FGI Webinar: Lessons Learned from Tailings Dam Failures

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Questions/Comments from Live Webinar:

1. Geochemical stability can be achieved with saturated conditions and establishing sub-oxic conditions. What are your thoughts on leaving a facility pond in place in closure, assuming there is a safe spillway sized adequately for extreme events?
   The "water dam" must be designed to remain stable in perpetuity, there must be sufficient rainfall runoff to maintain a suitable water cover (~2 m deep) and a spillway is required to discharge excess rainfall and runoff.

2. Do you have any suggestions for FEM courses that would help in modelling seismic and post-seismic behavior of a tailings facility?
   Not really my specialty. However, in-house expertise is needed to ensure that the ground model and parameters are appropriate (including "interrogation"), that the results are rigorously "interrogated" and that appropriate sensitivity analyses are undertaken (both to check critical layers and to assure the Consultant and the Client that the results are robust). FEM is appropriate when the "screening" LEM results point to inadequate stability (expressed in terms of factors of safety not achieving the minimum values recommended). Both static and dynamic FEM calculations should be done, starting with 2D before moving to 3D, if appropriate.

3. Has there been any movement to perform in-situ upstream improvement of tailings near the upstream toe of the dams, in order to improve the FS with upstream dam raising for more tailings storage? Such as deep soil mixing?
   Most simply, upstream "berms" have been added, although their limited depth and the difficulty of extended them over increasingly more soft and wet tailings down the beach is a challenge. Dumping waste rock and deep soil mixing has also been applied to facilitate further upstream raising.

4. Could you speak to the use of InSAR for monitoring and how much the back-analyses of those data has contributed to understanding these failures and the ability of the industry or a facility to identify, decide and respond if/when deformation trends are detected. (Recognizing that these failures occurred before InSAR was widely known and used).
   InSAR is difficult to interpret for tailings dams during raising and/or operation unless fixed ground stations are available as datums. Further, it should be recognized that InSAR is affected by atmospheric conditions, particularly moisture, which change, creating "noise" (which can be larger than the deformation you are trying to measure). Also, InSAR is at best every 6 days when both descending and ascending images are available (northern hemisphere and where it is paid for in the southern hemisphere) – Descending and ascending images allow "actual", although out-of-phase, deformations to be estimated. Descending only InSAR is only every 12 days and only allows line-of-sight deformations to be estimated – This makes east-west and horizontal deformations difficult to "see". Because InSAR is at best every 6 days, it is unable to provide an effective warning of a rapid failure, although it can be

useful in interpreting failures after the event, as was the case for Cadia and, to a lesser extent, Brumadinho.

5. How is the tailings facility doing at Prominent Hill Mine? I recall slope failure was occurring on the pit and we suspected a connection due to hydraulic connection and poor drainage patterns.
   I am aware of the issue, with the tailings dam close to the pit leading to seepage and potential instability of the pit wall.

6. For the Brumadinho, was there a 7% strain creeping deformation observed as shown on page 24?
   The plot is only schematic. The pre-failure rate of creep was about 30 mm/year roughly parallel to the downstream slope. The "strain" during failure was obviously much larger. % strain is deformation relative to a dimension and so varies according to that base dimension. It is not relative to say the height of the dam, which is too broad-scale to be meaningful.

7. In your view, has satellite-based remote sensing improved TSF safety yet?
   No, but it would be great to have a better "feel" for what creep rate may be of concern. It would be helpful if more sites measured their creep rates relative to dam height and other relevant parameters such as climate and seismicity.

8. Do you believe remote sensing has moved / will move the industry closer to prevent failures?
   It will contribute. It is not restricted to relatively infrequent InSAR, but includes prism survey and total station (automation), inclinometers and tiltmeters (preferably automated), LiDAR, ground-based radar (moisture creates "noise"), acoustic sensors, GPS / GNSS, Shape Arrays, etc. Redundancy is recommended, together with other instruments, including vibrating wire piezometer strings (preferably automated). See: https://www.researchgate.net/publication/348715525_Catalogue_of_real-time_instrumentation_and_monitoring_techniques_for_tailings_dams, https://www.researchgate.net/publication/333826615_Critical_review_of_tailings_dam_monitoring_best_practice, https://www.researchgate.net/publication/339914354_Real-time_monitoring_of_tailings_dams and https://www.ausimm.com/publications/conference-proceedings/mine-waste-and-tailings-conference-2021/trends-in-realtime-instrumentation-and-monitoring-techniques-for-tailings-dams/.

