# A FLOW-PARTICLE INTERACTION MODEL FOR THE ONSET OF QUICKSAND

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*Quicksand* refers to the condition when a saturated solid particle bed loses its strength under upward pressure gradient which phenomenon is responsible for many indrastrcture damages. The quicksand onset mechanism and transient development has been an open question in the literature and we address this problem via numerical simulation with coupled Discrete Element and Lattice-Boltzmann (DEM-LBM) method and the interaction between the two phases was computed by the Immersed boundary method (IBM).

In a box of incompressible Newtonian liquid, 3,000 mono-sized solid spheres were randomly packed to 2/3 box height (Fig.1(a)). Constant pressure are prescribed on the box top and bottom surfaces to create an upward hydraulic gradient, $I$, of various strengths. Sectional effective stress at different heights, $\tau(y)$, was computed as a Virial stress from particle interaction and the steady-state depth profile is examined in Fig.1(b). When $I$=0, spheres are in equilibrium contact and linear $\tau(y)$ was obtained; with increasing $I$, seepage force along $I$ degraded the contact strength and $\tau(y)$ decreases from the linear profile. At critical $I_c$, particles are fluidized and nearly zero $\tau(y)$ was measured and a few instantaneous profiles are shown in Fig.1(c). Solid-volume fraction $\varphi(t,x,y)$ was calculated across the section and the location with $\varphi<0.05$ are presented in Fig.1(d). Temporal degradation of $\tau(t,y)$ is observed to take place from the base and low $\varphi$ zones developed concurrently slightly below where $\tau(t,y)$ degraded to nearly zero. Swirling particle motion was observed in these low $\varphi$ zones (see Fig.2(a)) sugesting local concentration of fluid vorticity.

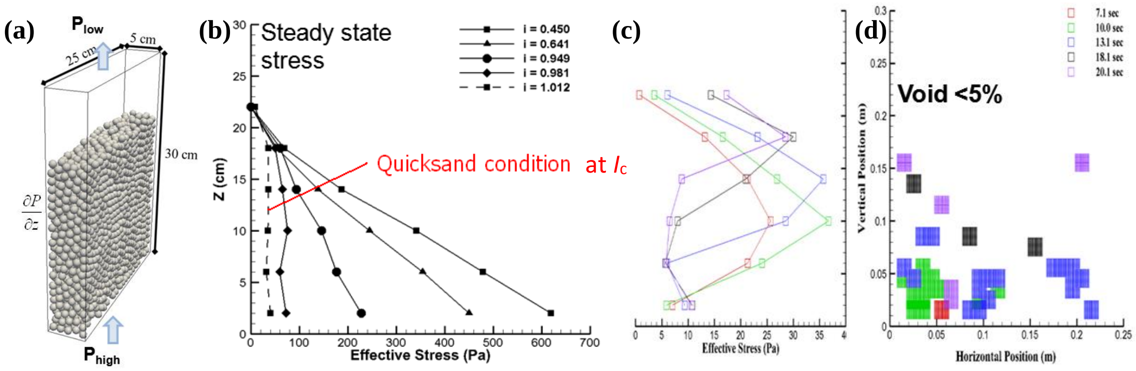


**Fig.1** (a) Schematic diagram of the problem; (b) depth profile of steady bulk effective stress $\tau(y)$ under different $I$; (c) temporal evolution of $\tau(t,y)$ and low-$\varphi$ regime under $I_c$ at t=7.1, 10.0, 13.1, 18.1 and 20.1s.

