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Methodologyproposals for the monitoringof activation levels and response plans for tailings deposits in Mexico

Proposed methodologies for dictation of trigger levels and response plans for tailings dams in Mexico

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ABSTRACT: This article presents a methodology proposed by Knight Piésold for the preparation of trigger action response plans or TARPs and is intended to serve as a technical guide for the global mining industry. A TARP provides a set of predefined indicators of failure of a tailings dam, which can be monitored through geotechnical instrumentation, each indicator triggers a set of actions that must be taken into account to prevent the failure or mitigate its impacts. Fault indicators are developed based on the results of geotechnical, geological and hydrological analyses. A TARP provides a method for detecting early warning signs and preventing dam failure, being considered one of the most important documents in tailings dam safety. Although a TARP has become an internationally required document for the safe management of tailings dams and water dams, there is little universally accepted guidance on what these documents should contain and how they should createthem.

ABSTRACT: This paper presents Knight Piésold's proposed methodologies for preparing a trigger action response plan, TARP, and is intended to serve as a technical guideline across the global mining industry. A TARP provides a set of predefined indicators of tailings dam failure which can be monitored via geotechnical instrumentation, with each indicator triggering a set of actions to be taken to either prevent failure or mitigate its impacts. Dam failure indicators are developed based on the results of various structure-specific geotechnical, geological, and hydrological analysis. A TARP provides a method by which to detect early warning signs of dam failure making it one of the most important documents in tailings dam safety. Although TARPs have recently become an internationally required document for safe management of tailings and water dams, there is little universally accepted guidance on what these documents must contain or how they must be created.

1 INTRODUCCION

1.1 *Background*

Risk mitigation planning consists of the preparation of an Operations, Maintenance and Surveillance (WHO) Manual, a Trigger Action Response Plan (TARP) and an Emergency Response Plan (ERP). These three documents govern the safe operation and monitoring of tailings dams and are part of the normal regulatory documentation package.

The guidelines for dictating activation levels are based on the following more rigorous standards and manuals:

- •Ministry of Environment and Natural Resources (SEMARNAT), Official Mexican Standard NOM-141-SEMARNAT-2003, September 2004.
- •United States Army Corps of Engineers (USACE), Instrumentation of Embankment Dams and Levees, Noviembre 2020.
- •International Council on Mining and Metals (ICMM), Global Industry Standard on Tailings Management, Agosto 2020.

These regulations will serve as a guide for different aspects of ART, such as determining which specific hazards will be governed by TARP, defining the level of hazard that will trigger a predefined response, and determining corrective actions for triggering events.

1.2 *Purpose of TARP*

The International Council on Mining and Metals (ICMM), The Global Industry Standards on Handling Jales defines a TARP as the following:

A TARP is a tool for managing risk controls, including critical controls. TARPs provide predefined trigger levels for performance criteria that are based on risk controls and critical tailings facility controls. Activation levels are developed based on performance objectives and the risk management plan for the tailings installation. TARPs describe actions to take if activation levels are exceeded (performance is outside the normal range), to avoid a loss of control. The range of actions is predefined, based on the magnitude of the activation level exceeded.

A trigger action response plan or TARP aims to provide a set of predefined indicators of dam instability using instrumentation, visual observation and analysis; each indicator triggers an action to make appropriate repairs and mitigate the problem or provide evacuation warnings through the Emergency Response Plan (ERP).

1.3 *Key definitions*

For use within TARP, a *fault* is defined as the uncontrolled release of tailings and/or water from a tailings reservoir (TSF) into the surrounding environment. A *hazard* is defined as a scenario that could lead to failure, either likely or unlikely, if not fixed. Any discussion of hazards and failures within this article should be understood within the context of this definition.

A *response* is defined as an action taken to eliminate a hazard before failure or to mitigate the consequences of failure. Finally, a *trigger* is defined as an observation (either physical or by an instrument) that indicates the need for a response. Engineer refers to the engineer of record (EOR).

2 ACTIVATION LEVELSANDMBRALES

Activation levels should be set taking into account site-specific conditions and possible failure modes. Each trigger aims to identify the development of a specific hazard in the tailings dam. Such hazards may develop rapidly or be long-term trends that justify different triggers and related actions.

To account for these different levels of response required, activation levels have been divided into three levels of action: Attention, Alert and Emergency. Each of these levels will entail a different set of actions that are detailed in section 3 of this article. In addition, thresholds that trigger each action level will be set to reflect the possibility of dam safety trends, both rapidly developing and long-term.

2.1 *Activation levels in vibrating rope piezometers and open piezometers*

Vibrating rope and open vertical tube (VWP and OSP) piezometers are installed inside and outside the tailings dam to monitor pore pressure conditions and understand the location of the water table or upper line of flow within the dam. . Piezometer data can be used to identify and prevent the development of potential stability-related faults by establishing the following types of activation levels:

1. Activation levels based on the safety factor, using agreed safety factor values.

2. Discrete value activation levels, intended to monitor any presence of water in areas where water is not expected and leak detection.

