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Strength reduction method applied to Hardening multi-plasticity model to numerically study flank collapses of volcanoes submitted to hydrothermal alteration

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Keywords: *Volcano; FEM; numerical simulation; flank instability; brittle-ductile transition; earthquakes*

Context

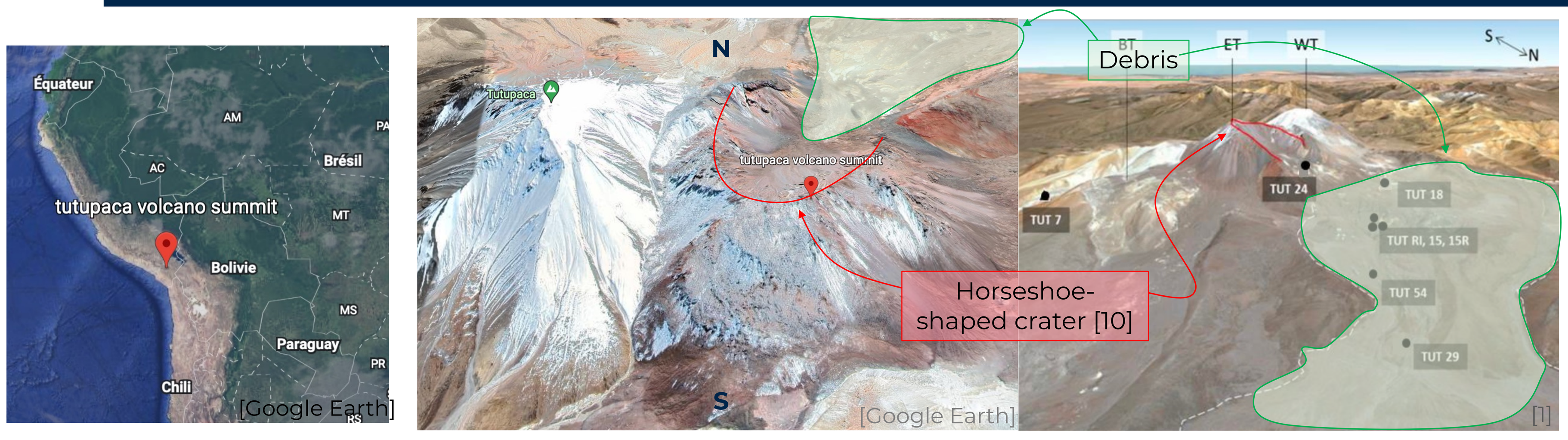


FIGURE 1 – The Tutupaca situation and the leftover of the late 18th century event.

The Tutupaca volcano, Peru, collapsed in the late 18th century, leaving a horseshoe-shaped crater. The Tutupaca site endured hydrothermal alteration in the prior decades of the event.

Hydrothermal alteration is the chemical and mineralogical changes induced by moderate to high temperature mineralizing fluids of a hydrothermal system [2]. Previous experimental investigation show that the hydrothermal alteration mainly affects the compressive cap (Fig. 3).

