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The coupling between compaction and pressurization in cyclically sheared drained granular layers: implications for soil liquefaction

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The dynamics of saturated granular layers during shaking is controlled by the coupling between grains and fluid. Understanding such systems is crucial for studies of soil liquefaction, seismically induced landslides and shear along faults. This study focuses on the compaction of a near surface well-drained saturated granular layer during seismic shaking. Compaction is known to promote soil liquefaction, but the exact feedback mechanism between compaction and pressurization remains poorly understood. We use Discrete Element numerical simulations composed of coupled solid grains and fluid phases under cyclic horizontal shear of the bottom undrained boundary and a free, completely drained, top layer. We compare the dynamics under two drainage conditions: First, simulations of "infinite" drainage, where the fluid pressure is maintained hydrostatic during the shaking. Second, simulations of "realistic" drainage in a high permeability layer, whereby fluid pressure dynamically deviates from hydrostatic values due to local granular compaction and dilatation. Simulation results show two end member behaviors, with a transition controlled by the magnitude of shaking acceleration: At low acceleration the system behaves rigidly, compaction is negligible and fluid pressure remains constant even during "realistic" drainage simulations, where it is allowed to evolve. At high acceleration, significant compaction occurs in both cases, but the compaction rate is higher in "realistic" drainage simulations. This rapid compaction trend is temporally correlated to a transient pore pressure increase that reaches lithostatic stress values before it drops back to a lower value. This is an evidence to a feedback mechanism in which compaction causes pressure increase that can persist under drained condition as long as the compaction rate is sufficiently high. On the other hand, this very pressure itself promotes the high compaction rate. From this we conclude that although well-drained soils are considered liquefaction-resistant, dynamic coupling between pore fluid pressure elevation and compaction during seismic shaking provides a previously unrecognized pathway to liquefaction.