Integrated 3D Laser Scanning Implementation for Monitoring Tailing Dams

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Abstract

Tailings or mine waste storage dams are structures designed to store discarded material from various stages of ore concentration, which accumulates into large volumes. This is primarily due to the fact that, over time, the metal grades decrease significantly (< 1%). In this context, where storage demands continue to grow, effective risk management for these large and dynamic structures becomes crucial. These dams evolve in shape and size over time, and their stability is influenced by hydrometeorological and seismic events, which directly affect safety, and, consequently, the population near the tailings ponds. Over the past two decades, incidents involving tailings dams have prompted the industry to address the risks associated with efficient operational management, environmental impact, and safety concerns stemming from potential collapses.This article discusses the integration of a system through the application of 3D laser scanning and monitoring software, which delivers accurate results for both monitoring the stability of tailings dams and managing their operations. The process involves measuring millimetric deformations by calculating base data at critical points on the dam's wall. The objective of the 3D laser scanning system is to provide a decision-support tool that helps professionals manage geotechnical risks, monitor in real-time, and report movements caused by slope instability that could disrupt mining operations and result in material and human losses.The system provides safe, real-time alerts through a network predefined by the geotechnical professional. Additionally, the system's point cloud database allows for subsequent analysis, meaning that each scan performed by the equipment can be reviewed and reconstructed if there is a need to investigate a displacement event. This enables the monitoring of surface changes as remedial work is carried out, offering a risk management tool that ensures the safety of the team and personnel.

Keywords: Laser scanning 3D, monitoring, tailing dams, hazard

Introduction

The system presented in this paper integrates both software and hardware technologies, specifically designed to monitor, analyze, and report displacements in critical areas or zones of interest, as identified by the geotechnical professional. In this case, it is applied to the containment walls of tailings dams, which are defined as storage structures where the wall is constructed from the coarser fraction of the tailings, compacted through a process that separates coarse solids from finer ones via water-driven flow.

Containment walls are structures designed to contain the solid waste discharged during the final stages of mining. These walls are also referred to as "Resistant Prisms," as they form the peripheral area of the tailings storage facility. They are artificially constructed to complement the natural perimeter, thus forming the basin area. These walls contain waste deposits that evolve over time due to factors such as an increase in volume, embankment heightening, or exposure to various hydrometeorological and seismic events that can affect the dam's structural stability. As a result, strict monitoring and control of embankment walls and potential rupture or failure zones are necessary.

Currently, large dams require continuous and meticulous surveillance and control through an instrumentation and/or geotechnical monitoring system (Oliva, 2015). The need for instrumental monitoring, as well as the number and placement of monitoring devices, depends on the uncertainties related to site conditions and the behavior of the structures under normal operating conditions or in the presence of external events. This paper focuses on an integrated monitoring system that enables the study and oversight of tailings dams, aimed at enhancing both operational safety and the safety of surrounding populations. The 3D laser technology offers a decision-support system that assists professionals in managing geotechnical risks, provides real-time monitoring, and facilitates the reporting of movements caused by instability that could disrupt mining operations and result in material and human losses.

Methodology

Laser Technology

The methodology employed for displacement monitoring and control involves the use of 3D laser scanners and specialized software to capture and process point cloud data with Gaussian weighting. The Deployable Monitoring System integrates a 3D laser scanner that generates high-resolution point clouds, which are visualized in real-time through the associated software. This software allows the configuration of monitoring windows, within which alarms can be set to notify users via email if displacement occurs beyond a predefined range, enabling quick responses to high-risk operational events.

The system collects detailed data on the tailings dam embankment walls, utilizing cells that are ideally composed of 36 points. The distance and diameter of these points depend on the resolution, the monitoring distance, and the data acquisition speed, all of which are influenced by the reflectivity of the material being scanned.

