

New Directions in Tailings Management

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ABSTRACT: Two Million Tonnes a Day – A Mining Waste Primer issued by MiningWatch Canada in December 2009 sets out conceivable ills associated with current and possible new tailings disposal methods. In this paper, we set out to examine current and proposed methods of tailings disposal and management.

While there have been failures of tailings impoundments, it is possible to design, operate, and close these facilities safely, and in ways that protect the environment. This paper will establish that the issues raised in MiningWatch and similar documents posted on other web sites that attack mining and tailings disposal practices are founded on a lack of technical knowledge; failure to collect, collate, and understand the facts; and a desire to make statements derived from pre-established prejudices and perspectives.

This paper summarizes the body of knowledge, new technologies, and practical experience, along with case histories that substantiate the fact that tailings disposal can be managed in compliance with international guidelines and standards; local regulations and requirements; in an environmentally responsible manner; and in a manner that provides employment..

1 BRIEF HISTORY OF TAILINGS DISPOSAL

1.1 *Initial operations*

Tailings disposal was initially a technique of trial and error. In the early 1900s in South Africa, Fraser F Alexander pioneered practical and inexpensive methods to construct tailings impoundments entirely with tailings (slimes dams). He and those who succeeded him, have a long history of successful impoundment construction and operation. However, this method in South Africa has had failures. For example, failures of the Bafokeng and Merrispruit slimes dams led to awareness of the consequences of failures, and changes in the laws.

Similar development in the knowledge and techniques for tailings disposal and impoundment monitoring occurred in Canada and the United States. Construction of the first embankments with tailings was by trial and error. The 1960s and 1970s included the beginning of the use of soil mechanics to assess tailings behavior and tailings impoundment stability. In the mid 1970s we find the first technical papers by civil and geotechnical engineers on tailings impoundments in North America. It is interesting to return to these papers and see the use of fundamental principles in design and operation of tailings impoundments, and to see the first words on vegetated covers as part of facility closure.

1.2 *Use of filtration*

In the early 1980s both authors were involved in the Greens Creek Mine in Alaska. This was one of the first mines to filter their tailings, truck them to a disposal facility, and compact the tailings as a solid material. This approach was dictated by the wet climate and seismic risk of the area, as well as limitations in impoundment area. But it showed that filtered tailings dis-

posal is practical under certain conditions, and is still used at the mine. Filtered and other dewatering treatments of tailings have been adopted elsewhere in recent years where impoundment space is limited or water reuse must be optimized.

1.3 *Earth and rockfill tailings embankments*

In the 1980s, the authors were involved with the Cannon Mine in Washington, which consisted of a rockfill embankment for containment of tailings, and the McLaughlin Mine in California, which consisted of an earthfill dam for containment of tailings. Both embankments were designed and constructed to applicable standards of dam design practice. Other rockfill and earth embankments have been constructed in a similar fashion. As demonstrated by the successful closure and productive ongoing use of both sites, mines close to communities and upstream from key water resources can be operated and closed successfully.

1.4 *Impoundment closure*

The authors were also involved with the closure of uranium mill tailings impoundments across the United States. As established by over twenty years of observation, these reclaimed impoundments are performing as expected (in terms of impoundment stability and cover performance). The performance criteria for these facilities are to be stable for the long-term period of performance (200 to 1,000 years).

Due to the volumes of materials involved and the cost and time associated with earthmoving and water management, tailings impoundment closure is not a simple or inexpensive exercise. The lesson learnt from the uranium mill tailings impoundment closures is that the technology and practice exists to achieve safe and stable long-term closure. New tailings impoundments must be assessed for feasibility and designed and constructed with closure (and its associated time and cost requirements) as part of the evaluation. Although “design for closure” has been discussed in tailings impoundment design for over 20 years, this concept still needs to be stressed.

Some mines are using or planning to filter their tailings and so dispose of them as solid or “dry stack” materials. Mines are also thickening and polymer-amending their tailings in order to create materials that can be used for mine backfill or enhance the settling characteristics of discharged tailings to hasten water recycling and tailings consolidation.

The case histories outlined above demonstrate that safe and effective tailings management is feasible and practical -- if the value of the ore body can accommodate the associated tailings management costs.

2 IMPOUNDMENT FAILURES AND LESSONS

2.1 *Information on failures*

Although there are significant amounts of publicity and documents on tailings impoundment failures, the important factors for engineers are the underlying causes of failures and how these can be prevented. Documents that have examined reported tailings impoundment incidents (from events requiring repair or mitigation to major failures) include USCOLD (1994), UNEP (1996), and ICOLD (2001). The major factors that can be drawn from this body of information are listed below.