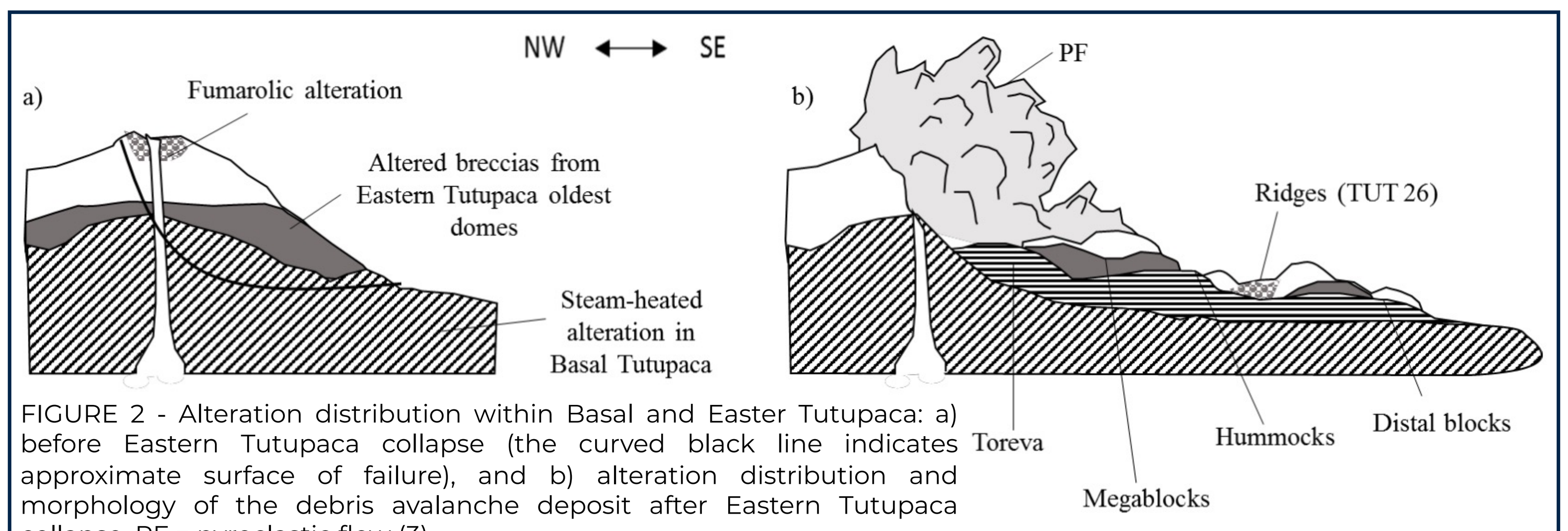


FIGURE 2 - Alteration distribution within Basal and Easter Tutupaca: a) before Eastern Tutupaca collapse (the curved black line indicates approximate surface of failure), and b) alteration distribution and morphology of the debris avalanche deposit after Eastern Tutupaca collapse. PF = pyroclastic flow (3).

To understand the evolution of Tutupaca structural stability, we implemented a FEM strength-reduction model based on prior experimental tests [soon to be submitted].

This model is decomposed into two parts: the Mohr-Coulomb criterion representing the brittle behavior (parameters: φ and c) and the compressive cap for the ductile one (parameters: p_c and M)

