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Tailings Impoundment Stabilization Using Ground Improvement Technologies

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85th Annual Meeting
of International Commission on Large Dams

Tailings impoundment stabilization to mitigate mudrush risk

New Afton Mine Site, BC

- Situated near Kamloops, BC

New Afton Mine Site

- Previously operated as an open pit copper mine from 1978 to 1997
- Starting in 2004 mine has been developed as an 11,000 tpd underground block cave mine
- Combination of historic and active facilities

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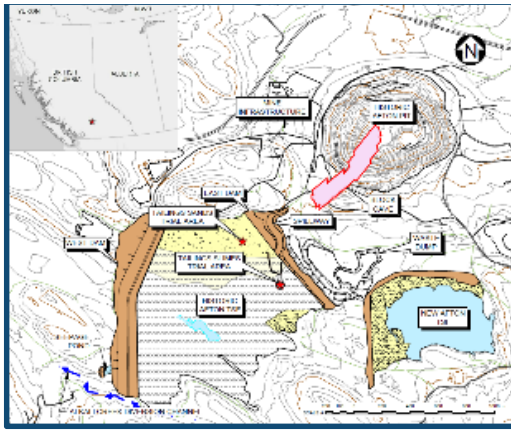
Historic Afton TSF



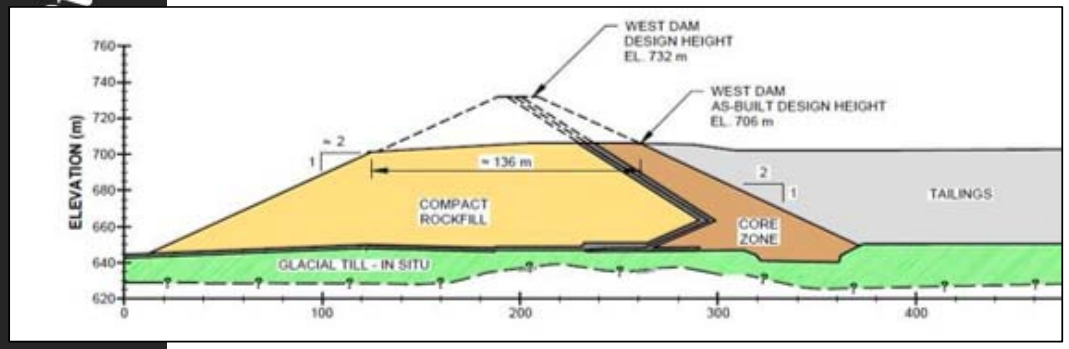
West Dam

- 65 m high
- >100 m wide crest
- Constructed to El. 706 m
- Planned Ultimate El. 732 m
- Downstream seepage collection and monitoring ponds

East Dam

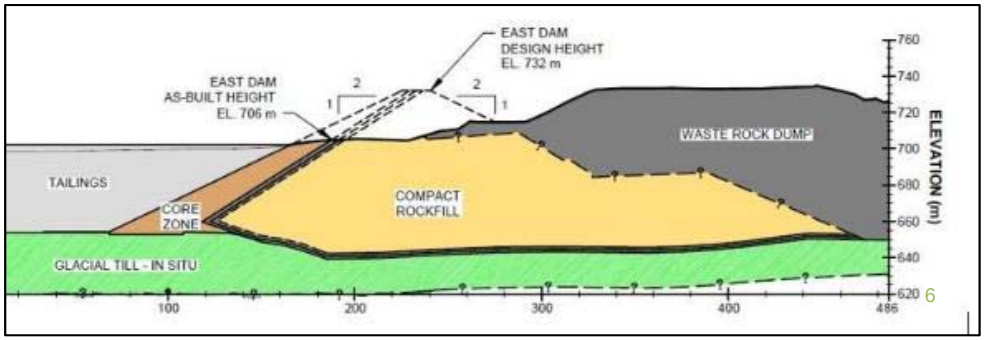
- 65 m high
- 100 m wide crest
- Constructed to El. 706 m
- Planned Ultimate El. 732 m
- Downstream Waste Rock dump higher than crest

