

## Ensuring Safety of Bauxite Dams through Digitalization

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### Abstract

The instrumentation set up around dams is a vital part of the surveillance and governance of tailings storage facilities (TSF) to monitor the geotechnical performance. The data collected in the field helps the geotechnical team, consultants, and governmental agencies take care of TSF during construction, operation, and closure. The conventional monitoring procedure often relies on collecting instrumentation data manually at a particular frequency, limited to adverse weather conditions, accessibility, reading errors, and human effects. Digitalization makes it possible to improve the information collection stage, increasing the frequency and adapting to individual local conditions regarding solar incidence, rain absorption, and others. The custom built reports and graphs have significantly improved the critical analyses of geotechnical engineering teams. However, technology and automation do not replace the field and operational activities. Instead, they complement a geotechnical engineer's important role and ensure safety for operating personnel, community, and the environment. This paper describes the monitoring system installed in the tailings storage facilities and the procedures and controls adopted while migrating from conventional inspections and data collection to a modern control center. It highlights the barriers to implementing the Hydro Paragominas' tailings storage facilities system.

**Keywords:** Bauxite dams, Geotechnical digitalization, Instrumentation.

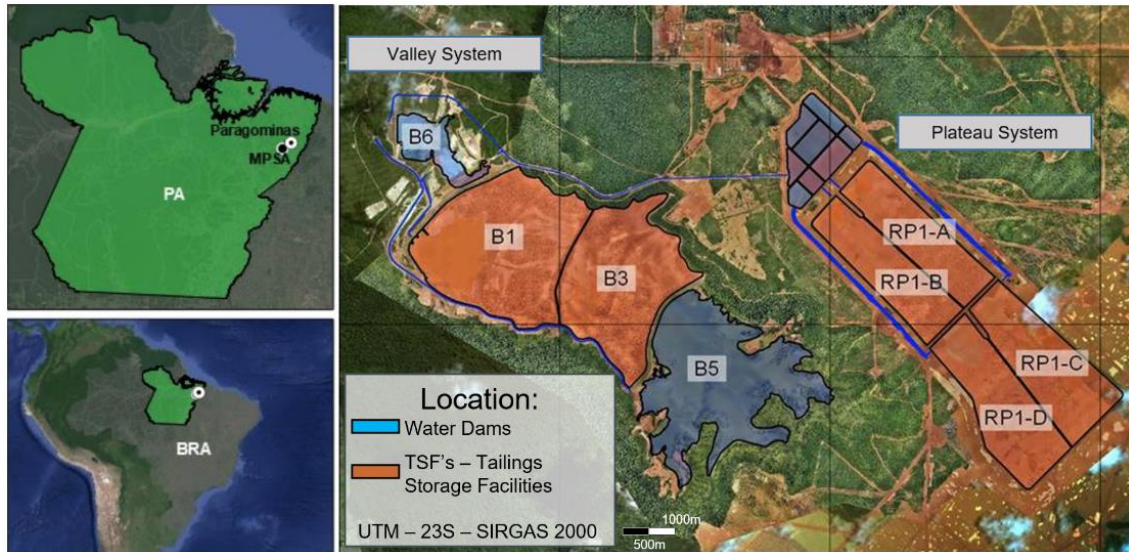
### 1. Introduction

Hydro currently owns and controls one of the primary mining operations in Brasil, the Paragominas bauxite mine. The bauxite mine is located in Paragominas, Pará, Northern Brasil. The installed production capacity is approximately 16 Mtpy of run-of-mine, producing about 11.5 Mtpy of bauxite and generating approximately 4.5 Mtpy of tailings. The mine started operations in 2006, six years after Hydro acquired the operations.

For the disposal of tailings and water recovery, Hydro Paragominas operated two different tailings systems – the Valley and the Plateau Systems. While the Valley System's design aimed for the final and permanent disposal of desiccated bauxite tailings, the Plateau System comprises four temporary drying areas. In contrast, the tailings are permanently deposited in the mined-out stripes through the patented backfilling methodology. Figure 1 shows the two tailings systems in Paragominas.

