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Monitoring preloading operations in the port of Barcelona

Surveillance des opérations de précharge dans le port de Barcelone

J. Raventós
BAC Engineering, Barcelona, Spain

ABSTRACT: Geotechnical works that includes ground improvent operations needs supervision on site in order to ensure the safety of the operations and the level of improvement. This also affects the monitoring and stresses the need of realiable instruments (in terms of measurement techniques, transduction system and data storage) but also on the quality of the data, including installation, organisation and post processing. This paper is related to this second isssue, in particular to the installation of piezometers in boreholes, a type of instrument where the classical installation approach -with sand filter and bentonite seal, using Casagrande piezometers- is complex, with a significant economic cost and likelihood of failing. The alternative to this, consists on an installation without bentonite seal with a continuous grouting. This paper describes the installation and data analyisis of two piezometric columns installed with the classical and fully grouted approaches, that allow to monitor pore water pressures in the ground during a consolidation process by the use of preloadings.The obtained results showed that fully grouted method results are as good as the traditional ones if attention is focused on the design of the grout mix.

RÉSUMÉ: Les travaux gétotechniques comprenant des opérations d'amélioration des sols nécessitent une supervision sur le site afin d'assurer la sécurité des opération mais également de garantir le niveau d'amélioration. Cet aspect affecte également la surveillance et surligne la nécessité de disposer d'instruments fiables (en termes de techniques de mesure, de systèmes de transduction et de stockage des données) mais également de la qualité des données, y compris l'installation l'organisation et le post-traitement. Cet article concerne ce deuxième aspect et en particulier l'installation de piezomètres dans les puits de forage, un type d'instrument dont l'approche classique – avec sable filtrant, bâton de bentonite en et utilisation des piézomètres de Casagrande- est complexe avec un coût significatif et une tendance à échouer. Une alternative consiste à réaliser l'installation sans joints de bentonite en utlisant un scellement complet. Cet article décrit l'installation et l'analyse des données de deux colonnes piezométriques installées avec chacune des deux méthodes pour surveiller la pression des eaux durant une consolidation à l'aide de précharges.
Les résultats obtenus permettent de montrer que que la méthode par scellement complet fonctionne aussi bien que la méthode traditionnelle si une attention particulière est données à la conception du mélange
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Keywords: Preloadings; Monitoring; Fully grouted; Piezometers; Wire vibrating

1 INTRODUCTION

Geotechnical monitoring is one of the essential elements to ensure 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 presuming design and to ensure that operations are safe. In projects involving ground improvent and /or treatment, the geotechnical observations provided by monitoring are also used to check if the improvement levels are those that had been previously designed.

This context streesses the need of reliable data that can only be obtained by reliable instruments. It is important to state that the reliability of the instruments is related to two main issues. The first one referes to the instrument itself (measurement technique, transduction and data storage). The second one is related to the use of the instruments on site. This second topic includes several processes such as installation, data acquisition and data management.

From all the forementioned aspects, the installation is the probably one of the less attented issues (see for example the papers on the publication of Arroyo et Alonso, 2010). Nevertheless, the installation of instruments on the ground can affect the quality of the data in a significant way. 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 particulary significant in pressure cells and extensometers. The installation can also impact on some other issues like resolution, response time, noise presence, etc.

The optimal installation process of a 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, cannot be appropiated if there is a change in the measurement system. This seems to be the case of the piezometers, as shown in this paper.

2 PIEZOMETERS INSTALLATION

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

Hvorslev (1951) described the two main types of error associated with the pore water pressure using piezometers. The first is related with the alteration of the hydraulical conditions on site by the installation of the piezometer, modifying flow conditions and consequently, 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 type is the hydrodinamic time lag (the time span between a change in the pressure occurred on the ground; this change is measured by the device). If the time is significant, the instrument loses precision.

