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Real Time Monitoring of Infiltration and Contamination from Paste Tailing Site

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ABSTRACT

Mining facilities store process water or paste slurry. Lateral and vertical water percolation may create major problems concerning dam safety and environmental impact. Means for monitoring the saturated zone is widely used, but none concerning the unsaturated zone (vadose zone). A novel Vadose Zone Monitoring System (VMS) was developed at Ben Gurion University in Israel. VMS units include a set of advanced water and pressure sensors along with sampling ports. The units are mounted on a flexible sleeve which is installed through dedicated uncased small diameter boreholes. Through a control panel on the surface, data is transmitted via a cloud-based server directly to the client's dedicated application.

Over the past decade, the VMS was successfully installed in a variety of scientific and commercial projects on water infiltration and contaminant transport from land surface to the groundwater in a variety of geological and hydrological setups. Recently, fertilizers' producer in Israel (ICL), installed several VMS stations under phosphogypsum waste lagoons for monitoring the potential leaks from the bottom of lagoons to the subsurface, and one system in in an earthen dam for monitoring its safety status. The case study deals with contamination that was discovered in the aquifer. Continuous monitoring of water percolation beneath the ponds indicated that the levels of water percolation and pollution potential from these ponds are relatively low and therefore environmentally safe. These findings were accepted by the environmental authorities and the client wrote: "The VMS already had an important use, in proving the authorities that the contamination is from another source and not from our cell. We couldn't have done it any other way".

Implementing of the VMS systems at the above case and other cases produced real time information which has proved to be critical for maintaining long term safe operation of tailing sites.

INTRODUCTION

Tailing dams support paste that may contain large amounts of water. Taking care of dam safety and functionality is one of the most challenging tasks in mine waste management. Failures can be originated from overloads, anomalous behavior of the material used to build the dam (normally tailings), or from problems with the drainage mechanisms, which result in an increase of pore water pressure and therefore a loss of slope stability. Obviously, periods of unusual rain may increase the number and severity of such events. The recent increase in dams' failures may be attributed to the combined effect of rapid uncontrolled dyke construction along with poor maintenance and few or no monitoring. Prevention and protection are therefore crucial and besides the improvement of dam construction, (real time) monitoring of the sediment composing its structure and the geological infrastructure underlying the facility is a key tool for the safety management of the embankments. The safety and stability of a tailings dam can be controlled by measuring key parameters of the material used to build it and the surrounding subsurface. Pore water pressure and embankment deformation in tailings dams are the most important physical characteristics to be monitored.

For decades, the monitoring carried out in tailing dams consisted of periodically visiting selected spots along the exposed faces of the dam, for taking soil samples, installing inclinometers and measurements of variations in phreatic water level via piezometers. In recent years, the installation of automated in-situ monitoring systems improved monitoring effectiveness as data is continuously available in real time, but what is the quality of this data? Why dams are still collapsing and how to control environmental contamination?

VADOSE ZONE WITHIN TAILING DAMS

The unsaturated zone (often called the vadose zone) is commonly defined as the geologic media spanning from the land surface to the groundwater level (see Figure1).

Whenever we build an earthen dam in order to retain water, sludge, tailings etc. water from the reservoir is always seeping and accumulating and likewise we must deal with those two zones within the dam structure. Earthen dam stability primarily depends on the water saturation degree and pressure built-up in the sediment composing its structure. Under non saturated conditions, above the phreatic water table, there is no water pressure that can influence the slope stability (Figure 1). On the other hand, under saturated conditions, below the water table, the water pressure is positive, and pressure may build up, decrease sloe stability and endanger the dam safety. Piping through earthen dam is another risk. Accordingly, water infiltration through earthen dams may weaken its stability and potentially lead to dam's breach. Today most monitoring programs in earthen dams are based on measurement of phreatic water level in piezometers (see Figure 1). But piezometers can be read only once the zone becomes saturated. Many times, it is too late, or the situation is so poor that extensive remediation actions are needed.

Those piezometers can give poor information, if any, about contaminants infiltration toward the environment and the groundwater.

