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Danger and Avoidance of Damage Related to Tailings Dams and Tailings Ponds

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Abstract

Tailings dams can present high environmental and human health risks. For this reason, emergency planning for all installations of tailings storage facilities is essential. Recommendations for measurements concerning the safety of tailings dams are given.

Keywords: Tailing dams; Hazards; Emergency planning

Introduction

The accidents at Baia Mare, Romania (30. 01.2000) and Aznalcóllar, Spain (25.04.1998) have shown that failures and incidents at tailings management facilities can have tremendous consequences for both the environment and for human health. Such failures have contributed to cross-border pollution via mass movement of wastes in the form of suspended solids and dissolved materials which generally contain heavy metals and hazardous and/or toxic compounds. As a result, such accidents in any part of the world have the potential to rapidly affect social acceptance for all operations of the mining industry in general.

Definition of Tailings Management Facilities

The following definitions largely follow those given in ICOLD Bulletin 106 [1].

Tailings: the fine-grained waste material remaining after the metals and minerals, recoverable with the technical processes applied, have been extracted, i.e. the material rejected at the "tail end" of the process.

Tailings Storage Facility: can include a tailings dam (i.e. an impoundment and a pond), decant structures and spillways.

Tailings Dam: a tailings embankment or a tailings disposal dam. The term encompasses embankments, dam walls or other impounding structures designed to enable the tailings to settle, and to retain tailings and process water, and are constructed in a controlled manner.

Tailings Impoundment: the storage space/ volume created by the tailings dam/dams where tailings are deposited and stored. The extent of the impoundment is bounded by the tailings dams and/or natural boundaries.

Construction of Tailings Dams

Normally, tailings dams are constructed using materials that are either imported from elsewhere, or using natural features of the landscape. To maintain stability, a distinction is generally made (particularly in relation to imported materials) between:

- dam axis shifted to the water side (poor stability in seismic areas),

- dam axis shifted to the air side (high stability), or
- fixed dam axis (acceptable stability)

The following types of internal structure can be distinguished according to stability:

- dam with no sealing core,
- dam with sealing core,
- dam with horizontal drainage,
- dam with vertical/horizontal drainage,
- dam made of "classic construction material", or
- dam made of "production material"

For details see [2].

Operation of Tailings

In addition to the normal production process (i.e. preparing the ore and discharging the unproductive material into the tailings), knowledge of the technical condition of the tailings, as well of as the tailings dam, is important. Only with sufficient knowledge can the following be estimated and–if necessary–calculated, so that targeted safety measures can be implemented where applicable:

- safety against sliding of the dam,
- shear failure safety of the dam,
- structural integrity of the dam,
- internal shear failure safety of the tailings,
- isostatic balancing movements within the tailings,
- geochemical development of the tailings material,
- toning down of the dam, and
- spread of pollutants in the groundwater stream

Necessary Investigations and Research

To conduct the investigation and research the following methods and procedures, some of which were developed by Deutsche Montan-Technologies GmbH (DMT), can be used:

Field Investigation

In the field the following investigation must be done:

- Research of the surrounding geology, hydrogeology and seismo-tectonic-setting, including seismic risk and known seismic activity;
- Blade explorations (to obtain an initial assessment of the degree of consolidation of the tailings);
- Drive tests (to obtain an initial assessment of the geochemical properties of the tailings);
- Groundwater measurement points (to check the water level within the dam or tailings);
- Cone penetration tests (to obtain an index of the mechanical strength of the tailings sediments);
- Hose core boreholes (to remove undisturbed ground probes);
- Pump tests (to determine the permeability and transmissivity of the dam and tailings);
- Electrical resistance mapping (to identify zones of increased water content that may be related to weaknesses in the dam);
- Settling profile measurements (to determine movements on the dam and also the tailings), and
- Inclinometer measurements (to determine movements in the dam and also the tailings)

Laboratory Research

To build up a stable dam, the following laboratory tests are necessary:

- Odometer tests (time settlement line/pressure settlement line, to describe settlement behavior in relation to time and height of coverage in detail);
- Shear tests (to assess the stability of the dam and tailings);
- Particle size analyses (to assess permeability and settlement behavior);
- Determination of permeability coefficient (to determine the permeability of the tailings and of the dam);
- Deposit thickness (to determine long-term settlement behavior);
- Water content (chemistry of the water; to determine the amount of free and used water; to identify the substances suspended in the water);
- Porosity (pore count; to determine permeability);
- Thickness (dry/damp; to determine the mineral composition); and
- Consistency barriers (flow barriers/overflow barriers/shrinkage barriers; to determine geomechanical properties)

