Extensive Real Time Monitoring of Ash Response to Construction-Induced Activity

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KEYWORDS: Instrumentation, pore pressures, earth retention, anchors, dewatering, drilling, working platform stability

ABSTRACT

The first large-scale, real-time geotechnical monitoring program of ash response to construction activity was deployed at a confidential site. The instrumentation for monitoring was implemented to be concurrent with steel sheet pile driving and drilled tieback anchor installation, all to facilitate excavation and removal of ash from a large surface water conveyance trench at the toe of a dam and closed CCR landfill stack. Monitoring was necessary to help mitigate safety risks during pile and anchor construction activities and to monitor performance of the completed temporary excavation support structure. Real-time monitoring included monitoring for pore pressure, vibration, and ground movement with in-place shape array (SAA) inclinometers. Sheet pile driving installation was performed with rigs weighing in excess of 200,000 lbs (90 metric tons). Drilling installation was performed with rigs weighing in excess of 60,000 lbs. (27 metric tons). Pore pressure monitors were installed at critical depths within the overburden CCR cross section. Inclinometer arrays were deployed during sheet pile installation to monitor dam and slope movement as well as for monitoring movement of the installed earth retention system. This paper examines the means of data collection, transmission, and lessons learned from the execution of the monitoring work.

BACKGROUND

The original trench had filled in over the years from run-off carrying ash and native material, evolving into a complex, highly layered mixture of mostly ash and layers of native soil. In addition, the ground water at the south end of the site was above grade with a shallow (3” to 12”) wet area consistently present. Moving north the ground water continued to be shallow at about 5 ft depth. This highly stratified ground can create problems for dewatering as the horizontal layers tend to inhibit vertical drainage. A large number of cone penetrometer tests were performed in the vicinity of the trench to ascertain the ground conditions along the alignment of the excavation support. Without retrieving a physical soil sample, the cone penetrometer work indicated soil behavior type, but there was difficulty in determining which material was ash and which was soil.
Regardless of the variation between ash and native soil, it was apparent that infilling was highly stratified.

In order to excavate the full depth of the ash to the trench width limits, structural support for the excavation was required. In anticipation of problems in fully dewatering to the depths required, steel sheeting was chosen to provide structural support as well as a groundwater cutoff (Figure 1.). This was in lieu of a free-draining earth retention system such as soldier piles and lagging. The sheeting was supported with two tiers of tieback ground anchors on the CCR Stack sheet pile wall and one tier on the dam wall. To achieve the necessary toe for the sheeting, the partially weathered rock had to be pre-drilled prior to driving. An optimal design for support of excavation was achieved by considering the partial relief of hydrostatic loading from the back side of the sheeting by wellpoint dewatering. A plan view of the shoring excavation alignment and limits and wellpoint locations is shown in Figure 2.

Figure 1. The trench excavation and shoring at the time of writing this paper.
Figure 2. Plan view of the shoring excavation alignment and limits and wellpoint locations.

With installation of the sheeting to depths reaching 40 feet and the need for predrilling the partially weathered rock, it was apparent the construction equipment required to perform the work (Figure 3) would be of a size and vibration signature unprecedented with use in coal ash. Working platform stability for the drilling rigs and stability of the adjacent dam and CCR landfill were imperative, thus warranting behavior monitoring.

Figure 3. Equipment utilized for the installation of the earth retention.
PREVIOUS REAL TIME MONITORING EXPERIENCES

At present, real time monitoring in ash has been practiced successfully, but only by a small group of geotechnical engineers and only on a few sites. There have been many instances of equipment getting mired or becoming partially buried in ash, but only a handful of sudden failures have been documented with real-time monitoring. These are failures which provide insight into understanding the catastrophic failure of a working platform which could take a large drill rig down and lead to possible loss of life.

Many of the instrumented failures have occurred during the construction of floating roads. The events appear to have been shallow, rotational-type failures, either due to the placement of several feet of road fill, construction equipment induced vibrations, or both. Pore pressure monitoring during these events revealed a rise in pressure of about twice the effective stress at transducer depth which varied from 4-10 ft (1.2-3.0 m). These failures were, on several occasions, preceded by smaller increases in pore pressure, on the order of 2-3 ft (0.601 m) of head, or about one psi.

