Tailings dams technology – learning from failure (Part 2): Mines rethink safety measures

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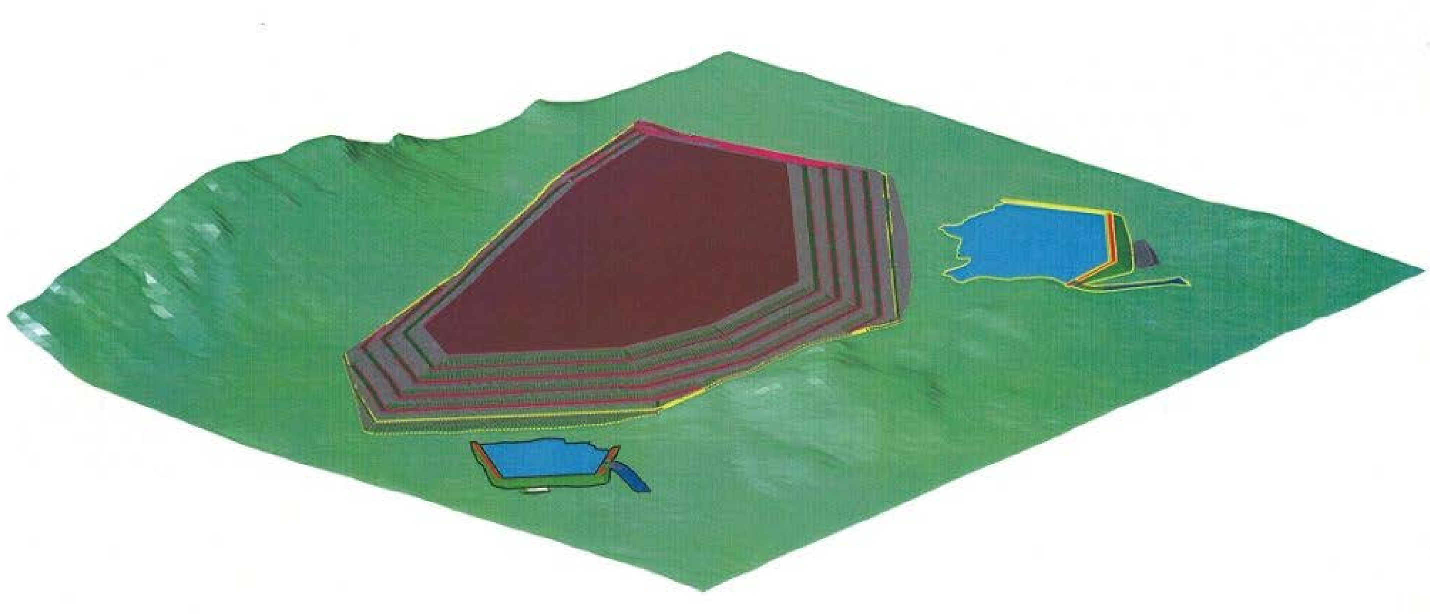
In the past few years, there has been renewed interest in finding ways to make tailings storage facilities (TSFs) safer, following very significant failures at facilities like Mount Polley in Canada and Fundão in Brazil, writes Adriaan Meintjes.

This interest comes not a moment too soon, opening exciting opportunities for engineers and scientists to bring both experience and technology to the daunting task of evaluating and mitigating a wide range of potential risk factors inherent to TSFs and rock dumps.

Tailings dam safety has always been close to our hearts at SRK, as it was the failure of the TSF at Union Corporation's Bafokeng mine in 1974 — the year that SRK was formed — that led to our involvement in designing under-drains for greater stability at Impala dams 3 and 4. These designs continue to function as planned more than 40 years later, and the future will continue to demand such innovations as the bar for TSF safety is constantly raised.



A 2006 tailings dam model. Image credit: IMD

Evolution of tailings dams

To look back briefly on the evolution of tailings dam engineering in South Africa, dams were initially very small when mining first started in the 1870s, reflecting the limited scale of the mining itself. Essentially, the tailings disposal practice was uncontrolled, with tailings just pumped into rivers, streams, and lakes.

Sand dumps then developed, which were constructed in an almost dry manner. When process plants became bigger, however, the tailings process waste was transported in a tailing's slurry, as plants increasingly used water as a medium in the extraction process.

Tailings were initially placed behind a small starter wall; deposition would be conducted in a way that allowed the coarser tailings material to settle on the outside (close to the deposition walls), and the finer material to be stored on the inside basin. This reflected the principles of sand and clay deposition and sedimentation along a river, and no specific under-drainage or internal drainage was provided.

Probably not appreciated in these early years were the implications of these dams growing; they would commonly double in size every 10 years as the process plant capacities increased. One of the results was that many failures occurred, even in the late 1800s, leading to the formation of Fraser Alexander in the early 1900s as a tailings dam construction specialist.

Continuous efforts are taking place to find ways of making tailings storage facilities safer. Image credit: SRK

Factors affecting TSF engineering

Among the factors affecting TSF engineering since about 1980, has been the ongoing focus on finer grind of material in the metallurgical process, to reduce particle size to increase extraction. This continuing focus on finer grind has had a very significant impact on tailings seepage flow, compressibility, and strength behaviour. In the past decade, there has been a renewed effort to grind finer — to improve the extraction of the metals and minerals. It is most likely that these latest finer grind focus areas are possibly going to change the fundamental designs of traditional tailings dam engineering in South Africa.