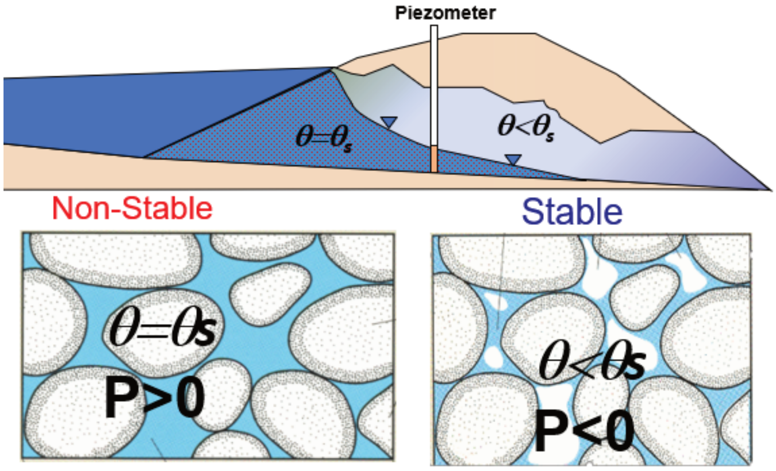

Fig. 1 Pore water pressure (P) in the saturated zone (left) and the Vadoze zone (right)

The advancing frontier of the saturated zone is marked by phreatic surface between the saturated and unsaturated zone starts to advance once the reservoir starts filling (see Figure 2). In steady state the rate of advancing is relatively slow, but it increases during the procedure of gradually adding more and more tailings upstream the dam. Excessive change occurs due to situations like heavy rainfall, the piling of big amounts of tailings and earthquakes, all of which may cause seepage inflow rates into the dam structure that are as much as 100 times bigger than the steady stage seepage rate (1). Normally before the phreatic line is reaching a certain point there are measurable changes in the soil moisture within the dam sediment. In all such cases getting early warning requires retrieving real time information from the unsaturated zone.

VADOSE ZONE MONITORING

Researches conducted in the beginning of this century (2) enabled the development of new types of humidity sensors based on the water dielectric constant, that proved to be effective in the Vadose zone. It was followed by developing a sophisticated sampling port for pore water. Based on those – the Vadose Zone Monitoring System (VMS) was developed by *Ben Gurion University* and licensed to *Sensoil*. The VMS is composed of a flexible sleeve hosting multiple monitoring units which are distributed along its length (Figure 3). Each unit includes the sensors and sampling ports as described above. Sleeve length and slope may vary according site conditions. It allows real time, continuous tracking of humidity change in the soil and thus sensing the approaching phreatic surface even before the area becomes saturated. The sampling capability allows collecting samples of liquid in a dedicated bottle located in the control box on the surface and sending them on demand for lab analysis.

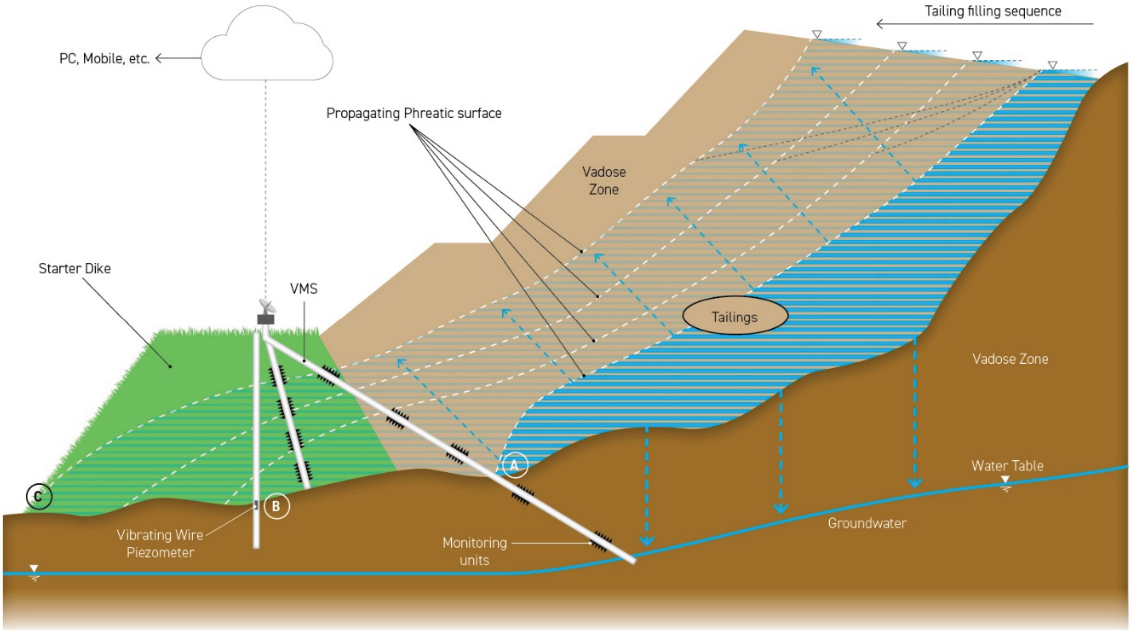

Fig. 2 Vadose zone Monitoring System (VMS) within tailing dam
Details of the monitoring units see Fig. 3

