Mine Tailings Surveying After the Brumadinho Dam Failure

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ABSTRACT: The investigation committee report into the causes of the Brumadinho Dam failure has re-emphasized on-going shortcomings in surveying methods and practices for tailings facilities. These shortcomings were also highlighted in the causes of failure report for Fundao dam which was published in 2016. The authors see some of these same shortcomings at many mines around the world.

These reports highlight the fact that many mines do not maintain complete, verifiable, as-built surveys of their facilities which can be used to show that the TSF was constructed and operated in accordance with the dam's design.

The authors have extensive experience in producing surveys of TSF and mine sites at a globally diverse range of locations. Based on this experience we will show examples and explanations of the shortcomings of commonly used survey methods that are highlighted in the dam failure investigation reports, with a real-world example of best practices.

1 INTRODUCTION

There have been several recent tailings dam failures with significant human and environmental impacts, notably the Feijão Dam I, Brazil (Brumadinho) and the Fundão Dam, Brazil (Samarco). Investigation reports have emphasized the critical nature of maintaining complete, verifiable, as-built surveys.

PhotoSat has completed over 1,200 mine tailings surveys around the world. This includes producing over 600 time-stamped surveys of mine tailings facilities since 2012, and three technical reviews of major mine tailings failures.

2 FUNDÃO AND FEIJÃO DAM FAILURES

Both the Fundão and Feijão tailings dams were designed to be upstream tailings dams composed of unsaturated sands. Some areas of the sands in both dams was water saturated, making the dams only marginally stable.

Fundão Dam I failed at the left abutment most probably due in part to the presence of tailings slimes beneath this portion of the raised dam.

Feijão Dam 1 failed most probably due to strains from internal creep combined with the influx of surface water from heavy rainfall in Q4 2018.

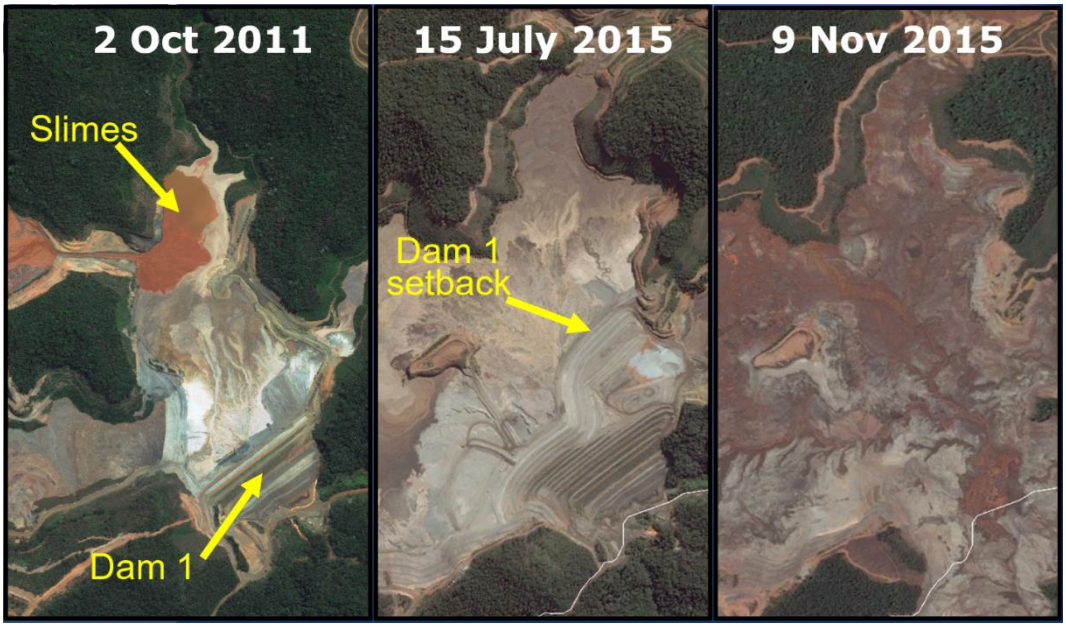

Figure 1. WorldView satellite photos of the Fundão dam. October 2011 showing the introduction of tailings slimes to Dam 1. July 2015 showing the Dam 1 setback over the tailings slimes. November 2015, four days after the failure of Dam 1.

