PhotoSat
Leaders in Satellite Surveying for Mining and Energy
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The role of mine site surveying in evaluating and mitigating risks of failure of mine tailings facilities

Submission to the Global Tailings Review

Unrestricted distribution
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Introduction:

Frequent, accurate, topographic surveys and photographic mosaics of the mine sites and surrounding areas are a key component of the safe design, planning, construction, operation, expansion and closure of mine tailings facilities. To that end PhotoSat has developed unique in the world knowledge and experience in comprehensive mine site, tailings facilities and surrounding area surveying. That knowledge and experience has exposed potential surveying deficiencies that may reduce mine tailing safety in tailings facilities in some areas of the globe.

PhotoSat gained our initial mine tailings surveying experience surveying the tailings facilities of the oil sands mines of northern Alberta Canada. The Alberta oil sands mines have the largest volume mine tailings facilities in the world. We believe that these are among the most meticulously engineered and carefully managed tailings facilities in the world.

The large size of the Alberta oils sands mine sites, some over 200 km^2 in area, required the development of new surveying technology. To meet this survey requirement PhotoSat developed stereo satellite surveying technology capable of surveying areas greater than 200 km^2 accurate to 15 cm in elevation. The stereo satellite photos covering the entire mine sites are collected in approximately one minute. This provides instantaneous survey snapshots of the entire mine sites. We deliver survey snapshots of some of these mine sites every two weeks.

Through having these instantaneous survey snapshots of the entire mine sites and surrounding areas PhotoSat has had many opportunities to learn about common errors and deficiencies in mine site surveying. PhotoSat's oil sands mine site surveys are continuously compared to other mine site survey data sets including drone surveys, LiDAR surveys, truck mounted and handheld GPS surveys, and various types of terrestrial laser scanner surveys, giving them an industry leading degree of accuracy.

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When we applied the knowledge and expertise gained surveying the oil sands mines' tailings facilities to mines in other areas of the world it became apparent that many mines surveyed had markedly lower mine site tailings facility survey standards than in the oil sands.

The most common deficiency that we see is that monthly tailings facility and mine site surveys are often compiled from several different surveys each acquired for a specific mine site operational requirement. These compilations of piecemeal surveys often miss significant changes in the tailings facilities. Our concern is that those lower mine site survey standards have contributed and continue to contribute to sub optimal mine tailings facility safety.

HOW TO IMPROVE MINE SITE SAFETY THROUGH IMPROVED SURVEYING

To improve safety, and in keeping with the high standards used in Alberta's oil sands, PhotoSat recommends the following mine site survey standards for mines with large tailings facilities:

a) Monthly surveys of the mine site:

1. Topographic survey of the mine site, including the tailings facility, and the areas within 1.0 km of the mine site
2. Survey
    a. At least 1.0 m survey grid spacing
    b. Vertical accuracy of better than 20 cm RMSE
3. Photographic mosaic
    a. At least 50 cm ground sample distance
    b. Horizontal accuracy of better than 1.0 m RMSE
4. Polygons of all the waterbodies with areas greater than 400 m^2 on and adjacent to the mine site
5. The topographic survey and photographic mosaic data for the entire mine site should be "snapshots", collected in a single day

b) Annual photographic surveys of the watershed upstream of the tailings facility:

1. Photographic mosaic
    a. At least 1.0 m ground sample distance
    b. Horizontal accuracy of better than 5.0 m RMSE

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2. Waterbody polygons of waterbodies with areas greater than 1,000 m^2

c) Topographic surveys of the watershed upstream of the tailings facility every three years:

1. Survey
    a. At least 5.0 m survey grid spacing
    b. Vertical accuracy better than 2.0 m RMSE

d) Annual photographic surveys of the potential inundation area downstream of the tailings facility:

1. Photographic mosaic
    a. At least 1.0 m ground sample distance
    b. Horizontal accuracy of better than 5.0 m RMSE

e) Topographic surveys of the potential inundation area downstream of the tailings facility every three years:

1. Survey
    a. At least 1.0 m survey grid spacing
    b. Vertical accuracy better than 20 cm RMSE

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

BACKGOUND

PhotoSat has completed over 600 surveys of mine tailings facilities

PhotoSat has carried out over 600 surveys of mine tailings facilities since 2012. Over one hundred of these surveys have covered the tailings facility for the Steepbank and Millennium oil sands mines in Northern Alberta. We have 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 m^3 of mine tailings per year.

