Risk and informed approach to TSF design and operation

With the introduction of the Global Industry Standard for Tailings Management (GISTM), the standards for tailings storage facility (TSF) design, construction, monitoring and closure have increased, particularly the requirements related to stability. While the GISTM does not prescribe factors of safety (FoS) for stability, it does require a robust design that considers credible failure modes.

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The following requirements and principles are outlined in the GISTM:

- Requirement 4.4: Select, explicitly identify and document all design criteria that are appropriate to minimise risk for all credible failure modes for all phases of the tailings facility lifecycle.
- Requirement 4.5: Apply design criteria, such as factors of safety for slope stability and seepage management, that consider estimated operational properties of materials and expected performance of design elements, and quality of the implementation of risk management systems.
- Principle 5: Develop a robust design that integrates the knowledge base and minimises the risk of failure to people and the environment for all phases of the tailings facility lifecycle, including closure and post-closure.

There are three levels of stability that need to be evaluated:

- Drained conditions, typically with a FoS > 1.5
- Undrained conditions using peak material strengths for materials below the phreatic level, typically with a FoS > 1.5
- Undrained conditions using residual strengths for materials below the phreatic level with a FoS > 1.1.

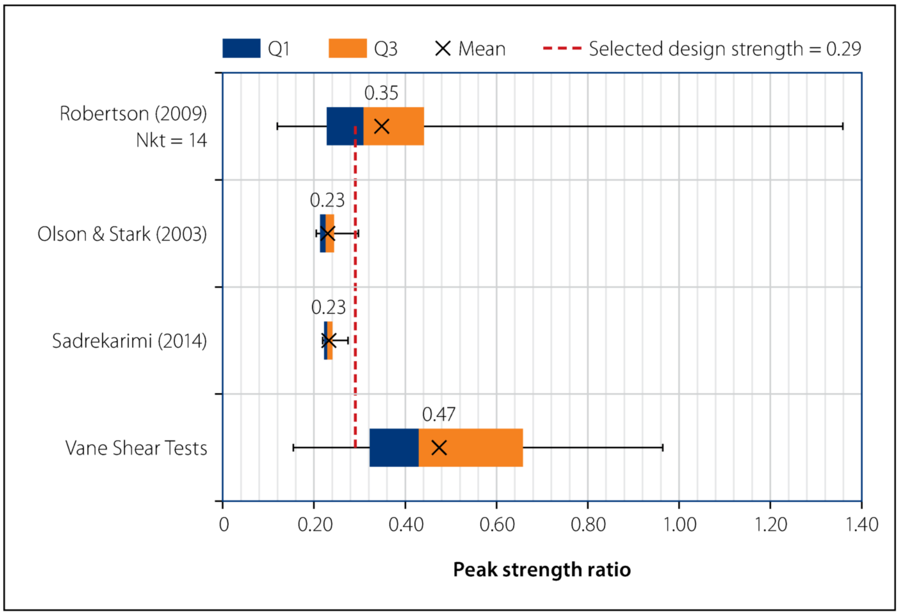

Figure 1 Box and whisker plot of undrained peak strength ratios from different CPT interpretations and vane shear tests

INTERPRETATION AND ANALYSIS

In order to comply with the GISTM and other standards, extensive geotechnical investigations have to be undertaken to improve the accuracy of the tailings, wall and foundation material properties. This typically includes piezocone testing with pore pressure dissipation (CPTu), shear vane testing, laboratory testing of undisturbed and remoulded samples using triaxial testing and other specialised tests. Stability analyses are undertaken on more informed wall slope geometries (layers identified from in-situ testing) and from well instrumented sections that provide pore pressure or water level data to correlate with CPTu data.

All the data is assessed and interpreted to establish parameters representative of the geotechnical investigation. The increased level of geotechnical investigations has improved the quality and quantity of the data (i.e. CPTu records data every 20 mm) and since soil is not a homogeneous material, historical knowledge of the TSF is paramount to understand its behaviour, as well as the risk appetite for the facility.

For a well-operated TSF with a long history of good operation, a higher design parameter could be supported (i.e. 25th percentile) rather than the lowest which would be used for a facility with a higher risk. In addition to material property variability, different interpretation methods give different answers for the same field data, as shown in Figure 1. Engineering judgement is required to select the analysis parameters.

