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Granular flow field around an obstacle and clogging at a bottleneck outlet

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Granular materials in the flowing state can form an arch structure at the bottleneck. Due to the arch formation, particles suddenly clog to arrest the flow. It has been empirically known that the clogging phenomenon cannot occur when the size of bottleneck is larger than approximately six times of diameter of particles [1]. Even in this flowing state without clogging, the flow rate would not be steady but vary depending on various parameters. In addition, the occurrence frequency of clogging could be decreased by inserting obstacles into the flow fields. Therefore, the effect of obstacles in the flow field must be an important key for the better understanding of granular clogging phenomenon. Furthermore, it is expected that the understanding of these phenomena will be helpful for structural design of buildings to control the flow of evacuating people. In this case, the flow of evacuating people can be regarded as a kind of granular flow. The nonlinear behaviors of granular matter such as the sudden clogging and arch formation could also relate to various geophysical phenomena, e.g., landsliding and avalanching.

In this study, we performed a simple experiment of gravity-driven granular flow controlled by the outlet and obstacle. First, we insert a disk-like obstacle into a two-dimensional cell, and fill the cell with stainless balls in diameter of 6.35 mm. Then, a small outlet is opened at the center of the bottom in the cell to create the granular flow toward the outlet. Granular flow field and the flow rate as well as the drag force exerted on the obstacle are measured using a high-speed camera and load cells. In particular, we experimentally examine how the flow field and flow rate are influenced by the parameters such as the size of outlet and the position of obstacle.

From the images of the granular flow acquired by the high-speed camera, we observe that the alternate flow, i.e., non-uniform (asymmetric) flow field, is generated by inserting the obstacle. On the other hand, the net flow rate at the outlet is found to be approximately steady. We further analyze the granular flow movie by Particle Tracking Velocimetry (PTV) method. Using PTV method, tracks of flowing particles can be measured. We divide the cell into three parts: an area right above the outlet and two sides (left and right) around the obstacle. Then, we calculate the flow field and packing fraction for each area. Besides, we also compute Mean Square Displacement (MSD) from the paths of the individual particle, on the basis of PTV data.

We discuss the relation between these values and physical quantities such as granular flow rate and drag force exerted on the obstacle, and then, we clarify how obstacles influence the granular flow fields through these parameter dependency.

[1] I. Zuriguel *et al*., Physical Review Letters **107**, 278001 (2011)

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