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Hydrothermal alteration and earthquake promote volcanic flank collapses

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Keywords: *Volcano; Flank collapse; Hydrothermal alteration; FEM; Simulation; Strength reduction; Earthquake*

Context

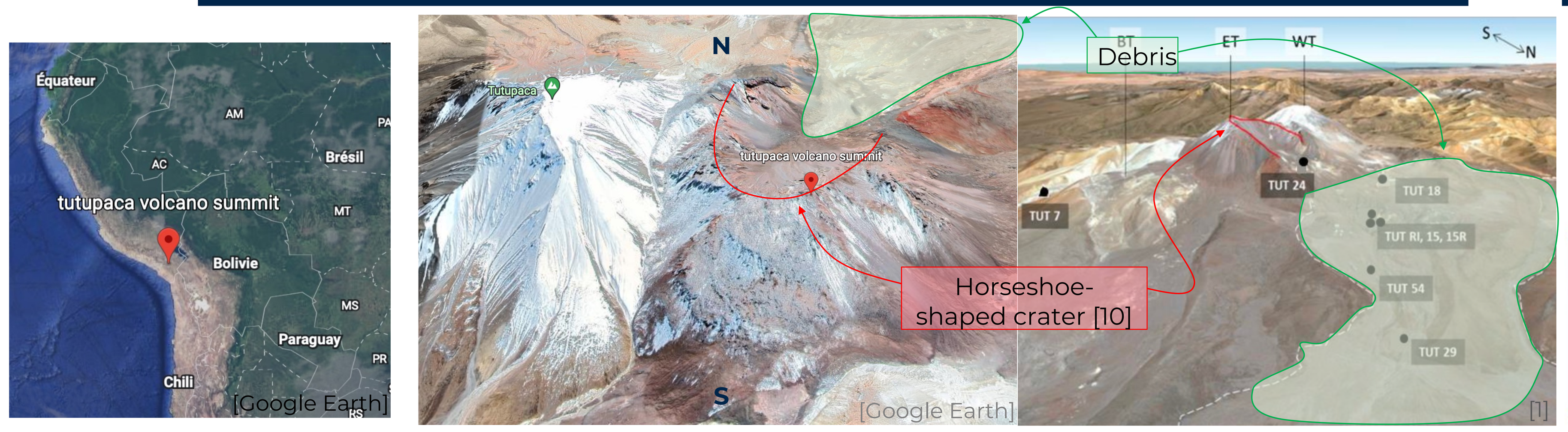


FIGURE 1 – The Tutupaca situation and the leftover of the late 18th century event.

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].

