11TH INTERNATIONAL SYMPOSIUM FIELD MONITORING IN GEOMECHANICS

Failure of Fully-Grouted Method Grout Column

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Abstract

The fully-grouted method (FGM) for installing vibrating wire piezometers (VWP) is a common practice used today for installing VWPs in boreholes. The success of the FGM installation is dependent on many factors including safe handling of the VWPs, compressibility and permeability of the formation, placement techniques, and experience of the individuals involved in the installation. However, even when VWPs are installed by experienced staff, site conditions may dictate how the installation will respond. In this case study, fully-grouted nested VWPs were installed in fine tailings beneath a coarse aggregate embankment dam at an operating tailings storage facility. Shortly after installation, heavy equipment traversed the embankment dam near the installation and track panels for a railroad project were stored immediately adjacent to the VWP installation. The VWP installed in the fine tailings layer beneath the dam began exhibiting cyclical changes in measured pore water pressure for a period of 18 days until the pressure jumped to a level consistent with the upstream pond level. It is hypothesized that the construction loading on the dam immediately adjacent to the VWP installation was transferred to the grout column in the softer, weaker fine tailings layer. Eventually, the grout column was loaded to the extent that the shear strength was exceeded, and the total head indicated by the VWP in the fine tailings increased to a level consistent with the upstream pond level. This paper discusses the installation, data collection, and observations from the VWP installed in the fine tailings along with a comparison of the VWP data from the sensor in the fine tailings and upstream pond levels. Additionally, potential measures to mitigate this situation for future installations in soft soils are discussed.

Keywords: Vibrating wire piezometer, tailings storage facility, fully-grouted method

1. Introduction

Vibrating wire piezometers (VWP) have been widely used in geotechnical monitoring since the 1990's to measure pore water pressure in boreholes. The fully-grouted method (FGM) (Mikkelsen and Green, 2003), including updates by Contreras et.al. (2008 & 2012), has been the standard of practice since the early 2000s due to the ease of installation, ability to install in a nested (multiple elevations in the same borehole) configuration, and lower cost of installation than a piezometer installed in a sand pack with a bentonite seal. The FGM for piezometer installation has also been supported by Dunnicliff (1993), Webber (2009), and Bayrd (2011) among others. Surface loading near nest FGM VWP installations have been shown to affect the pressures read by the VWPs as the load it applied. Dourado (2018) demonstrated that fully-grouted VWPs from 32.8 to 131.2 ft (10 to 40 m) below ground surface responded to surface loading under 15-min loading intervals adjacent to a nested FMG VWP installation.

The success of FGM installation depends on may factors that include, but are not limited to, the careful handling of the VWPs, compressibility and permeability of the formation, placement techniques, and experience of the individuals involved in the installation. This paper discusses a nested FGM vibrating wire piezometer installation at a tailings storage facility where construction activities caused cracking of the grout column resulting in data unrepresentative of the corresponding installation material for select VWPs.

2. Installation

The project site is a tailings storage facility (TSF) that consists of dams constructed between natural high points of elevation forming a tailings pond. Fine tailings are pumped in a slurry to the TSF and are deposited in the tailings pond following processing at the plant. Coarse tailings and a separated fraction of the coarse tailings used as a filter between the fine and coarse tailings are transported to the TSF by rail car and are placed at designated dump sites along the dams. The site operations crew subsequently uses heavy equipment and haul trucks to move the coarse tailings and filters to the dam construction locations matching the design.

Since 2005, nested FGM VWPs have been installed at the site to monitor pore water pressures within and beneath the dams. The nested VWPs generally target four different soil units presents onsite: coarse tailings, fine tailings, lacustrine clay, and glacial till. Historically, the data was collected from the VWPs twice a year during bi-annual monitoring events using a handheld vibrating wire reader. Starting in 2017, remote data collection equipment was installed at VWP nest locations to collect data in near real-time and posted to a data visualization website. The specific installation that will be discussed was installed in July 2020 with four nested VWPs. A summary of the installation is presented in Figure 1 and Table 1.