The Valley System, in operation from the very beginning of the mine operations, consists of three dams: the B5 dam, located upstream of the valley, is intended for water drainage storage; the B1

dam has the purpose of receiving bauxite tailings, and the B6 dam, located further downstream, is a sediment containment facility and is also essential for the plant water balance. As the Valley System approached the end of its useful life, the Plateau System started to operate.



**Figure 1. Valley and Plateau tailings systems in Hydro Paragominas.**

Tailings storage facilities are amongst mining companies' most critical structures of production and environmental matters. The safety of the tailings dam directly influences the mining operation, environmental protection, and the safety of the community's life and property [1], as evidenced after the last incidents involving tailings dams.

In this context, the mining operation and tailings management in the Amazon biome require a total commitment to safety, social and environmental standards, and best practices. Since adequate monitoring is an essential part of tailings management, as described in the recently published Global Industry Standards on Tailings Management, advances in the related technologies have supported the operation, maintenance, and surveillance of the TSF.

Amongst the well-known challenges of geotechnical monitoring, the current demand for automation imposed by federal agencies in Brasil has required more effort for the sector to provide suitable solutions. The sector's main challenges are data transferring, communication, power supply, reliability, and redundancy.

Authors [2] pointed out that the governance of data generated in the field and detailed monitoring must undergo constant evaluation, analyzing its performance and verifying if current conditions are satisfactory. It also mentions that a proper design will serve as the first step in providing adequate monitoring and that it should provide the conditions for evaluating the efficiency of the installed instrumentation and when it will be necessary to adjust it.

## 2. The Monitoring System

Both tailings systems, object of study of this work, are located in the northeast of Pará, at the Paragominas bauxite mine complex. The importance of instrumentation in dams is similar to regular industrial plant, measuring the performance, create key performance indicators (KPI's), develop control management, triggered action response plans (TARP's), while it creates value regarding environment, social and governance.

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Inspections and technical assessments must be carried out to assess the hydraulic, hydrological, geotechnical, and structural characteristics of the dam's various facilities. The monitoring process follows resolution 95/2022 from Agência Nacional de Mineração (ANM) [3] and the best engineering standards and procedures.

As published by the 95th resolution of ANM, operators must compute and register the real-time monitoring data gathered from the instrumentation of dams [4]. This resolution is an essential step for mining companies that intend to improve dam safety for operating personnel, communities, and the environment. If adherence to this regulation is not fully compliant, it would cause several administrative or fines penalties, which means it is mandatory for operational continuity.

Several instruments are used in dams to measure physical phenomena, tensions, deformations, pore water pressure, percolation, flow, earthquakes, and displacements [5]. The more straightforward instrumentation for operation and monitoring of tailings dam performance consists of piezometers for determining water levels in the dam body and its foundations [6]. The instrumentation monitors the settlement and deformation speed in the dam body and seepage through the foundation and buttress. All information collected is stored on the dam databook and checked by the technical team and external consultants. All data is reported to regulators. The reports are part of the lifetime information for the dam system.

The instrumentation available on the market to meet the demands of the area includes manual and automated equipment. Manual data acquisition has the disadvantage of depending on ease of access and is limited to partial readings with no continuity. On the other hand, the automated system has the disadvantage of relatively high investment and the need for specialist areas (instrumentation, automation, Information Technology – IT), which commonly requires digital transformation solutions to integrate the instruments with the company's monitoring system [7].