The classical piezometer installation consists on a filter (slotted section of a pipe or a filter tip in case of diaphragm piezometer) that is sorrounded by sand and/or gravel acting as the intake zone. This zone is hydraulicaly isoltated from the rest by a bentonite seal (Figure 1a). The sand or gravel function is reducing the hydrodinamic time lag, because those piezometers require a significant volume of water to get inside/outside the pipe to measure a change in the pressure.

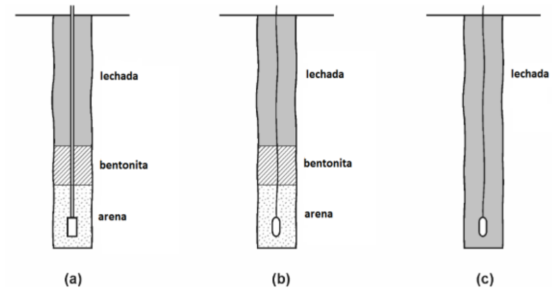

Figure 1 Installation of piezometers (adapted from Contreras, 2011)

Electrical, wire vibrating piezometers are also standard and have been used in the last decades. This piezometers have a very low time lag in comparision with the Casagrande's ones (Penman, 1960), as the volume of water required to measure a change in the pressure is significantly lower. In the usual practice, the installation procedure follows the classical approach (figure 1b).

The geometric conditions of the wire vibrating piezometer allows the installation of different units in one single borehole. This works as 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 sorrounding the piezometer is not necessary.

This question was formaly asked by Penman (1960) and Vaughan (1969). In fact, Vaughan (1969) stablished the possibility of avoiding sand filters and bentonite seal and to install piezometers directly embeded 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 two orders of magnitude that the ground are used, no significant errors occurr. Vaughan tested the proper performance of this arrangement installing piezometers in the clayey core of an earth dam.

The work of Vaughan didn't become popular within the industry, although it appears in reference publications [Dunnicliff, 1988], were the author constraints its use to particular situations. These discrepances can be related to some details of the elaboration of the mixture- commented in this paper, that are not clear enough 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), who presented a systematic approach in the monitoring of mining operations in heavy oil sands in Canada, highlighting economic and practical advantatges. Mikkelsen (2002), Contreras et al (2007, 2011), Simeoni et al (2011) in a civil engineering context, support the idea of Vaughan with theoretical and practical ideas. In particular, Contreras et al (2007) improve the numerical analysis started by Vaughan and state that the use of grouts with hydraulical conductivities up to three orders of magnitude largers than the ground ones can operate without significant errors. Other interesting statements are related to the need to correct the measurements with the barometric pressure and a detailed discussion on the composition and installation of the mixed grout.
Aligned with the previous papers, we described here, the first use of this technique in Spain.

3 EL PRAT QUARRY PROJECT

3.1 Geography and geology

The area of interest of the project is located in the Port of Barcelona, within the Llobregat river's delta. The sediments of this delta, of quaternary age, include two sandy-gravelly levels, and a clayey-silty (almost) normally consolidated layer in between. The upper detrictic layer is dominated by sands while the lower one is gravely dominated.

3.2 The project and the civil works

In the described area a civil enginering project has been developed in order to build a logistic platform for container storage of 750.000m^2. This platform is divided into quay line, maneuvring area and storage area.

Above the natural ground it is deposited a hydraulic fill that helps to obtain the necessary elevation of the platform, as it can be seen in Figure 2.

During the design stage, several potential geotechnical issues arose (low values of undrained shear strength, high compressive ratio and settlement rates), and several preloadings (8, 4.5 and 3m high) were designed to deal with that issues. For the geotechnical monitoring of the operations, the installation of different instruments was proposed (figure 2):

- Settlement plates in the contact between the preloading embankments and the natural ground, fully automatized with daily measurements using total stations.
- Sliding deformeters in boreholes, with manual data acquisiton.
- Piezometric wire vibrating columns in boreholes, fully automatic and daily measurements.