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PhotoSat regularly surveys mine tailings facilities in most of the world's major mining regions

PhotoSat regularly surveys tailings facilities at operating mines in most of the major mining regions of the world. Depending on the volume of tailings we survey these mines 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 the larger mines.

Current survey practices at many mine sites often limit the long-term management of the tailings facility

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.

Pumping volumes, on-foot dam inspections and boat bathymetry are insufficient for long term tailings facility management

Some mine owners and tailings engineers still believe that managing a tailings facility using pumping volumes, on-foot dam inspections and boat bathymetry is all that is required or is practically possible. They don't know how inconsistent and error prone their tailings facility surveys may be. Nor do they understand the impact of those errors on the long-term management of the tailings facility.

Surveying lessons from tailings dam failure studies

Since the Mount Polley dam failure in August 2014, there have been several investigations into tailings facility dam failures and their causes. These have resulted in the publication of studies on the causes of the dam failures. These studies contain lessons about best practices for surveying and the on-going monitoring of tailings facilities.

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Dam failure studies point to surveying deficiencies at tailings facilities

From a surveying perspective the dam failure investigations point to some deficiencies in surveying practices at some mine sites. While many of these deficiencies may seem obvious in hindsight, they may not be obvious during day to day and month to month mine operations.

The dam failure investigations applied procedures and processes that could have been deployed during mine operations

The dam failure investigation teams retroactively used procedures and processes to compile and review tailings facility survey data to help determine the causes of the dam failures. These procedures and processes could have been deployed by the mines as a part of their ongoing operations.

Survey data deficiencies at the Fundao dam

The Fundao Tailings Dam Review Panel report points to specific surveying deficiencies such as inadequate or missing records in some areas, sporadic collections of data, and the collection of data that was unsuitable or not intended for the use to which it was put. The report also notes the problems associated with patching together surveys which may have been done at different times or under different conditions.

What survey information did the Fundao dam tailings engineers have ready access to in late 2012?

The tailings engineers at the Fundao dam decided to setback the left abutment of the Fundao Dam in late 2012. It is unclear whether they had ready access to the survey data and photo records that show that they were raising an upstream sand dam over slimes that had been deposited in this area in 2011 and early 2012. According to the Fundao Tailings Dam Review Panel report the presence of tailings slimes within the upstream sand dam was one of the root causes of the Fundao dam failure.

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Mine site surveying errors and deficiencies are most often caused by trying to survey an entire mine by piecing together several different surveys

When PhotoSat surveys a mine site for the first time, we always try 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

Survey deficiencies caused by different survey contractors surveying different portions of the mine site at different times

Most often these mine site surveying errors and deficiencies are due to different survey contractors surveying different operating areas of the mine site at different times. With this piecemeal surveying approach, areas of important topographic changes within or adjacent to the mine sites are sometimes missed entirely. Some of these individual surveys often have horizontal and vertical errors relative to the rest of the mine site survey data.

An example of tailings facility survey deficiencies from an anonymous mine site

One example of the kind of survey errors that we often see for tailings facilities is shown in figure 1. We observed inconsistencies when we compared these monthly drone surveys of the tailings facility to satellite photos taken in the same time period.

Monthly drone surveys included areas of photographs from previous months

Upon further examination of the "monthly" drone photo mosaics of the tailings facility shown in figure 1 we saw that that the drone photo mosaic of each month included areas of photos that were identical to the photos from previous months. Since the appearance of active tailings beaches changes every day, this seemed very improbable. We eventually worked out the probable dates of the various portions or each "monthly" drone survey.