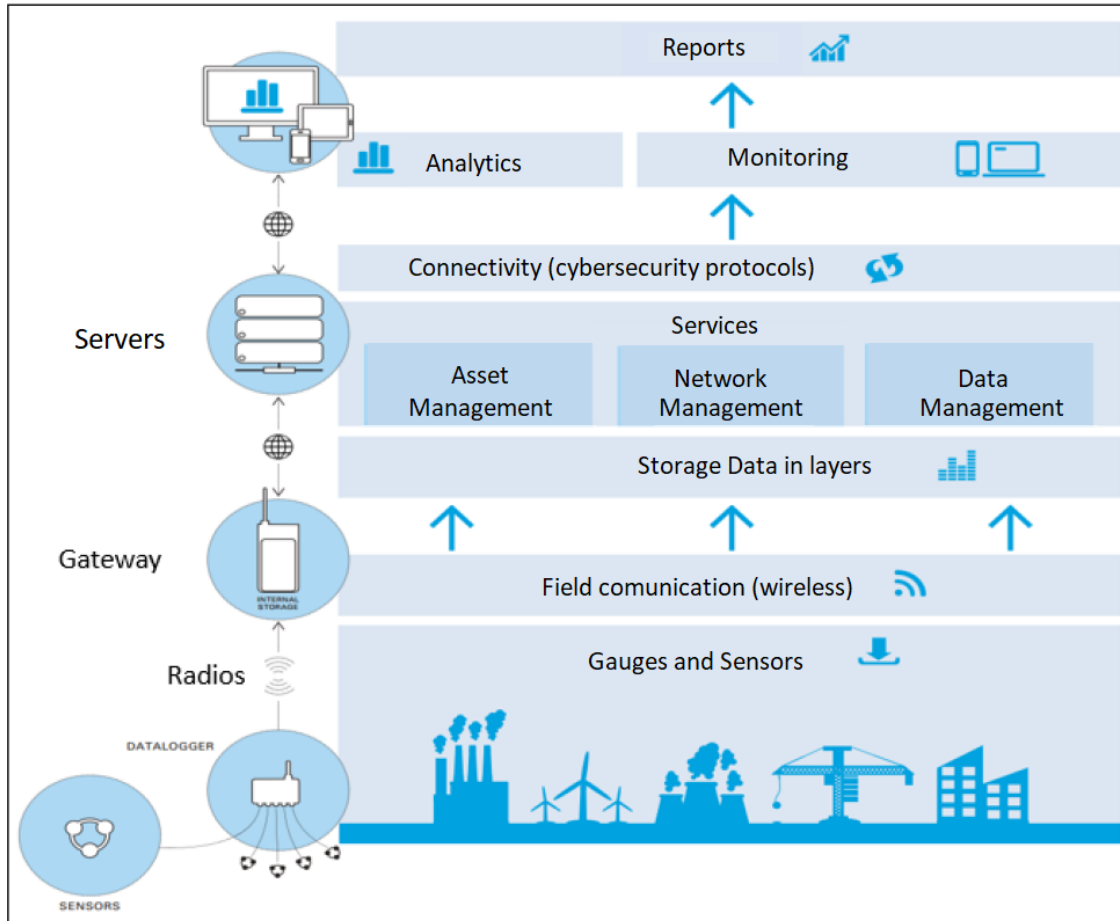
The advantages of automated systems in the dam's monitoring process are [8]:

- Online reading of variables, quickening decision-making face of anomalous occurrences;
- Improved data documentation, since they will be stored in electronic files, thus avoiding human interference in data entry;
- Availability of data to all members of the team responsible for monitoring the dam simultaneously;
- Improved data analysis, considering that it will be possible to generate graphs in real-time, make comparisons and correlations between measurements;
- Reliability of the data obtained.

### **3. The Path to Digitalization**

Digital technologies are reinventing the overall work experience in the mining industry. Technology advances in artificial intelligence, mobility, and analytics demand a new set of organizational capabilities to empower a more fluid, responsive, and innovative future workforce. [9].

Many organizations have implemented digitization to make their processes more accountable, transparent, and traceable [10]. The data infrastructure also allows companies to track and store the data created by systems that can be trackable. The flow in figure 2 shows the generic pathway for monitoring data:



**Figure 2. Example of network point-to-point. Adapted from [11].**

Moving towards digital transformation generally requires organizations to rapidly change organizational structures, strategies, IT architectures, methods, and business models [12]. This data-led management brings quick decision-making, leveraged to dam management and surveillance.

#### 4. Materials and Methods

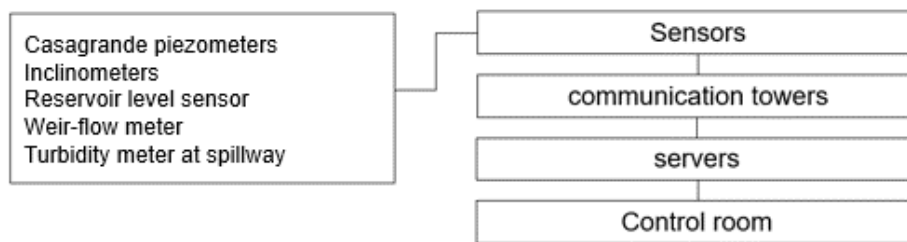
The automatic monitoring system and other safety systems have been focused on dams in recent years, aiming to bring robustness and reliability for real-time decision-making systems and integration with the corporation's data.