3. Activation levels of the rate of change to monitor any rapidly developing changes in the water table or upper line of flow within the tailings dam.

4. Activation levels based on standard deviation to monitor readings outside the expected range. These threshold levels require frequent updates because they depend on an accurate database and historical values.

These activation levels can be grouped into two subsets: value activation and trend activation levels. In the listing above the first two can be referred to as value activation levels because they are provided as fixed elevation values to monitor. The latter two are known as trend trigger levels because they predict future impact if a specific trend continues by monitoring rates of change or standard deviations.

Value activation levels are used to dictate the maximum level that the water table can reach before the stability of the dam begins to be noticeably affected. Discrete value activators apply to instruments where a set reading indicates a dam malfunction, such as a leak detection piezometer or piezometer placed on top of a gravity drain, where a non-zero reading would trigger the review regardless of the water table. Safety factor-based activation levels are applied to piezometers installed within the footprint of the structure and not immediately adjacent or hydraulically connected to the pond. For the levels of activation of value based on safety factor, it is recommended to take into account the load conditions, the values of the safety factor and the assumed resistance parameters listed in Table 1, a reliable geotechnical model must be available, based on an exhaustive exploration and laboratory tests, additionally a historical analysis of the growth of the deposit must be taken into account. Theserecommendations are not universally applicable and should be reviewed for specific project conditions and by *the engineer*. The procedure for setting these activation levels (value) is detailed below:

Step 1. Establish the reference level (datum) of the water table of the dam (shape and typical value) using historical data from the piezometer.

Step 2. Raise the water table to the reference form (datum) or to the realistic form, as determined by the engineer, incrementally.

Step 3. Perform stability analyses under the three load conditions listed in Table 1 on incremental water table elevations, to determine the associated safety factor.

Step 4. Repeat steps 2-3 to obtain the water table and associated safety factor or a level of care, alert, and emergency. The most unfavourable groundwater condition shall be selected to define the activation levels of the installation.

Table 1. Thresholds for piezometers

Loading Conditions	Safety Factor Thresholds				Assumed Resistance Parameters
	Normal operation	Attentio n	Alert	Emergency	
Static	FS≥1.5	1.5–1.4	1.4-1.1	FS<1.1	Maximum resistance of undrained tailings
Pseudo-Static	FS≥1.3	1.3–1.2	1.2–1.1	FS<1.0	Maximum resistance of undrained tailings.
Post-seismic	FS≥1.3	1.3-1.2	1.2–1.1	FS<1.0	The jales are totally or partially liquefied, depending on the project.

*D safety factorsfor a fault limit equilibrium analysis .
*safety factors based on ANCOLD and CDA.

*These thresholds may vary depending on the identified triggers and the ability to monitor them.

Trend trigger levels will be established once a historical database is compiled and there is sufficient data to identify typical fluctuations in the internal water table. Trend activation levels may be the first indicators of a rapidly developing condition within the dam.

The general approach for standard deviation thresholds is to establish an expected datum based on a review of historical data and then deviations from water levels or water level fluctuations are considered trigger events.

Exchange rate trigger levels can be calculated from the start of a project, but should be reassessed at least once a year to take into account any potential impact of changes in operating conditions. The reading frequency under normal conditions for piezometers is biweekly (every two weeks) considering piezometers that do not have an autonomous data acquisition system, that is, where readings are taken manually. However, if an instrument shows a significant increase over a two-week period and it is unknown when the surge began, it could indicate a rapidly developing failure scenario. As such, it is understood that the activation level of the rate of change is the modification of the water table normally collectedto that, if carried out at a daily rate, it would exceed the level of trend activation before the subsequent reading of the instrument. The method for determining the level of activation of the exchange rate is detailed below:

Step 1. Using the activation levels based on the safety factors (FOS) above, determine the height difference between the reference level and the threshold level.

Step 2. Divide the total delta in height from Step 1 by the normal reading frequency of the instrument (in days) to determine the rate of change of the activation level (in m/day) level of Attention.

Step 3. If the level of care assessment determines that the rate of increase in the water table is on track to exceed the threshold within the next two weeks and does not slow down, subsequent actions of the alert level should be taken to remedy the rise in the water table.

These activation levels are project-specific, the location of each piezometer and operating conditions in each facility should be updated periodically to avoid the occurrence of outdated activation levels that trigger actions incorrectly.

