Methodology for Determining Optimum Vibrating Wire Piezometer Pairing Relationships in VWP Monitoring Clusters

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ABSTRACT

Current trends in the mining sector and specifically tailings storage facilities have seen a significant increase in monitoring frequency, instrumentation installed on site and field tests conducted. Monitoring methodologies are also shifting away from analog and towards digital electronic systems. These instruments are also being integrated with online dashboards. Owing to all these factors, the instrument that is now most commonly being installed to meet these requirements are VWP's (Vibrating Wire Piezometers). However interpreting VWP results and deriving the phreatic surface from these are not as straight forward as initially assumed, it requires engineering judgement and a methodology to determine and verify optimum pairing of VWP clusters.

Obtaining the correct phreatic surface from VWP's is critical as this will have a direct impact on the trigger levels and TARP's of the online dashboard. Inaccuracies in calculating the phreatic surface can lead to the triggering of incorrect levels, which may result in flawed assessments of stability.

The primary approach relied on phreatic surface and hydraulic gradients from CPTu testing being compared to the phreatic surface and hydraulic gradient determined from various combinations of VWP's in a cluster at the time of CPTu testing. In cases where no historical VWP data is available at the time of CPTu testing, a methodology was also investigated using standpipe piezometers only. Piezometric head was converted to pressure and linear regression used to determine the phreatic surface.

Results from the primary approach showed that certain pairs of VWP's yield phreatic surfaces and hydraulic gradients that match the CPTu findings. Standpipe interpretation provided a good starting point and correlates with primary identified pairs. This methodology provides a verification tool to provide confidence when selecting VWP combinations for dashboard reporting.

Keywords: vibrating wire piezometers; phreatic surface; linear regression clusters; methodology

1. Introduction

Due to monitoring trends and the introduction of the Global Industry Standard on Tailing Management (GISTM) many tailings storage facilities around the world have had lines of vibrating wire piezometers installed. The challenge that now faces the engineers/technicians involved is to determine the phreatic surface from these instruments.

Generally, VWPs are installed in clusters and the phreatic surface is calculated by applying linear regression to a graph where tip elevations and pressures of VWP's are plotted. The y intercept of the graph is interpreted as the phreatic surface.

All the VWP's in a cluster can be used to determine the linear regression or certain pairs/configurations may be used and the others discounted. This has a major impact on the phreatic surface determined with different values generated. This creates a dilemma in which pairings to choose and confidence in these configurations.

The aim of this methodology is to simplify VWP pair selection and provide a degree of certainty/verification in chosen configurations. This paper provides a summary of the results and conclusions obtained when applying this methodology to real data.

2. Methods

A typical cross section of VWP's in clusters can be seen in Figure 2-1 below.

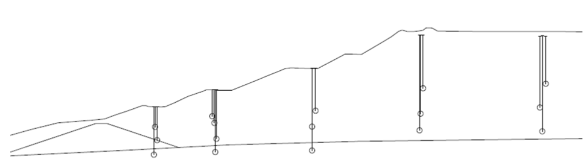

Figure 2-1 Typical VWP cross section

Clusters of vibrating wire piezometers are grouped around specific positions along sections of the tailings storage facility. Piezometers are installed at different elevations, with clusters typically consisting of three or more instruments. VWP's can also be installed to target specific layers of interest such as foundation (clay) materials of the TSF and tailings.

In this specific case the focus will be on VWP's installed in tailings only. Although it is widely accepted that a tailings profile is highly layered and anisotropic, the ambient pore pressure plot in Fig. 2-2 shows that the rate of hydraulic build-up is consistent. This was also found in the other CPTu profiles for this TSF. Therefore a uniform hydraulic gradient can be reasonably assumed within a particular tailings profile. It should be noted that the hydraulic gradient is not consistent between separate tailings profiles and each profile should be assessed individually

