2018 Tailings and Mine Waste Conference
Alternative Approaches to Management and Closure of Tailings Storage Facilities

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Scope

- Extending Net Present Value approach to tailings management and closure
- Conventional approach to tailings disposal and storage
- Tailings dam failure rates
- Risk of tailings liquefaction or flow
- Tailings closure and rehabilitation risks and costs
- Alternative approaches to tailings disposal, storage and rehabilitation
Net Present Value Approach

• NPV, with a high Discount Factor (typically 6 to 10%, several times inflation rate) is applied to achieve financing of high cost mining projects
• NPV is extended to tailings disposal, minimising short-term capital costs, with rehabilitation costs discounted by same high Discount Factor, which contributes to:
  – Increased risk of tailings dam failure
  – Initially inexpensive but too small surface facilities storing tailings slurry delivered by robust and inexpensive centrifugal pumps
  – Wet and soft tailings deposits, excessive stored water, and an ever-increasing stored volume and footprint.
  – A blow out in costs, as frequent tailings dam raises are required, and unintended and cumulative negative impacts
  – Difficult and costly rehabilitation, at a time when revenues cease
Constraints Under Which a Surface TSF Must Operate

- Climatic and topographic setting of TSF
- Dam foundation conditions, and availability and suitability of borrow materials
- 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 supernatant
- Need to meet discharge water quality licence conditions
- Need to maximise tailings settled dry density, and hence minimise wall raising and volume of tailings stored
- Desirability of upstream raising, where appropriate
- Need to rehabilitate TSF on closure
Conventional Approach to Tailings Disposal and Storage

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

- While downstream construction is understandable in wet climates, choice between upstream construction and sand dams is not so obvious – “What we’ve always done”
Tailings Continuum (adapted from Davies and Rice, 2004)

- **Slurry-like**: No particle/particle interaction, saturated, no effective stress
- **Tailings slurry** (typically segregating)
- **Thickened tailings** (dewatered, ideally non-segregating)
- **Paste tailings** (Dewatered, ideally non-bleeding)
- **"Wet" filter cake** (near-saturated)
- **"Dry" filter cake** (85 to 70% saturated)

- **Soil-like**: Particle/particle interaction, effective stresses and suction, shear strength

- **By gravity**: U/G or In-Pit

- **Low CapEx and OpEx, but high rehab. cost**
  - Inefficient water & process chemical recovery
  - Centrifugal pumps sufficient
  - Extensive water management
  - Containment required
  - High runoff & potential seepage
  - Rehabilitation difficult (soft & wet)

- **Improved water & process chemical recovery**
  - Positive displacement &/or diaphragm pumps
  - Discharge management required (steeper beach)
  - Reduced water management
  - Some containment required
  - Some runoff & seepage potential
  - Rehabilitation difficult (soft & wet)

- **High CapEx and OpEx, and high rehab. cost**

- **Efficient water & process chemical recovery**
  - Transportable by truck or conveyor
  - Minimal water management
  - Minimal containment required
  - Negligible seepage losses
  - Progressive rehab. possible
  - Stable tailings mass

- **Very high CapEx and OpEx, but low rehab. cost**

- **Clay mineral-rich tailings stuck here**

- **Pumpable**

- **Non-pumpable**
Conventional Approach to Tailings Disposal and Storage

• A commonly held perception, supported by NPV approach, is that transporting tailings as a slurry to a surface dam is most economic.
• Discounted cost of rehabilitating resulting TSF is not considered to be significant.
• However, few TSFs have been rehabilitated, due to difficulty and expense of capping a “slurry-like” (wet and soft) tailings deposit.
• Filtering tailings is perceived to be too expensive due to capital and operating costs of plant and transport.
• Filtered tailings occupy less volume, are relatively easy to cap, and may be rehabilitated to a high level of future land use and/or ecological function.
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%
- USA has reported highest number of tailings dam failures of any country, with 39%, 18% located in Europe, 12% in Chile, and 5% in Philippines
- Most tailings dams that failed were of moderate height – 5 to 20 m high
- Focus is on failures that occur in developed countries (e.g., Mount Polley in 2014, Cadia in 2018) or that involve global mining companies (e.g., Samarco in 2015)
- Recent, high profile tailings dam failures are threatening mining industry’s financial and “social licence to operate”!
Responses to Recent High Profile Tailings Dam Failures

• **Reviews** of existing tailings dams by major mining companies, or when required by Regulators

• **More conservative designs**, including using lowest bound parameters – Questioning safety of previous designs, or feasibility of failure through only lowest strength materials!

