Risk Profile and Management of Sylvania Tailings Storage Facilities in South Africa

Short Report Prepared by Senior Management of Sylvania Platinum

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1 Introduction

Following some unfortunate disasters associated with tailings dam failures in South America during recent years, there has been widespread international concern about the safety of such and similar facilities in South Africa. These concerns are often linked to the impact of a flow slide failure of a Tailings Storage Facility ("TSF"), which could result in significant environmental damage, damage to property, loss of production and/or loss of life.

Based on input and recommendation from the Sylvania Board, a study was launched to compare Sylvania's existing management systems and risk factors to those of typical South American tailings dams in order to ensure that learnings from recent TSF failures are taken into account and that the Company's existing strategy in terms of TSF management and safety remains adequate and effective.

The purpose of this document is to report on the risk profile, risk drivers and relevant management and controls on the Tailings Storage Facilities ("TSFs-") of the Sylvania Dump Operations in South Africa. The document includes a review of the relevant lines of responsibility and accountability, liability, legal framework, continuous review of operating performance linked to the risk profile on the TSFs.

This document deals specifically with the Chromite Tailings Dams operated and managed by Sylvania in South Africa.

2 Technical Causes of Failure – a Case Study of Feijão Dam I[1] in South America

Shortly after the TSF failure incident at Córrego do Feijão Iron Ore Mine in Brazil on 25 January 2019, a panel of four experts in geotechnical engineering with special expertise in water and tailings dams was commissioned by Vale to investigate the technical causes of failure of the TSF.

The Panel was instructed to use its expertise and professional judgment to review and assess requested relevant data and technical information to determine the technical cause(s) of the Dam I failure.

The Panel relied on assistance from consultants to review historical data and documents, evaluate specific subject areas, conduct field and laboratory testing, and engage in computer modelling.

The following summary of findings was included in the report, explaining the history that created the conditions for instability in the dam:

- A design that resulted in a steep upstream constructed slope;
- Water management within the tailings impoundment that at times allowed ponded water to get close to the crest of the dam, resulting in the deposition of weak tailings near the crest;
- A setback in the design that pushed the upper portions of the slope over weaker fine tailings;
- A lack of significant internal drainage that resulted in a persistently high water level in the dam, particularly in the toe region;
- High iron content, resulting in heavy tailings with bonding between particles. This bonding created stiff tailings that were potentially very brittle if triggered to become undrained; and

[1] Extract from Report of the Expert Panel on the Technical Causes of the Failure of Feijão Dam I, by Peter K. Robertson, Ph.D. (Chair), Lucas de Melo, Ph.D., David J. Williams, Ph.D. and G. Ward Wilson, Ph.D.

- High and intense regional wet season rainfall that can result in significant loss of suction, producing a small loss of strength in the unsaturated materials above the water level.

The Panel found that the failure and resulting flow slide was the result of flow liquefaction within the tailings in the dam. The history described above created a dam that was composed of mostly loose, saturated, heavy, and brittle tailings that had high shear stresses within the downstream slope, resulting in a marginally stable dam (i.e., close to failure in undrained conditions). Laboratory testing showed that the amount of strain required to trigger strength loss could be very small, especially in the weaker tailings. These were the main components that made flow liquefaction possible.

The Panel concluded that the sudden strength loss and resulting failure of the marginally stable dam were due to a critical combination of ongoing internal strains due to creep, and a strength reduction due to loss of suction in the unsaturated zone caused by the intense rainfall towards the end of 2018.

This followed a number of years of increasing rainfall after tailings deposition ceased in July 2016. The calculated pre-failure strains from this combination of triggers match the small deformations of the dam detected in the post-failure analysis of satellite images from the year prior to the failure.

The internal strains and strength reduction in the unsaturated zone reached a critical level that resulted in the observed failure on January 25, 2019.

3 Acceptable Risk in South Africa

TSFs are large geotechnical structures and in Southern Africa these facilities are managed on Civil Engineering principles and in accordance with approved engineering codes and standards. The term "Acceptable Risk" is often used when referring to TSFs. Acceptable Risk in the Civil Engineering Industry was quantified by D.J.W. Wium (The Civil Engineer in South Africa, December 1988). From this study, risk profiles acceptable to the South African society are indicated in Figure 1.