9. What tailings dewatering methods have you seen to be successful?
   "No one size fits all" / "no silver bullet". Sand-size tailings dewater naturally because of their relatively high permeability and hence can be used in "sand dams" (usually the cycloned sand fraction of the whole tailings, as is common in Chile and Peru). Fine-grained (silt and clay-sized) tailings, particularly those with clay minerals, are difficult to dewater. Dewatering methods include: (i) cycloning for (and to produce) sand-sized particles, (ii) centrifuging; (iii) vacuum filtration (limited to 95 kPa and limited by the residence time, which is usually too short; (iv) disc filtration; (v) pressure plate filtration (becoming the most common but not suited if sand [damages the filter fabric] and slimes [too difficult to filter] are included); (vi) screw filtration (common for in dewatering sewage sludges and being considered for tailings); and (vii) combinations of these.

10. Looking at large tailings dam failures since 2014, what instrumentation type, spatial distribution, and frequency of monitoring do you think would have informed of a pending dam failure? Which do you think is the most reliable and inexpensive?
Foundation failures show some early signs (over days) and automated piezometric and deformation monitoring could show a precursor. Liquefaction failures, whether earthquake or flow, develop in seconds with no warning, and no instrumentation shows a precursor.

11. I have always wondered about the mismatch between 1 in 10,000 for hydrology, and prescribed FS where the risk of failure is greater than 1 in 10,000.
Yes, one of a number of mismatches / anomalies.

12. It is worth noting that tailings are very fine and will typically pass through most geosynthetic filters – Potentially leading to piping issues. Have you seen such piping issues?
After foundation, liquefaction and overtopping failures, piping is probably the next most common. Geosynthetic filters alone are not considered effective in preventing piping because they are prone to clog, directing flow in an unintended direction. Drains and filters should not be encased in a geotextile for the same reason, although they have extensively been applied in the past. A sand filter or sequence of sand filters, obeying filter criteria, is / are needed to prevent piping of fines into coarser downstream zones.

13. Could you tell us where these dams were located? What countries?
El Cobre is in northern Chile, Mount Polley in British Columbia Canada, Samarco in Minas Gerais Brazil, Cadia in New South Wales Australia and Brumadinho in Minas Gerais Brazil.

14. Wouldn't the use of geomembranes reduce the risk of liquefaction?
A geomembrane would reduce seepage and the height of the phreatic surface and hence may reduce the rick of liquefaction of a tailings dam raise on liquefiable tailings, but would likely not prevent the liquefaction of susceptible foundation soils.

15. To what extent do you think that the influx of rainwater is (co-)triggering dam failures?
Brumadinho was a case in point. The wet climate led to seasonal wetting-up, and loss of suction and hence loss of strength, of the unsaturated zone of the tailings deposit on which post-closure stability relied. Wetting-up by fresh tailings would have a similar but more localized effect.

16. How (cost-)effective do you think covering of the tailings would be, compared to extensive additional dam constructions? What type of mineral covers have you seen?
There are two issues: (i) how to form the final tailings profile, which is most cost-effectively done by judicious hydraulic placement of further tailings (also serving to store more tailings for a given dam height if deposition is away from the dam) and (ii) what sort of cover is required and how it may be placed (for benign tailings, no cover may be required, although fertilizer and initial watering may be required; potentially contaminating tailings will require a permanent water cover if this is feasible or a soli cover that inhibits the net percolation of rainfall [that would generate potentially contaminated seepage] and/or oxygen ingress [to limit further oxidation of the tailings]).

17. Would horizontally drilled drainage systems be an option to improve stability in your opinion?
Horizontally drilled drainage systems are routinely installed in relatively stable slope materials to drain infiltrating rainfall and improve slope stability. However, their installation in potentially liquefiable tailings would at least temporarily reduce dam stability.

