SSIM 2021 - PM Dight (ed.)
© Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-1-0
doi:10.36487/ACG_repo/2135_09

Integrated three-dimensional laser scanning implementation for monitoring tailings dams

P Monreal *Maptek, Chile*

Abstract

Tailings dam incidents in recent years have forced the industry to consider the associated risks regarding efficient operational management, alongside the environmental and safety impact that a collapse can trigger. Waste management, either through deposit and/or tailings dam rehabilitation, is one of the final production stages in the mining execution chain. Notwithstanding its priority in the cycle, waste management deserves attention since it often impacts human settlements, where communities are increasingly concerned about the measures and governance surrounding mining projects. The impact of tailings dam failures has ramifications at any stage of a mining operation, including after remediation has been carried out. This makes it an absolute necessity to establish strict monitoring and control of the dam walls and fault alarming.

This paper will present how an integrated system, implemented through the application of three-dimensional (3D) laser scanners and dedicated software, can deliver improved safety outcomes both in controlling the monitoring of the stability of tailings dams and in their operational management. The 3D laser scanning approach provides a decision support system that aids professionals to manage geotechnical risk and monitor in real time, as well as report movements caused by slope instability that could interrupt mining activity and cause material and human losses.

An integrated hardware–software system can capture and report on data critical to slope stability monitoring. Informing operations about millimetric deformations from baseline measurements at critical points of the dam wall allows geotechnical engineers and management to perform back-analysis and receive predefined alerts instantaneously. Operations can also monitor the changes in surfaces as remedial work is carried out, providing a risk management tool that ensures safety of equipment and personnel.

Keywords: *tailings, laser scanning, safety, monitoring*

1 Introduction

The impact of tailings dam failures has ramifications at any stage of a mining operation, including after remediation has been carried out. This makes it an absolute necessity to establish strict monitoring and control of the dam walls and fault alarming.

This paper will present how an integrated system, implemented through the application of three-dimensional (3D) laser scanners and dedicated software, can deliver improved safety outcomes both in controlling the monitoring of the stability of tailings dams and in their operational management.

The 3D laser scanning approach provides a decision support system that aids professionals to manage geotechnical risk and monitor in real time, as well as report movements caused by slope instability that could interrupt mining activity and cause material and human losses.

2 Contextualisation

2.1 Stability analysis of a tailings dam

The stability of the tailings dam is associated with the possible occurrence of deformation during a seismic event, maintaining its integrity and operation after the occurrence of an earthquake. Consequently, to ensure proper behaviour of these structures, it is necessary to evaluate the stability of slopes and verify whether the necessary safety factors are above the recommended minimum values.

2.2 Slope failures

There are multiple ways a slope can fail due to different types of soil, complex stratigraphy and loading conditions. Broadly speaking, failures occur on soil slopes in one of four ways: transfer, wedge or flat, circular, and non-circular; a fault can also be composed of these four basic shapes. Table 1 summarises the geological conditions that affect how different types of fault surfaces develop (Abramson et al. 1999).

Table 1 Geological conditions that affect how fault surfaces develop

Geological conditions	Potential failure surface
Granular soils Residual or alluvial soils on alluvial rocks Hard fissured clays and marine alluvials with a heavily weathered upper zone	Shallow translation relative to its length
Sliding block Stratified and sloping rock or soil Material with weak layers or failure mirrors Hard, firm and intact cohesive soil on alluvial slopes	Flat surface
Sliding blocks in rocky masses Weathered and stratified sedimentary rocks Clay infill, hard and fissured clays Stratified floors Lateral debris on alluvial deposits	Multiple flat surfaces
Deep strata of residual or alluvial soil Soft marine clays Soft or firm cohesive soils	Circular or cylindrical shape

2.3 Factors associated with the generation of failure mechanisms in tailings deposits

The main factors that can be generated in tailings dams that have a direct impact on the failure mechanisms and according to the various antecedents are described in Table 2 (Sernageomin 2018).

