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Potential biological and chemical clogging of piezometer filters in acid sulphate soil

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Abstract

Instrumentation for performance monitoring of an embankment built on soft soils is vital for assessing the progress of consolidation and confirming (or refuting) soil parameters used in design when there are significant design uncertainties and the monitoring data can be used to calibrate the design soil parameters. A suite of instruments including settlement plates, extensometers, piezometers, inclinometers is often employed for this purpose. In the first Author's experience, erroneous readings interpretations of pore water pressure (PWP) readings have been reported in various case studies involving transport infrastructure development and reclamations works both in Australia and South East Asia, especially in low-lying acid sulphate soil floodplains. It has been observed that in spite of the presence of vertical drains (PVDs), excess pore water pressure readings from vibrating wire piezometers (VWPs) do not always dissipate as fast as expected especially after a certain period of time, typically a year. The article discusses the potential factors affecting the reliability of VWPs including filter tip clogging, extreme smearing of soil adjoining the filter, gas generation or cavitation, chemical alteration or corrosion of the filter, electro-osmotic effects and cavitation due to bacterial activity. Based on this, the response of VWPs may be divided into a distinct trilinear trend, observed for much of the Australian northern and eastern coastal belt that is predominantly affected by Acid sulphate soil (ASS) conditions where oxidisable pyrite layers are present within relatively shallow depths of the upper Holocene clay.

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POTENTIAL BIOLOGICAL AND CHEMICAL CLOGGING OF PIEZOMETER FILTERS IN ACID SULPHATE SOIL

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ABSTRACT

Instrumentation for performance monitoring of an embankment built on soft soils is vital for assessing the progress of consolidation and confirming (or refuting) soil parameters used in design when there are significant design uncertainties and the monitoring data can be used to calibrate the design soil parameters. A suite of instruments including settlement plates, extensometers, piezometers, inclinometers is often employed for this purpose. In the first Author's experience, erroneous readings interpretations of pore water pressure (PWP) readings have been reported in various case studies involving transport infrastructure development and reclamations works both in Australia and South East Asia, especially in low-lying acid sulphate soil floodplains. It has been observed that in spite of the presence of vertical drains (PVDs), excess pore water pressure readings from vibrating wire piezometers (VWPs) do not always dissipate as fast as expected especially after a certain period of time, typically a year. The article discusses the potential factors affecting the reliability of VWPs including filter tip clogging, extreme smearing of soil adjoining the filter, gas generation or cavitation, chemical alteration or corrosion of the filter, electro-osmotic effects and cavitation due to bacterial activity. Based on this, the response of VWPs may be divided into a distinct trilinear trend, observed for much of the Australian northern and eastern coastal belt that is predominantly affected by Acid sulphate soil (ASS) conditions where oxidisable pyrite layers are present within relatively shallow depths of the upper Holocene clay.

1 INTRODUCTION

For several decades, practising geotechnical and dam engineers have often been puzzled by piezometer readings that are not in line with conventional soil mechanics; for instance, significant settlements still occurring in saturated clay foundations while the excess piezometer readings indicate relatively constant values or at times even increasing. In general, as described elsewhere by others (e.g. Dunnicliff, 1988; DiBiagio, 1977), malfunctioning of various types of piezometers in the past has been attributed to the intrusion of microscopic (dispersive) soil particles, loss of anchorage, defective seals, corrosion of the vibrating wire (VW), inappropriate size of filter apertures or corresponding air entry valves as well as problems of installation including severely disturbed soil in the proximity of the filter tip. Preliminary investigations undertaken by the 1st Author have revealed that when installed in low-lying pyritic clays rich in organics (e.g. coastal acid sulphate soil floodplains), questionable readings in some VW piezometers may be attributed to potential clogging of their filters by organic biomass and iron oxide precipitates as a result of acidophilic bacteria responsible for pyrite (FeS_2) oxidation and resulting chemical constituents (e.g. Blunden and Indraratna 2000; Indraratna et al. 2009, 2011). In brief, both aerobic and anaerobic strains of acidophilic bacteria can oxide pyrite in the shallow soft soil (saturated or unsaturated) to form sulphuric acid and by-products include various iron precipitates and gases. Unfortunately, biotic activity will always continue without being noticed, as those piezometers once installed are not accessible for inspection or maintenance, except for standpipe or hydraulic type piezometers that can be maintained by backwashing/flushing when required. However, through personal communications the Authors have had with experienced practitioners in various projects involving salt-rich soils, ceramic filter tips have also been adversely affected as a result of salts being drawn into the filter possibly due to suction created during incorrect flushing operations. Moreover, it has been reported that acidophilic and anaerobic bacterial activity in organic-rich soil can lead to cavitation (e.g. gas bubbles of hydrogen, hydrogen sulphide etc.), and this may also adversely affect any type of piezometer readings (DiBiagio, 1977).

