An Innovative Approach for the Installation of Vibrating Wire Piezometers

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ABSTRACT

Vibrating wire piezometers, described hence forth as VWPs, are high precision geotechnical instruments installed into the ground to electronically monitor pore water pressures over extended periods of time. These instruments have use in a variety of geotechnical engineering settings such as: slope stability; basement excavation; consolidation under embankments and reclamations; and the performance of hydraulic structures e.g. dams. The piezometric data are useful for the design of these structures and for monitoring the performance during construction and in service. VWPs are traditionally grouted into drilled bore holes in a process that produces waste spoil and requires the use of additional materials for back filling. This paper discusses and reviews two case studies of an innovative, low impact and high-quality approach for the preparation and direct push installation of the VWPs. This installation approach eliminates the production of spoil, is fast and therefore low cost, completed with low impact plant and most importantly has a very high success rate using a locally manufactured push in adaptor and off the shelf VWPs.

Keywords: vibrating wire piezometer, ground water, in situ testing

1 INTRODUCTION

Vibrating Wire Piezometers are utilised in a variety of geotechnical engineering settings to provide information during the design, construction and in service of pore water pressures, at the sensor location.

VWPs have traditionally been installed directly into boreholes using a filter sand intake zone and bentonite seal or into a fully grouted borehole. The sand filter and bentonite seal technique in particular is prone to difficulties in the placement of backfill materials leading to installations ending up less than satisfactory (Mikkelson 2002). In situations where the VWPs are fully grouted into position, it is important that the grout properties are matched to the permeability and strength of the surrounding formation (Yungwirth 2013).

More recently the ‘nude’ VWP installation technique has been adopted on occasions. After placement of the VWP into a cased bore hole, this method relies upon the complete collapse of the borehole (Mazur 2015). This approach is contingent on the collapse of the bore hole around the VWP and not suitable in many conditions.

Another approach for installing VWP is to directly push them into the ground using the crowd forces of the drill rig. Whilst this approach has been available for some time, limitation with installation forces and the need to rotate rods to decouple from the VWP increases the risk of damage during installation. Several manufacturers recommend the VWPs are pushed a short distance into soft cohesive soils only, once again limiting the potential application.

This paper discusses an innovative technique using an in-situ testing rig fitted with a high capacity hydraulic pusher and small diameter Cone Penetration Testing (CPT) rods to push the VWP into the ground. A purpose built, high strength adaptor is required to enable installation using this approach and is discussed further in this paper.

This direct push technique eliminates the production of spoil, is fast and therefore low cost, completed with low impact plant, does not involve complicated grouting and most importantly has a very high success rate using a locally manufactured push in adaptor and off the shelf VWP.

2 MAIN TEXT

2.1 Basic Principle of a VWP

A VWP utilises a sensitive stainless-steel diaphragm to which a vibrating wire element is connected. The diaphragm is protected by a filter which is used to keep solid particles away from the diaphragm. There is a small gap between the filter and the diaphragm which requires saturation to provide rapid response to changes in pore pressures (refer Figure 1). During use, changes in pressure applied on the diaphragm by water cause it to deflect. This deflection is measured as a change in tension and frequency of vibration of the vibrating wire element located behind the diaphragm. The square of the vibration frequency is directly proportional to the pressure applied to the diaphragm (Geokon 2018).

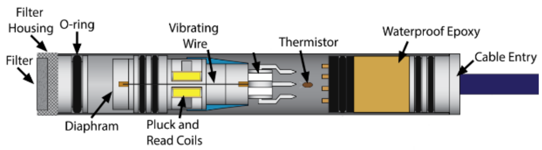

Figure 1. Typical Vibrating Wire Piezometer

The vibration signal is transmitted through a cable to either a portable handheld readout unit or to a longer-term data logging system.

2.2 Sacrificial Direct Push Adaptor

The speciality sacrificial push in adaptor was designed primarily to: (a) permit the use of almost any off the shelf 19mm diameter VWP; (b) protect the VWP and its filter from excessive bending and compressive stresses that can be generated during installation, noting that some direct push machines have the capability to mobilise 20t of pushing force and; (c) to positively seal the device in the ground when the CPT rods are extracted. This final point is important to note as this device does not require grouting into position or rely upon the collapse of the ground above to seal the VWP in the ground, reducing the possibility of seal bypass and the VWP reading pore pressures from outside of the target zone.

