NSW Planning & Environment
TAILINGS MANAGEMENT WORKSHOP
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A Moment of Reflection

B1 - CAM1 - Barragem
LEADING PRACTICE TAILINGS MANAGEMENT

Constraints
Cost driver for conventional tailings management
Deposition processes
Tailings dam failures
Guidelines
Good tailings management
Constraints Under Which TSFs Must Operate – Surface and In-Pit TSFs

- Climatic, topographic and seismic setting
- Nature of tailings, particularly presence of clay minerals
- Tailings production rate that must be stored and % solids at which they are deposited
- Need to manage, store, and recycle when possible, supernatant tailings water
- Need to meet discharge water quality licence conditions
- Need to rehabilitate TSF on closure to achieve agreed completion criteria, and land use or ecological function

**Good water management is usually key to good tailings management**
Constraints Under Which TSFs Must Operate – Surface TSFs

- Dam foundation conditions, and availability and suitability of borrow materials
- Need to maximise tailings settled dry density, and hence minimise wall raising and volume of tailings stored
- Desirability or need to facilitate upstream raising, where appropriate
- Risk of a spill of water and/or tailings

People, infrastructure and environment downstream key
Constraints Under Which TSFs Must Operate – In-Pit TSFs

- High rate of rise due to small footprint, particularly initially
- Difficulty of removing water
- Poor tailings settled density
- Risk of over-topping by water

_Potentially difficult to rehabilitate_
Conventional Tailings Disposal and Storage

**Commonly held perception, supported by NPV approach, is that transporting tailings as a slurry to a dam is most economic**

- Dewatering tailings to a paste or by filtration is perceived to be too expensive.
- Reduced storage volume occupied by tailings paste or filter cake, and relative ease of capping are discounted, as is potential for a higher level future land use.
- Cost of rehabilitating resulting soft and wet tailings is discounted and not considered to be significant.
- Few TSFs have been rehabilitated, due to difficulty and expense of capping “slurry-like” tailings, particularly at a time when mine is no longer producing revenue.
Relative Cost Comparison of Tailings Storage Alternatives

High cost of Dams in flat terrain

20-year coal mine in relatively flat terrain

NET PRESENT COST ($M)

Surface TSFs  In-Pit TSF  On-Off Surface TSF  Pressure Filtration  Surface TSF then In-Pit

High cost of Rehab  High cost of re-handling  High CapEx  Balancing Dam & Rehab Costs

Discount Factor = 2.5%  Discount Factor = 5%  Discount Factor = 10%
Conventional Tailings Disposal and Storage in a Dam

- Tailings slurry containment and method of construction and dam raising varies from region to region:
  - **Upstream construction**, using tailings where possible, is widely employed in South Africa, Australia and the south-west of the USA, which share a dry climate
  - **Downstream construction** is employed in wet/seismic regions
  - **Sand dams**, cycloned and/or compacted, are widely employed in South America, usually raised by centreline method
  - **Roller compacted concrete** dams are finding favour for high tailings dams in deep valleys of Andes in South America

*While necessity for downstream construction is understandable in wet/seismic regions, choice between upstream construction and sand dams is not so obvious – More a function of “what we’ve always done”*
Tailings Continuum (adapted from Davies and Rice, 2004)

Optimum for disposal to a surface TSF is likely to be thickened, otherwise filtered.
Consistency of Tailings

- High density slurry
- High slump paste
- Low slump paste
- Centrifuged (wet cake)
- Filtered (dry cake)
Sub-Aerial Tailings Deposition Processes

- **Beaching** – *Best assessed in field*
- **Hydraulic sorting** down beach according to particle size and specific gravity – *Best assessed in field*
- **Settling** – *Very large strain*
  - *Little shear strength*
- **Consolidation** – *Large strain*
  - *Large shear strength gain*
- **Desiccation** on exposure to sun and wind – *Minor strain, significant shear strength gain*
- **Loading** by upstream raise and/or a cover:
  - *Could cause bow-waving failure*
  - *Best loaded progressively on a broad front to avoid failure*
  - *Will result in shear strength gain over time*
Ongoing Tailings Dam Failures

• Average tailings dam failure rate over last 100 years is 1.2% or 2.2/year, >2 orders of magnitude higher than that for water retention dams of 0.01% – *Acceptable?*