Personal communications with several leading manufacturers of geotechnical instruments have also indicated the observation of dark biomass/slime in some ceramic filter tips over time in organically rich soils. Potential clogging of piezometer filters in organic-rich soils in various parts of the world was also pointed out by late Prof Peter Vaughan more than a decade ago through personal communications with the 1st Author. A related study by Rudens (2001) under the supervision of the 1st Author with the aid of microbiology laboratories at ANSTO, verified the existence of a specific strain of acidophilic bacteria (*thiobacillus ferrooxidans*) after culturing the materials sampled from the piezometer filters and its surrounding soil within an acid sulphate soil terrain in the town of Nowra, south of Wollongong City. Recently, concerted research efforts involving the University of Wollongong in partnership with Queens University, Canada (c/o Prof Kerry Rowe, who has also been researching on biological clogging in recent times; Rowe et al. 2002), geotechnical consultants and some instrumentation manufacturers have been launched to study the potential clogging of granular media including piezometer filters within a permeable reactive barrier (PRB) located in Nowra to remediate acidic groundwater. Based on our current experience, this problem seems to be less severe when stainless steel filter tips are used compared to ceramic fittings, but more research efforts are required to verify this.

Appropriate instrumentation in strategic locations including piezometers, settlement plates, extensometers and inclinometers to monitor the performance of embankments built on soft soils is vital when there are significant design uncertainties; also, the monitoring data can be most useful to calibrate the design parameters. In the 1st Author's experience, questionable pore water pressure (PWP) readings of vibrating wire piezometers (VWPs) over time have been observed in some case studies involving transport embankments and reclamation works in both Australia and overseas. In particular, Vibrating Wire Piezometers (VWPs) with ceramic filter tips installed in acidic ground with organic contents exceeding say 4-5% have shown impeded excess pore water pressure dissipation after about 1 year or so irrespective of the type of piezometers (standpipes, VWP, pneumatic, hydraulic etc.), it has also been observed that in spite of the presence of Prefabricated Vertical Drains (PVDs), excess pore water pressures have not always dissipated as fast as one expects especially after a certain period of time, t > 1-1.5 years, as explained earlier by the 1st author and co-workers (e.g. Indraratna et al., 1994, 2013; Indraratna and Redana, 2000).

While credible arguments for generating additional pore water pressure in some parts of a loaded clay foundation can be explained to some extent by the large lateral strains and the yielding nature of highly visco-plastic clays subjected to embankment loading (Yin and Graham, 1989; Indraratna et al., 1992), and further supported by cavity expansion models applied to PVD installation (e.g. Ghandaharioon et al., 2010), in practice, the retarded trends in pore water pressure can also be attributed to filter clogging over time, extensive smearing of soil adjoining the piezometer filter , cavitation, chemical alteration or acid corrosion of the filter itself, electro-osmotic effects in certain marine soils, among other factors (DiBiagio, 1977 and Dunnicliff, 1988).

2 CLOGGING PHENOMENON IN ACID SULPHATE SOIL (ASS)

In acid sulphate soil (pyritic) terrains prevalent in coastal Australia, partial clogging of VWPs with time caused by chemical precipitation (e.g. particles of iron oxides), bacteria-induced cavitation, chemical alteration and growth of biomass may also lead to inhibited pore water pressure dissipation over time (Indraratna et al., 2009).