The dimensions of the cone tip, inner tube and outer tube have been carefully selected to minimise smear, protect the VWP slot, seal the devise in the ground and aid simple installation. The adaptor is shown schematically in Figure 2.

These dimensions allow for a compression only connection to the CPT rods, resulting in an adaptor that stays in place upon extraction of the CPT rods from the ground, and the elimination of rod rotation to disconnect from the adaptor which can damage cables.

Two 1mm wide by 20mm long slots are positioned at the bottom of the adaptor to allow water to migrate towards the VWP filter.

Figure 2. Direct Push Adaptor with VWP mounted internally

The adaptors are manufactured locally from 316 stainless steel. This reduces lead times when compared to other adaptors coming from overseas.

Despite being durable, there is no intention or requirement for the adaptor to have long term durability.

2.3 Preparation of VWP in Adaptor

The filter on the VWP is carefully removed from the piezometer body by twisting and pulling. The filter and the VWP body are then submerged in water for 30 minutes to allow for temperature stabilisation and saturation before being carefully reassembled for an 'Initial Zero Reading' check of the VWP. For lower capacity VWPs (less than 700kPa), the pressure readings are collected during reassembly to ensure that the diaphragm is not overloaded. This value is compared to the 'Factory zero reading' detailed on the calibration certificate to ensure the VWP is in appropriate working condition.

The adaptor is then partially filled with dry coarse sand from the base to above the water entry slots. This small amount of sand is utilised to further protect the filter. Once this Initial Zero Reading check is completed the off the shelf 19mm VWP is placed inside the adaptor so that the filter of the VWP is bearing on the sand at the tip end. Some additional sand is added around the tip of the VWP to ensure there is embedment in the sand. As the VWP will become de-saturated in this process an additional re-saturation is conducted on the conclusion of the preparation.

Melted microcrystalline wax is poured down the inner tube to a level approximately 50mm above VWP, securing the VWP in position within the adaptor.

Crushed bentonite is then place within the inner tube to fill the remaining annulus to approximately 100mm from the top end of inner tube. Some tapping of the outer tube aids the bentonite to settle inside the tube.

While holding the VWP cable centrally in the inner tube, a final seal of wax is poured inside the tube to completely fill and seal the inner tube.

This preparation process is utilised to ensure moisture from above does not impact on pore water pressures measured at the tip.

The above preparation process can be conducted on site within the in-situ testing rig or prior to arriving on site at a workshop, site shed or similar.

Prior to site installation the tip end is submerged in water for a minimum of 30 minutes to re-saturate the sand, filter and annulus between the filter and the diaphragm. During this process water and air are compressed into the tip end, after a period of time the air will dissolve into the water, filling the fitter and the space above it entirely with water (Model 4500 Piezometer Manual). A final "on-site" Initial Zero Reading using the hand held readout unit is conducted. This value can be compared to the initial reading to demonstrate the VWP is in working condition after placement within the adaptor.

2.4 Plant Utilised for the Direct Push Installation

Purpose built direct push rigs, typically used to conduct various forms of in situ testing can be utilised to install VWP using this approach (refer Figure 3).

The common features of these machines include high mobility, low environmental impact, low track or tyre pressures, short setup durations, high hydraulic pushing forces and typically high reaction forces that can be mobilised when required.

These machines are generally readily available at all major centres throughout Australia and can be mobilised to remote locations.

Figure 3. Typical in-situ testing and sampling rig

2.5 Direct Push Installation

The in-situ testing rig used to install the VWP is set up on location. The pushing frame is then adjusted so that the force generated is perpendicular to the ground. This adjustment is made to reduce bending forces on rods that can be generated during the pushing.

In order to mitigate the risk of generating pore water pressures greater than the capacity of the VWP during the installation an initial 'dummy' push is conducted.

In this process CPT rods with either a CPT cone or dummy tip are pushed into the ground using the pushing frame. When using a CPT cone details of the soil profile and hole verticality can be measured. The target of this initial dummy push is 1.0m above the nominated VWP installation depth. The rods with cone or dummy tip are removed from the ground leaving an annulus for the subsequent VWP installation. No spoil is generated during this process.

The VWP cable is threaded through the CPT rods and the VWP adaptor secured to the lead rod. A pre installation check of the VWP is conducted using the handheld Vibrating Wire Readout Monitor and recorded on an Inspection and Test Plan Check Sheet. This reading becomes the initial zero reading for the VWP.