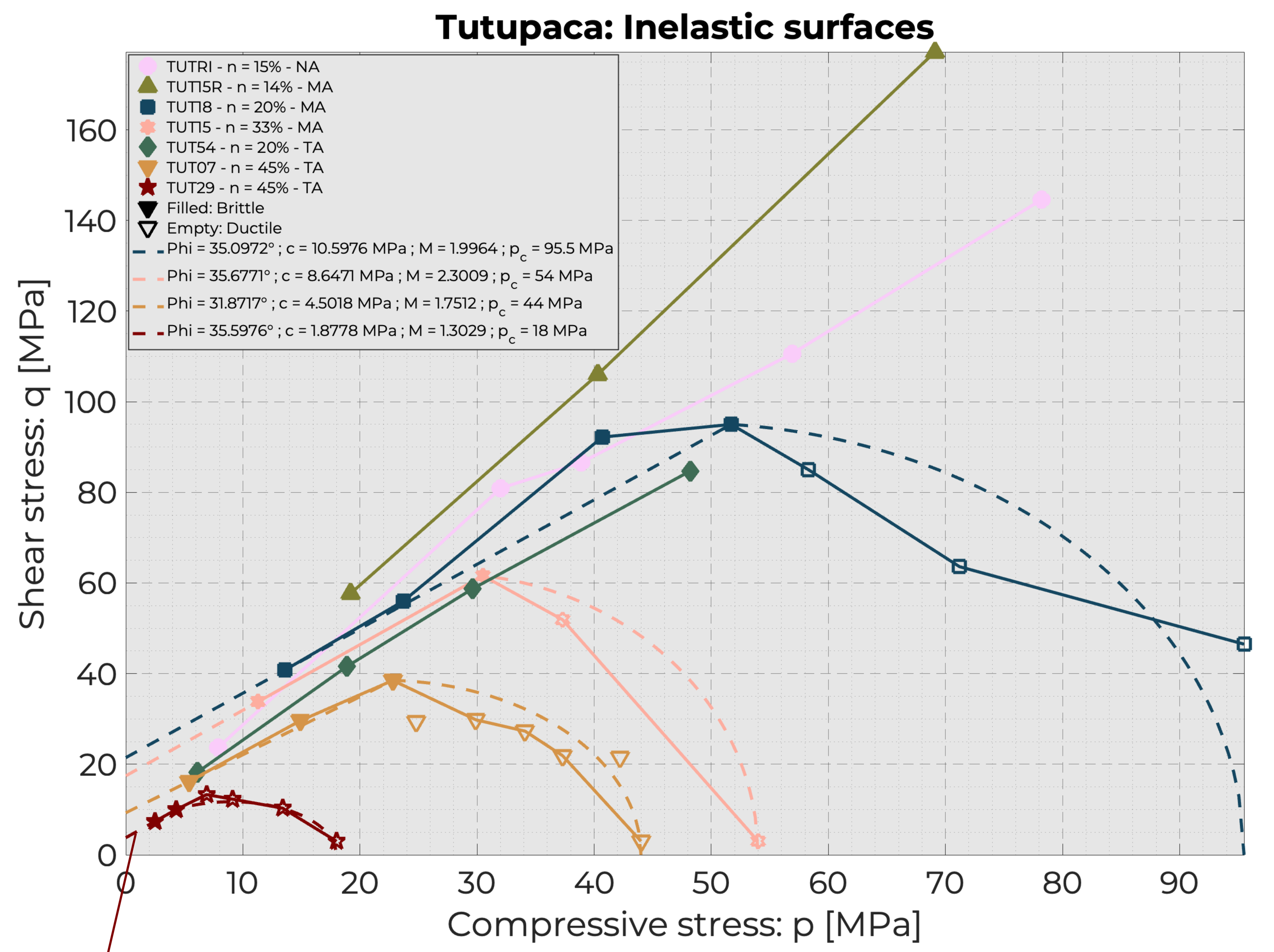
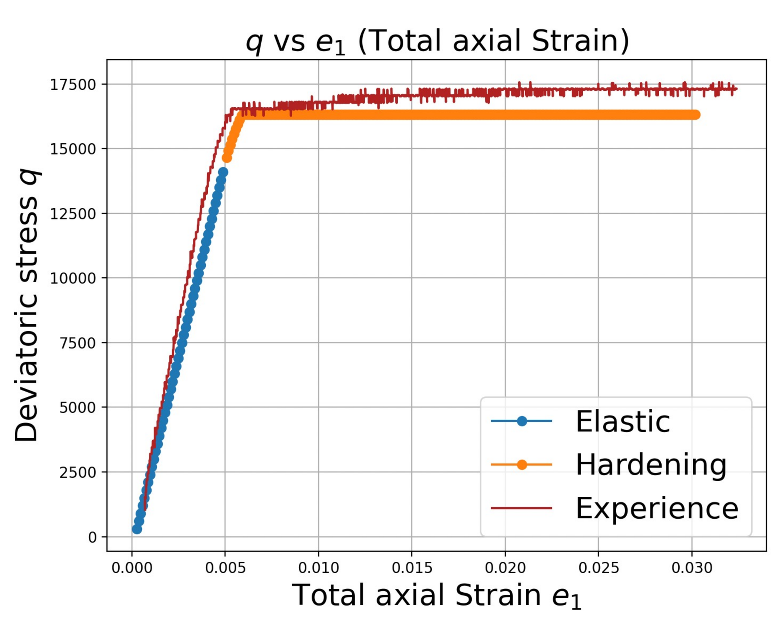
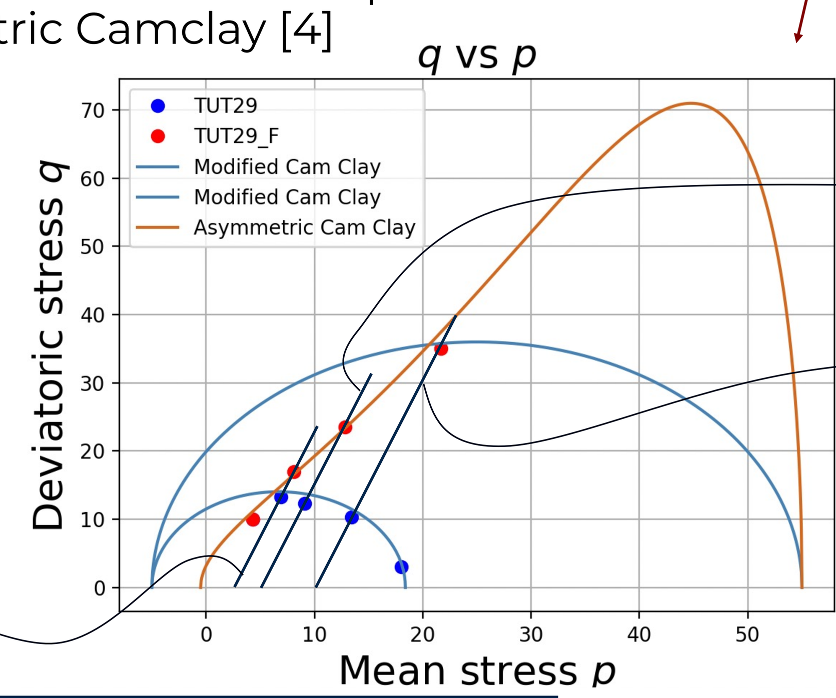