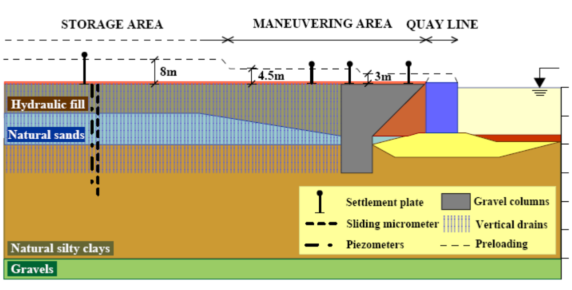

Figure 2. Geotechnical and monitoring cross section

4 GROUT MIXES USED FOR INSTRUMENT INSTALLATIONS.

In the context of the project in the Port of Barcelona, a systematic study on the hydro mechanical behaviour of grout mixes was developed for the instalation of instruments (Raventós, 2014). This study includes the installation of extensometers and piezometers. The installation of the former ones is out of the scope of this paper.

Former laboratory testing campaings on grout mixes are very scarce. Reliable contributions can be found in Marsland (1973), Dunnicliff (1988) and Contreras et al. (2007). The studies performed and related to bentonite-cement walls (Hinchberger, 2010), and related with ground improvement by deep mixing technicque (Lorenzo and Bergado, 2004) are also relevant, but those contains diferent ranges in the mixture.

4.1 Laboratory testing

In the context of this work, data coming from previous unpublished works [Solexperts (1985) and GeoPayma (2009)] has been used. To complement this information six new mixes are used with different contents of water, cement and bentonite. Table 1 includes the values of the different water/cement/bentonite (W/C/B) ratios used, and also the water/cement ratio (W/C) and the cement-bentonite ratio (A_w, as proposed by Lorenzo and Bergado for the deep mixing analysis). Table 2 shows the test schedule.

Table 1. Tested mixes

Id.	**W/C/B**	**W/C**	**Aw**
1	100/45/17	2.22	2.65
2	100/12.5/5	8	2.5
3	100/70/8	1.43	8.77
4	100/40/10	2.5	4
5	100/40/8	2.5	5
6	100/70/18	1.43	3.89

Table 2. Laboratory testing.

Id.	7 days	14 days	28 days	60 days
1,2, 3	Basic identification and uniaxial compression strength	Uniaxial compression strength	Basic identification, uniaxial compression strength and oedometric test	Basic identification and uniaxial compression strength
4,5, 6	-	-	Basic identification	-

4.2 Results

The laboratory testing campaing include basic identification tests, uniaxial compression strength and oedometric tests as well. In this laboratory test campaing a significant effort was performed in analyzing the effect of the curing time (Table 2). The most interesting findings are summarized as follows. Further dettails can be found in Raventós (2014):

- Samples showed a significant high void volume, with void ratios higher than 2 and up to 6. The evolution of the void ratio is significant in the curing age (Figure 3).
- In the studied range, the effect of the cement/bentonite ratio on the void ratio didn't play a significant role, while the effect of the water/cement ratio is significant.
- The role of the water/cement ratio on the uniaxial compression strength is well known and stablished in the concrete industry. It is important to note that the effect is almost the same for samples covering three orders of strenght magnitude (Figure 4).
- The compressibility has got an elasto-plastic behaviour and the preconsolidation pressure is related to the W/C ratio (Figure 5)
- In the same way as showed in the void ratio, the water-cement ratio controls the hydraulic conductivity, specially for samples with higher W/C ratios (Figure 6).

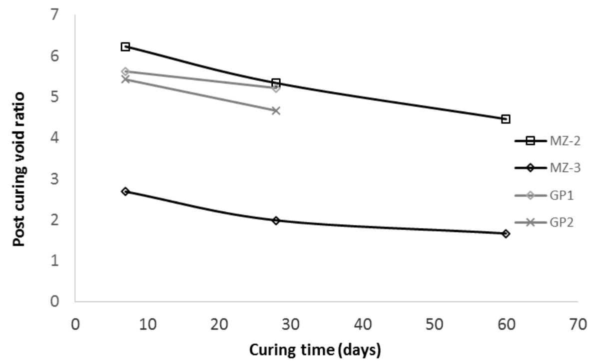

Figure 3. Void ratio variation in relation with W/C and curing time.

