Grout mixes in geotechnical instrumentation. Some insights

Leen DE VOS[1], Josep RAVENTOS[2]

[1]Flemish Government – Geotechnics Division, Gent, Belgium
[2]BAC Engineering consulting group, Barcelona, Spain
Corresponding author: Leen De Vos (Leen.devos@mow.vlaanderen.be)

Abstract

Grout mixes in geotechnical instrumentations are widely used, especially to backfill the gap between borehole and installed instrumentation. Even though it is well known and established that the mechanical and hydraulic characteristics of the grout mix can be critical for a good performance of the instruments, there is a lack of thorough knowledge of the grouts' real behaviour.

The paper reviews and presents the results of several laboratory tests to assess the hydro-mechanical characteristics of several grout mixes and provides some insights into some frequently asked questions related to them. In particular it focuses on the evolution in time for grout mixes with regard to permeability, strength and stiffness and the impact on the mechanical or hydraulic characteristics when using different types of cement/bentonite.

An example is presented, where the impact of the grout characteristics on the instrument behaviour is illustrated.

Keywords: Grout, installation, backfill

1. Introduction

For several decades, grout is used as a backfill material when installing geotechnical instrumentation. Even though the possibility of using grout to install borehole piezometers was mentioned in 1969 (Vaughan, 1969), it wasn't until 1988 that it was referenced again (Dunnicliff, 1988) and until around 2010 before it became a common installation method (Contreras et al., 2007). The main advantages of using grout as a backfill material are the effective sealing of the borehole and the ease of installation.

Grout is used as a backfill material for the installation of inclinometers, extensometers and piezometers. The objective is to mimic the ground characteristics with the backfill material, i.e. the grout. In the first two cases, the composition of the grout is determined by its strength. For piezometers however, the hydraulic behaviour (permeability) plays a very important role as well.

The mechanical and hydraulic characteristics of the mix are supposed to be mainly controlled by the water-cement ratio. Bentonite is used to control the volumetric stability of the mix when setting. By mixing water and cement first, the water-cement ratio is fixed and bentonite is added to reach the predetermined viscosity (to control the bleeding), required for stability. In the field, the amount of bentonite which is added depends strongly on the mix water chemistry, on the temperature, on the type of cement and bentonite which are used...

Even though the table of Mikkelsen and Green (2003) is often used as a guideline for the grout's composition, it isn't always clear what influence the type of cement and bentonite, which are used, and the amount of bentonite which is added have on the grout characteristics and the variation of the grout characteristics in time. A number of different laboratory tests have been performed to assess the role of the water-cement ratio, type of cement and bentonite, curing time, etc on the final characteristics of the mix.

When installing monitoring equipment in the field, one has to determine the characteristics of the soil (which is not straight forward) and determine the composition of the grout taking into account the type of instrumentation as well. Furthermore, instrumentation can be combined within a borehole (e.g. inclinometer and piezometers), which adds to the difficulty of determining the correct grout composition. Together with the above mentioned uncertainties of the grout's characteristics, this might lead to a deviation between the soil and grout's characteristics. An example is given of a test set-up, illustrating the effect of the grout parameters on the instrumentations response.

2. Laboratory testing

2.1 Performed tests

Several test series on grout samples were performed on two different locations. 2 series of tests were performed at the laboratory of the Geotechnical Division of the Flemish Government in Ghent (Belgium) and another test series was performed at the Geopayma Laboratory (Spain).

The grout mixes which are used have W/C ratio's (weight ratio) varying between 1 and 6.6. For tests GR1 to GR3, GR1bis to GR3bis and GR13 cement CEM 32.5R and Colclay bentonite are used; For tests GR4 to GR6, GR4bis to GR6bis and GR14 cement CEM 52.5N is used, combined with Cebogel as bentonite. Mixes MZ1 to MZ6 use lower amounts of bentonite than the mixes from Mikkelsen, and water cement ratios vary between 1 and 8. S samples refer to unpublished results coming from Solexperts with up to 24 different water cement ratios between 0.9 and up to 3 with different types of bentonites.