For the automation of the Hydro Paragominas system, the engineering team accompanied by consultants to research the best solution for a geotechnical integrated communication network. Since no standard solution fits the system, different companies worked to support the customized solutions for the Valley and the Plateau systems.

Hydro has deployed in Paragominas a robust monitoring framework with an integrated network that delivers data and maintenance reliability. The system used ensures data redundancy, where

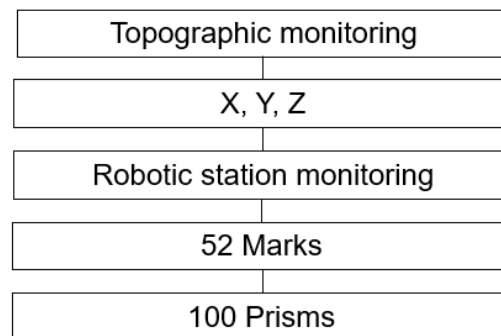
online gauges allow manual reading, fundamental to periodical calibration and cyclic redundancy check routines.

The digital solution was adapted to the existing piezometers and water level indicators standpipes. The operation, maintenance, and surveillance manual were revised to incorporate the excellent routine of the instrument readings and the execution of tests to certify its functioning. In addition to these existing instruments, the solution considered installing level meters, weir, internal drainage flow meters, and turbidity. All sensors can communicate data to the servers located in the processing area. The servers will be able to take the information instantly to the control room with the appropriate alerts and send the information to a data cloud as it is shown in Figure 3.



**Figure 3. Simplified network of automation of the different instruments on field.**

Another digital technology implemented is topographic monitoring. The system seeks the instantaneous analysis of potential displacements on the x, y, and z-axis. The procedure reads the current value of coordinates and compares it with the zero reading of the fixed marks installed at many locations around the embankment. The digital solution integrated an automated audible alert system based on sudden displacements. The system consists of a Robotic Monitoring Total Station (RMTS) installed in proper cabins, counts with reference prisms installed at points of controls, and performs a routine of scanning of pre-defined fixed points.



**Figure 4. Topographic monitoring.**

The triangulation, a vital step to keep the data accurate, is made by three reference points considered in each structure. The fifty-two existing topographic landmarks remained unaltered to maintain the monitoring history. Forty-eight additional prism marks supplemented the monitoring system, with a total of one hundred prisms operating in the geotechnical structures.



**Figure 5. a) Cabins topographic monitoring, b) Robotic Monitoring Total Station (RMTS), c) Reference mark and d) Monitoring prism.**

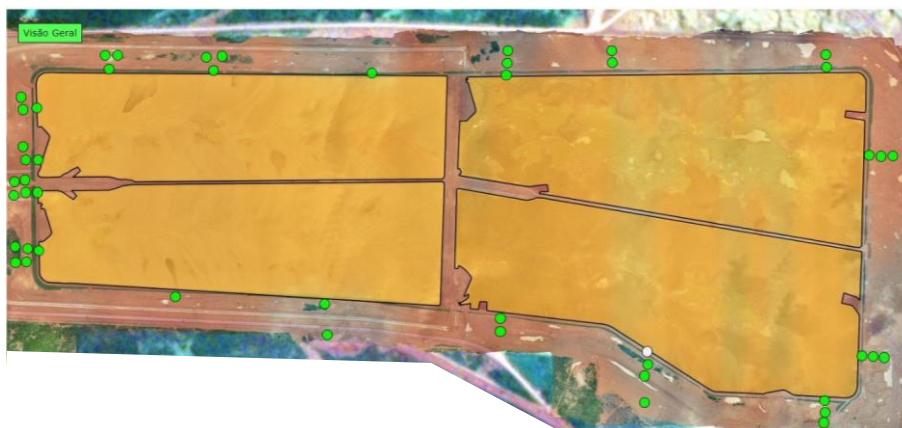
The data record and communication infrastructure must follow strict data security and IT protocols. These controls are essential to promote cybersecurity best practices; the fourth layer is related to cloud storage from the monitoring system.