It is thought, but not confirmed, that with these failure situations the ash was highly layered or stratified such that construction-induced increase in pore pressure could not dissipate to the surface. Thus, the ash was behaving like a confined aquifer. It is also surmised the shallow ash exhibited an undrained or wet shear strength even though it may have occurred above the phreatic surface or "water table". This may have been due to capillary action or the phenomenon of "pumping" where vibration rearranges the ash grains and what was previously unsaturated material becomes saturated. The catalyst for the potential of a sudden failure is believed to be the combination of confined ash, construction vibration induced pore pressure rise, and low shear strength material at shallow depth.

INSTRUMENTATION INSTALLATIONS

Instrumentation clusters were installed along the ash embankment side of the trench excavation, with distances between clusters varying from 100 to 150 ft (30-45 m). Instrument clusters were located behind the sheets and within several feet of the sheeting. The sheeting along the dam side of the trench was installed mostly in clay, however the equipment performing the installation was positioned over a triangular wedge of ash. It was deemed important to instrument and monitor the outer (deeper) side of the working platform. Figure 4 shows the work area and instrument cluster locations.

Each instrumentation cluster consisted of a pore pressure transducer, a borehole installed vibration monitor, a surface installed vibration monitor and an in-place inclinometer array. The pore pressure transducer and vibration sensors were installed deep enough to be within the saturated ash, but shallow enough so they could sense the effects of surface activity.
Reliable communication of data indicators to field personnel was critical. Several provisions were integrated into the instrumentation system to avoid delays in recognizing data which could lead to a potential failure. Each instrument cluster was fully automated and equipped with a visual and audible alarm that triggered when threshold criteria were exceeded. Figure 5 shows a single-cluster solar powered instrumentation station with visual and audible alarms. Figures 6 and 7 show data plots developed from pore pressure data. In addition, text messages were also sent to appropriate parties as threshold criteria were reached. All parties had access to the dedicated website that provided for archiving of data and viewing of data in a multiple of ways.
Figure 6. A typical data plot showing pore pressure values from several of the instrument clusters in the vicinity of the sheeting installation, available in real time on the website.

Figure 7. A plan view of the site area showing the immediate pore pressure data at several instrument clusters, also available in real time on the website.
IMPLEMENTATION IN THE FIELD

Previous project experience indicted that pore pressure rather than vibrations and ground movements was the critical parameter to observe and control, and threshold criteria were established on these measurements. Previous experience also provided a frame of reference to utilize this data more readily than that of vibration or ground movement data where there is limited experience in understanding the effect of vibration in ash.

Based on previous projects where failure occurred, the threshold value of one psi [2.3 ft (0.6 m) of water] was applied to trigger an alarm when a sudden rise in pore pressure occurred. A threshold value of 1.5 psi [3.5 ft (1.1 m) of water] resulted in a temporary stand-down of the nearest activity causing the pore pressure increase.

Pore pressure values can spike within several seconds and thus all instruments were programmed to measure and post data every 15 seconds. In the event pore pressures exceeded the 1.5 psi criteria, the operation causing the pressure rise would be ceased until pore pressures dropped to approximately 0.5 psi rise. To facilitate communication a field engineer with a tablet computer accompanied the pre-drilling and sheeting installation operations and drill operators had tablets indicating alarm conditions in their cabs.

OBSERVATIONS

During sheeting installation, there were no ground instability events observed. It is thought this is due to two factors: 1) the rigorous observance of data and stand-down protocol, and 2) dewatering the area to provide a dry crust working platform. Unlike previous documented failures, this project site was dewatered for both the interior of the trench to provide a dry crust for the large drill rigs and dewatering for the excavation of the trench. The thicker dry crust due to the dewatering of the working platform created the desired stable condition.

