Implications of Global Industry Standard on Tailings Management (GISTM)

Professor David Williams
D.Williams@uq.edu.au

Director Geotechnical Engineering Centre
Manager Large Open Pit Project
School of Civil Engineering
The University of Queensland, Brisbane, Australia

Tailings dam failures threaten the mining industry's financial and "social licences to operate" and control of their Operation!

Frustration for Mining Executives:

I asked three Tailings Consultants whether my tailings dam is safe – One said YES, one said NO, and the third said I NEED MORE INFORMATION!

What am I to do with that?

Frustration for Consultants and Contractors:

I am provided with a limited scope of work, to a limited budget, and expected to provide a Rolls Royce!

How can I do anything more than recommend a conservative

"What has always been done"?

Some route causes of tailings dam failures

- Tailings dams that fail are marginally stable – Most dams are stable and don’t fail!
- Failures typically have a combination of causes, with water a key element
- Tailings deposited as a slurry are susceptible to liquefaction, unless desiccated
- Weak foundation layers may cause tailings dam failures
- Potential triggers for tailings dam failures:
  - Large earthquakes
  - Flooding events or build-up of rainfall over time
  - Too rapid a rate of rise of tailings, or poor tailings and/or water management
  - Upstream raise construction with too steep a downstream slope and/or poor management

Importance of given site setting

- Climate – In particular rainfall/precipitation and evaporation:
  - A dry climate makes slurry tailings disposal easier (e.g., Australia, South Africa, S-W US)
  - A wet climate has the potential to maintain the tailings wet (e.g., wet tropics, Brazil)
  - A near neutral water balance can be tipped net positive by tailings deposition, or net negative post-closure by evaporation from stored water (e.g., Canadian oil sands tailings)
- Topography:
  - Dictates the volume of “free storage” available in valleys and dam height
- Seismicity:
  - High seismicity will often govern tailings dam/storage design (e.g., Chile and Peru)
  - High seismicity may need to be considered post-closure (in perpetuity) everywhere

Some site setting examples

Australia – Generally semi-arid, flat and low seismicity

Chile – Arid to semi-arid, steep and high seismicity

Brazil – Generally wet, steep and low seismicity

Fatal tailings dam failures that have brought real change

El Cobre, Chile, 1965:

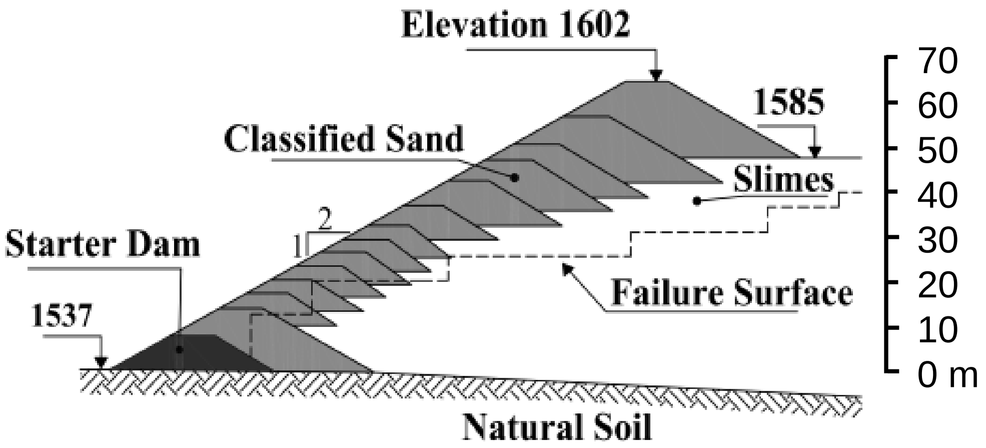
- Steep, wet upstream sand dams
- Liquefaction due to 7.4 earthquake
- 200-350 fatalities, town of El Cobre
- Rapid Industry response:
  - Questioned whether safe tailings dams could be built to sustain large earthquakes
  - Flattened/compacted downstream slopes and changed construction method to downstream mainly
- Regulations followed years later

Brumadinho, Brazil, 2019:

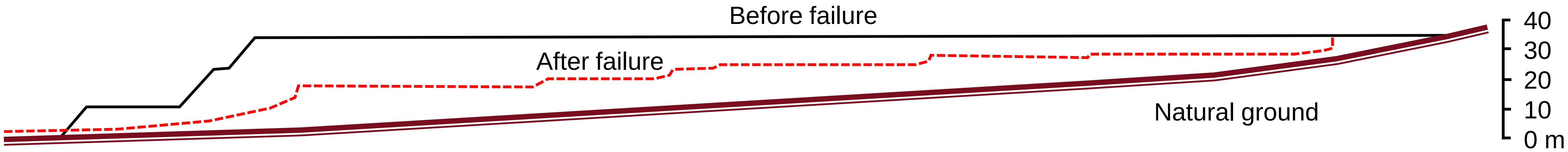
- Upstream, largely with tailings
- Too steep and too wet
- Liquefaction due to creep & rainfall
- 270 fatalities, mainly workers
- Rapid Regulator response:
  - Outlawed upstream construction
  - Required that unsafe dams be rectified
- ICMM, UNEP and PRI co-convened the Global Industry Standard on Tailings Management

Barahona and El Cobre tailings dam failures *(Troncoso et al. 2017)*

Barahona No. 1 Tailings Dam



El Cobre Old Tailings Dam



Rapid Industry response to El Cobre failure

- Downstream slope angles of existing upstream dams were halved and compacted by dozing to 1 in 4
- Raising was converted to mainly downstream construction, as for new dams
- Sand dams continued, and new earth and rock fill dams were also constructed
- Upstream faces were lined with a temporary geomembrane to limit water ingress into sand dams
- Central cyclone stations started to replace separate cyclones on the dam crest, which gave improved control over % fines and deposition

It took 5 years before regulators started to formalise these changes

Performance of Chilean sand tailings dams since 1965 *(Valenzuela, 2019)*

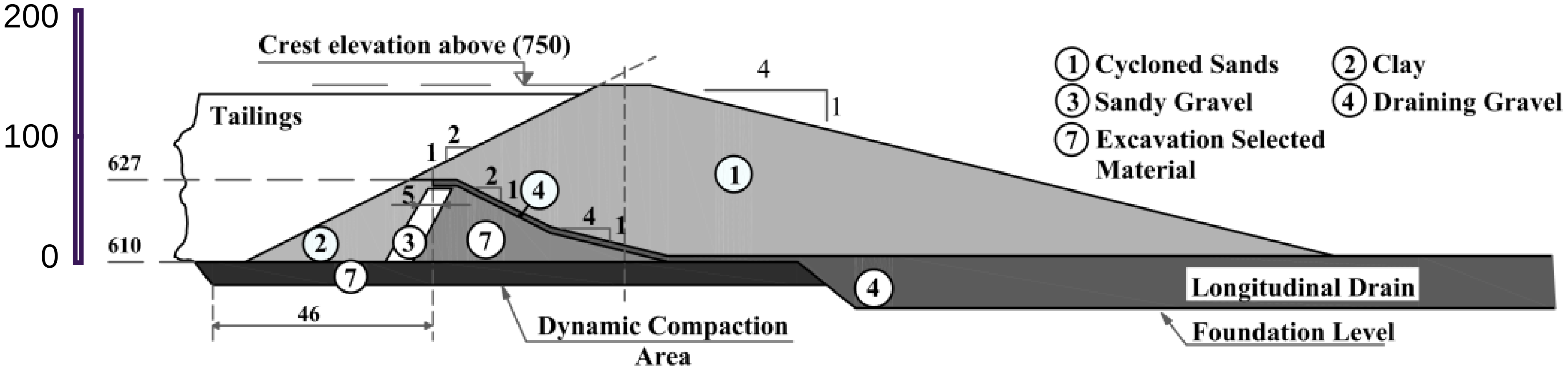
- Total number of tailings dams ~740:
  - Active tailings dams ~101 – Mostly downstream sand dams
  - Inactive tailings dams ~469 – Mostly upstream sand dams
  - Abandoned tailings dams ~170 – Mostly upstream sand dams

