Stockpile Stability – Understanding the Instability Triggering Conditions and How to Avoid Them

SME – Salt Lake City, Utah

February 2022

Carrie Hartford chartford@Jenike.com

Jenike.com

OUTLINE

- What causes stockpiles to fail
- Steps to take to analyze stockpiles for slope stability
- Computational analysis example

Who is Jenike & Johanson?

A specialized engineering firm focused on providing clients solutions to material handling applications

- 55+ years experience, all industries
- 13,000+ materials tested, 8,000+ projects
- 650+ accumulated years of solids experience
- Offices in Australia, Brazil, Canada, Chile, USA (Massachusetts, Texas, California)

Who is Jenike & Johanson?

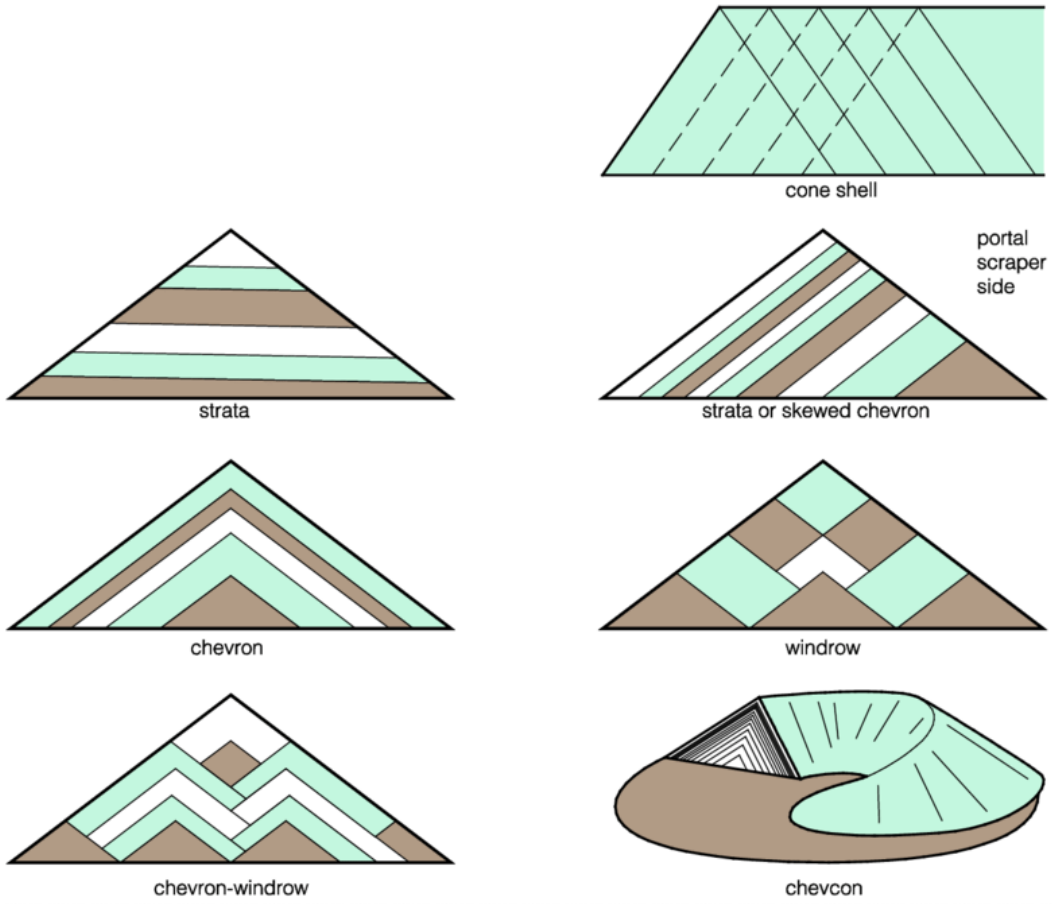
A specialized engineering firm focused on providing clients solutions to material handling applications

We are NOT a geotechnical firm!

Stockpiles

- Economical storage
- 5 to 500,000 tonnes
- Capacity of the stockpiles can range from 7 to 45 days
- Covered or not
- Built by stackers, trippers, loaders
- Mobile equipment - loaders, scrapers
- Stackers / reclaimers - drag, bucket wheel
- Gravity - hoppers, feeders, gates

Stacking Methods



Sloss, Lesley. 2014. Blending of coals to meet power station requirements, Research Gate ISBN 978-92-9029-559-4

Stockpiles

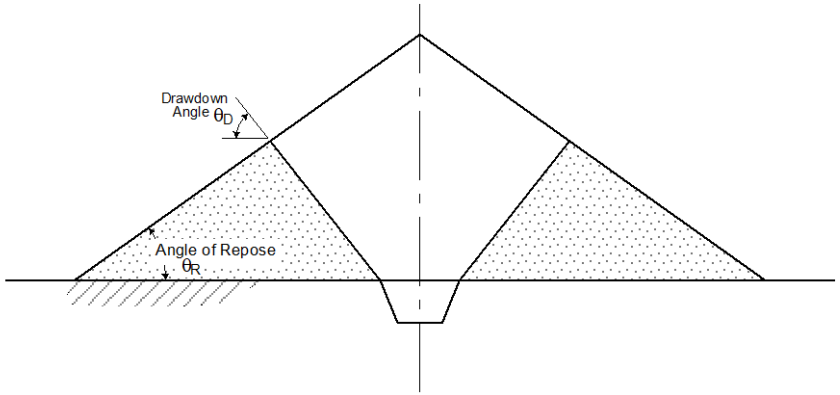
- Disadvantage: rainwater and infiltration in the stack as a result of long lasting and continuous rainfall, affect flowability and in some cases slope stability.
- High moisture content ore can have significant consequences in process steps downstream of the stockpile
  - liquefaction and flooding
  - moisture content above the Transportable Moisture Limit.

Stockpiles vs. Mountains

- Stability analysis by Geotechnical firms is for packed material using geotechnical software.
- However, stockpiles are a loosely filled pile, not compacted.
- Mountains have been compressed over time, so bench stability is a different calculation.

Angle of Repose

- Angle of the pile is based on angle of repose, not compaction



Stockpiles

$$FS = \frac{Shear\ Strength\ Available}{Actual\ Shear\ Stress}$$

Factor-of-Safety (FS)	Condition	Examples
FS>1.5	Stable stress > strength	Only major destabilizing factors lead to instability, even when soil is fully saturated
1.25 < FS < 1.5	Moderately stable stress > strength	Moderate destabilizing factors lead to instability
1 < FS < 1.25	Quasi-stable stress > strength	Minor destabilizing factors can lead to instability
FS < 1	Unstable strength ≥ stress	Stabilizing factors are needed for stability, even when soil is dry

Stockpiles have FS of ~1

Montgomery, D.R., Dietrich, W.E., 1994. A physically based model for the topographic control on shallow landsliding. Water Resources Research, 30: 1153-1171

Slope Stability "Flowslides"

- Flowslides have usually been attributed to liquefaction of saturated, cohesionless soils looser than critical density, where shearing is accompanied by generation of substantial excess pore water pressures with a resultant marked loss of strength
  (Bishop, A.W., 1973. The stability of tips and spoil heaps. Q.J. Eng. Geol., 6: 335-376)

