InfoMine
Mining Intelligence & Technology
Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

TAILINGS

PERSONAL PERSPECTIVES

Jack A Caldwell

Jnauary 2007

Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

Table of Contents

INTRODUCTION

This is a personal recollection on tailings impoundments and a justification of the contents of the remainder of this review. I grew up around the slimes dams of the East Rand gold mining district of South Africa. We would ride our bikes along the lonely paths that wound in and around the dams and we would endure the dust that blew off them into our faces as we cycled to school and which coated our desks when we arrived in the class room. Every year some child would be reported missing or dead after playing around the slimes dams, but we cared little and were even excited knowing there was real danger in our activities.

Most of those slimes dams are now gone; recycled for gold and uranium and put into one very large tailings impoundment. Houses and playing fields cover those glorious golden piles with their secrete byways and hues. Human health and the environment are no doubt better off, but something has been lost that I will not capture in this article.

I was sitting in the post-graduate class room on the high ridge of the University of the Witwatersrand when news came that the Bafokeng slimes dam had failed and killed thirteen and spread 50 miles and more down the valley. Before long I was the paid assistant to Professor Jennings who was retained to investigate the cause. I climbed the crusty sides of what remained of the dam, collected samples, made measurements, and took photos. I drank much wine with a friend who worked for the company that had operated the dam and we formed our own opinions which are not the same as those in the official reports on the failure; but we were young then and unversed in the language of formal avoidance and political correctness.

My field work led me to Oscar Steffan who was charged with designing the new tailings dam to replace the one that failed. I still recall my terror and fear as I walked the gray streets of Johannesburg from the offices of SRK to those of Union Corp where I was due to meet with Carl Van Rensburg, the manager in charge of building a new slimes dam. I had no ideas at all about how to layout a huge new impoundment that would not be susceptible to the factors that cause the first to fail. My mind was blank event though I had supposedly cogitated the issue for a week in preparation of the upcoming meeting. Twenty minutes into the meeting in response to a well-deserved dart, I stood up to the board and in blind panic and animal response sketched out the fundamentals of the new impoundment. The ideas came not from my conscious mind but from some deep reservoir of innovation. In the following week we quickly polished the ideas, put them on paper, and today the dam is still rising in accordance with the same principles that Carl and I formulated on a cold winter day decades ago.

My passage to North America resulted from the design and construction work I did for a phosphogypsum tailings impoundment at Richard Bay. On one-hundred feet of soft mud, we laid BIDIM 30-

meters wide and on this placed a sand dike one-meter high. Into the reservoir thus created went the tailings. We monitored the virgin clay's pore pressure increase and decay and tried to make sure that the gain of strength from loading was enough to give us a factor of safety to hold up the five to one slopes. After I left for Tucson, sand drains were installed at the highest part of the dam to increase the rate of pore pressure dissipation hence gain of strength.

In the U.S. I designed a thousand-foot high molybdenum tailings impoundment, but at that time so was everybody else and my dam never got built. My only implemented impoundment is now closed and reclaimed next to Wenatchee, Washington. After two years building the earth embankment we were in Albuquerque, New Mexico and on to uranium mill tailings pile reclamation. Today I am also writing the application for a Containment Zone designation of a site in California where there are many impoundments and rock dumps. We all hope that designation as a containment zone will make it possible to legally close the site.

The point of this person history is that I am a tailings impoundment aficionado. I know that the literature is vast, and the resources sprawling, and that there is no way anybody can consult them all. I often dreamed of writing the definitive book, but others did that first and better (see below), and at any rate the rate of change is too fast to use conventional print technology. So this review is my humble offering to a great body of knowledge and practice.

From here on I survey industry- and country-specific practice by the unusual approach of telling personal stories. This is hopefully a more interesting way of exploring the details and differences of place and time and type of mine than would result from a dry exposition of technical facts and fads. After all, the story of tailings is the story of people trying their best to keep the mines going and learning along the way to improve things. This is my story, but if you care to write down your story I will be honored to add it to this collection so that we my build up a person-oriented history and technology survey.

SOUTH AFRICAN GOLD MINE TAILINGS IMPOUNDMENTS

The slimes dams of my youth were build to a simple formula: dig a small trench around the perimeter, fill with tailings, get a team of laborers to dig the dried slime out and build a small wall, put the discharge pipes on the wall, discharge the tailings from the pipes into the area upgrade of the wall, collect the supernatant in an outlet pipe [penstock], and when the newly-placed slimes are dried, get the team of laborers back to dig and build another small wall. Repeat this process over and over to create those gorgeous piles with an orange-gold crust that tower into the red of the rising and setting sun.

Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

SOUTH AFRICAN PLATINUM MINE TAILINGS IMPOUNDMENTS

The gold mine slimes dam formula was used again and again with success on the gold mines. It was extended to the platinum mines where at least five large impoundments that I visited were built to the same formula. But there was a difference: the soils in the Bushveld are black clay a meter deep and have a plasticity index approaching fifty and cohesion of no more than 10 psi. These are weak soils because every season they expand and contract and move up and down and are riddled with heave and shrink failure planes along which only a low residual strength operates. The platinum tailings are sandier than the gold tailings and do not “stick” together by negative pore pressure as effectively as the gold slimes.

The Bushveld is dry and water is at a premium. The top of the tailings impoundment was the cheapest place to store the water needed to operate the plant. One day the water pool came to close to the edge of the wall and a bulldozer was sent to rectify the situation. What happened next is conjecture in spite of many learned tomes. Some believe seepage occurred preferentially along a sandy layer and initiated piping. Some believe that the bulldozer sent to raise the perimeter wall initiated vibration-induced liquefaction. Some believe the bulldozer just squashed the soft sand too much and pushed the top of the dike down below the water level. Regardless, the wall broke and the slimes flowed out inundating the shaft, killing thirteen, and spreading fifty miles downstream to clog the local dam.

I found myself examining this dam, designing a replacement, and examining those of surrounding mines. At one of the adjacent mines I installed piezometers to locate the phreatic line. The first set of data arrived on Friday—I was alarmed for the water was much higher than I had had courage to envisage. I arranged a meeting with mine staff for the following Monday. That weekend I hosted a famous American tailings impoundment consultant who was in the country to lecture. I invited him to accompany me to the impoundment. Imagine my horror when rounding the corner of the dam, I saw the 1,000-ft long face failed and slumped, and a fleet of dozers pushing away the clay and filling the trench with waste rock. We quickly surveyed the scene, got the gist from the foreman, and sped to the mine offices. I was still in my twenties with a baby face and would never alone have persuaded the plant manager that it was folly to remove the only support at the toe of the impoundment by bulldozing away the soil and that it would be better to build a buttress than dig a trench. My American visitor help and succeeded by using the strongest accent and the strongest language I had ever heard to speak his mind and bring authority to this crazy situation. The digging stopped, the buttress was built, the pond was drained, and a run-out failure averted.

The replacement dam I designed for the Bafokeng Mine involved a series of smaller dams that in effect were taken no higher than practice had proven safe to create a series of stair steps around the perimeter. This dam is still being used and I wish we could visit it and document its performance. I suspect my buttress dam is also still in use and I would love to find out how it is performing.

SOUTH AFRICAN DIAMOND MINE TAILINGS IMPOUNDMENTS

My first view of a diamond tailings dam was an endless vista that stretched over the horizon as uniform grey sheet. For decades the miners had simply discharged the tailings from a single point and let the slimes flow where they would and that was a long way. Eventually they had built a small dike a few miles from the discharge point to prevent further spread of the slimes. Now they were faced with a choice: raise the miles of dike or build a "conventional" slimes dam. The decision was to replicate the gold mine tailings impoundment approach and build a new "conventional" dam on top of the wide spread of old tailings.

We were young and in retrospect ignorant; so we acceded to the plan to pack up a perimeter dike on the existing tailings, install a penstock to return the supernatant, and proceed. The plan worked until the perimeter wall reached a height of two or three meters and then one fateful day the pool came too close to the edge and the water pressure in the outer slope rose and the wall failed. No harm was done for the flowing slimes merely spread across the age-old beach and I was left to quote my design report: to maintain perimeter wall stability, keep the water at least a 100 ft from the perimeter.

The new dam we designed was still on the age-old beach, but had substantive new walls, a much larger area, and more penstocks to remove water which still had to be stored on the impoundment but kept far from the outer perimeter walls. Last I heard this dam was still working.

SOUTH AFRICAN PHYSPHOGYPSUM IMPOUNDMENTS

The mud flats of Richards Bay were selected as the site of the new gypsum slimes dam. The northern edge of the site was bounded by sands of an old dune. The rest of the site was mud, soft unconsolidated clay and silt that increased in depth from zero at the dune to 30 meters a kilometer away.   We cut the reeds from a 30-meter wide strip around the one-kilometer square site, laid a blanket of the thickest Bidim geotextile then available, and placed a one-meter thick layer of sand on the 30-meter wide cleared, Bidim-covered strip. On this sand blanket we placed a perimeter road, an HDPE-lined ditch, and a 1.5-m high sand dike. The discharge pipes were laid on the top of the dike and the gypsum waste discharged into the interior.