Active Chilean downstream sand dams have performed well since 1965, due to improved construction methods

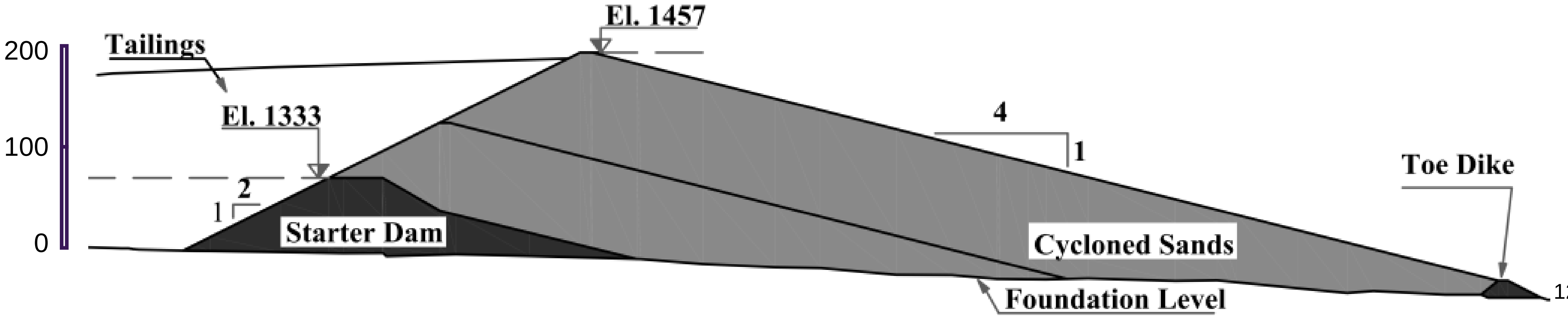
With the exception of a few inactive upstream sand dams in central Chile, most inactive and abandoned upstream sand dams have performed well since 1965, since they have drained down in the dry Chilean climate

Typical cross-sections of downstream sand dams *(Valenzuela, 2015)*

Las Tórtolas



Quillayes



Las Tórtolas main Tailings Dam – Dozed downstream slope

Quillayes downstream sand dam *(Luis Valenzuela, 2019)*

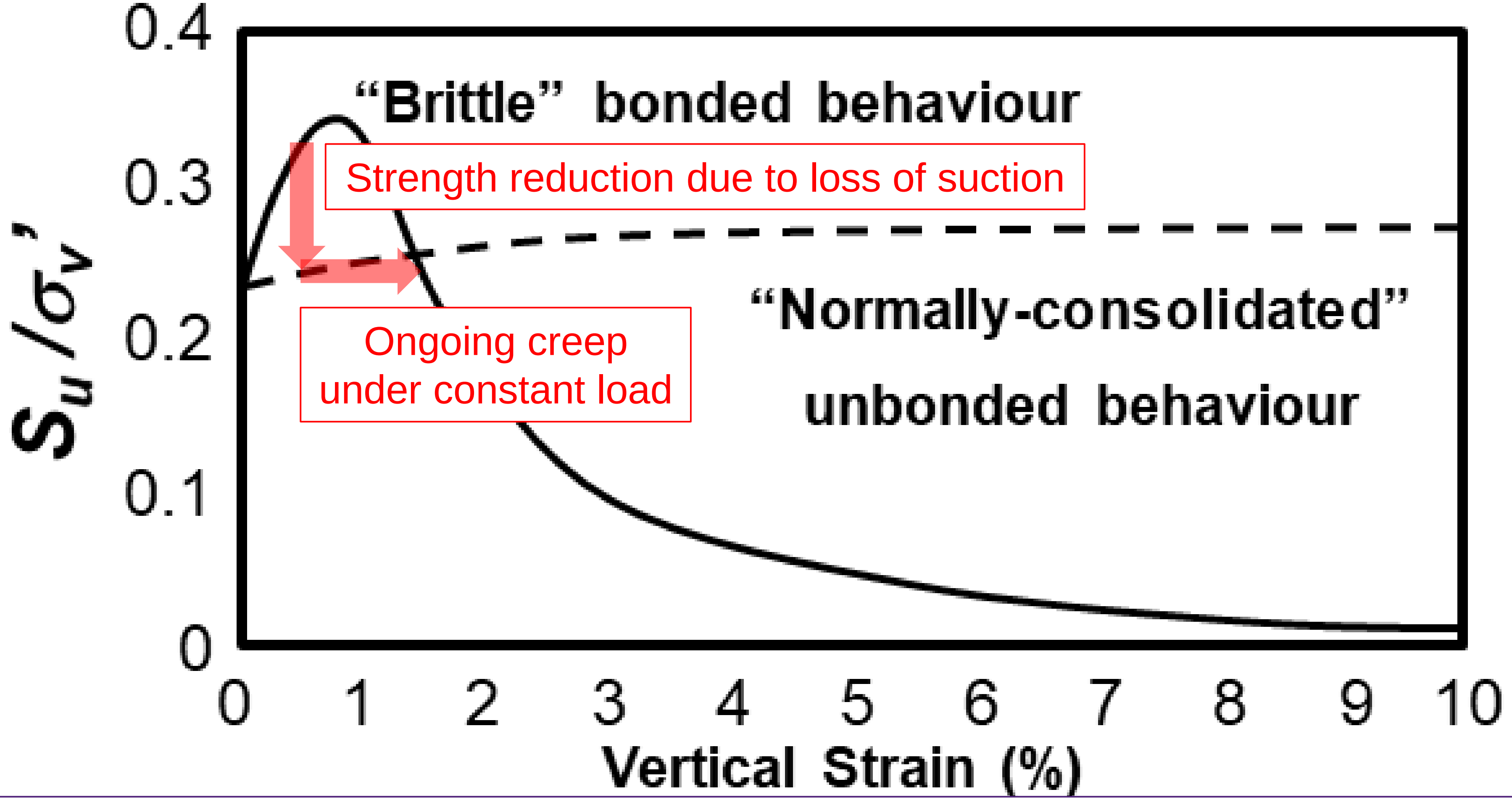
Brumadinho Tailings Dam I failure – After 18 s!
(Expert Panel Report: www.b1technicalinvestigation)

Brumadinho Tailings Dam I failure

Technical causes of failure of Dam I

- Dam I was marginally stable – Over-steep and too wet
- Sudden strength loss and resulting failure of this marginally stable dam was due to a critical combination of ongoing internal strains due to creep, and a strength reduction due to loss of suction in the unsaturated zone caused by intense rainfall towards the end of 2018
- This followed a number of years of increasing rainfall and intensity after tailings deposition ceased in July 2016
- Calculated pre-failure strains from this combination of triggers match well the small deformations of Dam I in the year prior to the failure
- Conventional Limit Equilibrium analysis assumes that all points on a slip surface at the same state – Not necessarily for a marginally stable dam!

Schematic of path to failure of Dam I



Critical combination of strength reduction and ongoing creep led to failure of marginally stable Dam I

Environmental, Social and Governance timeline for tailings management – Not new!