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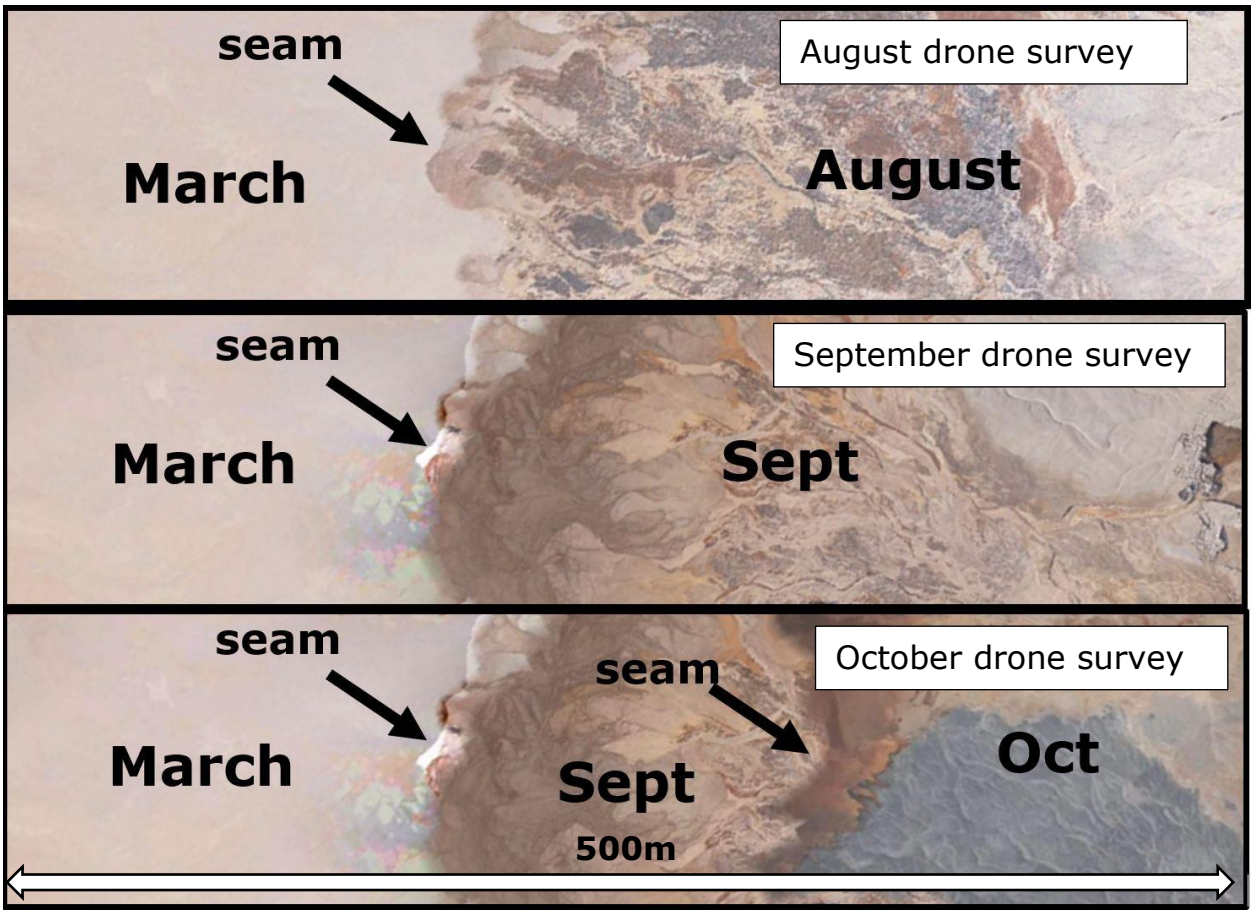

Figure 1. An example of monthly drone surveys of a portion of an anonymous mine tailings beach. In this example the drone survey contractor has apparently spliced in pieces of older drone surveys of the tailings beach to the make each "current" monthly tailings beach survey. The appearance of active tailings beaches change every day. Identical photos a month apart are extremely improbable. Due to issues such a sun glint off the wet surfaces of the tailings, drone surveys often have challenges surveying tailings beaches. The mine owner and tailings engineer were probably unaware that their monthly tailings beach drone surveys were incomplete. The date labeling on the different portions of the drone photos are PhotoSat's interpretation of the probable dates of each portion of the photo. These may not be the actual dates of these portions of the photos.