Sinec the dense particle bed rose vertically in bulk with seepage force, how these low φ regimes and particle swirling motions developed and moved in space and time is of great interest. Local particle trajectory and flow was examined carefully to reveal a possible mechanism as the following four steps: (1) seepage force under $I_c$ elevated particles to give upward $\overrightarrow{u_p}$ and modified packing configuration to create zones of lower φ; (2) excessive creeping fluid accumulated and turned in these zones to develop local vorticity and velocity field, $\vec{\omega}$ and $\overrightarrow{u_f}$; (3) vortical flow interacted with the surrounding particles to impart a lateral force, $F_x = \vec{F} \cdot \overrightarrow{e_x}$ with $\vec{F} \sim \rho C_L(\overrightarrow{u_p} - \overrightarrow{u_f}) \times \vec{\omega}$ , in analogy to *Saffman lift force*, to render particle lateral migration as shown in Fig.2(b); (4) local packing configuration was destroyed to create a passage for the interstitial liquid (as sketched the cartoon in Fig.2(c)) to create another cycle at an elevated height.

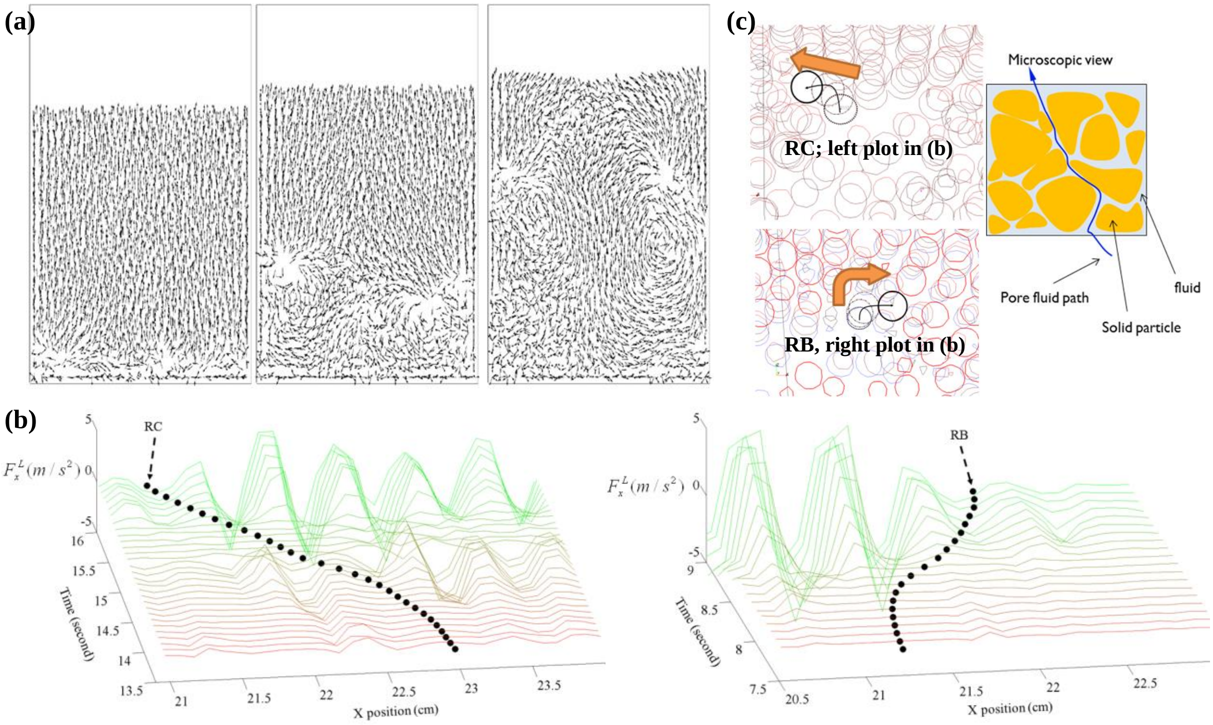


**Fig.2** (a) Sphere velocity vector at t=7.1, 13.1, and 20.1s; (b) spatial distribution and temporal evolution of $F_x$ for two selected spheres that exhibited lateral migration at different time and low-φ regimes; (c) particle migration trajectory and surrounding particle configuration and illustration of the fluid passage through these low low-φ regimes.

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