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Liquefaction under drained condition, from the lab to reality ?

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Liquefaction constitutes a significant natural hazard in relation to earthquakes and landslides. This effect can cause buildings to tilt or sink into the soil, mud-volcanoes, floatation of buried objects, long-runout landslides, etc. In this work we present a new understanding regarding the mechanism by which buildings sink and tilt during liquefaction caused by earthquakes. Conventional understanding of liquefaction explains most observed cases as occurring in an undrained, under-compacted, layer of sandy soil saturated with water [1]: According to that understanding, the under compacted sandy layer has the tendency to compact when a load is applied. In our case the load comes from ground shaking during an earthquake. When the soil compacts, the fluid pore pressure rises. Because in undrained conditions the fluid cannot flow out, the pore pressure builds up. The weight of buildings is in this case transferred from the grains of the soil to the pore water. The soil loses its rigidity and it flows like a liquid. From this model scientists made theoretical and empirical laws for geotechnical use and buildings construction.

Despite the success of this conventional model in many cases, liquefied soils were also observed under drained conditions, and in previously compacted soils, which doesn't agree with the assumption of the model quoted above. One of the famous liquefaction events is the Kobe port destruction during the 1995 earthquake. A simple calculation of the Deborah number following Goren et al ([2][3]) shows that the undrained constraint was not met below the Kobe port during the 1995 earthquake.

We propose another model, of liquefaction in drained granular media. According to our model the mere presence of water in granular media is enough to cause liquefaction during an earthquake, provided that the water reaches close to the surface. Our computations are based on the buoyancy force, and we take into account the static fluid pressure only. For small horizontal shaking our model predicts that the soil remains rigid. Under stronger accelerations, some of the particles, which constitute the medium, slide past each other, and the medium slowly rearranges. Yet, in this regime of shaking, the shaking is insufficient to cause the building to slide. The building sinks simply due to hydrostatic considerations, and since it is a static object in a dynamically rearranging medium. This is the case we call liquefaction. Eventually, for even stronger accelerations, both the particles and the building can slide and we predict convective movement.

To test this model we run numerical simulations (granular dynamics DEM algorithm) and laboratory experiments. The numerical experiments do not include pore pressure, and only simulate buoyancy effects of water. The controlling parameters are the amplitude and frequency of the shaking, and the water level. With a saturated medium, experiments and simulations display three different behaviors: rigid, liquefaction, and convection, in agreement with our theoretical model. The peak ground acceleration (PGA) is the decisive parameter. It is important to note that for dry media and for a case when the building is fully submerged underwater, both in experiments and in simulations, the liquefaction effect disappears. Based on our work we suggest that elevated pore pressure conditions are not necessary for inducing liquefaction, and that liquefaction can occur under well drained and highly compacted soils, in situations previously considered to be safe from liquefaction.

Références

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