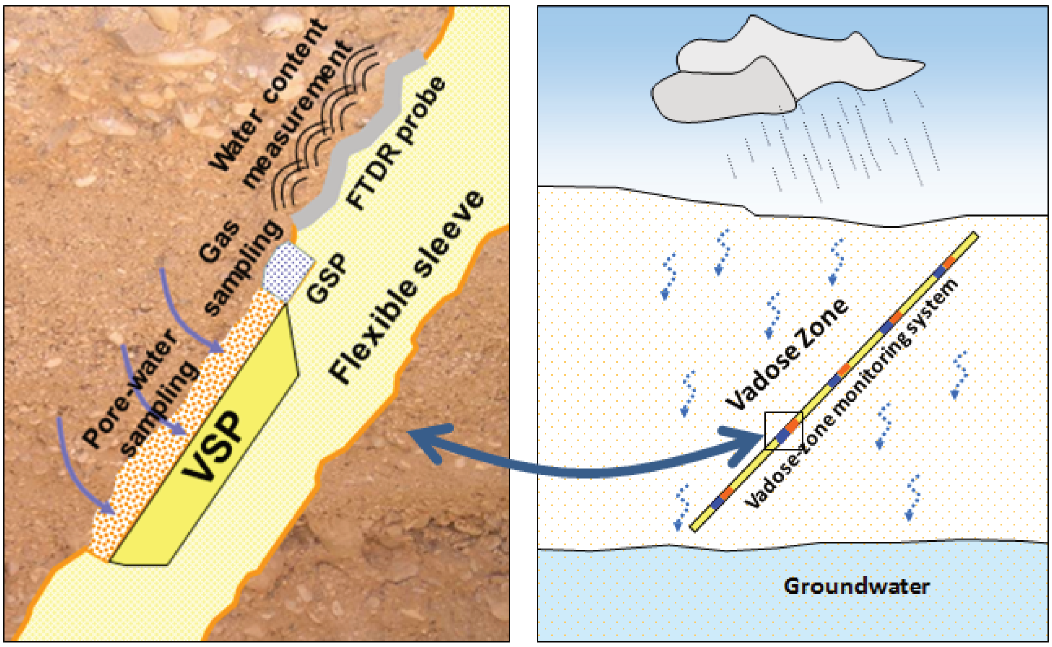

Fig.3 Schematic illustration of a monitoring sleeve installed in the vadose zone (right) and a monitoring unit (left)

Fig. 4 VMS flexible monitoring sleeve during its construction (left) and installation (right)

VMS APPLICATION IN TAILING FACILITIES

Tailing dams are typically structured through gradual filling of paste tailing upstream a dam (figure 2). With time and tailing build up a phreatic surface is being built behind and above the dam. Monitoring of the development of the moisture in the dam sediment provides early warning and a forecast to the phreatic surface development. The capability to predict the development of the phreatic water level is essential for controlling the safety of the dam and its surroundings.

The VMS is usually installed in slanted position across the dam and into the natural geological material underlying the dam and it provides real time continuous measurement of temporal variations in water content and pressure in the dam material. In addition, tracking the chemical composition of the water will enable taking measures to avoid environmental contamination. Those indications are sent continuously in real time and from different positions in the sleeve to the control panel and from there to a cloud database that is accessible to the dam's operators. In this way, the dam operators and safety engineers can get direct real time information about the rate of the phreatic surface propagation, the source of the water and their composition. This early warning facilitates precious time to make adjustments in the site operation and take safety measures. Standard piezometer that measures the depth to the phreatic water table provides will react much later supplying only limited information on the saturated part and no information on the saturation build-up in the unsaturated zone.

POTENTIAL APLICATIONS IN THE MINING INDUSTRY

Heap leach mining is considered to have a potential sever environmental impact on the quality natural water resources. The pollution potential of mineral production from ores heap emerges directly from the fact that it involves application of large quantity of water that is considered heavily polluted in large open areas. Though production water is applied on crushed ores that are heaped on pads covered with engineered impervious layers it appears that often polluted water leaks from the pad and production zone to the subsurface, infiltrates through the vadose zone, and finally penetrate the local aquifers. The lag time between initiations of infiltration events of polluted water through the vadose zone its appearance in observation well is in time scale of years to decades. Throughout this lag time large pollution mass may accumulate in groundwater to untreatable levels and cause irreversible damage to the local water resources.

Typical situation exists in production of Lithium in Chile today which is consider a "water-mined" extraction process by pumping saline groundwater up from the subsurface. The problem with this comparatively cheap method is that up to 95% of the extracted brine water is lost to evaporation and not recovered. Online monitoring water infiltration and contamination could help to get real time data in order to optimize the water utilization and avoid groundwater contamination. Further benefits should be developed in collaboration with lithium industries.

