Leading versus Lagging Indicators of Tailings Dam Integrity

Presentation to Tailings and Mine 2018
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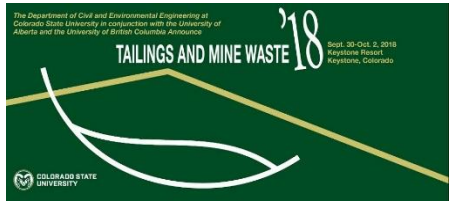

Introduction

Three recent dam failures:

- Aug. 4, 2014 Mount Polley, Canada
- Nov. 5, 2015 Fundão, Brazil
- Feb., 2017 Oroville spillway failure, USA

Led to substantial revisions in:

- Legislation and regulation
- Dam safety guidelines and bulletins

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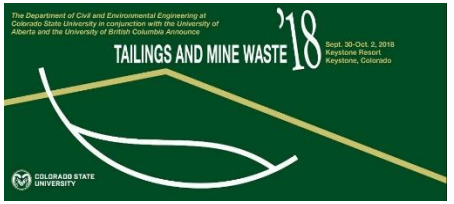

However…

despite the efforts and changes in the tailings community, tailings dam failures continue to occur.

The consequences of these failures and likelihood of future failures do not indicate an improving trend.

Over the past 12 months, 2 more dams failed with fatalities:

1. Mexico – La Cieneguita Mine tailings failure, 7 fatalities
2. Kenya – Patel water dam failure, 47 fatalities

Why Are Failures Still Occurring?

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Ten Reasons Why Failures Are Still Occurring

1. Unregistered dams
2. Poorly informed dam owners and management
3. Insufficient professional engineering involvement
4. Absent or insufficient dam safety laws and regulations
5. Insufficient or untrained regulators and inspectors
6. A checklist-only approach to dam safety

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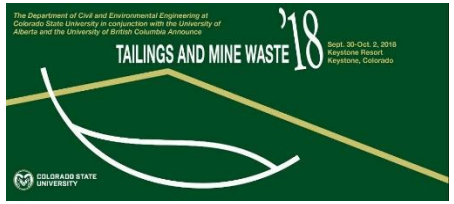

Ten Reasons Why Failures Are Still Occurring

7. Rising risk profiles
8. Lulled into instrumented complacency
9. Normalization of deviance

   Strong indications of normalized deviance before Fundão dam failure, warning signals which should have been picked up. Also applied to Mount Polley, Merriespruit and many others.

Ten Reasons Why Failures Are Still Occurring

10. Normalization of imponderable consequences
    - Imponderable consequences should be avoided altogether.
    - *"We should not be building tailings facilities with imponderable consequences. If the consequences of a catastrophic failure would repeat a Stava or an El Cobre, then no matter how small the probabilities of actual failure are, the design should be completely revisited."*

      - Boswell and Sobkowicz (2015) at TMW,

        3 weeks before Samarco tailings failure

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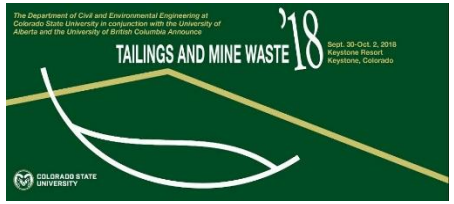

What else could we be doing to prevent failure?

- Is it possible to predict failure, rather than waiting for it to happen? Could we be more forward looking and anticipative in our vigilance, and if so how?
- There are alternative tools for not just tracking dam safety, but actually predicting it:

the use of leading rather than lagging indicators of dam integrity

Leading Structural Indicators of Tailings Dam Integrity

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Leading Indicators defined

According to Van der Poel (2012):

- L**agging Indicators**
  - Output oriented
  - Easy to measure
  - Hard to improve or influence
- **Leading Indicators**
  - Input oriented
  - Hard to measure
  - Easy to influence

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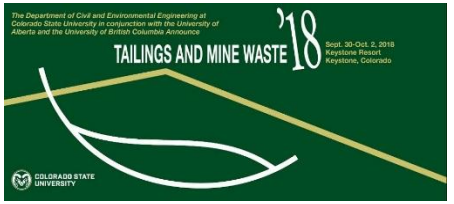

Leading Indicators:

A practical example closer to home

Lagging Indicator – measured weight loss on a scale
Leading Indicator - calories in and calories burned