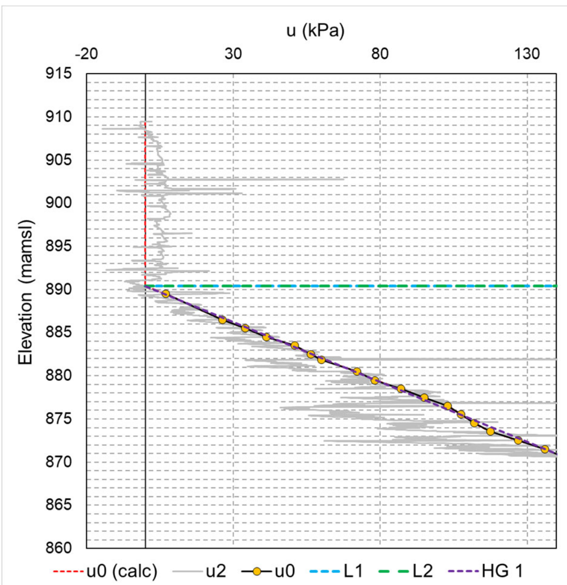

Figure 2-2 CPTu dissipation plot

Phreatic surfaces are determined from vibrating wire piezometers through the use of linear regression methodology.

This approach is shown in Figure 2-3. The y axis represents the tip elevation/instrument depth in meters. With the x-axis representing pore pressure in kilopascals. Points are plotted on the graph corresponding to each VWP's pressure and depth. A best-fit line is then drawn between the various points.

The gradient of this line is the hydraulic gradient and the intercept with the y axis where pore pressure is zero is the phreatic surface (Craig,2004). Depending on which points are selected different hydraulic gradients and phreatic surfaces are determined as can be seen below in Figure 2-3.

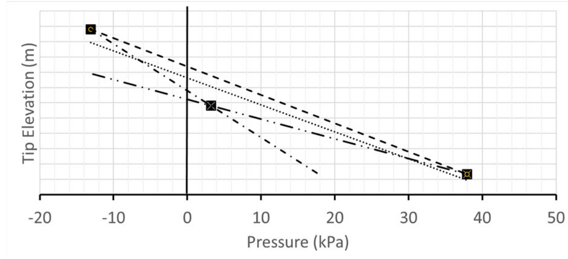

Figure 2-3 Linear regression

The primary approach consisted of obtaining the phreatic surface and hydraulic gradients determined by CPTu testing close to VWP clusters. Historical pressures at each VWP are then used to populate a linear regression graph. Various combinations of VWP's were then calculated to determine different phreatic surfaces and hydraulic gradients for differ pairings of VWP's per cluster.

The phreatic surfaces and hydraulic gradients are then compared to that obtained from CPTu testing. In ideal situations the hydraulic gradient and phreatic surface from a specific pair should match the values from CPTu testing. This serves as a good indicator to validate the VWP pairing decided on for reporting purposes.

In cases where no historical VWP data exists at the time of CPTu testing. Historical standpipe piezometer data was converted to pressure and applying the hydraulic gradient obtained from CPTu testing the phreatic surface was determined. Again, comparisons between these values and various combinations of VWP's can be used to determine optimum configurations.

3. Results

3.1. Historic VWP data and CPTu data

Table 3-1 Line 5 Cluster 3 pressuresbelow shows the historic VWP pressures recorded at the time that CPTu testing was conducted close to this specific cluster. It is cluster three on line 5 in this case with three VWP's installed at different tip elevations.

Table 3-1 Line 5 Cluster 3 pressures

ID	Tip elevation (mamsl)	Pressure at CPTu testing (kPa)
5-3A	875	5.444
5-3D	877.5	-3.4
5-3C	868.977	54.19

Table 3-2 Line 5 Cluster 3 pairing comparisons displays the CPTu phreatic surface as well as the CPTu hydraulic gradient in the top row. Subsequent rows display phreatic surfaces and hydraulic gradients determined from different VWP pairings.