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Surveying active tailings beaches with drones is frequently prone to errors

Clearly it would be difficult to impossible to determine the depositional history of this tailings beach based on these "monthly" drone surveys as the photos are not representative of the beach conditions for the specified month. We often see these types of deficiencies in drone surveys of tailings beaches. Tailings beaches are particularly challenging to survey with drones. Sun glint off the wet tailings makes it difficult to impossible to match some of the stereo drone photos. Consequently, the drone operators occasionally substitute drone photos from previous months in their monthly surveys.

What survey data should be readily available to tailings engineers?

This raises the question of what survey data should be maintained and be readily available and for a tailings facility. The Report on the Immediate Cause of the Failure of the Fundao Dam includes the comment that difficulties in maintaining consistent records is "typical for a large tailings dam" (Fundao Tailings Dam Review Panel Report on the immediate Causes of the Failure of the Fundao Dam, Section A5, page A-11).

Elevation survey accuracy of better than 20 cm RMSE is required for most tailings facilities

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.

Mine site owners and tailing engineers need consistent, routine surveys of the entire mine sites and the surrounding areas

Mine site owners and tailing engineers should have consistent, routine surveys and photographs of the entire mine site that satisfies both their immediate operational needs and the requirements for long-term management and monitoring of the tailings facility. This will provide them with a more accurate, consistent, chronological history of the evolution of their tailing's facility and the surrounding areas.

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A long-term auditable survey record of an entire mine site and surrounding area can be achieved by a monthly or quarterly series of uniform, single day, surveys

A monthly or quarterly series of consistent, uniform 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.

Mine site wide survey "snapshots" completed in a single day are important for mine site survey quality 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 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 enable better monitoring of the conformity to the tailings facility design criteria and to evolving standards and regulations

Consistent, routine surveys and photographic snapshots of entire mine sites enable mine owners and tailings engineers to better understand and demonstrate the safety and stability of their 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.

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Estimating the risk and consequences of failure for tailings deposits with little or no historical mine site survey data

Due to a variety of causes including armed conflict, political system changes and mining company failures, the historical survey data for some fraction of the world's existing tailings deposits do not exist. Determining the risk and possible consequences of catastrophic failure for these deposits requires recreation of the tailings facility construction and depositional history and a measurement of the volume of tailings.

Inundation studies of tailings deposits with no historical mine site survey data require measurements of the volume of tailings in each deposit

Inundation studies required to determine the consequences of failure for tailings deposits with no historical mine site survey data require a measure of the volume of the tailings in each deposit. To measure the volumes of these deposits it is necessary to have surveys of both the top and bottom surfaces of the tailings. The top surfaces of these tailings deposits can be surveyed with a variety of technologies. The bottom surfaces of these deposits are now buried. They can no longer be directly surveyed.

Measurements of the volumes of tailings deposits with no historical mine site survey data require surveys of the topographic surface prior to tailings deposition

Measurements of the volume of tailings deposits with no historical mine site survey data require surveys of the topographic surface prior to tailings deposition. There are several potential sources of survey data to construct the topographic surfaces of the base of these tailings deposits. These sources include government air photos and archive satellite photos.

By reprocessing these older topographic data and photos and referencing them to modern, highly accurate, topographic data and photos around the perimeter of the tailings deposits, accurate topographic surfaces of the base of these tailings deposits can often be constructed.

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PhotoSat is researching methods for estimating the risks and consequences of failure for tailings deposits with little or no historical survey data

PhotoSat is currently researching several methods for determining the topographic surfaces of the bases of tailings deposits with no historical mine site survey data to determine of the volumes of tailings. We will be happy to collaborate with companies and organizations who are addressing this challenge.