Consideration of Shear Strains in Design and Construction of Heap Leach Facilities

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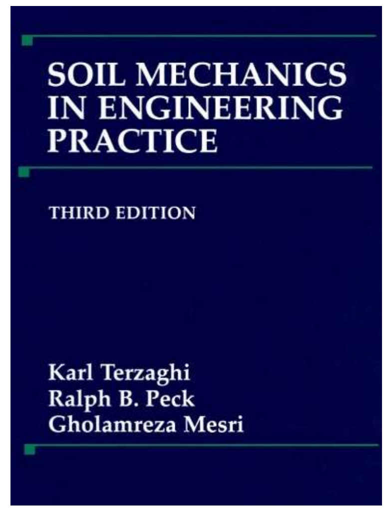
Paper Overview

- Why this paper?
  - Multiple heap leach failures worldwide recently
  - Standard of practice for stability analysis sufficient to all project environments?
  - Limit equilibrium analysis incapable of considering strain development
  - Need to consider advanced modeling as a tool and option to look into strains under certain situations
- Applications evaluated:
  - HLF Application 1: Liner interface strength
  - HLF Application 2: Loading over liner systems
  - HLF Application 3: Stacking over a saturated lift surface



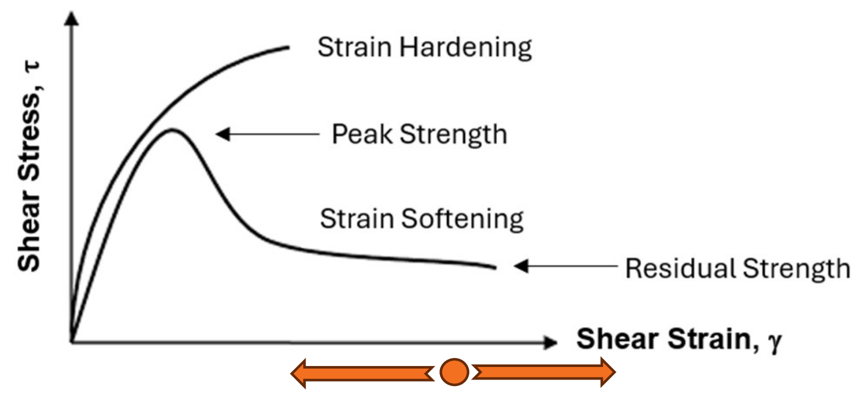
The book is there for a while – it is a matter of using it!

Strength and Strain-Stress Relationship

- Design safety margin (or factor of safety, FOS)

  FOS = Shear Resistance (Strength) divided by Driving Force

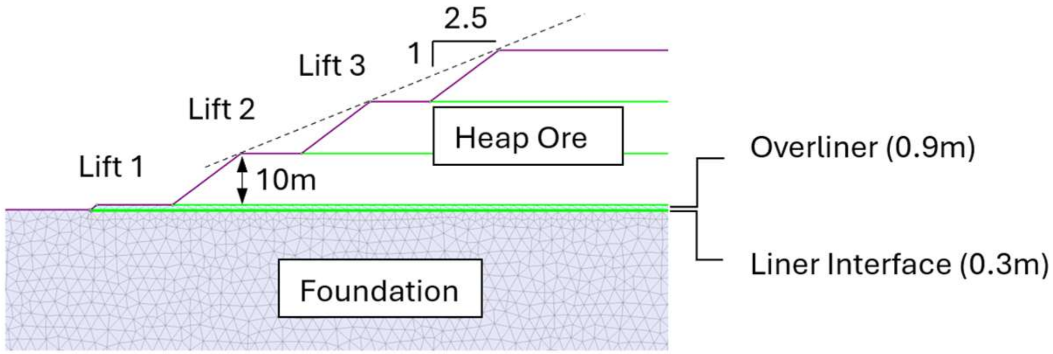
- Challenges in selecting strengths
  - Non-linear relationship between strain and stress (risk of failure to understand strain-stress behavior/influence)
  - Investigation/sampling
  - Lab testing limitations
  - …



