Guidelines for Determining Oil Sands Fluid Tailings Volumes

Canada's Oil Sands Innovation Alliance

June 2015

Table of Contents

List of Figures

1. Introduction

In 2009 the Alberta Energy Regulator (AER) implemented Directive 074 (D074). The main objective of the directive was to reduce the inventory of fluid fine tailings (FFT) across various leases of the mineable Athabasca oil sands. In response to the directive, operators implemented a variety of site specific tailings measurement methods to monitor progress towards meeting the regulatory requirements.

The industry realized that such a variety of measurement and reporting methods could create differing approaches in estimating fluid tailings volumes as well as tailings performance. To introduce consistency in reporting, the Canadian Oil Sands Innovation Alliance (COSIA) was asked to evaluate the technical merits of various measurement techniques, and propose a set of industry recommended practices.

To meet this need the COSIA Tailings Environmental Priority Area (EPA) tasked the Tailings Measurement Steering Committee (TMSC) to produce these recommended practices. The scope developed into four areas of focus, including; Fines measurement, FFT Volume determination, Deposit Characterization, Sampling and Geostatistics.

In March 2015, the Government of Alberta issued the *Tailings Management Framework for the Mineable Athabasca Oil Sands* (TMF) as a component of the *Lower Athabasca Regional Plan 2012–2022* (LARP). These policy documents aim to provide *direction to manage fluid tailings volumes during and after mine operation in order to manage and decrease liability and environmental risk resulting from the accumulation of fluid tailings on the landscape*. With the issuance of the TMF, the Alberta Energy Regulator (AER) was sanctioned to bring the policy direction into force through regulations.

A key feature of the TMF is that each operator is required to submit a plan for managing fluid tailings including a volume profile of fluid tailings to be reclaimed during active mining and at mine closure. The fluid tailings volume working group considered the potential implications of the policy statements contained in the TMF when developing this final report submission to the TMSC.

2. Purpose

This guideline sets out procedures for determining the volume of fluid tailings contained within tailings deposits. It is intended to provide guidance to operators of oil sands mines to meet the objective of controlling fluid tailings volumes to an approved plan consistent with the TMF and as outlined in *Guidelines for Performance Management of Oil Sands Fluid Fine Tailings Deposits to Meet Closure Commitments*.[1] The background, rationale and objectives to plan and control fluid tailings volumes are set out in that document and related COSIA guidance

[1] *Guidelines for Performance Management of Oil Sands Fluid Fine Tailings Deposits to Meet Closure Commitments*. Canada's Oil Sands Innovation Alliance (COSIA), February 2014.

documents.[2,3] This guideline relies on the definitions included in those documents. It is aimed at standardizing sampling and measurement of fluid tailings including the fluid fine tailings in conventional tailings settling ponds as well as treated deposits that may have significant coarse sand content but are still in a fluid state.

3. Fluid Tailings Volume

In a tailings deposit, the volume of fluid tailings lies between two defined surfaces: the top of the fluid tailings or mudline (typically around 5 per cent solids), and the solid bottom of the deposit. (See Figure 3-1: Typical Fluid Tailings Deposit Profile.)

In a fluid tailings deposit covered with a layer of water, the mudline lies within the transition zone between the upper water layer and the underlying fluid tailings. The transition zone is usually distinct and occurs over a short distance of less than 20 centimetres (cm). The mudline depth is determined using sonar surveys or density plate surveys, and then verified using interval depth sampling.

