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Geotechnical evaluations for tailings impoundments

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SYNOPSIS

The design, operation and reclamation of tailings impoundments require a knowledge of the geotechnical characteristics of the site and impoundment materials. This paper describes the general considerations and approaches involved in geotechnical investigations for tailings impoundments. Five case histories of geotechnical investigations for tailings impoundments are described to illustrate the approaches and methods discussed. The case histories vary from studies of tailings discharged into model ponds from a pilot plant (to predict full scale tailings behaviour) to site investigations in areas covered by alluvial clays and collapsing sands.

INTRODUCTION

Tailings impoundments are argueably the largest structures built by man. They are primarily geotechnical structures; built on soils and rocks, with soil and rock materials to contain ground-up rock that behaves essentially as a soil. The mining engineer, the mill manager and the geotechnical engineer all play a part in the safe design, economic operation and effective reclamation of a tailings impoundment. For this reason a broad understanding of the geotechnical nature and requirements of the foundations, earthworks and tailings is an essential requirement for the proper functioning of a tailings impoundment.

This paper sets out the elements of geotechnical evaluations required to design, construct, operate and reclaim tailings impoundments. Case histories are described in order to illustrate the principles discussed.

GEOTECHNICAL REQUIREMENTS

Geotechnical evaluations for tailings impoundments may be divided into the work required to characterize:

- the in situ foundation soils, rock and groundwater.
- the construction materials for embankment starter dykes and filter drains.
- the tailings.

Table 1 lists the geotechnical characteristics of the site, construction materials and tailings, which will most likely be used in the design, construction, operation and closure of a tailings impoundment. This information is required in order to perform at least those geotechnical analyses and evaluations listed in Table 2.

The tables referenced above are an attempt to define which geotechnical parameters are required and why they are used in tailings impoundment geotechnical evaluations. A general philosophy of approach might be that the designer or operater of a tailings impoundment must have a feel for the materials on which, of which, and for which the structure will be built. Quantifying the parameters in the list is only a part of the engineering synthesis that constitutes getting a feel for a tailings impoundment.

The geotechnical characteristics must be quantified in order to carry out calculations. The strength of the various materials must be defined in order to calculate the factor of safety or probability of failure of the embankment. Permeability must be measured to calculate the quantity of seepage from the impoundment, and hence to determine if this is acceptable. Consolidation properties must be known to allow an acceptable rate of rise for the impoundment to be calculated.

SITE CHARACTERISATION

In order to design a tailings impoundment, the geotechnical characteristics of the

TABLE 1 : SITE & MATERIALS GEOTECHNICAL CHARACTERIZATION

	PARAMETER	USE
	Site Materials	
1	Soils	
	- Distribution	Impoundment Layout
	Depth	Layout, Stability Analyses
	In Situ Description (MCCSSO)	Identification and Evaluation
	- In Situ Density	Definition of Strength
	- In Situ Permeability	Seepage Analyses
	- In Situ Strength	Stability and Settlement
	- Moduli	Seismic Stability
	- Grading Curve	Identification and Evaluation
	- Plasticity	Identification and Evaluation
	- Permeability	Seepage Analyses
	- Strength: Undrained	Stability Analyses - Short term
	- Effective Strength: c' Ø	Stability Analyses - Long term
	- Consolidation	Settlement and Strength
	- Chemical	Contaminant Mitigation
2	Rocks	
	- Distribution	Layout Definition
	- Depth	Layout Definition
	- Core Descriptions	Indentification and Evaluation
	- In Situ Permeability	Seepage
	- Jointing and Fracturing	Seepage and Stability
	- Bedrock Acceleration, Velocity, Displacement	Seismic Stability
3	Groundwater	
	-Distribution	Layout Definition
	- Depth	Layout Definition
	- Quality	Identification and Evaluation
	Construction Materials	
4	Soils	
	- Grading, Plasticity	Identification and Evaluation
	- Permeability	Seepage
	- Compaction Characteristics	Construction Specifications
	- Strength	Stability
	- Durability	Long-Term Behavior
	- Chemical Characteristics	Contaminant Control
5	Tailings	
	- Grading	Identification and Evaluation
	- Permeability	Seepage Analyses
	- Strength: Static	Stability Analyses
	- Strength: Dynamic	Stability Analyses
	- Consolidation	Settlement and Strength Increase
	- Beaching Angle	Impoundment Geometry
	- Deposited Density	Impoundment Volume
	- Deposited Moisture Content	Water Balance Studies
	- Chemical Characteristics	Contamination Potential
6	Slurry	
	- Slurry Density	Water Content, Depositional Characteristics
	- Slurry Supply Rate	Impoundment Size, Rates of Rise, Distribution Facilities
7	Mill	
	- Supply Rate	Impoundment Size
	- Rock Type	Tailings Definition
	- Grinding Process	Containment Potential
	- Chemical Process	Post Deposition Behaviour