1. The majority of reported incidents were during the period when larger impoundments were being constructed and soil mechanics theory was starting to be applied to tailings. The body of information does not cover unreported incidents prior to this period.
2. The majority of reported incidents were for smaller impoundments (with embankment heights less than 30 meters).
3. The majority of reported incidents were associated with embankments constructed with or over tailings using the upstream method (described in Vick, 1983; ANCOLD, 1999).

4. Most of reported incidents were associated with improper water management (overtopping, seepage and erosion) or seismic effects (liquefaction or excessive embankment deformation).

This information indicates that these incidents could have been prevented with proper design for site conditions, proper construction and operation, and effective operation and monitoring. While the body of information described above tries to assign one specific cause to an incident, the failure of a tailings impoundment is often the result of a string of small events that combine in a unique way to bring about an unanticipated failure.

2.2 *Lessons from failures and unanticipated results*

As an industry, we need to turn our attention and practice to the failure methods effects analysis (FMEA) and other systems analysis approaches that have long been used in the nuclear power generating and other industries. As long as the industry fails to take broad-based, comprehensive looks at the systems that constitute a tailings impoundment, failures will continue.

We can also simplify our approaches and emulate the way in which the airline industry achieves an enviable safety record by relying on simple checklists and duplicate oversight of every act. A similar approach (behavior-based safety procedures) has been successfully used in oil refineries and other industrial settings.

In addition, we must be bold in recognizing that there are some places where it simply is not practical to mine and construct impoundments that will be stable and endure in perpetuity. There are places where mining may not be practical, or the costs of site development, mining, and closure do not justify the development. In certain areas, the ore body must be rich enough to afford the expensive engineering works that are required to produce stable structures, maintain perpetual water treatment, and provide containment and erosion resistance under long-term closure.

3 CODES AND GUIDELINES

3.1 *Summary of guidelines and regulations*

As the brief history above illustrates, it is possible to design, operate, and close tailings impoundments that protect human health and the environment. What it takes is the mandate, effort, and capital outlay for effective design, operation, monitoring, and closure. The mandate includes applicable codes, guidelines, and regulations. These range from general guidelines to specific regulations.

Guidelines outline the accepted methods of tailings impoundment design, construction, operation, and closure in general terms (such as ICOLD, 1982; ANCOLD, 1999). General guidelines for embankment stability have been outlined in Wilson and Marsal (1979), U.S. Army Corp of Engineers (1982), ICOLD (1987), and ICOLD (1996). Guidelines for design storm events and embankment freeboard depend on the risk classification of the structure, as outlined in FEMA (2001), ICOLD (1987), and ICOLD (1992). Projects that include International Finance Corporation financing require compliance with their guidelines (IFC, 2007).

Land management agencies in the US have guidelines and regulations on mining. Some states have regulations affecting embankment stability administered by dam safety agencies. Other states have regulations on embankment stability and impoundment containment administered under groundwater protection regulations (such as ADEQ, 1998; NDEP, 1989). Nevada and other states require a closure plan and bond before construction of mine facilities.

Projects outside the US have varied regulatory requirements, ranging from specific regulations on facilities (typically in countries where there has been a mining history), to water protection standards or water use laws. Where there are not clear regulations, most international mining companies adopt North American or corporate standards or policies.

The guidelines and regulations are effective as long as there is an appropriate regulatory agency to administer the regulations in a fair manner (without political or external pressures) or a review board to check compliance with guidelines and follow-up of recommendations. These guidelines and regulations are useful only if they are followed to achieve the ultimate goal: de-

sign, operate, and close the impoundment so that it performs as a solid material and becomes a stable geochemical and geomorphic form in the environment.

3.2 *Variations in regulations*

There is a significant variation in specificity and practicality of regulations. The uranium mill tailings reclamation work mentioned above was conducted under the Uranium Mill Tailings Remediation Control Act (UMTRCA) of 1977. The regulations were structured as performance criteria (Appendix A of 10 CFR 40), stating that tailings will be isolated and impoundments will be stable to the extent practical for 1,000 years and at any rate for at least 200 years. How this performance criterion was achieved left room for creative analyses and engineering.

Compare this to the recent Directive 74 from the Alberta Energy Resource Conservation Board, that states that the tailings shall have a strength of 5 kPa one year after deposition. There is no indication of how to measure the strength or what kind of strength this is, and no guideline as to what is supposed to be achieved by this requirement. It is not clear whether this is a requirement upon discharge or a requirement for trafficability (5 kPa is a bearing capacity that is not sufficient for foot traffic or vehicle traffic).

The engineer is thus faced with translating these kinds of objectives and goals into practical engineering criteria: a thousand-year design life translates to design for the probable maximum precipitation and the maximum credible earthquake.