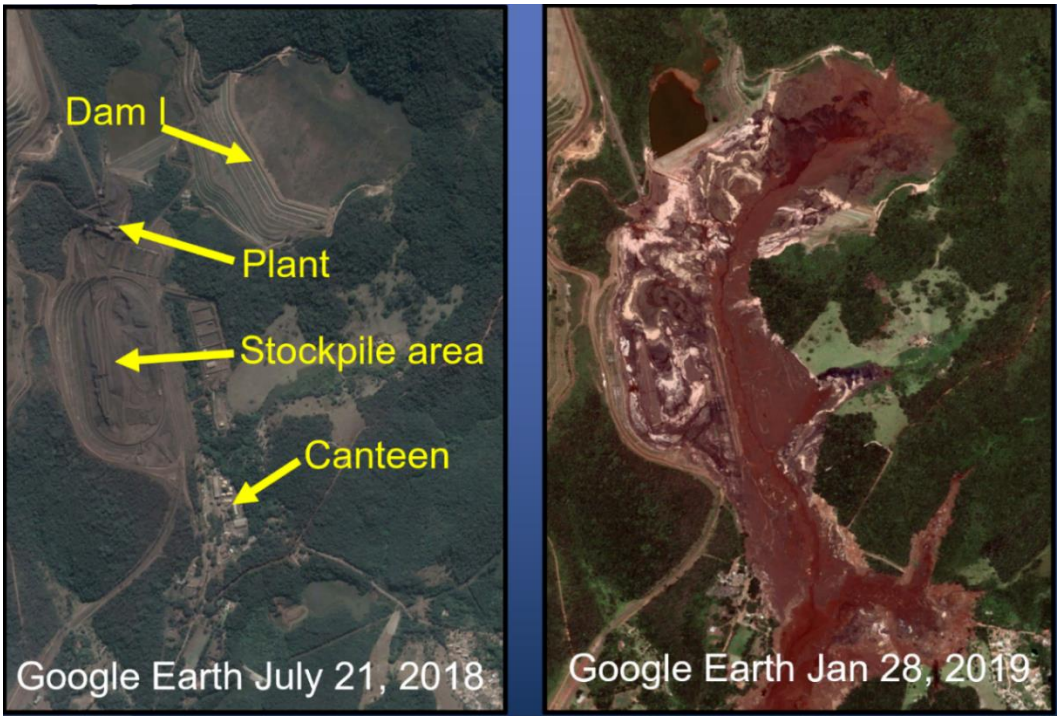

Figure 2. WorldView satellite photos of the Feijão dam I. July 21, 2019, six months prior to the failure. January 28, 2019, three days after the failure.

2.1 *Surveying issues at the Fundão Dam*

The Report on the Immediate Causes of the Failure of the Fundão Dam noted surveying issues "…typical for a large tailings dam…", including data inconsistencies, sporadic surveys that only covered a small area and did not appear to have been done for the purposes of monitoring tailings deposits, and the utilization of drone data patched over several survey periods and which did not follow accepted contouring standards.

2.2 *Surveying issues at the Feijão Dam*

The Report of the Expert Panel on the Technical Causes of the Failure of the Feijão Dam commented on the limited number of topographic surveys available for the investigation, and noted, "Because as-built drawings were either not prepared or not available for review, many of the design features and specifications described below are based on the Panel's understanding of the plan for dam construction, rather than confirmation of what was constructed."

3 GLOBAL TAILINGS STANDARD DRAFT REPORT

Global Tailings Standard Draft provides recommendations for officials and experts responsible for tailings facility safety oversight including a Responsible Tailings Facility Engineer (RTFE), Independent Tailings Review Board (ITRB), Senior Technical Reviewer, Engineer of Record (EOR), an Independent Tailings Review Board, and regularly conducted risk assessments with a qualified multidisciplinary team.

3.1 *Tailings facility surveying requirements*

Tailings surveying must meet daily, weekly and monthly operational needs, provide a long-term overview of the tailings facility development (i.e. monthly survey snapshots), meet external perceptions that the best technology and practices are being used to keep the tailings facility safe, and must fit within any budget constraints.

