Piezometer Filter Tip Clogging in Low-lying Acid Sulfate Soils

Senura Athuraliya
PhD Candidate, Transport Research Centre, University of Technology Sydney, Ultimo, NSW 2007, Australia.

Buddhima Indraratna
Distinguished Professor, Director, Transport Research Centre, Founding Director, ARC Industrial Transformation Training Centre for Railroad Technologies (ITTC-Rail), University of Technology Sydney, Ultimo, NSW 2007, Australia.

Ana Heitor
Lecturer of Geotechnical Engineering, School of Civil Engineering, University of Leeds, UK. Formerly Centre for Geomechanics and Railway Engineering, University of Wollongong, Australia.

ABSTRACT: Geotechnical field instruments are essential tools that assist in providing valuable monitoring data, especially when there are major design uncertainties. Piezometers have been reported to produce erroneous readings of pore water pressure (PWP) in numerous case studies attributed to filter tip clogging when installed in acid sulfate soil terrain. It was observed that the excess pore water pressures (EPWP) interpreted from vibrating wire piezometers (VWPs) indicate slowing down of the rate of dissipation after a certain period of time. This paper presents the potential factors that can affect the accuracy and reliability of the PWP measurements in VWPs with special mention to biogeochemical factors that influence clogging of piezometer filter tips. Piezometers affected by coupled clogging, is further evident from the microscopic images and analysis of clogging material.

1 INTRODUCTON

Practising geotechnical and dam engineers have often been puzzled by erroneous piezometer readings which do not follow conventional soil mechanics, for instance, when excess piezometer readings are constant or even increasing even though significant settlement is still taking place in saturated clay foundations. According to previous literature (DiBiagio 1977; Dunnicliff 1993; Hvorslev 1951) piezometers can malfunction due to reasons such as sedimentation and clogging of microscopic soil particles, defective seals, loss of anchorage, corrosion of metal elements, inappropriate aperture sizes of filters or corresponding air entry values as well as severely disturbed soil in the proximity of the filter.

When piezometers are installed in low-lying pyritic clays with a high organic content, erroneous readings may be attributed to biological and chemical factors resulting in the deposition of organic biomass and chemical precipitants such as iron oxides potentially clogging the piezometer filter tip and the surrounding soil (Indraratna et al. 2018; Indraratna et al. 2019). The accumulation of mineral precipitates (Fe and Al oxides/hydroxides) within the pore spaces of soil can result in reducing the porosity and hinder the overall ability for the groundwater to permeate (Indraratna et al. 2014). The bio-clogging is associated with acidophilic bacteria, which promotes biofilm growth as well as catalysing the chemical reactions of mineral precipitation.

2 CLOGGING IN ACID SULFATE SOILS

In low-lying coastal acid sulfate terrain, partial clogging of VWPs with time is mainly attributed to chemical precipitates (e.g. iron oxides and. hydroxides), bacteria-induced cavitation, chemical alteration and growth of biomass, all of which inhibits the dissipation of excess pore water pressure over time (Indraratna et al. 2017). The chemical clogging is further catalysed by acidophilic bacteria, *Acidithiobacillus Ferrooxidans*, where the biological and chemical clogging occurs in tandem, hence the term bio-geochemical clogging. A number of standpipe piezometers, observation and data logger wells that were installed in a coastal acid sulfate floodplain several years ago were exhumed and examined for potential clogging. The clogging had significantly deteriorated the filter zone and the deposition was mainly biological and chemical origin, including infiltrated particles of fine soil and organic matter, reddish-brown precipitates and dark brown to black biomass/slime that formed a blend of cohesive matrix lining the filters (Fig. 1). Furthermore, sampling of the clogging material revealed that iron oxidising bacterial count was of high aggressivity.

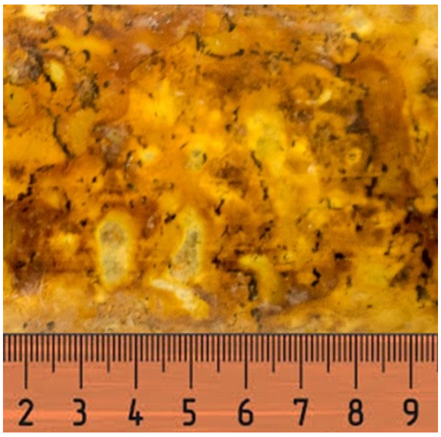

Fig. 1 Iron oxide/hydroxide precipitates clogging the pores of a granular cover surrounding the piezometer tip