Measures for Securing Tailings during Operation and Final Storage

For safety reasons it is necessary to dry the sludge first. For this procedure techniques are available. In a second phase the stabilized sludge must be covered to avoid the transport of fine material by wind. The following techniques were used by DMT in cooperation with leading firms for the protection and final storage of tailings and dams:

- Well drainage
  - Gravity drainage
  - Vacuum drainage
- Even distribution of surface weight
  - Geocell system
  - DMT system
- Drainage system with vertical drainage units
  - Sand drain
  - Flat drain
  - Wick drain (fleece)
  - Filter drain
  - Pipe drain
- Introduction procedure for drains
  - Boring
  - Driving
  - Compressing
  - Flushing
- Drainage system with horizontal drainage units
  - Drainage system consisting of a mineral layer
  - Drainage system consisting of fleece /drainage mat/plastic tracks
- Dynamic compacting
  - Vibration (vibration rolling, depth shaking)
  - Impact compression (blasting, falling plate compression)
- MENARD procedure (vacuum consolidation)

Risk Assessment

Sources of hazards at the tailings management facilities, as categorized by UNECE [3] as direct (location, tailings and site criteria) or indirect (related to management). For each tailings management facility the sources of hazard should be evaluated. Furthermore the assessment of significant consequences and the probability of its occurrence (risk assessment) must also be conducted.

Risk assessment distinguishes three classes of risk, as follows:

- green–low consequence and probability
- yellow–medium consequence and probability
- red–high consequences and probability

Depending on the assessed risk class, construction of the tailings management facility may either be permitted (green class), or be permitted with additional conditions (requiring conditions such as measures to reduce the risk in order to move from yellow to green class), or should be prohibited (red class) unless economically acceptable measures can be taken to reduce the consequences or the probability. The hazard and risk assessment, especially taking into account the direct sources of hazard, should provide the precondition for planning and designing a safe tailings management facility. The hazard and risk assessment should be constantly reviewed throughout all phases of the life cycle of the tailings management facility.

Safety Aspects

In planning and designing a safe tailings management facility, particular attention should be directed to a number of aspects. First, in regard to the tailings pond, the following parameters need to be assessed. accurately:

- stability of sludge (slurry density)
- groundwater level
- geological situation
- hydrogeological situation
- hydrological situation
- geophysical conditions

In regard to the tailings dam, the following parameters need to be assessed:

- slope stability of the dam
- stability of the tailings material (induced liquification)
- erosion of the dam (suffusion and outside erosion)
- slope sliding

All of the listed parameters need to be used to develop, frequently review and subsequently interpret the stability of the dam in context of a comprehensive ground model. The dam-raising method should be selected with careful consideration of local conditions, such as seismicity, tailings composition, or risks of severe weather conditions.

Measurements for Dam Safety

For safety reasons the following aspects must be monitored:

- water level in the tailings dam
- water level in the tailings pond
- water outflow
- weather conditions
- seismic activity
- dam movement

Observation of water in the dam

Measurement of water in the dam and in the tailings is done using observation wells.

Depending upon the water level in the dam, different actions are required, as follows (Figure 1):

1: no action (1 green);
2: daily water level control (2 blue);
3: hourly control and stop production (3 orange); and
4: stop production and take counter-measures (4 red)

The action zones indicated in Figure 1 will be dependent on the dam construction method.

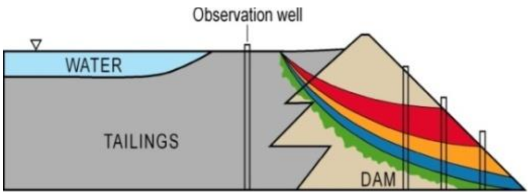

Figure 1 Observation of water in the dam.

Observation of water levels in the tailings pond

Overflowing water can cause dam erosion; it is therefore necessary to observe the level of impounded water level, as shown in Figure 2.

In the event of an overflow, the water level must be immediately lowered using counter-measures such as pumping.

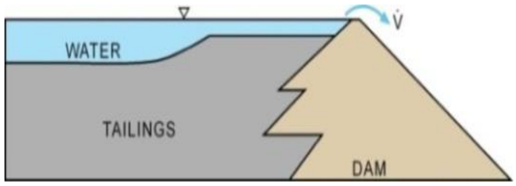

Figure 2 Overflow from a dam.

Observation of water outflow from dam

The dam must be inspected regularly to check if there is any outflow from the dam (Figure 3). An outflow can cause inner erosion to the dam and can seriously endanger its stability. If there is any outflow then counter-measures must be undertaken such as lowering the water level in the pond or sealing of the outflow.

