Phase field fracture modeling of hanging glacier failure

Darshan C R[1a], Gupta A[1b], Hrishikesh[1c], Annavarapu C[1a], Duddu R[1c]

[a] Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India
[b] Vanderbilt University, Nashville, Tennessee, United States of America
[c] Indian Institute of Technology Jodhpur, Jodhpur, India

1. INTRODUCTION & OBJECTIVE

Fracture-induced ice-rock failures pose a significant threat to the stability of hanging glaciers. Hanging glacier failures result in massive rock and ice avalanches and cause widespread destruction. Uttarakhand, India, is particularly vulnerable to such failures due to its geographical location. The Indian Himalayan region, including Uttarakhand, has experienced rising temperatures attributed to global warming, potentially resulting in more frequent failures in hanging glaciers. It has been hypothesized that increased ice surface temperatures not only lead to ice weakening and fracture but also to ice melting and water flow within the fractures, which can, in turn, cause fracture in the bedrock and basal sliding failure through the lubricating effects of water. However, numerical simulations are essential to establish the validity of this hypothesis. The objective of our study is to simulate the specific mechanisms of fracture-induced ice-rock failures in idealized hanging glaciers through an adaptively refined phase-field fracture model. Such a model can enable us to better understand the influence of topographical and environmental factors on the stability of hanging glaciers, ultimately contributing to the mapping of potential hazards in the Indian Himalayan region.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

We design an idealized model inspired by the hanging glacier failure observed during the 2021 disaster at Chamoli, Uttarakhand [1]. To match the actual environment, the ice-rock material properties and boundary conditions for this idealized model are specified as per the forensic details available in the literature. Damage initiation and propagation are modelled using an adaptively refined phase-field fracture model implemented in FEniCS – an open-source computing platform for solving partial differential equations [2, 3]. Several parametric studies are conducted to study the effect of topographical factors (such as ice-rock thickness, slope, and presence of weak planes) and environmental factors (such as temperature, and meltwater presence) on the initiation and growth of damage in the idealized model. Through these studies, we aim to gain fundamental insights into the causes of fracture initiation and propagation in the hanging glacier near Chamoli that preceded this catastrophic chain of events.

REFERENCES

1. D. H. Shugar, M. Jacquemart, D. Shean, and S. Bhushan., "A massive rock and ice avalanche caused the 2021 disaster at Chamoli, Indian Himalaya." *Science*, **373**, 300-306, 2021.
2. Hirshikesh, S. Natrajan, and R.K. Annabattula, "A FEniCS implementation of the phase field method for quasi-static brittle fracture". *Frontiers of Structural and Civil Engineering*, **13**, 30-396, 2019.
3. A. Gupta, U. M. Krishnan, T. K. Mandal, R. Chowdhury, and V. P. Nguyen, "An adaptive mesh refinement algorithm for phase-field fracture models: applications to brittle, cohesive, and dynamic fracture". *Computer Methods in Applied Mechanics and Engineering*, **399**, 115347, 2022.