Table 1 Example of stability analysis results

Stability case	Target minimum FoS	Section A	Section B	Section C
Drained	1.5	1.55	1.80	1.35
Undrained (peak)	1.5	1.31	1.51	1.09
Undrained (residual)	1.1	0.75	0.93	0.65
Possible actions		Build buttress, reduce production, lower phreatic level, risk-based approach.	Continue operating under risk-based approach unless credible failure mode exists.	Stop production, build new TSF. If no credible failure mode is identified, operate under risk-based approach.
Legend: Green cells – FoS is compliant; orange cells – FoS is marginal; red cells – FoS is non-compliant				

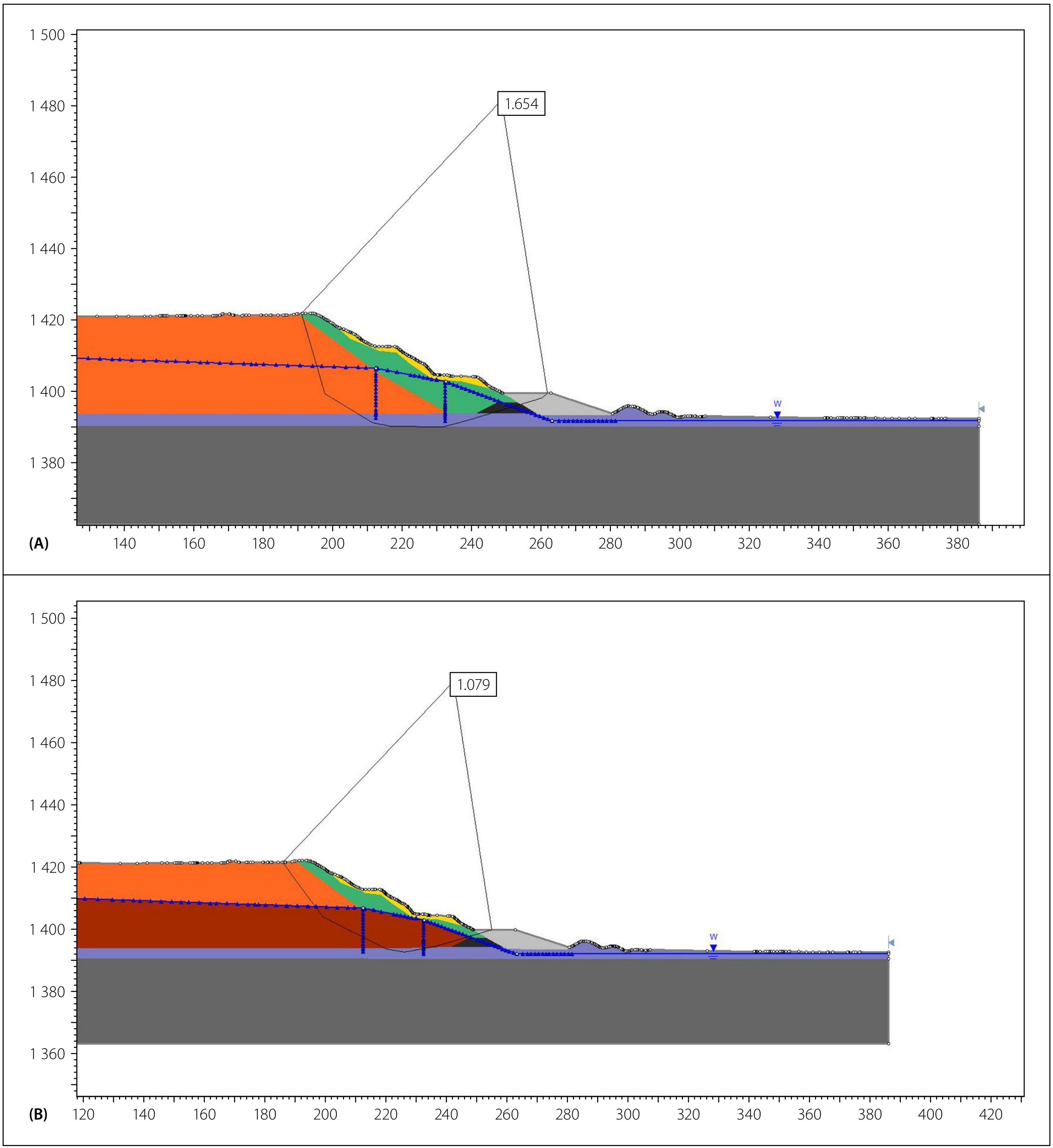

Figure 2 Stability results for drained (A) and undrained peak strength properties (B) for a typical upstream TSF

The stability of existing TSFs, and in particular upstream (self-impounded TSFs) with outer slopes of 1V:3H, often doesn't satisfy the target minimum FoS conditions. A common set of results might include examples given in Table 1.