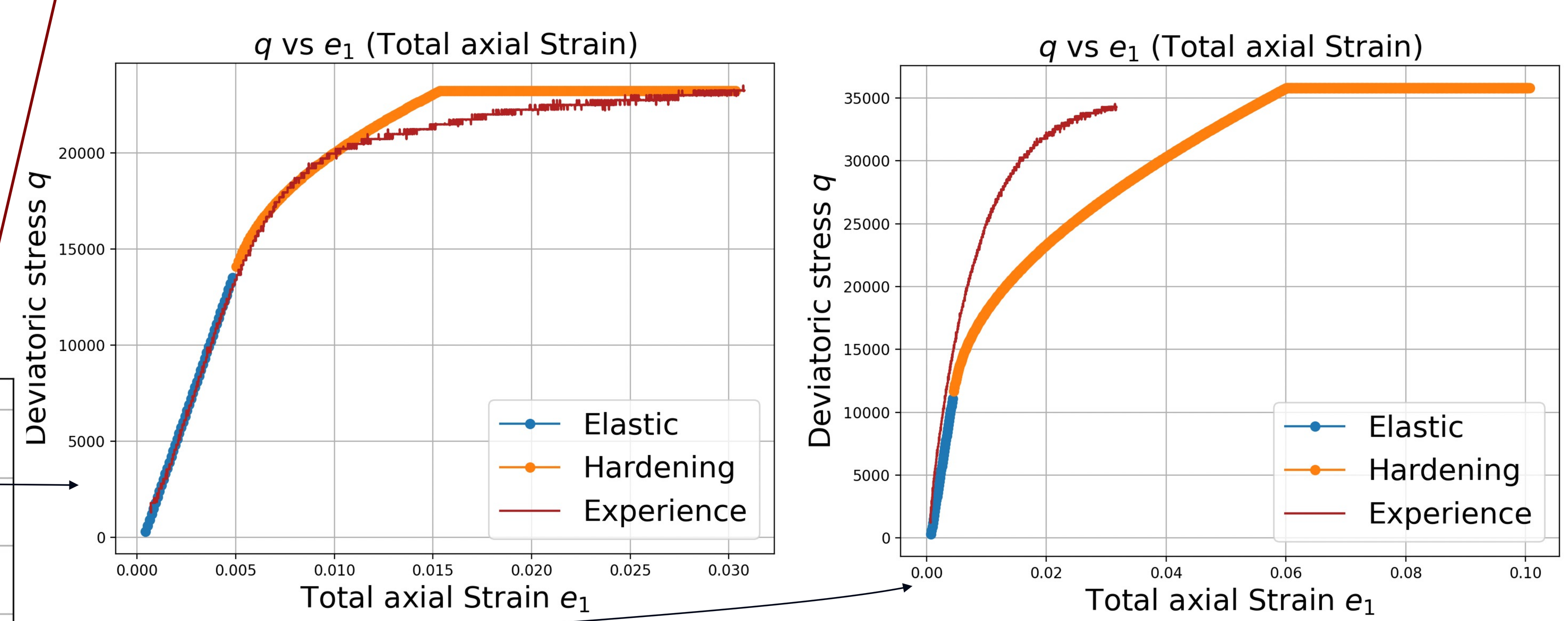
FIGURE 3 – Inelastic surfaces of Tutupaca altered volcanic rocks. The plain lines and points represent the experimental data. The dotted lines represent the extrapolated theoretical inelastic model.