WEST DAM

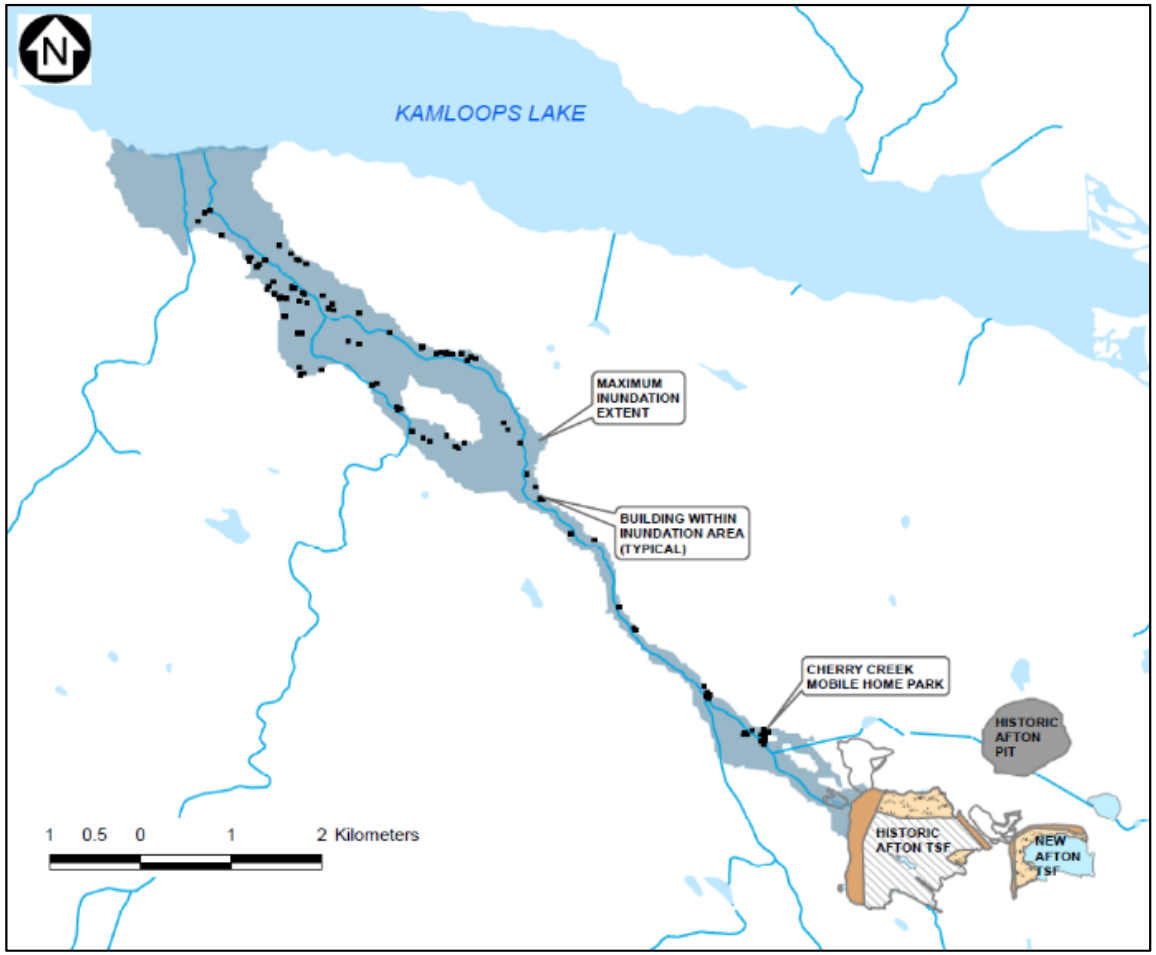


EAST DAM

WASTE ROCK DUMP

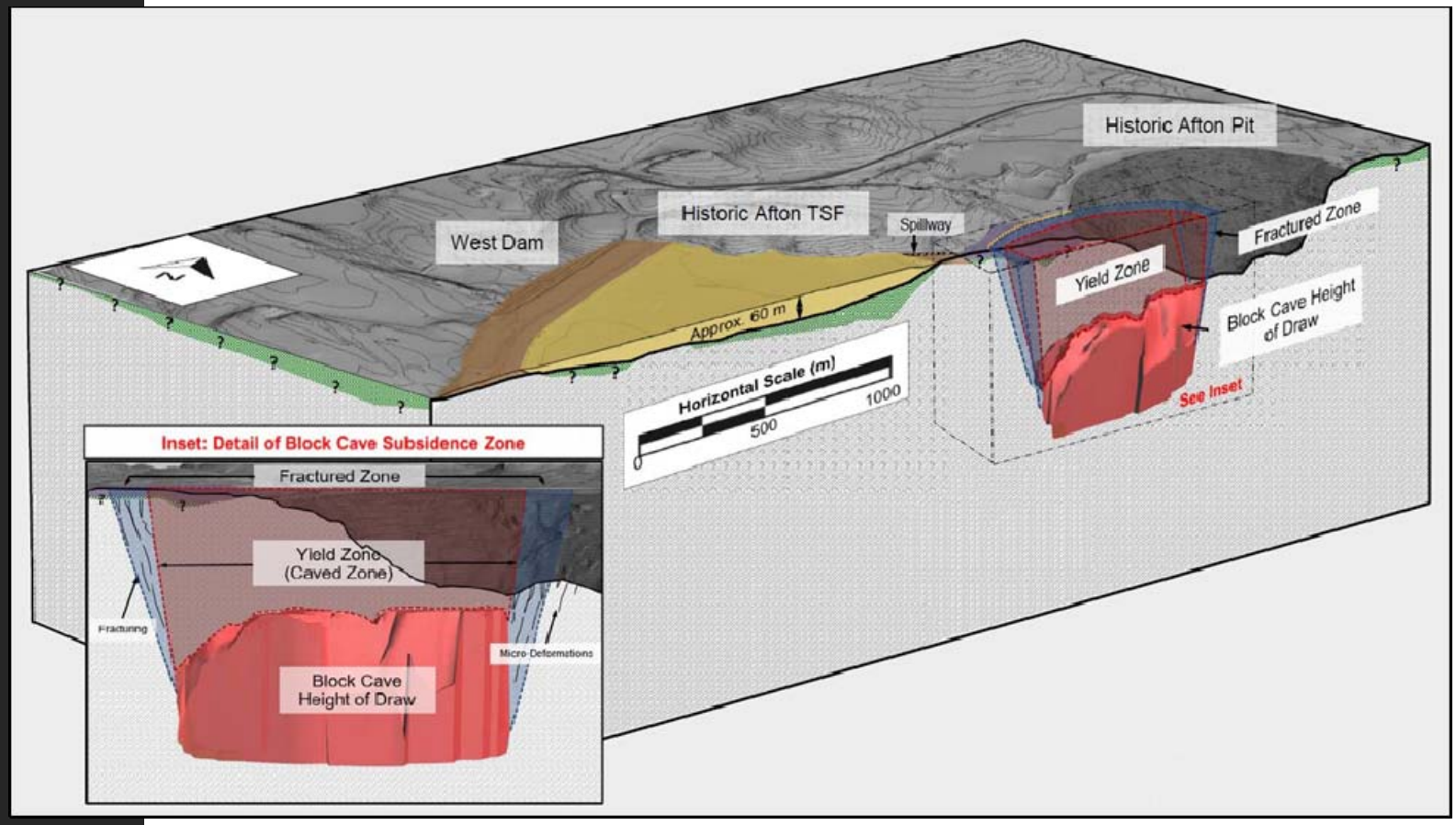


Historic Afton TSF – Dam Breach Analyses



- Dam breach analyses conducted to determine potential consequences of dam failure
- Breach runout could theoretically extend to Kamloops Lake if water and/or highly fluid tailings are present
- Extreme Consequences but Low Risk due to the robust embankments

Historic Afton TSF – Mudrush Risk for Underground Mine



- Block Cave mining method results in surface subsidence
- What could happen if mining induced bedrock cracking extended up into to the nearby Historic TSF?