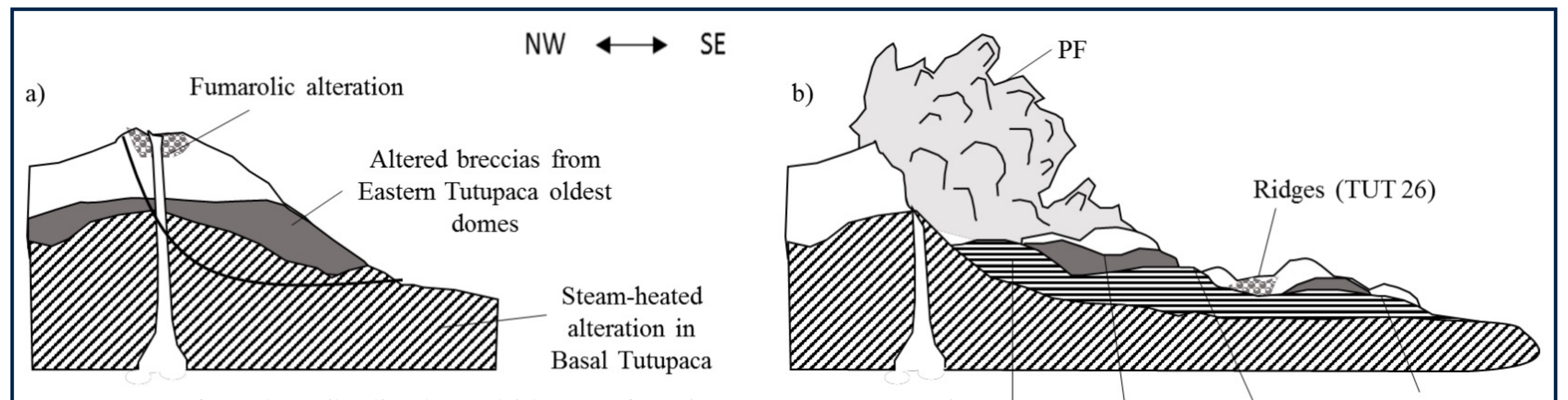


FIGURE 2 - Alteration distribution within Basal and Easter Tutupaca: a) before Eastern Tutupaca collapse (the curved black line indicates approximate surface of failure), and b) alteration distribution and morphology of the debris avalanche deposit after Eastern Tutupaca collapse. PF = pyroclastic flow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

