Static liquefaction-type tailings dam failures: understanding options for detecting failures

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Proceedings of Tailings and Mine Waste 2019
November 17–20, 2019, Vancouver, Canada
Published by the University of British Columbia, 2019

Static Liquefaction-Type Tailings Dam Failures: Understanding Options for Detecting Failures

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Abstract

Recent tailings dam incidents have highlighted the need for near real-time methods capable of detecting static liquefaction-type failure. Based on experience with recent failures it is unclear whether any pre-failure deformation could have been observed with industry standard in-situ instrumentation or remote sensing monitoring methods. Jefferies and Been (2016) state the observational approach is inappropriate as it is not possible for conventional geotechnical monitoring to provide adequate notification of an imminent failure, which can occur in seconds to minutes. Thus, to detect a tailings dam failure and provide warning, the system must be capable of identifying a near instant change of state and reporting the change with high confidence. An event warning detection and notification system (EWDNS) is defined by the authors as a system capable of near real-time monitoring (i.e., the detection) of a tailings dam failure, with configuration into an alarm system to support the facility's emergency preparedness and response plan (EPRP). Warning systems to notify downstream stakeholders that would potentially be impacted in the event of a tailings dam breach are an important component of an overall risk management plan.

Several near real-time monitoring methods were assessed to determine if they were capable of detecting a tailings dam failure with no observable pre-cursory deformation, as a component of an EWDNS.

The methods were rated based on four primary factors: sampling rate, areal extent, frequency of false alarms, and maintenance requirements. The failure detection methods evaluated included in-situ instruments (downhole and linear on surface), ground-based remote sensing (lidar, radar and InSAR), and satellite-based methods. Following review, a linear fiber optics system was selected for installation at an upstream tailings dam facility.

This paper will present the method and rationale behind the selection of the monitoring method.

Introduction

Recent tailings dam incidents have highlighted the need for near real-time methods capable of detecting static liquefaction-type failure. Current understanding dictates these failures experience minimal pre-failure deformation.

Geotechnical site investigations, at an upstream tailings facility (the site) were carried out in 2017 and 2018. The site investigations encountered a wide areal extent of potentially liquefiable soils within the structures at the site. Due to the brittle nature of these soils, which can result in rapid failure of the structure, the observational approach is considered inappropriate for liquefiable materials as it is not possible for conventional monitoring to provide adequate notification of an imminent failure which can occur in seconds to minutes (Jefferies and Been, 2016).

Several near real-time monitoring options for implementation at the site as a component of an event warning detection and notification system (EWDNS) were reviewed. The purpose of the EWDNS is to provide near real-time monitoring (i.e., the detection) of a dam failure at multiple tailings dams, as well as be capable of configuration to an external alarm system to support the owner's emergency preparedness and response plan (EPRP).

Assessment factors

Several monitoring options were evaluated based on four assessment factors. These were developed based on the requirements of the EWDNS to provide adequate notification and timely detection of a dam failure.

Sampling rate

Based on the rapid nature of a brittle failure, a short response time is one of the most critical elements of the above system. The sampling rate of the chosen system should be capable at a minimum of one reading every five minutes, including transmission and processing of the data.

Areal extent

The chosen system must be capable of monitoring an area that covers the narrowest width of a dam breach that can reasonably be expected to occur at the structures. Because of the wide areal extent of the potentially liquefiable soils encountered at the site, a system that is capable of greater coverage is deemed advantageous over a system capable of lesser coverage. Systems that can provide continuous spatial coverage (i.e., 2 dimensional) are categorized as "Continuous". Systems that can provide lateral spatial coverage (i.e., 1 dimensional) along a structure are categorized as "Linear". Systems that cannot provide continuous or lateral spatial coverage (i.e., installed at discrete points) are categorized as "Discrete".

Frequency of false alarms

Due to the number of parties involved if a signal occurs indicating a dam failure (i.e., mine dispatch, first responders), the system should have a low probability for an erroneous reading that would trigger a false alarm. Erroneous readings that occur less than once per year and that can be recognized as a false reading are categorized as "Low", whereas erroneous readings that occur more frequently (i.e., once every few months) and that are difficult to recognize as a false reading are categorized as "Medium". Erroneous readings that occur more than once per month are categorized as "High".

Maintenance

The system should be capable of functioning year-round with minimal downtime given the environmental considerations at the site. "Low" maintenance was defined as requiring less than one site visit per year. "Medium" maintenance was defined as requiring approximately one site visit per year. "High" maintenance was defined as requiring more than one site visit per year.

Summary of monitoring methods

A thorough review of available monitoring technologies was undertaken based on the above factors. Table 1 presents a summary of the primary monitoring methods that were initially considered.

Table 1: Summary of monitoring methods assessed

Monitoring method	Sampling rate	Areal extent	Frequency of false alarms	Maintenance
DAS fiber optics	< 5 minutes	Linear	Unknown	Low
Brillouin fiber optics	Varies	Linear	Unknown	Low
Trip-wire / Slide detector fence	< 5 minutes	Linear	Unknown	Unknown
Seismic / Geophones	< 5 minutes	Continuous	Unknown	Low
Tiltmeter	< 5 minutes	Discrete	Medium	Low
Vibrating wire piezometers	< 5 minutes	Discrete	Medium	Low
Accelerometer	< 5 minutes	Discrete	High	Unknown
Time domain reflectometry	Unknown	Continuous	High	Unknown
Wireline extensometer	< 5 minutes	Linear	High	Unknown
Shape Accel Array (SAA)	> 5 minutes	Discrete	Medium	Low
Lidar	> 5 minutes	Continuous	High/Low (Climate)	Medium
Doppler radar	< 5 minutes	Continuous	High/Low (Climate)	Unknown
GB-InSAR / Terrestrial radar	< 5 minutes	Continuous	High/Low (Climate)	Medium
Differential GNSS	< 5 minutes	Discrete	Medium	Medium
Robotic Total Station (RTS)	< 5 minutes	Discrete	High/Low (Climate)	High

