Particle-scale FSI computation for internal fluidization in gravel-particle bed by upward water jet

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Abstract. The internal fluidization in a gravel-particle bed by the vertically-upward water jet entering from the bottom surface was investigated with experiments and the computations taking account of the particle-scale fluid-solid interactions (FSI). In computations, the fluid forces acting on about 5,100 gravel particles, each of which is represented with multiple tetrahedron elements, were calculated from the pressure and viscous terms. As a result, it was shown that the calculated unsteady characteristics of the internal fluidization and failure are in good agreement with the experimental results. The consideration was also made in terms of the relationships between the fluid dynamic pressure p' and the effective stress σ' in the initial shape of the gravel layer.

Keywords: Internal fluidization, fluid-solid interaction (FSI), Parallel computation

1. Introduction

It has been reported that the serious ground collapses and failures sometimes arise due to the leakage of the fluids from the underground pipes through which water and oil are transported. Thus, such problems have been investigated from experiments and numerical simulations [1],[2],[3]. In this paper, in order to understand the internal fluidization and resulting failure of a gravel-particle bed by the vertically-upward water jet entering from the bottom surface. For that purpose, the unsteady processes are investigated with the experiments and the particle-scale fluid-solid interaction (FSI) numerical prediction using parallel computations. The predicted results were compared with the experimentally obtained behaviors. The mechanisms of the internal fluidization was discussed using the numerically obtained fluid forces acting on the particles and pore fluid pressures.

2. Outline of Experiments

Figure 1 shows the outline of the main part of the experimental setup and computational area. The lengths indicated in Fig. 1 are as follows: $l_1 = 350$, $l_2 = 40$ and $l_3 = 200$ [mm], while $h_g \approx 100$ [mm] and $h_w \approx 300$ [mm]. The inner diameter of the bottom pipe D is 31 [mm], from which the water jet of the average velocity 0.21 [m/s] enters in the vertically upward. As shown in Fig. 1, gravel particles of the average diameter 7 [mm] were filled in the gravel box. The approximate depth of the gravel bed is 100 [mm] and the porosity is about 0.44.

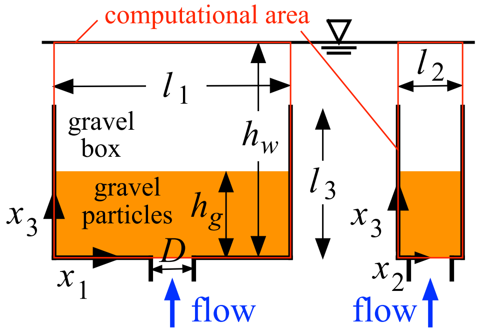
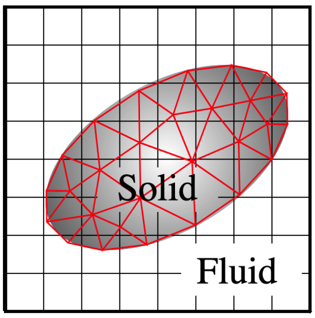


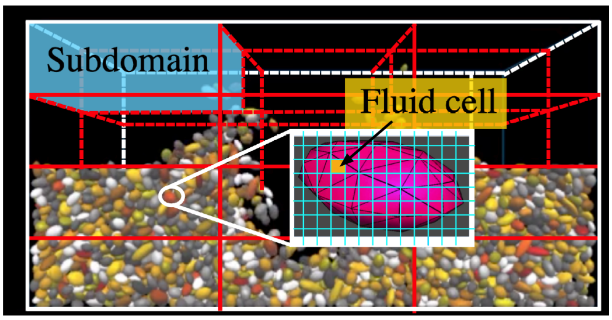
Fig.1: Experimental tank and computational area (left = front-, right = side-view)

3. Particle-scale FSI computations

The fluidized processes of the gravel bed were numerically simulated using the computation method proposed in [4]. Figure 2 (a) illustrates the Eulerian cells used for fluid computations as well as the Lagrangian unstructured cells representing a gravel particle. As schematically shown in Fig. 2, the Eulerian cell size is 0.6 [mm], which is sufficiently finer than the gravel particle size (7 [mm]), so that the surrounding flows around a particle can be resolved. The total number of the gravel particle is about 5,100, each of which is represented with about 100 tetrahedron elements. The massive computations were executed with 272 parallel computations with the domain decomposition as shown in Fig. 2 (b).