Table 2 Factors associated with tailings dam failures

Group	Name	Factors
1	Tank type	Tailings sand dam Tailings reservoirs Filtered tailings deposit Deposit paste tailings Deposits thickened tailings
2	Geometric configuration	Rematch height Crown width Global slope of the slope
3	Tailings quality and compaction levels achieved in the deposit	Granulometry and plasticity of the fine fraction Compaction level
4	Foundation soil	Characterisation of the foundation soil for the design project
5	Background analysed instrumentation and monitoring	Position of phreatic levels Drainage system operation Seismic accelerations Movements of walls and/or tanks Others
6	Mechanical behaviour during the operational phase (installation history)	Physical stability evaluated during the operational phase Incidents with an impact on operations Temporary closures due to incidents
7	Regional environment for closure condition	Seismicity Floods Wind regime
8	Degree of implementation of measures to ensure physical stability in the closure stage	Verification of works and actions implemented, as indicated in the approved closure plan

3 Methodology

3.1 Geotechnical monitoring system

Currently, large dams need to be subjected to permanent and meticulous surveillance and control through a system of auscultation and/or implementation of geotechnical instrumentation (Oliva Gonzalez 2015).

The need to include instrumental monitoring, and the quantity and location of the devices, depends on the uncertainties that exist in relation to the site conditions and the behaviour of the structures in normal operation of the project or in the face of external events.

Determining that the use of instrumentation is vital and necessary, the monitoring process should follow the phases that are illustrated in Figure 1.

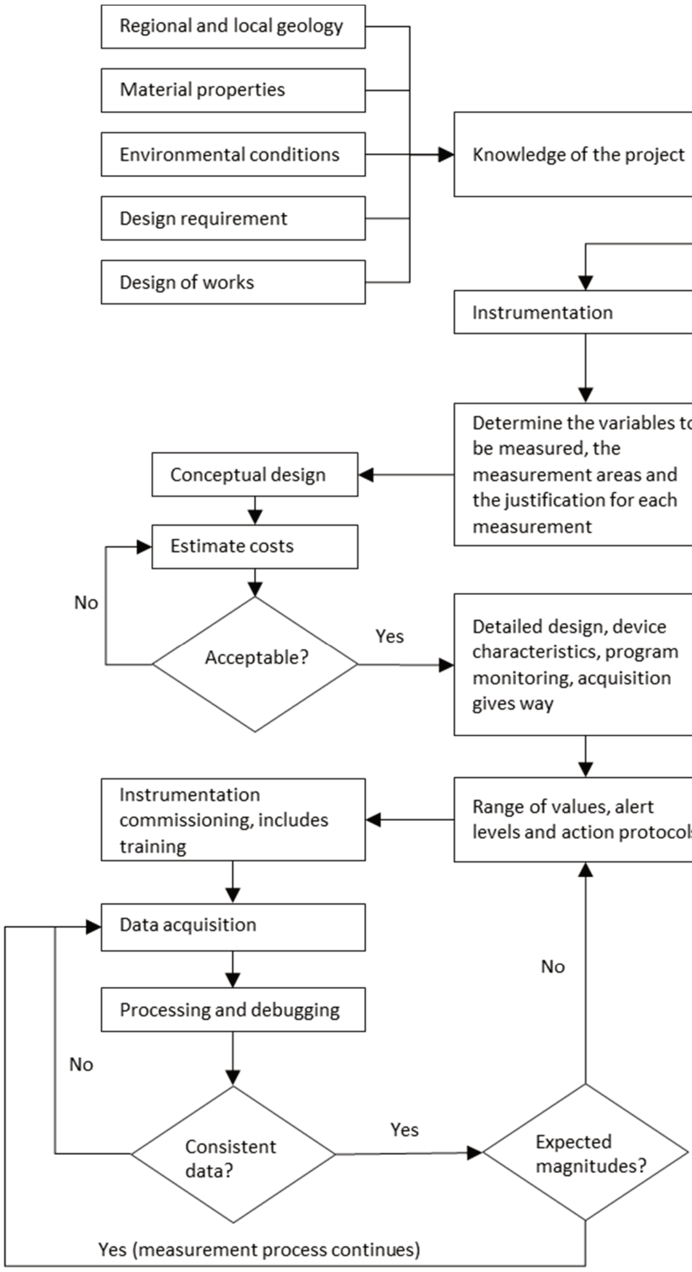

Figure 1 Monitoring process

3.2 Tailings dam monitoring with laser scanning

The following types of surface measurements are recommended for a tailings dam:

- Free edge with respect to the surface of the tailings or the water surface, that is, the vertical distance that the crest of the dam is above the water level of the pond.
- Horizontal and vertical movement of the crest of the starter dam and downstream slope.
- Vertical movements in tailings deposits are large and are due to own-weight compaction and consolidation.
- External movements are measured by means of a laser scanner without the need for reference points. The scanning hardware is combined with sophisticated software capable of instructing the system for repetitive scanning of the dam.