- The 1970 Mufulira underground tailings breach in Zambia resulted in the deaths of 89 miners

Tailings Stabilization by Ground Improvement

Eliminate Potential for Mudrush

- Step 1 – Remove surface water sources
  - Eliminate surface pond (evaporation)
  - Prevent surface water inflow (diversion ditch)
- Step 2 – Stabilize the tailings solids
  - Impounded tailings consist of sandy beach deposits and finer grained silts and clay sized slimes tailings
  - Thus a wide range of tailings materials need to be assessed and stabilized.

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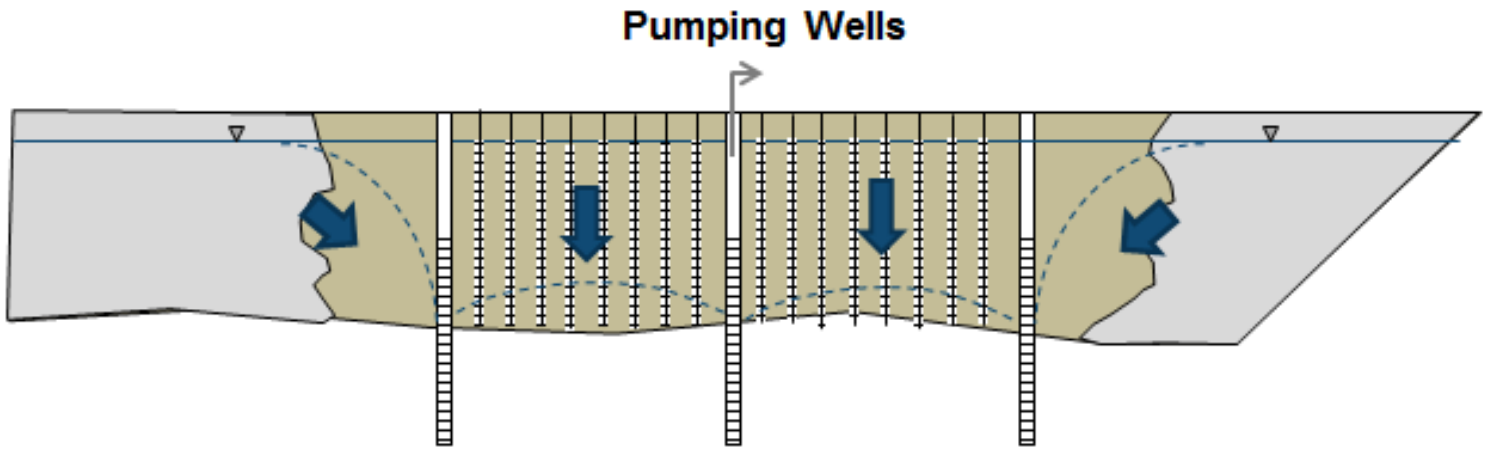
Ground Improvement Technology - Dewatering

