COLLAPSE, GROWTH AND MERGING OF CAVITY REGIONS IN A GRANULAR MATERIAL DUE TO VISCOUS FLOW

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Summary Experimental and theoretical studies of viscous flow are made on the effect of macroscopic cavity regions in an otherwise homogeneous granular material. The presence of a cavity enhances local velocity, which leads to collapse of the cavity boundary. The mutual interaction leads to faster growth of fluidized region, which plays an important role in network formation of water channel and onset of landslide.

VISCOUS FLOW THROUGH CAVITIES IN GRANULAR MATERIAL

The presence of a macroscopic cavity in an otherwise homogeneous granular material changes the flow field, which has great influence on the deformation and/or migration of a cavity, as well as merging of two or more cavities [1]-[7]. Here an important parameter is $\zeta_0(=R_0/\sqrt{k})$, where R_0 and $\sqrt{k}$ are the characteristic sizes of the cavity and the interstices in the granular material, respectively, and k is the permeability. The term "macroscopic" means that $\zeta_0 \gg 1$ in this paper. In our previous analysis on the viscous flow assuming the Stokes equation inside a cavity and generalized Darcy equation outside, we have shown that the volume flow rate into a circular cavity increases as much as 2 times, whereas the velocity at the center of the hole amounts to 3 times of the velocity without that hole for sufficiently large ζ_0 case [1][8]. In the presence of a spherical cavity, they become 3 times and 6 times, respectively[2]. These situations raise a question of accurate estimation of underground water flow in *natural condition*, because velocity measurement necessarily introduces a hole for the detector.

Flow through a cavity of fixed boundary

We first extend our theoretical study to a *slightly but arbitrarily deformed* macroscopic cavity [3]-[5], in view of applying the theory to practical situations where the hole drilled is not a complete circle or where the hole deforms into non-spherical shape (see Fig.1). Our analysis shows that the volume flux into the cavity becomes maximum for an elliptic cavity with inclination angle of about 50 degrees, the detailed angle of which depends on the eccentricity of the cavity.

Flow through two cavities of fixed boundary

Our second extension is to study the *interaction of two macroscopic circular cavities* of different center-to-center distance l and different orientation α of them with respect to the undisturbed uniform flow (see Fig.2)[6][9]. Our experiment revealed that at a certain range of l less than about $3R_0$ and α less than about 30°, the volume flux into the downstream-side cavity increases, whereas it decreases for l less than about $3R_0$ and α around 90°. We shall compare these results with our calculation.

COLLAPSE OF CAVITIES DUE TO VISCOUS FLOW

The enhanced viscous stress has greater possibility of destroying the cavity boundary in the local scale, which leads to global deformation and/or migration of the cavity.

Collapse of a cavity due to viscous flow

Here we shall focus our attention to *collapse of a cavity region* by the viscous flow. To do this we set an initially circular cavity, and experimentally observed its deformation with given velocity at infinity U_∞. When U_∞ exceeds a certain critical value $U_{\rm cr}$, the upstream-side boundary collapses, constituent granular material of which is carried to the other side of the boundary, so that the initial cavity region is filled up by the latter. At the same time, the fluidized region develops towards upstream direction. The growth of the fluidized region resembles an ascent of a bubble under gravity, but front of the former is not so clearly defined as that of the latter.

Collapse of cavities due to viscous flow

The *collapse of two initially circular cavities* is tested for their different arrangement. When two circular cavities are arranged in tandem, the downstream-side cavity is destroyed even below $U_{\rm cr}$, as a result of enhancement of the velocity by upstream-side cavity. This phenomenon shows a remarkable contrast to the case of two solid cylinders placed in a viscous flow, where downstream-side one in the wake of the other experiences smaller drag. Dependency of center-to-center distance and orientation of the cavities is examined, which reveals the presence of optimum growth rate of void fingers (see Fig.3). Finally the growth of randomly distributed mesoscopic cavities is simulated on the basis of the model taking account of fundamental processes mentioned above, which suggests *macroscopic waterway network formation* as well as sheet-like discontinuity in the granular region. The latter can explain the onset of *landslides* at the time of heavy rainfall.

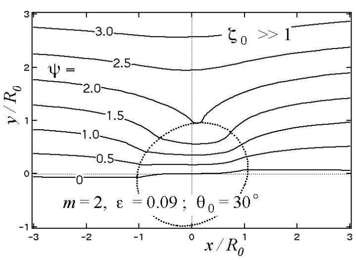

Fig.1. Streamlines around a slightly deformed cylindrical cavity: $r = R_0[1 + \epsilon\cos[m(\theta - \theta_0)]$, $m = 2, \epsilon = 0.09$, angle of attack $\theta_0 = 30°, \zeta_0 \gg 1$.

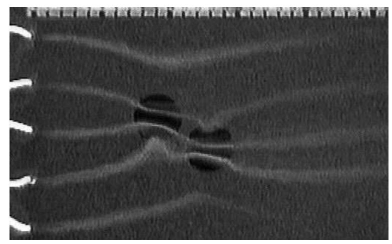

Fig.2. Interaction of two fixed circular cavities of an equal radius $R_0 = 18$ mm, center-to-center distance $l = 2.5R_0$, and angle of attack 30°. Granular material is glass beads of a diameter 1mm. Flow visualization by sodium fluorescein.

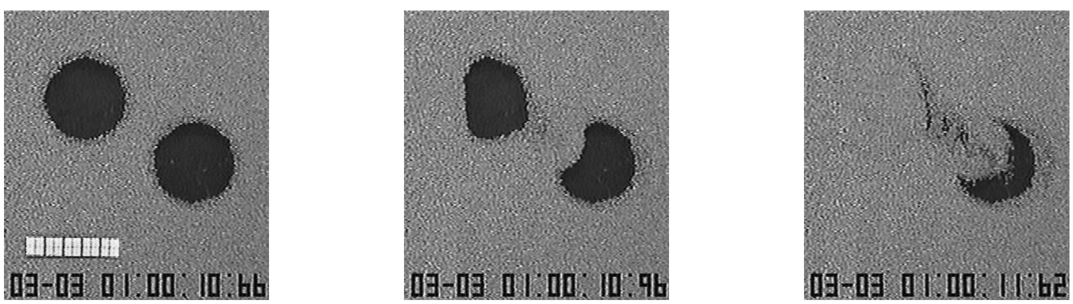

Fig.3. Collapse of two circular cavities. Initial radius $R_0 = 18$mm, center-to-center distance $l = 3R_0$, and angle of attack 30°. Granular material is glass beads of a diameter 1mm.

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