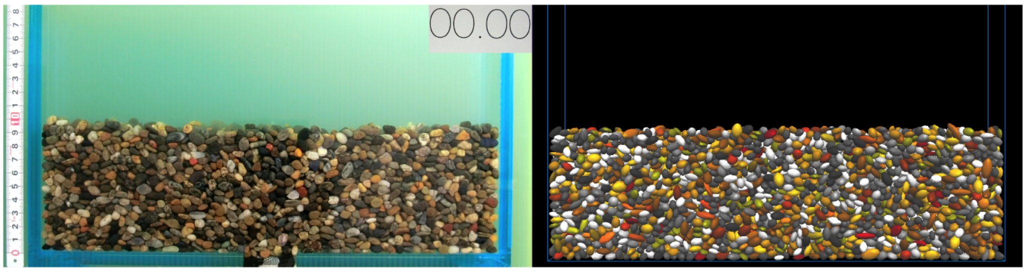
(a) Eulerian and Lagrangian cells



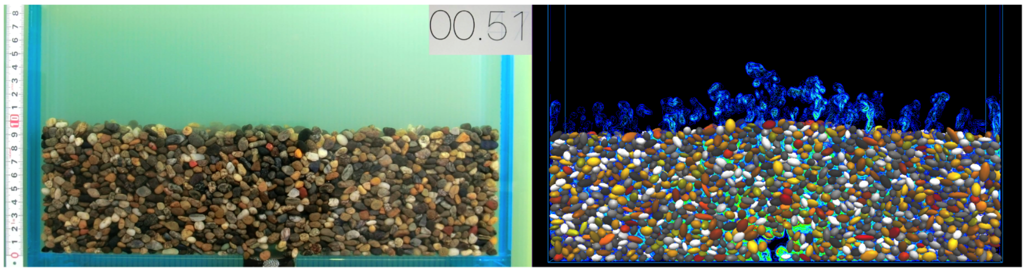
(b) Domain decomposition for parallel computation

Fig.2: Computation cells and parallel computation

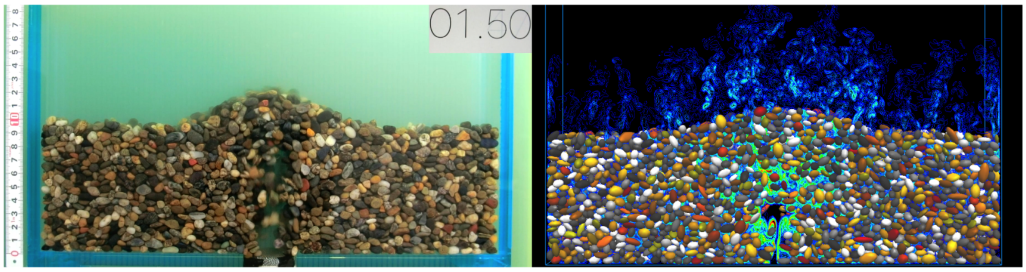
Figure 3 shows the comparisons between experiments and computations for the unsteady processes from initial condition to the fluidization of gravel particles and final penetration of the jet flow throughout the bed. The color contours in the calculated results show the magnitude ω of the vorticity vector of the fluid. The range of ω shown in Fig. 3 is between 0 [1/s] (blue) and 600 [1/s] (red).



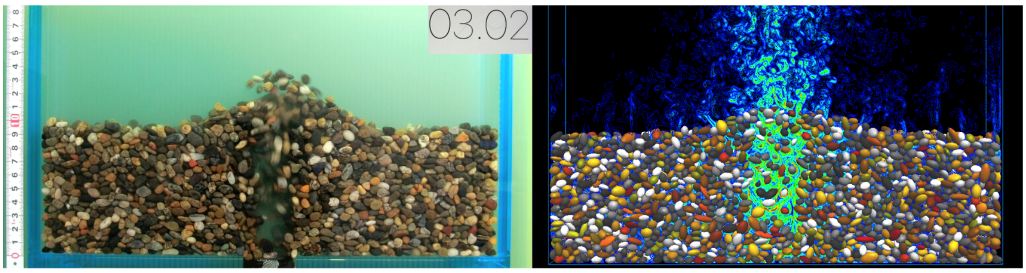
(a) experiment: t = 0.00 [s], computation: t = 0.00 [s]



