Fully grouted piezometers in a soft Champlain clay deposit -

Part I: Piezometer installation

Submitted to

Geotechnical News

by

Vahid Marefat[1,2*], François Duhaime[1], Robert P. Chapuis[2], and Vincent Le Borgne[3]

[1] Laboratory for Geotechnical and Geoenvironmental Engineering (LG2), École de technologie supérieure, 1100 Notre-Dame Ouest, Montreal, QC, H3C 1K3, Canada

[2] Department CGM, École Polytechnique de Montréal, P.O. Box 6079, Station CV, Montreal, QC, H3C 3A7, Canada

[3] GKM Consultants, 2141 Nobel, Suite 101, Sainte-Julie, QC, J3E 1Z9, Canada

[*]Corresponding author, Phone: 1-438-931-9797

vahid.marefat@polymtl.ca

July 2017

Introduction

The fully grouted method has been used since the 1970s to install piezometers for several geotechnical and mining applications. The method has several advantages including ease in installing and reduced costs, especially when boreholes are shared with other geotechnical instruments. Several authors have noted that grout permeability is the most crucial factor influencing the piezometric error (Vaughan, 1969; McKenna, 1995; Contreras et al., 2008; Marefat et al., 2014). For steady-state seepage, Vaughan (1969) proposed that the error may be negligible for a grout with permeability up to two orders of magnitude greater than the adjacent formation permeability. Moreover, based on numerical modelling, Contreras et al. (2008) found a negligible error when the grout had a hydraulic conductivity within 3 orders of magnitude of the surrounding formation. Based on a new analytical solution and numerical modelling results, Marefat et al. (2014) found that pore pressure measurements are reliable when grout permeability is up to one order of magnitude greater than the adjacent clay permeability. Field measurements reported by McKenna (1995) indicated that the grout must be less permeable than the formation to reduce the piezometric error for most soil conditions. Other than the results presented by McKenna (1995), there is very little published information on the field performances of fully grouted piezometers. In addition, there is no agreement on the acceptable permeability contrast between the soil and the grout. The grout hydraulic conductivity is not the sole factor influencing the piezometric error. The grout physical stability also is an important parameter for successful piezometer installation. The main objective of this project was to appraise the performance of fully grouted piezometers under natural field conditions. The paper introduces a new field site that was established in collaboration with GKM Consultants for this purpose. The paper also presents preliminary results regarding pore pressure measurements.

Site description and stratigraphy

The study area is located in Saint-Marthe, near Montreal, Canada. The intact Champlain clay has a thickness of around 10 m. It is located under a layer of stiff clay, which is fractured and sometimes oxidized. The fractures can reach down to 6 m from the ground surface. The intact clay deposit is soft and sensitive at depths between 6 and 12 m. Sensitivity can reach 200 at a depth of around 10 m (Figure 1). Falling-head laboratory tests provided an average hydraulic conductivity of 1.08×10^{-9} m/s for the intact clay. In the lower portion, the clay is mixed with sand, silt, and coarser material including erratic blocks. The silty layer is underlain by the bedrock. Figure 1 presents a preliminary geotechnical profile for the study site.

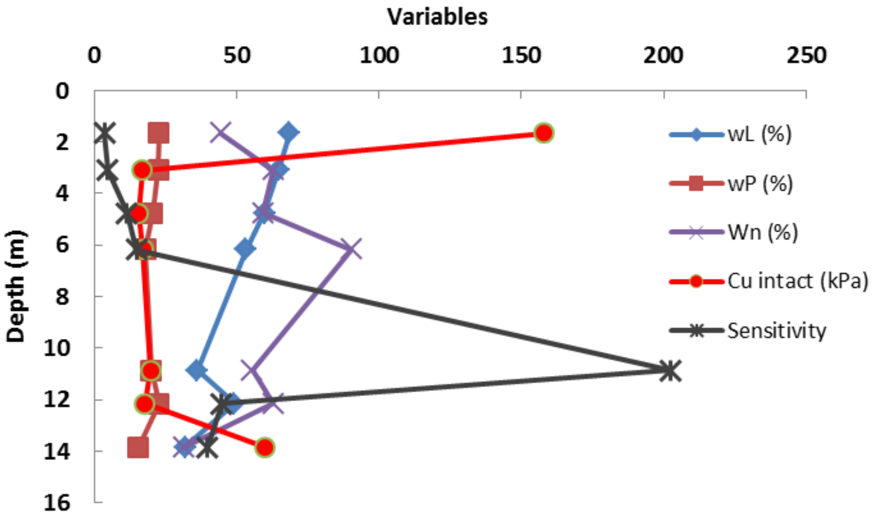

Figure 1: Geotechnical profile for the study site: wL, liquid limit; wP, plastic limit; wn, natural water content; Cu, undrained shear strength.