In all three example sections, the TSF may visually appear stable and may not have elevated seepage. In these cases, the FoS represents the minimum values for that wall section derived from limit equilibrium modelling. Therefore, there is a level of conservatism built into these analyses, because the upper bound strengths of the materials "cannot be relied upon". This is the standard and correct approach. In some cases, experts recommend using 16th or 25th percentile values as opposed to minimum or average values. This requires a reasonable database of test results, but will provide a conservative answer.

Figure 2 shows an example of a stability analysis compliant for a drained analysis, but non-compliant for an undrained analysis.

RISK-BASED APPROACH

What then do we do with these results, in particular the non-compliant undrained peak and residual FoS? Whether it is ANCOLD, ICOLD, CDA or any other standard, they are not compliant. GISTM provides the opportunity to explore a risk-informed approach.

Requirement 4.7 of GISTM states, "Existing tailings facilities shall conform with the requirements under Principle 4, except for those aspects where the Engineer of Record (EOR), with review by the Independent Tailings Review Board (ITRB) or a senior independent technical reviewer, determines that the upgrade of an existing tailings facility is not viable or cannot be retroactively applied. In this case, the Accountable Executive (AE) shall approve and document the implementation of measures to reduce both the probability and the consequences of a tailings facility failure in order to reduce the risk to a level as low as reasonably practicable (ALARP). The basis and timing for addressing the upgrade of existing tailings facilities shall be risk-informed and carried out as soon as reasonably practicable."

The following risk-informed approach should be considered:

- If the risks are high that a credible failure mode could occur, and there is a realistic triggering event for the TSF now or in the foreseeable future (TSF located in a moderate to high seismicity area), then mitigation measures must be put in place, such as a buttress, dewatering boreholes, reducing or stopping deposition.
- If there is a credible failure mode for which there is a very low probability of a triggering event (low seismic area), then the EoR should explain this to the AE such that the AE can make an informed decision and sign for it (typically includes an extensive and rigorous monitoring system).
- If there is no credible failure mode or triggering event for the undrained residual condition, then this must be documented and reviewed by the ITRB, such that the EoR can explain to the AE and agree that an appropriate level of monitoring/instrumentation is in place to assure all parties that an undrained peak or residual strength condition is unlikely.

The construction of buttresses is one option to mitigate a low or non-compliant FoS. This may be feasible on open pit mines where overburden/waste rock is available, but not easily justified on underground mines where there is little to no source of construction material available without a large borrow pit being exploited (with its own issues). All other risk mitigation measures must then be considered.

MONITORING AND SURVEILLANCE

There has been a proliferation of instrumentation on TSFs in recent years to not only improve monitoring data but also to move from manual to automatic real-time data. This has been a learning curve for all parties. There is no point in installing significantly more instrumentation if it does not work or provides unreliable data. This is a waste of resources, and the system is not trusted. For a well-instrumented TSF to be trusted it requires:

- A well-defined instrumentation plan based on stability analyses, considering which critical controls will provide early warning of a trigger.
- Selection of the right instruments that are robust and require minimal maintenance or battery replacements.
- A well planned and executed installation programme by a competent installer following approved procedures and/or specifications.
- Testing in the factory before delivery to site.
- Calibration on site and checking of data before handover.
- Protection of the equipment/cables and knowledge transfer to the stakeholders on site.
- Robust links between instruments and data loggers and on to gateways that are well located.
- Data in the right format.
- Converting the data into a dashboard format or alert system that is not full of errors and false alarms.
- Critical controls linked to a trigger action response plan to alerts and a culture of response. This requires a reliable and accurate system.

A TSF team must now include an information technology specialist and a control and instrumentation engineer to maintain the system. These are new roles on the TSF, and mines need to be educated on the importance of these TSF team members, especially for TSFs operated under the risk-informed approach (many TSFs in Southern Africa). Such monitoring systems cannot be ignored or perceived to be any less important than control systems in the process plant. This is an education and discipline gap yet to be fully grasped on most mines, and requires a management of change process.

