon Mine is a joint venture between Asamera Minerals (U.S.) Inc and Breakwater Resources to develop a new gold mine that will produce between three and four million tons of tailings at a rate of about 2,000 tons per day.

The mine is adjacent to the town of Wenatchee, Washington, a community of 40,000 people on the banks of the Columbia River. The impoundment is above the town and part of the main embankment will be visible from populated areas.

The site chosen for the impoundment, after a detailed site selection study as described below, is in Dry Gulch, a valley southwest of the mine. The valley is part of a valley and ridge system that rises from the flatter alluvial terraces of the Columbia River on which the mine and the town are situated. The elevation of the gulch rises from 300 m at the alluvial terraces through 400 m at the impoundment site to 1,500 m at the upper end of the catchment, which has an area of about 450 ha.

The climate of the area is relatively mild and dry. Winters are characterized by light precipitation and cool temperatures, while summers are hot and dry. The mean annual precipitation is 230 mm and the gross annual evaporation is 760 mm.

SELECTION OF THE SITE FOR THE IMPOUNDMENT

Because the mine and hence the impoundment are close to a town, and the local populace has a direct interest in the chosen site, a formal procedure for selecting the site of the impoundment was adopted. The approach incorporates the formal use of Utility Functions and a ranking of alternative potential sites.

First an area within a 16 km radius of the site was examined. Areas that are not potentially suitable for impoundment sites were excluded. Reasons for excluding an area are that it is too steep, access is too difficult, the watershed is too large, or the area is populated. Twelve potential sites were identified. Each was visited, data about the area collected, and a conceptual layout of the impoundment formulated.

Catagories defined by Keeney (1982) to be considered in selecting a site were used in ranking sites. For each category, characteristics (Attributes) that could be used as a measure of the impact of the impoundment in the given catagory were defined. The catagories and examples of attributes used are: Health and Safety (Potential for constructing a safe impoundment); Economics (Capital, operating, and reclamation cost of the impoundment); Environmental Impact (Area of the impoundment, length of the tailings delivery pipeline); Socio-Economics (Current land use); and Public Attitude (Visibility, perceived public attitude).

For each of the characteristics (Attributes) we defined a Utility Function, which is no more that a graphical relationship between the Attribute scale and the Utility Number - a number between zero and one. An example is a straight line Utility Function relating the impoundment cost and the Utility Number.

For each alternative site the value of each of the Attributes was determined, hence the Utility Number determined. Not all Attributes have the same importance in assessing the rank of a site, hence various weightings were applied as part of a series of sensitivity analyses. The sum of the weighted Utility Numbers are compared in order to establish the relative ranking of the alternative sites - the higher the overall Utility the higher the ranking.

This site selection procedure resulted in the highest ranking for the site at which the impoundment is currently being constructed.

Two sites to the south of the mine were examined. The disadvantages of the sites are distance from the mine and the need to convey tailings in a pipe through populated areas. One site was ideally suited to the construction of an impoundment with a small catchment and low embankments, but it would be visible from well used roads.

Three sites close to the mill were assessed. Their advantages are that little pumping would be required. Disadvantages include visibility, and difficult foundation conditions and seepage control.

The chosen site and a second in the area were evaluated. Their disadvantages include the need to pump tailings against a head of at least 200 m. Advantages are screening by the surrounding hills, suitable foundation bedrock and practical seepage control, and the preexisting impact from silica quarry operations.

THE LAYOUT OF THE IMPOUNDMENT AND THE DESIGN AND CONSTRUCTION OF THE EMBANKMENT

The principal geological feature of the project area is the Chiwaukum graben. As the graben developed in the native Biotite Gneiss, fluvial and lacustrine deposits of the Chumstick Formation accumulated. Igneous activity occurred during this period. The major part of the area to be covered by tailings is underlain by the Chumstick Formation. The Wenatchee Formation which underlies the embankment was deposited on the eroded surface of the Chumstick. The Wenatchee rocks are interbedded sandstones and siltstones. The beds vary in thickness from about 100 mm to five and six meters. Sometime after deposition, the Wenatchee and other formations were extensively folded and faulted.

The hydraulic conductivity of the Wenatchee rocks decreases from 10-6 m/sec at the surface to less than 10-10 m/sec at about 50 m depth. A grout curtain has been installed beneath the embankment through these rocks - see Figure 1 for the embankment cross section. The grout curtain consists of two lines 3 m apart. On average tertiary holes were required for satisfactory closure, and frequently quarternary holes were required. The average hole spacing was about 1 m and the hole depths increased from 12 m at the crest to a maximum depth of about 50 m beneath the highest part of the embankment.