The monitoring platform allows real-time visualization of the dam's instrument readings and the correspondence with the threshold limits.

## **5. Results of Safety trough Digitalization**

Hydro Paragominas have automated real-time observation of the dam safety monitoring results, aiming to fully comply with the dam safety protocols and governance based on a multi-technology real-time monitoring network.

The monitoring system pictures from 6 to 9 show the instrument's status with a geographic position.



**Figure 6. RP1 geotechnical monitoring.**



Figure 7. B1 dam geotechnical monitoring.

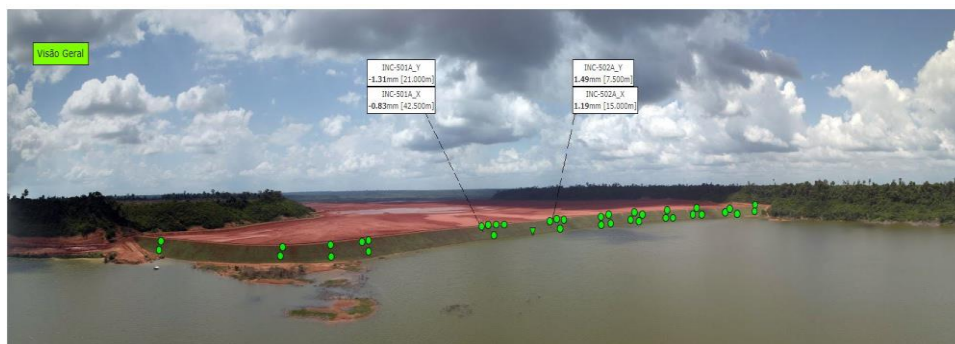
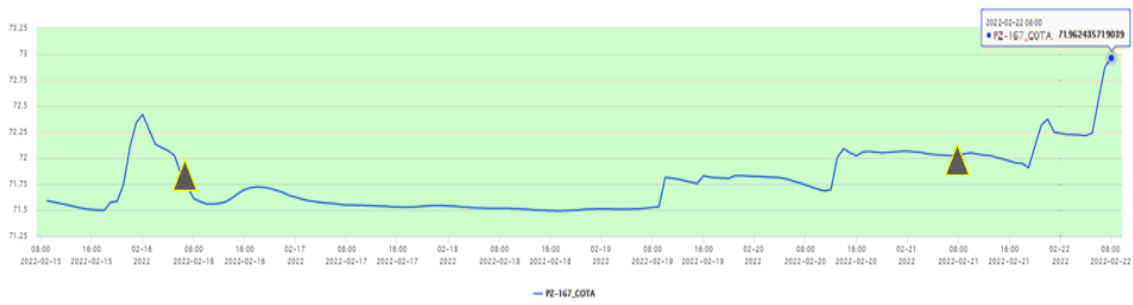


Figure 8. B5 dam geotechnical monitoring.