Table 3-2 Line 5 Cluster 3 pairing comparisons

	Cluster 3	
	CPTu phreatic surface (mamsl)	**CPTu Hydraulic Gradient (kPa)**
	876.2	-8.3
Pairs	**Calculated phreatic surface (mamsl)**	**Calculated hydraulic gradient (kPa)**
A-D-C	876.45	-7.2
A-D	876.54	-3.5
D-C	877.00	-6.8
A-C	875.67	-8.1

From Table 3-2 Line 5 Cluster 3 pairing comparisonsit can be seen pairing A-D-C phreatic surface is the closest to the CPTu test phreatic surface. However, the calculated hydraulic gradient is not similar to that determined by CPTu testing. The most probable reason for this is the fact that VWP 5-3D has a negative pressure of -3.4 kPa and is above the phreatic surface.

Viewing A-C it can be seen that both the phreatic surface and calculated hydraulic gradient are close to CPTu values. This is the pairing that was chosen for this specific cluster. Figure 3-1 gives a visual representation of the different VWP pairs.

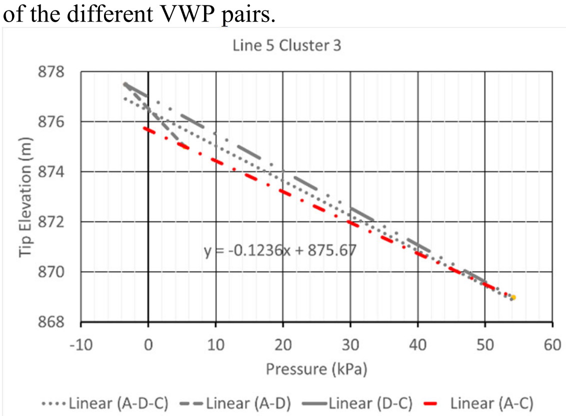

Figure 3-1 Graph of line 5 cluster 3 linear regression

Line 5 cluster 5 has the following pressures shown in Table 3-3.

Table 3-3 Line 5 Cluster 5 pressures

ID	Tip elevation (mamsl)	Pressure at CPTu testing (kPa)
5-5C	888.061	13.4
5-5B	880.471	25
5-5A	872.176	81.432

Table 3-4 Line 5 Cluster 5 pairings comparisonsdisplays the CPTu phreatic surface as well as the CPTu hydraulic gradient in the top row. Subsequent rows display phreatic surfaces and hydraulic gradients determined from different VWP pairings.

Table 3-4 Line 5 Cluster 5 pairings comparisons

	Cluster 5	
	CPTu phreatic surface (mamsl)	**CPTu Hydraulic Gradient (kPa)**
	884.2	-7
Pairs	**Calculated phreatic surface (mamsl)**	**Calculated hydraulic gradient (kPa)**
C-B-A	888.462	-4.855
C-B	896.828	-1.528
B-A	884.15	-6.8
A-C	891.19	-4.283

Viewing Table 3-4 Line 5 Cluster 5 pairings comparisons B-A was the chosen pair (highlighted in green) it can be seen that the calculated hydraulic gradient and phreatic surface are essentially an exact match for the CPTu values. A Visual representation can be seen in Figure 3-2 Graph of line 5 cluster 5 linear regressiongiving a graphical overview of the various cluster pairs and corresponding intercepts. The equation of the chosen pair is also displayed on the graph.

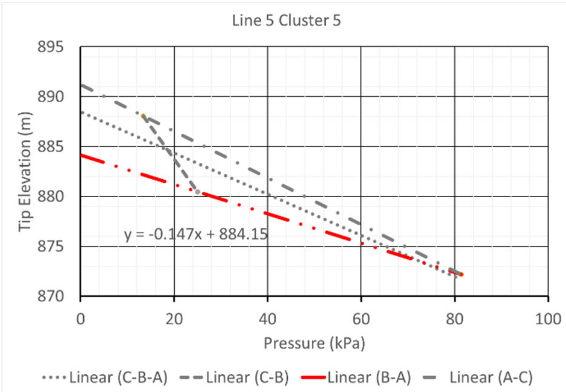

Figure 3-2 Graph of line 5 cluster 5 linear regression

Moving to Line 12 we have cluster 4 on that line pressures shown in Table 3-5 Line 12 Cluster 4 pressures

Table 3-5 Line 12 Cluster 4 pressures

ID	Tip elevation (mamsl)	Pressure at CPTu testing (kPa)
12-4D	894.792	-13.0708
12-4C	889.818	3.211
12-4B	885.352	37.95

Table 3-6 Line 12 Cluster 4 pairings comparisonsdisplays the CPTu phreatic surface as well as the CPTu hydraulic gradient in the top row. Subsequent rows display phreatic surfaces and hydraulic gradients determined from different VWP pairings.