Data acquisition is governed by both the reflectivity of the materials and the scan acquisition speed. For this process, a standard scan mode of 50 kHz was used, allowing the

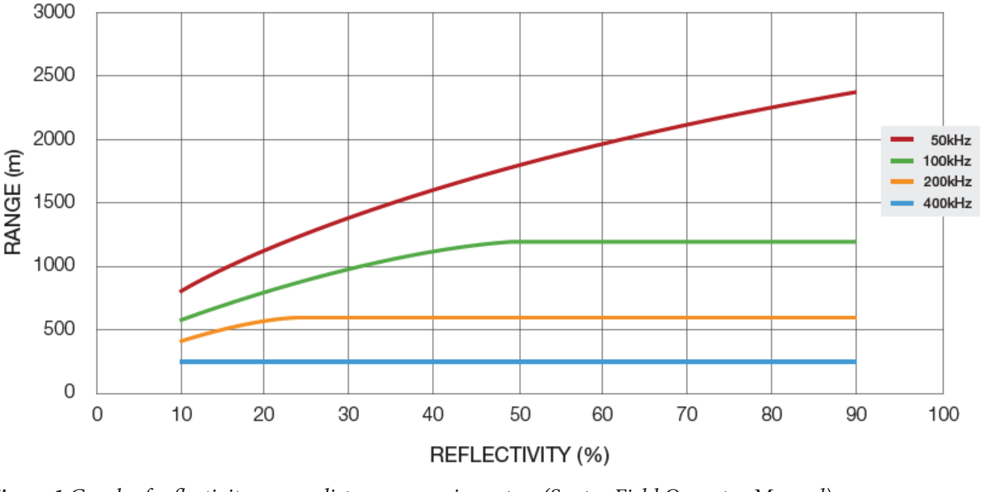

Figure 1 Graph of reflectivity versus distance range in meters (Sentry Field Operator Manual).

scanner to achieve a range of approximately 1600 to 1800 meters with a reflectivity of 40 to 50%, as shown in Fig. 1.

Implementation Process

The implementation process for the Geotechnical Monitoring System follows a series of key steps, as outlined in Fig. 2. First, it is crucial to assess the geological, geotechnical, and structural conditions of the area to be monitored, including the properties of the soil and the environment that will require monitoring. The next step is to determine whether visual monitoring or instrumental monitoring is needed. If instrumental monitoring is chosen, the following step involves identifying the specific parameters to be measured. Given that the focus is on monitoring tailings dam walls, a monitoring plan must be established using a laser scanner. This plan should include, at a minimum, the following key points:

- **Control Areas:** The monitoring system should be installed in critical areas where key parameters need to be measured.
- **Threshold Values:** The measurements obtained through monitoring will serve as an early warning mechanism within the risk management program. Maximum reference values will be set, which must not be exceeded.
- **Scan Frequency:** Regular monitoring and analysis of data enable the detection of abnormal trends in mass behavior, allowing for timely corrective actions when necessary.
- **Contingency Plan:** A response protocol will be developed for situations where deformation thresholds are exceeded. This protocol will include clear communication among all parties involved in controlling the mass movements

Selection of Monitoring Areas on the Tailings Dam Wall

For monitoring the tailings dam wall, the following surface measurements are recommended:

1. **Measurement of Freeboard:** This refers to the vertical distance from the crest of the dam to the surface of the tailings or water, specifically the distance from the dam's crest, which is situated above the water level in the pond.
2. **Measurement of Horizontal and Vertical Movement:** This includes monitoring the initial crest of the dam and the downstream slope for any horizontal or vertical movement.
3. **Measurement of Vertical Movements in Tailings Deposits:** These movements are significant due to the compaction from self-weight and consolidation of the tailings deposits.

Once the monitoring process is initiated, data is collected daily for post-processing. This allows for back analysis, which involves reviewing the data day by day to identify trends in the displacement curves. These trends can indicate various conditions, such as inactive, regressive, transgressive, linear, progressive, or critical behavior. Each curve is based on the accumulated displacement observed in each zone created at the start of the monitoring, or whenever the geotechnical professional decides to establish a new zone. Zones can be created at any point during monitoring, and they will reflect all data from the beginning of the monitoring until the zone creation date. Since the system continuously stores and preserves the data, the point cloud is always accessible for evaluating and interpreting the accumulated displacement in the monitored area.

In addition to graphically representing displacement, the software also provides information on inverse velocity and displacement velocity of the data. To ensure accurate data interpretation, it is recommended to capture as many point clouds as possible. In other words, the more data available, the more precise the interpretation of the displacement curves will be.