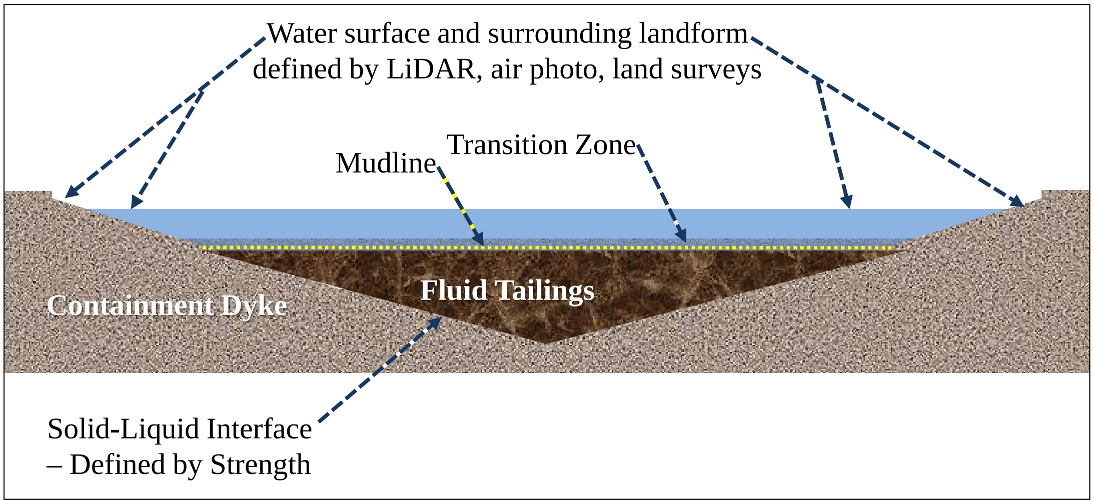

Figure 3–1: Typical Fluid Tailings Deposit Profile

The methods for determining the mudline depth in a water covered deposit described herein are based on ponds with a narrow transition zone from clear water to fluid tailings. In a fluid tailings deposit with no substantial surface water layer, the mudline is effectively the top of the deposit. Under this circumstance the top of the deposit can be measured using airborne or land based LiDAR, air photo surveys, or traditional land survey techniques.

The bottom of the fluid tailings deposit is defined by a surface representing the transition from fluid to solid. The transition can be sharp, for example where the fluid tailings meet a sand beach, or more gradual, such as in a consolidating tailings

[2] *Technical Guide for Fluid Fine Tailings Management.* Oil Sands Tailings Consortium/COSIA, August 2012.
[3] *A Guide to Audit and Assess Oil Sands Fluid Fine Tailings Performance Management*; Canada's Oil Sands Innovation Alliance (COSIA), May 2014.

deposit. The bottom of the fluid tailings layer is determined using drop sounding tools and cone penetration tests.

Once the top and bottom fluid tailings surfaces and the spatial coordinates of the containment structure have been determined, the volume of fluid tailings can be calculated using commercially available 3-D modeling software.

4. Measuring the Mudline

Four methods are used to define the mudline surface for a fluid tailings deposit:

4.1 Sonar Surveys (water covered deposit)

A fish finder is mounted on a boat and continuous depth and GPS location readings are recorded as the boat travels across the pond.

4.2 Density Plate Measurement (water covered deposit)

A density plate calibrated to the target density of the fines in water is lowered from a boat, the depth at which the plate stops is measured.

4.3 Interval Depth Samples (water covered deposit)

Physical samples are taken at measured intervals (10 cm) and analysed for solids content.

4.4 Land Survey Techniques (deposit without overlying water)

In a fluid tailings deposit that has no substantial water layer, the mudline is effectively the top of the deposit. In this case, the top of the deposit is measured using standard airborne or land based LiDAR, air photo surveys, or traditional land survey techniques.

For water covered deposits, the mudline depth is measured using either sonar surveys or density plate surveys. In both cases, the measurements are validated using interval depth sampling.

Further details of current practice for the three water covered methods are provided in the Appendices A, B and C.

5. Measuring Hard Bottom

Two methods are used to define the hard bottom interface of fluid tailings deposits:

5.1 Drop Soundings

With a drop sounding tool, the bottom of the fluid tailings is determined by dropping a heavy weight probe from a boat and recording the depth to the hard bottom when the weight stops.

5.2 Cone Penetration Testing (CPTs)

With CPT, a cone on the end of a series of rods is pushed into the tailings deposit at a constant rate while continuous measurements are made of the resistance to penetration of the cone and of a surface sleeve. The fluid tailings bottom surface is determined based on resistance measurements.

Drop sounding measurements are validated with selective CPT measurements. When dense bitumen mats or debris cause difficulties with drop sounding, the CPT tool is used in conjunction with drop soundings to get the hard bottom interface. Appendices D and E provide further details on the two methods.

