Real Time Pore Pressure Monitoring of Ash and Construction-Induced Responses: The State of the Practice

Paul Schmall, P.E.[1] Chris Hardin, P.E.[2], Kenneth Campbell[3], and Ryan Smith, P.E.[1]

[1]Keller North America, 7550 Teague Road, Suite 300, Hanover, MD 21076; [2]EEIF, LLC, 52A Ervin Street, Belmont, NC 28012; [3]GeoInstruments, 24 Celestial Drive, Narragansett, RI 02882

KEYWORDS: CabSafe™, automated piezometers, real-time pore water pressure monitoring

ABSTRACT

Real-time geotechnical monitoring of pore water pressures in ash has been deployed on several sites to date for the purpose of creating an early warning for liquefaction and instability in ash due to construction induced vibrations. Early applications were typically for monitoring during the construction of floating roads, but more recent applications have been concurrent with the driving of steel sheet piles through ash and subaqueous construction of a working platform within an ash pond. This paper discusses the instrumentation installations, the means of data collection, transmission, and lessons learned from the execution of the monitoring work.

INTRODUCTION

Ash pond closures call for instrumentation and monitoring systems for two broad purposes; to monitor the performance of permanent or semi-permanent features such as slopes, embankments, etc., and to monitor for construction-induced responses. The purpose of this paper is to discuss the more recent applications of real time pore pressure monitoring of construction induced responses, a unique and highly specialized practice that is driven by the difficult and peculiar geotechnical behaviors of fly ash.

The primary failure mechanism of concern related to construction activity is liquefaction. Repetitive motions of equipment such as truck traffic, dozer tracking, and repetitive movements of excavators over nearly saturated or saturated ash can result in rapid loss of shear strength and flow in a liquefaction-type phenomenon. Figure 1 shows sand boils associated with liquefaction in an ash pond. Liquefaction occurred after a tracked amphibious drill rig repeatedly turned over an area of ponded ash. In addition, the site geotechnical engineer observed progressively worsening ground pumping as the rig made multiple passes over the ash, also an indication of approaching liquefaction.

Figure 1. Sand boils associated with liquefaction in an ash pond

Fly ash exhibits other unfavorable geotechnical characteristics that make liquefaction more likely.

- Fly ash is susceptible to the phenomenon of “pumping” and capillary action. “Pumping” or “rutting” occurs when construction traffic causes the water level in the soil to rise due to the rearrangement of soil (ash) grains. Continued vibration will further increase the soil moisture content and result in liquefaction and complete loss of strength of the material.

- Capillary action or “capillary rise” occurs when water is drawn upward against the force of gravity through soil pores or the spaces between soil particles. The height to which the water rises is a function of pore size. The smaller the soil pores, the higher the capillary rise. Coal ash is a silt-sized particle that is highly susceptible to capillary action because it has a relatively high permeability for silt sized particles. Coal ash that increases in saturation through capillary action will is more prone to instability. It is common to observe instability in open excavations several feet above where the water level or phreatic surface is measured. This is due to the increased moisture content in the zone of capillary rise.

- Highly layered ash, with horizontal layers of lower permeability, allows pore pressures to remain confined and unable to dissipate to the surface.

In addition to the difficult behaviors of saturated and nearly saturated ash, when one considers the influences of precipitation, ponded surface water, construction water, and stormwater management practices, the need for a good instrumentation and monitoring plan is apparent. The instrumentation should act as an early warning indicator of liquefaction or a liquefaction susceptibility monitor.

PREVIOUS REAL TIME MONITORING EXPERIENCES

Up until about 5 years ago, real time pore pressure monitoring in ash had been practiced successfully, but only by a small group of geotechnical engineers and only on a few sites, but with the successful monitoring of several very sudden failures. These early failures provided insight into the catastrophic failure of a working platform which could take a large drill rig down. Those early 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 1.2 3.0 m (4-10 ft). These failures were, on several occasions, preceded by smaller increases in pore pressure, on the order of 0.6-1 m (2-3 ft) of head, or about one psi. Each failure was believed to occur with the combination of highly layered ash, construction vibration induced pore pressure rise, and low shear strength material at shallow depth.