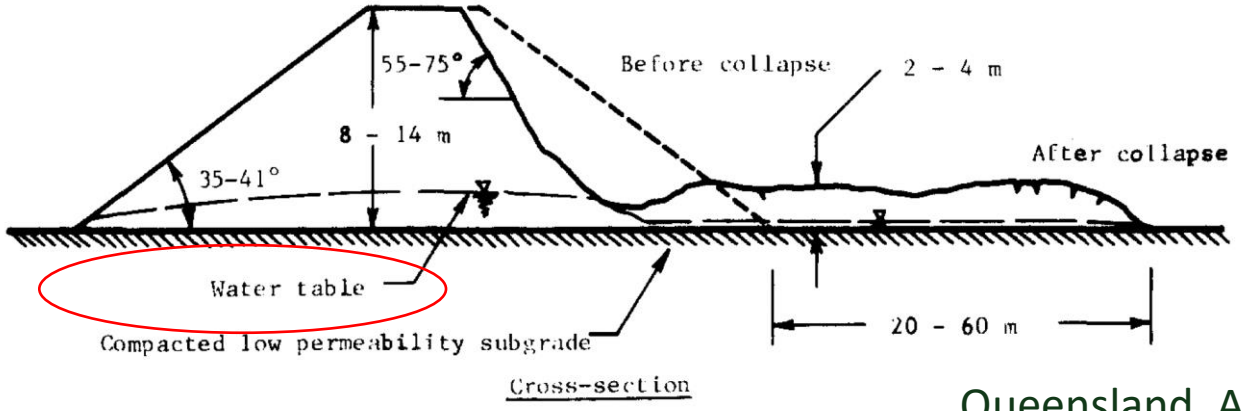


Fig. 1. Typical flowslide in Hay Point coal stockpiles.

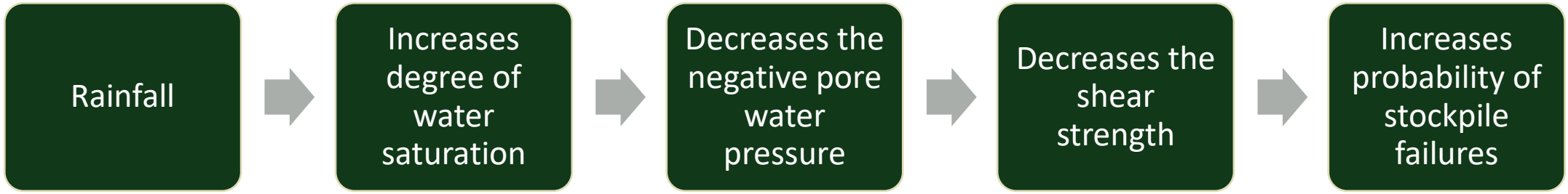
Queensland, Australia

Eckersley, J.D., 1985. Flowslides in Stockpiled Coal. Eng. Geol., 22:13-22

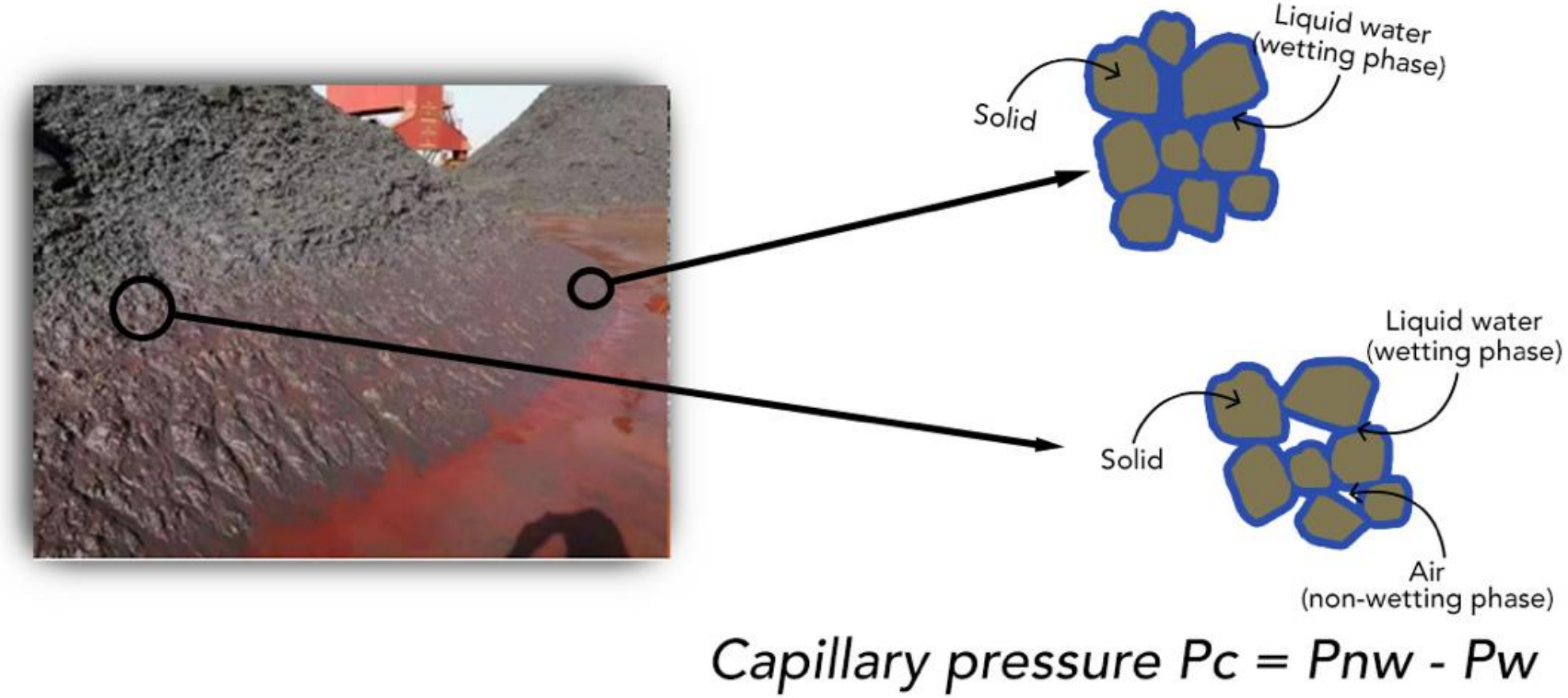
Flowslide

What primarily triggers stockpile instability?

What primarily triggers stockpile instability?



Moisture Seepage and Drainage



Capillary pressure Pc = Pnw - Pw

What primarily triggers stockpile instability?

WATER

- Water pore pressure opposes particle-to-particle pressure, reduces material strength.
- Consider moisture migration into, within, and out of the stockpile.
- Rainfall can either infiltrate the stockpile or directly run off the stockpile. Infiltrated water will either remain in the stockpile or drain
- Other factors: mine operation, local hydrological conditions, material properties of the ore, properties of the underlying base and surrounding material, etc.

Added complexity

Everything can change within the stockpile!