6. Acknowledgements

This guideline was prepared by the COSIA Tailings Measurement Working Group whose members were Paul Cavanagh (chair), Robert Donahue, Al Hyndman, Adam Langer, Bruce Li, Wayne Mimura and Sean Wells. COSIA would also like to thank David Baldrey of Total and Andrea Larson of the AER for their review and guidance on the document preparation.

Appendix A Sonar Survey

For water covered deposits, surveys to determine the mudline surface are conducted with the use of a sonar GPS recording instrument. A commercial sonar tool (fish finder) is commonly used in the oil sands industry. This utilizes sonar signals to measure recycle water depth to the tailings beach or to the top of the fluid tailings deposit, whichever comes first.

Sonar (SOund NAvigation and Ranging) uses high frequency sound signals (~ 200 Khz) to determine the depth of water by measuring the time it takes for an emitted sound signal to bounce off the bottom or interface and return to the transducer.

The advantage of sonar is that it provides a continuous surface trace across the transection of the pond. Sonar reflection is intended to detect the mudline. However, the mudline is not a distinct surface so reflection may occur over a range of solids contents (typically less than 5%). As a result, the sonar depth reading is validated at several locations by interval sampling as described in Appendix C. The number of interval samples required depends upon the consistency of readings and the uniformity or variation of the mudline surface elevation.

Sounding locations should transect the fluid tailings deposit. The lateral extent of the fluid tailings terminates at the intersection of the mudline with the bottom of the pond containment – for example, a sand dyke beach. Depending upon the overlying depth of water and the slope of the containment beach, different methods may be necessary to define the perimeter intersection of the fluid tailings with the beach.

For each sonar survey the following data are recorded:

- The depth of the sonar transducer below the water surface. (Typically the transducer is at the surface or assumed to be at constant depth below the surface, but may be affected by wind induced wave action or by the speed of the vessel over the water. Ideally, surveys are conducted in calm weather without wave action.)
- The XY location of the sonar transducer relative to its position on the water.
- The GPS coordinates of each sounding.
- The elevation of the water surface.
- The sound pulse frequency (typically 200 kHz).
- Alignment of the transducer. The sonar signal should be transmitted down vertically to ensure accurate delineation of the mudline. Any deviations from the vertical are recorded.

Appendix B Density Plate Survey

A density plate survey is conducted using a plate of a calibrated density which has neutral buoyancy at the mudline.

A density plate is a plastic plate with an area of approximately 3600 cm^2 and a thickness of 25 mm. (See Figure B-1: Density Plate Schematic). The plate has symmetrically placed holes that are used to hold stainless steel bolts and nuts. The bolts and nuts are used to ballast the plate so that it has a density equivalent to water with 5% solids content (1.032sg approx. depending on temperature of fluid). A thin stainless steel wire is attached to each corner of the plate. These wires meet in the middle of the plate at a height of about 20 cm. At this point the support and depth measuring wire is attached, with the zero point of the measuring wire referenced to the mid-thickness of the plate. The wire is marked at 0.25 m intervals for measurement reference.

The density plate is calibrated at least once a year. The plate is suspended in a saltwater solution beginning with of 20 litres (L) of water containing 800 grams (g) of dissolved salt. Salt is added until the plate reacts. The plate should float in a 55 g/L solution and sink in a 45 g/L solution. Calibration is performed with wires attached, imitating field testing methods. Ballast in the form of stainless steel nuts, bolts, and screws is added or removed until the plate is fully submerged and floating freely in the solution.