soils and rocks at the site must be known. To do this one carries out a site investigation.

Aspects unique to site investigation for tailings impoundments are discussed below. Most impoundments cover a considerable area. This may include the hillsides surrounding the impoundment (if in a valley) and the associated catchment areas. The impoundment areas of the case histories described later in this paper vary from 1 km^2 to 4 km^2.

For such large areas the first step in a site investigation is what may be termed a preliminary or medium scale survey. The emphasis is on the definition in a broad sense of the geology and soils at the site.

As described by Brink et al (1982), the first step in a medium scale survey is to consult existing topographic, geological and pedological maps, and any other publications of interest for the area. After studying maps and airphotos the site is visited, and an attempt is made in the field to identify and delineate landforms, land-use, vegetation type, and soil and rock types and their distributions.

As described in Case Histories 1 and 5, the next step in the medium scale survey may be to have the area flown so as to define rock outcrops, soil zones, faults, dykes and zones of moisture using infra-red imagery. This technique is most efficient where the soil cover is thin (Warwick et al, 1979). If the soil cover is thick, and thus may affect the design of the impoundment, seismic refraction can be used to define soil depths over large areas at reasonable cost. As tailings impoundments normally cover large areas the use of geophysics is usually an attractive economic solution.

A medium scale site survey may include a limited number of trial holes or pits to record the soil profiles. Around the perimeter of a tailings impoundment, a trial pit spacing of 200 to 500 m is usually sufficient. Where rapid changes of topography, soil or vegetation occur closer spacing may be warranted, but closely spaced trial pits normally constitute the approach which may be termed detailed site evaluation. Soil samples may be taken for identification and testing.

In many cases, particularly in southern Africa, there may be extensive experience, gained from other tailings impoundment investigations of the soil types and their characteristics. In such cases a preliminary or medium scale survey may be all that is required to characterise the site, to identify sources of construction material, and hence design the impoundment.

Detailed investigation is necessary when :

- an extensive body of experience is not available of successful impoundments on similar foundation soils.
- it has not been possible to describe the soil profile properly, particularly where the consistency of individual soil horizons has not been assessed.
- local variations occur along the perimeter of the impoundment, or along critical structures such as penstock decant pipelines.
- the design involves a short high embankment, eg in a narrow valley (see Case History 2).
- the impoundment is to retain water and also serve as a water storage dam.
- groundwater contamination from impoundment seepage is of concern.
- special soil problems which require further evaluation have been identified during the preliminary investigations (see Case History 4).

The preliminary survey will have defined the constraints imposed by the site. The detailed investigation is planned to provide data to solve the problems so defined.

During a detailed site survey more detailed stratigraphic definition may be done with closely spaced reflection or refraction seismic studies or electrical resistivity profiling (see Case History 2). Detailed on-site profiling and recovery of soil and rock samples is carried out, with frequent test pits or core rigs. In situ testing may be done. The SPT test provides a good measure of sand consistency; the Dutch Cone and the piezocone are useful for defining soil layering and groundwater conditions; in situ pressure meters measure the soil strength and deformation characteristics.

Packer testing and in situ tests in piezometers can be used to define the hydraulic conductivity (permeability) of the soil and rock layers.