Since that time, real time pore pressure monitoring has been utilized to address potential working surface instability under several different construction operations.

Access for Large Drill Rigs

The first recent, large-scale, real-time pore pressure monitoring of ash response to construction activity was deployed concurrent with a large support of excavation installation involving steel sheet pile driving and drilled tieback anchor installation, all to facilitate excavation and removal of ash from a large surface water conveyance trench. Monitoring was utilized to help mitigate safety risks during installation and to monitor performance of the completed temporary excavation support structure. Sheet pile driving installation was performed with a rig weighing in excess of 90 metric tons (200,000 lbs). Pre-drilling for the sheeting installation was performed with a rig weighing in excess of 27 metric tons (60,000 lbs).

The original trench which was to be excavated out 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. This was a layered condition which was anticipated to provide confinement and buildup of deeper pore pressures.

Wellpoint dewatering was included behind the sheeting for partial relief of hydrostatic loading as well as drainage of the upper 4.6+ m (15+ ft) of ground for surface access for the large drills. Geogrid and stone were also used for rig support as well.

During sheeting installation with the large equipment, there were no ground instability events observed attributed to dewatering the area to provide a dry crust working platform and the rigorous observance of data and stand-down protocol when pore pressure spikes were observed. Of the different construction activities– equipment movement, predrilling, and sheeting installation– the effects of the equipment vibration and predrilling were relatively minor. Driving of the sheets resulted in sudden pore pressure spikes but dissipated quickly as well.

Figure 2. Support of excavation installation involving steel sheet pile driving and drilled tieback anchor installation.

Figure 3. Equipment utilized for the installation of the earth retention.

More Driven Steel Sheeting

Subsequent to the sheeting project with the large drill rigs, 24-4 m (80 ft) deep sheeting was installed on another project through a causeway built with bottom ash through the middle of an ash pond. The sheeting was installed to allow one side of the causeway to be maintained flooded and the other side excavated. After observing on the previous project, the improvement to the working surface provided with dewatering, wellpoints were used to provide a dry crust working surface for the crawler crane used for the sheeting installation. Instrumentation was installed to verify the depth to water (i.e., crust depth) as well as any pore pressure responses due to the construction activity. An automated total station was also installed to monitor movement of causeway during and following installation of sheeting.

Figure 4. Using a crane on ash to drive sheets.

Subaqueous Working Platform Construction

Another project where real time pore pressure monitoring was utilized involved the construction of a dry-land crossing across an ash pond. The crossing was constructed to act as a working platform for the construction of a soil mixed gravity dam to bifurcate the pond. The dry-land crossing was built by placing upstream and downstream berms of crushed stone and an interior sand fill. These berms and sand fill zone were placed subaqueously, and over ash at the bottom of the pond. Prior to the placement of any berms, vibrating wire piezometers were manually driven into the ash at the bottom of the pond from a rowboat so that pore pressure buildup could be measured as the berms were placed. Early in the stone berm placement progression, pore pressures were observed to rise rapidly in the underlying ash, but slow to dissipate. In order to allow the pore pressures to dissipate, the placement of the stone berms was sequenced with incremental placement of upstream stone, downstream stone, interior sand fill, and repeated as the dry-land crossing was placed across the pond.

Figure 5. A significant thickness of new fill on a subaqueous soft pond bottom

Brittle Crust Access

Most pond closure projects occur in predominantly fly ash, with some bottom ash. One of the most challenging sites was a fly/bottom ash pond with a thin crust of gypsum. Previous instability was observed in the pond where the ash liquefied beneath the stiffer gypsum and the overlying gypsum failed in a very brittle manner. In order to safely put 18+ metric ton (40,000+ lb) drill rigs out on the gypsum to install dewatering wells, vibrating wire piezometers were installed and tied into a “spike sensor” which would set off audible and visual alarms if a pore pressure spike was measured.