Borehole drilling, grout recipes and piezometer installation

Boreholes F1, F2 and F3, with a diameter of 114 mm, were drilled in October 2016 using wash boring. The boreholes are spaced 3 m apart. Borehole F3 was drilled to the lower third of the clay layer to a depth of 12.5 m from the ground surface while the other two boreholes (F1 and F2) were drilled into the bedrock down to a depth of 22 m. The clay layer was sampled using thin-walled tube samplers (3”) at 1.5-m intervals. Figure 2 shows a cross-section of the boreholes. Two monitoring wells (MWs) were installed in F1 and F2. The MWs’ intake zones were located at the interface with the fractured bedrock and silty layers. In each borehole, two multilevel piezometers were installed approximately at the lower and upper third of the clay layer. The multilevel piezometers monitor pore pressure fluctuations within the clay layer. Boreholes F1 and F3 include two vibrating wire piezometers (VWPs), which were fully grouted at depths of 6.1 and 12.2 m below the ground surface. Borehole F2 contains two standpipe piezometers with a sand filter around their screen. The center of the intake zones for the standpipe piezometers was located at the same depth as the VWPs (Fig. 2).

The vibrating wire piezometers were calibrated before the installation. The piezometers were kept under water until their installation. Once the boreholes were drilled, the VWPs were attached to a ¾-inch grout pipe, which was lowered into the borehole to the appropriate depth. After having positioned the piezometer assembly in the borehole, grouting was started from the bottom up.

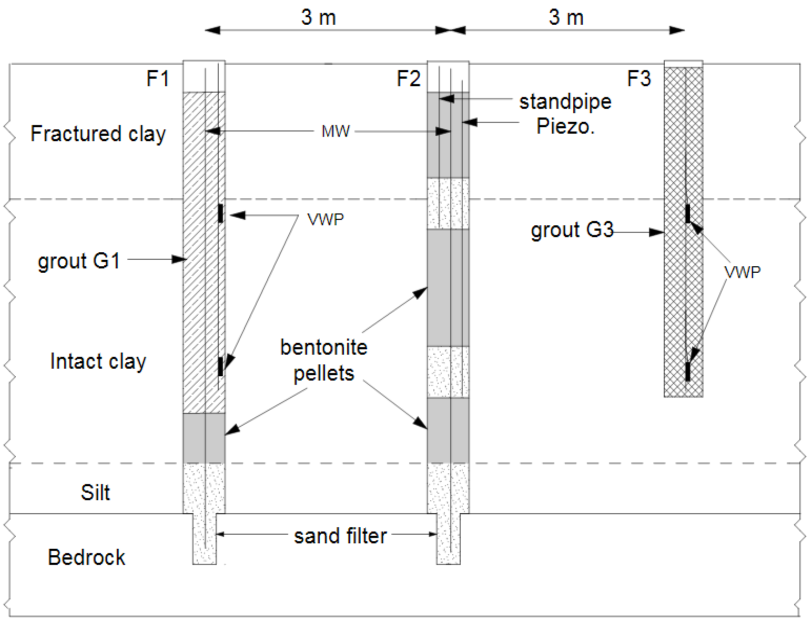

Figure 2: Cross-section of the piezometer installations.

Two grout recipes were used to seal the VWPs in boreholes F1 and F3. The grout for F3, later referred to as G3, corresponds to the grout recipe suggested by Mikkelsen (2002). The weight proportions were 6.5 parts water: 1 part cement: 0.4 parts bentonite. Mikkelsen (2002) suggested adding bentonite to this recipe for viscosity adjustments. Bentonite was not added in this case to obtain the properties for the exact recipe. A new grout recipe (G1) was designed for borehole F1 with a higher bentonite content. The weight proportions for the new recipe were 5 parts water: 1 part cement: 1.2 parts bentonite. The higher amount of bentonite made the grout more viscous. A viscous grout does not easily flow into narrow spaces, for example between the piezometer cord and grout pipe. Therefore, a liquid and chloride free superplasticizer (SP) was added in recipe G1 in order to increase the grout flowability. The concentration of SP was about 2.0% of the solid weight. The laboratory values for the Marsh funnel viscosity were 55 s and 29 s respectively for grouts G1 and G3.