Soil samples for classification, strength, consolidation and hydraulic conductivity testing may be obtained from Shelby tubes, cores, and block or bulk samples. The choice of equipment to obtain the sample depends on the soil type.

Field and laboratory data obtained from preliminary and, if required, detailed investigations, are used to compile geological maps and cross-sections of the site, to record detailed soil profiles and quantify those geotechnical parameters to be used in the design and analysis of the impoundment.

Due to the large areas normally covered by tailings impoundments, a fence diagram is a useful tool at this stage as it displays the lateral extent of the soil profiles along with depth.

CONSTRUCTION MATERIALS

Construction of a tailings impoundment usually requires starter dykes, embankments or tailings guide walls. These may be constructed of soils or quarried rocks that are available within reasonable proximity to the impoundment. To the extent that these materials are soils, conventional geotechniques may be used. Essential tests include moisture-density determinations to assess compaction characteristics, triaxial tests on compacted material for shear strength, and permeability tests to measure the water retention or drainage characteristics of the compacted material.

Many mines usually have large quantities of waste dump rock available. This dump rock may be cheaply used to construct starter embankments. The characterization of the geotechnical properties of dump rock is certainly not a matter of conventional practice (Barton and Kjaerusli, 1981). If only rock core is available this may be examined in an attempt to determine the characteristics of the rock as-mined. Joint spacings may give an indication of the grading of the rock, although blasting is likely to break the rock into smaller fragments than those estimated from joint spacing only. If there is an existing waste rock dump, this may be examined in order to obtain the grading, particle shape, and uniaxial strength of the rock.

TAILINGS GEOTECHNICAL CHARACTERIZATION

The methods used to characterize the geotechnical properties of tailings depends on whether an existing impoundment of similar tailings exists locally. Table 3 lists the methods used to establish the geotechnical characteristics of tailings. A different level of knowledge of the tailings properties may be required depending on whether the impoundment containment dykes are to be constructed of tailings or borrow material.

If an impoundment of similar tailings exists, this should be examined in detail and a careful note made of the success and problems associated with the impoundment, especially deposition techniques employed. Table 4 is a checklist for examining existing tailings impoundments. Samples may be taken from the existing impoundment and tested in the laboratory. These parameters, previously listed in Table 1, may be measured for disturbed or undisturbed samples. Thus, the strength, permeability or consolidation behaviour may be determined using standard testing methods.

The behaviour of the tailings as-deposited may be quantified simply by measuring such parameters as the beach angle, moisture content, drying time, and solids-settling rate within the pool. Piezometers can measure the water pressures that develop.

In situ testing with piezocones (Jones and Van Zyl, 1981), pressure meters, SPT or shear vanes may be used to determine the in situ geotechnical properties of the deposited tailings.

If there is no tailings dam of similar materials locally available, then the designer (in order to characterize the tailings) must adopt a different approach.

First, the literature should be reviewed to ascertain previously measured values. Next, the designer may test bench-scale samples of tailings. Such bench samples are not always representative of the prototype mill grind, and caution when using the results is therefore especially warranted. Again, standard geotechnical tests may be used to measure grading, strength, permeability and consolidation characteristics.

If possible, pilot plant tailings should be discharged into a small model pond and the properties of the deposited tailings can be measured. Case History 3 describes such a pond and the studies performed. While not traditionally viewed as a geotechnical parameter, the chemical composition of the tailings must be determined so as to study the pollution potential of the impoundment.

OPERATION AND CLOSURE

The process of geotechnical evaluation does not cease once the tailings impoundment is designed, constructed and commissioned. Geotechnical instrumentation and monitoring are important aspects of the proper operation of a tailings impoundment. The data obtained from an instrumentation and monitoring programme determines the actual geotechnical performance of the tailings impoundment and allows this to be compared with the predicted or design performance.

Monitoring is an essential part of the practice often referred to as the "Observational Method" (Peck, 1969). This approach essentially consists of the following steps:

- exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail.
- assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions.

- establishment of the design based on a working hypothesis of behaviour anticipated under the most probable conditions.
- selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis.
- calculation of values of the same quantities under the most unfavourable conditions compatible with the available data concerning the subsurface conditions.
- selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis.
- mesurement of quantities to be observed and evaluation of actual conditions.
- modification of design to suit actual conditions.