Table 3-6 Line 12 Cluster 4 pairings comparisons

	Cluster 4	
	CPTu phreatic surface (mamsl)	**CPTu Hydraulic Gradient (kPa)**
	889.99	-7.5
Pairs	**Calculated phreatic surface (mamsl)**	**Calculated hydraulic gradient (kPa)**
B-C-D	891.64	-5.7
C-D	890.80	-3.3
B-C	890.23	-7.8
B-D	892.37	-5.4

B-C is the VWP pair identified for selection as it reflects the values closest to historical CPTu values. Visual representation in Figure 3-3 Line 12 Cluster 4 linear regression below.

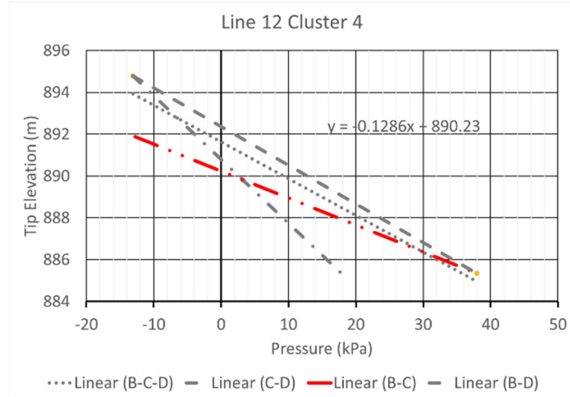

Figure 3-3 Line 12 Cluster 4 linear regression

Line 12 cluster 5 pressures and elevations shown in Table 3-7 Line 12 Cluster 5 pressures

Table 3-7 Line 12 Cluster 5 pressures

ID	Tip elevation (mamsl)	Pressure at CPTu testing (kPa)
12-5C	893.17	13.616
12-5B	889.184	36.05
12-5A	885.2	55.074

Table 3-8 Line 12 cluster 5 pairings comparisonsdisplays the CPTu phreatic surface as well as the CPTu hydraulic gradient in the top row. Subsequent rows display phreatic surfaces and hydraulic gradients determined from different VWP pairings.

Table 3-8 Line 12 cluster 5 pairings comparisons

	Cluster 5	
	CPTu phreatic surface (mamsl)	**CPTu Hydraulic Gradient (kPa)**
	894.76	-6.5
Pairs	**Calculated phreatic surface (mamsl)**	**Calculated hydraulic gradient (kPa)**
A-B-C	895.88	-5.2
C-B	895.59	-5.6
B-A	896.73	-4.8
C-A	895.79	-5.2

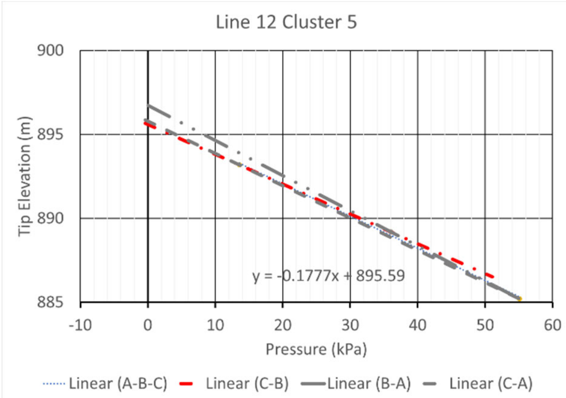

Figure 3-4 Line 12 cluster 5 linear regression

Referring to Figure 3-4 Line 12 cluster 5 linear regressionit can be observed that the lines of linear regression are spaced close to each other and display similar phreatic surface intercepts. Cases like these highlight the need for a methodology which can be fallen back on to provide the reader with a degree of certainty when pairs are selected. As cases are sometimes too close to make an informed decision without a verification methodology.