• Focus is on failures that occur in *developed countries* (e.g., Mount Polley, Canada in 2014; Cadia, Australia in 2018) or that involve *global mining companies* (e.g., Samarco [BHP Billiton/Vale joint ownership], Brazil in 2015; Brumadinho [Vale], Brazil in 2019)

*Recent, high profile tailings dam failures are threatening mining industry’s financial and “social licences to operate” and threatening industry’s control of its destiny!*
Guidelines and Standards – Operation to Post-Closure (in Perpetuity) Design

• **ANCOLD (2012) Guidelines on Tailings Dams** – Planning, Design, Construction, Operation and Closure is de facto standard for tailings dams:
  
  – Post-Closure Annual Exceedance Probability (AEP; up to 1:10,000) may be 10- to 100-fold higher than Operational AEP, depending on Consequence Category
  
  – Australia has <200 years of earthquake data and is of low seismicity, hence a lack of earthquake data – A 1:10,000 earthquake for Australia is likely to be ≈ 1:100 for San Francisco!
  
  – A dam designed for an Operational AEP of 1:100 or 1:1,000 may be difficult (and expensive) to retrofit for a Post-Closure (in perpetuity) AEP of 1:10,000
  
  – **Post-closure Factor of Safety (FoS) of 1.5 may be > Operation FoS of > 1.3** – A dam designed for an Operational FoS of 1.3 may be difficult (and expensive) to retrofit for a Post-Closure FoS of 1.5
Findings:

- Some corporate documents were found to be comprehensive, with examples of good practice.
- Majority of ICMM member companies have corporate documents that substantially follow good practice.
- A minority of ICMM member companies either have corporate guidance documents or adopt a surrogate that partly follows good practice; hence most member companies either conform or partly conform to good practice.
ICMM Golder Review of Tailings Management Guidelines, Dec 2016

• **Recommendations:**
  – TSF *classification* based on consequences of failure, with commensurate safety standards
  – Have a formal *change management* process for life-of-facility
  – Have prescriptions for formal *communication* between Engineer of Record and operators and owners to transfer and confirm shared understanding of intent and constraints of TSF design and operation
  – Undertake formal *risk assessment* for TSF by suitably-qualified persons and ensure that mitigation measures arising are embedded into design, life-of-facility plan and operating manual
  – *Independent review* by suitably qualified and experienced professionals
• **Coverage:**
  - Sustainable development & tailings
  - Life-of-mine risk-based approach
  - Tailings disposal & storage
  - Planning & design
  - Construction
  - Operation
  - Rehabilitation & aftercare
  - Future directions
Good Tailings Management

- **Divert** clean rainfall runoff around TSF
- **Discharge** tailings as thick as can be effectively managed
- **Spigot** tailings in thin layers and cycle deposition
- Maintain a **small decant pond** to maximise dewatering, desiccation, densification and strengthening of tailings
- Ideally, have **separate evaporation or tailings water storage ponds**
- However, potentially acid forming (PAF) and otherwise potentially contaminating tailings may benefit from being kept under water, which would restrict desiccation
- **Move towards** tailings minimisation, dewatering and integrated disposal with waste rock
Good Tailings Management

Spigot in thin lifts

Maintain a small decant pond
KEY LIFE-CYCLE TAILINGS MANAGEMENT RISKS

Risk of tailings liquefaction
Risk assessment
Tailings security deposit
Closure from geotechnical and cost perspectives
Financial impacts of tailings dam failures
Way Forward

• Risk assessments of tailings dams are common-place
• Defining what is an “acceptable” risk level is difficult
• Ongoing rate of tailings dam failures is unacceptable
• Approaches to tailings management need to improve
• Tailings minimisation & dewatering need to be pursued
• Design, construction, operation and closure of tailings dams and facilities needs greater reliability and resilience
• Monitoring and interpretation of tailings dams needs to be more comprehensive, and in real-time, linked to triggers:
  – Green, for safe operation
  – Amber, requiring assessment by a Geotechnical Engineer
  – Red, initiating Emergency Response Plan
Risk of Tailings Liquefaction

• Risk of earthquake-induced liquefaction:
  – Fine-grained sandy or silty sand tailings – √
  – Loose (contractive, brittle) state – √
  – Near-saturated – √
  – Earthquake magnitude > 5.5 and peak ground acceleration >0.13g – ?