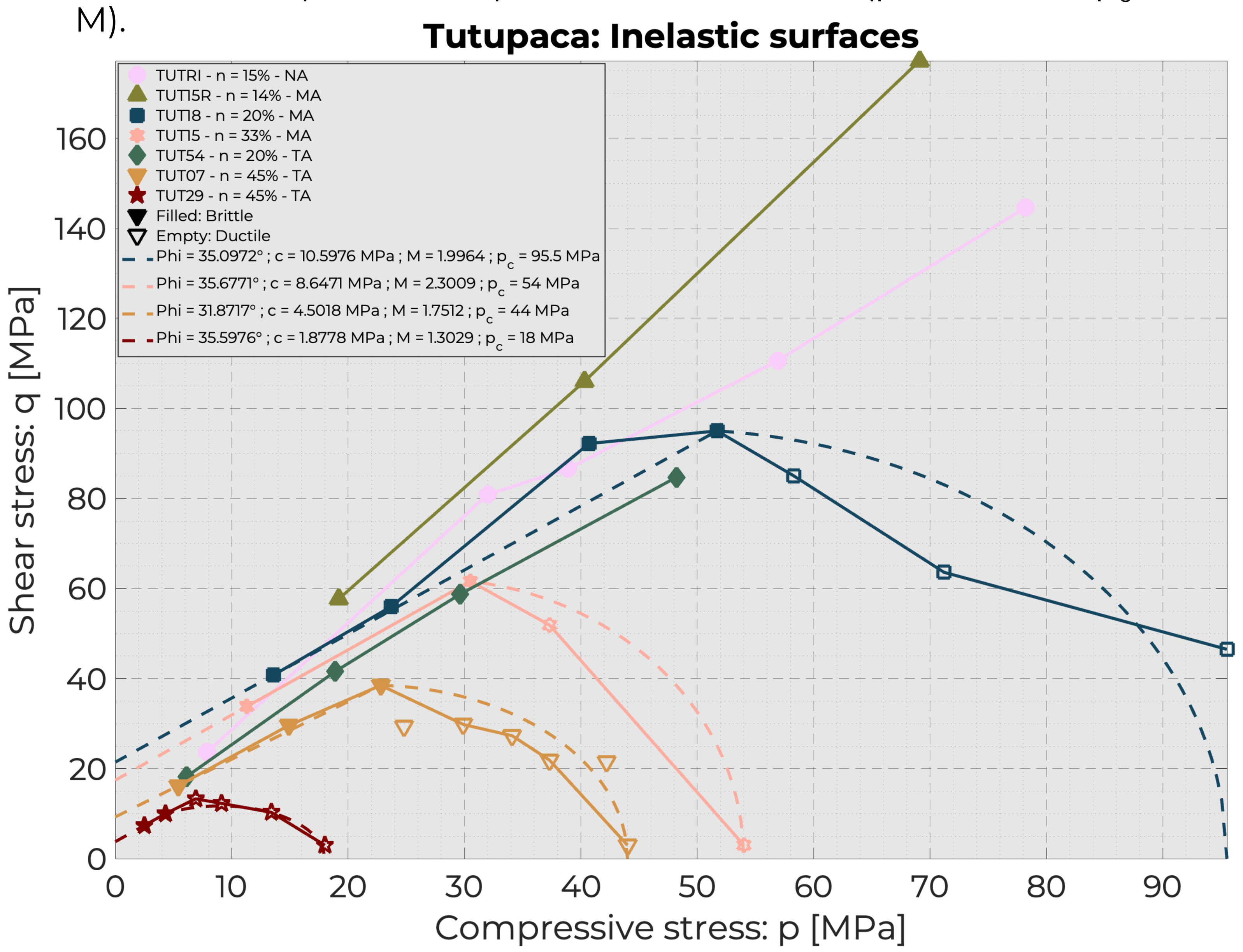
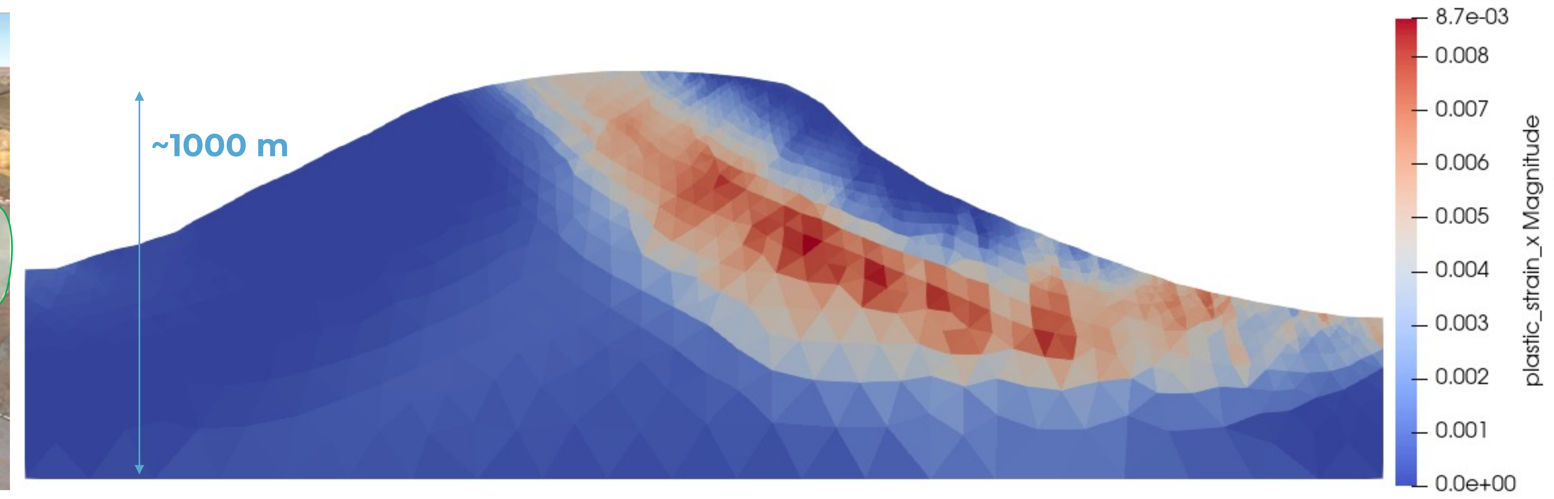