The VWP, secured inside the VWP adaptor, is then pushed into the ground to the required depth. Again, no spoil is generated during this process and because the adaptor is sealed in the ground no cement-bentonite grout seal is required.

It should be noted that where there are concerns regarding confined aquifer conditions within the soil profile, a small quantity of bentonite cement slurry can be poured down the centre of the rods during the extraction process (much like a traditional tremie pour) to fill the annulus left by the CPT rods.

The above process to install a VWP, once prepared, occurs in a time period not much longer than a typical CPT sounding.

On conclusion of the installation any excess cables are coiled up and secured above ground level. The in-situ testing equipment leaves the installation location, without generating any spoil, using limited water and often without creating any discernible disturbance of the surroundings.

2.6 Site Example #1

A site investigation was conducted for a new facility located near the banks of the Markham River in the Morobe Province approximately east of Lae, Papua New Guinea (PNG). The area has annual average rainfall of 4.3m and has high levels of seismicity.

The remote location meant innovative approaches for conducting the investigation were required. A portable in-situ testing and sampling pushing system was mobilised to site, with reaction force provided by a locally sourced excavator (refer Figure 4). The excavator was also utilised to clear vegetation at testing locations, and handle plant and equipment on the site.

Figure 4. Portable in-situ testing rig supported by excavator

Initial CPTu probing was conducted across the site to profile soil conditions and aid decision making for further testing and VWP installation. The finalised VWP depths were chosen by the Geotechnical Consultant based on a combination of project requirements and soil conditions encountered on the site. Typical CPT data from the site are presented in Figure 5.

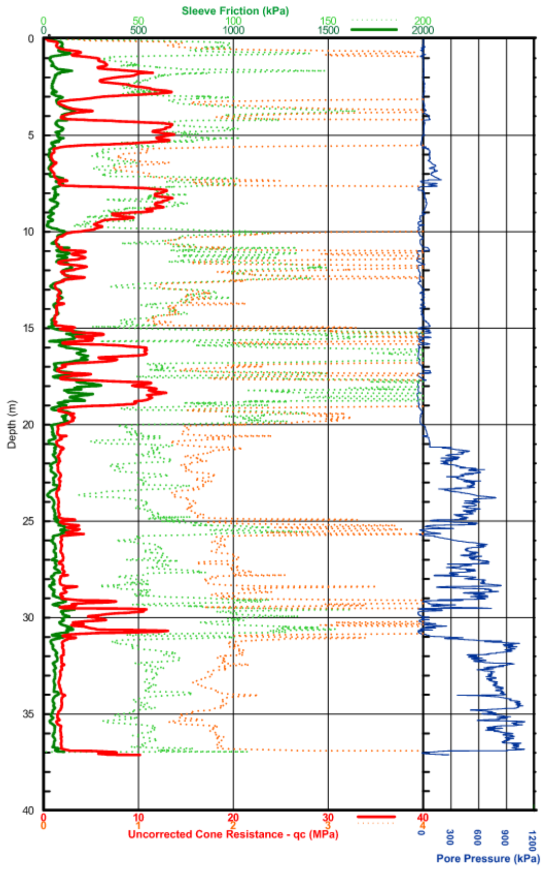

Figure 5. Typical CPTu sounding from project site (Site Example #1)

VWPs were procured and prepared within the VWP adaptor within the controlled environment of a workshop in Australia prior to transport into PNG. The prepared VWPs were transported in padded Pelican cases to mitigate the risk of damage.

The on-site installation was conducted in accordance with the procedure detailed above using the portable pushing frame. The VWPs were pushed to a depth of 20m below the existing ground level.

On completion the VWPs were connected to individual data loggers secured within an IP66 enclosure. The logger was programmed to collect data at the desired frequency. The data collected by the VWP over time was in line with expectations. An example of the data collected is presented in Figure 6.

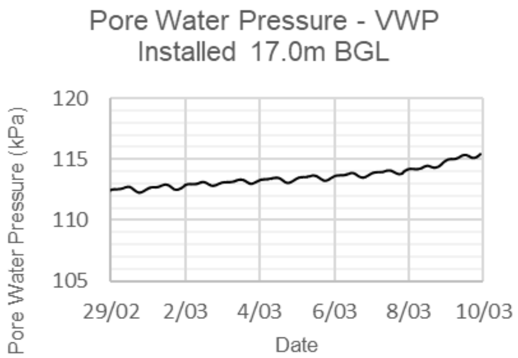

Figure 6. Pore Water Pressure data

2.7 Site Example #2

A site investigation was required on a tailings storage facility in remote central Australia where access to water was restricted at the time of the investigation. The purpose of this investigation was to confirm design parameters and to allow monitoring of conditions during the construction of an embankment raise.