18. Given the role that foundation conditions and soil behavior play in tailings dam and pad stability, how are operators integrating geosynthetic solutions, such as the geomembranes and non-woven geotextiles offered by companies like Inland Tarp & Liner, to improve subgrade stabilization, drainage, and erosion control as part of their risk-reduction and monitoring strategies?
Geomembranes are used extensively as seepage barriers, mostly on the upstream slope of tailings dams and particularly in Chile where it is mandated by law. Geomembranes are also used as internal seepage barriers and in covers to limit rainfall infiltration into the underlying tailings (e.g., at Gove in the Northern Territory in Australia). Geotextiles have in the past been used to wrap drains; however, they tend to block (more so than the drain itself that has multiple pathways) and the practice is now discouraged. Geotextiles are sometimes used as separation layers on soft foundations (where it is not feasible to remove soft layers), although not as regularly as in civil engineering; e.g., roads. Geogrids have occasionally been used to reinforce tailings for upstream raising and in foundations and beneath covers. Geotextiles have been used for temporary erosion resistance.

19. Thank you, Professor Williams! Most informative and timely seminar. Is there a technology, process or standard that geotechnical engineers should promote and apply to promote better design of tailings dams? Or, specifically, to better manage the water in tailings dams?
Follow existing Guidelines such as ANCOLD and CDA, with the intent of managing both the tailings and water. Ideally, supernatant water and rainfall runoff (minimized using interception drains upstream of the TSF) should be removed from the TSF and stored separately, if not directed straight to the processing plant. All too often, the TSF is used to store tailings, supernatant water and rainfall runoff, leading to excess water stored on the TSF and reducing stability (and capacity for tailings solids).

20. In terms of the Brumadinho tailings dam failure, was the rise in phreatic surface considered sufficiently, with the tailings dam being in a valley and thus likely enabling an increase in pore water pressure? Were there any under drainage systems in place?
Brumadinho tailings dam had been closed for some years and the deposit showed some drop in the phreatic surface due to drain down and seepage. The wetting-up of the unsaturated tailings was independent of the phreatic surface (little rainfall infiltration reached the phreatic surface due to the low permeability of the unsaturated tailings and seepage from the dam). It had no underdrainage (apart from drainage layers beneath later upstream raises to collect immediate surficial seepage) and no spillway or collection of upslope runoff (70% of the catchment was above the TSF). Being "closed" there was little if any "management" of water.

Questions from Follow-Up Survey:

1. What FEM courses would help in modelling seismic and post seismic behavior of tailings?
   See Question 2 above.

2. Is it Prof. Williams' opinion that the upstream method cannot be used for TSF construction or has he seen successful, cost-effective stabilization of the upstream materials that allowed for upstream construction at TSFs that satisfy post-closure conditions?
   Upstream construction can be quite appropriate for low seismicity and low to moderate rainfall regions without underlying landslide risks, and for tailings that consolidate and desiccate, provided that a number of roles are adhered too: (i) limit the rate of rise ot ~2 m/year, (ii) maintain an adequate tailings beach width to allow necessary desiccation (in a dry climate) to form an acceptable tailings foundation to support the next raise, and (iii) never have water against an upstream embankment even following high rainfall events, which may required a spillway.

3. What tangible safety improvements, if any, have you seen in TSF management as a result of using satellite-based remote sensing data?
   Satellite-based remote sensing data is a compliment to other monitoring data, but in itself it has not led to tangible safety improvements. LiDAR is now being used routinely to assess tailings volume (in combination with the dry mass of tailings produced for settled dry density estimation) and also for monitoring the decant pond size and exposed tailings beach width, both of which have improved tailings management and contribute to dam safety.

4. Do you see independent remote sensing as improving confidence and trust among regulators, boards, or communities?
   Yes, as above, and both satellite and LiDAR images are readily visually informative.

5. In practice, what types of TSF risks could be better managed today because of satellite deformation or change-detection data?
   In particular, improved operation to meet the "design intent", leading to reduced risks and improved stability.

6. Do you believe remote sensing has moved the industry closer to preventing failures?
   It has contributed, as indicated above.