Strength reduction not recoverable in many cases

<u>Important to reduce strain development!</u>

Model Development - Geometry



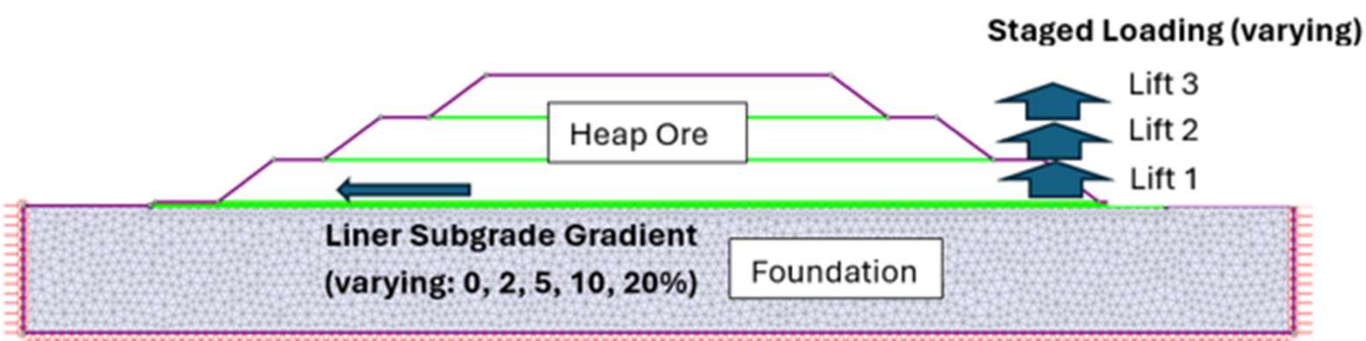
- Liner Interface assembly: 0.3m
- Overliner thickness: 0.9m
- Height of each stacking lift: 10m (maximum)
- Overall stacking slope: 2.5H (horizontal): 1V (vertical)
- Angle-of-repose slope (lift slope): 1.33H:1V or about 37 degrees
- Subgrade (foundation) slope varies

Model Development – Properties and Modeling Tool

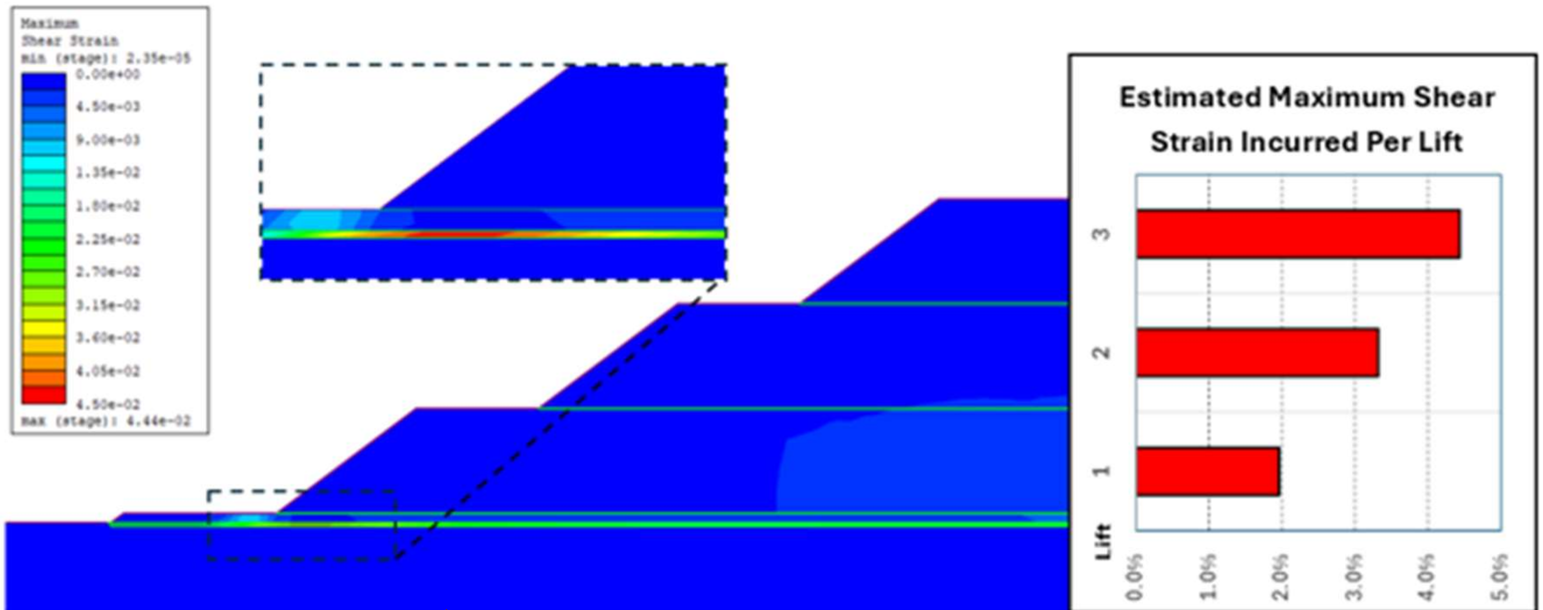
©2D Finite Element Analysis Software by RocScience