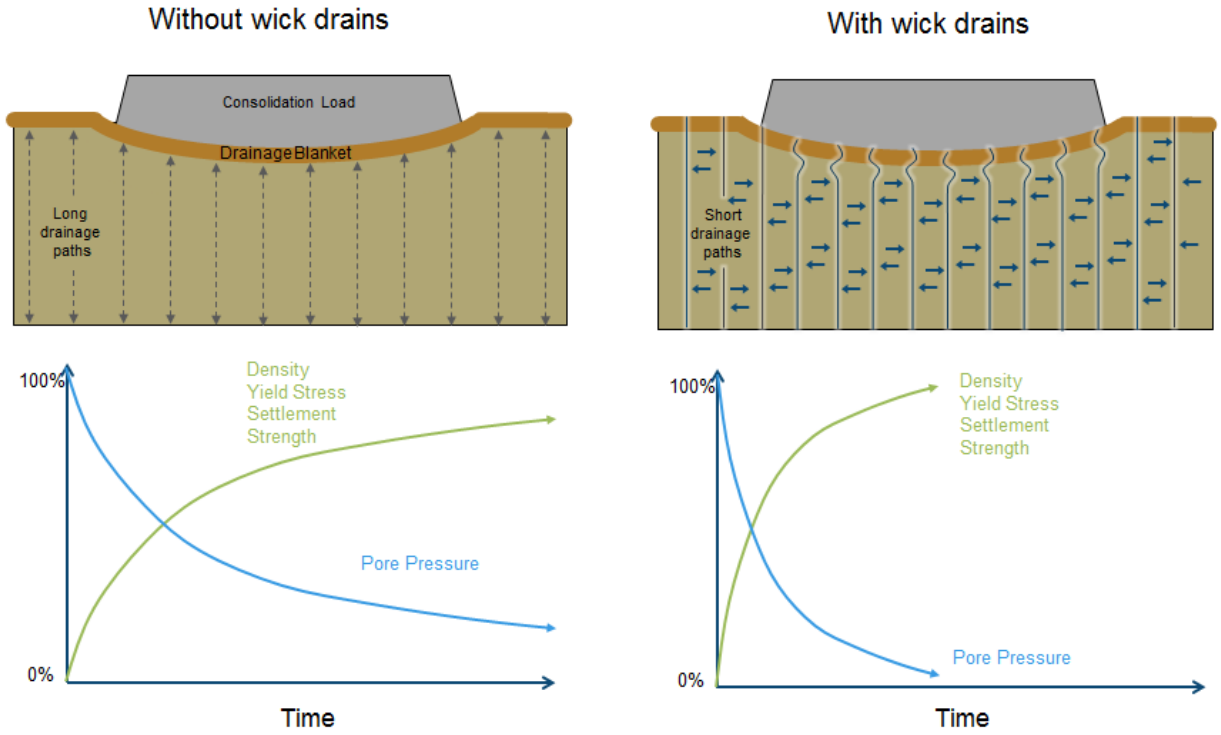
Coarse Sandy Tailings

- Dewater sandy tailings with pumping wells + wick drains
- Dewatered sandy tailings will have similar characteristics to filtered tailings
- Create unsaturated conditions to preclude liquefaction and/or flowability



Fine Tailings - Consolidation Loading

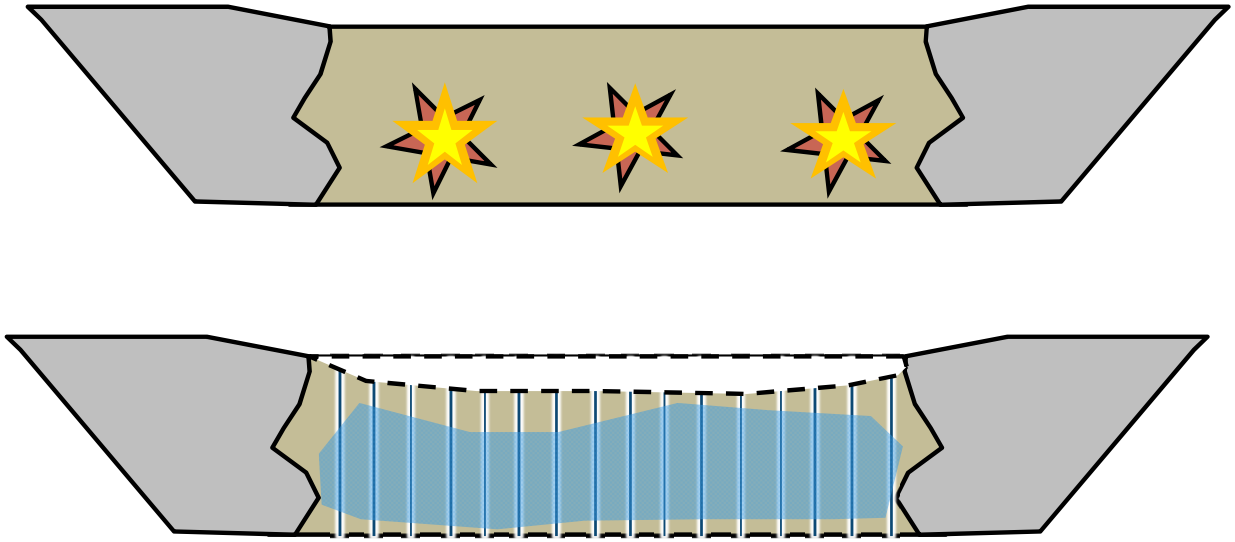
- Densify fine tailings with consolidation load (accelerated with wick drains)
- Increases yield stress for tailings with cohesion and plasticity
- Develop stable non-flowable soil deposit



Explosive Compaction

Tailings Densification

- Explosive charges installed and detonated at depth
- Causes sudden increase in pore water pressure as the tailings densify
- Install wick drains to allow pore water pressures to dissipate under self weight



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Best Available Stabilization Technologies

Summary

- Sandy tailings - Pumped dewatering that is enhanced with vertical wick drains
- Slimes Tailings – Surcharge consolidation to densify (and dewater) the fine tailings. Wick drains required to enhance drainage. Install wick drains to allow pore water pressures to dissipate under self weight
- Interlayered tailings within transition zone stabilized by combination of both options