- Ore chemistry
  - Friable hematite vs. hydrated ore vs. a blend (including various blend ratios)
- Particle size distribution
  - Fines vs. coarse
- Loading conditions as pile forms
  - Rainy vs. dry conditions during loading
- Consolidation pressure within the pile – effects compaction of material
  - Lower consolidation pressure at the pile surface vs. higher consolidation pressure at the bottom

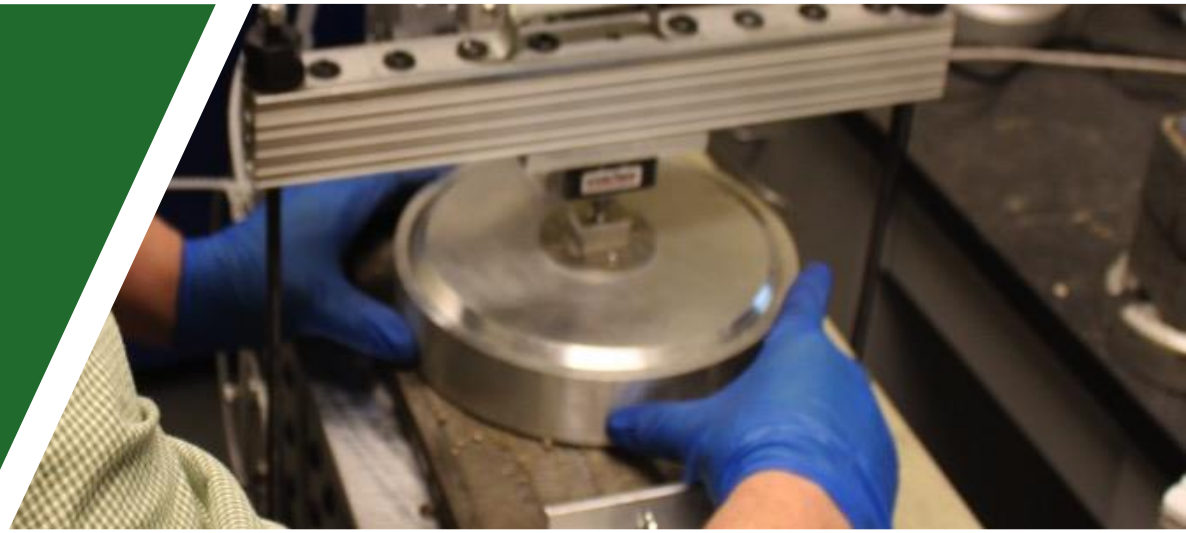
Moisture Drainage Analysis Approach

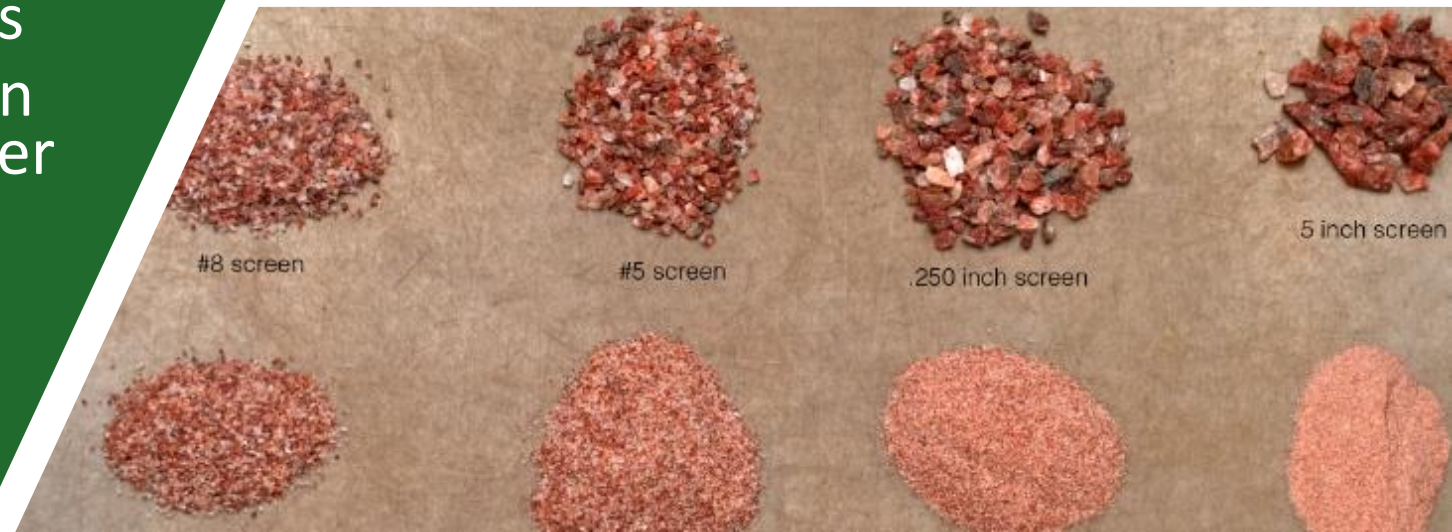
- Material testing to determine intrinsic hydraulic properties of the ore and other important physical properties.
- Computational analysis of drainage in stockpile to determine:
  - Moisture profile in stockpile as a function of storage time
  - Analysis of different stockpile configurations and its effect on drainage
  - Water infiltration due to rainfall
  - Effectiveness of subsurface drainage systems
- Computational analysis to determine moisture evaporation from stockpile surface coupled with drainage, when important. e.g, dusting
- Computational model validation when necessary
  - Drainage pipes
  - Wind tunnel and surface evaporation

Material Properties Needed for Analysis

Standard tests:

- Cohesive strength
- Bulk density/compressibility
- Particle density
- Liquid permeability
- Particle size distribution
- Chemical mineralogical analysis
- Hydraulic properties (saturation hydraulic conductivity and water retention curves)
- Segregation potential



