Tailings Facility Risk, Resilience, and Robustness

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It is all about Judgment

THE THESIS OF THIS PAPER
Summary of this Presentation

• Key to the future success of tailings management is the exercise of professional judgment founded on the engineering philosophies, methods, and tools now at our command.
The Best Tools

- Engineering Judgment
- The Observational Method
- Risk Analysis
Peck on Engineering Judgment

• The successful practice of engineering requires a high degree of engineering judgment.

• Judgment involves and requires a “sense of proportion.”

• Theory and calculations are not substitutes for judgment---but are the basis for sounder judgment.
Morgenstern on the Observational Method

• Risk in geotechnical engineering is best managed by diligent application of the observational method.

• The observational method is a form of consequential risk analysis that emphasizes robustness, the capacity for intervention and adaptability.
Engineering Judgment in Peck’s Time

- Site Observation
- Site Geology Understanding
- Geotechnical Testing
- Precedence
- A feel for the way soil behaves
Engineering Judgment Today

- Detailed Topography and Drones
- Sophisticated Geotechnical Investigations
- Advance Laboratory Soil Testing
- Computer Simulation and Sensitivity Studies
- Risk Analysis
- New Design and Operating Philosophies
TAILINGS FACILITY SYSTEMS ANALYSIS
System Risk Analysis Using Bow Charts
CASE HISTORY: SAMARCO
Samarco
Hazards

• Open Pit: Variable Ore=>Variable Tailings
• Mill: Variable Grind=> Varying Sand/Slimes Ratio
• Slime Surge Tank: Too full=>overflow to sand surge tank=>compromised sand tailings
• Sand Surge Tank: Too full=>overflow to slime surge tank=> more slimes deposited than planned
Hazards

- Slimes: Too much => encroach to crest
- Sand: Too little => too thin to support slimes
- Penstock: Break or Leak
- Drains: Block
Failure Root Causes

- Too much slime
- Slime layers near downstream perimeter
- Blocked drain => saturated sand layers
- Outward embankment slope deformation
- Sand collapse-induced liquefaction
The Absence of Judgement

• Inexperienced operators
• Very limited observation
• No performance analyses
• No risk assessment
• No acknowledgement of precedence
RESILIENCE & JUDGMENT

No Judgment
Definitions

• Initial Failure Resilience
  – The ability of the facility to manage change and to avoid initial failure.

• Progressive Failure Resilience
  – The ability of facility and the flow path to minimize the pathway distance and area impacted.

• Consequential Resilience
  – The ability of the impacted area to manage or recover from the impact.
High Resilience Tailings Facility

- The perimeter embankment is low, the sideslopes flat, the crest wide, the beach broad, and the pool far from the embankment.

- Judgment would conclude that such a system is robust and reliable.
Moderate Resilience Tailings Facility

- The perimeter embankment is getting higher, the crest is being narrowed, the sideslope being made steeper, and the pool is getting closer to the embankment.

- *Judgment would conclude that this system is beginning to become less robust and certainly its reliability is decreasing—or put another way, its probability of failure is increasing.*
Low Resilience Tailings Facility

- **Low resilience.** The perimeter embankment is high, the crest narrow, the sideslope very steep, the pool is lapping against the upstream side of the embankment.

- **Judgment must lead to the conclusion that this system is not robust, not reliable, and probably has a high probability of failure regardless of the calculated factor of safety.**
Progressive Failure Resilience

Filter Pressed Tailings?

High Waste Rock Berms

Hydraulic Placed Tailings

Moderate

Low Poor
Consequential Resilience
A few controversial ideas

ROBUST, RESILIENT, LOW RISK, SAFE TAILINGS FACILITIES
Human Habitation

• Rule: No tailings facilities upstream of human habitation or sensitive environments.

• Violations re Human Habitation:
  – Stava
  – Merrispruit
  – Samarco

• Violations re Sensitive Environments:
  – Mount Polley
No Slimes Near the Perimeter

• Rule:
  – No slimes near the perimeter or in the zone of potential slope failure.

• Violations:
  – Bafokeng – Piping through sand between slimes layers
  – Samarco
    • Promoted horizontal deformation leading to loose sands
    • Impede free drainage leading to saturated sands?
No Cascading Dams

• Rule:
  – No cascading tailings dams.

• Violations:
  – Stava: one failed causing the other to fail
  – Merrispruit: flow from upper to lower exceeded storage capacity

Fig. 5. Aerial view of the basins in October 1972, nearly two years after the construction of upper basin; in this one is in progress the raising of the embankment from the orography left side (photo Impresa Rossi, Brescia).

Fig. 6. The decantation basins photographed in September 1978. The geometry of the upper basin seems altered with respect to the previous photo: works to raise the embankment according to the scheme “upstream” are clearly in progress (photo Impresa Rossi, Brescia).
No Clay Foundations

• Rule:
  – Limit or avoid clay in the foundations.

• Violations:
  – Bafokeng and other Rustenburg Dams: foundation failure when reached 30-m high
  – Mount Polley:
    • Failure to locate clay layer
    • Complex clay behavior not understood
No Water on Top Deck

• Rule:
  – No or very small pool; or
  – Pool distance from crest = 5 x embankment height

• Violations:
  – Bafokeng: pool at crest
  – Mount Polley: pool at crest
Low Slope Embankments

• Rule:
  – Tailings embankments slopes of 5H:1V
  – Rockfill embankments as rockfill permits

• Non-Violations:
  – UMTRA: all piles reconfigured to 5:1
  – Cannon Mine: good-quality, compacted rockfill at 1.73:1
No Penstocks

• Rule: No penstocks through tailings or adjacent abutments

• Violations:
  – Bafokeng: cavitation in penstock suspected as main or contributory cause
  – Padcal: Pipe break lead to large tailings loss
Tolerable Risks

- If dam break consequences tolerable, proceed.
- Otherwise change design or do not construct