4 RECOMMENDATIONS

4.1 *Variations in site conditions*

If there is a solution to these issues, we submit it rests in recognition that a set of detailed regulations does not apply world-wide. Because mineralized deposits occur in all parts of the world, mined materials vary enormously from country to country, from region to region, and from climate to climate. Standard practice for the construction and operation of tailings impoundments differs from place to place for many reasons, including these:

- **Ore Host Rock:** The host rock in which gold occurs in South Africa is different from the sands from which oil is extracted at an oil sand mine in Alberta.
- **Processing:** The crushing, grinding, and milling that may be necessary to make it possible to extract platinum in the Bushveld is different to what needs be done to liberate diamonds from kimberlite in the Canadian Northwest Territories.
- **Chemicals:** The chemicals added to liberate the ores impacts the waste disposal facilities. Cyanide added to a Nevada heap leach pad imposes vastly different constraints than sulphuric acid added to liberate copper or the lixiviant in Namibia to liberate uranium.
- **Topography:** In the steep valleys of British Columbia you have to design and operate the tailings impoundment and waste rock dump in a completely different way to what you may do in the flat deserts of Australia.
- **Climate (precipitation):** If it rains eight meters a year, as is the case in Papua New Guinea, waste facilities will be different than those at a mine near Tucson, Arizona. Too much water is an issue in the first case; too little water may be an issue in the second case.
- **Climate (temperature):** In Northern Canada, planning for snow, ice, winter freeze and spring thaw is necessary in the design or closure of a mine waste facility. Conversely in the heat of Northern Chile, sun drying and evaporation may lead to a limited water management approach or a very different closure cover.
- **Laws and Regulations.** While there are international guidelines and codes to abide by, the ultimate reality is the law of the country where the facility is located. In California mine pit backfilling is required, with the idea being that the mine waste will be used to backfill the pit. In Canada, it may be allowed to put mine waste in a lake and plan for a long-term water cover.

- Historical Practice and Precedent. In South Africa, Fraser F Alexander is the name of the leading contractor building and operating slimes dams. In practice, Fraser F Alexander (who started as a foreman on a mine's tailings impoundment, and started his own company when he realized he could make a profit operating tailings impoundments) succeeded and established precedents for operation that prevail today. Similar people in all countries have had decisive impacts on standard practice—many of which have found their way into laws and regulations.

The only common factors from the variables listed above are the principles and practice of science and engineering, specifically geotechnical and civil engineering. To ensure adherence to these principles, implementation of standard practices include the following steps made in the stages of the project.

4.2 *Initial studies and documents*

At the start of the project, information on the site is collected, with information included in the following documents, as they pertain to the facility:

- Site Selection Report
- Alternatives Evaluation Report
- Conceptual Design Report
- Preliminary Closure Plan

These reports go by many other different names. But the purpose is the same, regardless of the name: characterize the area, identify and compare potential waste facility sites, compile plans and cost estimates to build, operate, and close the facilities. In addition, reports on site and facility information should be produced that include the following information:

- Regional and site geology and geohydrology
- Regional and site seismicity
- Regional and site climate (precipitation, evaporation, temperature, wind)
- Relevant aspects of air and water quality in the region and at the site
- Site characterization information (surface and subsurface)
- Construction materials identification and properties
- Tailings and mine waste geotechnical and geochemical characteristics

This information is used to realistically evaluate the feasibility of the project. If the feasibility of the project is favorable to proceed, permitting and planning activities proceed. Additional documents typically produced at this stage include:

- Design Criteria Document
- Regulatory Compliance Plan
- Risk Assessment Evaluation
- Peer Review Reports

4.3 *Design studies and documents*

With these reports (or the local variants or equivalents) in place, detailed design may proceed, typically with the following elements:

- Design drawings
- Technical specifications
- Design report, including supporting design calculations and analyses
- Engineer's cost estimate

Design calculations and analyses are a very important part of the design process, and require clear documentation for thorough checking. Analyses and calculations that should be prepared include:

- Foundation seepage and stability analyses
- Slope stability analyses (with deformation analyses as necessary)
- Water and chemical mass balance calculations
- Settlement and consolidation analyses of tailings and other structures
- Hydraulic analyses of channels and other hydraulic structures
- Hydraulic analyses of impoundments for appropriate embankment freeboard or spillway capacity

- Cover performance analyses on final surfaces

4.4 *Construction and operation documents*

After the financing is arranged, the permits are in place, the mining team is assembled, and contractors are selected, construction and operation may begin. The key documents at this stage include:

- Management and Operating Manual
- Instrumentation and Monitoring Plan.
- Emergency Response Plan

The Management and Operating Manual should set out in clear and specific language how the facility will be operated and managed. This includes the personnel involved and their roles and responsibilities—also their contact details and how often they should be involved and consulted. The manual should also describe (by way of simple diagrams) the components of the facility and how they tie together. The level of detail should be such that the field personnel can use the diagram and text to understand how it all comes together and should work. The manual should include brief checklists of how to operate each component. Common items include:

- Delivery pipes and valves
- Penstocks and return water barges
- Sediment ponds and runoff control facilities
- Dikes and embankments

A recommended section in the manual is an Incident Management Plan. This consists of documentation of incidents (or near misses in safety nomenclature), with root causes and mitigation measures. We believe that ten incidents make for one accident, and ten accidents make for one serious accident—or worse, a catastrophic failure of the facility and a significant environmental impact.