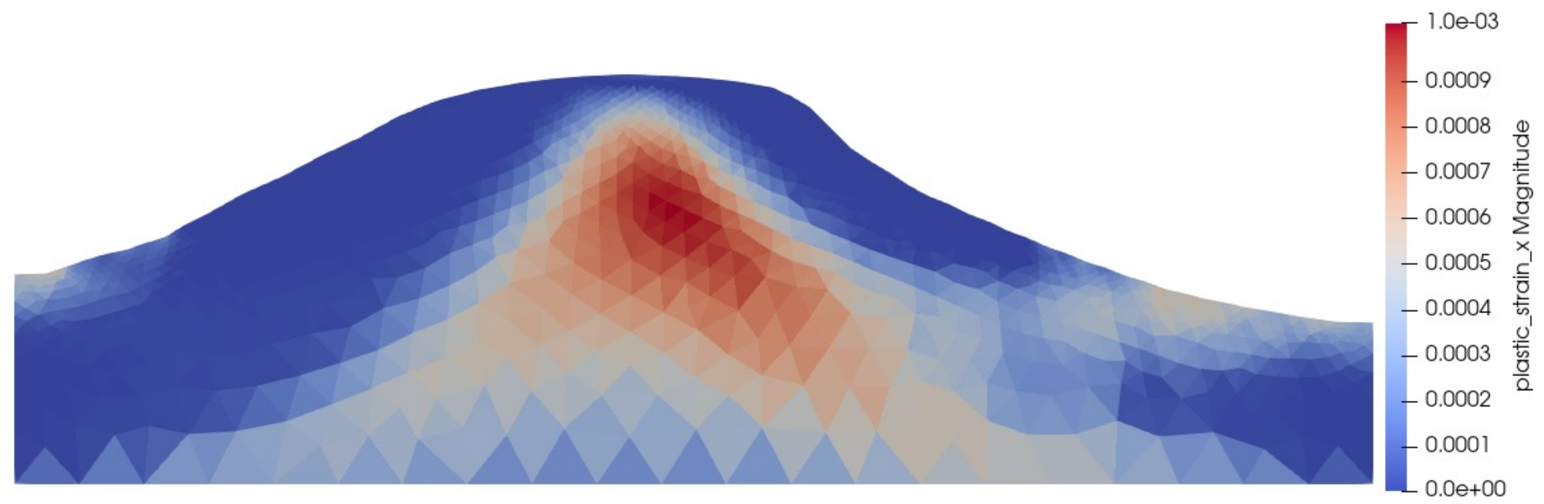
FIGURE 3 – Inelastic surfaces of Tutupaca altered volcanic rocks. The plain lines and points represent the experimental data. The dotted lines represent the inelastic model used for the FEM simulations.

Simple Mohr-Coulomb



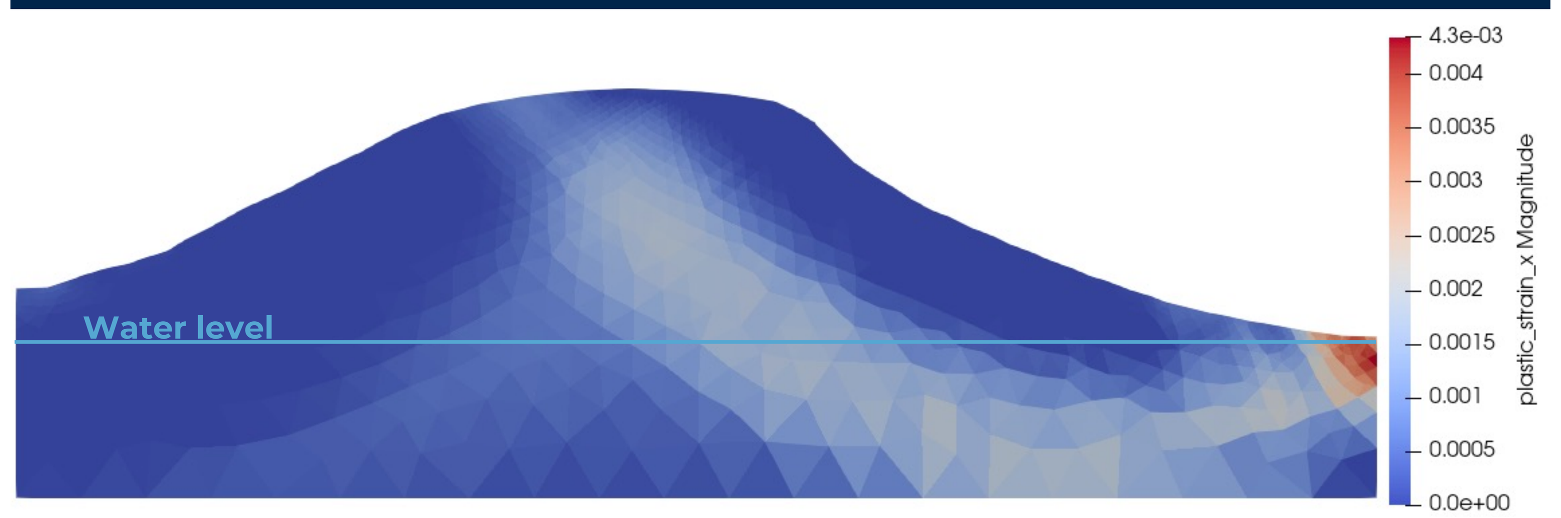
- Right slope is unstable
- Rotational shear failure
- **SF = 3.78**

