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A novel optical method for estimating the near-wall volume fraction in granular flows

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Geophysical phenomena, such as debris flows, pyroclastic flows and rock avalanches, involve the rapid flow of granular mixtures. Today the dynamics of these flows is far from being deeply understood, due to their huge complexity compared to clear water or monophasic fluids. To this regard, physical models at laboratory scale represent important tools for understanding the still unclear properties of granular flows and their constitutive laws, under simplified experimental conditions. Beside the velocity and the shear rate, the volume fraction is also strongly interlinked with the rheology of granular materials. Yet, a reliable estimation of this quantity is not easy through non-invasive techniques.

In this work a novel cost-effective optical method for estimating the near-wall volume fraction is presented and, then, applied to a laboratory study on steady-state granular flows. A preliminary numerical investigation, through Monte-Carlo generations of grain distributions under controlled illumination conditions, allowed to find the stochastic relationship between the near-wall volume fraction, c_{3D}, and a measurable quantity (the *two-dimensional volume fraction*), c_{2D}, obtainable through an appropriate binarization of gray-scale images captured by a camera placed in front of the transparent boundary. Such a relation can be well described by $c_{3D} = a\exp(bc_{2D})$, with parameters only depending on the angle of incidence of light, ζ. An experimental validation of the proposed approach is carried out on dispersions of white plastic grains, immersed in various ambient fluids. The mixture, confined in a box with a transparent window, is illuminated by a flickering-free LED lamp, placed so as to form a given ζ with the measuring surface, and is photographed by a camera, placed in front of the same window. The predicted exponential law is found to be in sound agreement with experiments for a wide range of ζ ($10^{\circ}<\zeta<45^{\circ}$).

The technique is, then, applied to steady-state dry granular flows. A 2m-long laboratory flume, with an upper reservoir connected to the lower part of the channel through an adjustable sluice gate, is employed. The granular material, loaded in the reservoir, is the same of the previous tests. The flume inclination is 30° and different openings of the sluice gate are investigated. The apparatus is also equipped with a digital scale at the channel outlet for measuring the mass flow, a LED lamp and two high-speed cameras, placed laterally and above the chute to capture the flow motion at a given cross section. Side wall and free surface velocity profiles are obtained through PIV techniques. The volume fraction profiles are also obtained from side images. The joint information of the velocity and volume fraction profiles allowed to estimate the mass flow, which is found to be in good agreement with the mass flow, directly measured by the scale. These results confirm the robustness of the proposed cost-effective approach for the simultaneous measurement of velocity and volume fraction.