Table 1: Material Properties Used in RS2 Models

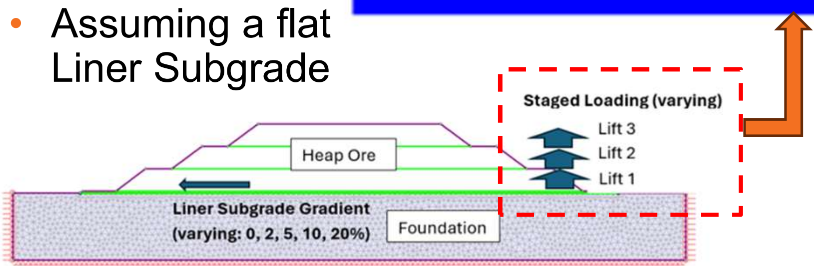
Material	Foundation	Liner Interface	Overliner	Heap Ore
Strength Parameters (Mohr-coulomb Criterion)				
Cohesion (kPa)	0	0	0	0
Friction Angle (°)	38	15	36	36
Deformation Parameters (Elasto-plastic Model)				
Young's Modulus (MPa)	200	14	50	50
Poisson's Ratio	0.3	0.3	0.3	0.3
Density (kN/m^3)	19.6	15.7	19.6	19.6



Application 1 – Interface Strain Development Under Stacking

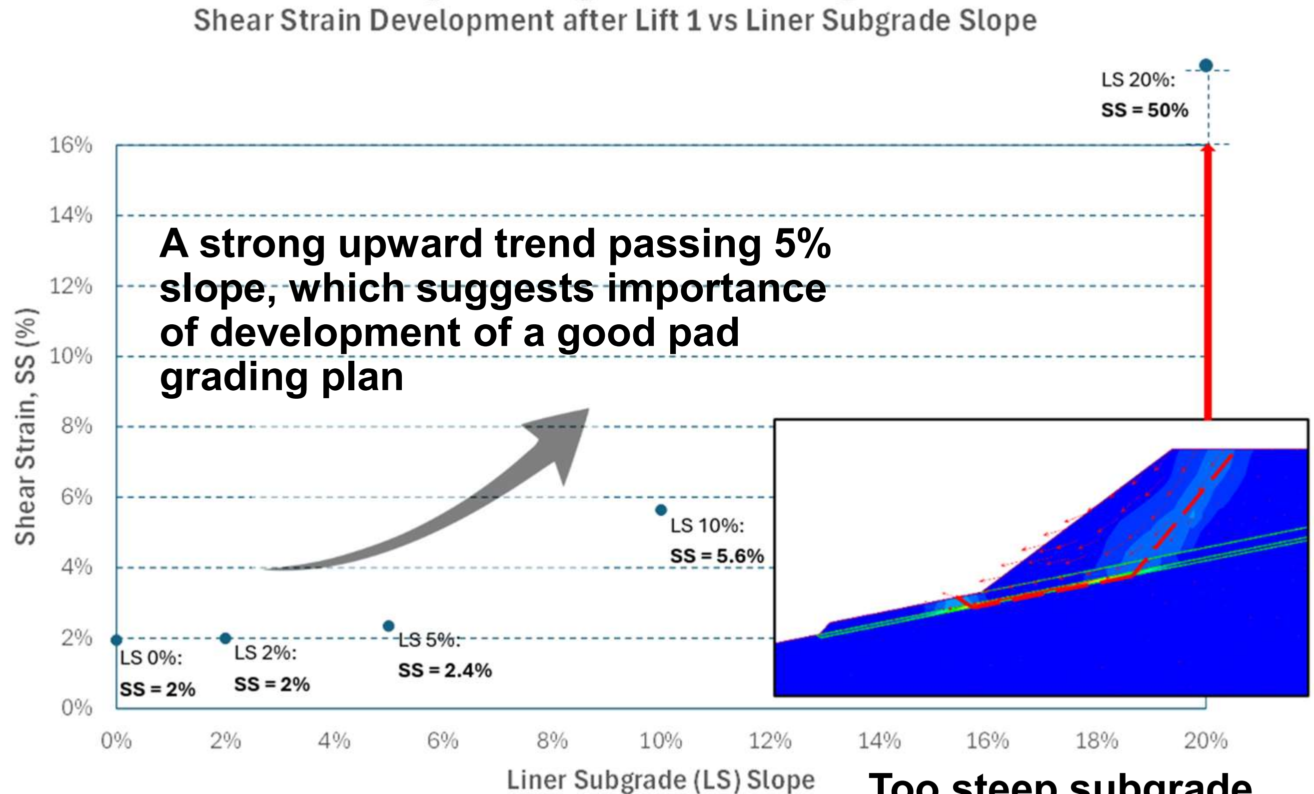


- Assuming a flat Liner Subgrade

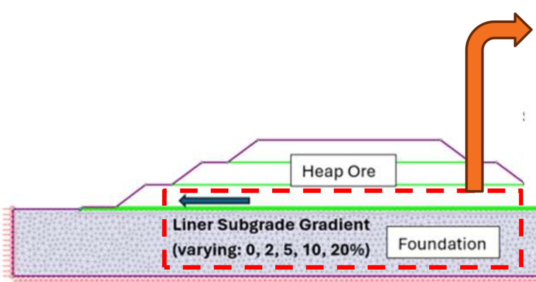


- Estimated maximum shear strain sufficient to mobilize the interface passing that of peak strength
- Residual strength should be used for liner interface!