In the instance of cluster 5, the values exhibit less correlation with the CPTu measurements compared to other cases presented.. This trend has been observed in other lines with clusters deep into the basin of the TSF.

Potential reasons for this observation might encompass the reduced permeability of materials situated deeper within the tailings storage facility. Additionally, there is a heightened variability in the phreatic surface levels in these areas due to their proximity to the pool, which leads to more immediate reactions to deposition events. It should also be noted that the VWPs on this facility were installed not long ago and might necessitate additional time to achieve full saturation.

3.2. Standpipe data phreatic surface alternative

New VWP installations may have no historical VWP pressures available at the time of CPTu testing as installation occurred after CPTu testing. In this case standpipe piezometer data may be used to validate current VWP pressures.

The process is as follows:

- Standpipes close to VWP clusters are identified and data collected.
- Standpipe head of water multiplied by $9.81 m^2/s$ to obtain hydrostatic pressure.
- Hydrostatic pressure is then divided by the hydraulic gradient determined at this position with CPTu testing.
- This value is then added to the tip elevation of the standpipe which gives the phreatic surface.

The phreatic surface using the methodology described above is then compared to the phreatic surface at the time of CPTu testing and phreatic surfaces obtained from VWP pair calculation with current pressures. This phreatic surface height can be helpful in VWP pairing to validate calculated values. This approach was followed for Line 10 cluster 4. Table 3-9 Line 10 cluster 4 pressuresshows current VWP pressures.

Table 3-9 Line 10 cluster 4 pressures

ID	Tip elevation (mamsl)	Current Pressure (kPa)
10-4A	882.913	56.597
10-4B	875.775	107.261
10-4C	872.16	129.952

Referring to Table 3-10, the value highlighted in orange represents the inferred phreatic surface derived from the latest standpipe data, which closely aligns with the CPTu-determined phreatic surface. This close correlation suggests that there has been minimal fluctuation in levels since the time of testing. A comparison with the phreatic surface and hydraulic gradients obtained from the current VWP pairs indicates that either cluster A-B-C or C-A could be selected based on the data.

Table 3-10 Standpipe phreatic surface and VWP phreatic surface

	Cluster 5	
	CPTu phreatic surface (mamsl)	**CPTu Hydraulic Gradient (kPa)**
	891.67	-6.866
	Standpipe Calculations	
Hydrostatic pressure (kPa)	133.28	
Phreatic head (m)	19.35	
Phreatic surface elevation (mamsl)	891.72	
Pairs	**Calculated phreatic surface (mamsl)**	**Calculated hydraulic gradient (kPa)**
A-B-C	891.212	-6.866
A-B	890.886	-7.098
B-C	892.863	-6.276
C-A	891.209	-6.821

This method provides the reader of VWP clusters a degree of assurance in terms of chosen phreatic surfaces. While also providing a metric to gauge how much the phreatic surface has fluctuated over a time duration in the absence of historical VWP data.

4. Conclusions

The findings demonstrated that CPTu results can yield phreatic surfaces and hydraulic gradients that closely align with certain combinations of VWP clusters. Thereby providing an indicator of which combinations are optimal for reporting phreatic surfaces.

It also highlights the utility of standpipe piezometers as a supplementary or alternative method for determining and validating phreatic surfaces, particularly in scenarios where historical VWP data is absent.

The aim of this paper was to provide the designer confronted by numerous pairing options with a methodology that can provide validation and metrics to underpin a cluster VWP pairing choice in terms of reporting.

In conclusion this methodology provides a simplified way for professionals to justify their choices in terms of optimal instrument pairs chosen in VWP clusters. Providing confidence and a road map when confronted by a myriad of options and interpretations.

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References

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