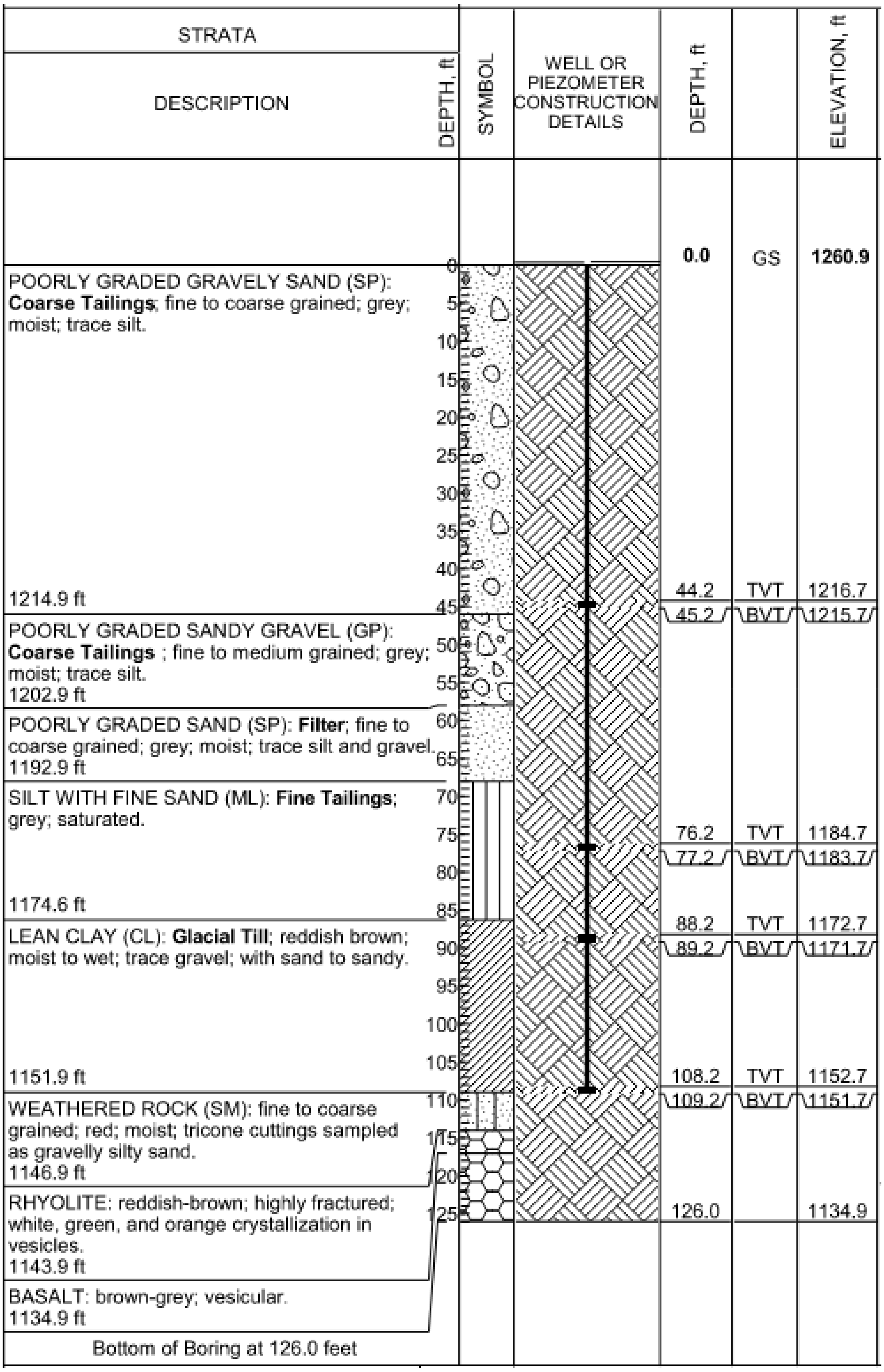

Figure 1: Vibrating wire piezometer installation summary with top of sensor (TVT) and bottom of sensor (BVT).

Piezometer Pressure Range, MPa	Piezometer Tip Depth, ft (m)	Piezometer Tip Elevation, ft (m)	Installation Soil Unit
0.7	44 (13.4)	1216.7 (370.9)	Coarse Tailings
0.7	76 (23.2)	1184.7 (361.1)	Fine Tailings
1.0	88 (26.8)	1172.7 (357.4)	Upper Glacial Till
1.0	108 (32.9)	1152.7 (351.3)	Lower Glacial Till

Table 1: Summary of vibrating wire piezometer installation.