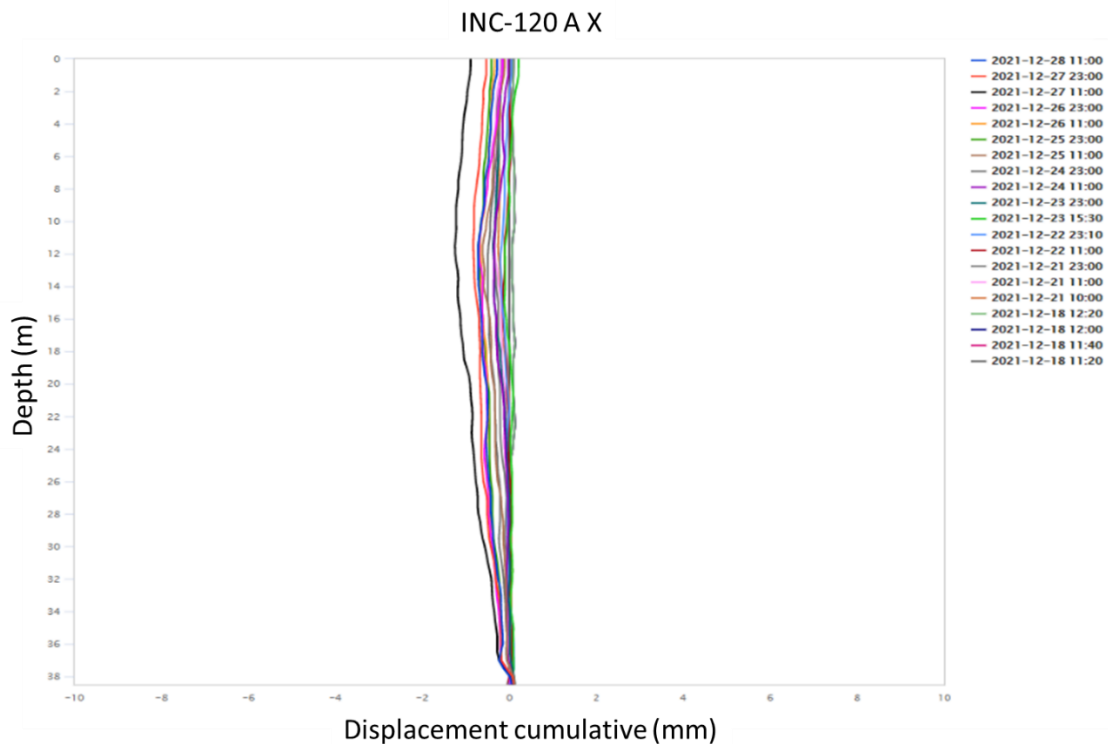
Figure 9. B6 dam geotechnical monitoring.

The monitoring and surveillance of the system has two different user levels of access. They are divided into administrators and ordinary users. Administrators can perform the remote server management and server settings, such as establishing data acquisition time, setting the server port, and customizing the dashboards and reports. Ordinary users can verify data and state of the browser, check the video monitoring historical, and download graphs and reports. The operator manager delegates the permission to the entire team. Figure 10 shows the piezometric height registered by piezometer PZ-167. The continuous line shows the automated readings, while the triangle shows the manual readings, showing evidence of the phreatic behavior missed by the traditional monitoring method. While the automated systems can gather real-time variations in the phreatic, providing more clarity to engineering team, the traditional methodology only registered the pore water pressure at the very time of reading.



**Figure 10. B1 dam – Automated x Manual Piezometric Monitoring.**

Figure 11 presents the deformations captured every 12 hours by the automated inclinometers.



**Figure 11. Graph with inclinometer automatic reading with one-hour interval.**

The system of instrumentation and auscultation covers a total of 273 instruments before being read manually. The previous routine demanded field campaigns that required at least one day a week to achieve total data collection of instruments every fifteen days.

The digital implementation has taken 18 months to complete, and now the system can monitor with continuous readings, using small intervals, varying between 10 minutes and 1 hour, depending on the instrument. This technology transition improves the geotechnical assessment reliability and operational safety by using a much larger amount of reliable and verified data through the statistical framework.

## 6. Conclusions

The trend towards digitization of mining dams, motivated by the automation of geotechnical instruments and constant recordings of Closed-Circuit Television (CCTV), generates a significant volume of data compared to the old monitoring conditions, primarily manual and on site. This approach provides much larger data bank and enable the possibilities for statistical analysis, better visualization and improved management of assets. In addition, they require a more significant number of people and a multidisciplinary team from planning to implementing the entire IT/AT (automation technology) structuring, culminating in the proper analysis of the images and geotechnical monitoring information.

Field evaluations and manual readings of the instruments remain good practices and are of paramount importance for identifying the dam's performance on site and carry out calibration for to allow analysis of the data coming from automated instruments.

By conducting analysis, Hydro Paragominas could use digitalization in the industrial area, which is considered crucial for the environmental, social, and governance business. The main driver for this innovation path has been to deliver increased productivity, reduce risks and improve technical team analytic capacity.

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