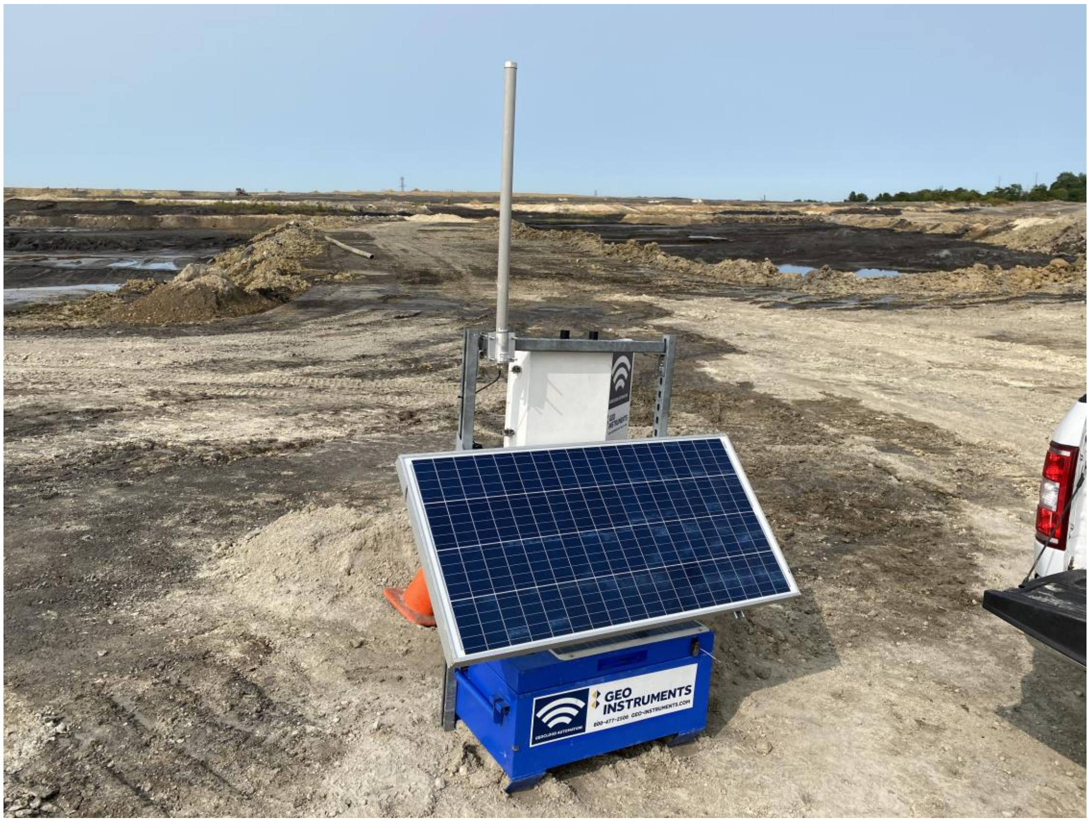

Figure 6. In order to safely put 18+ metric ton (40,000+ lb) drill rigs out on the gypsum, vibrating wire piezometers were installed and tied into a "spike sensor"

Lessons learned

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.

With future applications of this real-time monitoring, it is desirable to refine the threshold criteria.

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.

PORE WATER PRESSURE INSTRUMENTATION AND MONITORING

Effectively measuring pore water pressure in CCR has been a challenge from the outset. One of the biggest drawbacks of traditional methods is the tardy, static nature of the data collection, processing, and reporting, along with potential for gaps in the data stream and failure in the communication pipeline leading to no data at all and leaving work crew unknowingly vulnerable.

A complete “back to the drawing board” approach has been necessary to better understand the conditions and events leading up to a failure and maximizing the accuracy, output and usefulness of the data, together with simplifying the installation and streamlining the visualization of data. It’s important that this optimization occurs after every project to maximize the lessons learned and continually develop the technical solution.

Lessons Learned, Geotechnical Aspects

Instrumentation and monitoring is only one element of a Safe Access Plan. Field observations and the “feel” of experienced equipment operators should be considered of similar importance.

The ponds that are more stratified, layered and complexly deposited are the more problematic ones. The Soil Behavior Type (SBT) of “sensitive fines” as indicated by the CPTs usually indicates problematic material for both drainage and shear strength.

Beware of situations where elevated pore pressures are very slow to dissipate. These are the places where the energy of the equipment will continue to elevate pore pressures.