The advantage of a comprehensive monitoring system is that it provides the operators with an advance warning of potential and developing problems. The assumptions made at the design stage can be reassessed during the operation of the impoundment. Such a reassessment can allow the introduction of more economic operating techniques or an extension of the life of the impoundment.

Instrumentation and monitoring should continue after reclamation and abandonment of the tailings impoundment. Tailings impoundments are large structures which have great potential to adversely affect their surroundings over a long period. Consequently, a long term instrumentation and monitoring programme should be designed to provide the information required to minimize long term problems and impact.

CASE HISTORY 1

The new tailings impoundment for a gold mine is situated on dolomite on the Malmani Subgroup, Transvaal Supergroup. The dolomite rock has a thin soil cover over most of the site, but some thicker soil zones are present.

The main objective of the geotechnical investigation was to locate borrow material for the construction of the toe walls for the tailings impoundment and for the walls of the return water dam. In addition information on the permeability of the soils and rocks and on the possibility of sink hole development within the impoundment area was required.

The fieldwork for the investigation was done in two phases, the first of which was the excavation of test pits in positions determined from air photo interpretation. This was found to be unsatisfactory as the air photos showed insufficient detail and siting of test pits could only be done on a "wild cat" basis. The conditions on site were considered ideal for obtaining optimum results from an airborne thermal infra-red linescan survey. The infra-red imagery gave extremely good resolution of the rock structure and showed zones of probable deeper soil cover.

The second phase of fieldwork consisted of further test pits excavated in positions determined from the interpretation of the thermal infra-red imagery.

A geological and pedological map was prepared to show areas of potential borrow material. The north-western and south-eastern corners of the area mapped were considered to be the best sources, but were not in the immediate area of construction. Other scattered areas were more suitable in this respect.

However, during construction it was found that in the latter areas the soil contained disseminated large dolomite boulders which make workability difficult. It was therefore decided to use the deeper sandy soil in the south-eastern part of the site for construction.

Laboratory tests of samples taken in the potential borrow pits showed the soil to have acceptable shear strength and permeability for use as construction materials and as foundation materials below the impoundment walls.

The imagery obtained from the thermal infrared linescan survey clearly showed areas of potential sinkhole development, such as along soil-filled fracture zones in the dolomite. Recommendations were made to prevent drainage of water into these zones as downward percolation of water will accelerate sinkhole development.

The spectacular detail of the rock structure obtained from the thermal infra-red imagery was the most important aspect of this investigation. It provided the basis from which much of the information required to satisfy the main objectives of the investigation was obtained. The case history illustrates that the use of less conventional methods may be very informative in the right conditions and should be considered when planning geotechnical investigations.

CASE HISTORY 2

This investigation was performed for a proposed valley-type impoundment, the bedrock of which is hard banded schist. The valley is filled with glacial sandy gravels, overlain by silts and clays, and covered by peat and an extensive muskeg deposit. Site investigation involved seismic profiling, drilling for soil and rock samples, and in situ testing.

2 000 m of refraction seismic lines were performed. These showed that bedrock beneath the impoundment embankment forms two trenches, one 30 m deep, the other 17 m deep. Bedrock velocities are about 4 500 m/s.

Five holes were drilled with a tripod drilling rig. Standard penetration tests were done and they showed very low blow counts. Intact samples of silts and clays were recovered with Shelby tubes and split spoons. A pitcher sampler was used to recover sandy gravels. Rock cores were taken.

Plastic standpipe piezometers, slotted at the bottom, were set in all holes. The bedrock permeability was measured with packer tests.

Pressuremeter testing was performed in two holes. The pressuremeter was inserted into the ground and inflated to expand horizontally. The inflation pressure and corresponding radial strain were measured. Tests were performed at 1,5 m depth intervals down the hole, and thus an accurate profile of the in situ soil strength was measured.

At one hole, a piezocone was driven into the valley fill. Hence, the layering of silts, clays and sands was measured. Standard soil classification tests and mineralogical analyses were done on the silty clays.