The downstream grout curtain involved about 10,000 m of rotary drilled holes. The upstream line contained about 6,500 m of hole. About 8,500 bags of cement mixed to a slurry of between 1 and 3 parts of water to cement by volume were grouted into the holes. The grout was injected mainly into major joints and fractures as indicated by the fact that about 50 percent of the grout went into only 2 percent of the hole length.

After the faulting of the Chumstick and Wenatchee Formations, the Columbia River Basalt Group was deposited, probably covering the entire area. The Ancestral Columbia River, and its tributaries, breached the basalt as the entire area was raised as part of the uplift of the Cascade mountains. The basalts have weathered and mass wasted. These decomposed basalts, a well graded mix of slightly plastic clayey silt, sand, and gravel, are now being used as the compacted shells of the embankment. They are placed in 400 mm lifts and compacted by at least four passes of a smooth drum vibratory compactor.

The downstream slope of the embankment at 2 horizontal to 1 vertical, and the angle of friction of the basalt (about 37 degrees) provide satisfactory factors of safety for both static and seismic conditions.

Near the end of the Pleistocene, the upper areas of the site were covered with a fine windblown clayey, silty sand, that is now being used to form the core of the embankment. The material is compacted in 150 mm lifts usually just slightly dry of optimum. The hydraulic conductivity of the core is at least 10-8 m/sec, hence seepage will be small and potential contaminant migration controlled.

Recent alluvial deposits filled the valley at the site of the embankment to a depth of 15 to 20 m. Beneath the major part of the embankment these deposits were removed. This was not possible - both for practical and economic reasons - at the upstream and downstream toes of the embankment. Accordingly, as shown in Figure 1, berms were formed on the in situ materials in order to provide the required stability for the embankment.

Seepage through the embankment will be controlled by the filter and drains, which are constructed of material brought to the site from deposits of alluvial sands and gravels along the Columbia River. The filter is a well graded fine to medium sand which has been shown by extensive testing to prevent piping of the core material even when the core material is slurried to simulate the material that may collapse into a crack through the core.

Thus the embankment has been designed to deal with the natural geological features encountered at the site, and to make as much use as possible of the soils and rocks occuring at the site. Geotechnical engineering in the design and construction of the technical aspects of the embankment certainly can be seen primarily as an activity which is directed to the containment of the fluids and solids in the impoundment. In this sense the Morgenstern approach of treating environmental geotechnology as the set of geotechnical activities related to environmental interests is valid.

No discharge of water under normal circumstances is permitted from the impoundment. In order to achieve a zero water balance in the reservoir, a diversion pipeline leads water from the upstream catchment around the impoundment.

A spillway to pass the probable maximum flood, occurring on the 20 year snow pack, is cut into the right abutment. The spillway is 10m wide and will convey 40 m3/sec flowing 3 m deep at 2 m/sec.

SEEPAGE FROM THE IMPOUNDMENT

The three routes by which seepage may occur from the impoundment are: through the embankment; through the abutments; and through the foundation materials in the valley.

The quantity and rate of seepage are influenced by several factors, the most important of which are: the geohydrological regime of the impoundment and reservoir foundation; the hydraulic conductivity of the tailings and bedrock; the geometry of the impoundment and embankment; and the construction and operation sequence of the impoundment.

A comprehensive analysis of seepage losses from the impoundment is difficult because of the complexity of the impoundment and the many variables involved. In order to estimate seepage from the Cannon Mine Tailings Impoundment, different impoundment stages of operation were defined and a range of simple but conservative analyses carried out.

Seepage was estimated for the following conditions (estimated seepage quantities given in brackets):

- o Current flow through the foundations (45 l/min).
- o The probable maximum flood behind the embankment and no tailings in the impoundment (100 l/min).
- o The impoundment half full of tailings (30 l/min).
- o The impoundment full with tailings (100 l/min).
- o The previous two cases but with the addition of the probable maximum flood on top of the tailings (250 and 150 l/min).

The varying potential for seepage in each case is shown by this analysis. In no case is the seepage from the impoundment unacceptable; the drains will control the water and ensure embankment stability. As discussed below, groundwater quality will not be significantly impacted by the predicted seepage quantities.