Calibration (TUT29)

MOOSE ComputeMultiPlasticityStress [Material] offers the opportunity to combine several SolidMechanicsPlasticModels [UserObject] to evaluate the inelastic behavior of solid materials. Here, two custom made plastic models were implemented: Modified Camclay and Asymetric Camclay [4]







MOOSE also permits to evaluate the plastic strain-stress behavior thanks to the SolidMechanicsHardeningModels [UserObject]. A custom subclass was written to reproduce at best the behavior observed during the experiments.

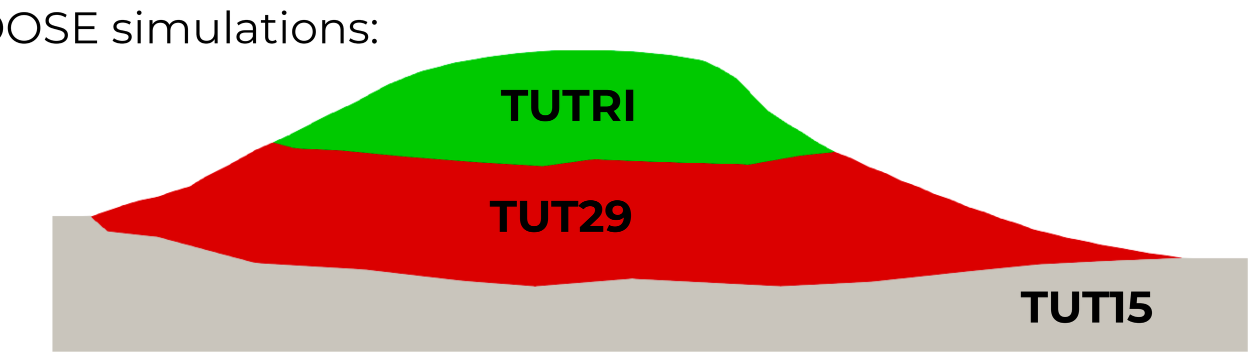
Strength reduction method

Strength reduction is a widespread numerical method assessing the stability of a geological edifice by gradually reducing its strength properties. The reduction factor provoking the instability is called the safety factor (SF).

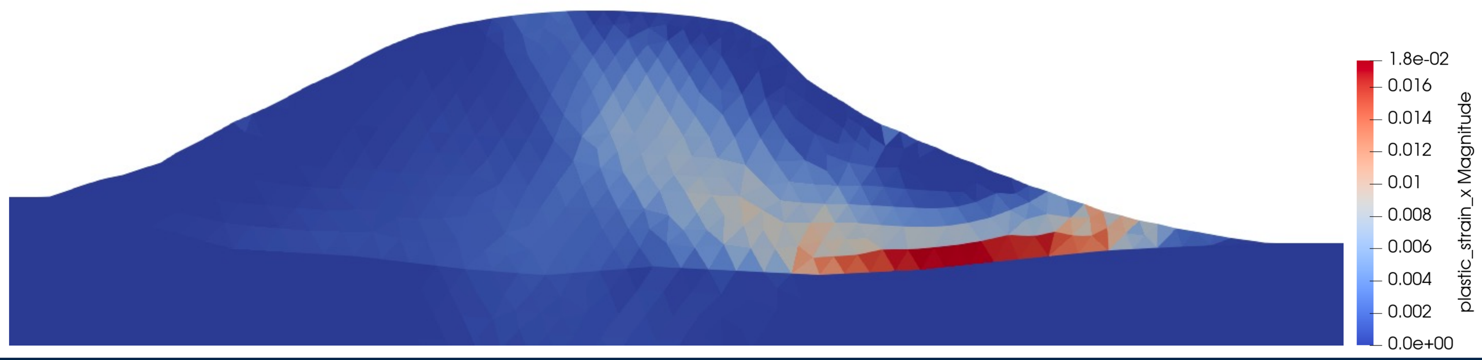
Widely different mechanisms of failure depending on the reduced strength property.