To support the clogging phenomenon, a comprehensive microscopic analysis was performed on VWP filter tips before (i.e. a fresh filter) and after clogging (i.e. a filter retrieved from the field 1.5 years after installation) at the UOW-EMC laboratory. These piezometer filter tips were extracted from the Ballina bypass trial embankment, which is an acid sulfate 'hotspot'. A scanning electron microscope (SEM) (JEOL JSM-6490LV) was used to examine the surface of the filter tips. The SEM micrographs show the distinct contrast in the void spaces of the fresh filter prior to clogging (Fig 2(a)), compared to the clogged filter with clogging material deposited within the pores of the filter (Fig 2(b)). An Energy Dispersive X-ray Spectroscopy (EDS) analysis was then coupled with SEM to identify the elemental composition of the filter surface. The primary elemental composition of the filter surface prior to clogging consisted mainly large peaks in Fe, Cr, and Ni, (Fig 3(a) – Spectrum 1) confirming the elemental composition of the stainless steel alloy, whilst the primary elemental composition of the clogging material comprised of Si, Al, Fe and O (Fig 3(b) - Spectrum 2). This further affirms that chemical precipitates deposit on piezometer filter tips, which are transported in their soluble form in acidic groundwater (Indraratna et al. 2010).

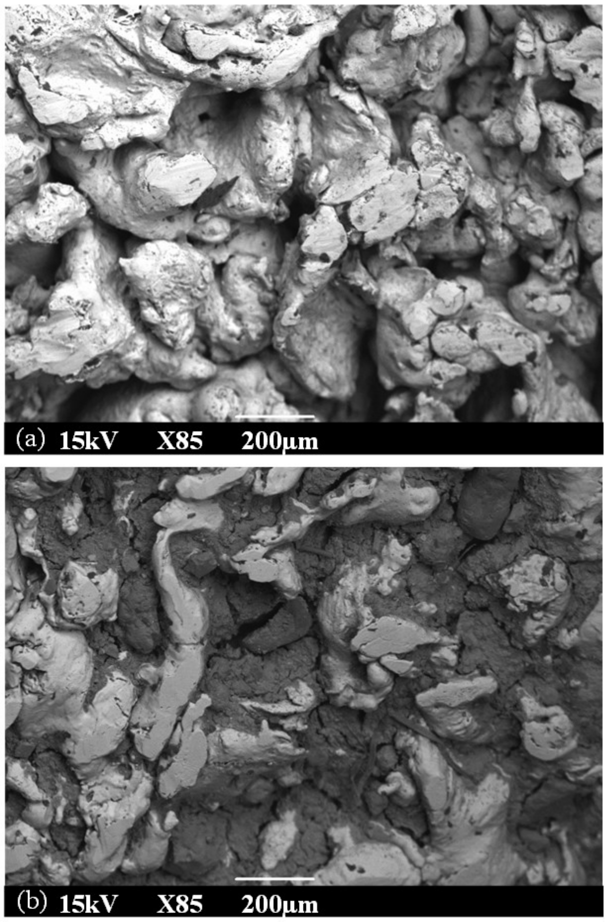

Fig. 2 SEM micrographs of piezometer filters: (a) filter tip prior to clogging, (b) clogged filter tip after deposition of clogging material in filter pores (after Indraratna et al. 2019)

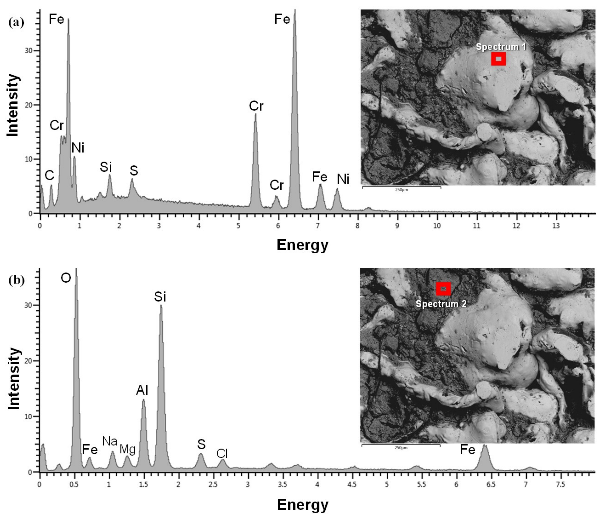

Fig. 3 Comparison of EDS spectra for (a) filter material (spectrum 1); (b) clogging material (spectrum 2)

The potential clogging of VWPs exacerbated by the acidophilic bacteria suggests that for long-term monitoring traditional standpipe piezometers can be easily maintained by flushing would complement the use of VWPs, although given the longer time lag for standpipes. Recently, fully grouted installations of VWPs have been popular (Dunnicliff 1993), however even then Kelly et al. (2018) have observed discrepancies in pore pressure readings, possibly due to cracking of grout annulus due to large-strain soil movement resulting in tensile strains, paving acidophilic bacteria contaminated groundwater to infiltrate the pore space surrounding the piezometer tip.