In addition, efforts to save water by ongoing and further re-use of the water decanted from the TSFs have meant that mines' tailings water circuits are becoming more saline. This increased salinity, combined with finer grind, reduces density and therefore also the shear strength of tailings material.

Another important reference point in TSF design in South Africa was the failure of the Merriespruit tailings dam near Virginia in the Free State in 1994 — caused by overtopping as a consequence of heavy rains and insufficient water management at the facility. Seventeen people died when 1.2 million tonnes of tailings flowed out the impoundment to the town of Merriespruit two kilometres away. This led to a renewed and specific focus on the vertical and beach freeboard requirements of TSFs, and how to ensure that suitable freeboard was available at any TSF at any time. SRK made a significant contribution to this aspect of TSF design, construction, tailings deposition, and water management as part of ongoing tailings dam operations.

Since the 1990s, higher levels of urbanisation have meant that less land is available for TSFs, so these tailings dams had to cover a smaller footprint and, therefore, be higher than previously. Cyclone deposition was employed as a strategy to allow for these designs.

Urbanisation have meant that less land is available for TSFs, so these tailings dams had to cover a smaller footprint.

Image credit: IMD

Safety concerns

Today, the growing concern with TSF safety has triggered a range of demands in the field of tailings dam engineering. Legal responsibility has become more onerous and more focused; mines must now stipulate who the responsible engineer (person or entity) is for the design, construction, and operating of the dam. Contractual clarity is required on the respective responsibilities and duties of the owner, designer, construction companies, operating team, QA/QC and monitoring team, and any other stakeholders.

The tailings dam site's foundation conditions must be fully investigated from a geotechnical perspective, to inform the design, construction, operation, and monitoring of the facility. It should be remembered that the initial portion of the Mount Polley failure was a foundation shear strength failure condition. Foundation failure conditions are also relevant to safe operations of waste rock dumps, of which the well-known case history of Bukwa rock dump in Zimbabwe is but one example. More recently, a rock dump failure caused by a shear strength failure of the clayey soils in the rock dump foundations, took place at a mine close to Machadodorp in Mpumalanga.

Investigation of tailings behaviour has also taken centre stage, as the Fundão failure, for example, was related to inadequate drained and undrained shear strength of the tailings. Once again, the design, construction, operation, and monitoring of TSFs now must take this behaviour into account. This requires a better appreciation of soil mechanics applied to tailings behaviour, and a framework for how we consider tailings properties using advanced geotechnical field and laboratory testing and then applying these tailings behavioural properties in appropriate 2D and 3D numerical models.

While effective stress analyses were part of the previous requirement for TSF design, there is now a new requirement for both undrained and effective stress analyses — also considering real-time modelling of behaviour of the tailings facilities. Increasingly detailed investigations and testing — from both the field and in laboratories — are required, to better understand tailings dam material property behaviour. The testing results are then used to model, including seepage behaviour, consolidation behaviour, compressibility behaviour, shear strength behaviour (static and dynamic conditions), static liquefaction behaviour, and tailings deformation behaviour under seismic conditions.

Many appropriate developments and advances in modelling software are currently being made as computing power becomes increasingly more affordable; for example, fully coupled seepage, consolidation and (static and dynamic) stress modelling is now possible. A step change in these engineering tools should become more user-friendly and affordable within the next decade.

Waste management critical

Water management on and off the facilities is also becoming more critical. At many mines, there is a requirement to co-dispose of mining waste streams — sometimes from the process plants and sometimes from mining and plants. This can lead to complex residue storage design, and no single solution fits all construction and operating requirements. Many design innovations are required to provide safe storage facilities, considering waste stream material incompatibilities from a material behavioural point of view. However, many site-specific innovations have been achieved by SRK. We have also been able to assist clients in reducing costs by additional optimisations.

The use of HDPE-type liners as barrier systems has a major effect on the stability behaviour of tailings dams, as above- and below-liner drainage systems have to be provided, and the design criteria for both cases are still in a process of development and evolution. The design of monitoring systems is likely to undergo considerable development — in the past, the practice was to provide for instrumentation such as stand pipe piezometers and drain flows, which could be read on a weekly or monthly basis. A recent development is to install instrumentation that can be read on a real-time basis — and making use of satellite technologies will become common within the next decade.

Considering the mining sector's heightened concern with safety regarding TSFs — and the potential for technology to gather and analyse ever-larger quantities of real-time data — the scope for engineering even safer tailings dam solutions is within our grasp. It is exciting to know that the questions that mines are now asking about TSFs can and will be answered.

If you missed Part 1 Click here

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Adriaan Meintjes has been involved in civil and geotechnical engineering for over three decades and has worked for SRK Consulting SA since 1992. His speciality areas include soil and rock mechanics, numerical modelling, foundation design, water and tailings dams, and risk assessment. Through his extensive experience serving the mining industry, he has developed wide-ranging expertise in the geotechnical behaviour of tailings dams, dams, and fills, among other fields.
Adriaan has worked on projects across South Africa, southern Africa, and other regions of Africa, as well as South America, publishing and presenting over a dozen papers at professional and scientific forums. His qualifications were earned at Stellenbosch University and London University, and he is a registered professional engineer and member of the South African Institution of Civil Engineering (SAICE).