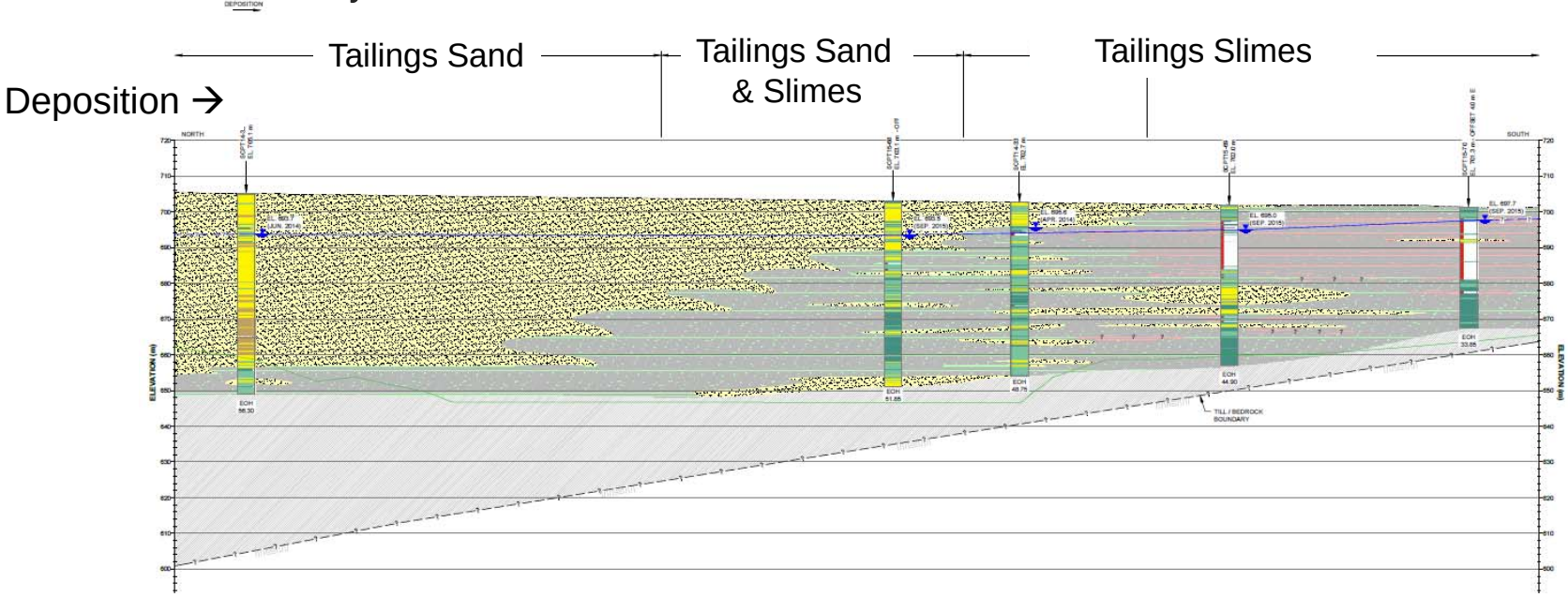
- Explosive densification excluded as base case stabilization option, but retained as contingency measure for surgical densification - if necessary

Site Investigation & Lab Rheology Testing

Tailings Characterization

Site Investigations and Depositional History

- Tailings site investigations characterized nature and distribution of sands and fine tailings (slimes)
- Coarser sandy fraction deposited closer to the point(s) of discharge along north side of facility



Rheological Testing

Sandy Tailings

MC = 37%

MC = 33%

MC = 30%

MC = 24%

- Pumpability (Flowability) decreases as moisture content reduces
- Sandy tailings are fluid (flowable) at higher moisture contents but become non-flowable as moisture content is reduced
- Partially saturated sandy tailings become stable soils

Rheological Testing

Tailings Slimes – MC vs Yield stress

MC = 48%

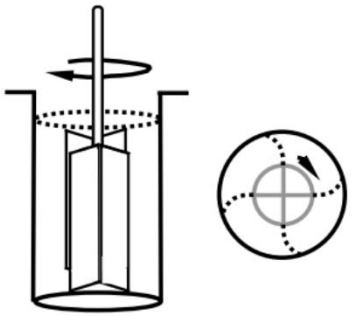
MC = 43%

MC < 40%

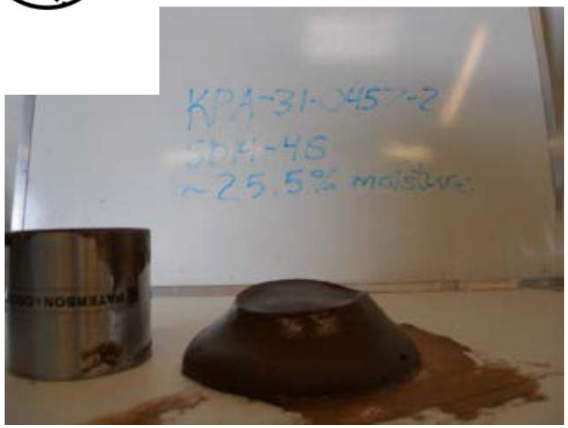
- Yield stress (strength) increases as moisture content decreases during consolidation
- Flowability decreases as moisture content decreases

Rheological Testing

Laboratory testing



- Vane shear
  - Torque applied to vane, high rotation speed
  - Measures fluidized state
- Boger Slump
  - Slump on removal of confining cylinder
  - Change from static state
- Crack Simulation – slurry flow
  - Slowly open a crack below tray;
  - Unpressurized
  - Static state