In this instance environmental geotechnology may be viewed as a predictive tool: standard and long established methods of geotechnical engineering are used to predict seepage quantities which are a starting point for an assessment of the environmental concern of groundwater impact due to seepage.

THE HYDROGEOCHEMISTRY OF THE IMPOUNDMENT

The gold at the Cannon Mine occurs as a hydrothermal deposit in the siltstones of the Swauk Formation. The ore will be ground and crushed to 90 percent less than 200 mesh and the gold removed by flotation, pressure oxidation, and leaching. At the time the analysis described below was carried out the intention was to further pressure oxidize, leach, and pass through a carbon-in-pulp system between five and ten percent of the tailings. The waste slurry was to be neutralized and the residual concentrate mixed with flotation tailings prior to discharge to the impoundment. Current plans call for the deposition of flotation tailings only, although a change in the gold price and further underground work might result in a resumption of the original plan.

In order to assess the potential for environmental impact of the seepage from the impoundment on the groundwater, the analysis described below was performed.

The chemistry of the flotation tailings and the mixed tailings measured on sample tailings from pilot studies is given by Caldwell et al (1984). The tailings chemistry after they have been mixed with a 10 percent sodium bisulphate solution was determined in order to represent the likely tailings chemistry after hydrogeochemical reduction of the tailings supernatant in the impoundment. In order to study the potential modification of the tailings chemistry that might occur on the top of the tailings and in the pool, mixed tailings were equilibrated with simulated rainwater (distilled water mixed with hydrochloric acid to a pH of 5).

The studies showed that the bulk of the residual cyanide is chemically complexed, hence chemically unreactive and non-toxic. Dilution with rainwater increases the level of free cyanide and iron slightly, but the overall chemistry of the liquid is better than that of the initial tailings slurry.

The quality of water seeping from the deposited tailings through the foundation bedrock may be modified by hydrogeochemical attenuation. These processes, which include neutralization, redox effects, precipitation and co-precipitation, ion exchange, and ion fixation, are important as they normally reduce the levels of dissolved species in tailings seepage.

The attenuation capacity of the foundation materials was evaluated with standard EPA test procedures; batch tests were performed on the mixed tailings supernatant and the foundation bedrocks. The test procedure is described by Caldwell et al (1984).

The sub-site materials have a significant capability to attenuate total dissolved solids, sulphate, total cyanide, sodium, arsenic, and copper. There is also some attenuation of cobalt, but free cyanide is not attenuated. These data provide input to the solute transport model which was developed to predict contaminant migration from the impoundment; the model is described below.

The linear flow pattern down the axis of Dry Gulch from the impoundment indicates that a relatively simple, one-dimensional solute transport model can be used to simulate contaminant loss from the facility. The analytical model incorporates the effects of advection, hydrodynamic dispersion, and hydrogeochemical attenuation.

Seven cases were analyzed using the model. Partition coefficient values used vary from zero to ten.

The results of this study show that, with zero attenuation, solute concentrations at the downstream toe of the embankment are reduced by advective and dispersive processes to approximately 50 percent of their input value. For partition coefficients of 3 and above, solute concentrations are reduced to less than 0.0001 percent of the original seepage concentration. Sulphate, total cyanide, arsenic, cobalt, and copper are reduced to below their detection limits before the seepage reaches the downstream toe of the tailings impoundment embankment.

Similar simulations were made for solute transport to the seepage control dam, some 200 m beyond the toe of the embankment. At this point, all species except iron and free cyanide are significantly below their background concentrations, and thus do not impact the downstream water quality. The predicted free cyanide concentration is well below the

U.S. Public Health Services (1962) mandatory limit of 0.2 mg/l.

The model did not include any facility for incorporating the effects of redox changes in the system. Consideration of the hydrochemistry of iron indicates the strong control that relatively oxidizing conditions exert on iron solubility. In the oxidizing condition that will be found in the downstream ground water and at a neutral pH, the iron concentration predicted by the model is significantly greater than its theoretical solubility by at least an order of magnitude. The value predicted by the model is considered to be high.

The solute transport model indicates conclusively that there is very little possibility of adverse quality impacts on the ground water downstream of the tailings impoundment. Groundwater water quality monitoring wells are installed at five positions around the impoundment. These will be used to monitor actual seepage and water quality effects due to tailings deposition.