3.3 Monitoring solution

The magnitudes to be measured and the periodicity must be carefully defined to carry out a geotechnical monitoring campaign. The parameters should be derived directly from a correct definition of the geotechnical problem posed. As these are relatively fast movements, the measurement periodicity will be high (minutes). This provides an important statistical base for defining a monitoring plan so that the laser scanner can carry out data captures (surveys) in other areas of interest to the tailing's environment, such as the lagoon, crown, support slopes etc.

3.4 Planning of an instrumentation program

The planning of an instrumentation program should be logical and detailed because measuring a particular problem may require different types of instruments collecting information along a range of different scales. Furthermore, due to physical and economic limitations, all parameters cannot be measured with equal ease and success.

Any monitoring plan with a laser scanner must detail and consider, as a minimum, the following:

- Control zones: the installation of the monitoring system and the number of them that are in critical areas whose parameters need to be measured.
- Limit values: the measurements obtained from the monitoring can be used as an alert mechanism of the risk management program and maximum reference values will be established that should not be exceeded.
- Frequency of scans: the control and interpretation on a regular basis of the recording of the monitoring readings allows for the detection of anomalous trends in the behaviour of the massif and the necessary corrective measures to be taken.
- Contingency plan: a response protocol will be established in the event of the deformation thresholds being exceeded, which includes communication between people who have implications for the control of the massif.

To carry out the monitoring of the tailings wall, a series of technologies available in the market were analysed, among them, there is the capture of point cloud through a laser scanner. It was decided to use this type of instrument since it allows obtaining a wide range of information, which can be complementary to those already existing on the slope. In addition, it can, unlike other devices, obtain updated topographies instantly, with short post processes that can be used for updating databases, mapping and surface changes, which allows a retro-analysis to be carried out in each monitored sector and to create new scenarios in areas that are of potential risk. This approach allows the visualisation and monitoring of hotspots in real time. The system can detect and analyse small events in real time (Figure 2).

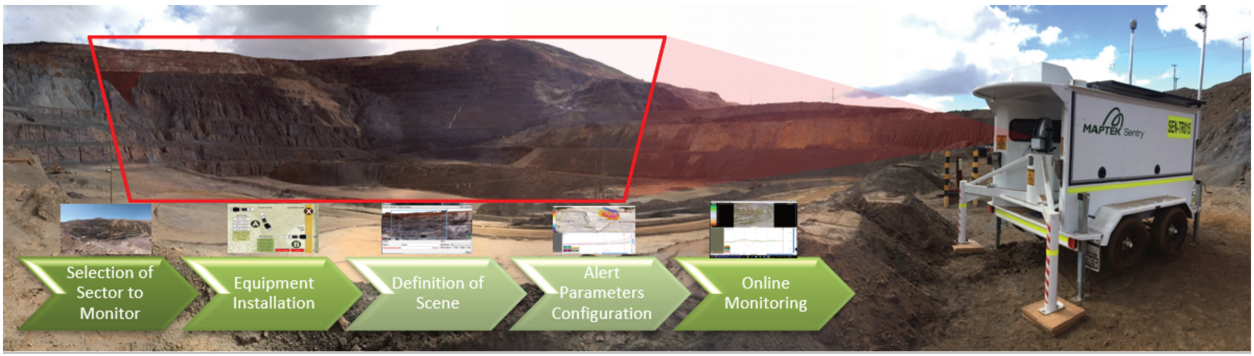

Figure 2 Monitoring plan configuration

4 Results

A plan involves monitoring several variables already mentioned. The results obtained by the proposed solution help make effective and timely decisions by minimising risk and structural damage to equipment and people (including all stakeholders related to the project). The precision and reliability of the system allows millimetric readings of the deformations presented in the monitored dam to be followed online in a timely manner according to the predefined thresholds.