The Instrumentation and Monitoring Plan outlines the instrumentation to be installed in the facility, how it is operated and maintained, how often the readings are taken, and how often the data is downloaded or collected. There should be precise instructions on frequency of documentation and sending the results of observations and monitoring up the chain of command to responsible engineers and managers.

We hardly need go into the contents of an Emergency Response Plan. Suffice it to say it lists all personnel who need to be informed, called in, or set to work to deal with an emergency. The challenge to the geotechnical engineer is to make sure all emergencies that may occur are identified. The most basic items are listed below:

- Embankment slope movement or failure
- Overtopping of embankment
- Release of tailings or process water
- Fire

An additional document is a plan outlining response to the ever-changing mining conditions (Observational Method Implementation Plan) that typically evolve as the mine develops. This plan is different from an emergency response plans, and is a long-range planning document. Recommended provisions responding to changing conditions include the following:

- Foundation material characteristics and performance
- Construction material properties
- Tailings, waste rock, and/or heap leach material characteristics
- Water balance performance (precipitation, runoff, and too much process water or too little makeup water)
- Erosion and sediment buildup
- Capacity for tailings, waste rock, process water and other materials

Another recommended document during operations is a community relations plan. Many mining operations have a community relations person or department to address local and regional concerns and issues. These issues change during mine operation and as the facility transitions into closure.

4.5 Closure documents

As the mine's end of life approaches, ideally the existing closure plan has been updated during operations, so that actual closure is consistent with existing plans. Key documents associated with closure include the following:

- Updated Closure Plan
- Closure Construction Design Documents (drawings, specifications, design calculations and analyses)
- Post-Closure Monitoring Plan
- Post-Closure Emergency Management Plan

The focus of closure and post-closure becomes water management, including surface water management and erosion protection, residual process water evaporation or treatment, and tailings porewater management.

5 CONCLUSIONS

Mining and associated tailings disposal involve relatively large areas and volumes, and consume significant quantities of water. The changes in topography from mining and disposal of tailings create landforms that will remain for centuries. This makes mining a visible target for anti-mining groups and NGOs, even without failures and unanticipated incidents. The efforts of these groups are seen in pressures placed on legislatures and regulatory agencies, and in challenges in the permitting process and after permits have been issued. These efforts are despite the fact that development of natural resources is a key component of a productive society.

There is a credible body of information about tailings impoundments, including failures and their causes, as well as guidelines for proper design, construction, operation, and closure. Land management agencies have requirements for mining and tailings disposal on their lands, and individual states have regulations for embankment safety and tailings containment. Both land management and state agencies have surety bonding requirements to cover closure and reclamation costs. These requirements and regulations are effective if the regulatory agencies have support and enforcement mandates, and the regulated mining companies are serious about quality operations and community relations.

In addition to these guidelines and regulations, procedures for safety management and documentation used in other high-risk industries should be adopted for operation of tailings impoundments. Review of operation and closure of impoundments by knowledgeable and experienced regulatory agency personnel or (if not available) third-party reviewers should be used.

The MiningWatch document, referenced in the abstract of this paper, outlines the failures of tailings impoundments and problems with mining activity. This is done to stress the point of limiting where and how tailings can be disposed and recommending recycling of metals to reduce the need to mine. The MiningWatch document is one of many written products that are founded on truth, but are created to make a specific point, without independent review or cross examination.

An egregious example of prejudice in engineering analysis that the authors were involved with was an accusation that a mine was the cause of cracks in houses in the vicinity of the mine. The logic for this accusation was that there was no other simple explanation for the damage to the houses. This false engineering conclusion has since been refuted with sound data collection and interpretation from experts in seismic analyses. But it will take time to undo the publicity created from the initial false accusation.

This example is not an isolated incident. It may be argued that such people, engineers included, serve a purpose in prompting the mining industry to act to examine the truth and act proactively to negate the potential for slander from such people. But, as long as the mining industry does not operate properly and to the highest standards, mine facilities are fertile stalking ground for bad publicity and misinformation.

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