Undrained triaxial tests with pore pressure measurements were performed on the silts and clays to measure friction angles. Consolidation tests were performed both in an oedometer and in a triaxial machine so as to measure soil response to earthquake induced stresses.

The silty clay, composed of quartz and feldspar with illite and chlorite, had 40 to 50% silt size particles and 20 to 40% clay. The material has a low plasticity index of about 10. The natural moisture content is between 15 and 30%, and in some cases the natural moisture content exceeds the liquid limit. Drained friction angles are between 30° and 35°. High pore pressures were generated on shearing. The undrained strength measured with the pressuremeter shows that within the top 6 m, the soil is slightly overconsolidated with a strength of 40 kPa. Below this the silty clay is normally consolidated with an undrained shear strength falling between 10 m and 15 m to 40 kPa to 30 kPa respectively; thereafter, the strength increased to a maximum of 70 kPa.

The coefficient of consolidation varies between 10^{-5} m^2/s and 10^{-8} m^2/s. Soil hydraulic conductivity calculated from these tests varies from 10^{-9} m/s to 10^{-10} m/s.

The sandy gravels beneath the silty clay have SPT blow counts of about 14 and an angle of friction of 30°. Bedrock core recovery was good and hydraulic conductivity from 10^{-8} m/s to 10^{-10} m/s was measured in the intact rock.

CASE HISTORY 3

Pilot plant studies were performed to establish the extraction process of copper and zinc from a massive sulphide ore body. About 100 T were milled and the tailings discharged into a small pond. The floor was an existing concrete pad and the walls were pre-cast concrete sections of about 1 m height. The pond was approximately triangular in plan, the hypotenuse about 22 m, and the equal shorter sides of about 15 m length. Tailings were discharged into the pond at one corner by open-ended discharge.

The purpose of the study was to obtain data on :

- the beach angle of the sedimented tailings. Deposition was sub-aerial, slurry oozed down the beach to form an average beach angle of 4,7°.
- the tailings density. The known volume of the pond and the tonnes deposited were used to calculate an average dry density of 2 018 kN/m3. The specific gravity of the tailings is about 4,5.
- the grain size distribution along the beach. The tailings gradation, 95% less than 0,075 mm, 0% less than 0,01 mm, did not vary down the beach.
- the consolidation characteristics of the tailings. Undisturbed samples were taken with a Shelby tube and with a consolidometer ring. An average value of $C_v = 4 \times 10^{-8}$ m^2/s was measured.
- the effectiveness of different drain designs. Drains of three different designs were installed at the base of the pond. The drain designs were monitored by measuring both short and long-term discharge; measuring fines discharged through the underdrains; monitoring pore pressure between drain lines to quantify in situ drainage charac-

teristics of the tailings; and visual inspection of the drainage material when the tailings were removed.

CASE HISTORY 4

This investigation was performed at the site of a proposed ring dyke tailings impoundment for power station ash. The proposed impoundment is to replace an existing impoundment which is nearing the end of its useable life.

The site is essentially level and is underlain by clay. An air photo mosaic revealed only surface drainage features.

Phase one of the preliminary investigation included drilling large diameter trial holes with a bucket auger machine. Holes were spaced between 300 and 500 m over the site and taken to depths of between 5,5 m and 11,3 m. The trial holes were profiled with particular emphasis on soil characteristics that provide an indication of shear strength, compressibility and permeability of the subsoil. In situ hand vane shear tests were carried out in two of the trial holes. The peak vane shear strength varies from 56 kPa to 110 kPa; residual values varies from 15 kPa to 24 kPa. Undisturbed block samples were cut for laboratory testing scheduled to determine foundation conditions.

Selcted disturbed samples were taken from the soil horizons identified during visual profiling. Laboratory testing was performed to provide index properties, detailed soil classifications and compaction properties of potentially suitable borrow material.

The trial holes revealed near surface clayey sands over soft to stiff, highly slickensided and micro-shattered sandy clays, which in turn overlie medium dense and dense clayey and silty sands. These soils overlie sandstone bedrock which occurs at depths from 5,5 m to 10,5 m. Extensive water seepage into the trial holes occured below 4 m.