Operations can then cross-validate this information with other control systems in the tailings deposit, thus improving operational control overall.

A very important feature is that the software can generate new monitoring zones, which were not originally configured, and it is possible to reconstruct the complete history of the zone. Sentry (Maptek 2021) stores all the information in the photographic image captured alongside scanning, during the entire execution of the monitoring. This is important, as it may identify new areas of structural instability, which did not exist when monitoring began.

The new zones created after the initial monitoring period allow to generate the same graphs and to recover the monitoring data of the history of the zone as if it had been created from the beginning.

This feature allows us to analyse in real time or in retrospect each scanned scene for any sector, without stopping the monitoring. The user only needs to determine the sector in which they record the monitoring history and thus create the monitoring zone. All graphical and analytical data for the newly created zone will be automatically generated.

The following image shows a progressive deformation curve over time, which, although it does not necessarily represent a future collapse, does give an indication of the behaviour of each of the selected areas (Figure 3).

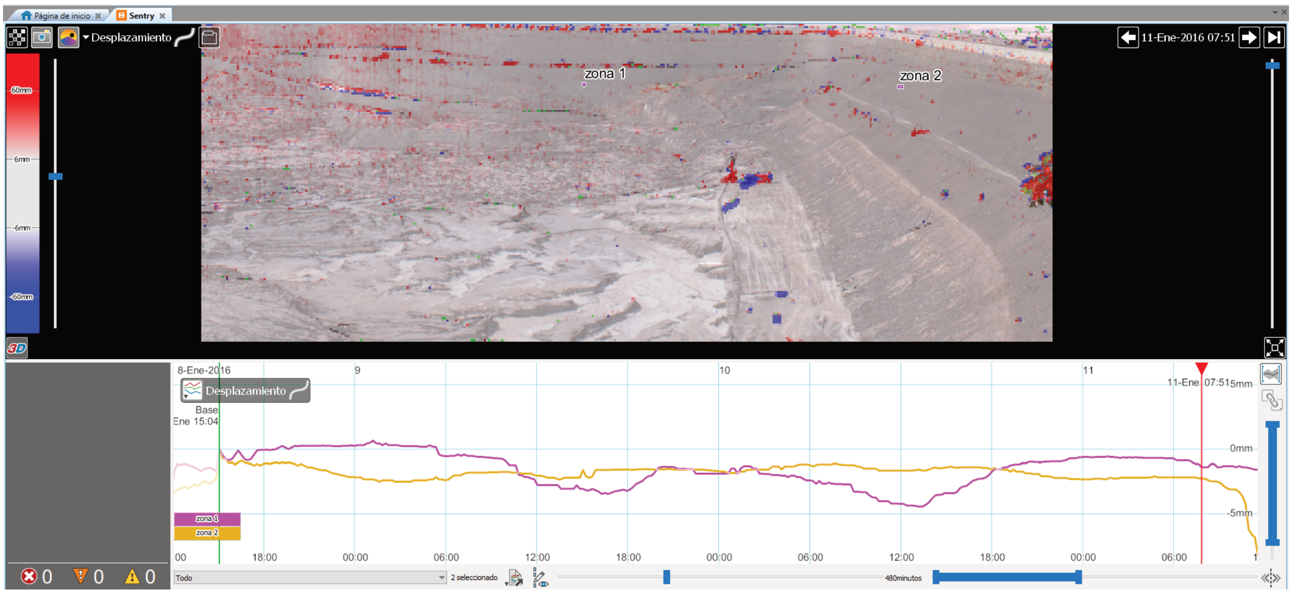

Figure 3 Progressive deformation according to active zones

Another important factor derived from this technology is the reading of displacement vectors without the need to install prisms on the wall. This reduces costs and the risk of exposing people in areas that are prone to failure.

This innovative result is obtained by capturing 3D data and the large amount of information that the laser scanner collects in each scan. The interoperability of the solution with other point cloud processing solutions allows both back-analysis and post-analysis to be performed quickly and easily (Figure 4).