Moreover, the routine tidal effects and flooding in low-lying coastal floodplains also influence the measured pore water pressures, unless continual real-time calibration can be ensured based on the site geo-hydraulic data and local meteorological records. Various types of piezometers located in the low-lying coastal floodplains of NSW have shown significant clogging and rapid deterioration of their filter tips when examined after a few years (Fig. 1a). The clogging constituents could be identified as materials of chemical and biological origin including infiltrated fine soil particles and organic matter, reddish rust precipitates (e.g. iron oxides - Fig. 1b) and dark brown to black biomass/slime forming a blend of cohesive matrix lining the filters. Furthermore, granular cover protecting the piezometer tips (i.e. filter material) can become armoured by accumulated ferric oxides/hydroxides (as shown in Fig. 1c), and this may dramatically reduce the flow towards the piezometer affecting the time lag and pore pressure measurements. Microbiological examination of specimens taken from the filter medium of extruded piezometers and observation well tubes revealed the predominant presence of iron precipitating bacteria (*thiobacillus ferrooxidans, TBF*) and other strains of sulphur reducing bacteria which clearly thrive under acidic (low pH) conditions in acid sulphate floodplains. Sampling from a piezometer recovered from the Shoalhaven floodplain revealed a *TBF* bacterial count exceeding 5000 (i.e. moderate to high aggression) and a less aggressive sulphate reducing bacteria count of about 200. Given that a significant fraction of these anaerobic bacteria may have perished upon exposure to the air during sampling and test specimen preparation, the above biotic count is an underestimation of the actual bacterial presence. Potential biological clogging exacerbated by *TBF* bacteria suggests that for long-term monitoring, traditional standpipe piezometers which can be easily maintained by flushing would complement the use of VWPs, albeit a longer time-lag of the standpipe piezometers. Authors note that various filter materials are used for both piezometers and observation tubes (usually larger diameter than standpipes). While low air entry stainless steel filters may be the most robust (and often the most expensive), materials such as copper alloys or bronze, galvanised iron, ceramic/porcelain and finely perforated steel pipe sections (wrapped in non-woven geotextile) may be more prone to clogging or deterioration, in the opinion of the authors.

(a) (b) (c)

Figure 1(a) Extensive deterioration and damage to piezometer tip with accumulated organically-rich sediments and biomass; (b) iron oxide/hydroxide precipitates clogging the pores of granular cover surrounding piezometer tips; (c) filter grains armoured by ferric precipitates leading to significantly reduced flow or partial clogging.

Due to chemical and bacteria-induced clogging and flow disequilibrium at the filter tips due to cavitation (e.g. gas bubbles of hydraulic sulphide, hydrogen etc.) in pyritic (FeS_2) soil, as well as potential corrosion of filter tips in acidic groundwater, the VWPs may become less reliable with time. According to the Authors' observations it is after about 1 year when these discrepancies became obvious. The excess PWP dissipation trends for different case histories (i) Port of Brisbane (POB), Australia (ii) Muar clay embankments, Malaysia, (iii) Pacific Highway-Ballina Bypass, Australia and (iv) Second Bangkok (Suwarnabhumi) International Airport (SBIA), Thailand, have been presented in Fig. 2. While an acceptable rate of PWP dissipation is observed for some (e.g. POB and SBIA), a sudden retardation of PWP dissipation is shown for the Pacific Highway-Ballina Bypass embankment after about 1 year.

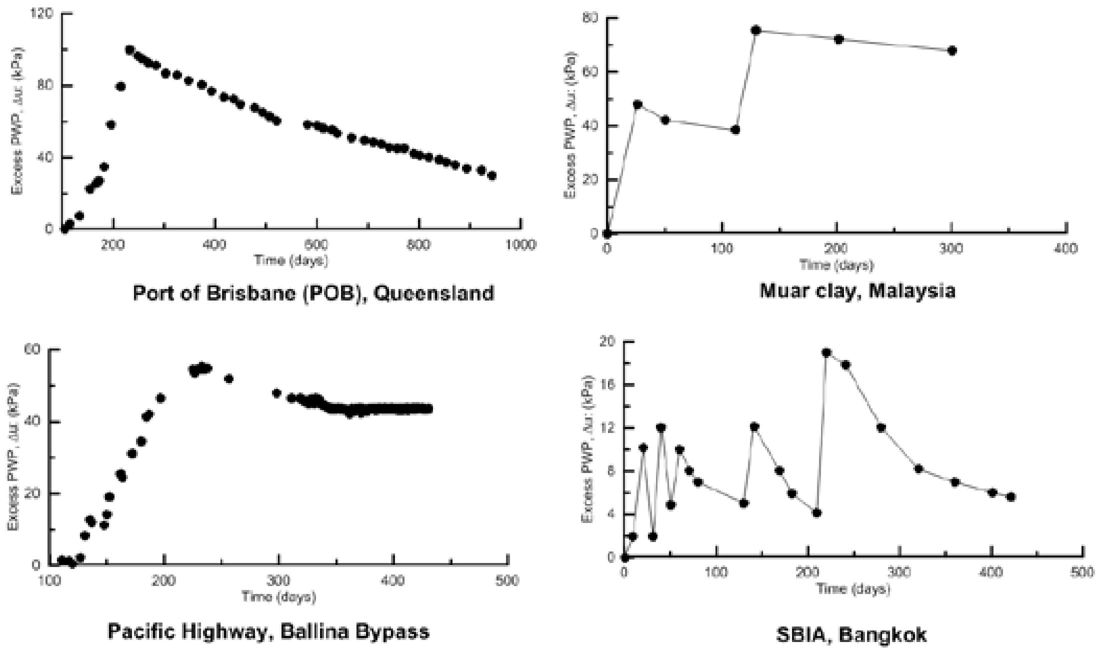

Figure 2: Selected trends of excess pore pressure dissipation for various case studies