Ref bodywisetherapyfitness.com

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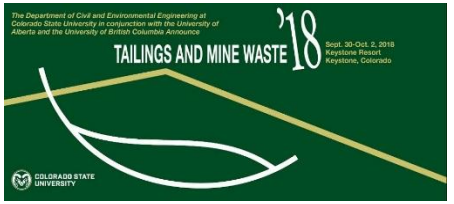


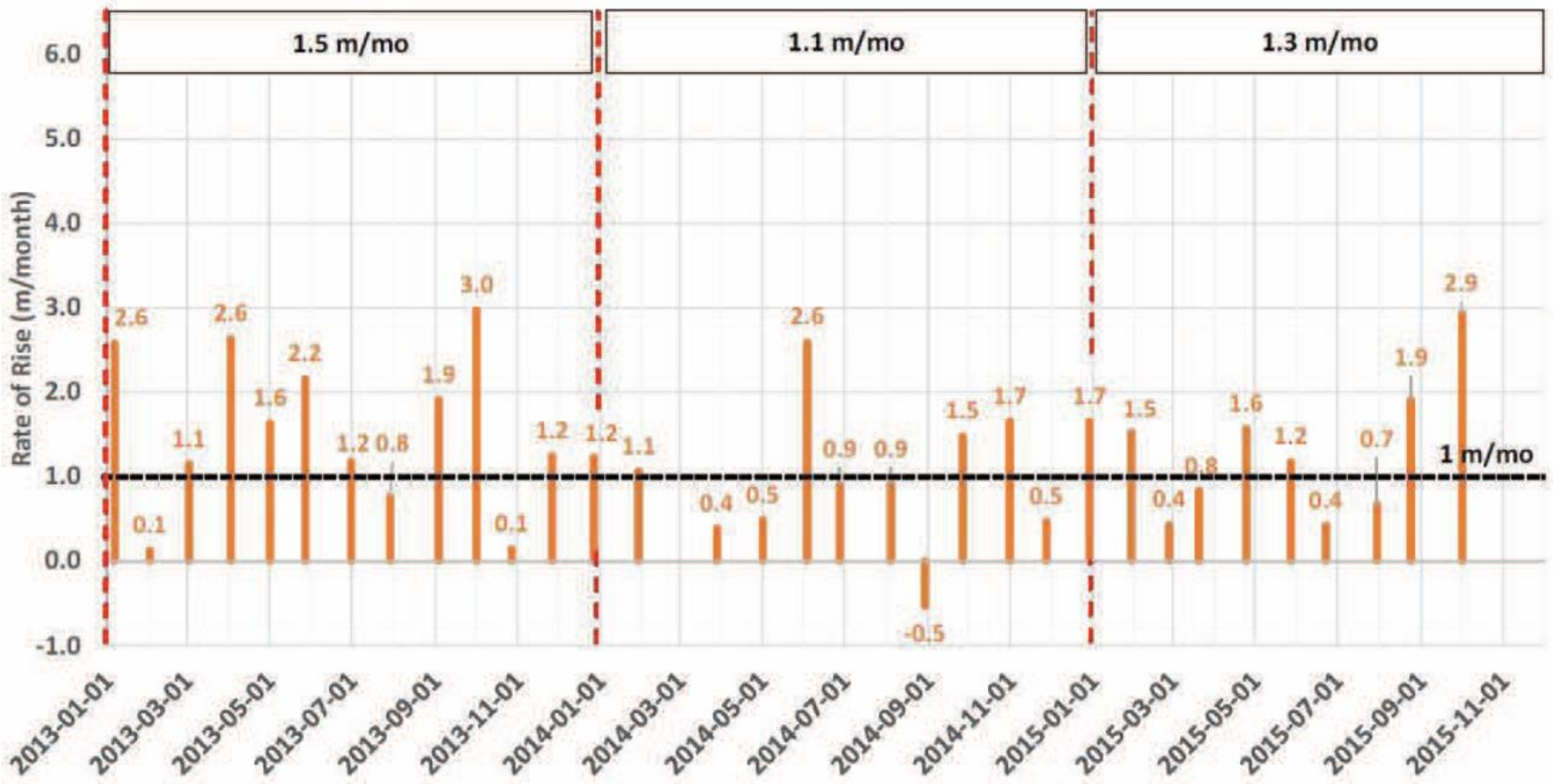
Eight Leading Indicators of Impending Failure