Capped Mohr-Coulomb



- Right slope is unstable, but left slope is less stable
- Rotational shear failure
- Inelastic compression
- **SF = 3.5**

Capped Mohr-Coulomb, and water



- Right slope is unstable
- Rotational shear failure
- Inelastic compression
- Deeper failure mechanism
- **SF = 3.18**

References

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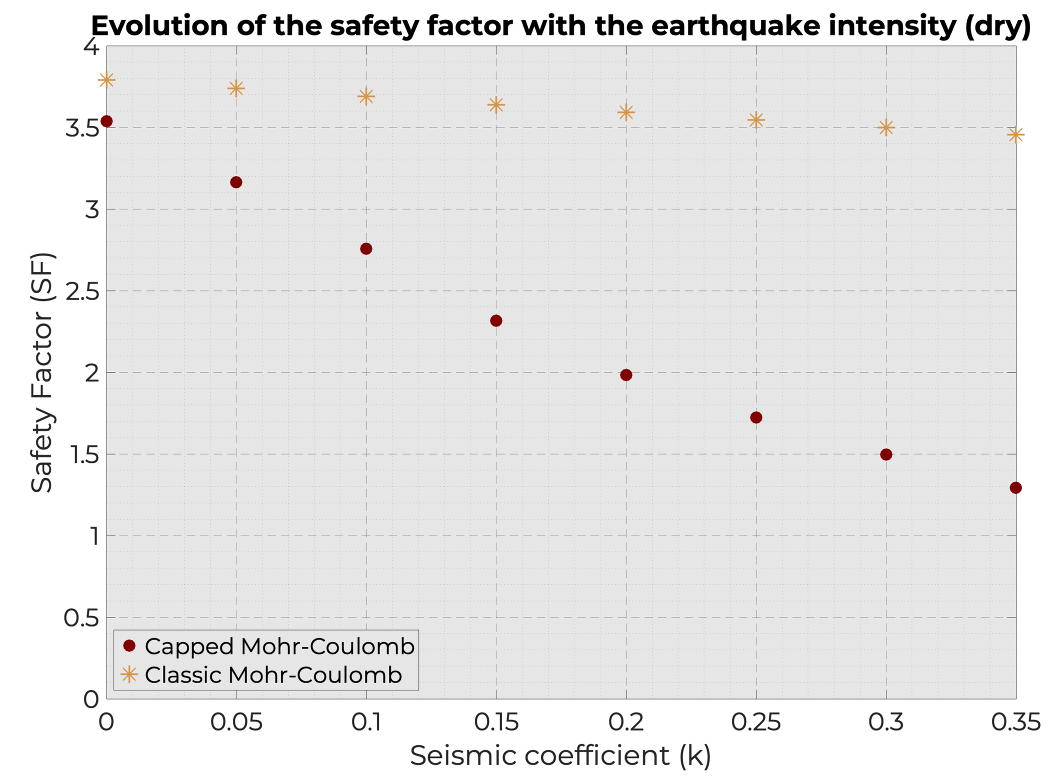
[4] Jonathan D. Bray and Thaleia Travasarou (2009), "Pseudostatic Coefficient for Use in Simplified Seismic Slope Stability Evaluation", *J. Geotech. Geoenviron. Eng.*, 135(9): 1336-1340