• **Banning some tailings containment practices**, such as upstream construction in Chile’s seismic environment

• **Increased liability** of “Engineer of Record”/Design Engineer

• **Concern about personal liability/prosecution** of senior executives, driving tailings management

• **Increased Security Bonds and Guarantees** for TSFs
Responses to Recent High Profile Tailings Dam Failures

• Responses have not (yet) included a major shift in existing tailings slurry disposal and containment
• What has occurred is:
  – Increased tailings dam monitoring (in real-time), particularly at failure sites
  – Inclusion of buttresses as an “insurance policy”, sometimes forced by inadequate tailings management and monitoring
  – Conditions being imposed on tailings management at new mines
  – Filtering of tailings being considered beyond desert sites, possibly including co-disposal with waste rock
570 mm January 2016 Rainfall-Induced Tailings Run-Out
Risk of Tailings Liquefaction

• **Conditions for liquefaction of tailings:**
  – Silty sand to fine-grained sandy tailings
  – Loose (contractive, brittle) state
  – Near-saturated
  – Trigger event:
    • Earthquake magnitude > 5.5 and peak ground acceleration > 0.13g
    • For “static” liquefaction:
      – Too rapid a rate of upstream construction
      – Too rapid a rate of rise of tailings
      – A flooding event, possibly leading to overtopping and erosion of embankment

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

- Davies et al. (2002) claimed that tailings impoundments have demonstrated more static liquefaction events than any other cause.
- Risk of static liquefaction may be higher at sites with low design earthquakes, such as in Australia.
- Tailings potentially susceptible to liquefaction are difficult to sample and assess.
- A precautionary approach is to assume that identified “loose” tailings will be susceptible to static liquefaction, and to outlaw upstream construction.
- However, well-managed upstream construction can safely support this method.
Tailings Operation, Closure and Rehabilitation Costs

• Use of NPV and an artificially high Discount Factor result in:
  – Apparent cost savings in tailings management in short-term
  – Increasing operational and capital costs over time
  – Unintended cumulative detrimental impacts over time
  – Ever-increasing closure and rehabilitation risks and costs in long-term

• To illustrate this, simple NPV analyses are applied to alternative management and closure approaches for:
  – Coal tailings from open pit mining operations
  – In relatively flat terrain of Eastern Australian Coalfields
  – Mine life of 20 years
  – AUD75,000/ha for rehabilitation
Relative Comparison of Tailings Storage Alternatives

- High cost of Dams in flat terrain
- High cost of Rehab
- High cost of re-handling
- High CapEx
- Balancing Dam & Rehab costs

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2.5% Discount Factor Applied to Tailings Operations & Rehabilitation

A more realistic Discount Factor of 2.5% indicates more realistic, higher rehabilitation costs.
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.

- To these are added costs for land preparation and revegetation, and maintenance, giving a 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 a high Security Deposit, possibly continuing in perpetuity.
Alternative Approaches to Tailings Disposal, Storage and Rehabilitation

• Rather than focussing on lowest NPV, manage tailings for safety and with end game of lease relinquishment uppermost

• Consider constraints over time, including changes in ore grade and geochemistry

• This will likely bias tailings management away from slurry disposal, unless enhanced operation and control is in place

• If upstream construction is favoured, tailings disposal must be managed to ensure a low rate of rise, discharge away from dam, and decant pond/stored runoff stored well away from dam – Avoid loose, liquefiable tailings and tailings that cannot readily be rehabilitated
Alternative Approaches to Tailings Disposal, Storage and Rehabilitation

- Recognise high cost of managing and rehabilitating tailings slurry
- Develop cost-effective dewatering of tailings addressing:
  - Perceived high cost of filtration
  - Difficulty in scaling-up filtration for high production rates
  - Need to ensure stability, which may include compaction
- Develop cost-effective co-disposal of filtered tailings and scalped waste rock addressing:
  - Required moisture content of tailings
  - Scalping (crushing, screening) of waste rock
  - Mixing of filtered tailings and scalped waste rock
  - Transportation of mixture
  - Need for compaction and encapsulation of PAF material