3 RESPONSES OF VIBRATING WIRE PIEZOMETERS (VWPs)

Figure 3 compares selected responses of selected VW piezometers at the Port of Brisbane (POB) with the Pacific Highway (Ballina Bypass, south of Brisbane), where both embankments are raised on similar soft Holocene clay. In both cases, the piezometer data were recorded at similar depths in the upper Holocene clay at the embankment centreline below the groundwater table. The piezometers were fitted with stainless steel filter tips for measuring the excess pore water pressure (EPWP) in saturated clay. For the purpose of comparison, EPWP has been normalised to the maximum fill height (h_m). For this selected VWP at POB, the dissipation trend of EPWP can be predicted well using an elastic visco-plastic model (Baral, 2017) over 2.5 years. In contrast, for the VWP at the Pacific Highway's Ballina bypass site, the same choice of soil model could only match EPWP up to about 1 year, beyond which the measured data remained significantly higher than the computed or predicted values, and this disparity increased with time. Compared to the Port of Brisbane site, the Ballina bypass site is located in an acid sulphate 'hot spot' with a relatively high organic content (4-6%) and the groundwater pH in this low-lying floodplain was often below 5.5. This implies that in the longer term, VW piezometers 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, noting that the pyrite oxidation problem at the POB site is not as acute as in the Ballina floodplain.

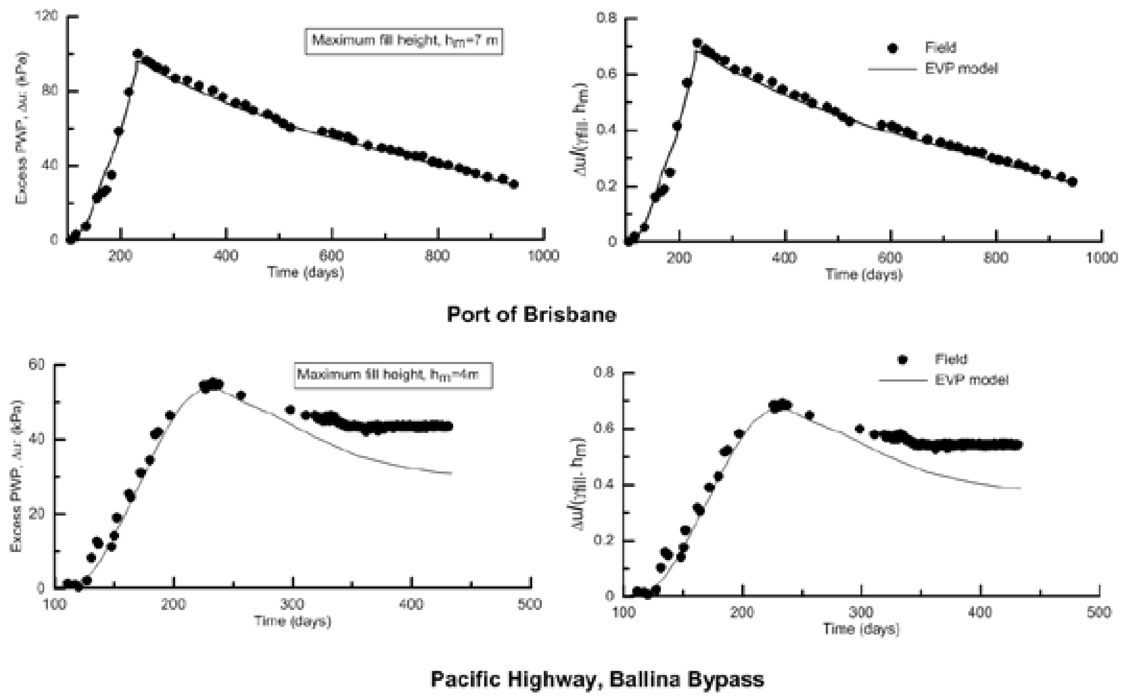

Figure 3: Prediction of VWP behaviour using elastic visco-plastic model at the Port of Brisbane (POB) and Ballina bypass embankment. [Note: in both cases, VW piezometers were located in the upper Holocene clay at a depth of about -6 m RL]

Based on these observations, the response of VW piezometers may be divided into a distinct trilinear trend as shown in Figure 4. At the initial stage, (say up to 1 year) the piezometer functions well with high reliability. In the second stage, the filter may become partially clogged and a significant time lag may be required to establish the equilibrium at the soil-filter interface. In the third stage, filter clogging may become substantial to the extent that EPWP readings remain almost constant, as the 'hydraulic connection' to the filter tip is now prevented. This type of excess PWP trends have now been observed for much of the Australian northern and eastern coastal belt that is predominantly affected by Acid sulphate soil (ASS) conditions where oxidisable pyrite layers are present within relatively shallow depths of the upper Holocene clay.