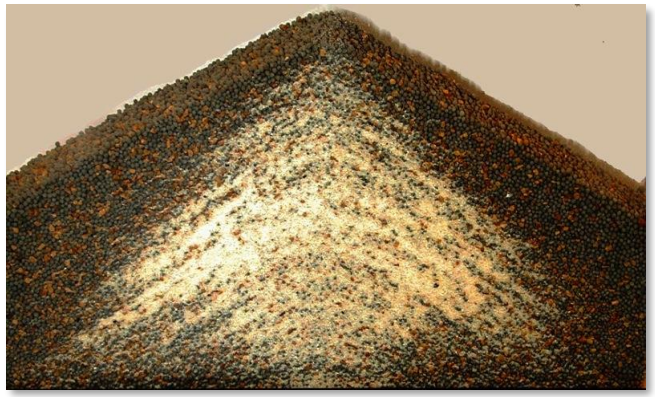


The Role of Sifting Segregation

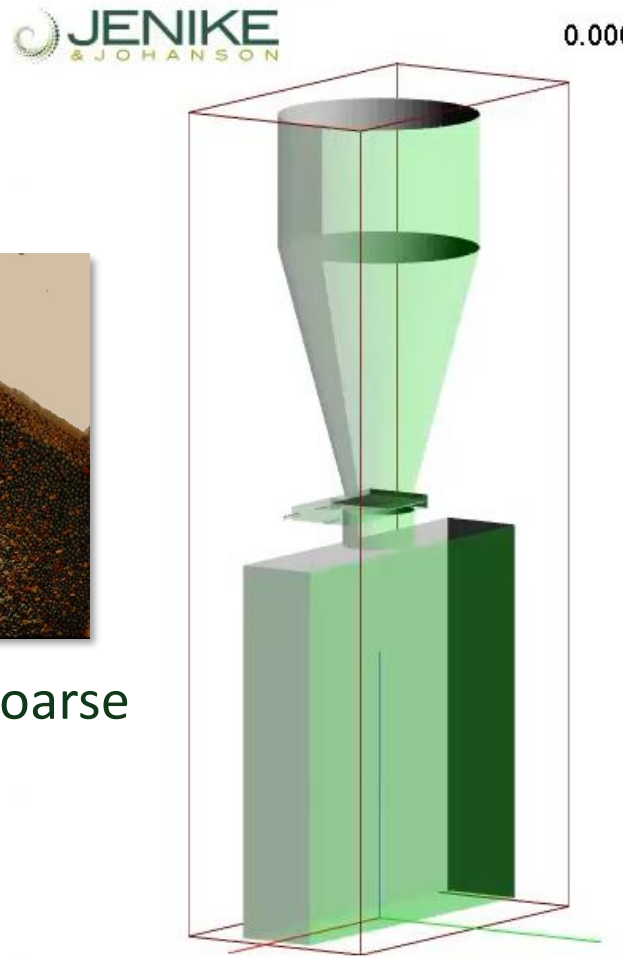
The draining characteristics or permeability of the material changes based on the PSD.

Coarse → high permeability: water will accumulate between particles

Fines → low permeability: water will accumulate on those planes and failure can occur at those points.