Quite large amounts of bentonite were added to the mixes GR1 to GR6, compared to the table from Mikkelsen and Green (2003). The outside temperature was cold when making the grout (possibly explaining the larger amounts of bentonite), but there was some doubt on the mixing quality (a simple mixing rod was used) and the tests were reproduced about 1 year later with the same composition, but using an industrial mixer to obtain a better mix. For the lower strength mixtures, the applied amount of bentonite was even higher for the second test run, because a more viscous mix was aimed for (quite a lot of bleeding was noticed during the first test series). The bentonite/cement ratios vary between 0.1 (for W/C = 1) up to 1.1 (for W/C 6.6).

The following laboratory tests were performed on the samples:

- Unconfined compression tests (UC)
- Bender element tests
- Permeability tests: both tests with constant decay and variable decay are performed
- Identification, including void ratio, water content and density

2.2 Sample conditions

The samples were mixed and poured in a PVC liner (+-10cm). The samples were stored vertically in a controlled 15.2°C room to mimic the field conditions in which the grout hardens. It is of course impossible to completely mimic field conditions in the lab and it remains uncertain what the impact is of possible water transport from and to the grout mix in the field.

Before each test, the part of the PVC liner which would be used for the test was cut and the PVC liner was sliced open gently not to create cracks in the grout sample. The grout samples were tested in their original sizes, again not to disturb the grout by subsampling.

2.3 Results

2.3.1 Mechanical characteristics

Both short term (tests at 7-14-21 and 28 days) and long term (tests at 28-56 days and 1 year-2 years) behaviour was investigated for the samples described in 2.1.

The results for the unconfined compression tests are shown in Figures 1 and 2. Figure 1 shows the UCS value at (approximately) 28 days as a function of W/C factor. Some values, taken from Contreras et al. (2007), within a wide range of W/C factors are added as a reference to this figure. The results of a test series performed by Solexperts are added to this graph as well.

As can be seen from Figure 1, the compression strength decreases quickly when the W/C factor increases. The variation between the individual samples is quite large, especially for the lower W/C factors (higher strength samples).

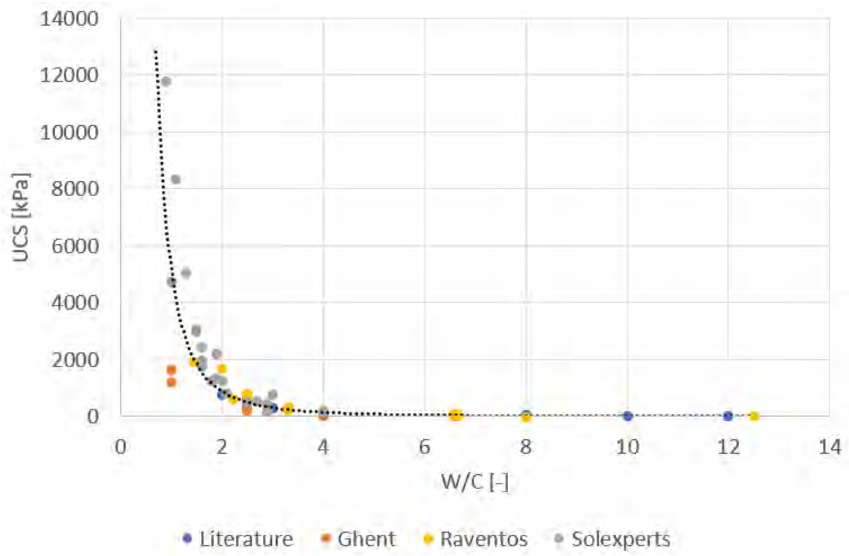
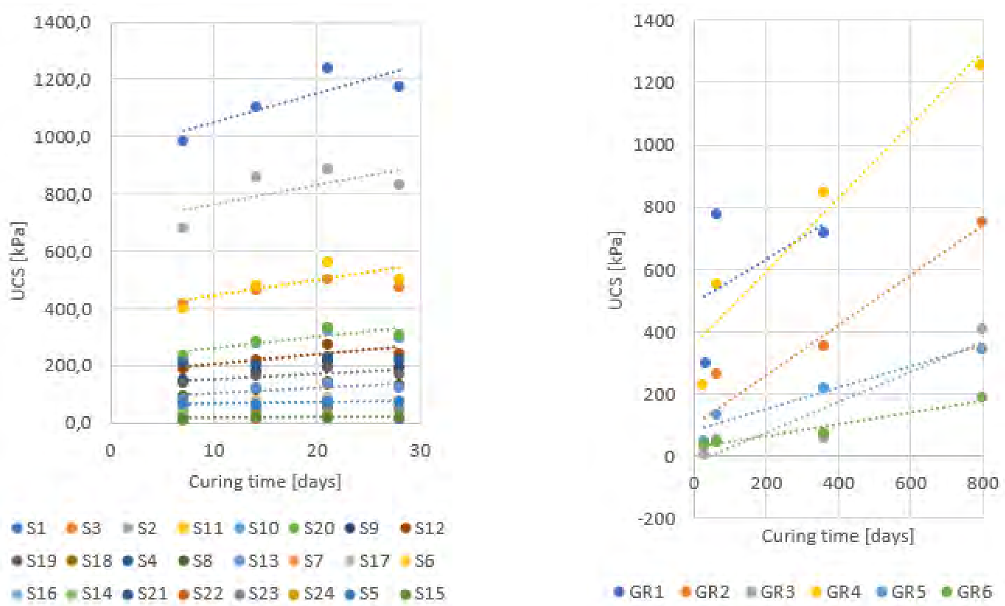