2.1 Grout Selection

The grout mix for installation using the FGM was targeted to match the suggested grout mix published by Mikkelsen (Mikkelsen and Green, 2003), updated by Contreras (Contreras et al. 2008 & 2012), and that published in the manual by the vibrating wire piezometer manufacturer. Table 2 summarizes the grout mix that was used for the installation.

Grout Component	Component Weight, lbs (kg)	Water-Cement-Bentonite Ratio by Weight
Portland Cement Type 1	94 (42.6)	1:2.5:0.3
Bentonite	28 (12.7)	
Potable Water	242 (109.8)	

Table 2: Grout mix used for nested FGM vibrating wire piezometers.

The shear strength of the grout was estimated by comparing the grout mix in Table 2 to a similar grout mix published by Contreras (Contreras et al., 2007). It was determined that the shear strength of the grout column was approximately 6,200 pounds per square foot (psf) (300 kPa) based on 28-day unconfined compression testing (Contreras et al. 2007). This mix is consistent with the mix recommended by the piezometer manufacturer for use in medium to hard soils which is published as a 50 pounds per square inch (psi) (344 kPa), or 7,200 psf.

3. Results

The nested VWPs were installed on July 31, 2020. The boring was advanced using rotosonic drilling techniques with a 4-inch sampler and 6-inch override casing. The VWPs were installed on a sacrificial 1-inch diameter PVC pipe that was used to tremie grout the borehole. The automated data logger was connected 19 days after installation on August 19th, 2020 at which point data was collected on a 4-hour sampling interval. The VWPs indicated relatively stable pore water pressures with a slight upward gradient from the glacial till into the fine tailings, which is common for this site. It should be noted that the VWP installed in the coarse tailings was dry at the time of this analysis and is not measuring excess pore water pressure above the sensor installation elevation of 1216.7 ft (370.9 m).

3.1 Loading from construction

Beginning on May 1, 2021 the VWP in the fine tailings began to exhibit a series of sharp increases in pore water pressure followed by more gradual pressure dissipation. This cycle was repeated for a duration of approximately 18 days until the pressure increased and did not dissipate. Figure 2 shows the irregular behaviour exhibited by the VWP installed in the fine tailings.