Results

The results obtained from the monitoring solution provide a real-time representation of the monitored area through the point cloud captured every 12 minutes, with photographic coloring, as shown in Fig. 3. Thanks to the system's high accuracy and reliability, it enables real-time tracking of millimeter-scale

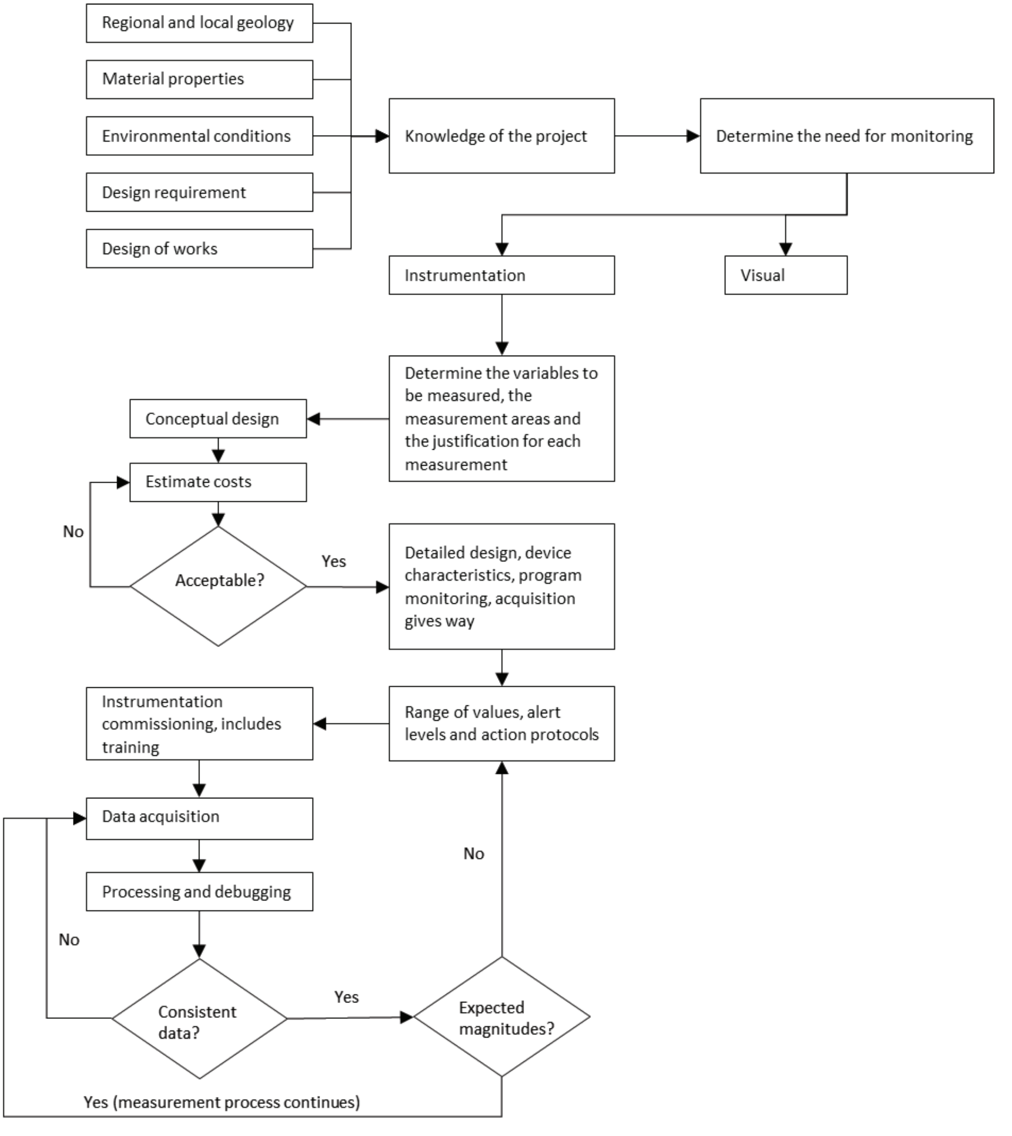

Figure 2 *Sequential diagram for implementing instrumental monitoring.*

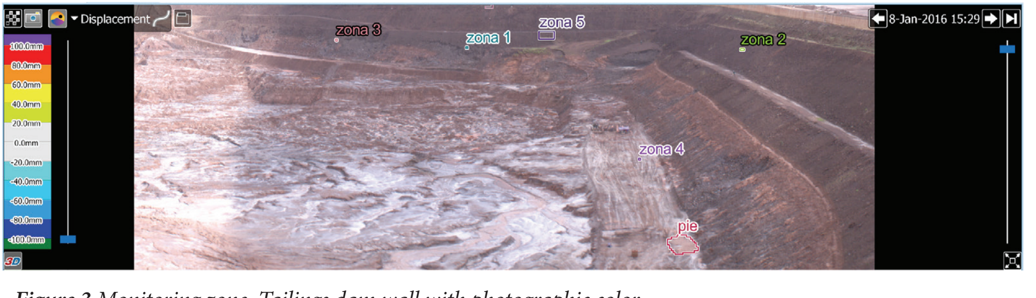

Figure 3 *Monitoring zone, Tailings dam wall with photographic color.*

deformations in the dam, with timely updates according to the predefined threshold values.

In Fig. 4 and 5, the monitored area is divided into subzones labeled Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, and Pie. These subzones are depicted in colors indicating either positive or negative displacement. Positive displacement represents forward movement of the material, while negative displacement indicates a setback in the monitored sector. The warm colors in the legend correspond to positive displacement, meaning that the cells within the Foot zone have moved approximately 40 mm closer to the monitoring equipment over a span of 4 days

In Fig. 6, the displacement graph shows the monitored zones as a function of time. Zones 1, 2, 3, and 4 exhibit a regressive to inactive trend over time. However, starting from January 12th, the Pie zone transitions from an inactive state to a critical condition, with the curve indicating instability at the base of the wall. On that date, the Pie zone shows a positive displacement of 30 mm, signaling a potential issue.