NEW DESIGNS

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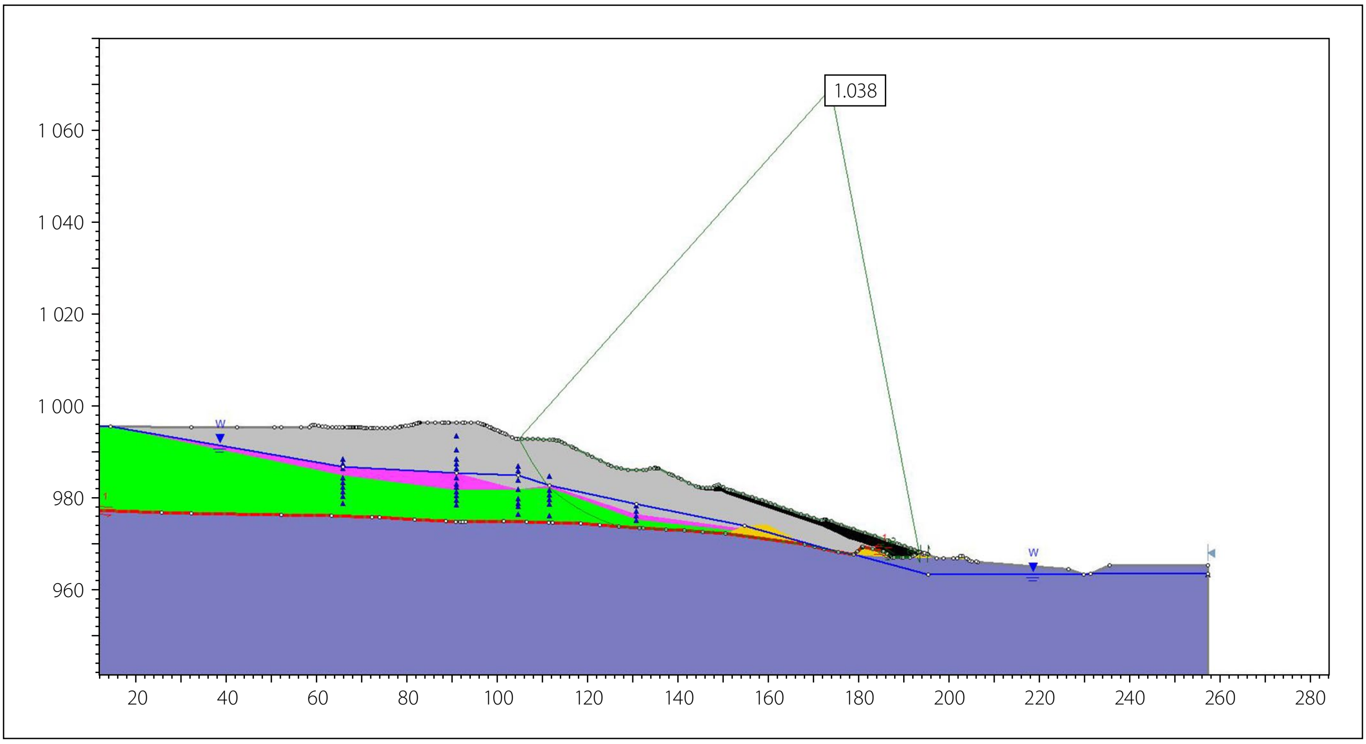

Figure 3 Stability of a TSF with a failure plane along the barrier system

analyses need to take these materials and their properties into account in the design. However, their shear resistance is lower than most materials, even clays. The design may pivot on the barrier system properties, rather than on the tailings or foundation materials, as shown in Figure 3.

Therefore, a high level of reliability in the barrier material testing campaign is required, using a large shear box to test failure planes along interfaces between materials in the barrier system. The design must then try to reduce risks of failure, such as:

- Sloping the TSF floor inward to increase the shear resistance.
- Using high shear resistance materials such as double textured geomembranes.
- Considering inverted barrier systems.

The designs and stability analyses must include multiple drainage systems (even more extensive in the presence of a barrier system). However, it is critical to design them to account for a design life well beyond the life of the mine, with an adequate FoS (from 10 to 20) to account for long-term flow reduction. Extensive monitoring is required to check the performance of the drains, otherwise stability may not be realised as per the design.

CONCLUSIONS

While stability analyses rightly use conservative properties, they will often result in non-compliant FoS for many existing TSFs in Southern Africa due to their historical designs based on drained properties or "so called" tried and tested practices. This invokes a risk-based approach which may take a few years to mitigate, or a sustained rigorous monitoring and surveillance programme.

With many existing TSFs falling under the "risk-informed" status, it is very important not to think that that this is the norm. It already allows some relaxation of the standards, and the ALARP principle should not be abused (stretched) such that low risks become high risks. The approach must be supported by a robust and continuous surveillance and monitoring system. The EoR should alert the AE of the risks and then manage the TSF according to an agreed action plan that is reviewed by the ITRB. ◻