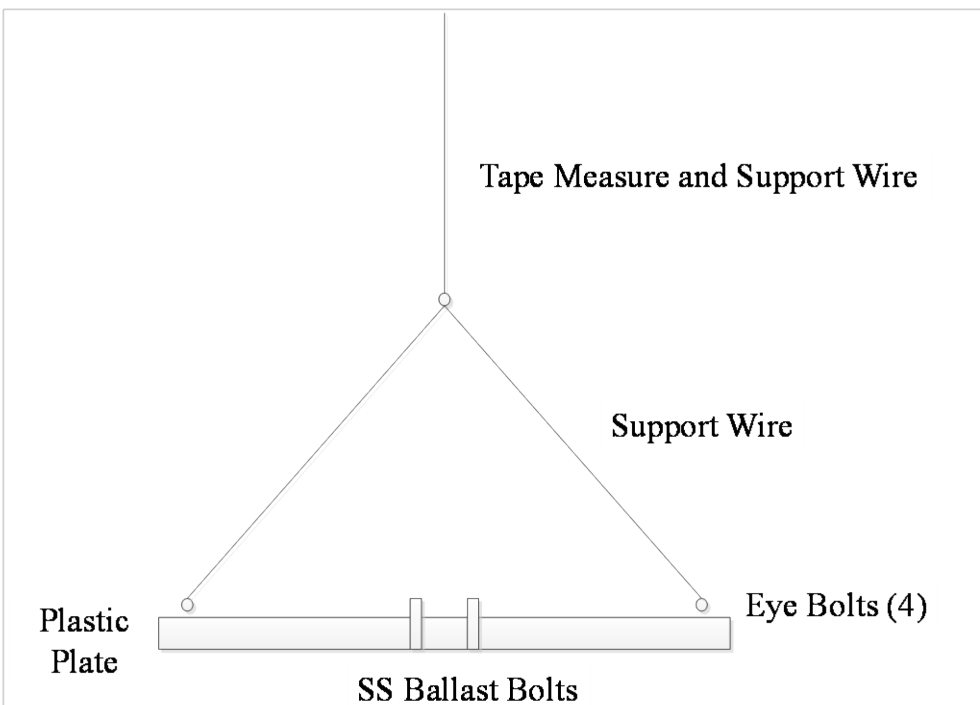

Figure B-1: Density Plate Schematic

At each survey point, the measurement platform (e.g., boat, barge) must be stationary, allowing the platform to position itself for two to three minutes to minimize the effects of current and wind. Movement that causes the wire attached to the density plate to deviate from vertical affects the accuracy of the measurement. The greater the depth of the mudline, the greater the error will be.

At each survey point, the plate is placed in the water on a horizontal plane. The plate is allowed to sink under its own weight until it stops. Once the plate has stopped, it is slowly raised by 1 cm to 2 cm, and then allowed to fall again. If the second measured depth deviates by more than 1 cm from the first, the test is repeated.

A number of factors can complicate the use of the density plate and the determination of the mudline:

- Crimps in the depth measuring wire may occur and cause errors in the mudline depth measurement. To prevent this, crimps or kinks in the wire are smoothed out.
- Accumulated debris or bitumen on the density plate will skew measurement of the mudline depth. The plate is cleaned after each use. Areas with surface accumulation of bitumen are either avoided or the bitumen cleared away before the test.

While the sonar method provides a continuous trace of depth across each transection, the density plate provides only spot measurements. Therefore, the number of measurement points needed to define the surface is a function of the mudline depth variation and its impact on the total fluid tailings volume determination.

The apparent depth of the mudline, determined by density plate measurements, is validated at a minimum of three locations across the tailings deposit by interval sampling as described in Appendix C.

Appendix C Interval Sampling

Interval sampling is used to validate the measurements generated by sonar or by density plate surveys. At each location, the solids content of samples taken at the mudline and at 10 cm intervals 0.5 m above and below the mudline is determined. The mudline is the transition from clear water to fluid tailings, where the suspended solids content in the water increases by ≥ 5% solids content over a 10 cm interval. (See Figure C-1: Confirmation of Mudline using Interval Sampling.)