Phase two of the preliminay investigation consisted of a laboratory testing programme to establish the nature and engineering properties of the subsoil profiled in phase one. The results of this work were used for the conceptual design of the proposed tailings impoundment.

Laboratory testing of undisturbed samples was carried out to assess the suitability of the sandy clays as a foundation for the tailings impoundment.

Moisture-density and indicator testing was carried out on disturbed samples from areas of near surface clayey sands which confirmed their suitability as compacted fill in starter walls. These tests confirmed the suitability of the sands. The sandy clays were also tested but were not recommended for use provided sufficient clayey sand is available.

The results of indicator testing performed on samples taken over the entire soil profile confirmed the medium to very high potential expansiveness of the soils observed during visual profiling.

From the results of the preliminary investigation it was concluded that the site was suitable for the construction of the proposed tailings dam.

Subsequent to completion of the conceptual design, more localised, detailed investigations were carried out by means of test pits and further laboratory testing.

Before setting out the borrow pit area, further soil samples were taken from test pits for moisture-density and indicator testing. These enabled the extent of the borrow area and the compaction characteristics to be accurately defined.

The potentially expansive nature of the soils poses no problem to the tailings impoundment performance. It does, however, affect the design of the foundations of various service structures. Consequently detailed foundation investigations were carried out for the return water pump station, the electricity switch house, the main penstock towers and an ablution block.

A detailed investigation of near surface soils was required for the return water dam, which is to be constructed on a slight slope. Laboratory permeability testing of undisturbed samples was carried out to confirm the suitability of the in situ soils as side walls to the dam in areas of cut.

Moisture-density and indicator testing was carried out to assess the suitability of the soils from the areas of cut for use in constructing compacted side walls.

The chemical effect of return water on the soils was assessed. The clay minerals in the soil are sodium-based and highly prone to rapid dispersion, which would lead to erosion and piping when subject to hydraulic gradients. However, on analysis the return water was found to be high in calcium ions and low in sodium ions. Therefore cation exchange between the water and the soil resulting in dispersion of the soil would not occur and the return water dam walls will be stable.

TABLE 2 : GEOTECHNICAL EVALUATIONS FOR TAILINGS IMPOUNDMENTS

MATERIAL	DESIGN	CONSTRUCTION	OPERATION	RECLAMATION
Site or Foundation	- Define Site Geology			
Soils and Rocks	- Impoundment Layout - Embankment Stability - Embankment Flow Nets	- Construction Rates - Sources of Materials	- Contamination Potential or Migration Route - Seepage - Foundation Movements or Settlements	- Restoration Requirements - Long-Term Response
Construction Materials (Soils and Rocks)	- Identification and Availability - Embankment Design Requirements	- Construction Techniques - Construction Control Specifications	- Definition of Expected Response and Monitoring Program Evaluation	- Covers - Vegetation Potential - Re-shaping Requirements
Tailings	- Definition of Impoundment Type - Layout Requirements - Rates of Consolidation		- Rate of Placement - Operating Requirements - Monitoring Program Specification - Contaminant Potential - Cyclone Operation	- Cover Requirements - Long-Term Behaviour

The investigation was carried out in close collaboration with the impoundment designers. Consequently, rather than providing a general comprehensive site investigation from the outset of the project (which could have been unnecessarily costly), the work was programmed to provide specific information as required at each stage in the design process of the tailings impoundment.

CASE HISTORY 5

The new tailings impoundment was planned as the main tailings disposal site for the remaining life of a platinum mine. The geotechnical investigation of the site entailed the excavation and profiling of test pits, air photo interpretation and the interpretation of imagery obtained from thermal infra-red linescanning. In addition laboratory testing of the soils to determine their engineering properties was undertaken.

The site is on the Bushveld Complex which in this area is composed of gabbro rocks with pegmatoid zones (coarse grained feldspar rich zones). The rocks have been completely decomposed in the upper 0,6 m to 1,5 m to form a black "turf" clay which is highly expansive. The clay is relatively impermeable, but in the upper 0,5 m is highly fissured. This makes it possible for water to flow into the profile, causing expansion and in turn closing the fissures.