All materials used in this work were produced in Canada. The cement was a general use (GU) cement and the sodium bentonite (Opta Minerals) was supplied as neat powder. Tap water from the city of Sainte-Marthe was used. The mixing was conducted within a barrel which had an effective capacity of around 150 liters. The ingredients were measured in the field with a portable balance. The water was first poured into the barrel. Then, the cement was slowly added to the water and mixed thoroughly. Next, bentonite powder was gradually added into the barrel to avoid forming clumps.

Samples of both grouts were poured in cylindrical plastic moulds after grout mixing. The grout samples were left in the field to set for a week, and then transferred to a humid room for further curing. During setting, grout G3 was not stable and experienced significant segregation. This segregation was also observed in borehole F3, where grout G3 was used for piezometer sealing. The volume of grout G3 decreased by 25-30 % in both the mould and borehole F3 after the setting period. The low grout viscosity was most probably responsible for the segregation.

The 28-day permeability and compressibility tests were conducted on the hardened 4-inch grout specimens following standards ASTM D5084 and ASTM D4767 (Table 1). The average hydraulic conductivity values of grout G1 and G3 were respectively 6.1×10^{-9} and 1.2×10^{-6} m/s (Table 1). Given a hydraulic conductivity of 1.08×10^{-9} m/s for the clay, this results in permeability ratios of around 1100 and 6 respectively between grouts G3 and G1 and the surrounding clay.

Table 1: Grout recipes, permeability and compressibility for grouts G1 and G3.

	Borehole F1		**Borehole F3**	
Grout	G1		G3	
Material	M (kg)	Ratio	M (kg)	Ratio
Water	120	5	120	6.5
Cement	24	1	18.5	1
Bentonite	28	1.2	7.5	0.4
SP[1] (% of solid)	2.0		none	
permeability (m/s)	6.1×10^{-9}		1.2×10^{-6}	
compressibility (kPa^{-1})	4.15×10^{-5}		5.9×10^{-5}	

[1] SP = Superplasticizer

Pore pressure response of fully grouted VWPs

Figure 3 presents the change in groundwater level in the fractured clay and hydraulic head in the lower portion of the intact clay. All data were presented with respect to their respective mean values observed during the study period (November 2016 - June 2017). The observed pore pressure and groundwater level data were corrected for barometric pressure (BP) effects using the multiple regression technique as described in Marefat et al. (2015). As shown in Fig. 3, the groundwater level in the fractured clay responded to several precipitation and snow melting events. Secondly, in the lower portion of the clay layer, the pore pressure response of fully grouted piezometers F1B and F3B differed significantly. The response of F3B, backfilled with high permeability grout (K=1.2×10^{-6} m/s, a permeability ratio of 1100), mimics the groundwater level change in the upper fractured clay. This is a consequence of the hydraulic connection between the fully grouted piezometer and the upper aquifer due to the relatively high hydraulic conductivity of grout G3. On the other hand, piezometer F1B backfilled with the low permeability grout (K=6.1×10^{-9} m/s, a permeability ratio of 6) registered a smooth pore pressure response as expected for an intact clay layer.