- **1984** – BHP Ok Tedi tailings dam failure
- **1994** – Ok Tedi class action against BHP
- **1996** – MAC Tailings Task-Force established
- **2002** – BHP Ok Tedi divestment
- **2004** – MAC TSM Tailings Management Protocol launched
- **2014** – Mount Polley tailings dam failure
- **2015** – Fundão dam tailings failure
- **2016** – ICMM Review of Tailings Management Guidelines
- **Jan 2019** – **Brumadinho tailings dam failure**
- Investor Mining and Tailings Safety Initiative launched
- **Aug 2020** – **GISTM launched**

GISTM – Let's drill down

"Zero harm to people and the environment"

What does this mean?

Is it reasonable/achievable?

"Extreme" Consequence Classification Default

Is this reasonable?

How many tailings facilities currently accommodate "Extreme"?

What are the implications? – 1 in 10,000-year return period!

Assessing tailings facility stability

"Factor of safety"

Simplistic and "attractive"

What do we take it to mean, and is this reasonable?

"Probability of failure"

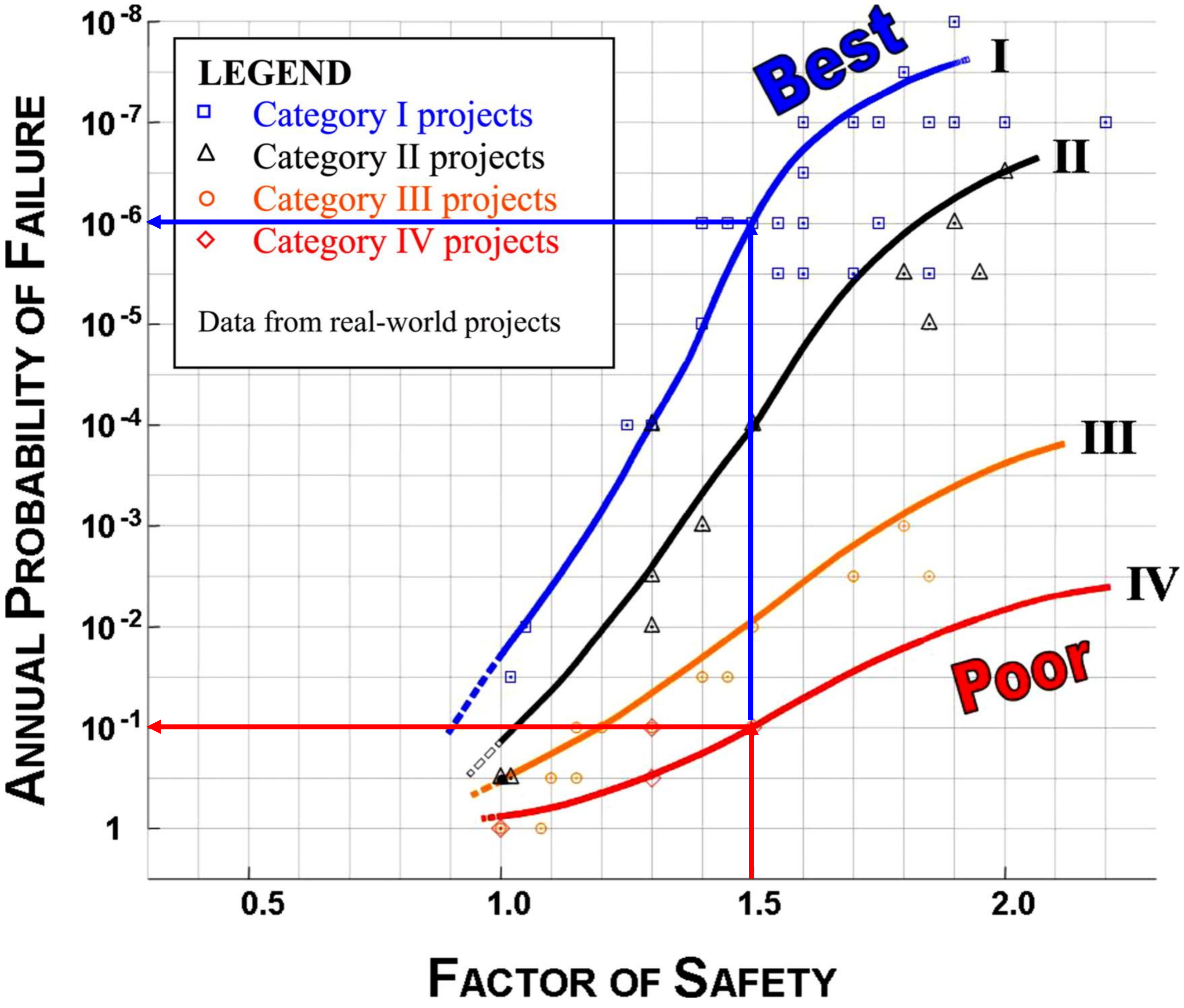
Complex and "unattractive"

Is this a better representation of uncertainty?

"Accepted" vs. "Acceptable"?

"Status quo" vs. "Sense of exposure to risk"

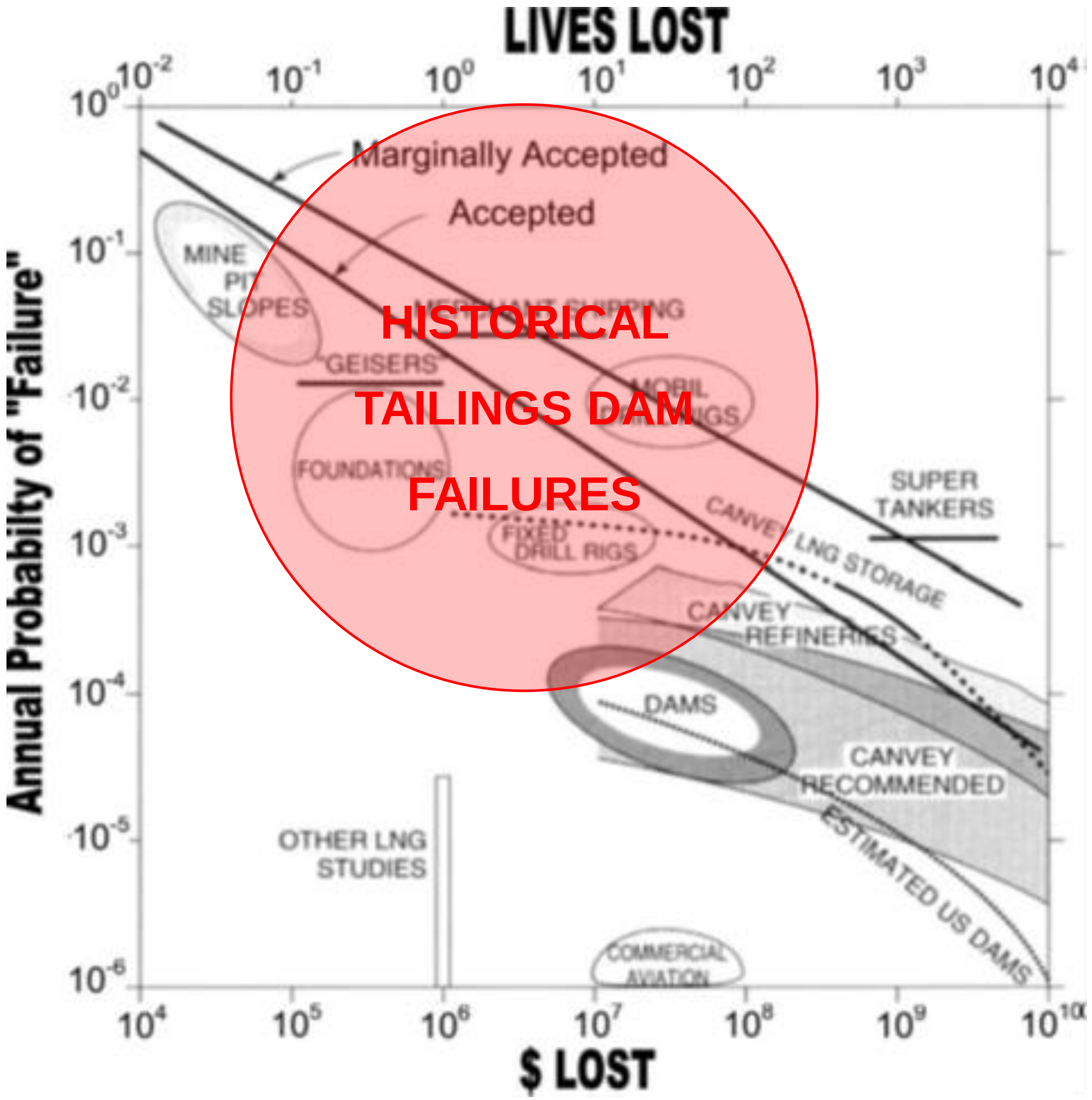
"Margin of safety" *(Silva, Lambe and Marr, 2008)*