Figure 1: UCS-value versus W/C ratio (in weight)

Figure 2 shows the variation of the UCS value as a function of the curing time. In Figure 2a) the short term behaviour of grout is plotted (curing time up to 28 days). This figure shows that, even though the strength of the grout develops quite quickly (also depending on the cement type), the UCS value increases over time. Figure 2b) shows the long term behaviour (curing time up to 800 days). After 2 years, the strength has increased significantly compared to the UCS value after 1 year (50% to even 550% for the highest W/C ratio). The increase over time seems to depend on the cement-type which is used and on the composition of the mix.



a) short term UC tests

b) long term UC tests

Figure 2: unconfined compression strength (UCS [kPa]) as a function of curing time

Figure 3 shows the comparison between the shear modulus G_0, obtained from the bender element tests, and the UCS value, obtained from the UC tests (tests performed at different curing ages). The result shows an almost linear relation between both parameters, especially for the lower strength values.

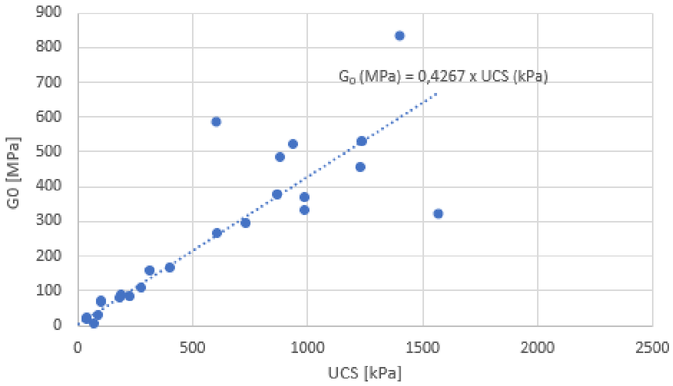


Figure 3: Shear modulus G_0 versus UCS value

From these tests it can be concluded that the mechanical behaviour of the grout is not only controlled by the water/cement ratio but also depends strongly the curing time (up to a curing time of two years). The effect of an increase in the curing time is similar to the effect of an increase in the cement content: a higher uniaxial compression strength and a higher stiffness modulus. The effect is comparable for the water content, void ratio and permeability: the higher the water cement ratio, the lower the density, the void ratio and the water content. Again, an increase in the curing time has the same effect as an increase of the cement content.

2.3.2 Hydraulic characteristics

Figure 4 shows the evolution of the permeability k versus the curing time for 1 set of tests (second test series, variable decay). As the UCS value increases, the permeability decreases over time. The evolution of the permeability varies depending on the grout mix.