4 PHOTOSAT'S MINE TAILINGS SURVEYING EXPERIENCE

PhotoSat has carried out over 600 surveys of mine tailings facilities since 2012. Over 100 of these surveys have covered the tailings facility for the Steepbank and Millennium oil sands mines in Northern Alberta, Canada. PhotoSat surveyed this facility monthly during the winter and twice monthly the rest of the year since January 2013. This is one of the largest tailings facilities in the world, handling over 40 million m3 of mine tailings per year.

PhotoSat regularly surveys tailings facilities at operating mines in most of the major mining regions of the world. Depending on the volume of tailings at these mines, surveys may be completed monthly, quarterly, or twice annually. The watersheds upstream from the mine sites and the potential inundation areas downstream tend to be photographed annually and surveyed every three years at larger mines.

Currently, many mine owners and tailings engineers rely on various survey reports from ground GPS, terrestrial scanners, and drones to build a comprehensive view of their tailings facility. They believe this process provides them with enough information to maximize the long-term safety and stability of their tailings facility. They often underestimate the extent to which their current survey data limits their long-term overview of the facility.

A few mine owners and tailings engineers continue to manage tailings facilities using only pumping volumes, on-foot dam inspections and boat bathymetry. They may unaware that their tailings facility surveys may be inconsistent or error-prone, or that more reliable surveying is practically possible. It is also possible that the potential impact of those errors on the long-term management of the tailings facility is not well understood.

4.1 *Understanding common mine site surveying errors and deficiencies*

When surveying a mine site for the first time, PhotoSat always tries to compare our first survey to the existing mine site survey data. This existing survey data is usually a combination of ground GPS and drone surveys. This experience has given PhotoSat insights into common exceptions and errors in mine sites surveying, particularly mine tailings facility surveying.

In reviewing survey data from many mine sites over the past several years, the most-frequently observed survey problem is that mines attempt to produce monthly site wide survey overviews by patching survey data from multiple sources. Each of the individual surveys are usually

collected for specific operational needs and are not designed nor intended to be part of a regular site wide survey overview.

PhotoSat's experience working with tailings engineers has determined that elevation surveying accuracy better than 20 cm RMSE in elevation is required to accurately monitor tailings dam heights, tailings beach lift thicknesses and deposition locations.

5 MINE SITE SURVEY CONTROL

Mine site topographic surfaces are continually changing. Some mine site-wide surveys are composed of mosaics of several smaller surveys completed on different days. When check surveys and other survey data sets are compared to these mine site wide survey mosaics, it is often difficult to determine the actual date of the relevant portion of the overall mine site survey. Survey difference and discontinuities are then often dismissed as being due to topographic changes between the survey dates.

Individual, separate, mine site survey data sets may be compared to the time-stamped, mine site wide survey. Mismatches between the individual topographic surfaces and/or the photos of each of the individual surveys and the mine site wide survey often reveal survey errors. Once these survey errors are identified most mine site operators usually move quickly to rectify them.

Consistent, routine surveys and photographic snapshots of entire mine sites enable mine owners, tailings engineers, and independent reviewers to better understand and demonstrate the safety and stability of the tailings facilities. With consistent, routine surveys and photographic snapshots they are better able to monitor the tailings facility's conformity to, or departure from, the design criteria and evolving national and international tailings facility safety standards.

A monthly or quarterly series of consistent, uniform time-stamped surveys that cover the entire mine site and surrounding areas, with each survey completed in a single day, provide a long-term auditable record of the state of the mine site including the tailings facility. Surveying of an entire mine area in a single day can currently be accomplished with air photo, airborne LiDAR and satellite surveying. Only satellite surveying can survey an entire mine site in a single minute.

6 EXAMPLE OF GOOD TAILINGS FACILITY SURVEYING PRACTICES

The Suncor Millennium Mine is PhotoSat's best example of good mine site surveying practices. The oil sands mines of northern Alberta Canada have the world's largest volume mine tailings facilities. In PhotoSat's view, these are among the most meticulously engineered and carefully managed tailings facilities on the globe.