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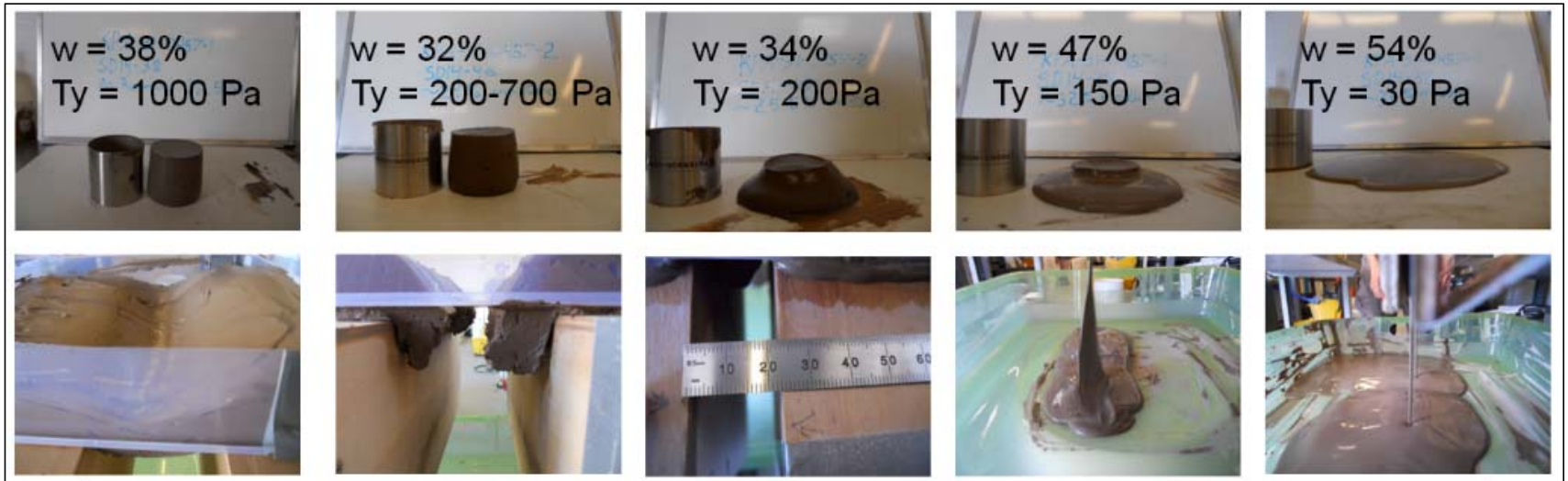
Rheological Testing

Boger Slump, Crack Simulation

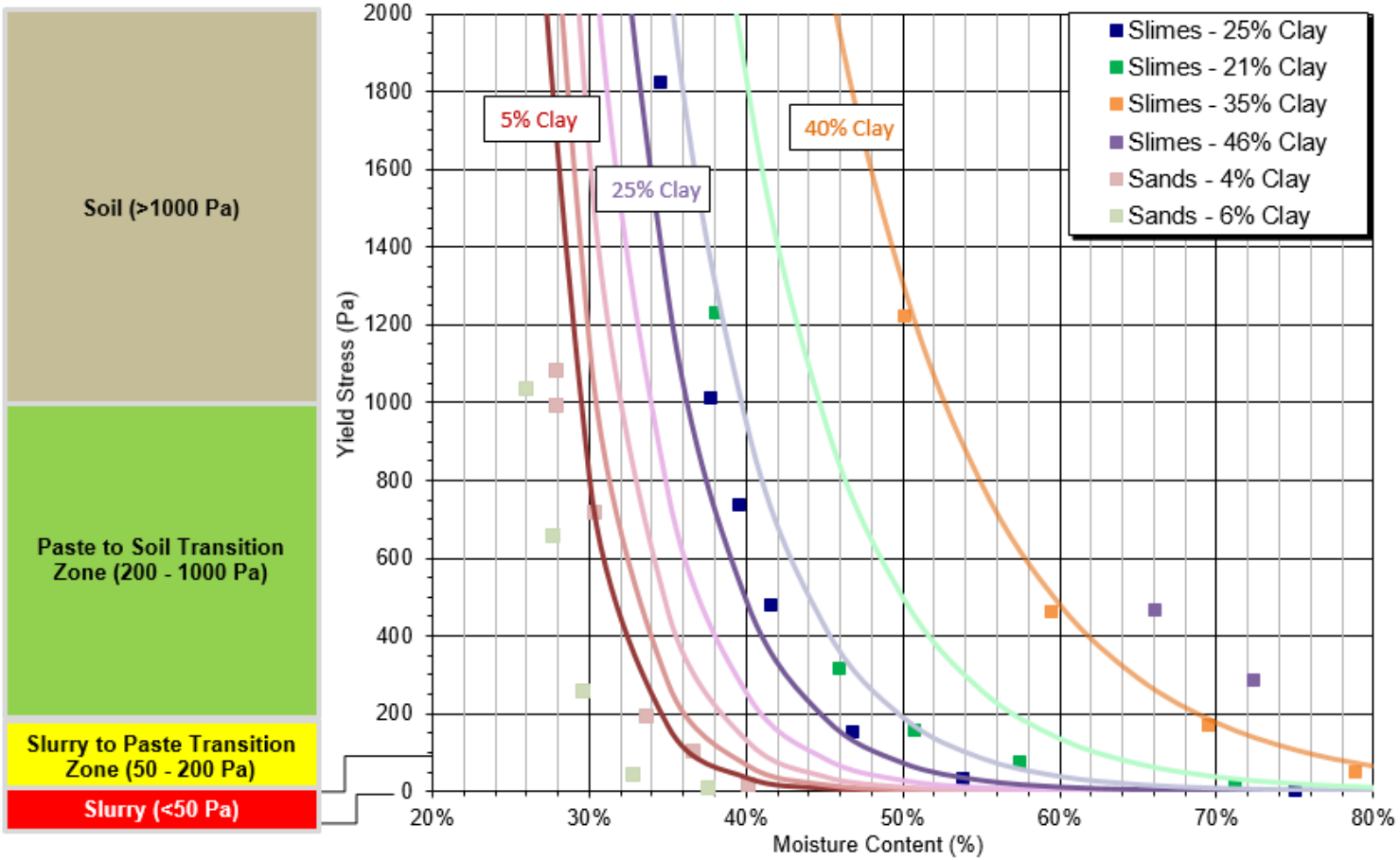


Not Flowable | Transition Zone | Potentially Flowable

Soil (>1000 Pa)	Paste to Soil Transition Zone (200 - 1000 Pa)	Slurry to Paste Transition Zone (50 - 200 Pa)	Slurry (<50 Pa)