Historical Tailings Failure, Date / Reference	Buffalo Creek, 1972 Blight et al ('03)	Bafokeng, 1974 Blight et al ('03)	Stava, 1985 Morgenstern (2000)	Merriespruit, 1994 Wagener et al ('97)	Los Frailes, 1998 Alonso & Gens ('06)	Mt. Polley, 2014 Morgenstern et al('15)	Samarco, 2015 Morgenstern et al('16)
Leading Indicator							
Rate of rise	×		×	×	×	×	×
Beach freeboard	×	×	×	×	×	×	×
Height of dam	×	×	×	×	×	×	×
Contained volume of fluid	×	×	×	×	×	×	×
Changes in water level	×	×	×	×	×	×	×
Slope steepening		×			×	×	
Recycle water capacity	×	×	×	×	×	×	×
Foundation geotechnics					×	×	

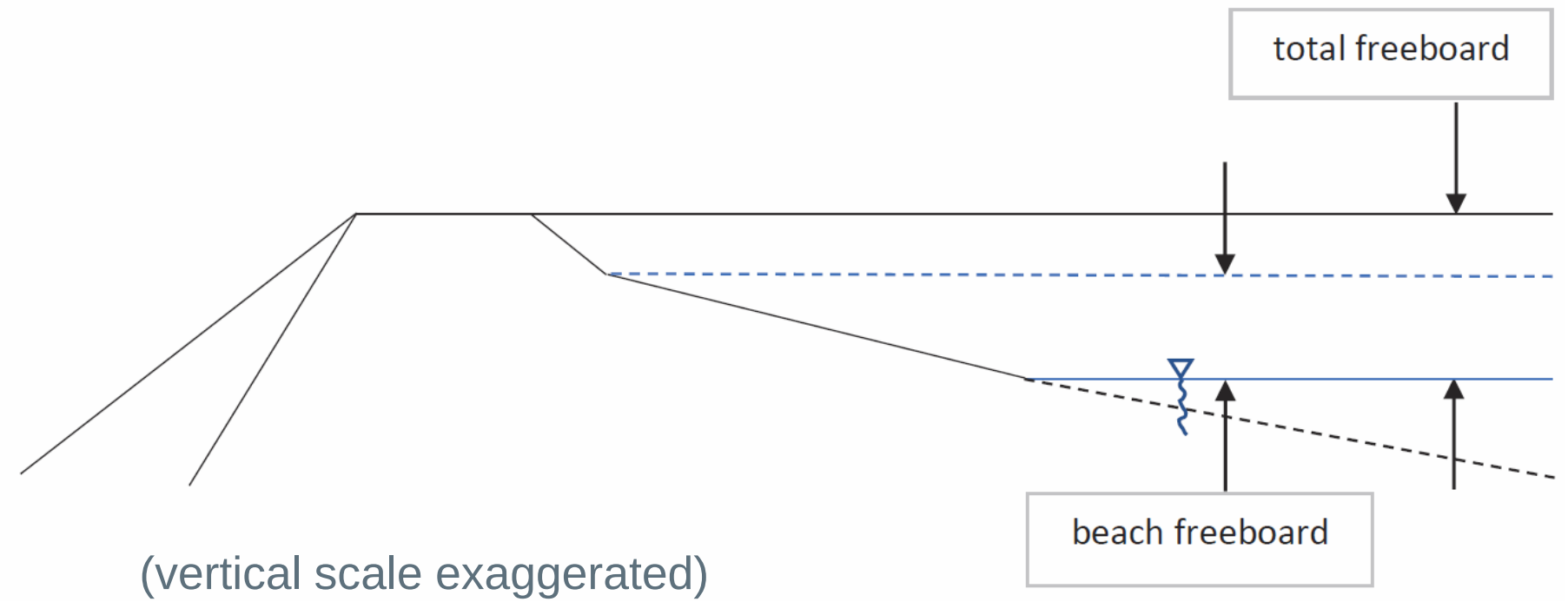
1) Rate of Rise

Rate of dam crest rise at Fundão left abutment setback

(Ref Morgenstern et al, 2016)



2) Beach Freeboard



(vertical scale exaggerated)

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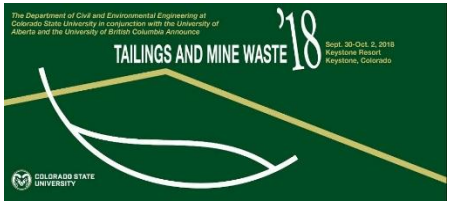


Beach Freeboard

Cadia mine tailings failure, Australia

The development of substantial beach freeboard avoided overtopping and other far reaching consequences.