2.2 *Activation levels in inclinometers and topographic monuments*

Settlement and displacement over time are common phenomena in tailings dams. However, a fast, uneven displacement, in the wrong direction or in combination with other internal conditions may indicate unsafe prey conditions. In general, displacement activation levels are set similarly to phreatic activation levels, as an expected reference motion level is set and then deviations from this normal displacement are considered activation events. Inclinometer and topographic monument readings can be used to identify and prevent the development of potential faults by establishing the following types of trigger levels:

1. Erratic movement of a magnitude greater than expected or in an unexpected direction (value).

2. Constantly accelerating, rather than slowing down, displacement trends (trend).

These two indicators become especially noticeable when other triggers, such as internal water tables and visualization of leaks, are observed simultaneously. As such, the level of action can be increased at the discretion of the engineer. Based on the experience and manual of the United States Army Corps of Engineers (USACE), the following levels of displacement activation are recommended:

Table. 2. Displacement thresholds

Instrument	Level of action		
	Attention	Alert	Emergency
Topographic monument	- 12 mm/month, or - A change in the direction of travel	- 12 mm/month accompanied by additional instrument activators in the section	- 6 mm/week, or - Acceleration of the displacement trend, such that failure is imminent
Slope inclinometer	- 12 mm/month, or - Any localized displacement on a probable fault surface	- 12 mm/month accompanied by additional instrument activators in the section, or - 12 mm/month in isolated area suspected of being a fault plane.	- 6 mm/week, or - Acceleration of the displacement trend, such that failure is imminent

It should be noted that these trends do not take into account the accuracy of the instrument and measuring equipment and that instruments that vary greatly from reading to reading should not be used for activation levels.

2.3 *Visual activation levels*

Methods and practices for regular monitoring of tailings dams (TSFs) are provided in the Operations, Maintenance and Monitoring Manual (WHO). However, there are several distinct indicators of dam instability that can be observed visually and indicate the need for a predefined response. These visual triggers will be dictated by one of the following methods:

1. A visual observation of damage that does not pose a known threat to the integrity of the dam, but could eventually lead to a major problem, shall be considered a care situation.

2. A visual observation showing damage to the dam that, over time, could cause a dam safety problem will be considered an alert situation.

3. Any visual observation indicating that an active fault is occurring shall be considered an emergency situation.

4. A visual observation that when combined with abnormal readings of the instrument indicates a prey safety problem. Visual investigation should be combined with abnormal reading or vice versa, to determine whether a higher level of alertness is appropriate.

3 DICTATION OFELEMENTS OF ACTION

3.1 *Response to levels of activation attention*

The answer items to be taken for this activation level are as follows:

Instrumentation:

- Check the reading by checking the procedure and then take another reading.
- Take a reading for adjacent instruments, particularly those in the same section.
- Notify and send readings to the Engineer of Record (EOR), tailings dam owner and mining plant operations team.
- Increase the monitoring frequency of the instrument in question and surrounding instruments until readings normalize.
- Inspect the area for visible damage or changing conditions and report to the Registration Engineer (EOR).
- Prepare possible mitigation measures

Visual:

- Photograph the damaged areas and note the location in a weekly report.
- Notify the Registration Engineer (EOR) and the tailings dam management team.
- Develop and document subsequent repairs.

3.2 *Responding to alert activation levels*

The answer items to be taken for this activation level are as follows:

Instrumentation:

- Check the reading, check the procedure and then take another reading.
- Take a reading for adjacent instruments, particularly those in the same section.
- Notify and send readings to the Engineer of Record (EOR), the tailings dam management team and the mining plant operations team.
- Increase the monitoring frequency of the instrument in question and surrounding instruments until readings normalize.
- Inspect the area for visible damage or changing conditions and report to the Registration Engineer (EOR).
- Stop all construction activities in the area and stop the operation that could affect the tailings dam warning area (TSF).
- Prepare and implement a mitigation plan.
- Pump and remove the pump in operation from the installation.
- Notify those responsible for implementing the Emergency Response Plan (ERP) of the development conditions (do not implement the ERP to the emergency level, but prepare the team to implement it if necessary).

Visual:

- Photograph the damaged areas and note the location immediately.
- Notify the Registration Engineer (EOR) and the tailings management team.
- Stopany activity that may contribute to the problem.
- Immediately prepare and implement a mitigation plan.

3.3 *Response to emergency activation levels*

The answer items to be taken for this activation level are as follows:

- Implement the emergency response plan (ERP).
- Immediately stop all construction and operation activities in the area and evacuate.
- Notify the Registration Engineer (EOR), technical staff, mining company stakeholders and local community.
- Prepare and implement a mitigation plan.

4 CONCLUSIONS

Currently there are tailings dams in the world that do not comply with international standards, some of these dams do not even have instrumentation, for this reason, the determination of activation levels is complicated, mainly the levels of trend activation because there is no historical data that allows defining a trend, which may be the first indicators of a rapidly developing danger condition. For this reason, it is essential that new and existing projects have the appropriate instrumentation to measure in a timely manner any change in the conditions of the dam.

Activation levels must be determined considering the specific conditions of the site and possible failure modes, for this stability analysis must be performed, have an exhaustive geotechnical characterization that grants a greater degree of reliability in the stability models, and Compare these results with applicable operating and stability standards. The defined threshold levels are used to determine the allowed values, which limit the actions to be taken into account in case of exceeding these values.

For existing tailings dams, it is essential to review the current safety factor of the dam and mitigate the associated risks, with the aim of avoiding dam failure in the short and long term. Once these risks have been mitigated, new activation levels and response plans for the final project must be established.

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