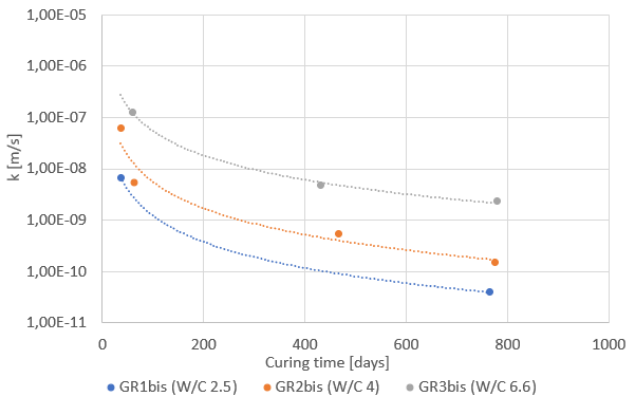


Figure 4: Evolution of permeability as a function of curing time for GR1bis-GR3bis (variable decay)

Figure 5 shows the results of all permeability tests which were performed in Ghent (first and second test series, constant and variable decay).

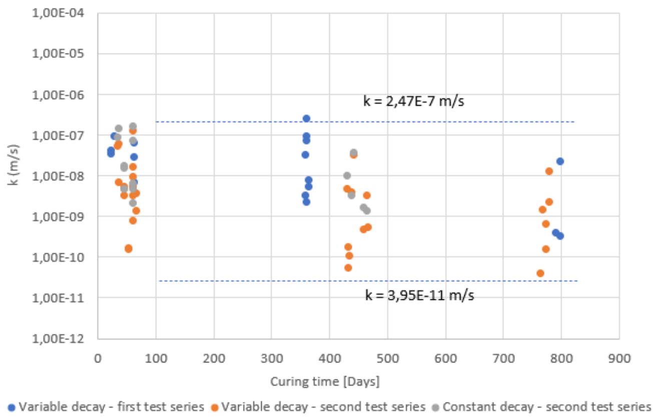


Figure 5: Permeability as a function curing time, both constant and variable decay.

The measured permeabilities vary approximately between 2.5E-07 m/s and 4E-11 m/s. The lowest permeabilities are obtained at the largest curing time. Although permeability clearly decreases over time, there is quite some variation in the results, possibly due to small variations in the subsets of the samples. It is not unusual for the permeability to decrease with a factor of 10 or even 100 with an increase in the curing time.

3. Impact of grout characteristics on measurements: example

An extensive monitoring program was set-up to measure (among other parameters) pore water pressures and horizontal deformations with the aid of inclinometers on a full scale loading test of diaphragm walls in the Boom clay in Antwerp. The loading test and main results are described in Couck et al. (2022).

Both push-in piezometers and fully grouted piezometers were placed close to the base of the diaphragm wall, prior to the construction of the diaphragm wall. Inclinometers (also fully grouted) were installed next to the diaphragm walls. The push-in piezometers were installed at the bottom of the borehole which was made for the inclinometer casing. The fully grouted piezometers were attached to the inclinometer tube (see Figure 6) but at a certain distance of the casing. This way the grout could fully surround the piezometers.

Figure 6: Fully grouted pore water pressure sensors attached to the inclinometer casings

The main objective was to measure the behaviour of the tertiary Boom clay when loading the diaphragm wall panels. The characteristics of the Boom clay are shown in Table 2. As described above, for inclinometers the strength of the back-fill material determines the grout mix, typically aiming for a slightly stronger mix than the surrounding soil. For piezometers, permeability is assumed to be the most important characteristic, even though the strength might have an impact on the measurements.

Initially, the field tests were planned to take place shortly after the installation of the diaphragm walls and the design of the grout mix was based on this assumption. The W/C/B ratio (in weight) was 2.8/1/0.4, the cement type was CEMII/B-S 42,5N (Ultipro) and bentonite was DantoCon Pure C 0/0,315 (Bentoniet Import Nederland). A second field test was performed a few months after the initial test.

Grout samples were taken (the grout was poured freshly in a PVC liner in the field, transported to the laboratory and cured in a 15.2°C room, as described in 2.2) and unit weight, water content, permeability and undrained shear strength of the grout were tested in the lab. The tests on the grout samples were performed at the curing time of the field test.