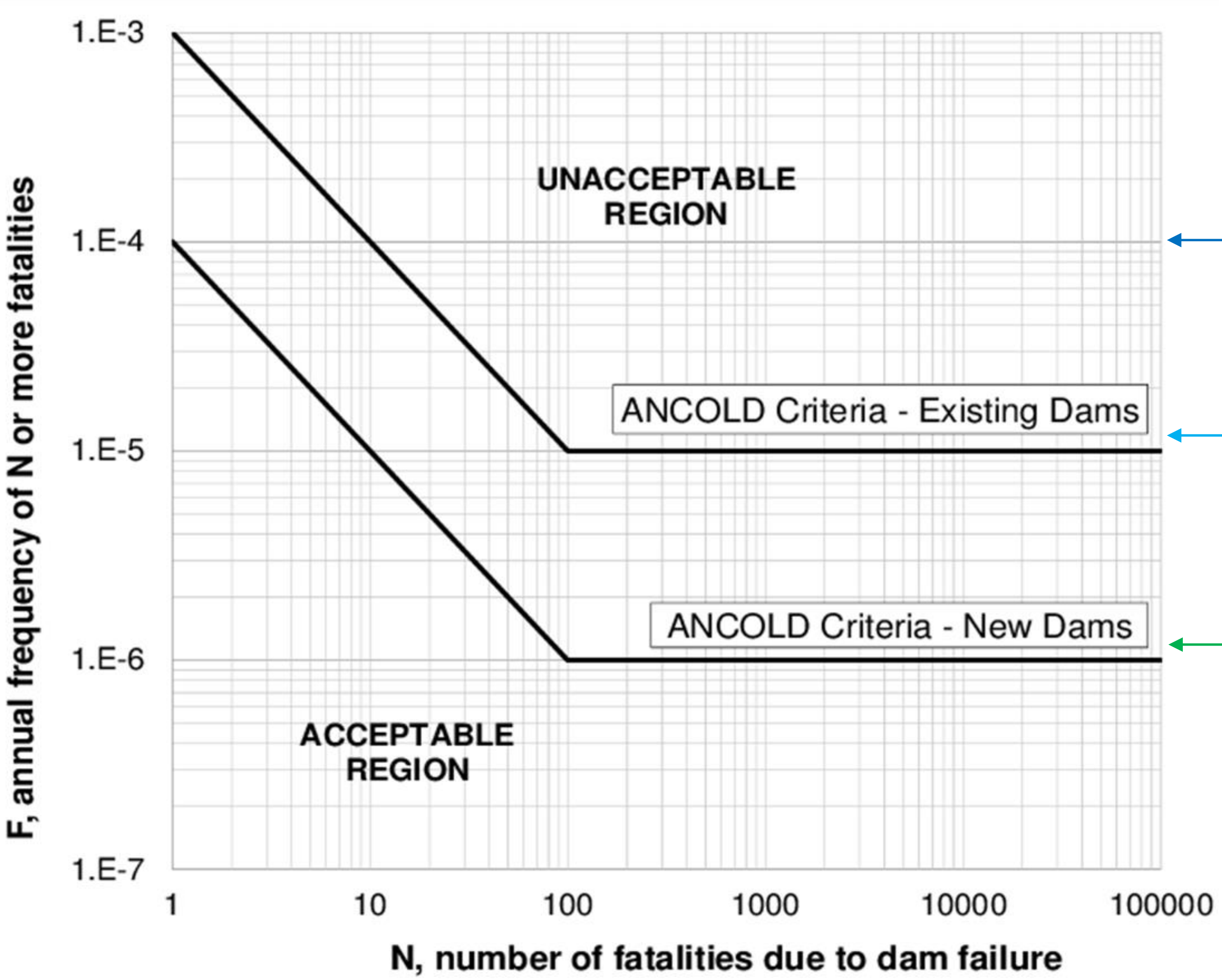
Design and Construction

Design and Construction

"Accepted" level of risk ≠ "Acceptable" *(Whitman, 1984)*



Acceptance criteria for dams (ANCOLD, 2003)



Corresponding to water dams

Corresponding to car travel

Corresponding to air flight

Some of internal governance dimensions of the GISTM

- The Board of Directors shall adopt a policy on commitment to the safe management of the tailings facilities
- The Accountable Executive(s) is (are) responsible for the safety of the tailings facility and for minimising social and environmental consequences
- An Independent Tailings Review Board (ITRB) or a senior independent technical reviewer will be appointed to provide ongoing senior review
- An Engineer of Record (EoR) shall prepare a Design Basis Report that provides a basis for monitoring and risk management of all design phases
- Internal audits will be conducted to verify consistent implementation
- Incentive payments will be based partly on public safety and facility integrity
- Whistle-blower protections in accordance with international best practices

Some of external governance dimensions of the GISTM

- Meaningfully engage project-affected people at all phases of the *tailings facility lifecycle* – Including closure and post-closure
- Ensure management decisions respect human rights and act in accordance with the UN Guiding Principles on Business and Human Rights (UNGP)
- Co-develop community-focused emergency preparedness measures
- The Operator shall share information to support the inclusion of project-affected people in the building of a knowledge base and decisions on safety
- Publicly disclose and provide access to relevant information to support public accountability
- Engage with public sector agencies and other organisations to create post-closure failure response strategies

Next steps for Operators and their Consultants

- Some regions have been refused insurance for tailings dams, others have had their coverage reduced (by about one third) and their premiums increased (by about twice), and some major companies are self-insuring
- Access to finance could be withheld from companies that do not comply
- An ICMM Guideline on the implementation of the GISTM (mainly technical) is due for release in April 2021
- The ICMM is essentially charged with implementing the GISTM through their member companies, which is expected to involve:
  - 12 months to "re-classify" existing tailings facilities
  - A further 2 years to address (plan for) high priority tailings facilities
  - A further 2 years to address (plan for) all tailings facilities

"In the wake of recent tailings dam failures, improved Management Resilience is leading over Improved Engineering Resilience, which would reduce Liability"