Application 1 – Interface Strain Development with Varying Subgrade

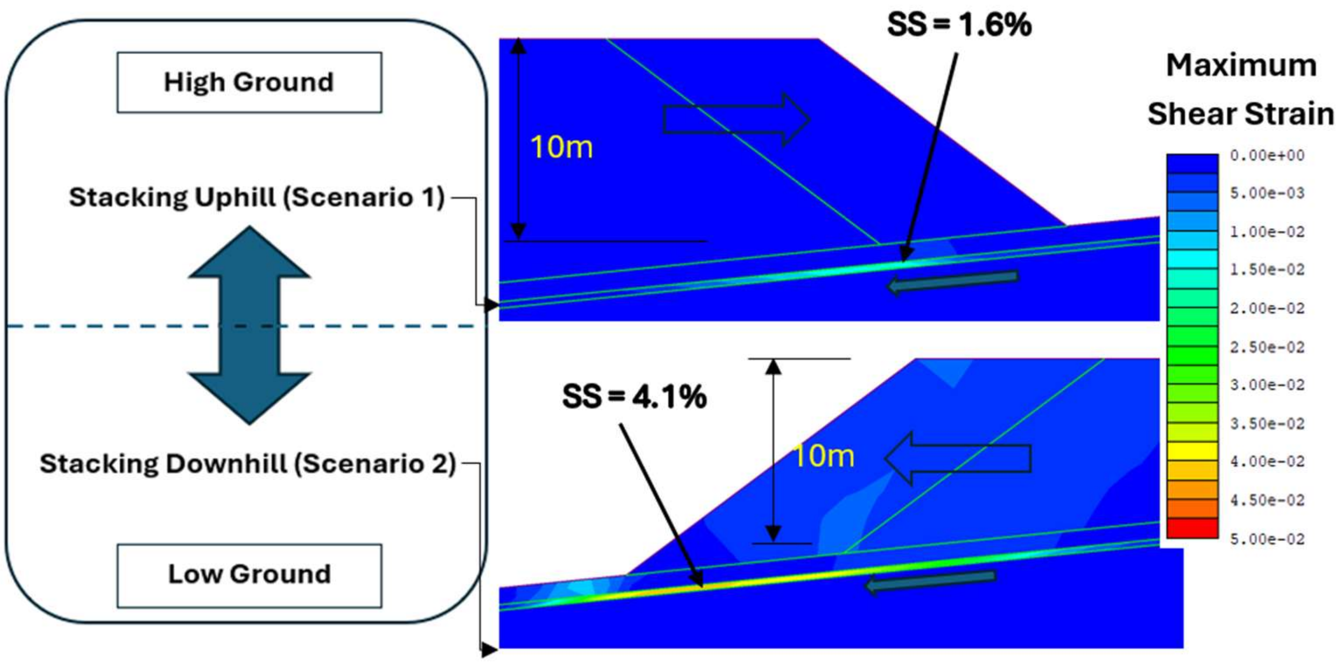


Too steep subgrade resulting in a plastic slip surface (instability)