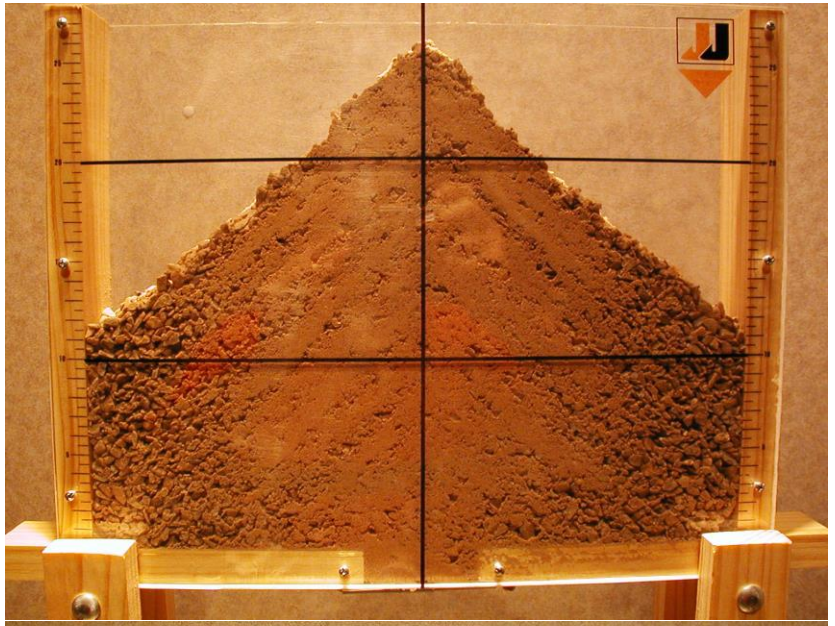


Coarse Fines Coarse



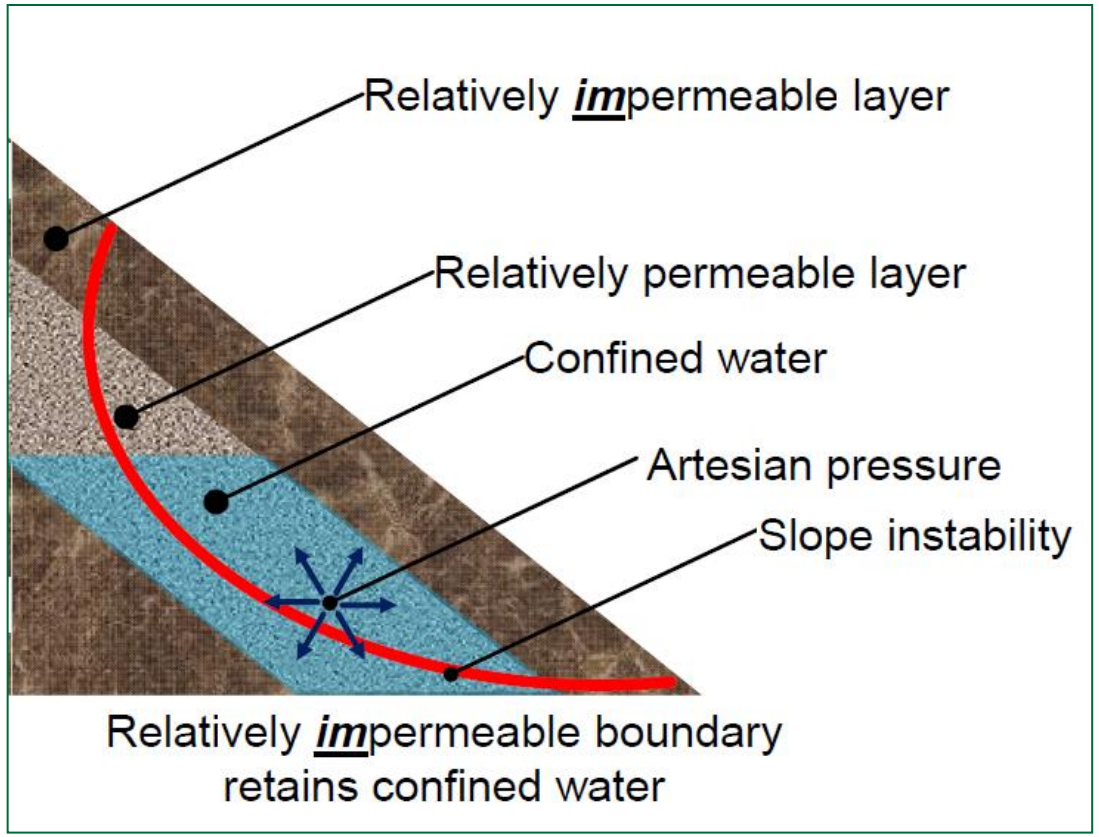
Coarse Stockpile

Coarse and Fines Stockpile

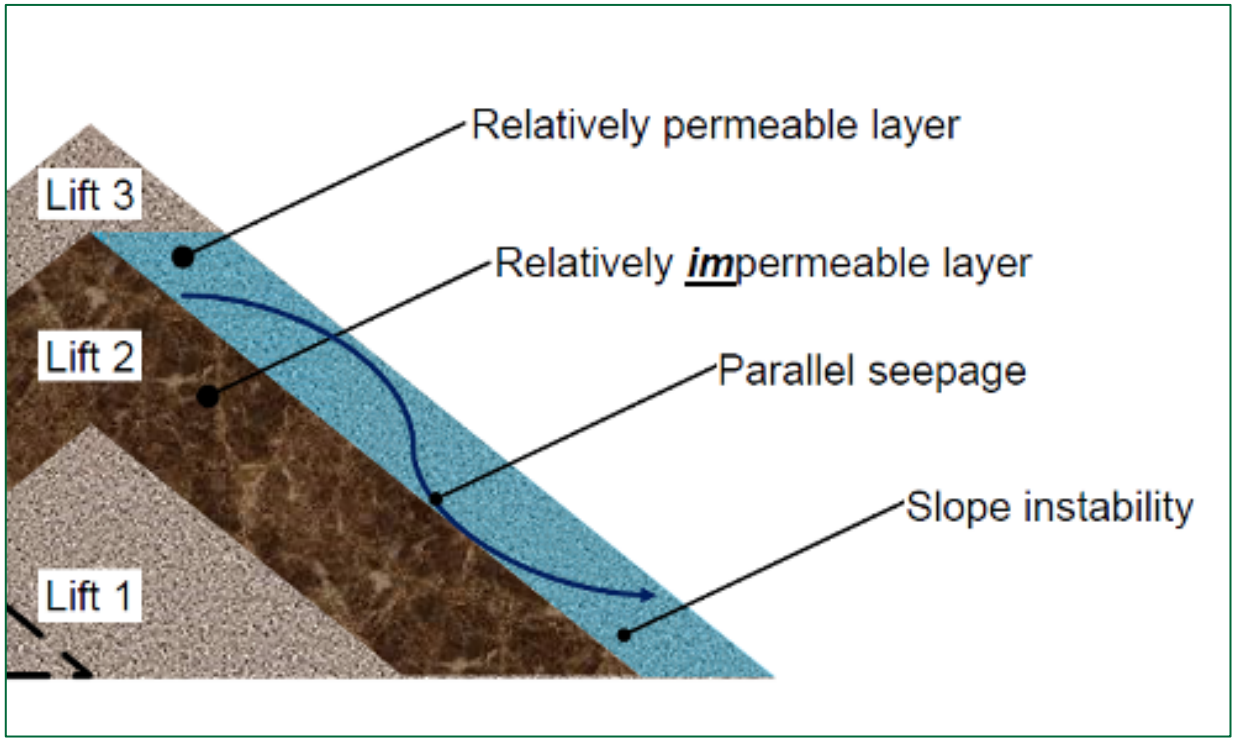


Fines Stockpile

Slide due to layering of coarse and fine material and/or mineral ore grades with different hydraulic properties

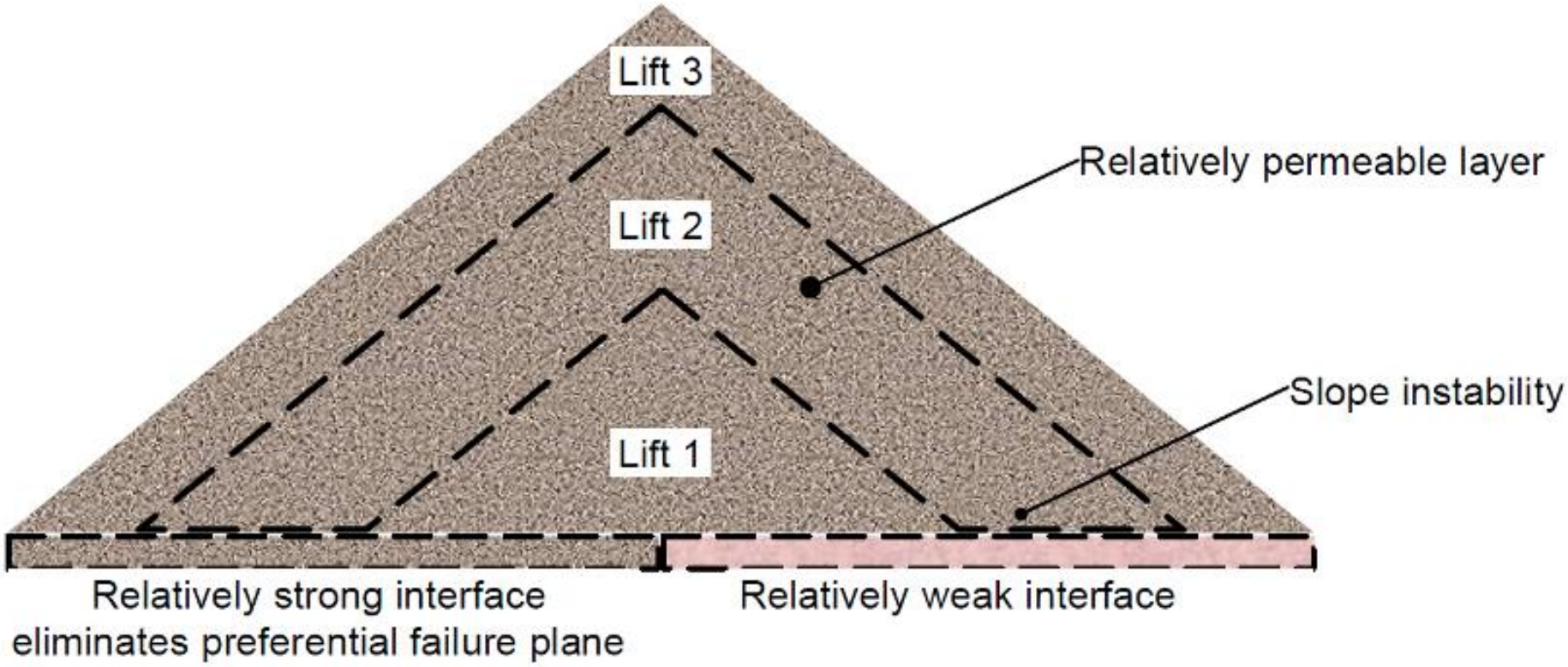


Confining layer



Parallel seepage

Slide Due To Weak Planes



Conditions to be Analyzed

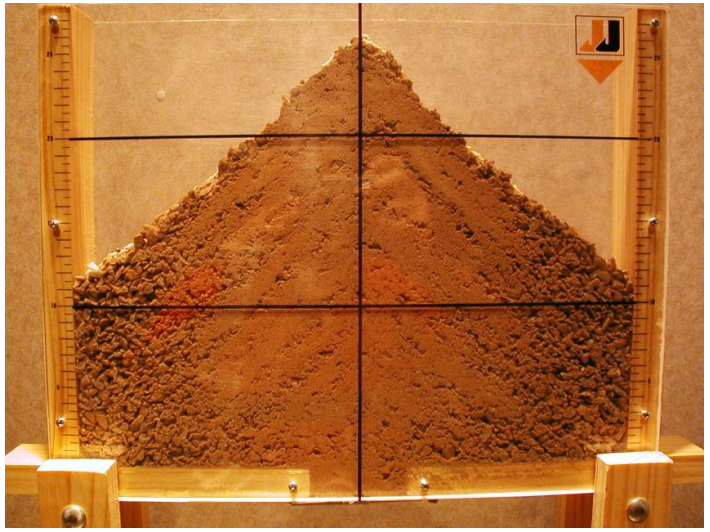
- Rainfall – intensity and duration
- Initial moisture condition as a percent of saturation
- Various material blends
- Height of stockpile
- Permeability of the base (stockyard pad)
  - The permeability of the stockyard pad will change overtime if not maintained properly as fines accumulate and block the drainage system.
  - The pad needs to be as permeable as the bottom of the stockpile.