Andy Robertson, 2018

Drivers of conventional tailings management …

- The commonly held perception, supported by NPV accounting, is that transporting tailings as a slurry to a surface dam is most economic
- Discounted long-term and rehabilitation costs “become” insignificant
- Filtering tailings is perceived to be too expensive, despite reducing the storage volume and being easier to rehabilitate to a high level of future land use and/or ecological function
- This has led to:
  - Widespread adoption of surface tailings storage facilities to store slurried tailings delivered by robust and inexpensive centrifugal pumps and pipelines
  - Small storages, leading to soft and wet tailings deposits, storing entrained water!
  - Increasing operating costs over time to avoid capital expenditure
  - Unintended increased storage volumes and more difficult rehabilitation

Barriers to implementing innovative tailings management

- NPV Accounting and use of a High Discount Factor (6 to 10%; 3 to 5 times CPI), which favours tailings management options that are cheap (particularly CapEx) in the short-term, and delayed expenditure, which in turn are likely to exacerbate impacts and blow-out long-term and closure costs
- Perceived high costs, supported by NPV accounting, of alternative tailings management options, such as mechanical dewatering and co-disposal
- Perceived and real technical difficulties (e.g., high clay mineral content, and handling coarse-grained wastes) of mechanical dewatering and co-disposal
- Resistance to do other than what we have always done
- Uncertainty about new approaches

When asked ***"What would you do about liquefiable tailings?"***

Dr Izard Idriss answered

"I'd avoid them!"

"You wouldn't build a water dam using liquefiable materials

or on a liquefiable foundation,

why would we do this for tailings dams!"

This is not to say that upstream raising cannot be made to work

We could build robust (buttressed) tailings dams

using waste rock (plus clay cores and drains as required)

possibly for little (if any) extra cost,

from which tailings of any consistency could be deposited

with negligible risk

Alternative tailings disposal, storage and closure

- From 1990s – On-off tailings cells, dried and harvested
- From 1990s – Co-disposal of tailings and coarse-grained wastes
- From 2000 – Red mud scrolling and dozing – "Farming"
- Ongoing – Thickening, paste disposal, and dry stacking of filtered tailings
- From 2000 – Integrated Waste Landforms
- Paste Rock™, and GeoWaste™ – Not yet at operational scale
- Tailings reprocessing and reuse
- Facilitating closure

In-plant vs. Atmospheric dewatering??

IN-PLANT DEWATERING	ATMOSPHERIC DEWATERING
Increasingly expensive from compression thickening, paste thickening, centrifuging, filtration, to briquetting (too expensive!)	Requiring an evaporative climate, thin deposition (<300 mm), and sufficient cycle time (>10 days), possibly aided by "farming"
Increasingly sensitive to variable inputs, particularly clay mineral type and content, and % fines, in the same order as above	Somewhat sensitive to variable inputs, but more robust than in-plant dewatering
Potentially, increasingly effective in the same order, up to dry stacking	Can be very effective and robust, potentially allowing harvesting
Recovers process water and chemicals	Loses process water (to evaporation and seepage) and chemicals (bound-up in tailings or in seepage)

What is the optimum balance between in-plant and atmospheric dewatering?

Appropriate dewatering *(adapted from Davies & Rice, 2004)*

Inefficient water & process chemical recovery
Robust, inexpensive centrifugal pumps sufficient
Extensive water management required
Containment required
High runoff & potential seepage
Rehabilitation difficult (wet & soft)

Low CAPEX and OPEX, but high rehab. cost

Improved water & process chemical recovery
Expensive positive displacement pumps required
Discharge management required (steeper beach)
Reduced water management
Some containment required
Reduced runoff & seepage potential
Rehabilitation difficult (wet & soft)

High CAPEX and OPEX, and high rehab. cost

Efficient water & process chemical recovery
Transportable by truck or conveyor
Minimal water management required
Minimal containment required
Runoff, but negligible seepage potential
Progressive rehabilitation possible

Very high CAPEX and OPEX, but low rehab. cost

Slurry-like: No particle-particle interaction, saturated, no effective stress

Tailings Slurry
(segregating)

Clay mineral-rich tailings stuck here

Thickened Tailings
(ideally non-segregating)

Paste tailings
(ideally, non-bleeding)

Or by gravity u/g or in-pit

Pumpable

Non-pumpable

"Wet" filter cake
(near-saturated)

e.g., by centrifuge, cycloning

"Dry" filter cake
(85 to 70% saturated)

e.g., by belt-press, filter plate or screw filter

Soil-like: Particle-particle interaction, unsaturated, effective stress and suction, shear strength

Optimum for disposal to a surface TSF is likely to be thickened, otherwise filtered

Importance of clay mineralogy – Coal tailings

Smectite-rich @ 25% solids

Non-smectite-rich @ 40% solids

Shallow on-off coal tailings cells (Charbon – from 1990)

Harvesting wet tailings by excavator

Harvesting desiccated tailings by loader

Dumping harvested tailings

Pumped co-disposal of coal washery wastes – Jeebropilly from 1990

Metalliferous in-pit co-disposal – From mid-1990s


"Accidental" co-disposal


Coarse + Wet tailings (15:1)


Coarse + Wet tailings (10:1)