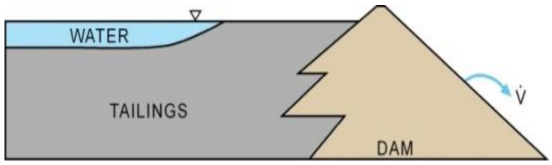

Figure 3 Outflow of a dam.

Weather observations

Heavy rainfall can damage the dam either through erosion or by raising the level of impounded water (which increases pressure on the dam wall). Also, protracted periods of rain can weaken the dam's stability. Thus, a weather station is essential (Figure 4). Based on rainfall records for Central Europe, actions can be classified as follows:

45 $l/(m^3 \cdot d)$	= no action
45-60 $l/(m^3 \cdot d)$	= field control
60-80 $l/(m^3 \cdot d)$	= safety actions
80-125 $l/(m^3 \cdot d)$	= possible emergency actions
> 125 $l/(m^3 \cdot d)$	= emergency actions

[$m^3 \cdot d$ = cubic metres per day]

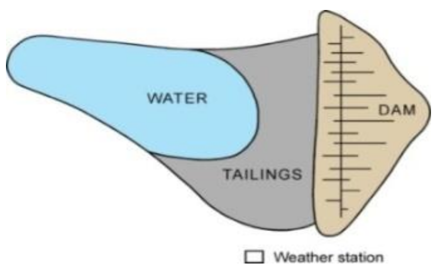

Figure 4 Observation of the weather.

Observation of seismic activity

When a tailings storage facility is located in an active seismic area a seismological station is necessary (Figure 5). The impact of any seismic activity must be evaluated by an expert in dam stability to assess compliance with any seismic criteria used in the dam design and construction.

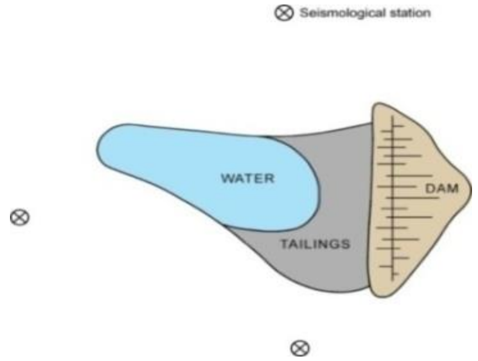

Figure 5 Observation of seismic activities.

Observation of dam movement

Dam movement can occur for several reasons; for example through seismic activity or heavy rainfall. Internal movements are measured by inclinometers (Figure 6) and can be classified as follows for conditions in Central Europe:

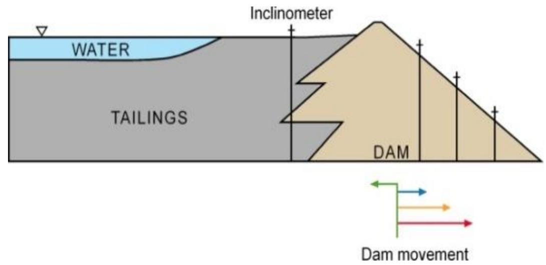

Figure 6 Observation with inclinometer.

- Linear movement (1)
- Movement acceleration:

1 mm/3 months = field control (2)
5 mm/3 months = safety actions (3)
10 mm/3 months = emergency action (4)

External movement can be measured by conventional ground surveying equipment such as automatic laser monitoring (Figure 7).

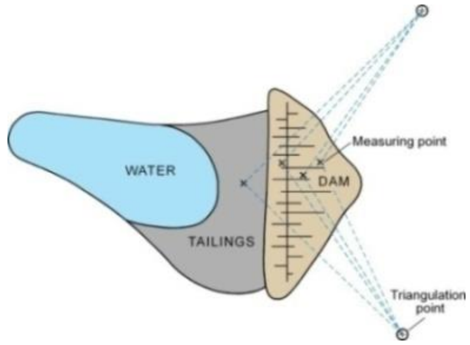

Figure 7 Observation by surveying.

Other measurements

Other measurements may be called for, depending on criteria such as type of dam, tailings material, meteorological conditions and seismological factors.

References

[1] ICOLD, 1996. Guide to tailings dams and impoundments. ICOLD Bulletin, 106.

[2] Vick, S. G. 1983. Planning, Design, and Analysis of Tailing Dams. John Wiley & Sons, New York.

[3] UNECE, 2008. UNECE safety guidelines and good practices for tailings management facilities.