Characteristic	Boom clay	Grout mix after 16-55 days	Grout mix after 126-165 days
UCS [kPa]	400	480- >826*	586 - >1574*
Vertical permeability k_v [m/s]	$10E^{-11}$	4.10^{-7}->2.10^{-7}	2.10^{-7}->3.10^{-8}

Table 2: Characteristics of Boom Clay and grout; * the value was limited due to the laboratory test set-up

The piezometers located underneath the diaphragm wall were installed after making the diaphragm wall and the back-fill grout was only cured 16 -21 days during the first test series. As the other instrumentation was placed prior to the installation of the diaphragm walls, the grout was approximately 45-50 days old at the time of the load test. Table 2 and Figure 7 give an overview of the strength and permeability of all the tested grout samples. As for the lab tests in section 2, the UCS value increases over time and the permeability decreases over time. It should be noted that the samples which hardened in lab conditions (15.2°) showed settlements/loss of height of 5 to 40%, implying that there was quite some excessive bleeding of the grout.

During the first series of field tests, the grout was on average twice the strength which was aimed for, and the permeability of the grout was a factor 2.10^4 to 3.10^4 lower than the permeability of the Boom Clay. During the second test series, the strength increased even with a factor 1.5 (on average) and the permeability lowered with a factor 4 (on average) over this period.

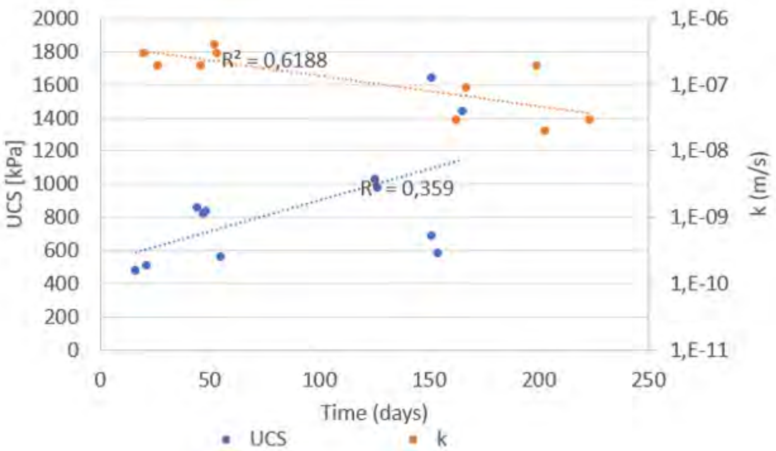


Figure 7: Grout characteristics, tested in the lab at the moment of loading in-situ panels

The behaviour of the piezometers during field test 1 (shortly after installation) and during field test 2 (4 months later) is illustrated in Figures 8 and 9. Sensor P2c is a push-in piezometer located approximately 0.7m below the 2 fully grouted piezometers P2b and P2d, both installed at the same level. For the sake of comparison, the reference pressure is put to 0 at the start of the loading test in the figures (initial pressures were not the same for all piezometers in reality due to the different levels, installation method and loading of nearby panels).

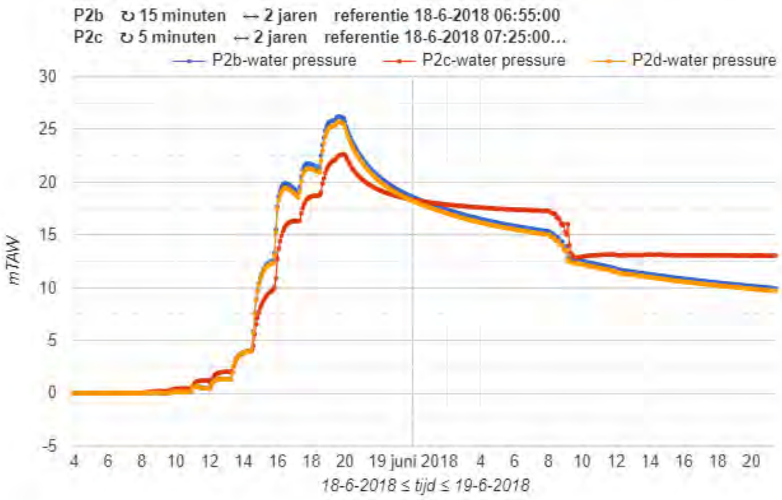


Figure 8: Comparison between push-in and fully grouted piezometers, timescale approx. 1.5 day, phase 1