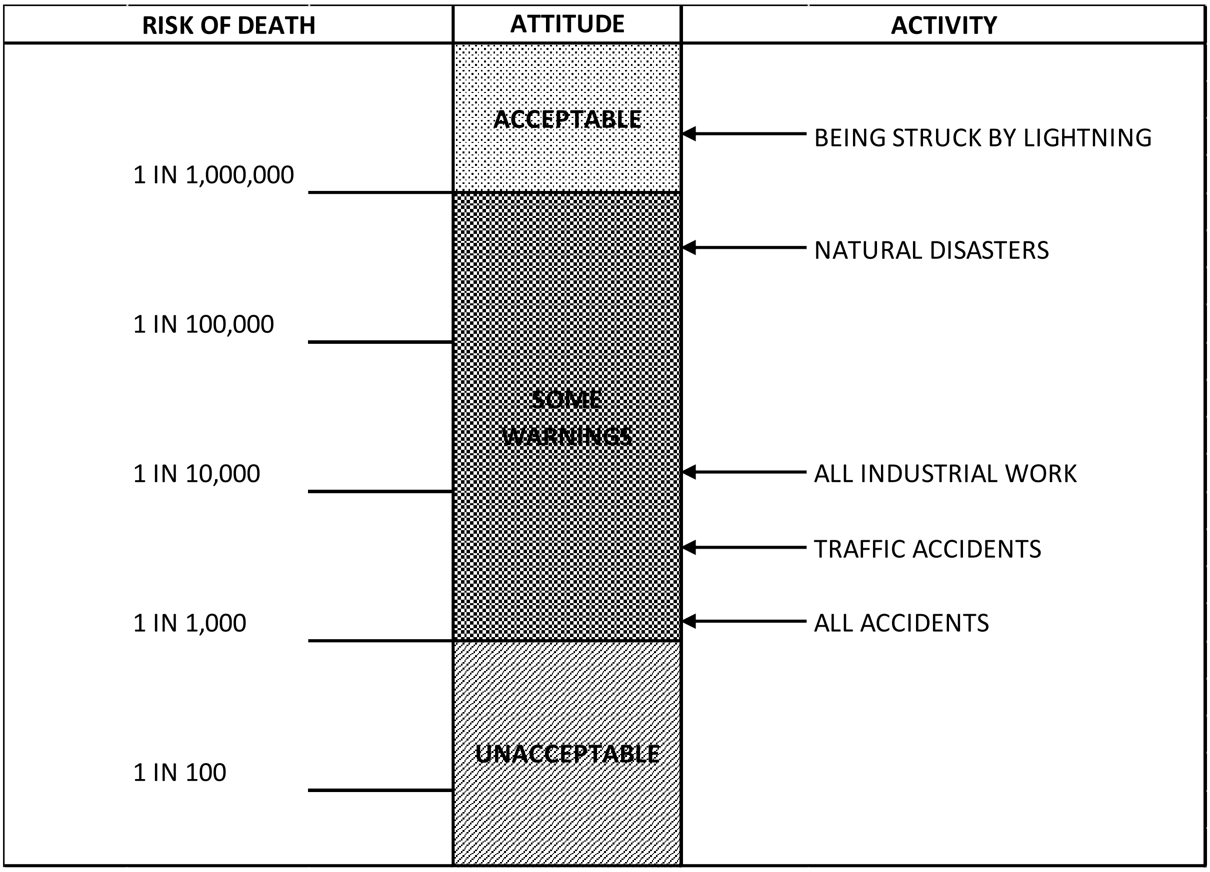

Figure 1 Acceptable Risk (Wium)

It is common practice in the South African tailings industry to manage TSF slope failure (not flow slide failure) at $P_{(failure)}$ < 1:500 000. Experience has indicated that only 1:50 slope failures in South Africa results in a flow slide of any magnitude.

4 Risk Drivers / Triggers

Risk drivers / triggers are directly related to the South African (and African) method of TSF construction and operation. The following should be noted regarding the Sylvania TSF operations:

- Southern Africa is a net evaporation area, i.e. in most cases the annual evaporation is almost double the annual precipitation. This phenomenon creates soil suction, having been measured up to 2kPa in soils that classifies as Sandy-Silt (USCS system), typically the classification of the outer perimeter tailings;
- A combination of down-stream (at start-up of a new TSF) and up-stream deposition methods are used;
- Tailings placement is done with on-wall cyclones; the cyclone underflow is used for perimeter construction and to contain the cyclone overflow, layer thickness being less than 500mm, with the cycle time being longer than the consolidation time;
- Supernatant water is decanted with a standpipe in-dam system (penstock with concrete rings). This configuration allows for the water pool depth on the TSF at any given time to be less than 300mm.

- Cyclic tailings placement is not only used to construct the perimeter wall, but also to shape the TSF basin in such a way that the clean water is always concentrated around the decant intake and away from outer perimeter walls.
- The TSF design allows for:
  - Sub-surface drainage, maintaining the outer perimeter wall dry and at full consolidation. Soil strength parameters of cohesion and friction angles are fully developed (i.e. with high level of confidence through many years of practice, measurement and strength analysis to develop Industry Codes). TSFs are thus managed as drained facilities in terms of consolidation and water removal;
  - Installation of standpipe piezometers to determine and continuously monitor and record the interstitial water table; and
  - Structural stability as provided by heel walls (providing additional stability for perimeter walls) and the cycle underflow wedge.