The copper industry in Chile is facing sometimes situations of groundwater contamination due to lack of maintenance in their transportation systems or heavy rain during highland summer (January to March). For example, in march of 2011 in Iquique (II region of Chile) was saw a demand from an aggrupation called "*Atacama sustentable*" where they claim that a copper company that operates in the region was contaminating their water after a heavy rain and presence of acid water in the environment was draining to underground water. The disaster of Vale with the collapse of *Brumadinho* dam, in 2019, resulted in 270 casualties and total cost estimation of around €1.500 million is also attributed to poor monitoring of water percolation through the tailing dam.

CASE STUDY: ICL PHOSPHOGYPSUM TAILING SITE MONITORING

ICL (Israel Chemicals Ltd. - NYSE and TASE), a global manufacturer (44 plants 13 countries) of specialty fertilizers and a leading provider of pure phosphoric acid, produces phosphoric acid from phosphate rock and sulfuric acid reaction. The by-product of the reaction is phosphogypsum (hereinafter "the gypsum"). The gypsum flows to the ponds as sludge (slurry) where it is deposited, and the remaining water returns to the Phosphoric acid production process. A new gypsum settling facility was instrumented with 4 VMS stations to monitor the potential leak of contaminated water to the unsaturated zone and underlying groundwater. Each station is composed of multiple monitoring units installed at selected depth. Each monitoring unit includes: (i) FTDR probe for continuous measurement of variations in sediment water content as an indication for water percolation, (ii) VSP for frequent sampling of the sediment pore water for characterization of the chemical composition of the percolating water (see fig. 5 -left) . Stages of installation see Fig. 6.

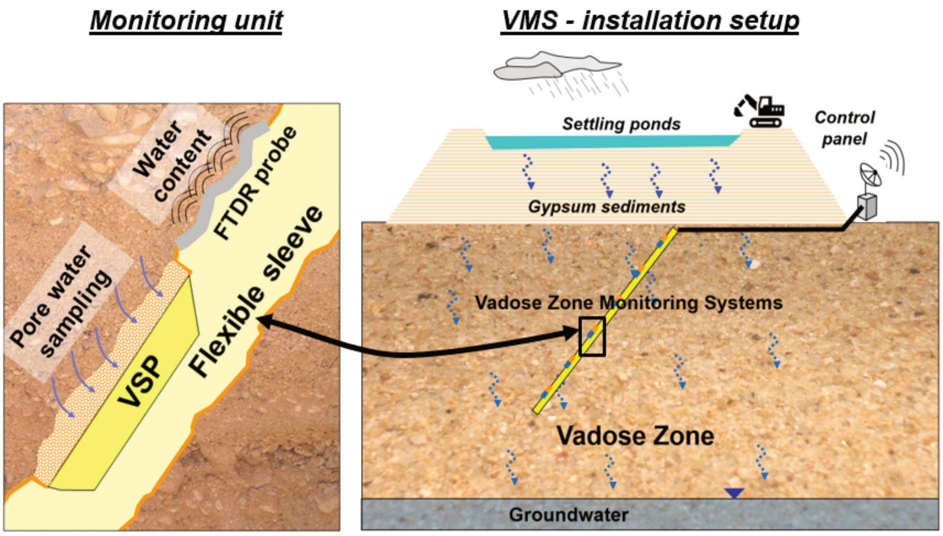

Fig. 5 Schematic illustration of a Vadose zone Monitoring system (VMS) installed in the unsaturated zone underlying a gypsum settling pond (right

Continuous measurements of changes in sediment water content as well as sampling the sediment chemical composition enabled assessment of the water percolation and contaminant transport fluxes

Fig. 6 VMS (top)installation in the slanted borehole: sleeve carried for installation, (left) Sleeve insertion into the cased borehole, (right) VMS sleeve in the borehole

A few months after installation and initiation of the settling pond operation, the authorities detected contamination of the groundwater. Obviously, it was assumed that the source is related to water leaks from ICL settling pond. The Continuous monitoring of water percolation beneath the ponds indicated that the levels of water percolation and pollution potential from these ponds is relatively low and therefore environmentally safe. Those finding were accepted by the authorities and later the real source was found, it belonged to other utility. ICL stated that If this wasn't detected in time, they would have been ordered by the authorities to build another pond. An investment of tens of millions of USD (three magnitudes bigger than the cost of one complete VMS system).

CONCLUSIONS AND RECOMMENDATIONS

Innovative systems dedicated to operate in the Vadose zone enable today to look farther and deeper into the soil and to retrieve very valuable data about potential problems in earlier stages of their development. This allows more time to assess the risk, take preventive measures and avoid catastrophes, closing procedures or heavy investments that, as demonstrates in the case studies above can be in the magnitude of tens of millions of USD (ICL- Israel) and as much as €1.500 million (*Brumadinho* dam in Brasil)

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