During the first test, the maximum overpressure measured by the fully grouted piezometers p2b and p2d (26m overpressure) is slightly higher than the overpressure measured by push-in piezometer P2c (23m overpressure), even though the fully grouted piezometers loose some overpressure in between different loading steps for the higher load steps (loss max.6% in 30 minutes). This higher overpressure could explained by the location of the sensors (piezometer p2c is located slightly deeper under the diaphragm wall and the overpressure can thus be slightly less) or to the fact that, as the grout is slightly stiffer than the ground, the grout column attracts a higher force than the ground (resulting in a larger overpressures). Due to porewater dissipation, the consolidation in the fully grouted piezometers appears to be faster than the push-in piezometer, but considering the difference of a factor of 20.000 to 30.000 between the permeability of the grout and the permeability of the ground, the behaviour of the fully grouted piezometers seems to be acceptable for this application.

During the second test, the loading was applied and relieved much more slowly and the maximum overpressure measured by the push-in piezometer P2c (11.5m overpressure) is significantly lower than the overpressure measured by the fully grouted piezometers p2b and p2d (18m overpressure). The fully grouted piezometers still lose some of their overpressure in between the different loading steps, but much slower than in the initial phase (max. 8% in 14 hours). The higher overpressure in the fully grouted piezometers could be allocated to the increased strength of the grout column.

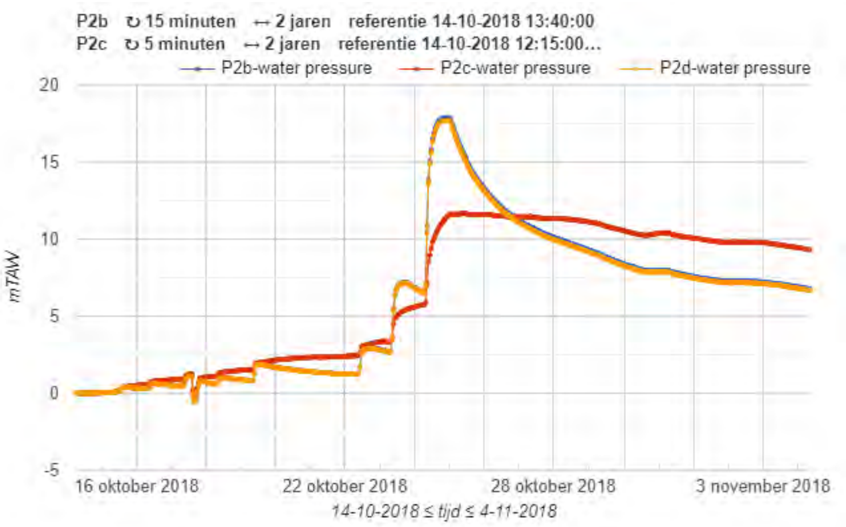


Figure 9: Comparison between push-in and fully grouted piezometers, timescale approx. 20 days, phase 2

Some conclusions, based on the measurements:

- even though the permeability of the back-fill grout is much higher than the Boom clay, the fully grouted piezometers respond acceptably for this specific short term test set-up. Typically a maximum factor of 1000 is recommended for the difference in permeabilities;
- the strength of the grout might have an impact on the pore water overpressures which are measured in the piezometers during a loading test.

4. Conclusions

Grout is often used as backfill material when installing geotechnical monitoring, aiming to mimic both mechanical and hydraulic characteristics. In literature, some guidelines on the choice of grout mix for certain ground stiffnesses are suggested, taking into account the characteristics at 28 days strength. Several tests were performed, showing the variation over time of the grout characteristics and implying the necessity of taking the curing time of the grout into consideration when designing the grout mix. An example of field measurements show the possible influence of varying backfill characteristics on the response of piezometers.

Acknowledgements

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