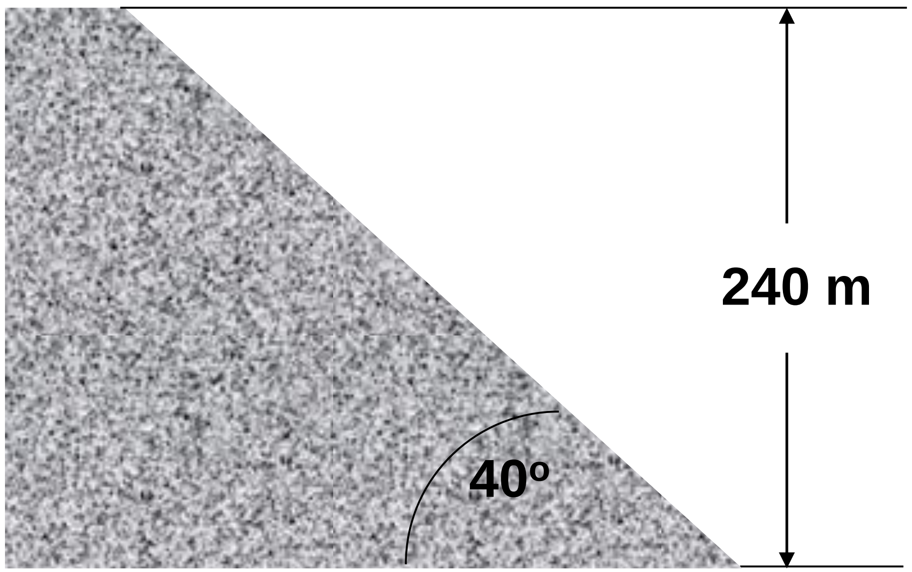

In-pit co-disposal


240 m high in-pit WRD

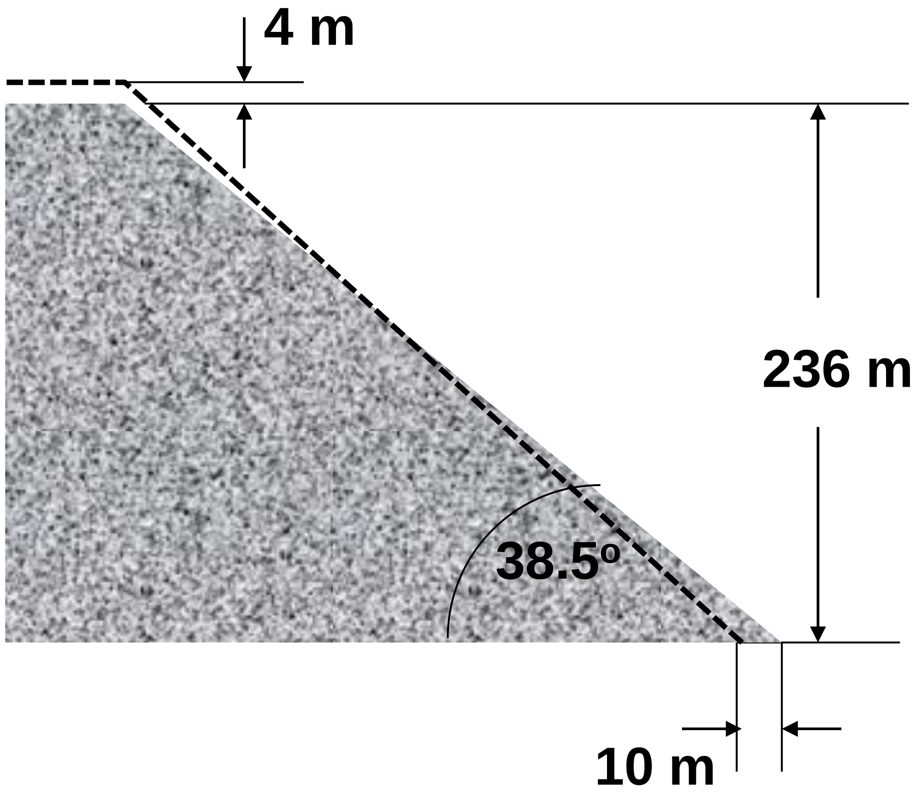

1 m scarp above bench

Deformation of in-pit waste rock dump

On initial dumping:



Settled profile:

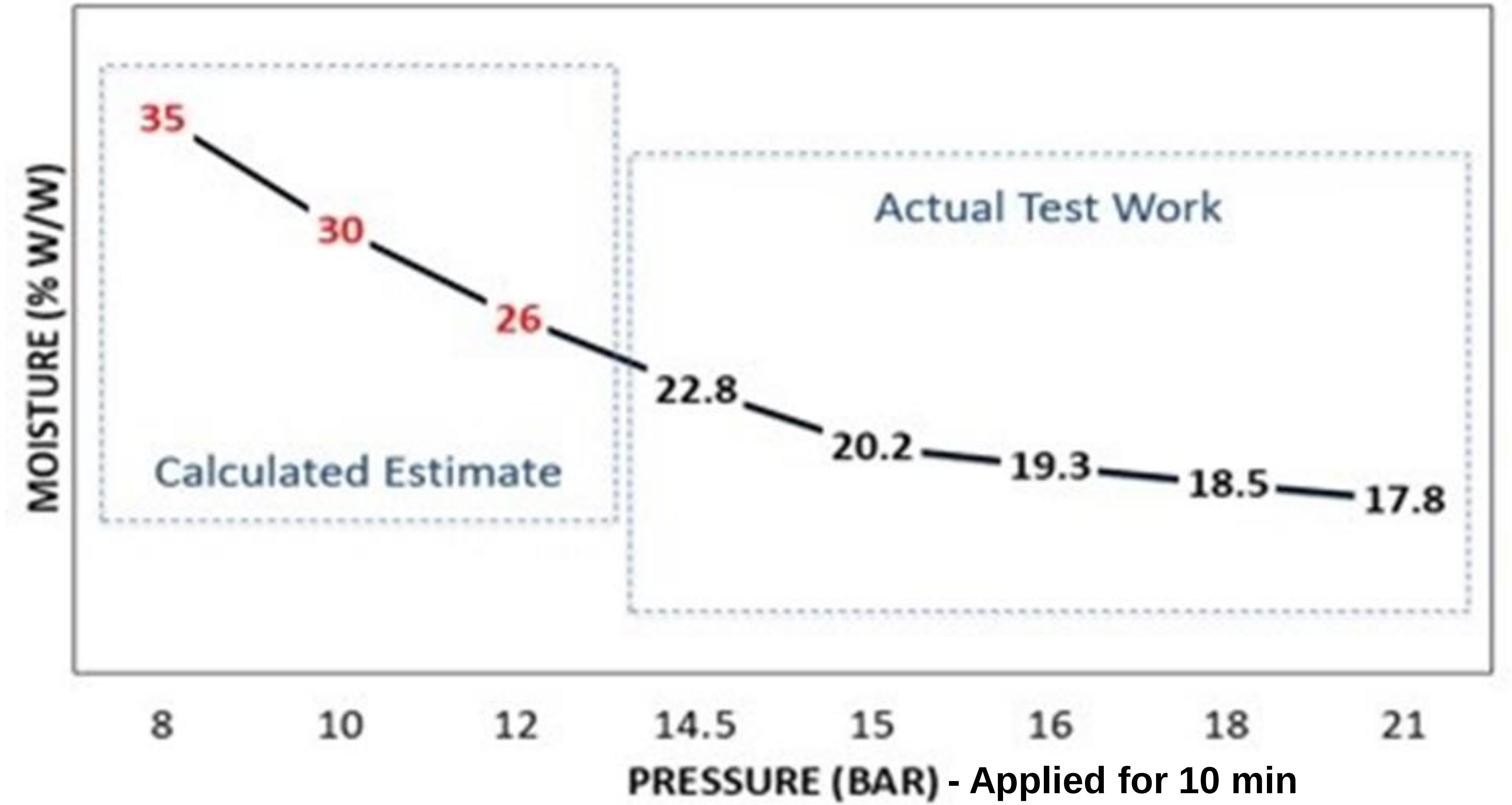


Red mud disposal, scrolling and dozing

Dry stacking of tailings

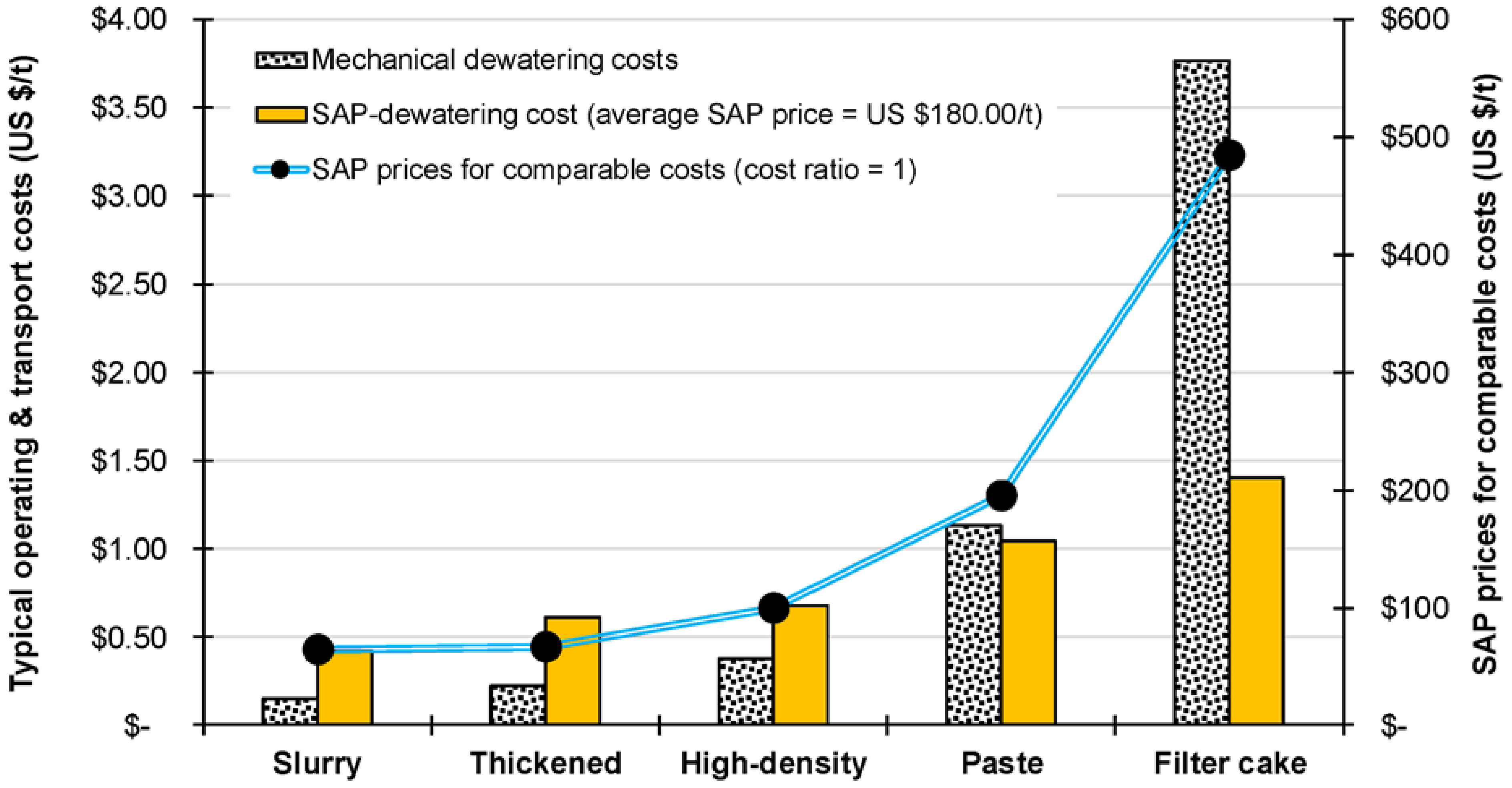
ADVANTAGES	DISADVANTAGES
Greater water recovery where water is in short supply (>70% saving)	High capital and operating costs of filtration (although competitive with desalination; e.g., USD5/m^3 in Atacama), but these are reducing
Improved recovery of dissolved metals and process chemicals	Vacuum filters are not effective at high altitudes, while filter presses are
Reduced risk of facility failure	Difficult to scale-up for large production rates (<20,000 dry tpd), requiring filter presses
Greater community acceptance	Belt-presses and centrifuges are only effective for small tonnages
Higher seismic resistance	Upstream and rainfall runoff diversion is required to prevent inundation
Reduced containment material volume	Surface contouring is required to divert incident rainfall runoff and limit erosion
High rates of rise can be accommodated	Cannot store water on the facility
Smaller footprint and volume (>50% saving)	Oxidation of filtered sulfidic tailings
Trafficable	Difficult to manage (poor trafficability and compaction) during the wet season
Reduced seepage	May require compaction for stability against possible liquefaction
Progressive rehabilitation is possible, and final rehabilitation is easier	

Pressure filtration = fn (tailings, pressure and duration)



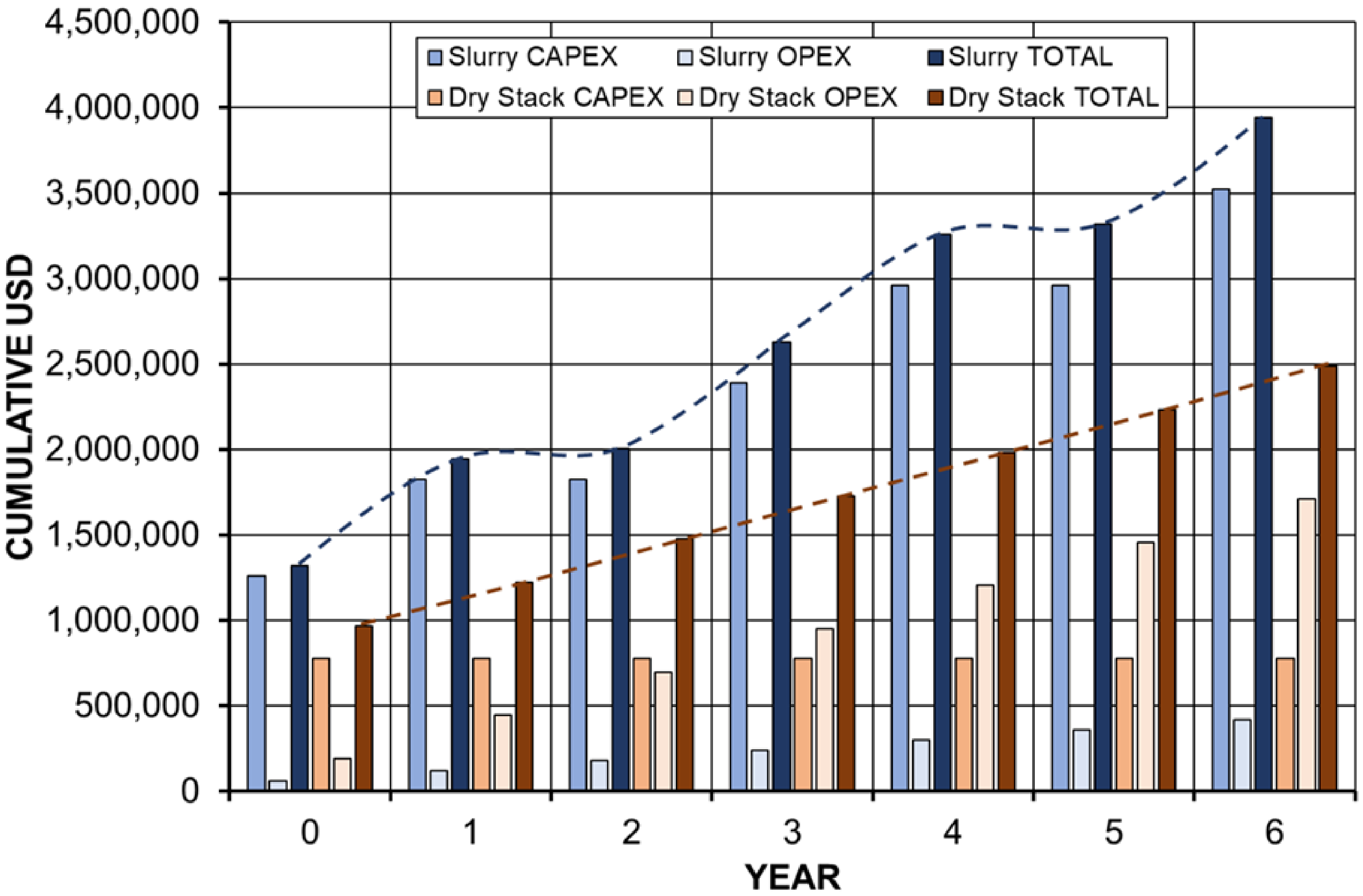
- Applied for 10 min

Indicative costs of dewatering tailings *(Sahi, 2019)*



But this is only part of the story, as it excludes other costs!