Many of the above monitoring methods, including lidar, GB-inSAR and RTS, are heavily influenced by climatic factors (frost or snow cover, or precipitation) and as such, would not function year-round without additional maintenance and/or data processing. As such, these methods were deemed inappropriate for use as the primary monitoring method in an EWDNS designed to detect a sudden static-liquefaction type failure. Although differential GNSS, accelerometers, SAAs, vibrating wire piezometers and tiltmeters were considered, the discrete point coverage was such that, alternative methods which provided linear coverage were considered more advantageous. In addition, the cost of a higher density coverage of a discrete point monitoring method, due to equipment, drilling and other installation factors, is generally much higher than the cost of a higher density coverage of linear or continuous monitoring methods.

Geophones and other seismic techniques were considered but ruled out due to uncertainties in the number of false alarms potentially generated at an active tailings and mine site, the lengthy calibration process, and the amount of pre-processing required.

Distributed fiber optics using Brillouin backscattering, traditionally used in geotechnical applications to measure strain, were deemed inappropriate due to the longer data acquisition time over longer lengths (Muanenda, 2018).

Monitoring methods deemed to meet the requirements of detection of a static liquefaction type failure from the above table are summarized below.

Doppler radar

Doppler radar calculates the velocity and direction of an object based on the shift in received frequency and can be applied to measure fast processes (few meters to few tens of meters per second) (Meier et al., 2016). Doppler radar has been used successfully in alpine settings to detect avalanches and automate closure of highways based on alarms across Europe. To the authors' knowledge, doppler radar has not yet been applied to detect tailings dam static liquefaction-type failures. As such, a period of calibration in the order of several months would be required before it could be implemented in either an event detection or early warning system.

Trip-wires or slide detector fences

Trip-wires (also referred to as wire sensors) and slide detector fences represent a simple concept of an alarm triggered by a break in a wire. To the author's knowledge, this type of system has not yet been applied in a tailings dam setting.

Trip-wires are more commonly used in geohazard applications to detect debris flows, landslides, and lahars (Keys and Green, 2008). Slide detector fences operate in a similar manner to trip-wires, consisting of a fence with a series of parallel wire sensors, and have been used to detect rock fall occurrences along railways (Pritchard et al., 2008).

Distributed acoustic sensing

Distributed fiber optic sensing systems provide a means of using a fiber optic cable as an array of sensors (Miah and Potter, 2017).

Distributed Acoustic Sensing (DAS) uses Rayleigh backscattering along a fiber optic cable to monitor multiple dynamic events in real time (Muanenda, 2018). This type of fiber optic method may consist of a standard telecommunications-grade fiber optic cable and a centrally-located signal processing module. The signal processing module transmits and receives beams of light through the fiber-optic cable. Vibrations or movement around the cable cause reflections in the beam of light to be sent back to the module, which are processed and configured to send an alarm at specific thresholds.

Rayleigh backscattering is considered advantageous over Brillouin backscattering in the EWDNS as it is capable of fast, distributed measurements over longer distances (Muanenda, 2018).

DAS has been used to monitor rockfall along long stretches of railway (Akkerman and Prahl, 2013).

Supplementary monitoring considerations

Where the notification of a dam failure extends to multiple stakeholders, it is critical to reduce the number of false alarms emitted to avoid desensitization of the different parties.

In addition, the following considerations are recommended for implementation of an EWDNS:

- Separate components of the systems should be duplicated for redundancy (i.e., if a cell modem goes offline there should be a separate radio network to connect to an adjacent modem and transmit the data. Additionally, a backup satellite communication system could be implemented for back-up coverage if a cell tower goes down).
- An infrared camera with weatherproof enclosure would provide the potential to view the tailings dams in near real-time and provide verification of the event of a dam breach.
- Existing instrumentation on site could be used to supplement the EWDNS. This may involve trenching piezometer cables directly to a datalogger to provide near real-time monitoring of pond levels.
- Seismic monitoring, such as geophones, could be implemented alongside the primary monitoring method to supplement the EWDNS. This could monitor for the potential of low seismic events that could act as pre-cursory triggers to a static liquefaction type failure, as well as detect vibrations associated with a ground disturbance caused by a dam breach event.
- dGPS/dGNSS sensors could be used as a supplementary system to detect surficial displacement of the structures.

- Parallel sensors should be integrated into the system to minimize the event of false alarms (i.e., multiple trip-wires installed in parallel).

Conclusion

Multiple monitoring methods were assessed to detect a static liquefaction-type failure of a tailings dam to be used as a component of an EWDNS. Following a thorough review of the assessment factors, the linear fiber optics system using DAS sensing was chosen as a primary monitoring method of the EWDNS.

Supplementary components, including redundant telemetry (i.e., a separate radio network), complementary sensors (i.e., geophones), dam breach verification (i.e., an infrared camera) were also considered for implementation to improve the robustness of the EWDNS. Research is currently ongoing to improve the understanding of the failure mechanisms of static liquefaction; this may lead to improvements in the prediction of tailings dam liquefaction failures in the future.

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