Piezometers installed following the classical approach: from installation to data interpretation.

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ABSTRACT

Piezometers are instruments that can produce high-quality information if suitable and effective installation and monitoring procedures are followed. In order to minimise errors and optimise quality of the obtained information, we must pay attention when prescribing the type of piezometer and its installation, as highlighted in the ISO/EN18674 standards. The use of piezometers as a geotechnical instrument is a commodity.
This paper aims to exemplify how the use of piezometers can be optimised and how the most common errors can be avoided.

Keywords: ISO; geotechnical instruments; pore water pressure; piezometers; fully grouted

1. Introduction

Geotechnical monitoring is one of the essential elements of ensuring an economic and safe execution of geotechnical projects. Monitoring is used to measure particular parameters (settlements, horizontal displacements, pore water pressure...) during the execution of the project, in order to confirm or modify the design assumptions and to ensure the safety of the operations. In the particular case of projects that require ground improvement and /or treatment, the geotechnical observations provided by monitoring are also used to check if the improvement levels are those previously designed.

This role of the monitoring is highlighting the need for more reliable instruments. It's important to state that the reliability of the instruments is related to two main issues. The first one referred to the instrument itself (measurement technique, transduction and data storage). The second one refers to the use of the instruments on site. This second topic includes several processes from installation, data acquisition and data management.

From all the aforementioned aspects, probably the installation is the one of the less attentions (see for example the papers on the publication of Arroyo and Alonso, 2010). Nevertheless, the installation of instruments on the ground can affect in a significant way the quality of the data. The major impact of the installation is on accuracy: the capacity of the instrument to measure the real value of the parameter. This problem is particularly significant in pressure cells and extensometers. The installation can also impact on some other issues like resolution, response time, noise presence in the measurement.

The optimal installation process of an instrument should include a detailed knowledge on the behaviour of the instrument. From that point of view, an installation method that works for a particular instrument and a particular parameter to be monitored, may not be appropriated if there is a change in the measurement system. This seems to be the case of the piezometers, as shown in this paper.

2. Theoretical and practical framework: errors in the use of piezometers

The goal of a piezometer is to measure the pore water pressure in the ground where it is installed. The pore pressure changes from point to point and its measure should be assigned to a particular elevation in the ground.

The two main types of error associated with the pore water pressure using piezometers were described by Hvorslev (1951). The first one is related with the alteration of the hydraulic conditions on site by the installation of the piezometer, modifying the water flow and as a consequence, the pore water pressure distribution that is intended to be measured. This problem arises if, for example, a significant flow in the direction of the borehole appears. The second problem is the hydrodynamic time lag (the time between a change in the ground pressure and the same change captured by the device). If the time lack is significant, the instrument loses precision.

The classical piezometer, named Casagrande, consists of a pipe with a slotted section that is surrounded by sand and/or gravel. This area is separated from the rest by a bentonite seal (Figure 1a). This bentonite seal isolates the filter zone. The sand or gravel reduces the hydrodynamic time lag, as these piezometers require a significant volume of water to flow inside the pipe to measure change in the pressure.

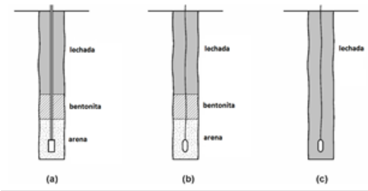

Figure 1. Installation of piezometers. Adapted from Contreras (2011)

Electrical, wire vibrating piezometers are also standard and used in the last decades. These piezometers have a very low time lag in comparison with the Casagrande's ones (Penman, 1960), as the volume of water required to measure a change in the pressure is significantly lower. Actually, vibrating wire piezometers can be considered non-flow instruments (Win Bo, 2023). In the usual practice, the installation procedure (figure 1b) follows the trend established for the installation of Casagrande piezometers: sand pack and bentonite seal.

The geometric conditions of the wire vibrating piezometer allows the installation of different units in one single borehole. This is an important advantage, but the placement of several bentonite seals is difficult from the practical point of view. In those conditions we can ask if the classical installation procedure can be modified taking into account that the sand surrounding the piezometer is not necessary.