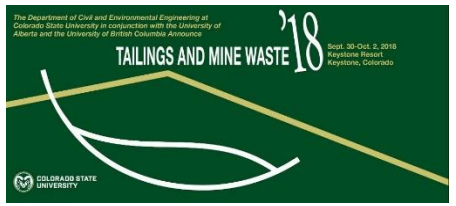
Ref: Cadia mine press release

3) Contained Volume of Fluid

- Without the fluid and liquefiable material contained within the tailings dams, the catastrophic failures referred to in this paper would not have occurred
- An increasing trend in contained liquid volume is a reliable indicator of rising risk profile
- Liquid volume includes liquefiable tailings
- Should trigger additional precautions

A Further 5 Leading Structural Indicators of Impending Failure

4. Height of dam
5. Changes in Water Levels
6. Slope Steepening
7. Recycle Water Dam Capacity
8. Foundation Geotechnics



Conclusion

- For every failed dam, there are a large number of stable, well managed tailings dam facilities
- Nevertheless, there is an unacceptable rate of failure of tailings dams, worldwide, even under the watch of reputable engineers
- We urgently need a step-change improvement in engineering practice

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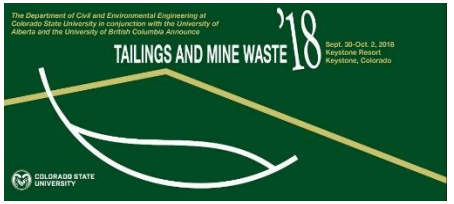

Path Forward

- One path forward: place more weight on leading indicators of dam structural integrity
- Enact appropriate regulations
- Use expertise to manage dams safely
- Engage top management in a culture of integrity
- Mobilize the will to effect change
- Senior professionals must exert leadership to effect this change

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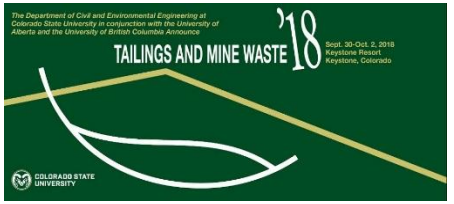

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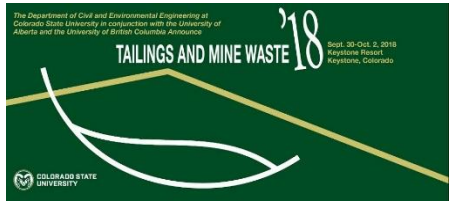

Thank you for your attention

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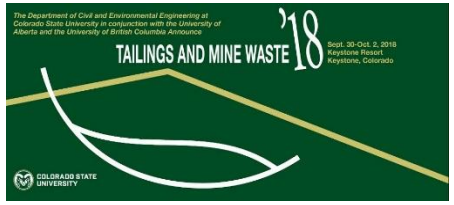
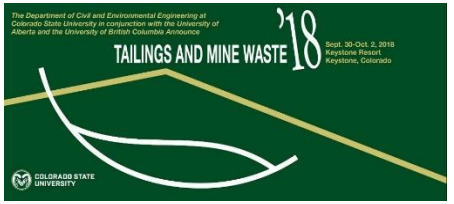


Backup Slides

5) Changes in Water Level

- Long established practice – piezometers and other instrumentation
- Usually very good indicators of reducing stability and/or increasingly severe consequences of failure



6) Slope Steepening

- A desperate remedial measure
- To contain increasingly large amounts of fluid and to maintain sufficient freeboard
- Poor choice of defense
- Beach freeboard a far more reliable remedy

8) Foundation Geotechnics

- Understanding of underlying geology and geotechnics of the foundation
- Mount Polley
- Los Frailes
- Increased loading of an over consolidated clay
- Preconsolidation pressures exceeded
- Will eventually lead to undrained behaviour and possible failure

General Leading Indicators

Human Performance Indicators:

- Management commitment to dam integrity
- Dam safety leadership
- Documented roles and responsibilities for Engineer of Record (EOR) and Designer of Record (DOR)
- Up-to-date OMS, EPP and ERP manuals
- Documented procedures for design changes, including “management of change”
- Key staff turnover
- Changes in contractor or operator
- Changes in ownership (potential loss of records and institutional memory)

Other Leading Indicators

- Mine profitability
- Commodity price
- Changes in production and storage capacities
- Changes in the regulatory domain
- Changes in environmental milieu
- Stakeholder influences and changes