Surface sloughing and mudflows

Other Effects of Poor Drainage

As water drains from the top of the pile to the center, the fines may not drain and will accumulate moisture.

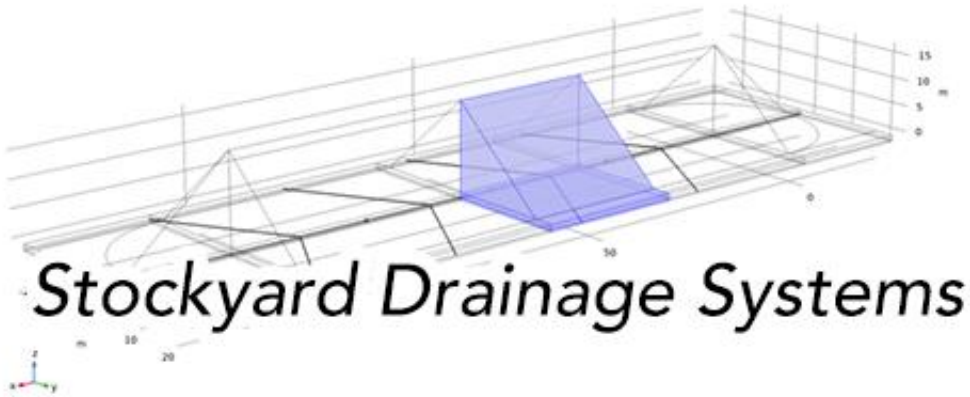
- If gravity reclaim stockpile, the fines will have higher moisture thus higher cohesive strength, plugging may occur in feeders below center of pile versus feeders on the outer edge of pile.
- Based on that moisture migration, ports need to be aware that material that was initially below the Transportable Moisture Limit (TML) may not be below where water has accumulated