- Assuming varying Liner Subgrades

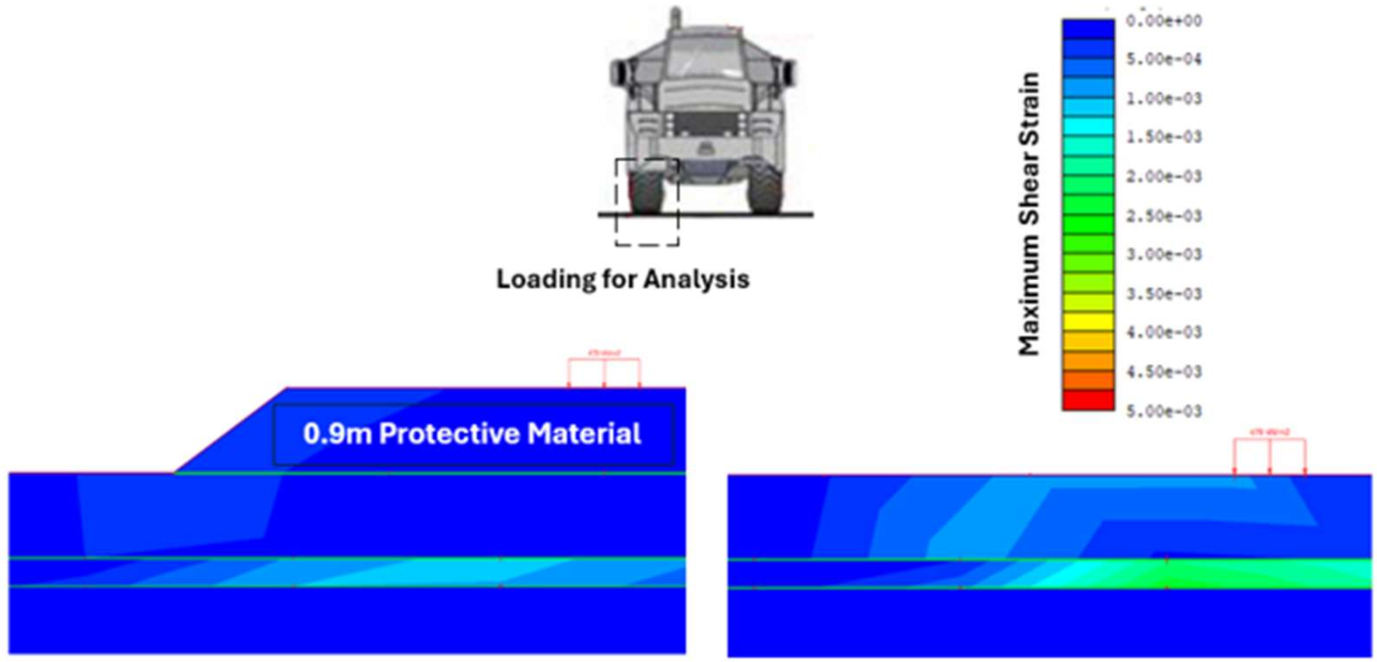
Application 2 – Loading Over the Liner System (Case 1 – Ore Stacking Direction)