This hydrogeochemical study is the heart of the assessment of the environmental impact of tailings deposition on the environment. It is the benign master aspect of environmental geotechnology in that it controlled all other decisions: for if the impact of seepage had been shown to be detrimental another site or a completely different design would have been adopted.

OTHER ENVIRONMENTAL CONSIDERATIONS

The site and the design of the impoundment were approved by the various State and local authorities after the public review process which included an EIS and hearings by the county planners.

Few of the objections to the project related to the impoundment. Questions were asked most frequently about the ability of the impoundment to deal with floods. We consider that the detailed planning of the impoundment in the spirit of the dictates of environmental geotechnology, plus the presence of a successfully reclaimed impoundment in an adjacent valley, are the main reasons for the ready acceptance of the impoundment.

During construction runoff control was achieved with the coffer dam and a sediment pond at the downstream side of construction activities.

The major environmental problem during construction was control of dust from the contractor's haul roads. The steep grades of the roads and the heavy equipment rendered all conventional dust suppressants ineffective. Two water trucks were used constantly to spray the roads and the fill. During operation the rocky outer zones of the embankment will prevent dust escape from the embankment. Proper discharge of the tailings will keep the surface of the tailings wet and suppress the dust.

The definition of environmental geotechnology proposed by Morgenstern does not include control of dust. And yet this airborn problem can effectively be controlled by geotechnics and proper planning.

RECLAMATION PLANS

The objectives of reclamation of a tailings impoundment are primarily to create a new topographic form which responds to the forces of the environment sculpturing the landscape in a way that is similar to the response of the natural surrounding landscape to those same forces.

The geotechnical engineer with an understanding of the engineering properties of materials, the geologist with an understanding of geomorphology, the plant scientist with knowledge of how to make things grow on an old impoundment, and the sociologist who understands what society wants and will accept, all play a part in the planning of the reclamation of an impoundment. This interdisciplinary activity is unquestionably an issue in environmental geotechnology.

Present plans call for using the impoundment at the end of tailings deposition as a flood control structure. To this end it will be reclaimed by proper contouring of the top surface of the tailings, construction of riprap lined channels at the interface of the tailings and the natural hillside on the right abutment of the reservoir, provision of sizeable freeboard for flood attenuation and sediment control, and the securing of the spillway.

During the final phases of deposition, tailings discharge will be altered in order to create the final reclamation contours. The tailings line will be advanced from the operating position at the crest of the embankment to a position along the northern perimeter of the impoundment. Tailings will be managed to form a beach sloping from the left flank towards the south flank, and from the back end of the impoundment to the embankment. As the topography of the top of the tailings will have been created by controlled discharge of the solids as a slurry, the shape is optimum for equilibrium with the flow of water across the surface, and the erosion potential is minimal.

Most of the top surface is anticipated to be sufficiently solid to traverse and begin revegetation at the end of deposition. This opinion is based on observations of an older impoundment in an adjacent valley where similar tailings are deposited - an apple orchard has been established on top of this old impoundment.

Topsoil that is now stockpiled above the impoundment will be spread on the tailings, or, depending on the results of a vegetation test program, topsoil will be created of the tailings themselves by the addition of suitable materials and nutrients.

A new stream channel along the right flank of the reservoir will be riprap lined with basalt boulders, an abundant supply of which is available from the embankment borrow areas. At regular intervals a Revett Mattress and gabion basket structure will be installed. The purpose of this is to provide a base level for erosion along the new stream channel.

CONCLUSIONS

This paper has described the environmental geotechnological considerations involved in the design of the Cannon Mine tailings impoundment.

Environmental geotechnology as an interdisciplinary activity was used as a planning and decision making tool in the design. In this regard the selection of the site involved a detailed understanding of the geology, soil mechanics, the environment, and the social, and economic aspects of alternative sites. The design of the embankment is premised on the interplay of the geology of the site and the geotechnical characteristics of the soils in close proximity to the impoundment.

Viewed as a procedure for the control of pollution and the mitigation of environmental hazard, environmental geotechnology entered the design and construction of the Cannon Mine tailings impoundment in:

- the assessment of contaminant seepage from the facility;
- the installation of the grout curtain;
- the design of the various zones of the embankment - such as the drains and filters - which contribute to seepage control and stability; and
- specifications and provision for reclamation of the facility.

Construction of the embankment is in progress. The mine is in operation and tailings deposition has just begun. Most people in the town are comfortable with the impoundment and see it as a positive part of a project which is bringing employment and prosperity to the region.