Considering an earthquake acceleration drastically reduces the safety factor.

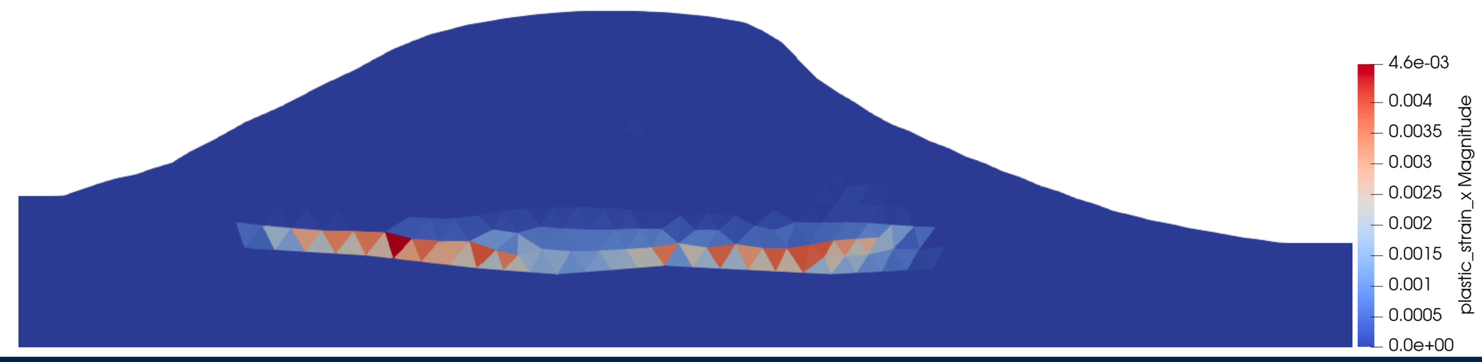
3 layers MOOSE simulations:



Reduction on the shear-strength properties ➔ **SF = 4.8**



Reduction on the compressive-strength properties ➔ **SF = 2.3**



Conclusions

- Triaxial tests on Tutupaca specimens were conducted to determine the mechanical properties of these volcanic rocks.
- MOOSE FEM plastic models reproducing a shear behavior capped in compressions were implemented.
- MOOSE FEM hardening model reproducing the evolution of the stress with the inelastic strain was implemented
- Strength reduction method was applied to the reconstructed Tutupaca's geometry, with several inelastic surfaces corresponding to the layers of rocks.
- Simple considerations of the ground acceleration (earthquake) and the water table were applied.
- **Perspectives:**
  - Better model the water table
  - Better model the earthquake ground acceleration
  - Considering an internal overpressure due to hydrothermal fluids

References:
[1] McGuire W.J. (2003). "Volcano instability and lateral collapse", *Revista*, vol. 1, 33-45
[2] Detienne M. (2016). "Unravelling the role of hydrothermal alteration in volcanic flank and sector collapses using combined mineralogical, experimental, and numerical modelling studies", PhD thesis, Université de Louvain-la-Neuve, Belgium.
[3] Samaniego P. Et al. (2015). "The historical (218±14 aBP) explosive of Tutupaca volcano (Southern Peru)", *Bull Volcanol*, 77: 51.
[4] Marcos Samudio. Modelling of an oil well cement paste from early age to hardened state: Hydration kinetic and poromechanical behaviour. Géotechnique. Université Paris-Est, 2017. English. NNT: 2017PESC1041. tel-01781441
[/] Jonathan D. Bray and Thaleia Travasarou (2009), "Pseudostatic Coefficient for Use in Simplified Seismic Slope Stability Evaluation", *J. Geotech. Geoenviron. Eng.*, 135(9): 1336-1340