In addition to working platform stability, it is believed that the dewatered condition provided capacity for the ground to absorb “free” water which was created locally with liquefaction during sheeting installation. During the monitoring period, there were a couple of instances where water was observed flowing to the ground surface during sheet driving. Where pore pressure data would spike, the pressure would dissipate as quickly as they would increase. The highest pore pressure spike observed was an increase in pressure of 10 ft (3 m) of water, at an instrument outside the dewatered area.

Pre-drilling operations resulted in relatively little pore pressure response, but ground movements could be sensed at an instrument cluster when the predrilling was within the immediate vicinity. At many instrument clusters, a slight rise in pore pressure was observed, and in several instances a pronounced dip in pore pressure with predrilling,
most likely due to relief of perched water build-up within the highly layered and mixed stratigraphy (Figures 8 and 9).

**Figure 8.** Observed pore pressure relief with predrilling.

**Figure 9.** Pore pressure response with driving of steel sheets. The installed sheeting creates a barrier between the instrument and the wellpoint system. The resulting effect is the sustained rise in pore pressure.

Data from pore pressure response due to predrilling and the driving of sheets was compiled to ascertain a “pore pressure radius of influence”. Similar data was compiled to ascertain a vibration radius of influence as a function of different construction activities. There were no consistent trends observed, probably due to the variability of ground conditions between instrument clusters. However, a discernable trend was observed showing a greater responsiveness of pore pressures with a greater thickness of saturated ash.
LESSONS LEARNED

Based on the significant difference between the pre-dewatered ground and post-dewatered ground conditions, the single most significant contributor to working platform safety was the temporary working platform dewatering. With the instrumentation system utilized, sizable construction equipment could be used safely for the installation of an unprecedentedly large shoring system.

Of the different construction activities monitored— equipment movement, predrilling, and sheeting installation— the effects of the equipment vibration and predrilling were relatively minor. In several cases, the predrilling was observed to relieve pore pressures. It is believed that the penetration of both the predrilling and the sheeting installation provided a localized “path of least resistance” which allowed pore pressure relief.

Instrument locations, coordination of their installation, and oversight of monitoring were controlled by the contractor. This approach kept responsibility for the reliability, continuity, and seamless communication of data with one party, and proved beneficial. There were no shut-downs of the work due to any down time of the monitoring system.

There was considerable value in the entire project team having a good understanding of the procedures to be followed upon receipt of an exceedance alarm, as well as through conducting regular discussions on the actions to be carried out by both project managers and field crews.

Early in the project, the number and frequency of exceedance alarms was overwhelming. At that time, all threshold criteria were considered as having equal weight. Managing the high volume of alert threshold alarms in the early stages whilst equipment was still being installed and base line data was being established was critical. It was imperative that the project team did not become desensitized due to the frequency of alarms and miss a potential real event.

Some significant pore pressure responses were observed with driving of sheets, and it is believed that the stand-downs kept unsafe conditions from developing. However, with no ground instability incidents observed, we suspect the threshold criteria were conservative. Without ever experiencing a ground failure, we do not know how conservative the criteria were.

With future applications of this real-time monitoring, it is desirable to refine the threshold criteria. The pore pressure measurements would be given precedence over the ground movements and vibrations. It was realized, after countless alarms, that ground movements that occurred with predrilling, but without accompanying pore pressure rises were innocuous. Given the opportunity to repeat the project, the predrilling work would be monitored less or with less rigorous threshold criteria.
Periods of time when stand-down was required aggregated to a total of slightly more than ten percent of the total time to install the 2,100 linear feet (640 meters) of sheeting currently in the ground. It is the opinion of the authors that the cost associated with this additional time was offset by the measure of safety it provided.

One consideration with further work would be to perform additional field vane shear tests to go hand in hand with the instrumentation. This would help to further understand the relationship between shear strength, pore pressure response and working platform stability. The correlation between pore pressures and vibrations could be understood further as well. Due to all the project variables, we do not believe a calculated criterion for stability can be confidently determined at this time. This project did, however, confirm the influence of dewatering and the difference in behavior of wet ash versus dry ash.