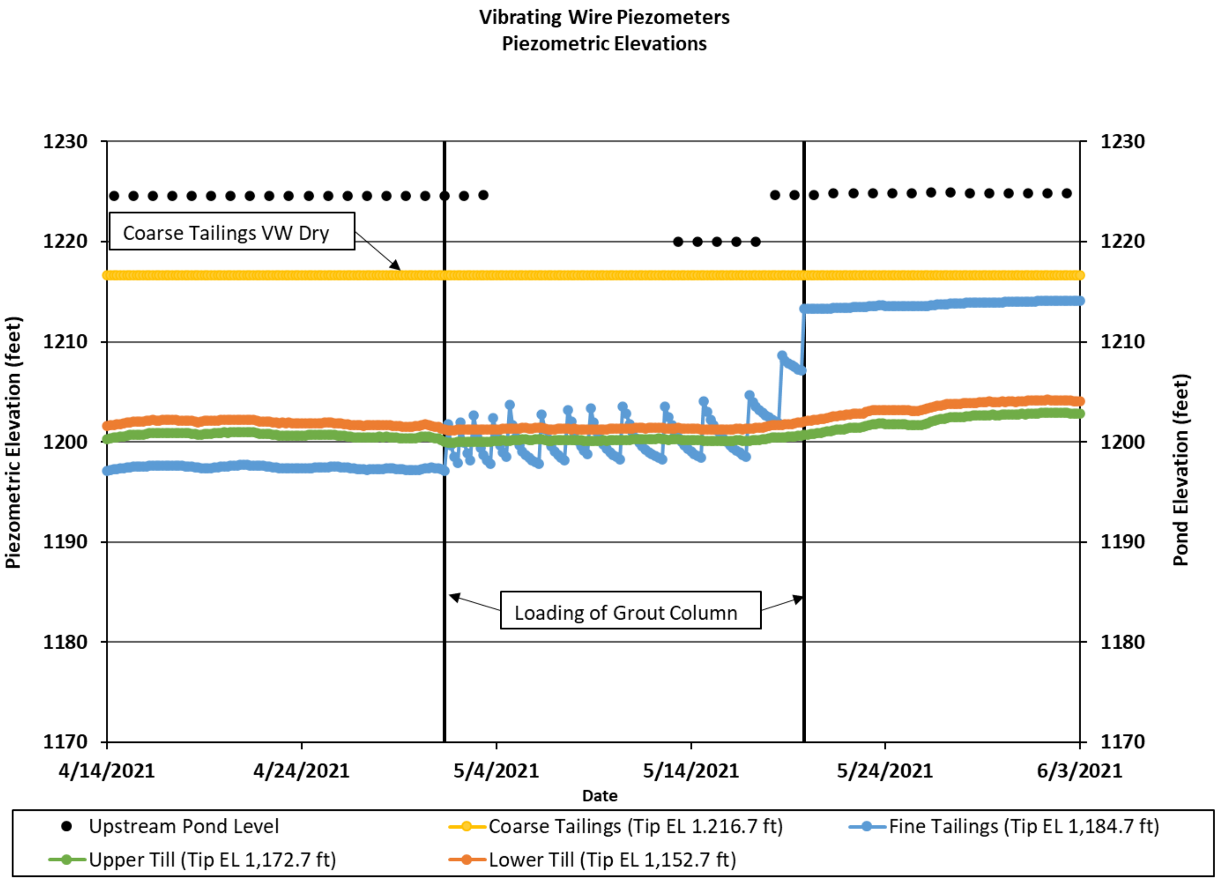

Figure 2: Plot of pore water pressures measured by nested piezometers.

A site visit was conducted after the 18-day period of irregular piezometer behavior where it was observed that two potential loading mechanisms near the VWP installation were occurring. First, the VWP was very near a dump site that the TSF operator used for cycles of coarse tailings dumping, storage, and subsequent transportation around the site. This dump site was used frequently during the period where irregular VWP readings were being collected.

Furthermore, immediately adjacent to the VWP installation, new rail track panels were being constructed, moved, and stored using heavy machinery. Track panels were stacked and stored within 10 feet (3 meters) of the completed VWP installation. Figure 3 shows the VWP installation, and the rail track panels that were constructed and stored at the site.

Figure 3: Track panel storage adjacent to VWP installation.

3.2 Grout Cracking

The behavior of the VWP installed in the fine tailings indicated that pore water pressures increased during the afternoon hours and then dissipated overnight to approximately the morning value. Generally, the measured pressure head increased by 5 to 6 feet (1.5 to 1.8 meters) during working hours each day over the 18-day period. Starting on May 17, 2021 the measured pore water pressure did not dissipate back to the original value and continued to increase on May 18, 2021 until the measure pressure head jumped 12 feet (3.7 meters) on May 19, 2021. After the large pressure increase on May 19, 2021 the measured pore water pressure in the fine tailings began to level off and has since shown a consistent pressure reading. It has been hypothesised that the grout column itself cracked due to repeated loading cycles during the construction activity from May 1, 2021 to May 19, 2021. The cracked column then created a conduit for water to travel along the annulus or through the grout column and affect the VWP in the fine tailings. Great care was taken during this installation by experienced staff to ensure no cables were bundled but were spread out around the tremie pipe to mitigate the risk of creating a preferential flow path through the column.

Although the grout mix was selected to match the strength of the encountered soils, the shear strength of the grout was likely greater than the shear strength of the fine tailings. Any additional load transferred to the fine tailings from the construction activities could have created localized stress increases in the stronger grout column. As the column underwent multiple loading cases, it began to degrade and ultimately cracked to the point where water could migrate down the column to at least the elevation of the VWP in the fine tailings layer.

4. Conclusions

The success of the FGM installation is dependent on many factors including safe handling of the VWPs, compressibility and permeability of the formation, placement techniques, and experience of the individuals involved in the installation. However, even when VWPs are installed by experienced staff, site conditions may dictate how the installation will respond. The nested VWP installation was in close proximity to an area serving as a coarse tailings dump site as well as a staging area for construction and storage of rail tack panels which caused excess, repetitive loading on the grout column and surrounding soils. Eventually, after several load cycles, the grout column cracked, pressures measured by the vibrating wire piezometer in the fine tailings no longer represented the actual pressures in the material unit, and readings corresponded to the approximate elevation of the upstream pond. Future plans for the site include blind drilling through the upper coarse tailings and installation of a drivepoint vibrating wire piezometer in the fine tailings for areas were high traffic and construction activity are anticipated.

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