3 CASE HISTORIES: PIEZOMETER RESPONSE IN ACID SULFATE TERRAIN

The dissipation trends of excess pore water pressure for four case histories, (i) Port of Brisbane (POB), Australia with wick drains of 1.3 m spacing, (ii) Muar clay embankments, Malaysia with wick drains of 1.3 m spacing, (iii) Pacific Highway-Ballina Bypass, Australia with wick drains of 1.0 m spacing, and (iv) the Second Bangkok (Suwarnabhumi) International Airport (SBIA), Thailand, with wick drains of 1.2 m spacing are presented in Fig 4. For some of the cases, acceptable PWP dissipation rates were observed (e.g. POB and SBIA), however, a sudden retardation of PWP dissipation was observed for the Pacific Highway-Ballina Bypass embankment in Australia after about a year, even with drains installed.

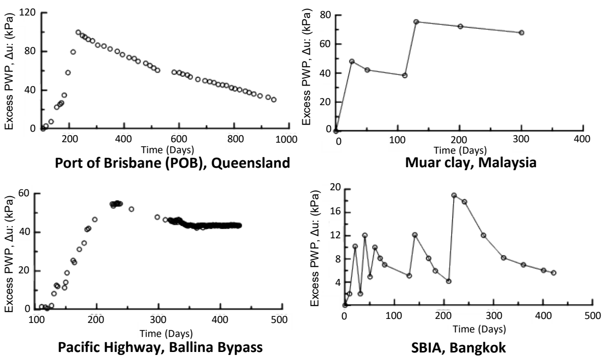

Fig. 4 Selected trends of excess pore water pressure dissipation for various case studies (adapted from Indraratna et al. 2017)

A comparison was made of the Excess PWP trends of embankments at POB and the Pacific Highway (Ballina Bypass, south of Brisbane) to further provide evidence in clogging. Both embankments were raised on similar upper Holocene clay and the piezometer data were recorded at similar depths and at the centreline of each embankment below the groundwater table as shown in Fig 5. VWPs for both cases had stainless steel low air entry filter tips to measure the EPWP in saturated clay.

An accurate prediction of the Excess PWP trend from the selected VWPs were made using the elastic visco-plastic (EVP) model (Baral 2017). This model predicted Excess PWP behaviour very accurately for POB, however, the same model when used to predict the Excess PWP for the site in Ballina, it was only comparable for about a year, after which the measured data remained much higher than the computed or predicted values; whilst the disparity increasing with time (Fig 5).

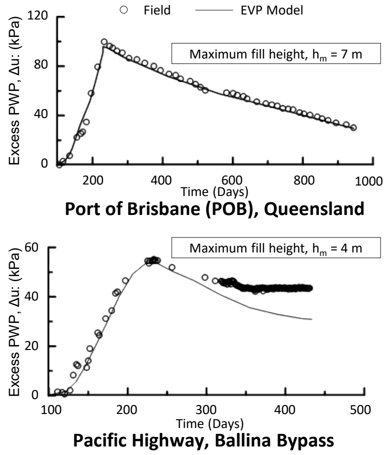

Fig. 5 Vibrating wire piezometer prediction using the EVP model for the Port of Brisbane (POB) and Ballina bypass embankment (adapted from Indraratna et al. 2017)

Unlike the site at POB, the Ballina embankment site is located in a low-lying coastal floodplain in an acid sulfate 'hotspot' with a high organic content (4-6%) and groundwater pH below 5.5. This implies that in the longer term, VWPs installed with ceramic and stainless steel filters can experience clogging when installed in acid sulphate (pyritic) floodplains. At the POB, the stainless-steel filter tips may have been more resistant to bacteria-induced clogging, but the pyrite oxidation problem is not as acute as the Ballina floodplain.

The sudden retarded dissipation of excess PWP at Ballina bypass can be attributed to the potential clogging of piezometers. Based on the EPWP dissipation curve for Ballina Bypass, such clogging in acid sulfate soil conditions can be described using a distinguishable tri-linear trend (Fig 6). During the initial stage of soil consolidation, a piezometer is very accurate and reliable, up until around a year after installation. In the second stage, the piezometer filter tip may begin to partially clog in acid sulfate soils with the continuous deposition of chemical and biological material. Clogging will restrain the flow surrounding the filter tip and will disrupt the pore water pressure dissipation over time. As a result, a large time lag may be required to establish equilibrium at the soil-filter interface. In the third and final stage the filter may get fully clogged and produce near constant EPWP readings and almost no dissipation. During this stage it can be assumed that the soil would have no 'hydraulic connection' to the filter tip.