- Assuming a 5% Liner Subgrade

- Difference in estimated maximum shear strains is significant
- HLF stability is a teaming effort!

Application 2 – Loading Over the Liner System (Case 2 – Overliner Placement)



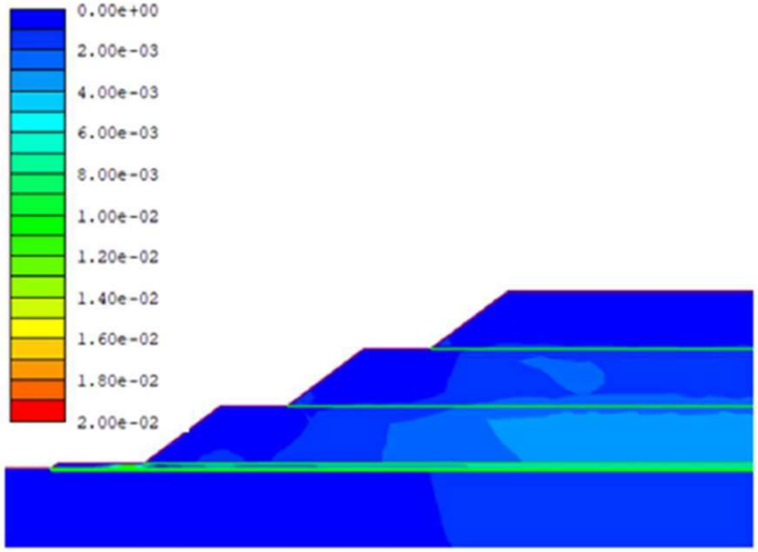
Scenario 1: with protective material

Scenario 2: without protective material

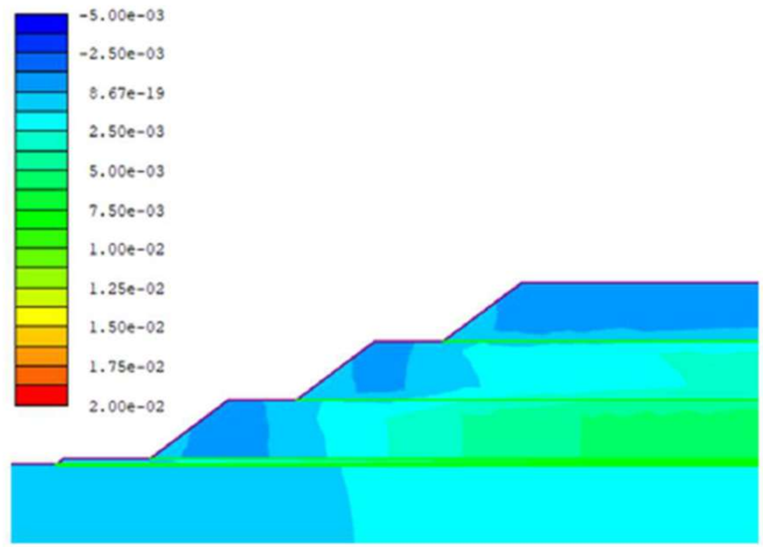
- Assuming a flat Liner Subgrade

- Difference in estimated maximum shear strains is significant
- HLF stability is a teaming effort!