• Risk of static or flow liquefaction, triggered by:
  – Loss of containment due to dam instability
  – Overtopping and erosion of dam
  – Pore water pressure increase due to dam raise
  – Rise in phreatic surface due to heavy rainfall or fresh tailings

  **Susceptible tailings can behave in an undrained, contractive, strain-softening manner, and liquefy or flow**
Risk of Tailings Liquefaction

• However, tailings state (loose or dense) *in situ* is difficult to determine, particularly if tailings are loose:
  – They can’t be sampled
  – CPT data plot in bottom left-hand corner of chart, where few correlation data exist
  – Some use of SPT
  – Some use of “simple shear” testing, but samples may not represent *in situ* state

*In absence of laboratory test data, post-liquefaction shear strength may be estimated based on correlations between liquefaction case histories (notably mainly in natural soils) and CPT cone resistance*
Geotechnical Closure Risks and Challenges for TSFs

• TSFs:
  – Dam geotechnical instability – Tailings are expected to drain down on cessation of deposition, but may be recharged by high rainfall if this is not discharged via a spillway
  – Dam erosional instability, particularly in a dry climate if slope is flattened and topsoiled
  – Differential settlement, affecting slope profile and drainage
  – Poorer water quality (saline, and/or acidic, or alkaline), after a lag:
    • Ponded water, and runoff leading to ponding below dump
    • Emerging at low points around toe
    • Infiltrating to groundwater resource

*Few TSFs have been successfully rehabilitated, with reprocessing and in-pit disposal increasingly being considered*
Regulatory Requirements

• Resources Industry’s social and financial licences to operate are under increasing and high threat

• There is a risk that industry’s control will be taken away due to a “lack of trust”, arising from past poor performance

• Everyone brings “bias” to a discussion, discouraging innovation and improvement

• (Progressive) Mine Closure needs to genuinely be front of mind from Planning, throughout Operations, to Rehabilitation and ongoing Maintenance

• A range of Government Departments should be engaged, depending on post-closure land use and/or function

• Governments are moving to have Rehabilitation Bank Guarantee amounts paid to them for abandoned sites
Tailings Security Deposit

- Queensland and NSW indicative costs for reshaping, capping/sealing tailings are:
  - $170,000/ha for tailings likely to present considerable difficulties due to reactive and/or soft tailings.
  - $108,000/ha for tailings likely to present moderate difficulties due to reactive and/or soft tailings.
  - $81,000/ha for benign and strong tailings.

- Plus land preparation and revegetation, and maintenance

  Total Security Deposit from $85,300 to $215,000/ha

- Actual cost could be far less, under favourable conditions

- A Bank Guarantee would cost ~1.5 to 3% pa of Security Deposit, possibly based on an over-estimate of actual costs, and could continue in perpetuity
Divergent Perceptions of Rehab. Cost over Time ($100 M Base Cost)

Which approach is more realistic of actual rehabilitation costs delayed over time?
Early Impact of Brumadinho Tailings Dam Failure on Share Prices

Vale down initially 25.9%, recovering to 16.3% down

BHP up 15.1% since 25 January 2019

Rio Tinto up 18.2% since 25 January 2019

Fortescue up 34.4% since 25 January 2019

Market Capitalisation of all Iron Ore producers remained about same!
Impact on Iron Ore Price (62% Fe in USD)

Up 24.2%, retreating to 16.2% up, since 25 January 2019

SOURCE: TRADINGECONOMICS.COM | OTC
Failure on a soft glacial clay foundation layer, leading to overtopping and erosion.
Fate of Imperial Metals

Mount Polley Tailings dam failure

Newcrest buys 70% of Imperial’s Red Chris Mine

1.98 CAD  Mar 8, 2019
Imperial on Brink of Bankruptcy

https://thenarwhal.ca/what-happens-if-imperial-metals-goes-bankrupt/

- Imperial Metals’ share price dropped from a peak of almost CAN14 in early 2014 to CAN1.05 in late 2018
- Imperial Metals is currently surviving on debt, with CAN75M/year in interest payments, covered by shares offered to creditors
- Failure clean-up cost CAN67.4M, not counting 12 months lost production
- Environmental liabilities costed at CAN173.6M have been discounted to CAN100.9M, with only CAN14.3M cash secured in reclamation deposits
- An estimated CAN86.3M is expected to be spent on reclamation between 2018 and 2046, leaving an undiscounted liability post 2046 of ~CAN100M
Cadia Tailings Dam Failure
9 March 2018