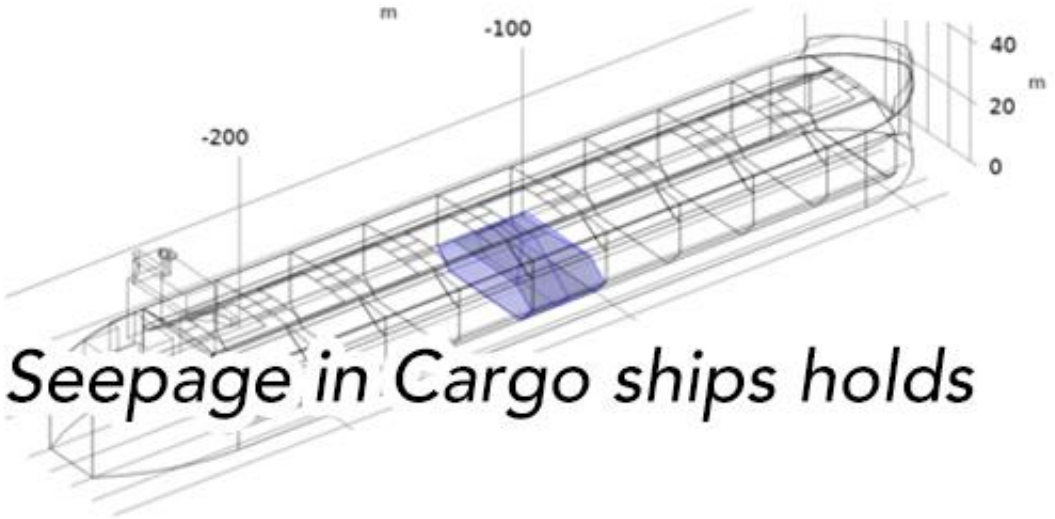
Computational Analysis

Finite Element Method Modeling

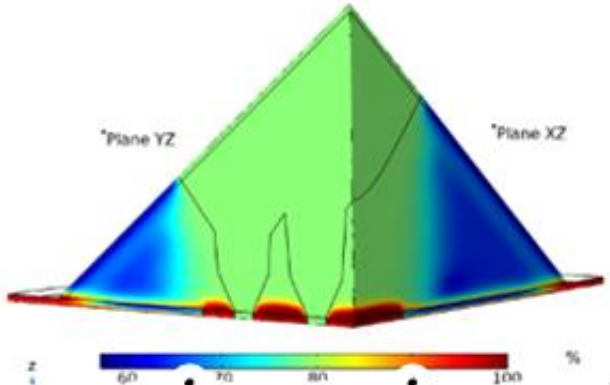
Drainage



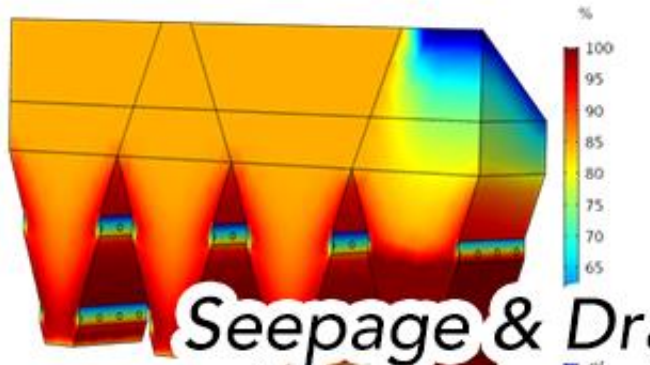
Stockyard Drainage Systems



Seepage in Cargo ships holds



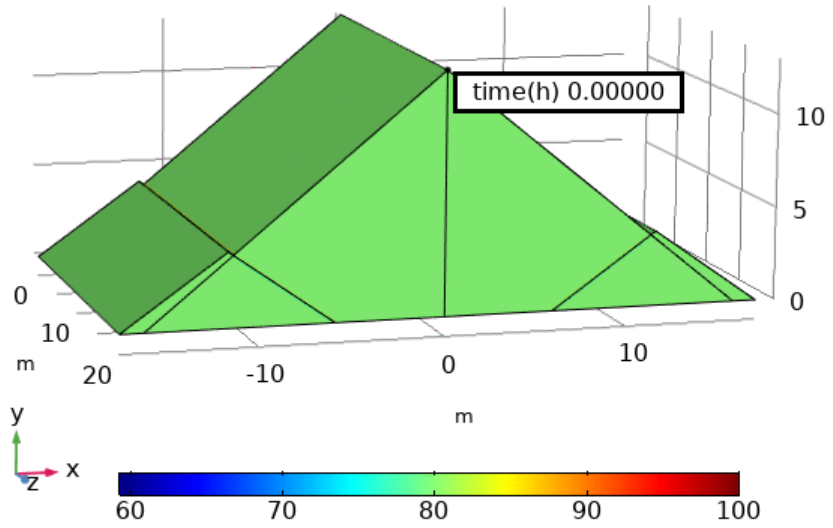
Seepage in gravity reclaim stockpiles



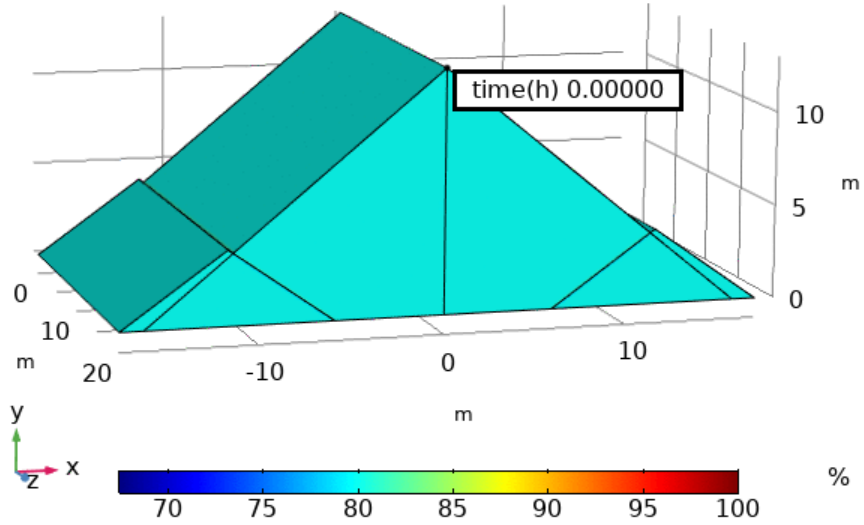
Seepage & Drainage in storage silos

Stockpile Drainage Analysis – FEM Analysis

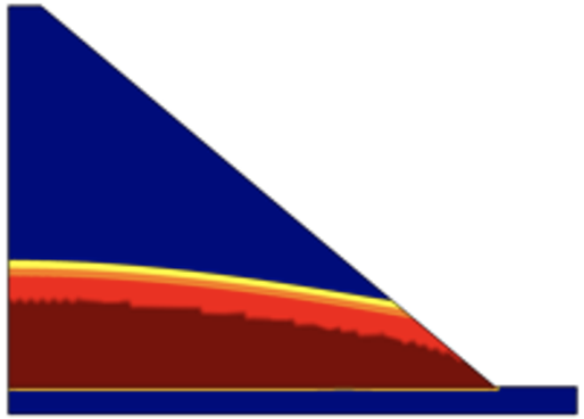
Hematite 100%



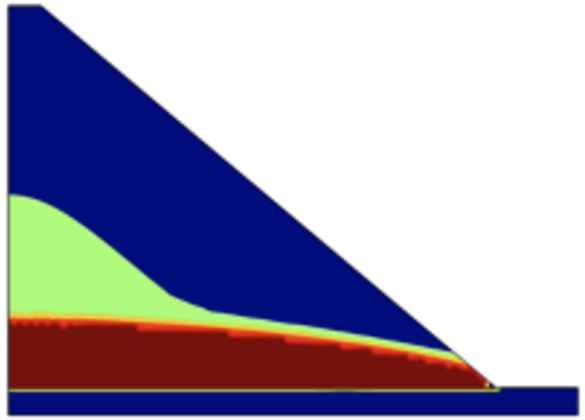
Hematite 20%



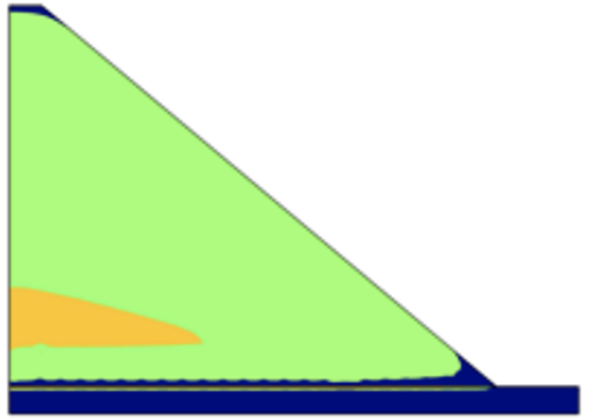
Influence of Ore Chemistry on Stockpile Drainage – Example