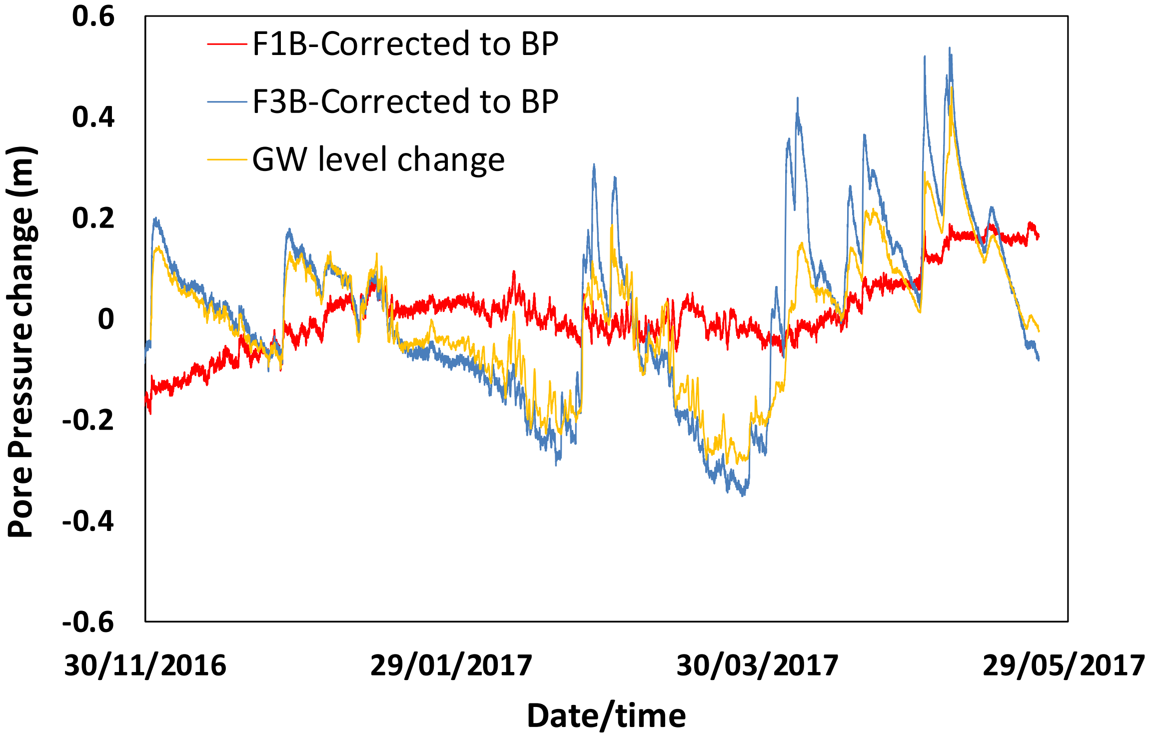

Figure 3. Groundwater level changes in the fractured clay and pore pressures registered in the lower portion of borehole F3 (high-permeability grout) and borehole F1 (low-permeability grout).

Discussion

The viscosity of the grout mix and hydraulic conductivity of the hardened grout are very important parameters to register representative pore pressure with fully-grouted piezometers. There is no agreement on the acceptable permeability contrast between the soil and the grout. Furthermore, the proper grout viscosity is qualitative. Our field observations have shown that using a grout with a hydraulic conductivity ratio of less than 10 resulted in pore pressure response that was smooth and dampened as expected for intact clay. However, a grout with a permeability ratio of around 1100 resulted in a totally differed response. A hydraulic conductivity ratio of 1100 created a hydraulic connection between the fully grouted piezometer and the upper aquifer. As mentioned in Mikkelsen (2002) the current recipe for the installation of fully grouted piezometers in soft soil is only an initial guide to prepare a suitable grout. This study showed that following the proposed recipes by Mikkelsen (2002) without considering grout consistency can result in an unstable grout. According to Mikkelsen (2002) the grout mix should be like “thick cream or pancake batter” to be physically stable and pumpable. However, it appears desirable to evaluate grout consistency of using a less subjective method, like the Marsh Funnel for instance. Marsh Funnel tests can easily be conducted in the field. Further work is needed on the relationship between grout stability and permeability, and Marsh Funnel viscosity.

Conclusion

This paper investigated field performances for two sets of fully-grouted piezometers sealed within a Champlain clay deposit using two grout recipes. The study showed that grout hydraulic conductivity and stability are very important parameters for a successful fully-grouted installation. Baseline pore pressure monitoring demonstrated that a grout with a ratio of around 1100 between grout and surrounding clay permeability resulted in a hydraulic short-circuit between the piezometer and the upper aquifer. However, the piezometer that was sealed with a grout with a hydraulic conductivity ratio of less than 10 gave a smooth and dampened response as expected for an intact clay deposit. Our field and laboratory tests also indicate that the physical stability of grout is an important criterion which needs to be considered for fully-grouted installations.

Acknowledgment

The authors would like to acknowledge the funding of NSERC and GKM Consultants for this project.

References

Contreras, I. A., Grosser, A. T., and VerStrate, R. H. 2008. The use of the fully-grouted method for piezometer installation. Geotechnical News, 26: 30-37.

Marefat, V., Chapuis, R. P., and Duhaime, F. 2014. Piezometric error for fully grouted piezometers Installed in clay layers. *Proceedings of the 67th Canadian Geotechnical Conference,* Regina, Canada, October 2014. Canadian Geotechnical Society, 8 pages.

Marefat, V., Duhaime, F., and Chapuis, R. P. 2015. Pore pressure response to barometric pressure change in Champlain clay: prediction of the clay elastic properties," *Eng. Geol.*, Vol. 198, pp.16-29.

McKenna, G. T. 1995. Grouted-in installation of piezometers in boreholes. Canadian Geotechnical Journal, 32(2): 355-363.

Mikkelsen, P. E. 2002. Cement-bentonite grout backfill for borehole instruments. Geotechnical News, 20(4): 38-42.

Vaughan, P. R. 1969. A note on sealing piezometers in boreholes. Geotechnique, 19(3): 405-413.