Estimated time of failure: 7:00pm 9 March 2018

Initial backs scarp cracks – 9 March
Circular failure cracks first observed 9 March
Newcrest’s Share Price

- Cadia Tailings dam failure
- Newcrest buys 70% of Imperial’s Red Chris Mine
SOME EXAMPLES

“Apple skin” covers
Slope treatment
Capping surface and in-pit tailings
Some closure lessons
Performance of Covers in Australian Climate

Eroding rainfall-shedding cover

Robust store and release cover
Over-Dumping of Fines on Angle of Repose WRD Slope and Revegetating
Rock Covers on Flattened Mine Slopes

- Rock on sodic spoil at 3(H):1(V)
- Rock on TSF wall
Abandoned Capping of Smectitic In-Pit Coal Tailings at Wambo (~$1M/ha)

Anchored geotextile and geogrid

D2 Dozer for pushing CR

Abandoned capping
Capping Surface Coal TSF – New Acland, Queensland

Pushing initial 1 m coarse reject capping by D6 Swamp Dozer

Rise in water table & drainage      Hydraulic fracturing      Start of bow-waving
Successfully Capping Surface Coal TSF – New Acland ($60,000 to 80,000/ha)

Before capping – August 2009

During capping – April 2013

During capping – March 2014

Completed capping – December 2017
Wet Tailings – Hydraulic Placement OR End-Dumping of Coarse Material

Hydraulic placement

End-dumping

5 m
20 m
1% slope

COARSE REJECT - 1
COARSE REJECT - 2
COARSE REJECT - 3
Mixing Zone - 1
Mixing Zone - 2
Mixing Zone - 3
TAILINGS

SPOIL

Water table

1% slope
Successfully Capping In-Pit Coal Tailings – New Acland ($70,000 to 80,000/ha)

Before capping – March 2014

During capping – September 2016

During capping – February 2016

Completed capping – December 2017
TSF Perimeter Peat and Central Water Cover in Tasmania (Brett, 2011)
Successful Rehabilitation of 100 m High TSF Slope – San Manuel, AZ

During construction

Sandy alluvium only over upper third of slope

Crushed rock over sandy alluvium over lower two-thirds of slope

After 2 years

After 12 years
Some Closure Lessons

• Have a **clear closure aim** in harmony with surroundings, and plan and actively operate to facilitate this

• **Question NPV** applied to operation/closure costing

• **Environmental Conditions** pertain to operations (imposed due to mistrust that environment will be protected):
  – Not Closure Criteria
  – Zero discharge and sediment containment create legacies and are not feasible post-closure

• **Aim for mine lease relinquishment**:
  – Operations that facilitate this
  – A viable post-closure land use or ecological function
  – Rehabilitate in a way that facilities (not inhibits) future land use
  – Liaise with ultimate custodians of land, not just Regulators
Some Closure Lessons

• Question conventional “What we have always done” approach
• Take climate, topography, seismicity and nature of mining and processing wastes into account
• Treat mining and processing wastes as potential construction/rehabilitation materials, and segregate/stockpile suitable materials for future use
• Identify, segregate and encapsulate potentially contaminating wastes
Key Leading Practice (or Innovation in) Tailings Management

• Integrated waste rock and tailings disposal in one facility:
  – Using waste rock to form a substantial containment for tailings, preferably thickened or filtered
  – Co-disposal of tailings and coarse-grained wastes, by combined pumping or mechanical mixing

• Filtered tailings to enable dry stacking (and compaction, if desired)

• Combining filtered tailings and crushed or screened waste rock in a stack; e.g., GeoWaste

• Pit backfilling using co-disposed tailings and coarse-grained wastes

• Disposal of tailings in a way to facilitate rehabilitation and add value post-closure
Barriers to Implementation of Leading /Innovative Tailings Management

- NPV accounting and use of a high discount factor, which favours tailings management options that are cheap (particularly CapEx) in short-term, and delayed expenditure, which in turn are likely to exacerbate impacts and blow-out rehabilitation costs
- Perceived high costs, supported by NPV accounting, of alternative tailings management options, such as mechanical dewatering and co-disposal
- Perceived and real (e.g., high clay mineral content, and handling coarse-grained wastes) technical difficulties of mechanical dewatering and co-disposal
- Resistance to do other than what we have always done
- Uncertainty of new approaches