The art of sinking: influence of water on seismic liquefaction and quicksand dynamics

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During earthquakes, certain soils may loose their ability to support shear and liquefy. This effect can cause buildings and man-made constructions to sink into the soil. As a first step we aim to understand the behaviour of an object sinking into liquefied granular media: can we predict the velocity of sinking and the final depth of intrusion if it exists?

We study this using sinking of geometrically simple objects in shaken, well controlled, granular media. We study what mechanical parameters (for the medium, shaking and intruder) control the response and govern the intrusion of the objects and liquefaction of the granular medium.

We run numerical simulations and laboratory experiments to study the behaviour of a model system, namely the mechanics of an intruder (sphere) initially placed bove a shaken model soil, modelled as (saturated or dry) granular medium, shaken by horizontal movements at a controlled frequency. The simulations are done with frictional elastic granular dynamics models (models similar to those used to describe fault dynamics, as [Goren et al 2010, 2011], but taking into account buoyancy in parts of the system, and neglecting fluid viscous drag). The experiments are monitored using optical data and accelerometers.

Simulations and experiments show that the sphere displays three different ways to enter the granular medium:
(1) slow liquefaction, (2) fast liquefaction, (3) convection. The peak ground acceleration (PGA) is the decisive parameter. The final depth of intrusion depends on isostasy, and on the severity of shaking. It can be entirely determined by isostasy, when the shaking entirely unjams the edium and suppresses the average friction around the intruder. For moderate shaking, the liquefaction is absent, or partial, and the sinking is subisostatic. The initial penetration velocity of the sphere is often sufficient to determine which of the three behaviours takes place in the experiment. We show that the macroscopic response of the medium, once classified in the right regime, can be collapsed on a master curve, with a reduced depth as function of reduced time. The non-dimensionalisation is done using an immersed volume determined by isostasy, and a time determined by the imposed frequency.

Next, we study systematically the effect of the presence of water, of the horizontal peak ground acceleration (PGA) imposed, of the medium particles density, of the intruder size and density, and eventually of the intruder shape.

Both numerical and physical experiments show that the water and the PGA are the most important influencing parameters. We show that the liquefaction effect is maximal when the water table reaches the surface of the granular medium and when the PGA allows the small particles to slide on each other but is not strong enough to allow the intruder object to slide on small particles.

As a second step we study the response of the granular medium, how it evolves during liquefaction. With numerical simulations we study the velocity field and find a phase difference between the intruder velocity and the surrounding medium. In complementary laboratory experiments we compare the accelerometric signals between one accelerometer fixed on the moving box and one accelerometer inside the sphere. We find again a phase difference which may explain how the object penetrates into the granular medium. From the velocity field computed during numerical simulations, we also compute an excitation parameter which gives us comprehension on the strain along the vertical axis.

References :
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