Rheology Model – Vane Yield Test Results

Yield Stress vs. Moisture Content and Clay Fraction



Field Scale Trial Programs

Field Scale Trial Programs

Tailings Sands - Dewatering

Pumping Trial Program – Positive Results

- Dewatering wells yielded flows above expectations
- Wick drains were observed to accelerate the development of the drawdown cone and prevent perched water tables
- The sandy side of the tailings impoundment has since been designated as a make-up water source for the mine
- Water supply is a bonus – additional pumping wells have since been installed to further exploit the ‘tailings aquifer’

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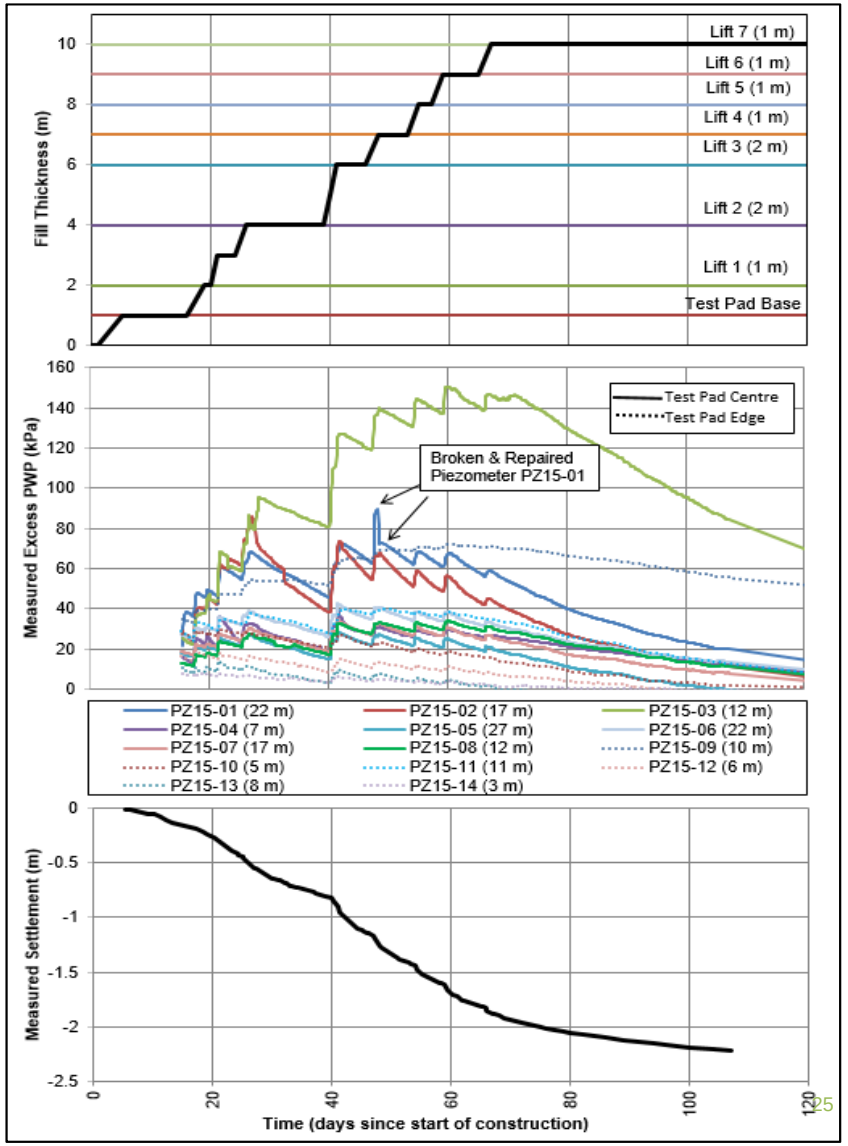
Tailings Slimes - Surcharge

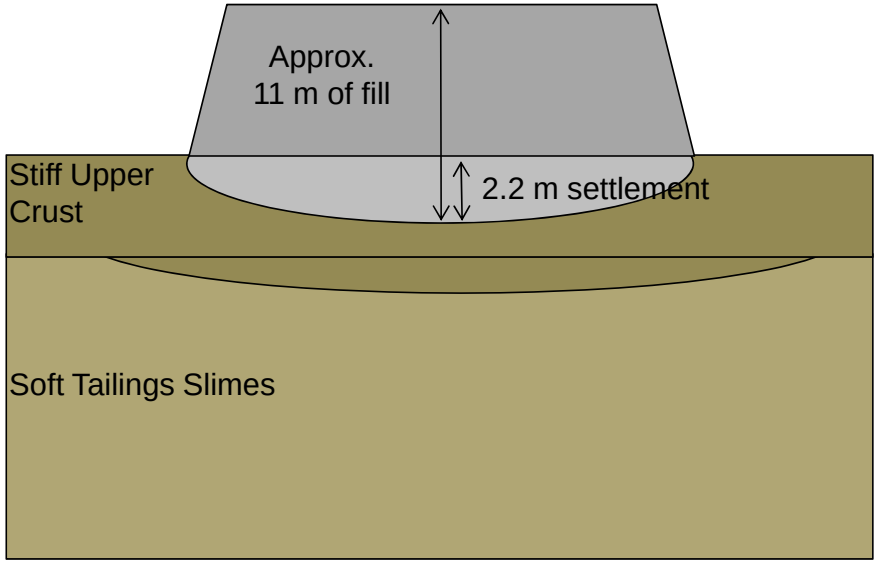
Surcharge Consolidation

- Staged construction
- 10 m fill placed in stages over 2 months
- 2.2 m settlement after 3.5 months
- Piezometers monitor pore pressures in tailings foundations
- Fill loading rate coordinated with pore pressure dissipation rates to maintain pile stability during loading