This question is formally asked by Penman (1960) and after that by Vaughan (1969). In fact, Vaughan (1969) established the possibility to avoid sand filters and bentonite seals and to install piezometers directly embedded in a grouted mix of water, cement and bentonite (Figure 1c). This author also showed, from the analytical point of view, that if grouts with hydraulic conductivities no more than one order of magnitude that the ground are used, no significant errors occurred. Vaughan tested the good performance of this arrangement by installing piezometers in the clayey core of an earth dam.

The work of Vaughan did not become so popular within the industry, nevertheless it appears in reference publications [Dunnicliff, 1988], where the author constrains its use only to a very specific situation. The discrepancies between Vaughan and Dunnicliff can be related to some details of the elaboration of the mixture- commented in this paper, that are not too clear in the paper of Vaughan- and are of a critical importance for the success of the technique.

The possibility of installing several piezometers within the grout is also mentioned in the work of McKenna (1995) that presented a systematic approach in the monitoring of mining operations in heavy oil sands in Canada, highlighting economic and practical advantages. Mikkelsen (2002), Contreras et al (2007, 2011), Simeoni et al (2011) in a civil engineering context, supports the idea of Vaughan with theoretical and practical ideas. In particular, Contreras et al (2007) improves the numerical analysis started by Vaughan and stated that the use of grouts with hydraulic conductivities up to three orders of magnitude larger than the ground ones can operate without significant errors. Other interesting statements (Contreras, 2007; Contreras 2011) are related with the need to correct the measurements with the barometric pressure and a detailed discussion on the composition and installation of the mixed grout.

Other types of measurement errors are related to a lack of attention based on the concept of "we have been doing it that way for decades". Among others, these errors are:

- Incorrect positioning of the instrument/measuring point due to a lack of geotechnical detailed information of the site.
- Not installing the appropriate instrument according to the velocity of change of the measured parameter. This is related to the use of slow response time piezometers in undrained conditions and/or measurements at low frequency (Raventós, 2022)
- Improper installation procedure and/or improper drilling operations

To avoid or, at least, minimize errors and to decide the best installation procedure and the appropriate instrument, it is strongly recommended to follow the instructions of ISO 18674/4 "Geotechnical monitoring by field instrumentation- Measurement of pore water pressure: piezometers".

3. Case study

This section illustrates the importance of understanding what is to be measured, the geotechnical and hydraulic conditions on site, and the range of available technologies that allows for appropriate design, installation, data reduction and reporting.

The purpose of the project was to analyse the slope stability issue in a road project. The geotechnical conditions on site were a natural in situ rock mass composed of a clay mass lying between hard soil and soft rock with granular layers in between the clay. Those granular layer allows water flow into the clay mass. Above these rock mass, several embankments of different heights were constructed to cope with the road elevation as designed.

In between the end of the construction and the commissioning of the infrastructure several geotechnical pathologies appear and a geotechnical survey including geotechnical instrumentation plan was needed.

The monitoring plan includes inclinometers to assess the general pattern of displacement in the slopes and piezometers to understand the role of the water flow and generation of pore water pressure in the overall stability.

Figure 2 shows the results of an inclinometer located in one are of significant displacement. The results are largely compatible with a significant failure within the natural in situ ground.

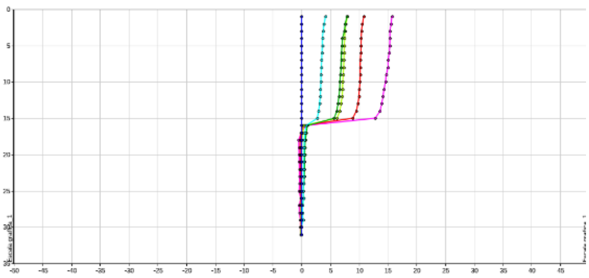

Figure 2. Inclinometer data showing failure in the rock mass.

Several fast responses vibrating wire piezometers were installed into the boreholes following the traditional approach. These piezometers were installed i) in the granular layers within the clay mass and ii) at different elevations within the embankments and iii) the contact points between the embankment and the clay mass. Data was acquired through wireless vibrating wire nodes that measure the piezometers on an hourly basis.