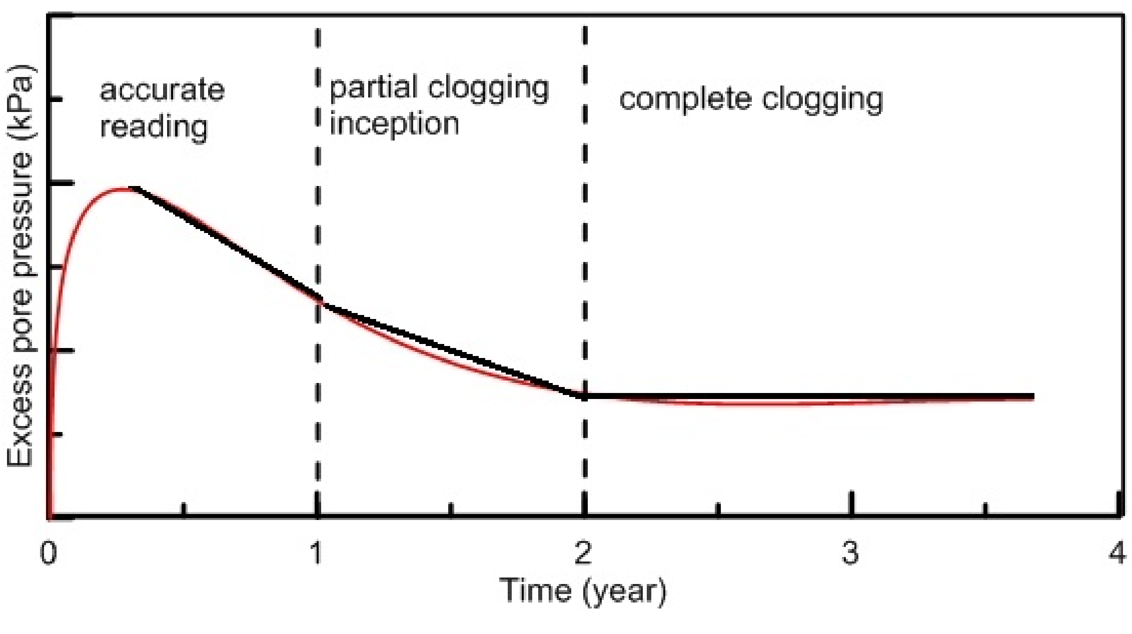

Figure 4: Excess PWP dissipation simplified as a trilinear trend

4 CONCLUDING REMARKS

In spite of closely spaced vertical drains (1.2 m) promoting dissipation, at some piezometer locations, the measured excess pore water pressure may not always reduce as swiftly as one expects. When the dissipation of excess pore pressure is clearly impeded while significant consolidation settlement is still occurring, this mimics apparent clogging of the piezometer filters. It is known that in acid sulphate floodplains, the piezometer response can be influenced by tidal intrusion and flooding conditions (needs to be corrected when determining the excess pore water pressure), filter corrosion or chemical alteration in acidic groundwater, armouring by minute rust particles (i.e. precipitated iron oxide) and formation of biomass (result of acidophilic bacteria) and associated gas cavitation, in addition to potential physical clogging by the intrusion of very fine (dispersive) particles over time. In embankments constructed in acid sulphate soil floodplains with a notable organic content, both climatic and biological (bacterial) factors may contribute to an increasing loss of accuracy of vibrating wire piezometers over time, as their filters cannot be flushed once installed, unlike the maintenance of standpipes.

It is important that practitioners continue to use standpipe piezometers that can be flushed to maintain the filter tips over time, in addition to vibrating wire or any other types of piezometers whose filters are not accessible and cannot be maintained once installed. Given the relatively low cost of standpipes compared to say vibrating wire piezometers, the long term reliability of standpipes cannot be ignored albeit the technological advancement towards more fashionable and often perceived as more accurate instruments.

Applied research under the direction of the 1st Author through industry linkages is now underway to identify the types of bacteria causing potential clogging of ceramic filters over time, and to identify the possible benefits of using stainless steel, bronze or other robust materials that are possibly less prone to biological clogging compared to ceramic fittings, and thereby develop technically sound and cost-effective corrective measures for piezometers.

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