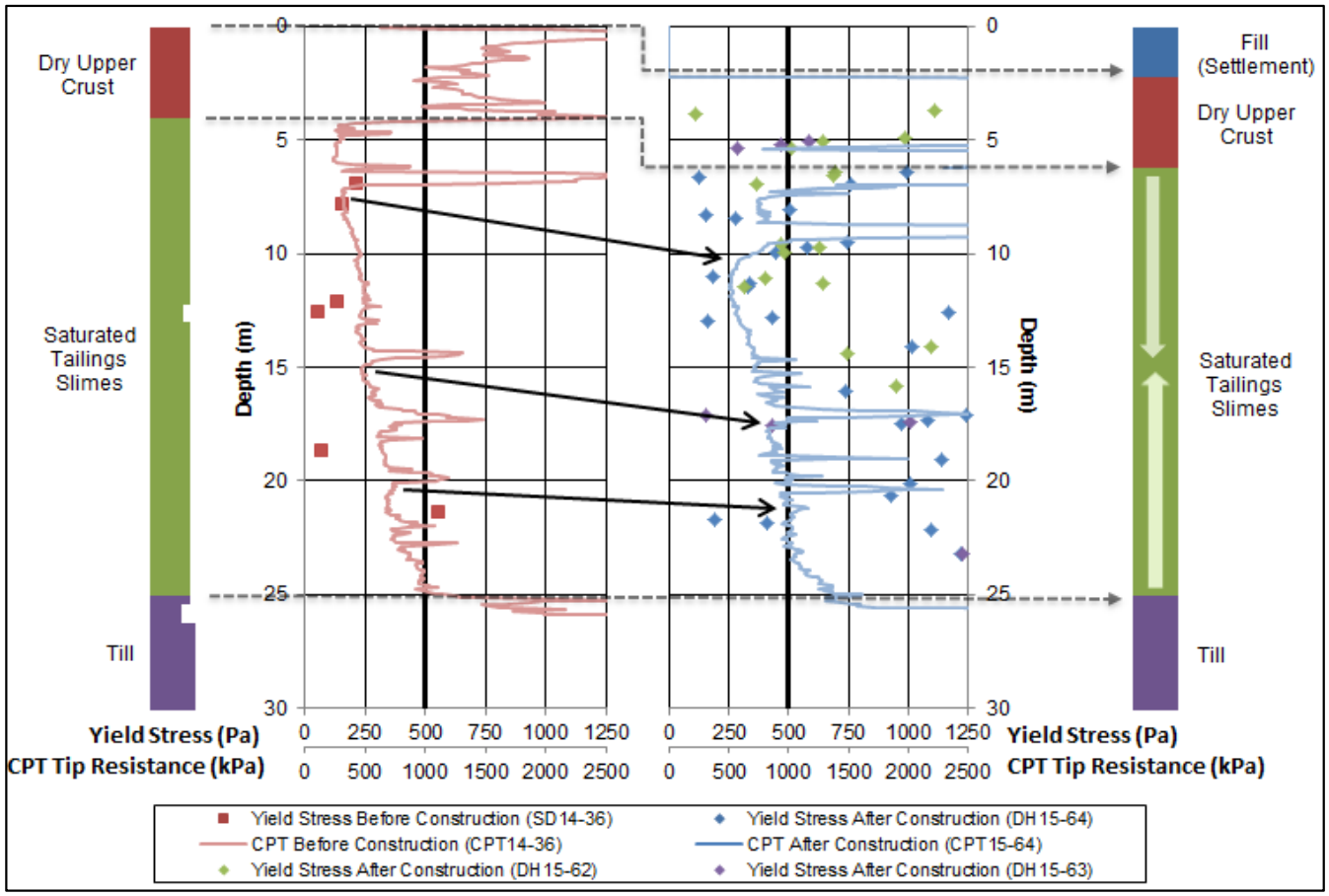
Before/After Site Investigations

- Cone Penetration Testing (CPT)
  - Compare CPT tip resistance before and after consolidation
  - Adjusted for measured settlements to allow better comparison
- Auger Drilling and Shelby Tube Sample Collection
  - Mechanically actuated stationary piston sampler
  - No water used during drilling or sampling to preserve in-situ moisture
  - Lab testing to measure improved yield stress after consolidation



Tailings Slimes – Consolidation Results

- Increase in tip resistance and yield stress



Summary

Effectiveness of Ground Improvement Technologies

Sandy Tailings:

- Pumping shown to effectively dewater the deep sandy tailings along the northern half of the tailings impoundment.
- Wick drains help to accelerate drawdown during pumping
- The sandy tailings will become non-flowable at low moisture contents and when partially saturated.
- Water supply a bonus – trial pumping program has been expanded

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Summary

Effectiveness of Ground Improvement Technologies

Slimes Tailings:

- Surcharge consolidation is effective in increasing tailings yield stress.
- Wick drains accelerate consolidation process
- Consolidation results in densification and increase in yield stress
- Fine tailings transition from fluid to a more stable soild when consolidated.

Surcharge Trial confirmed that densification due to loading will reduce moisture content (increase in-situ dry density) and mitigate mudrush potential

Thank You