(b) experiment: t = 0.51 [s], computation: t = 0.495 [s]



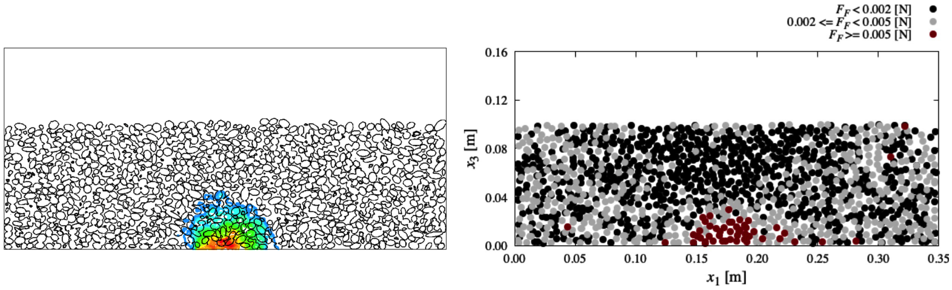
(c) experiment: t = 1.50 [s], computation: t = 1.50 [s]



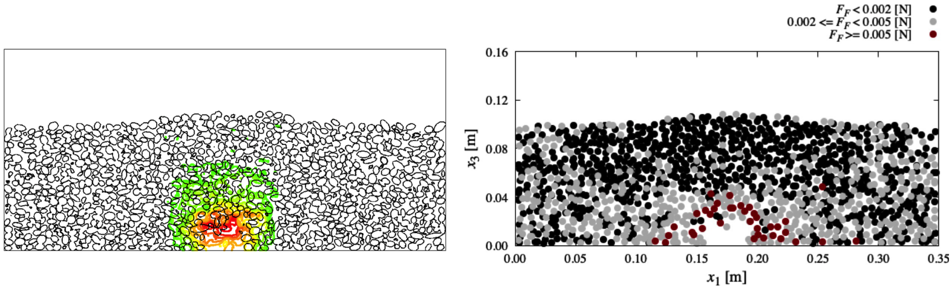
(d) experiment: t = 3.02 [s], computation: t = 3.00 [s]

Fig.3: Comparisons of gravel particles (left = experiments, right = computations)

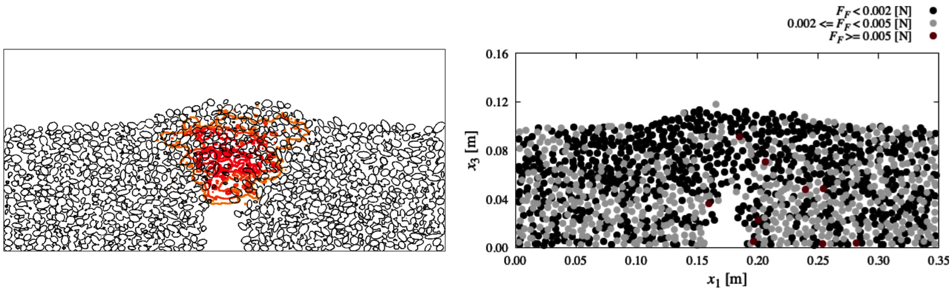
Figure 4 shows the distributions of positive $p' - \sigma'$, where p' is pore dynamic pressure among particles and σ' is the effective stress in the initial gravel bed shape calculated with the specific gravity (about 2.59) and the porosity (about 0.43). The range of $p' - \sigma'$ shown in Fig. 4 is between 0 [Pa] (blue) and 600 [Pa] (red). Figure 4 also shows the fluid forces $F_F = |\boldsymbol{F}|$ calculated from the pressure and viscous terms in the fluid computations. It can be seen that the fluidized areas, where $p' - \sigma'$ and F_F are relatively high, are closely related to the unsteady behaviors of gravel particles in the bed.



(a) $p' - \sigma'$ ($t = 0.045$ [s], left) and F_f ($t = 0.15$ [s], right)



(b) $p' - \sigma'$ ($t = 0.495$ [s], left) and F_f ($t = 0.495$ [s], right)



(c) $p' - \sigma'$ ($t = 1.50$ [s], left) and F_f ($t = 1.50$ [s], right)

Fig.4: Distributions of $p' - \sigma'$ (left) and F_F (right)

References

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