Tailings facilities are large, complex geotechnical structures, constructed over time under changing circumstances: operating conditions vary from site to site and are dynamic (i.e. changes with time as the facility develops towards its design life). It is the responsibility of Management to identify, quantify, pre-empt and react to these variables through compliance with a Code of Practice and an Operating Manual for each facility, as well as Industry Best Practice and Codes and Standards for operation of TSFs. Compliance, in turn, is monitored by a competent engineer at short intervals.

Table 1 explains the risk triggers to slope failure how these are typically identified and managed uniquely for each TSF.

Table 1 Slope Failure Triggers for an Appropriate Monitoring and Response Strategy

No	Main issue	Slope Failure Trigger	Responsible / Liable Party
1	Operational	Deposition method Site Activity Management conformance	All legal appointees All legal appointees All legal appointees
2	Geotechnical Failure	Foundation stability / strength Piping trough tailings Seepage Consolidation	Appointed engineer Appointed engineer Appointed engineer Appointed engineer
3	Overtopping	Freeboard management Excess water Rainfall	Operational practitioner Mine management Operational practitioner
4	Infrastructure Performance	Pumping capacity constraints Decant performance Reticulation failure	Operator (reporting) Mine management/ Mine engineer Mine management/ Mine engineer

The following should be noted from the above table:

- All triggers are mathematically summed to determine a probability of slope failure;
- The triggers listed under item 2 are usually the focus of independent (i.e. external) consultants in the Civil Engineering Industry. Yet, these triggers are considered in isolation for risk profiling, a skew perception on the real and overall potential causes of slope failure would be presented as reality;
- Experience in the South African Mining Industry has indicated that more than half (estimated at around 70%) of all structural incidents on TSFs had as root cause triggers under item 4 (Infrastructure Performance);
- The importance of sound operational practice is obvious;
- The above-mentioned triggers to failure identify the potential causes / drivers to slope failure, aimed at preventing an incident through early warning and pro-active response measures, rather than trying to install emergency procedures / mitigation measures, diversion structures or the like; and
- This monitoring and response strategy is a live system, adapted pro-actively and immediately with measurable changes in conditions on the TSF.

5 Legal compliance (South Africa)

The study and investigation of the two recorded and published flow slide failure incidents in South Africa, namely Bafokeng (1973) and Merriespruit (1994), were instrumental in creating the following legal framework for TSF management:

- A formal management structure is created. In this structure all persons, from mine management to operators of the TSF, are appointed in their personal capacity to manage activities mentioned in Table 1. Responsibilities are updated as and when required;
- Management involvement in the daily operation of the TSF is directly linked to the Zone of Influence[2] and consequential Hazard Classification as per SANS 10286-2003. This is revised through updating of the Operating Manual for the TSF at least annually;
- Freeboard and the separation of “dirty” and “clean” water is controlled by GN 704 of the National Water Act (Act No. 36, 1998). Measurement against these requirements is reported monthly to management; and
- A mandatory Code of Practice (“CoP”) for the safe operation of the Tailings Storage Facility is developed in terms of the Department of Mineral Resources (“DMR”) directive. This document is based on SANS 10286-2003.

The TSFs are regularly audited by a legally appointed (in terms of regulation 2.13.1 of the Minerals Act and Regulations), independent consultant for compliance with this specification, specifically in terms of the following:

- Management of the facility;
- Construction performance;
- Risk identification; and
- Report on CoP at specified intervals (quarterly and annual)

[2] The 'zone of influence' is the area within which a development has material impacts or can influence impacts due to the development and/or other developments. Typically the zone of influence is unique to each project, is larger than the actual project footprint, and encompasses the area of direct disturbance.

6 Sylvania (SA) comparison to typical South American Iron Ore TSFs

Sylvania currently has six chrome tailings dam complexes which utilise a combination of downstream and upstream deposition methods. The downstream method is used for the first period after start-up of a new dam until the pre-constructed drains and starter walls are covered and then an upstream deposition method is utilised thereafter. Sylvania monitors and reviews its Tailings Storage Facilities on a scheduled and continuous basis. Although it is accepted that TSFs are widely considered and often criticised for having a high inherent risk profile, it is noteworthy to point out that the chrome tailings dams of Sylvania are significantly different, and inherently safer, than the typically much larger iron ore, copper or gold tailings dumps around the world and especially in South America:

- The Feijão Dam I of Vale, for example, contained approximately 11.7 million cubic metres of tailings, was 86m high and occupied an area of ~249.5 thousand square metres (according to Vale's press release at the time), in comparison to Sylvania's current largest chrome ore tailings dam containing approximately 1.5 million cubic metres of tailings, with a height of less than 15m and occupying approximately 137 thousand square metres (typically ranging capacities of 0.5 to 1.5 million cubic metres of tailings);
- The Feijão Dam I had a rate of rise (RoR) of approximately 10m/year, sustained for 7 years, whereas Sylvania's maximum allowed rate of rise is 4m/year, which enable significantly better consolidation and provides good structural stability; and
- Chrome ore tailings typically have a significantly coarser particle size distribution and higher specific gravity than iron / copper ore tailings which also assists with better consolidation and wall stability.