Application 3 – Stacking Over Saturated Lift Surface



(a) Shear Strain



(b) Volumetric Strain

- Assuming a flat Liner Subgrade
- Evaluating strain development in ore after multi-lift stacking

- Initial shear strain development within the ore insignificant
- Volumetric strain higher than shear strain. Contraction of material may result in pore pressure development and strength reduction for certain ores (saturated or near saturated, loosely placed, rapidly loaded, fine zones…)

Application 3 – Stacking Over Saturated Lift Surface

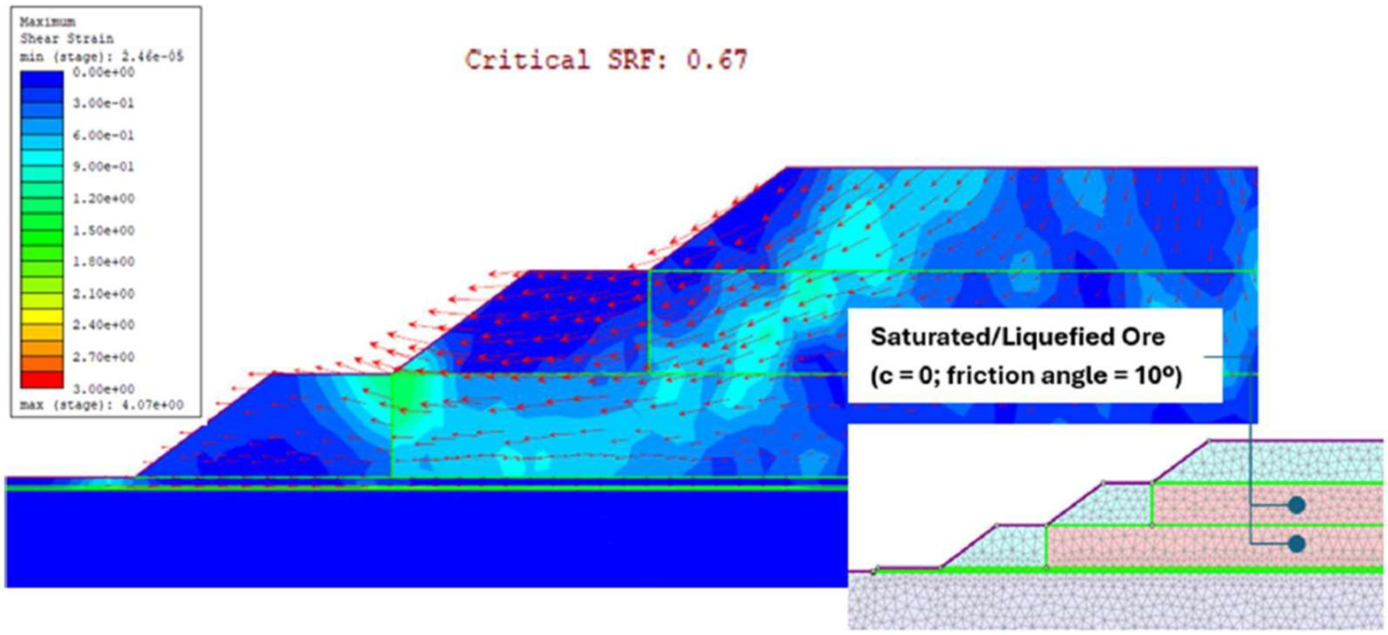


Figure 11: Shear Strain Development under Undrained and Liquefied Conditions

- Liquefaction in ores (both earthquake-induced or static) may result in progressive flow failures that happen rapidly and with little to no early warning

Conclusions and Recommendations

- This paper evaluates several cases/applications of HLF development suggesting consideration of shear strain is important under certain project settings
- The current standard practice method for slope stability (limit equilibrium analysis) is incapable of strain modeling
- Advanced analytical tools are recommended for some projects, dependent on level of project development, site condition, ore material and design
- There are many ways to reduce shear strain and “protect” the strengths of the geomaterials by optimizing designs and implementing good construction/operation practices. Minimizing and mitigating geotechnical risks in HLF design and operation is a teaming effort between the engineers, contractors and mine operators.

Questions and Comments?