Laminar-turbulent transition in saturated granular free-surface flow

*Sakai Yuichi[1], Norifumi Hotta[1]

1. Graduate School of Agricultural and Life Sciences, The University of Tokyo

Flows of granular and fluid mixture driven by gravity are important sediment transport processes in subaerial and submarine environments. Their fluidity varies by grain size. Flows containing principally coarse grains are considered laminar and those featuring largely incohesive fine grains turbulent. When we focus on saturated granular free-surface flow, the transition from laminar to turbulent flow has been shown to depend on the ratio of flow depth to grain size (i.e., the relative flow depth). Flows with relative flow depths of approximately 10 are entirely laminar; those with relative flow depths over approximately 20 exhibit transitional flow behavior from entirely laminar to partially turbulent. This transitional flow has been investigated in a laboratory using resistance law and the vertical distribution of streamwise velocity. The flow exhibits a two-layer structure; the lower layer remains laminar but the upper layer becomes turbulent. However, transition modeling remains incomplete given the lack of data on the internal stresses associated with transitional flow. Here, we studied the laminar-turbulent transitions of saturated granular free-surface flow by measuring basal pore fluid pressures using flume tests.

We flowed saturated monodisperse granular materials over an open-channel rigid bed; we used sand particles of diameters 2.9, 2.2, 1.3, 0.8, 0.5, and 0.2 mm. When the flow attained a steady state, the flow depth and basal pore fluid pressure were measured using an ultrasonic sensor and pressure gages, respectively, and the basal total normal stress was estimated using the bulk density of the flow assessed at the downstream end. The relative flow depths ranged from 5 to 130.

Comparisons among the measured pore fluid pressures and the hydrostatic and total normal stresses indicated that a pore fluid pressure of 0.2 mm differed greatly from the hydrostatic pressure, equaling the total normal stress and indicating fully turbulent flow. In contrast, pore fluid pressures of 2.9, 2.2, and 1.3 mm were slightly higher than the hydrostatic pressures, indicating that the Reynolds stresses of the pore fluid due to strong shears imparted by the sediment particles were in play; flow was entirely laminar. Pore fluid pressures of 0.8 and 0.5 mm were intermediate between the hydrostatic and total normal stresses, indicating the transition from fully laminar to partially turbulent flow.

We investigated these transitions based on the non-dimensional number, which is similar to the Reynolds number for Newtonian fluid (the ratios of inertial to dynamic stresses due to both interparticle collisions and the Reynolds stresses of the pore fluid). This identified the critical non-dimensional number in terms of transition commencement. We describe transitional flow behavior using a two-layer model in which the position of the between-layer interface is estimated based on that critical non-dimensional number.

Keywords: Debris flow, Turbidity current, Granular flow, Turbulent flow, Pore fluid pressure