Besides having existing reviews and monitoring and control measures in place, Sylvania initiated an additional independent auditing and review process to evaluate legal compliance and operational preparedness in terms of some specific tailings dam related emergencies, following the failure of some South American tailings dams in recent years.

Combined, formal quarterly tailings dam reviews are conducted by a composite team consisting of Sylvania's management team members, the appointed specialist tailings dam operator, management team members of the host mine, as well as the independent professional civil engineer, to ensure each tailings dam operation is managed according to the approved Code of Practice for the Safe Operation of the Dam, and complying to relevant national standards and applicable legislation.

The following available information about the Feijão Dam I failure, based on the extract from the Expert Report[1] mentioned earlier, is worthwhile comparing:

Table 2 Vale Incident Comparison with Sylvania TSF Operation and Risk

Vale	Sylvania	Comments
Design resulting in steep upstream constructed slope.	Sylvania's dams are mostly constructed on flat or gentle slopes, which lend itself to relatively shallow slope designs for good stability.	Stage deposition curves are regularly developed for existing facilities, using quarterly LIDAR survey data, to model remaining safe operating life of facilities at current and future planned deposition rates.

Vale	Sylvania	Comments
Water management within the tailings impoundment allowed ponded water to get close to the crest of the dam. This deposited fine material to the outer perimeter	There is no need for water accumulation within the tailings impoundment, as storm water infrastructure is designed and operated to cope with seasonal rainfall and the operating principles dictate that water may not be stored for longer than 24 hours at a time during an emergency	Management and Operators ensure that no water is stored within the impoundment area. Any deviations are immediately reported for action.
Setback in the design that pushed the upper portions of the slope over weaker fine tailings	There is adequate coarse material in the tailings deposited to avoid a scenario where a setback, designed for slope stability, causes the coarse outer wall to be constructed on weak finer tailings	The appointed engineer inspects each facility for any signs of stress during quarterly visits. With a rate of rise not exceeding 4m/a, these quarterly visits are more than adequate to react to any early signs of stress.
A lack of significant internal drainage resulted in a persistently high water level in the dam, particularly in the toe region	• Interstitial water levels are monitored using piezometers, with good drainage underpinning all coarse walls. • Drainage is managed as part of compliance monitoring and reaction to deviations. • Tailings facilities are operated as drained facilities. This is confirmed by the installed instrumentation.	The appointed engineer reports on drainage efficiency and interstitial water levels at each quarterly visit, while the Operator monitors and records these on a weekly basis.
Production increase on the Mine due to lower than planned mineral grade, possibly pushing production and therefore tailings deposition rates beyond design limits	Tailings deposition rates are maintained within the design limits of the TSF, measured monthly as well as with quarterly aerial LIDAR survey technology	The Vale management system not in operation
The TSF was 86 metres high at the time of failure, exposing weak material at the toe to excessive loading	None of the TSFs operated by Sylvania exceed 20m in height	The driving force differentiation due to height, especially that associated with the foundation material, should be noted
• External audit focused on geotechnical aspects only	Refer Table 1: holistic management structure,	• Compartmentalisation of responsibility without a holistic

Vale	Sylvania	Comments
• The drivers of geotechnical issues, embedded in operational practices, were not identified	considering combination of potential failure triggers	management structure has proven to be fatal • The misconception of a perception of issues covered in the "external" audit

7 Conclusions

From the discussion in this document, the following can be concluded for the Tailings Storage Facilities of Sylvania in South Africa and the operation thereof:

1. The Sylvania TSFs operate at an acceptable risk profile, within the legal framework of South Africa;
2. Review and evaluation of the SA operations, including its conditions and behaviour, are structurally embedded in the management system and controls for each facility;
3. The required management structures are in place. Persons filling these positions are legally appointed and are liable in their personal capacity for the duties described in their appointments.

Under the Mandatory CoP, review and audit by external parties is allowed for where the need for such review or audit exists. However, it is important to note that many ad-hoc audits are at best "a point estimator" of the risk profile at the time of inspection or review, whereas Sylvania currently has a continuous risk management protocol in place for all its South African operations.