Understanding what depths in the ash to place sensors is a significant challenge, again requiring guidance from the geotechnical engineer. Of note, is the importance in making sure that there is a sufficient number of sensors in vulnerable zones to ensure a comprehensive network of coverage. Installed deep enough to be in saturated ash but shallow enough to feel the impact of equipment of operating equipment.

The important part of this process is identifying what failure mechanisms are likely and then applying a monitoring strategy to each one. There should be careful selection of the appropriate sensor, data collection device and data presentation software. The sensor should be capable of taking readings at the desired interval with sufficient resolution and accuracy.

Lessons learned, Instrumentation Installation

Provide an easily deployable, lightweight solution that can be installed on the ash with minimal footprint prior to the construction of the work platform.

The method of piezometer installation in ash is critical so that minimal, light impact is applied during the installation so as to not trigger a failure. Keep in mind that the pore water pressure monitoring system installation is usually one of the first work items to be carried out, even prior to the construction of stable work platforms.

Standard piezometers are typically installed using a traditional geotechnical drilling rig. This can be risky due to the larger, heavier footprint of this equipment. Within the combined companies of Keller, sharing resources, intelligence and situational awareness is standard practice. This allows piezometers to be installed concurrently with the installation of the dewatering system, with both work crews sharing the same equipment.

A less impactful method is to use drive-in VW piezometers connected to EW casing or ConeTech casing and driven into the ground using lightweight equipment. Care must be taken to not damage the sensor during installation so that the piezometer can be removed and reused with relative ease.

Porewater pressure monitoring is accomplished using either standard or drive-in vibrating wire (VW) piezometers installed in the ash at various depths. Open standpipe piezometers are not suitable. It is crucial that multiple VW piezometers are installed at each location to capture the obvious change in pore water pressure but also if the water level in the ash rises or falls. Having multiple piezometers provides for greater confidence in the data and understanding what is occurring in the ground (ash).

The VW piezometers are available in various ranges. Typically, 10, 25 and 50 psi sensors are used in CCR. The piezometers are connected to a fully automated datalogger for data collection, processing, and signaling an alarm.

Lessons Learned, Communication of Data

The primary objective of pore water pressure monitoring in CCR is to provide near-real time, rapid notification to the onsite team of a change in conditions in the ash. Have a simple, user friendly graphical interface display that all parties can quickly and easily understand the situation in real time.

The speed in which a failure can occur makes it challenging to capture with enough speed to enable sufficient time for emergency procedures to vacate the area. It truly is a situation where every second counts.

Have complete redundancy built in the datalogging, communication and reporting platform.

Data processing and collection is always done fully autonomously and in two ways. The immediate notification system (CabSafe™) uses onsite data processing and radio network to ensure rapid processing, transmission, and display of data with alerts being triggered if the threshold value has been exceeded. The sensors have wireless data logging nodes at each location that transmit the readings to the base station for processing. The base station is equipped with an audio-visual alarm system for immediate notification.

Secondly, the data is also transmitted to the cloud via cellular communication networks. The data is then processed and displayed in the project specific website for reporting and viewing by the wider project team. This process is typically much slower (30 seconds to minutes) and at higher risk of interruption and or failure due to its reliance on cellular communication and remote cloud server.

SUMMARY OF BEST INSTRUMENTATION PRACTICES TO DATE

It is difficult to boil down best practices to rules of thumb or rigid protocols. The most important thing to consider is that flexibility must be built in:

- The ash conditions and behaviors vary wildly from pond to pond, even though on paper the conditions may look exactly the same.
- The water levels and saturation conditions are always changing. The instrumentation installation must always assume that the zone of difficult-behaving ash will change and may change quickly. The installation work should be done once but anticipating that the pressures or phreatic surface can be almost anywhere.
- The site conditions and construction activity will be always changing as well. That may mean that multiple failure mechanisms may have to be considered.

Additionally, in many circumstances the data must be acquired in as close to real time as possible and the communication of that data should likewise be as timely and as efficiently processed as possible to permit immediate understanding of what is occurring on site. Safety of our people is at stake and therefore the best practice is always warranted.