We believe that application of the fundamental tenents of environmental geotechnology, however defined and viewed, is a major factor in the social acceptability and technical success of the project.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Asamera Minerals (U.S.) Inc. and all their staff who have: provided the opportunity to work on the project; happily encouraged an approach that emphasises environmental awareness; and given permission for us to publish this paper.

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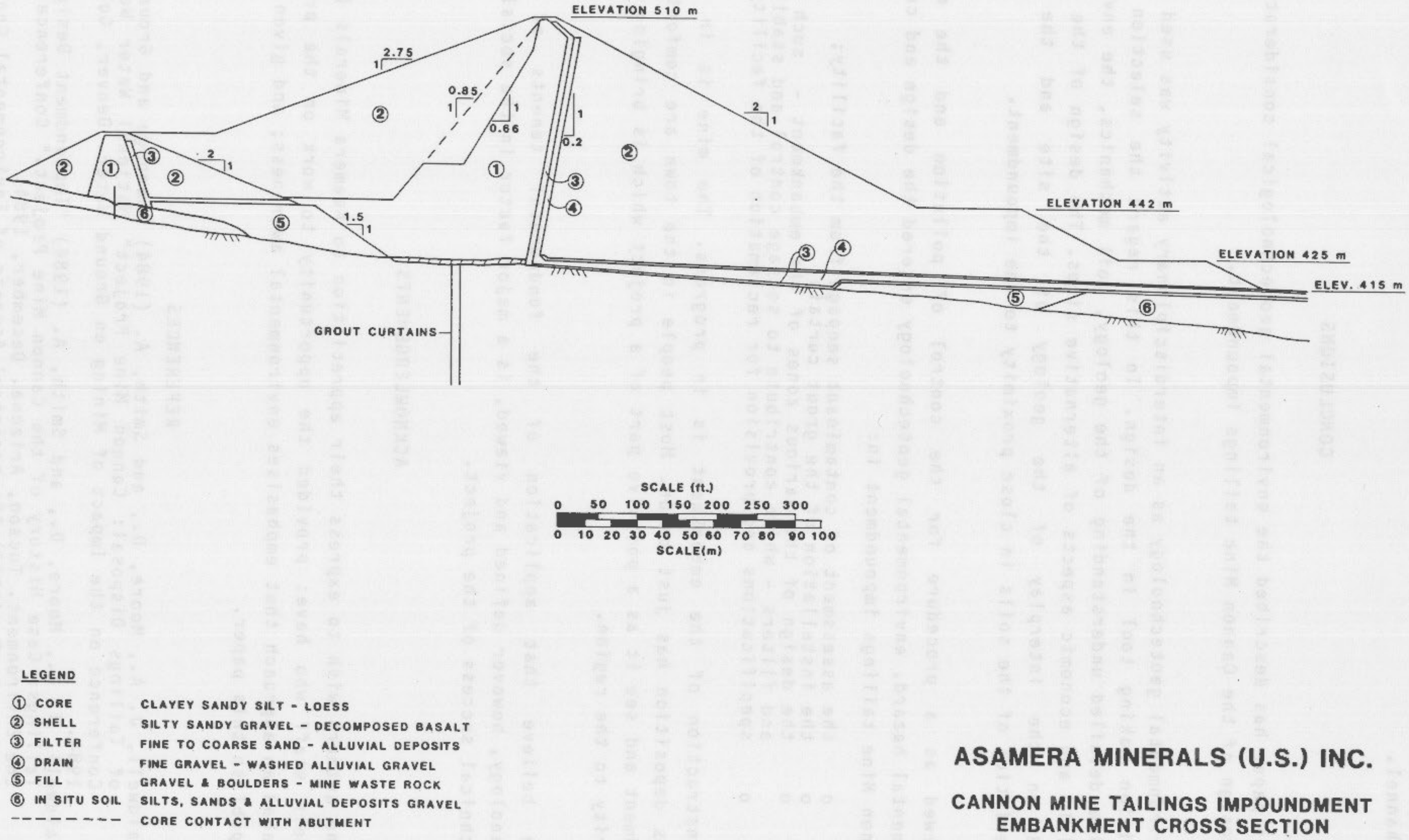

ASAMERA MINERALS (U.S.) INC.

CANNON MINE TAILINGS IMPOUNDMENT EMBANKMENT CROSS SECTION

FIGURE 1