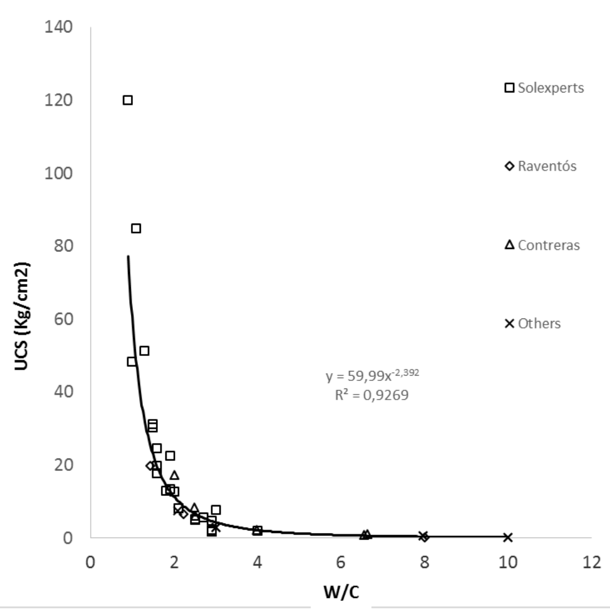

Figure 4. Uniaxial compression strength and its relationship with the W/C ratio.

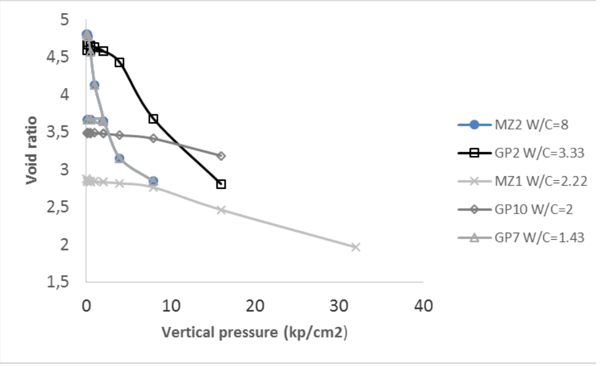

Figure 5. Oedometric curves for samples with 28 days of curing age and different W/C ratios.

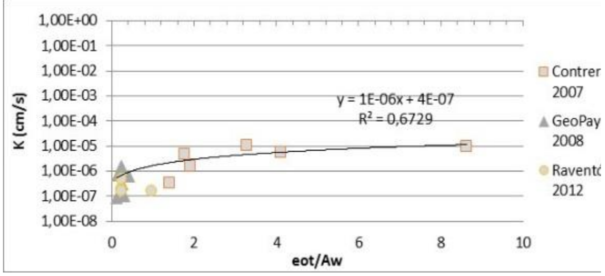

Figure 6. Permeability values for different W/C ranges.

5 INSTALLATION IN THE PORT OF BARCELONA

Three different piezometric columns were installed in the area of the project with devices at different elevations (Table 3). Two of these installations followed the classical approach and the third one followed the fully grouted method. The clayey-silt layer showed a significant variation in the values of the hydraulical conductivity. The lower values are in the range of 10^{-6} cm/s.

Taking this value into account, all the tested mixes meet the requirements of Contreras et al (2007) -not higher than three orders of magnitude than the ground. A low permeability mix was designed (W/C/B 100/45/17) in order to prevent an increase of the void ratio and permeability during the insitu curing of the mix due to the possibility of the water flowing from the ground to the mix.