[5] Peru, Arequipa, Thursday, May 13, 1784, at 12:35 pm

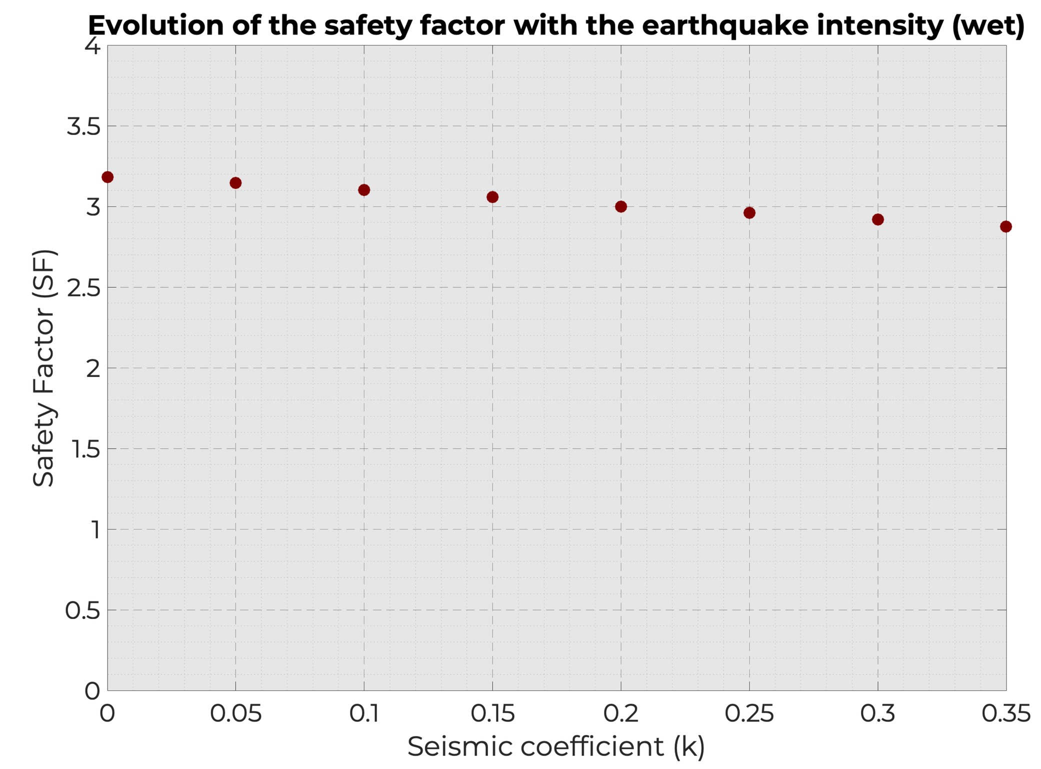
Capped Mohr-Coulomb, earthquake

- For k = 0.1, M~6, and k = 0.2, M~7.5 [4] : intensity VII
- Highest intensity recorded around 1800 is X [5]
- Reduction of SF with the augmentation of magnitude
- Logarithmic



Capped MC, water and earthquake

- For k = 0.1, M~6, and k = 0.2, M~7.5 [4] : intensity VII
- Highest intensity recorded around 1800 is X [5]
- Slight reduction of SF with the augmentation of magnitude
- Linear



Conclusion

- Triaxial testing on Tutupaca specimens was conducted to determine the mechanical properties of these volcanic rocks
- A FEM model of the Capped Mohr-Coulomb inelastic surface was implemented
- Strength reduction method was applied to the reconstructed Tutupaca's geometry, with several inelastic surfaces
- To properly simulate the 18th century flank collapse of the Tutupaca volcano, all elements must be considered: the Mohr-Coulomb model with a compressive cap, the water, and the earthquake acceleration.

- **Perspectives**
  - Considering the earthquake acceleration on the water
  - Better model the water table
  - Considering an internal overpressure due to hydrothermal fluids
  - Considering several layers instead of one