Initially an extremely lightweight, extremely low track bearing pressure CPT rig conducted an investigation of the tailings crust using shallow CPT profiling. This initial testing indicated that the strength of the tailings crust was suitable to safely support a larger and heavier in situ testing rig capable of mobilising greater pushing forces.

The investigation consisted of CPTu testing, Dilatometer testing (DMT) and direct push Vane Shear Testing of the tailings. This testing was conducted from the low strength tailings surface with the in-situ testing rig tethered to support vehicles on the existing embankment. Typical CPT data from the site are presented in Figure 7.

The tethering of the in-situ testing rig to an on land ‘fixed’ point enables the quick and safe recovery should localised failures of the tailings crust occur.

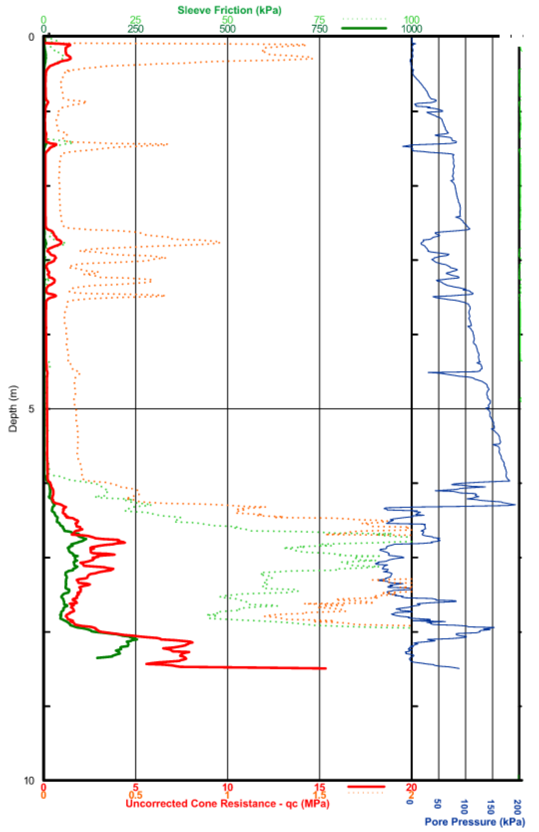

Figure 6. Typical CPTu sounding from project site (Site Example #2)

On completion of the site investigation component of the works, VWPs were installed on the upstream side of the embankment. The purpose of the VWPs was to monitor changes in pore water pressure during construction loading.

For this particular project there was limited site facilities due to the remote location. As such the VWPs were prepared on site the day before installation. Re-saturation of the VWPs was conducted in a bucket of water.

The in-situ testing rig again traversed across the tailings to the desired VWP installation location and successfully installed the VWPs to a depth of 5m below the existing surface level.

On completion, excess cable was coiled locally in a safe position for connection to a logging system by others.

Traditional investigation and VWP installation approaches would have required the mobilisation of earth moving equipment to construct causeways into the tailings to enable access for drilling plant, equipment and personnel. The drilling operation would have generated spoil which is then bought to the surface creating potential environmental disposal issues.

3 CONCLUSIONS

The direct push method with the utilisation of a purpose built adaptor has been utilised on numerous projects. It provides the project team confidence that the VWP is: installed at the correct depth without over stressing the VWP, is housed within a filter sand, is not impacted by smearing during installation and sealed from unexpected effects of ground water from above or below and therefore will provide reliable data. It reduces the requirements for complicated and problematic post grouting activities that may damage or impact on data reliability.

Furthermore, this method of VWP installation utilises low impact and readily available plant and equipment. These machines typically have low impacts on the work site, due to large low-pressure tyres or rubber tracks and therefore generally require limited additional access to be constructed. Once prepared the installation process is fast and efficient, minimising the time on site for machinery.

This installation approach does not generate any spoil, eliminating the risk of exposure to contaminated soils and issues associated with Acid Sulfate Soils. Due to being pushed directly into the ground, the use of a bentonite-cement grout slurry to secure the VWP in location are not required reducing material consumption.

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