Liquefaction experiments with a low permeability upper layer : dependence on layer thicknesses

*Moe Mizuno[1], Ikuro Sumita[1]

1.Graduate school of Natural Science and Technology, Kanazawa University

When a water-immersed granular layer is shaken strongly enough by an earthquake, liquefaction occurs. If this layer consists of a low permeability upper layer, flame structures form and sand boils are observed. Previous liquefaction experiments have shown that when such layers are shaken the number and the area of sand boils decrease as the ratio of the thicknesses of the upper to lower layer increases (Yamaguchi et al. 2008). However no physical interpretation of these results have been made, and the effect of each layer thickness has not been clarified. Here we conduct a series of experiments with a range of combinations of the two layer thicknesses to quantitatively study how liquefaction and related phenomena depend on the thickness of each layers.
We use a small case filled with a mixture of glass beads and water. The glass beads are size graded such that the upper layers consist of fine particles with a diameter of 0.05 mm and the lower layer consists of coarse particles with a diameter of 0.22 mm. As a result the upper layer is 32 times less permeable compared to the lower layer. We vary the thicknesses of each layer in the range of 0 to 40 mm. The cell is shaken vertically for 5 s at an acceleration of 30 m/s^2 and a frequency of 100 Hz. We use a high-speed camera and record the images which are then analyzed in detail.
From a series of experiments we recognize three phenomena, the compaction of the whole layer, formation of the flame structure, and eruption of water and glass beads. These phenomena are the consequence of gravitational (Rayleigh-Taylor) instability at the two-layer boundary (Yasuda & Sumita, 2014, 2016). Compaction occurred in all experiments whereas the formation of the flame structure or eruption water and glass beads occurred only when the upper layer is sufficiently thin. We studied the upper layer thickness dependence in detail for the case in which the lower layer thickness is in the range of 22-26 mm. We find that the wavelength of flame structure increases and the growth rate decreases as the upper layer becomes thicker. It appears that there is an upper limit wavelength. We also find that the peak amplitude becomes largest when the upper layer is at an intermediate thickness. We classified the results of all experiments using the values of the growth rate of the instability. We find that when the lower layer is thin, the growth rate depends on both the upper and lower layer thickness. However when the lower layer becomes thicker it depends on mainly on the upper layer thickness.
Our experimental results can be understood as follows. From Coulomb's law of friction, the interparticle friction increases with depth z as $\sigma=\mu\Delta\rho\Phi gz$···(1), where $\mu$is the coefficient of friction, $\Delta\rho$is the particle-water density difference, $\Phi$is the packing fraction, g is the gravitational acceleration. As a result, we estimate that when the z is greater than a critical, friction exceeds inertia, and fluidization does not occur at the two-layer boundary. Linear stability analyses for viscous fluids (Whitehead & Luther, 1975) indicate that the wavelength$\lambda$and growth rate p of the instability can be expressed as $\lambda\propto\varepsilon^{13}h$···(2),$p\propto\varepsilon^{-23}h$···(3), where $\varepsilon$is the upper to lower layer viscosity ratio and h is the thickness of the fluidized layer beneath the two-layer boundary. It follows that our result can be interpreted as a consequence of increasing $\varepsilon$with the thickness of the upper layer. Substituting the measured$\lambda$and p into Eq.(2),(3), we estimate that ε increased from 3 to 495 as the upper layer become thicker. This result is consistent with the increase of friction at the 2-layer boundary according to the Eq.(1). We consider that our results of upper layer thickness dependence can be interpreted as a result of the increase of effective viscosity of the upper layer.

Keywords: Liquefaction, earthquakes, low-permeability layer, gravitational instability, thickness dependence