By January 15th, the area labeled "Pie" reaches an average accumulated displacement of 61 mm across an area of 61.60 m^2, making it the region with the highest displacement on the dam wall. The average point count per cell in this area is 35 points. Fig. 7 illustrates the color variation in a northward view of the wall. In the first image, the Pie zone appears gray, indicating no movement or a displacement of less than 20 mm. The second image, taken on the last day of monitoring, shows that the displacement in the central zone has exceeded an accumulated 100 mm.

Conclusion

The primary objective of this monitoring solution is to assist geotechnical professionals in making informed decisions based on displacement data derived from highly accurate point clouds captured using long-range laser technology. This provides reliable information that optimizes time, financial resources, and personnel. Additionally, the system streamlines processes, reduces operational costs, and enhances productivity within mining operations, all while maintaining a strong focus on safety in areas that require the most attention from a geotechnical perspective. The safety of personnel in fields such as surveying, geology, geotechnics, and other mine-related roles is consistently prioritized.

The laser scanner operates 24/7, continuously collecting valuable data and

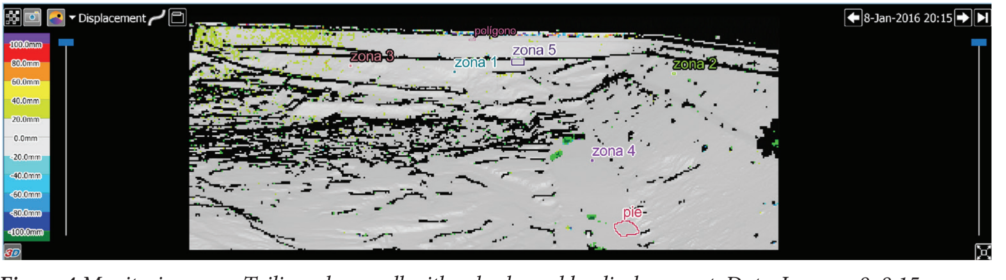

Figure 4 *Monitoring zone, Tailings dam wall with color legend by displacement. Date: January 8, 8:15 p.m.*

