Rheology, wave patterns and energy dissipation in a shear zone undergoing flash heating in earthquake-like discrete element models

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Résumé

This research presents a comprehensive discrete element modeling study of granular shear zone behavior during seismic rupture, investigating the coupled effects of rheological evolution, wave dynamics, and energy dissipation mechanisms. Using a semi-periodic numerical system with cohesive micrometric disks confined between rigid walls, we simulate millimeter-scale fault segments to understand the fundamental physics governing earthquake rupture processes.
Our discrete element model consists of a 2 mm × 1.5 mm sample of micrometric cohesive disks traversed by a pre-existing fracture and subjected to realistic confining pressures (112.5 MPa) and seismic slip velocities (1 m/s). The elasto-brittle contact law is calibrated to reproduce peak and residual strength envelopes from rock mechanics tests.

The rheological analysis reveals three distinct phases of shear zone evolution. Phase 1 involves rupture initiation with shear instability propagation, where friction and dilatancy form asymmetric peak functions controlled by confining pressure. Phase 2 exhibits intermediate behavior approaching steady state under quasi-static conditions despite high shear rates, with friction and dilatancy remaining roughly constant. Phase 3 involves flash heating-induced shear weakening, with friction dropping to approximately 0.1 through sigmoidal decay curves.

The wave dynamics component reveals that dynamic rupture generates two primary phenomena: resonant oscillations of fault blocks resembling normal modes, and propagating guided elastic waves within the granular shear zone. These create complex interactions between harmonic motion and shear-induced vibrations, producing out-of-phase dilatancy and normal stress waveforms whose periods lengthen as shear zones thicken and elastic properties degrade.

A critical discovery is the identification of vibrational shear events (VSEs) that correlate with friction drops, triggered by guided wave interactions with stress fields. These VSEs exhibit quasi-periodic behavior influenced by adjacent rock mass properties, demonstrating that dynamic shearing is fundamentally an oscillatory process modulated by frictional strength fluctuations.

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*Intervenant

Energy analysis reveals that breakdown energy differs fundamentally from conventional fracture energy concepts in seismology. Dilatancy emerges as the primary energy sink in damage zones, while decohesion and debonding processes dominate gouge formation. Breakdown energy exhibits long-period damped oscillations and scales with confining pressure, representing only a fraction of total fracture energy that nearly triples when pressure doubles.

Mots-Clés: Earthquake dynamics, Rheology and friction of fault zones, Shear zone, Flash heating, Guided waves, Granular mechanics