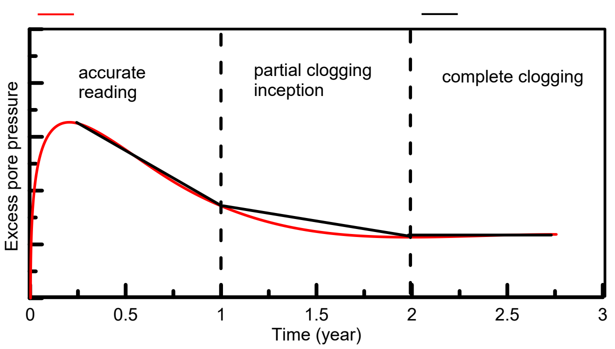

Fig. 6 Trilinear trend for excess PWP dissipation (after Indraratna et al. 2018)

4 CONCLUSIONS

Piezometers may not always respond accurately and reliably as one expects. This is apparent in the case histories discussed, as the piezometer filter tip may be clogged when a retarded dissipation of excess pore pressure is measured even when significant consolidation is still occurring.

In embankments constructed in ASS floodplains with high organic contents, chemical and biological (bacterial) factors may cause VWPs filter tips to gradually lose the reliability and accuracy over time because their filters cannot be backwashed once installed, unlike standpipes piezometers where backwashing is possible as and when required during its entire service life. Therefore it is important that practitioners continue to use alternative methods to verify the VWP readings, such as standpipes that can be backwashed after installation.

ACKNOWLEDGMENTS

Helpful comments from instrumentation manufacturers and discussions with industry colleagues who have had problems measuring the correct pore pressures in the field are greatly appreciated. The authors would like to acknowledge the help from CSIRO, ANSTO and SMEC scientists and engineers in interpreting some past data. The support from of field technicians (Bob Rowland, Frank Crabtree, and Alan Grant) and more than a dozen past PhD and Honours thesis students are acknowledged in the field of acid sulfate soils. The use of facilities and equipment within the University of Wollongong Electron Microscopy Centre (UOW-EMC) should also be acknowledged.

REFERENCES

Baral, P 2017, 'Anisotropic Visco-Plastic Behaviour of Soft Soil with Special Reference to Radial Consolidation', Doctor of Philosophy thesis, University of Wollongong.

DiBiagio, E 1977, 'Field Instrumentation - a Geotechnical Tool', *Norwegian Geotechnical Institute Publication*, no. 115, pp. 29-40.

Dunnicliff, J 1993, *Geotechnical Instrumentation for Monitoring Field Performance*, John Wiley & Sons, New York.

Hvorslev, M 1951, *Time Lag and Soil Permeability in Ground-Water Observations*, Bulletin No. 36, Waterways Experiment Station, Corps of Engineers, US Army, Vicksburg, Mississippi.

Indraratna, B, Baral, P, Ameratunga, J & Kendaragama, B 2017, 'Potential Biological and Chemical Clogging of Piezometer Filters in Acid Sulphate Soil', *Australian Geomechanics Journal*, vol. 52, no. 2, pp. 79-85.

Indraratna, B, Baral, P, Ameratunga, J, Kendaragama, B & Athuraliya, S 2018, 'Potential Biological and Geochemical Clogging of Vibrating Wire Piezometers in Low-Lying Acid Sulphate Soil', in *Proceedings of Australian National Committee on Large Dams (ANCOLD) Conference*, Melbourne, Victoria, vol. Paper ID: 6 (5B).

Indraratna, B, Medawela, SK, Athuraliya, S, Heitor, A & Baral, P 2019, 'Chemical Clogging of Granular Media under Acidic Groundwater', *Environmental geotechnics*, vol. Special Issue: Testing and Modelling of Complex Rockfill Material, 6 (3) doi: 10.1680/jenge.18.00143.

Indraratna, B, Pathirage, PU, Rowe, RK & Banasiak, L 2014, 'Coupled Hydro-Geochemical Modelling of a Permeable Reactive Barrier for Treating Acidic Groundwater', *Computers and Geotechnics*, vol. 55, pp. 429-39.

Indraratna, B, Regmi, G, Nghiem, L & Golab, AN 2010, *Performance of a PRB for the Remediation of Acidic Groundwater in Acid Sulfate Soil Terrain*, Research Online.

Kelly, R, Sloan, S, Pineda, J, Kouretzis, G & Huang, J 2018, 'Outcomes of the Newcastle Symposium for the Prediction of Embankment Behaviour on Soft Soil', *Computers and Geotechnics*, vol. 93, pp. 9-41.