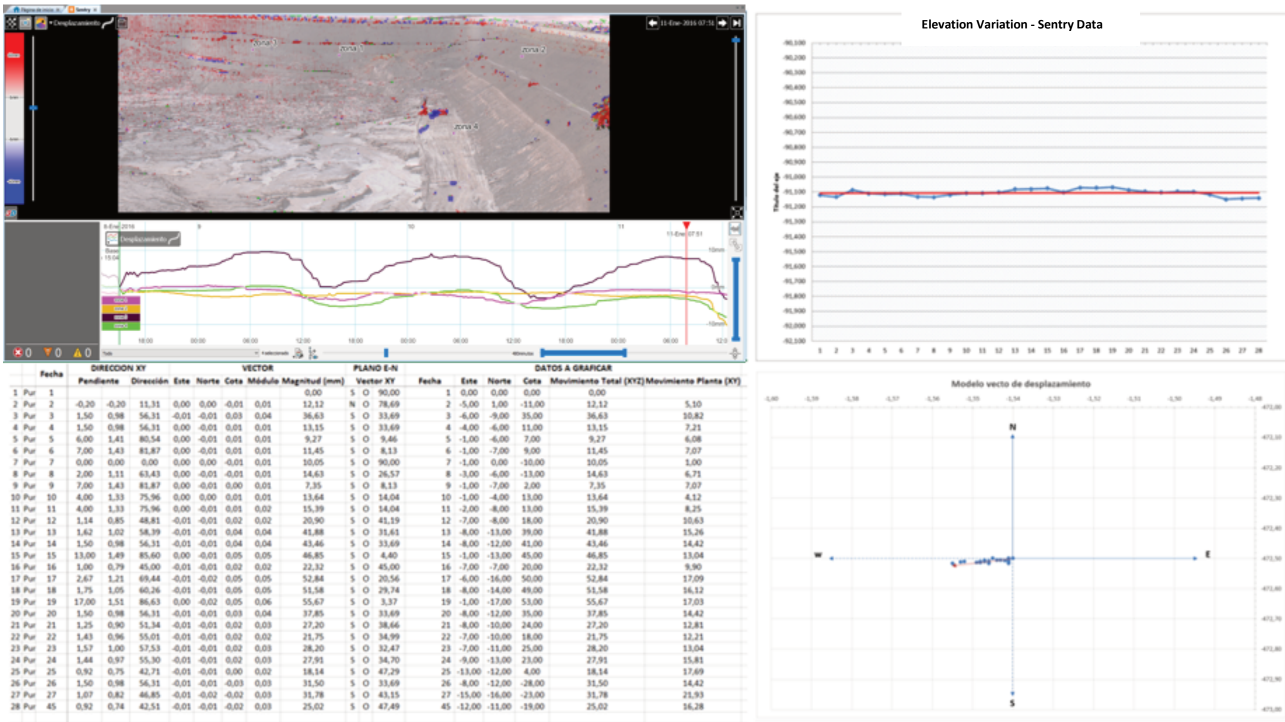

Figure 4 Interoperable data for calculating the displacement vector

5 Conclusion

This laser-based monitoring solution optimises time, and financial and human resources to streamline monitoring processes while constantly focusing on the main safety factors in areas where greater geotechnical attention benefits the operation. The risks are mitigated by having a lower exposure of personnel working in surveying, geology, geotechnics, and other collaborators of the mine. This technology can operate 24 hours a day, continuously extracting useful information from the data and with great versatility for the operating equipment of a mine and complete monitoring of the deposit, with all the main geotechnical parameters necessary to analyse its stability. The practicality and portability of the hardware allows it to be quickly relocated to monitor events as they unfold, allowing a decision support system for safe and productive mining.

References

Abramson, LW, Lee, TS, Sharma, S & Boyce, GE 1999, *Slope Stability and Stabilization Methods,* Wiley & Sons, New York.

Maptek 2021, *Sentry*, computer software, https://www.maptek.com/products/sentry/index.html

Oliva Gonzalez, AO 2015, *Instrumentación y Control de Taludes y Laderas (Instrumentation and Control of Slopes and Hillsides)*, technical report, Grupo Iteico Euroamericano.

Sernageomin 2018, *Guía Metodológica para Evaluación de la Estabilidad Física de Instalaciones Mineras Remanetes (Methodological Guide for the Evaluation of the Physical Stability of Remanetes Mining Facilities)*, Valparaíso, http://www.sernageomin.cl/wp-content/uploads/2018/04/Guia_Metodologica_E_Fisica.pdf