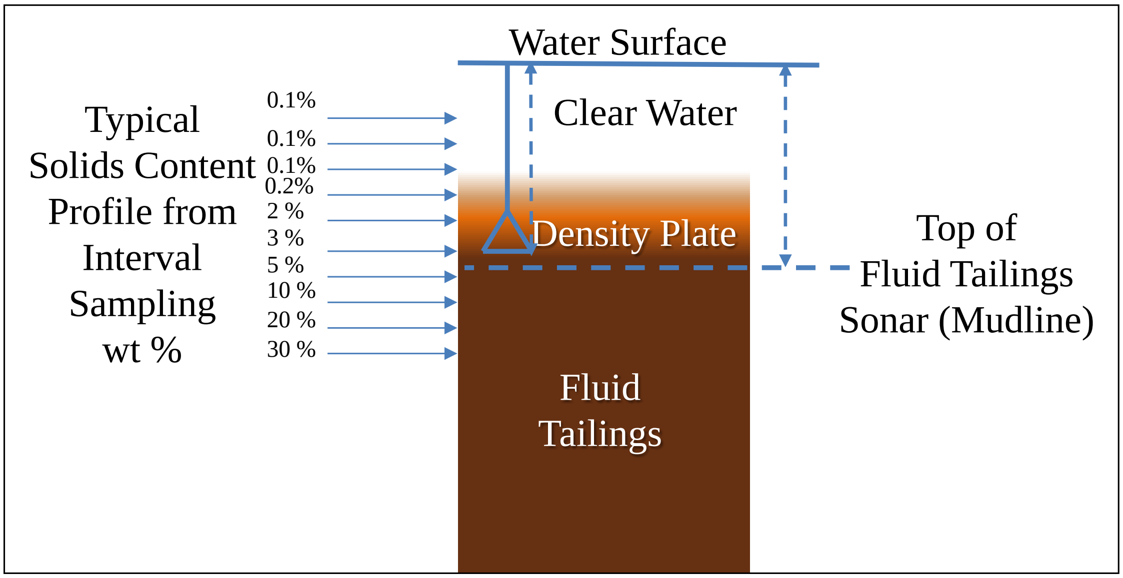

Figure C-1: Confirmation of Mudline Using Interval Sampling

Appendix D Drop Sounding

Drop sounding is a rapid method of determining the bottom surface of the fluid tailings layer and is typically used to profile soft tailings deposits. It works best in tailings deposits with sharp transitions between fluid tailings and hard bottom (sand or overburden).

The drop sounding tool is deployed from a platform using a winch line that is calibrated to measure depth. The sounding tool is allowed to drop freely at the slower of the winch speed (maximum of 1 m/s) or the maximum dropping speed of the sounding tool. If the deposit becomes thick, the drop speed slows and the winch speed is adjusted to follow. When the sounding tool stops moving (refusal point, defined as less than 5 cm over a 30 second period), the bottom of the fluid tailings layer has been found, the test is terminated and the sounding tool is retrieved.

The schematic for design of an acceptable drop sounding tool to determine oil sands pond bottoms is shown in Figure D-1: Drop sounding Tool Schematic.

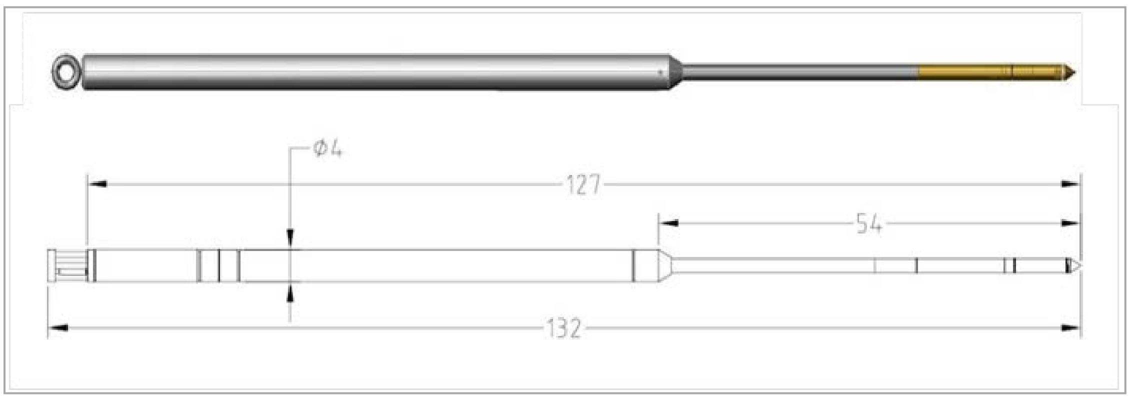

Figure D-1: Drop sounding Tool Schematic
(Dimensions in inches)

General specifications for a drop sounding tool are:

- 300 lb. total weight
- 132 inches long
- 4 inch diameter weighted section decreasing to 1.75 inches for the last 54 inches of length
- A Piezocone penetrometer capable of measuring inclination, pore pressure (U2), and tip resistance forms the end of the tool (not a mandatory requirement but beneficial).

