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How do sediments cohesion and peak strength, control failure initiation and timing of slope destabilization? A 3D Discrete Element study

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Mass wasting deposits, resulting from various submarine slope failure events are observed worldwide. Numerous studies revealed that sediment physical properties play a key role in influencing the size and kinematics of submarine gravitational mass movements. It is widely accepted that sediment strength, particularly cohesion and the coefficient of friction of the slope sediments, control the location and dimensions of failure and the temporal evolution of slid masses. However, direct observations of the initial location, size and the temporal evolution of the buried failure plane, are almost impossible to achieve. Numerical simulations can augment observations of the initial location and size of the failures in elucidating the failure process itself and assessing future slide events.
We conducted 3D numerical simulations to gain a better understanding of slope failure processes and subsequent slide events, while testing different sediment types. This work's major aim is to develop a conceptual model, which sheds light on the interplay between sediment physical properties and the location, as well as dimensions of submarine landslides. Therefore, we analysed the location, size and volume of the initially failed masses as a function of different slope sediment's strength.
Using the Discrete Element Method, we simulated simplified 3D numerical sediment-bearing slopes. In each simulation, an undeformed stable slope was created. Evaluation of failure initiation in slopes was investigated under progressive oversteepening conditions. Using the particle's displacement, we evaluated the slope deformation formed and consequently the initiation of slope failure. Two endmembers of slope "sediments" were designed to represent low cohesive sediments (sandy) and high cohesive sediments (muddy). For each endmember, we simulated three materials: high, medium and low peak strength via particles' contacts and bonds.
With increasing slope angle, both in sandy and muddy slopes, failure occurred. All experiments showed that once each slope reaches the critical factor of safety, small, localized failures were initiated in different slope segments. As soon as the steepest slope angles were reached, massive slope failure occurred in both sedimentary systems. However, these massive failure events were observed along the entire slope (upper and lower slope segments), resulting in widespread slope collapse only in the case of sandy-low peak strength slope. Contrastingly, massive failure initiation was observed along the muddy slope with high peak strength. This, however, was focussed on the upper slope section.
Our results imply that in environments where low cohesive sediments are being deposited with little consolidation or compaction, massive and widespread slope failure may initiate in the form of seafloor sediment flow. This confirms field observations, e.g. Monterey Canyon and the Nile deep fan system, which are characterized by high sand contents.
In environments where high cohesive sediments are deposited, usually smaller failure would be assumed. However, our model also suggests that with increasing strength, even in cohesive slopes, large failure can occur which correlates with field observations from the 44-North Slide and The Traenadjupet Slide where large and blocky failure occurred.
These numerical observations provide a link between sediment's strength – particularly cohesion behaviour, and characteristics of initiated failure along different slopes.