Suncor Millennium Mine does monthly surveys which provide photos and topography that cover the entire site plus a large area surrounding it (no patching), are consistent to 15 cm vertical accuracy in all areas of the site, ensure consistent accuracy month-to-month, are tested and validated monthly, are used as operational data by many groups daily. Site-wide surveys have been conducted at least monthly since 2013.

6.1 *PhotoSat survey specifications for the Millennium Mine*

PhotoSat provides the Millennium Mine with:

Elevation Grids: (1 m or 50 cm grids of elevation values, vertical accuracy of 15 cm RMSE, thinned versions for engineering software, mine grid and UTM projections, and tiled to match application areas)

Toes and Crests: (breaklines of the toes and crests of all step changes in elevation on the mine site)

Waterbody Polygons: (boundaries or all ponds and water bodies over 400 m^2)

Orthophoto: (50 cm or 30 cm resolution satellite photo, precision orthorectified)

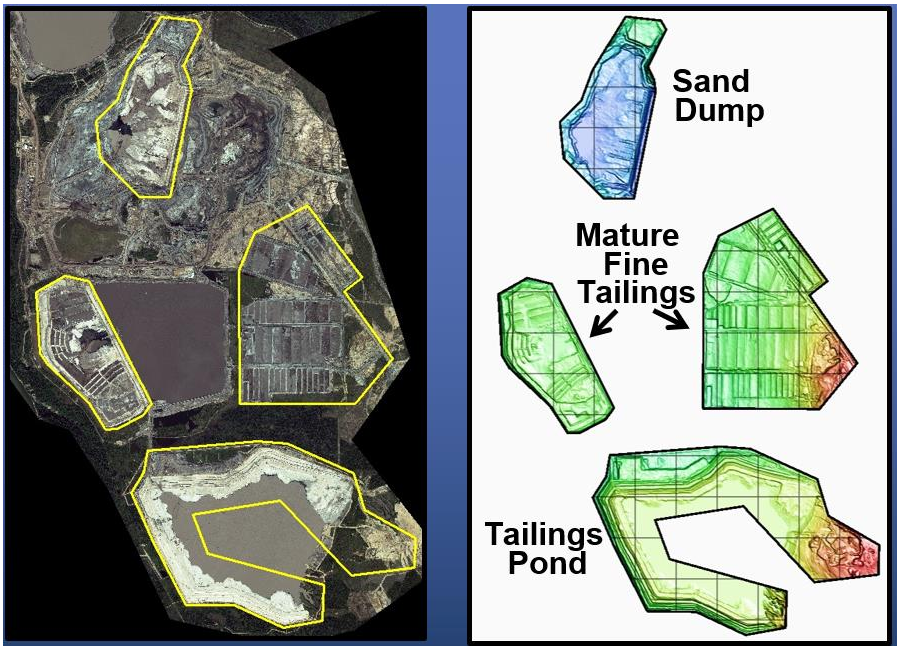

Figure 3. PhotoSat surveys of the Millennium Mine tailings facilities. Surveys accurate to 15 cm in elevation. Figure from a published Suncor presentation.

7 IMPROVING MINE SITE SAFETY THROUGH BETTER SURVEYING

Highly accurate and reliable survey data leads to a better-informed decision making process, with the potential to improve safety and management practices. PhotoSat recommends the following mine site survey standards for mines with large tailings facilities: monthly, time-stamped, surveys of the mine site; annual photographic surveys of the watershed upstream of the tailings facility; topographic surveys of the watershed upstream of the tailings facility every three years; annual photographic surveys of the potential inundation area downstream of the tailings facility; and topographic surveys of the potential inundation area downstream of the tailings facility every three years.

8 CONCLUSION

Both the Fundão and Feijão tailings dams investigations documented poor or incomplete surveying practices which are common in many mines with large tailings dams.

A long-term, auditable record of the state of the tailings facilities can be achieved with a monthly or quarterly series of consistent, uniform time-stamped surveys that cover the entire mine site and surrounding areas.

Surveying of an entire mine area in a single day can currently be accomplished with air photo, airborne LiDAR and satellite surveying. Only satellite surveying can survey an entire mine site in a single minute.

In our experience the above recommendations will improve the surveying deficiencies that are the result of the piecemeal surveying currently employed in many mine tailings facilities in various places in the world.

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