Table 3. Installed piezometers

	Id	Elevation (m)	Geotechnical level
PJ11A_classic approach	PJ11A_20	20	Clay 4
	PJ11A_28	28	Clay 11
	PJ11A_36	36	Sand 2A
PJ13C_classic approach	PJ13C_5	5	Fill C2
	PJ13C_16	16	Clay 1
	PJ13C_20	22	Clay 12
	PJ13C_28	29	Clay 11
PJ13A_fully grouted	PJ13A_17	17	Sand 2
	PJ13A_25	25	Sand 1B
	PJ13A_33	33	Clay 3

5.1 Installation

There are, within the community, different opinions and approaches in relation to the way of mixing the components. Dunnicliff (1988) suggests mixing bentonite and water first: if the cement is mixed with water first, this can affect the expansion of the bentonite. McKenna (1995) and Mikkelsen (2002) in a different direction, support the idea of mixing water and cement first as it is the W/C ratio who plays a major role on the hydro-mechanical behaviour of the mix. As the laboratory testing confirmed the idea of the critical role of the W/C ratio, the water and the cement were mixed first and, after that, the bentonite was added to the mix.

Following Contreras (2007,2011) statements, the piezometers were fixed to the injection hose on the ground surface with the tips pointing upwards to avoid water cavitation during the descending of the system inside the borehole. Once the borehole excavation was finished and cleaned (by injecting water) the devices were descended inside the casing and then the mix was grouted.

Regarding the injection operations, in order to avoid failure of the soil inside the borehole, the injection was made inside the casing in the granular materials (sands and gravels), while the injection in clays was done after removing the casing.

5.2 Results

Results for each one of the piezometric columns installed on site are plotted in Figures 7 and 8, following the conventional and fully grouted methods.

Although there are significant differences in the embankment construction and elevation and also the permeability of the ground, the final results showed a clear effectiveness of the fully grouted method. Both installations showed similar trends on the magnitude of the measured excess pore pressure and also on the velocity of increase or decrease of the pore pressure.

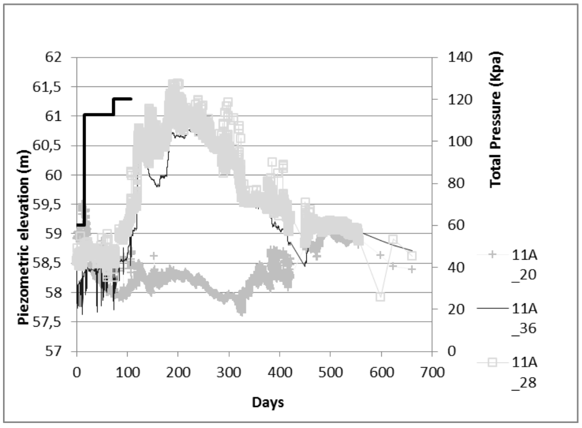

Figure 7 Resuls obtained in the column 11a, installed following the traditional approach.

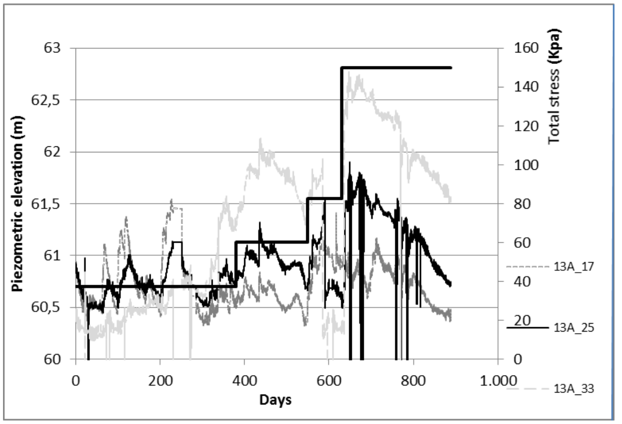

Figure 8. Measurements obtained in the column installed following the fully grouted method.

6 CONCLUSIONS

The installation of piezometers following the fully grouted method allows to obtain measurements of the same quality than the ones installed following the traditional approach, but with a lower economic cost and a higher prevention of installation failure. This method makes the installation of several piezometers and other instruments in the same borehole easier. In order to obtain good results it is crucial to focus on the design of the mix to be grouted and the installation procedure.

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