Figure 3 and 4 shows some details of the installation. In particular, figure 3 shows the orientation of the piezometer with the filter pointing upwards. This orientation avoids cavitation and filter desaturation during the installation.

Figure 2. Piezometer installation detail with the filter pointing upwards.

Figure 3. Detail of the granular filter to surround the piezometer following the procedure of the classical approach.

The installed piezometers showed a significant variety of behaviour.

Figure 4 shows data from a piezometric column built with two sensors. The initial role of the borehole where those instruments were installed was purely for geotechnical survey purposes, but as artesian conditions appeared, it was finally instrumented. Flexibility plays a major role in those kinds of projects.

The challenging issue with the installation was to ensure the proper functioning of the bentonite pellets cap taking into account the significant uplift pressures in the borehole. With the final arrangement, piezometers showed pressures 50kPa above the hydrostatic pressure distribution as can be seen in figure 4.

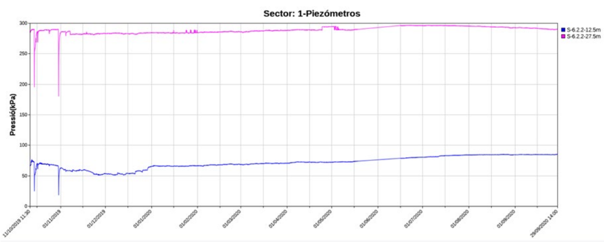

Figure 4. Piezometers measuring artesian conditions.

Figure 5 shows data from another borehole drilled in the area where major displacements were detected, close to the inclinometer on figure 2. In this case, a column of three piezometers was installed: one piezometer at the elevation of the major displacement and the others distributed in different granular layers within the clay mass. All three piezometers showed similar behaviour with sudden increases in the measured pressure when it rains. This behaviour is related to the fact that granular layers are responsible for the water flow into the ground. The response to these increase in the water pressure is drained as fast excess dissipation are also observed.

The piezometer installed at the elevation of maximum displacement is lost after some years of monitoring, probably due to excess displacement damaging the cables and/or the instrument.

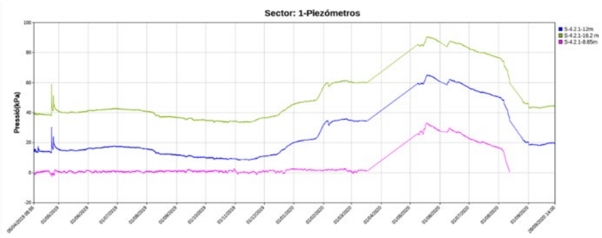

Figure 5. Piezometric values.

Figure 6 shows data from one of the last installations in the project. This borehole was designed specifically for this purpose and located close to an area that was showing displacement. In this case, the borehole was completely dry after the drilling operations. Therefore, water must be added after the piezometer installation to ensure the bentonite pellets can swell and become a cap. This creates an artificial increase in the pressure that should be considered in the analysis. The installation of the piezometer was made in a period of sustained low atmospheric pressures. This phenomenon also affects the data, as the zero reading was measured with the piezometer fully saturated at the ground surface elevation, with the atmospheric pressure measured on site.

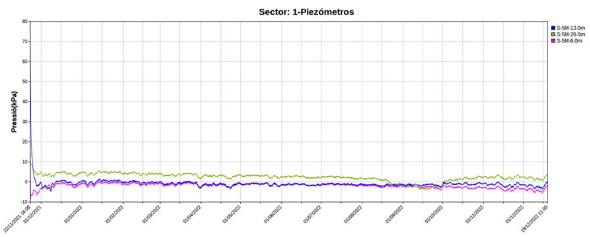

Figure 6. Piezometer measurements.

4. Conclusions

The use of piezometers as a geotechnical instrument is a commodity. This situation can create, under certain circumstances, a false sense of confidence with the design, installation and use of these devices as geotechnical instruments.

The paper exemplifies the need for a more conscient understanding of some theoretical terms- for example the hydrodynamic time lag according to Hvorslev definition- and some practical topics to optimise data quality and overcome some installation issues.

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