Cost comparison for slurry and filtered gold tailings



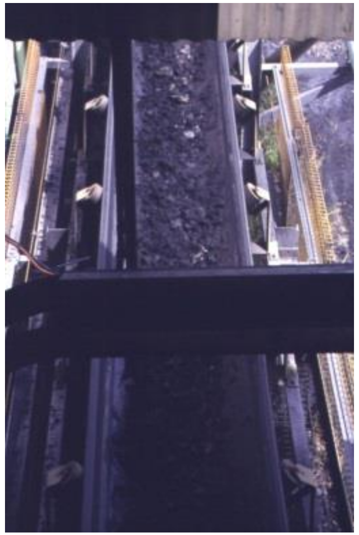
This ignores cost savings in reduced stored volume, ease of rehabilitation, and greater future land use or ecological function

Wall construction CAPEX for slurry tailings >> filtration, stacking and compaction OPEX!

Belt-press filtration of coal tailings – Howick in Late 1980s

1. Flocculation tank

2. Belt-press filtration



3. Conveying filter cake and coarse reject

4. End-dumping in spoil piles

Bengalla belt-press filter operation

Dry stacking at La Coipa – Driven by scarcity of water

Reprocessing and reuse

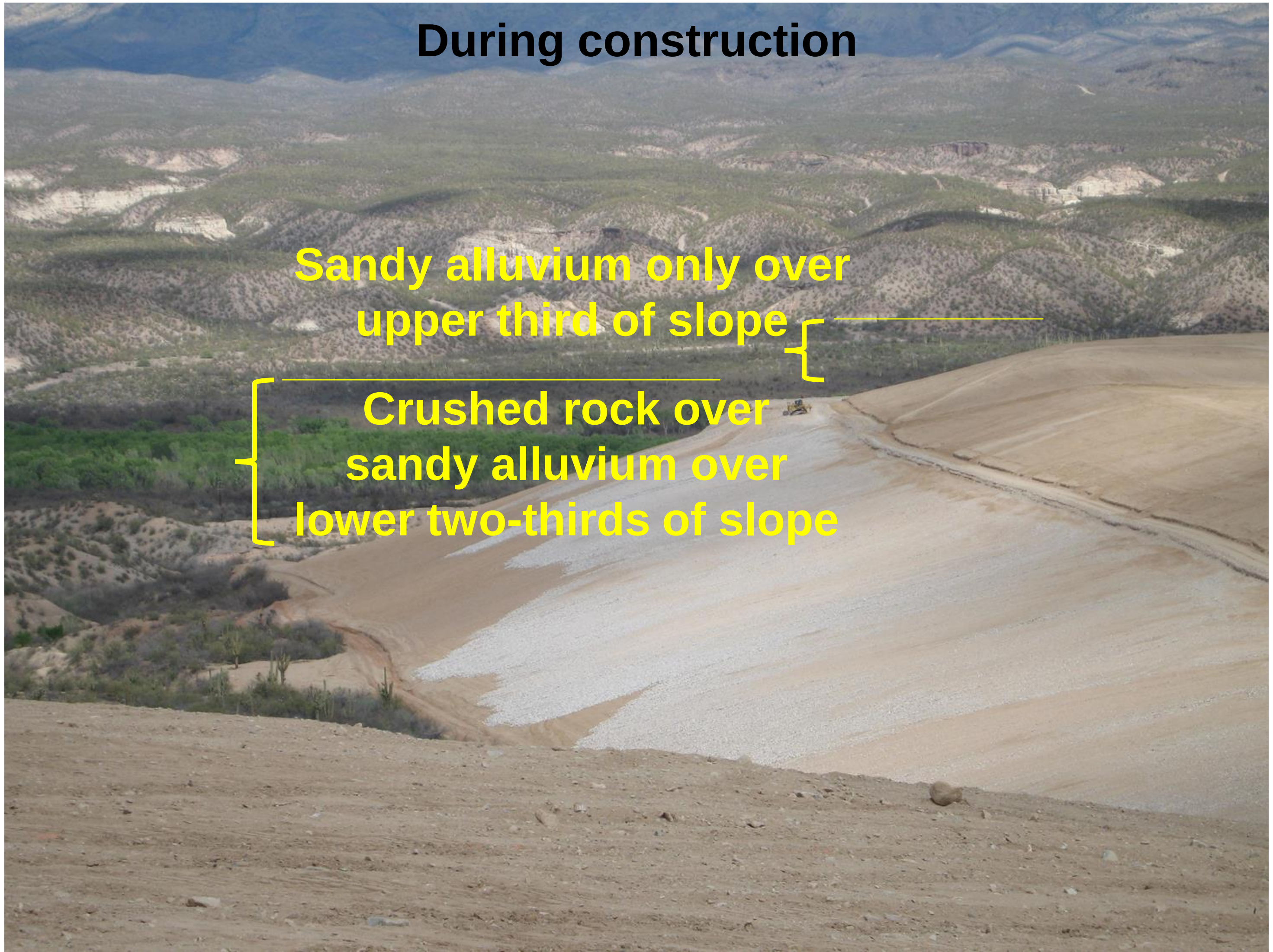
- There is a long history of reprocessing gold tailings, sometimes more than once, such as in Johannesburg and Kalgoorlie
- What is new is reprocessing metal tailings, such as at Century Zinc Mine, which has become the world's 10th largest producer (formerly third):

- Tailings reuse includes in bricks and as a pozzolan (cementing agent)

Rehabilitation – “Focus on adding value” rather than “cost”

CONVENTIONAL “COST-BASED” REHABILITATION	“VALUE-ADDED” REHABILITATION
Production rules	Post-closure “value” is identified upfront
Rehabilitation is seen by operator & regulator as a “cost”	Examples include: • Renewable energy (NIMBY) – solar, wind and pumped storage, delivered to grid via mine transmission lines • Agriculture and/or fishery dams • Tourism and heritage (older the better)
Operator discounts cost over time, discouraging rehab	
Infrastructure such as power lines are stripped	
Rehabilitation is limited to “smoothing” and “greening”	
Post-closure land use and function are limited	“Value” sets rehabilitation budget
Operator loses social and financial licences to operate	Potential wins for operator, future land user and Government

Successful rehabilitation of 100 m high tailings Slope at 3:1



Capping of New Acland surface TSF (~AUD70,000/ha)

Capping New Acland in-pit coal tailings (~AUD75,000/ha)


Before capping – March 2014


During capping – February 2016


During capping – September 2016


Completed capping – December 2017

Concluding remarks and further questions …

- Tailings dams that fail are marginally stable, and there is typically a combination of causes, with water a key element
- Fatal tailings dam failures can bring real change:
  - El Cobre revolutionised tailings dam construction in Chile’s highly seismic setting
  - Brumadinho led to the GISTM, with the ambition of zero harm from tailings facilities, affording Operators flexibility as to how best to achieve this goal
- We have some tools for improving tailings management
- Where will the GISTM take the industry?
- Will it lead to actions that improve confidence and trust?

AusIMM Professional Certificate in Tailings Management

Gain competency and expand your knowledge on the fundamentals geotechnical, geochemical, governance, closure and socio-economic considerations of tailings management, including GISTM insights

Quick facts:

- After two highly successful intakes, the next intake is closing soon:
  ausimm.com/courses/professional-certificates/tailings-management/
- Commences 8 June 2021 (next intake October 2021)
- Interactive, online in 6 x 90-minute Webinars over 6 weeks
- Plus Comprehensive Assessment

Coming soon from AusIMM

Later in 2021:

Master class on "Tailings Fundamentals for Company Directors and Senior Executives"

Also being considered:

AusIMM Professional Certificate in Geotechnical Design, Construction, Operation, and Closure of Tailings Facilities