A number of dykes and fractures crossing the site were identified on the aerial photograph and thermal infra-red imagery. In another area of the property undermining has caused surface displacement along a fault. Such an occurrence below a tailings dam could be catastrophic. Although the depth of mining below the new dam is considerably deeper than where the ground surface displacement took place, it was agreed in discussions with mine management that a modified mining method would be used beneath the new tailings dam. This would ensure more stable conditions at ground surface.

CONCLUSIONS

This paper has discussed the geotechnical considerations affecting tailings impoundment

TABLE 3: METHODS TO ESTABLISH TAILINGS GEOTECHNICAL CHARACTERISTICS

Existing Dams

- Literature Study
- Examination of Design Reports
- Sample Testing in the Laboratory
- Field Measurement
  - beach angles
  - drying rates
  - settling rates
  - piezometers
  - shear vane
  - piezocone
  - pressuremeter

No Existing Dams

- Literature Study
- Test Samples from Similar Dams of Similar Ores and Milling Processes
- Test Bench Scale Samples in Laboratory
- Test Pilot Plant Samples in Laboratory
- Tests of Interest
  - standard classification (specific gravity grading, permeability, strength, consolidation)
  - settling times

TABLE 4 : EXISTING TAILINGS IMPOUNDMENT DESCRIPTION

1 GENERAL

Mine
Owner
Location
Personnel: Mine Manager
Mill Superintendent
Impoundment Supervisor
Designers
Others

2 OPERATION

Ore Body
Type of Mine
Rock Types
Size of Ore Body
Production History

3 MILLING PROCESS

Grind
Chemicals Used
Slurry Treatment (thickness, pH, other)
Slurry Density
Slurry Temperature
Water Intake to Mill

4 SITE CHARACTERISTICS

Precipitation
Evaporation
Other
Topography
Geology
Groundwater
Seismicity
Geotechnical

5 TAILINGS

Description
Grading Curve
Geotechnical Parameters (PI, c, Ø, k, C_v, C_c, SG)
Chemical, etc (including radioactivity and toxicity)
Delivery SG and w/s Ratio

6 TAILINGS IMPOUNDMENT

6.1 General

Construction Method
Area of Impoundment
Area of Pond, Distance from Crest, and
Freeboard
Current and Planned Heights
Slope Angles
Beach Angles
Rate of Rise
Estimated Remaining Life

6.2 Tailings Delivery and Distribution

Pipes (distance from mill, type, slopes, operation, wear, valves, etc)
Other Delivery Features (launders, drop boxes, spigots, cyclones)
Behaviour of Tailings on Discharge

6.3 Water Control

Decant Facility (type, size, capacity, operation)
Return Water Dam (type, area, capacity, pumps, spillway, operation)
Diversion Facilities (type, length, size, capacity, slope, operation)
Water Recovery

6.4 Seepage Control and Instrumentation

Drainage Blankets (location, size, effectiveness, outlet, seepage quantities)
Impermeable Linings
Others (filters, slurry trenches, wells, etc)
Piezometers (number, location, type, monitoring, water table)
Other Instruments (inclinometers, flow meters, water quality wells)

7 EXTENSIONS

Time Planned or Required
Location
Area
Ownership
Current Use
Description (topography, geology, soil, etc)

8 ABANDONMENT PLANS

Sides
Top
Water Diversion
Vegetation
Monitoring
Current Test Programs

design, construction, operation and reclamation. Methods of measuring the geotechnical characteristics of the soils and rocks on which, and of which, the impoundments are constructed have been described. Similarly, the measurement of tailings geotechnical properties has been considered. Some relatively new techniques have been described, and reference made to methods that are standard practice.
Actual case histories are described with details of testing apparatus, and the definition of material parameters.

This paper has attempted to establish the geotechnical nature of tailings impoundments, provide checklists for those who will design or review the design of impoundments, and provide a framework for further discussion of ways of ensuring that tailings impoundments are treated as, what indeed they are, the largest geotechnical structures built by man.

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