The deployment platform must be stationary. Platform drift causes non-vertical deployment of the sounding tool resulting in depth measurement errors. The maximum drift of the deployment platform should be no greater than 5 % of the recorded depth of the sounding.

The following data are recorded for each sounding location:

- Pretest GPS coordinates
- GPS coordinates of refusal point
- Depth of refusal point
- Drop time to refusal point
- Drift of drop sounding tool
- Pond surface elevation.

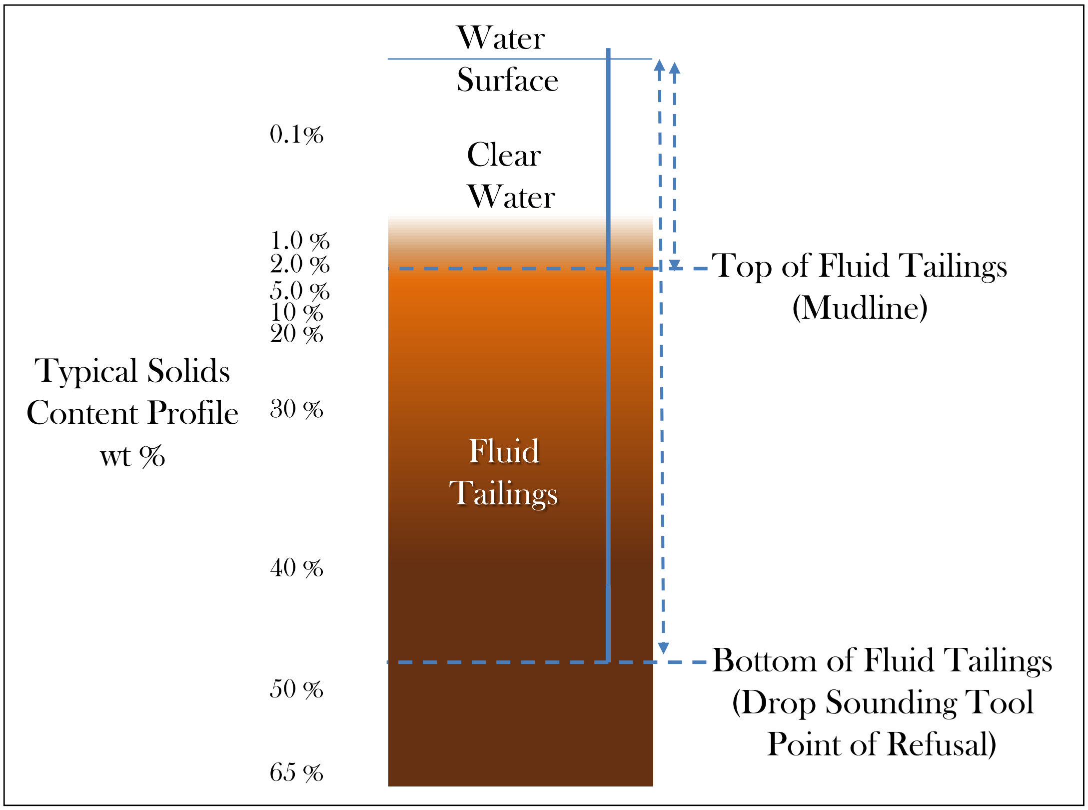

Figure D-2: Bottom of Fluid Tailings Measurement

A number of factors may complicate the use of the drop sounding tool and determination of the bottom surface of the fluid tailings layer:

- In tailings deposits where the solids content is increasing (e.g., CT), or with significant bitumen content, the drop sounding tool may stop due to other factors including skin friction, tip resistance, or viscous strength effects.
- Floating muskeg or bitumen mats may cause the tool to prematurely refuse. Several drops in the same location may punch through the obstruction, but this may not always be successful.
- In areas of interlayered hard and soft zones, the drop sounding tool will stop at the first hard zone and the true bottom of the fluid tailings layer will not be recorded.

