Submarine Slope Failure Dynamics in Sand-Rich Systems: Insights from Physical Experiments and Numerical Models

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Abstract

Submarine slope failures and the tsunamis they generate pose risks to coastal communities and infrastructure. While slope failures on passive margins represent some of the largest mass failures on Earth, little is known about their dynamics. The recurrence interval of submarine slope failures on passive margins is longer than on active margins, which facilitates thick sediment accumulation before failure, yields larger failures, and may be associated with higher potential for tsunami generation. While numerous studies model failure likelihood based on temporal distribution, overpressure, or earthquake proximity, there is limited insight linking initial conditions, preconditioning, slope failure initiation, and failure evolution. We observed dynamic submarine slope failure processes via physical experiments in a benchtop flume. Submarine slope failures were induced under controlled pore pressure with varied sand-clay mixtures (0%, 2%, 4%, and 5%, clay, by weight) constrained to a constant pre-failure slope geometry. Commercially obtained fine-grained sand (subangular quartz; 87% SiO_2; D_{50} = 195 µm) and clay (dioctahedral smectite; 63% SiO_2 and 21% Al_2O_3; D_{90} = 44 µm) were used. Pore pressure required to induce slope failure, slope-failure initiation and evolution, and post-failure morphology were recorded and analysed via photogrammetry. Numerical models were developed to quantify the physical processes observed in flume experiments. Increased clay content corresponded to increased cohesion and pore pressure required for failure. Subsurface fractures and tensile cracks were only generated in experiments containing clay. Falling head tests showed a log-linear relation between hydraulic conductivity and clay content which we used in our numerical models. Models of our experiments effectively simulate overpressure (pressure in excess of hydrostatic) and failure potential for (non)cohesive sediment mixtures. Overall our work shows the importance of clay in reducing permeability and increasing cohesion to create different failure modes due to overpressure. Ongoing work is investigating the effects of higher clay content and the role of seismic energy in slope failure morphology.

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