I still awake in a sweat from the dream of getting the computer print out of my first slope stability analysis of this impoundment. I had put in a slope of three horizontal to one vertical and a mud strength pulled from some old reference. The factors of safety were so far below one, about 0.2 to 0.4, that I scurried to check my input for mistakes. I found none and after consulting with colleagues was forced to admit that the analysis was correct. Next I tried five horizontal to one vertical, an unheard of flat slope in South African tailings practice. In those days you prepared your computer run on cards which were duly delivered to the University computing center. If you were lucky they put the cards in the reader overnight and assuming no input errors, the code ran. If you were sloppy or plain unlucky, the cards kicked out and you had another go the next evening. All I can recall is that it took about three tries to get this card set to run—three days of anxiety and curiosity and the result came back with a factor of safety still less than one.

I could not possibly reduce the slope; that left no volume in the impoundment. All I could do was increase the clay strength. But I could find no justification for this in the literature. A professor suggested shear vane testing of the soil to establish actual strength and we set about importing a shear vane from a Canadian company that was just then pioneering the device. I cannot recall the exact process of how I came to realize that only by slowly loading the clay and allowing the excess pore pressure to dissipate to yield a gain of strength could I build this impoundment to a slope of five to one. I have a vague recollection of reading a paper by Skempton on pore pressure dissipation and gain of strength. I have another vague recollection of a paper by engineers in Quebec who had used this approach to build a road embankment across a swamp in the north of the province.

I reran my slope stability analyses, one case each evening with carefully chosen higher strength and slowly the answers came out: we could just manage to get enough strength gain if we increased the gypsum height slowly enough for the pore pressure to dissipate. So we installed piezometers in the clay and started gypsum deposition. I was alarmed by how quickly the pore pressure rose on first gypsum deposition. Along some parts of the perimeter the pore pressure dissipated rapidly enough: in those areas where I had logged sand lenses in the clay. But along other stretches of the perimeter, there was little to no pore pressure dissipation. In time we installed vertical sand drains in these stretches and the gypsum was deposited, the impoundment completed, and reclaimed. I have never been back to see what it looks like.

U.S. MOLYBDENUM MINE TAILINGS IMPOUNDMENT

When the Columbia River was dammed by glacial ice, sediments deposited in the deep valleys of northern Washington State. Amax sought to develop a molybdenum mine just off the Columbia in the Colville Tribe reserve. I was brought across to design the tailings impoundment at the selected site. I was brought across because preliminary surveys had revealed up to 30 meters of soft, unconsolidated mud filling the selected valley, and after all, I had just succeeded with a similar soil deposit in South Africa.

To contain the calculated volume of tailings from the proposed mine, the impoundment would have to be 1,000-ft high, an unprecedented height in 1980, but more common now. A quick calculation revealed that the rate of rise was so fast that no amount of expedited drainage of excess pore pressure would yield a fast enough gain of strength to provide the required stability. We had to find another way.

In concert with the mining engineers, we came up with the idea of building a 300-ft high starter dike of waste rock. Stripping overburden would provide the waste rock and if we dumped it in fifty-foot lifts we could have the starter dike ready before the mill came on stream. If we cycloned the tailings, there would be enough coarse material to fill in behind the dike and then go on to raise the embankment above the rock dike. The fine cyclone overflow would be discharge behind the sand embankment. Sketches and drawings were generated, and stability analyses undertaken (a junior colleague got his master thesis completed on the strength of the stability analyses).

We consulted with the experts including a memorable visit to Arthur Cassagrande to discuss piping of tailings through the segregated waste rock. I came across that new American institution, the peer reviewer and I was eviscerated by them for my early mistakes. Finally the local authorities include Roy Soderberg of the Spokane mining department approved the design and we were ready to go to construction. But Carter became president, the economy collapsed, mining projects were shelved in every state, and engineers in the mining industry were thrown out of work. House prices collapsed, the interest rate shot up, and Reagan became president. The mine never opened. Rob Dorey, now an independent consultant in Denver, took the ideas, ran with them, expanded them, improved them, and formulated the design of a great tailings impoundment that was built in Idaho.

Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

U.S. SILVER MINE TAILINGS IMPOUNDMENTS

Along the way to the 1983 collapse of mining, I found myself on Admiralty Island off the coast of Juneau, Alaska. We helicoptered in to the old cannery and all over the island seeking sites for the impoundment for the new silver mine. I found a great site with the right topography and the right location to the proposed mill. We drilled and found bedrock sufficient to hold the embankment, but whatever I did I could not get the impoundment water balance to come out right. It rains almost all the time in the panhandle that is rightly called a rain forest.

To pay a mortgage of 18.5 percent, I returned to South Africa to pick up work on South African diamond and platinum tailings impoundments. Others solved the water balance challenge: squeeze the water out of the tailings in the plant and dispose of them as an essentially dry solid.

U.S. GOLD MINE TAILINGS IMPOUNDMENTS

If you go on the web and search out the Cannon Mine in Washington you can get all and more than I tell here about a successful gold mine tailings impoundment. Credit to those who operated it and even more credit to those who closed it and reclaimed the site.

In a small valley immediately above Wenatchee, WA was a gold deposit. Behind the mine site was a high, steep valley with 20 or so feet of alluvial deposits. The embankments are friable and crumbly sandstone. On top of the hills are sound basalt and windblown silts. We chose an earth and rock fill embankment; the outer shell is compacted basalt; the core is compacted silt; and the drains are the sandstone of the abutment hills.

The tailings are inert: the result only of crushing the ore and floating out the gold. All chemical processing was done in Canada. The only issue that obsessed us was the danger of seepage and piping through the embankments. The country rock is the same as that which failed in at a famous dam built by the Corp of Engineers a few years before our work. We strove to avoid a replicate failure by putting a blanket drain on the flanks downstream of the core and planning tailings deposition to push the water pool as far from the embankment as possible.

Today the mine is worked out and the impoundment is reclaimed. As I said above, go to the internet to see pictures and read more on the success of those who followed my two years on site during construction designing and refining as we went.

U.S. URANIUM MILL TAILINGS IMPOUNDMENTS

The U.S. Department of Energy chose Albuquerque, New Mexico, as the project office location for the $1.5 billion Uranium Mill Tailings Remedial Action (UMTRA) Project.

Congress mandated the project in response to findings of high cancer rates in Shiprock, NM, and Grand Junction, CO resulting from the old

Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

uranium mill tailings impoundments left over from the Manhattan Project.

A headhunter interviewed friends from my days as a tailings engineer in Tucson and Denver. They did not want the job, but both said I could do it, namely be the manager of engineering for the Technical Assistant Contractor which consisted of a consortium of companies retained by the DOE. Thus I found myself in that most beautiful of American cities bounded by the mighty Sandia Mountains that rise 4,000 feet above the desert. For five years, with a team of brilliant and committed colleagues we closed twenty four sites in ten states. The technical approaches we pioneered in concert with the Nuclear Regulatory Agency engineers, the engineers in the state agencies, and the design engineers with the Remedial Action Contractor still set the yardstick for long-term closure and stability of tailings impoundments.

I am convinced we met the congressional mandate to stabilize for 1,000 years to the extent reasonable and at any rate for at least 200 years. Personally I believe the piles will be there and stable for thousands of years: our model was always the geomorphologic forms around the sites. Admittedly, some of the sites are performing in ways we did not anticipate, but none in a way that imperils their stability. The cost was high and hardly to be replicated by the average mine. But the piles were where the miners had left them in the hurry of a major war effort. Today mines can select sites under less pressure and must make decisions based on the knowledge that sites can be reclaimed for the long term.

Tel: +1 (604) 683-2037
Fax: +1 (604) 681-4166
Email: info@infomine.com
www.infomine.com

DRAIN BLOCKING

The drains of the first major slimes dam that I designed, blocked within three month of start of operations. (I use the terminology we used back then.) I never conceived of this happening; it was a major embarrassment. Luckily my best friend worked for the contractor and he managed to clean out the gunk with pipes and much manual labor. The same thing happened three month later, and six month later, and then I called in Adrian Smith. He came up with the geochemical explanation, but to the best of my knowledge drain cleaning continued for a long time.

I had forgotten this incident, but was reminded of it when I read a paper in the Infomine library from a 1984 copy of Geotechnical News. In the paper Adrian Smith describes the conditions that give rise to blocked drains. He writes: "The most widely experienced drain blockage process is the precipitation of iron species. Iron, in solution in its ferrous state, is oxidized to its less soluble tri-valent ferric state when interstitial liquids come into contact with free oxygen in the drain. The result is precipitation with its attendant drain-blocking potential. Eventually, complete blockage of the drain can result." He was being kind: complete blockage does occur, believe me.