Therefore, the estimated bottom of the fluid tailings layer is validated with CPTs. The number of CPTs required depends upon the consistency of the hard bottom surface readings. Other methods such as sampling, vane shear testing, tailings behavior type, passive gamma, and full-flow penetration testing may be used to verify the location of the bottom of the fluid tailings.

For each type of tailings material encountered during drop sounding (sand, CT, thickened fines, froth tailings, coke, overburden), CPTs are conducted at selected locations to validate the drop sounding measurement of pond bottom.

Appendix E Cone Penetration Test

In areas where the tailings deposit limits the use of a drop sounding tool (e.g., subaerial deposits), or where the drop sounding measurements must be verified, the bottom surface of the fluid tailings layer is determined using CPTs. With CPT, a cone on the end of a series of rods is pushed into the tailings deposit at a constant rate. Continuous measurements are made of the resistance to penetration of the cone and of a surface sleeve. The fluid tailings bottom surface is determined based on resistance measurements.

A cone penetration test with pore pressure measurement (CPTu) is conducted following ASTM D 5778-12. Pore pressure measurements are conducted with the piezometer in the U2 position (behind the shoulder of the cone). For a Ball-CPTu, ASTM D5778-12 is followed along with modifications suggested by Dejong (2010)[4]. This entails locating the pore pressure measurement at the equator of the ball, with a penetration rate of 0.2 to 0.3 diameters per second with appropriate calibration and recording measurements conducted on both extraction and penetration of the ball

The fluid tailings bottom is determined by measuring the net CPTu tip resistance. In a CPTu, the undrained shear strength in a deposit can be determined as follows:

$S_u = q_{net}/N_{kt}$

Where:

S_u =undrained shear strength

N_{kt} = cone factor

q_{net}= net tip resistance (This factor is calculated differently for ball and cone but is essentially a measure of the measured tip resistance, corrected for pore pressure effects and subtracting the overburden stress.)

The main source of uncertainty in interpretation from deposit to deposit lies in the selection of the cone factor. Assuming a standard cone factor for all deposits, while simplistic, eliminates this issue in interpretation. N_{kt} for the ball is usually between 10 and 11 and N_{kt} for a cone is usually between 14 and 15.

Therefore the fluid tailings bottom surface can be defined as the point where $q_{net} < 75$ kPa for measurements with a cone tip and $q_{net} < 55$ kPa for measurements with a ball tip.

Solid bottom determinations by CPT measurements are based roughly on peak undrained shear strength greater than 5kPa.[5]

[4] DeJong, J.T., Yafrate, N.J., DeGroot, D.J., Low, H.E., and Randolph, M.F. *Recommended Practice for Full-Flow Penetrometer Testing and Analysis*, ASTM Geotechnical Testing Journal, 2010, Vol. 33, No. 2, pp. 137-149.

[5] The peak undrained shear strength of 5kPa represents an approximation to the liquid limit of a cohesive deposit.

The following factors are taken into account when generating high quality CPTu data:

- Selecting a suitable load cell capacity (full scale output)
- Stringent load cell calibration at the low end of the scale
- Minimizing transient temperature effects
- Measuring zero load stability and drift
- Recognizing the effect of soil layers ahead of and behind the penetrating cone (typically about 4 times the cone radius for depth effects in soft soils).

The interpretation of CPT data including its correlation with drop tool soundings, and where appropriate, the selection of the N_{kt} value, is carried out by experienced personnel having familiarity with the depositional environment in which the soundings were obtained. It is considered prudent to interpret the CPT data in conjunction with other available relevant data (e.g., particle size distributions, deposition environments, etc.) to identify false bottoms or to characterize deposits where the measured pond bottom appears to be above the original pond bottom.