Hematite – after 40hour
FS:1.13

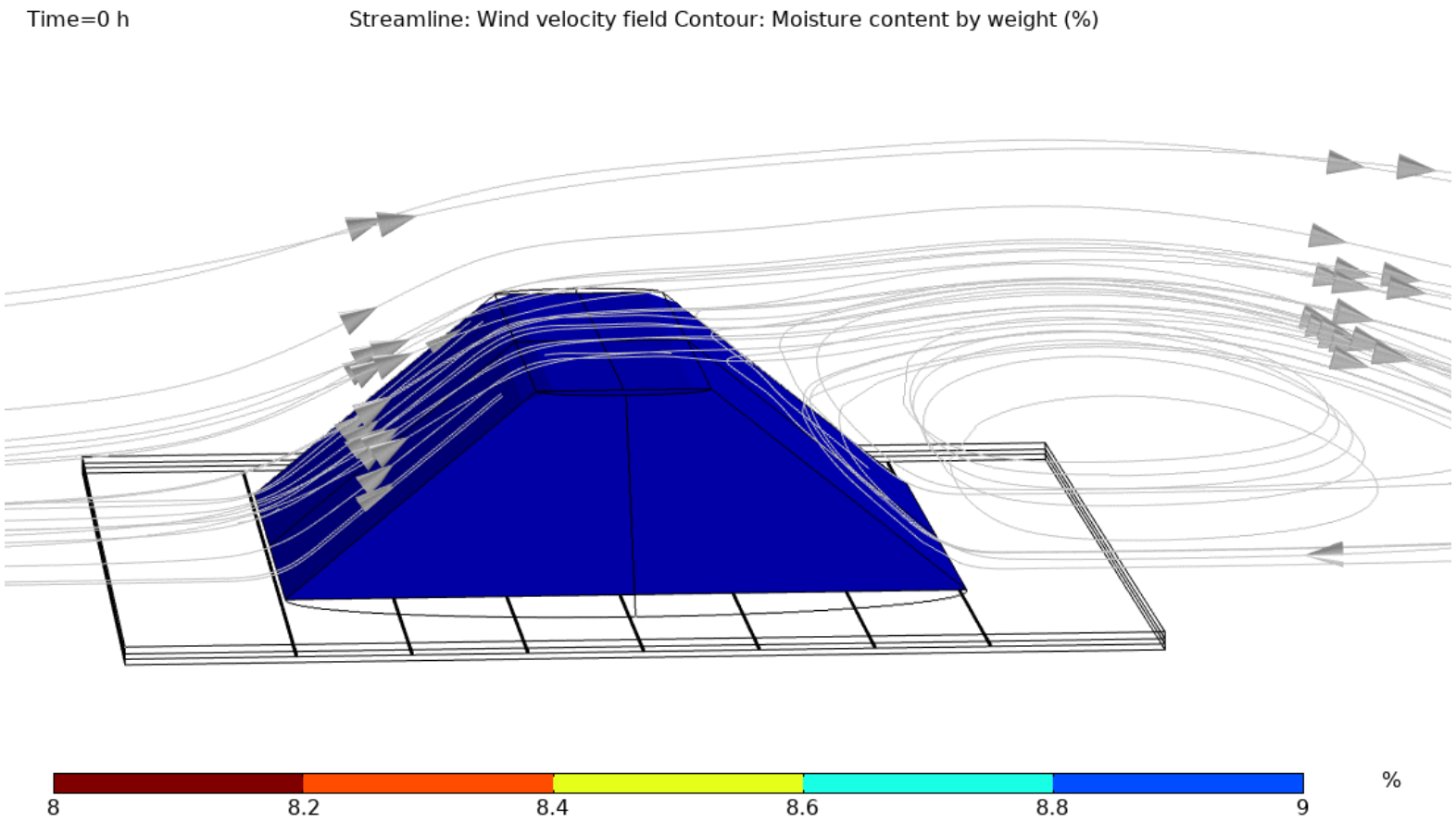


Blend – after 40hour
FS:1.29

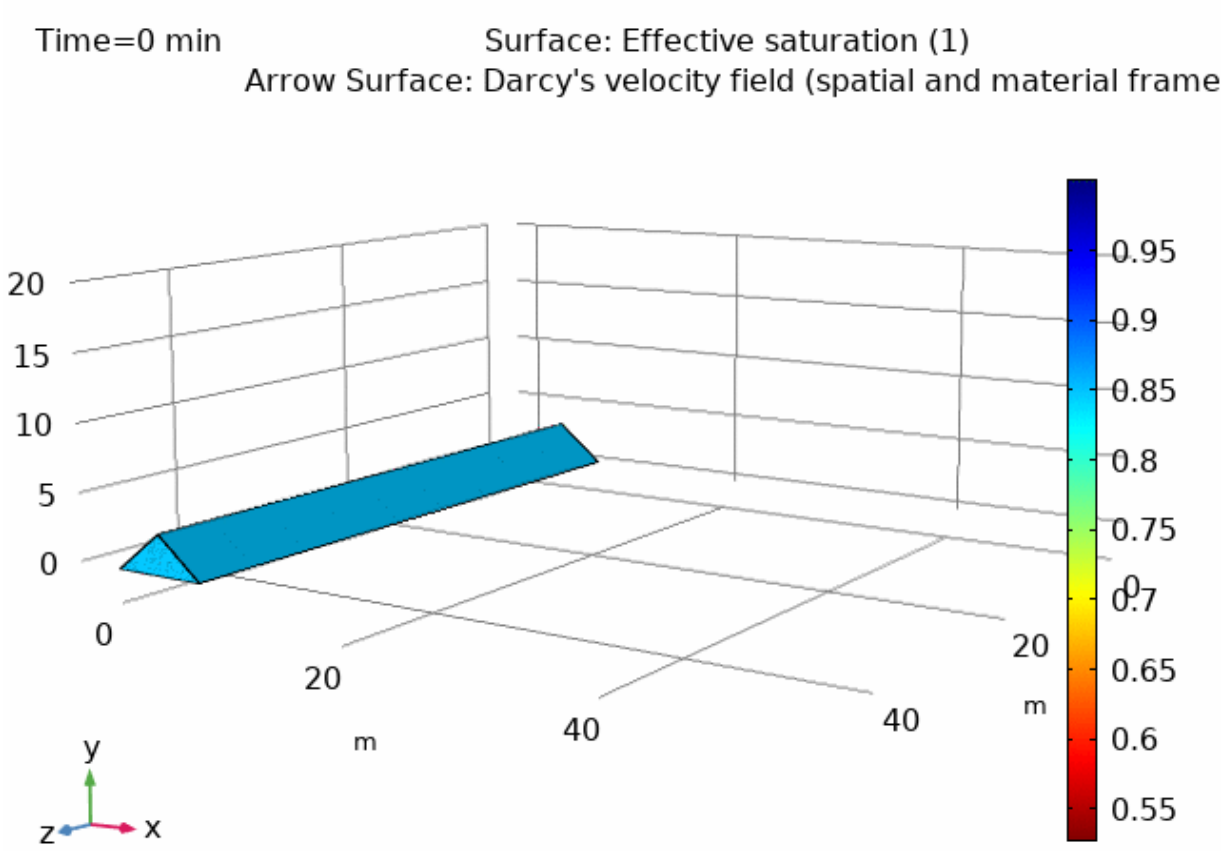


Hydrated O. – after 40hour
FS:1.46

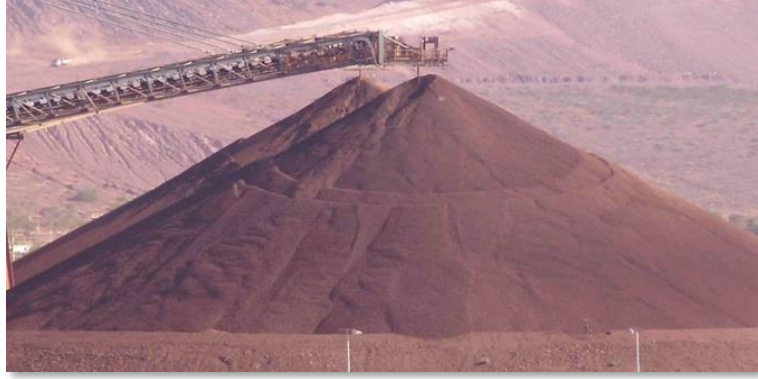
Wind Tunnel and Surface Evaporation



Moisture Seepage/Drainage Analyses

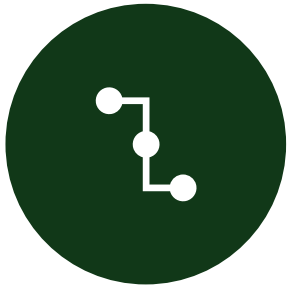


Summary of Analyzing Stockpile Stability



- Understand draining properties of the material
  - Used to determine what type, size and shape the stockpile should be formed and how the stockpile should be operated.
- Analyze stacking methods for stockpile formation
  - Prismatic piles formed with a chevron shape – layered approach exposes the material to more moisture layer by layer.
  - Cones formed and then another conical pile formed next to it so less exposure to rain.
- Assess stockpile footing and/or a permeable base and how it is maintained
- Consider how stockpiles are managed to minimize time material is in the stockpile.
- Consider stockpile height – but lowering height reduces bucket wheel efficiency
- Consider how stockpiles are reclaimed - bench reclaim or top down.

Conclusion



Material characterization is key in providing inputs to the analysis

Testing must be performed on representative samples and at anticipated process conditions

There are numerous challenges in addressing this potentially dangerous situation.

Calculations need to consider numerous scenarios – allow enough time for the assessment

JENIKE & JOHANSON

SCIENCE ENGINEERING DESIGN

Stockpile Stability

SME – Salt Lake City, Utah

February 2022

Carrie Hartford chartford@Jenike.com

Jenike.com