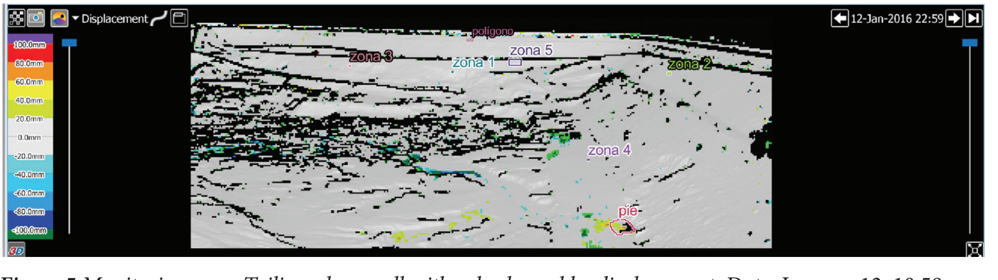

Figure 5 *Monitoring zone, Tailings dam wall with color legend by displacement. Date: January 12, 10:59 p.m.*

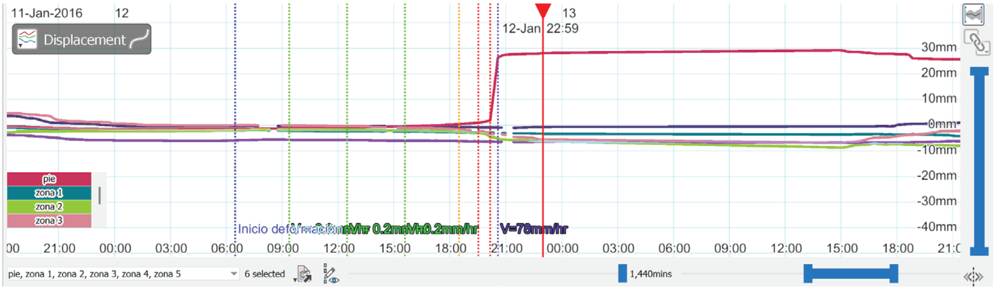

Figure 6 Monitoring zone, Tailings dam wall with color legend by displacement. Date: January 12, 10:59 p.m.

offering exceptional versatility for the mine's operational teams. It provides comprehensive monitoring of the tailings dam wall, capturing all essential geotechnical parameters required for stability analysis. The hardware's practicality and portability enable it to be swiftly relocated to monitor events in real time, offering a robust decision-support system for safe and efficient mining operations. This system can be rapidly deployed to any area that requires continuous, 24-hour monitoring.

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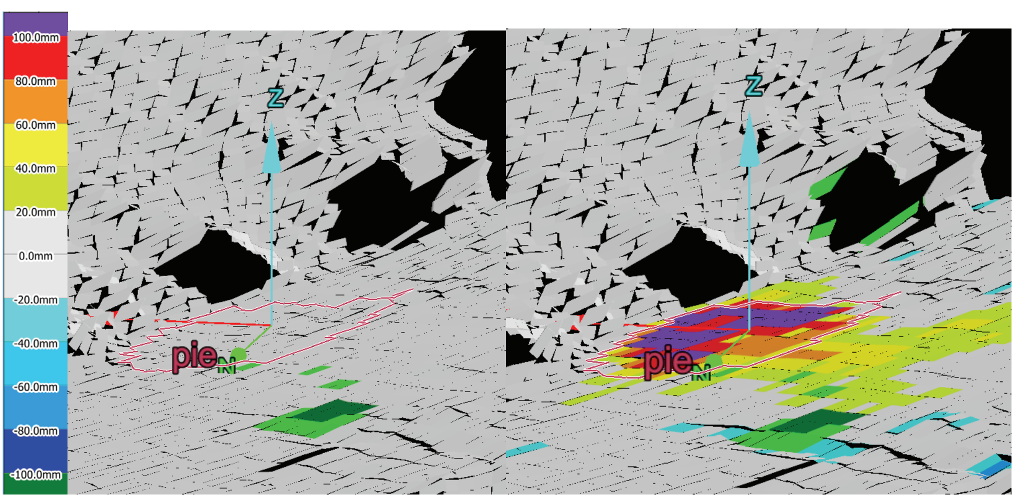

Figure 7 A comparative image, from the first day of monitoring versus the last day in the same "Pie" area.