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Authors
Vowinckel, Bernhard
Biegert, Edward
Meiburg, Eckart

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Phase-resolved simulations of sediment erosion due to unsteady pressure drag

Bernhard Vowinckel, Edward Biegert, Eckart Meiburg
Department of Mechanical Engineering
UC Santa Barbara
Santa Barbara, CA 93106
Email: vowinckel@engineering.ucsb.edu

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Abstract

The most catastrophic flows in environmental fluid mechanics and hydraulic engineering are unsteady flows such as turbidity currents or dam break flows. Another, albeit less extreme example, is the situation of a turbulent channel flow, which is unsteady given that the timescale of observation is sufficiently small. Yet, very few studies are available addressing the unsteady hydrodynamic forces onto sediment beds resulting in a poor understanding of the processes involved. Hydrodynamic forces can be decomposed into drag (streamwise) and lift (wall-normal) forces with each part comprising a viscous stress component and a pressure component, although the separation of these components is by no means trivial. It was argued for turbidity currents and powder snow avalanches in recent years that pressure signals have the potential to propagate rapidly within the sediment bed, so that they can affect downstream bed locations in front of the current resulting in eruption events. The present study explores this particular scenario. We carry out phase-resolved Direct Numerical Simulations (DNS) of a pressure pulse propagating through an open channel filled with an otherwise quiescent fluid (Figure 1). The sediment bed introduced as individual spherical particles is represented by an Immersed Boundary Method (IBM). This computational setup allows us to isolate the drag and lift forces induced by the pressure pulse separating it from the viscous component.

We will present a parameter study based on the imposed pressure pulse to identify the scaling behavior of the drag and lift forces on wall-mounted particles. As desired, the forces exerted on the particle scale linearly with the pressure increase given that the Reynolds number is sufficiently high. As the pressure pulse propagates in positive streamwise direction, it induces a period of positive drag followed by a period of negative drag as it passes over a particle. Interestingly, it was found that the sediment packing gives rise to considerable lift forces at the beginning and end of the pressure pulse, which could serve as an explanation for the eruptive events discussed above. In addition, the magnitude of the forces strongly depends on the time rate the pressure is increased. The more abrupt the pressure change happens, the stronger the forces become. Finally, we will present simulations of the same kind with a mobile sediment bed. This is done using a sophisticated particle collision model to account for the complex interaction in dense granular media elucidating the role of energy transfer between

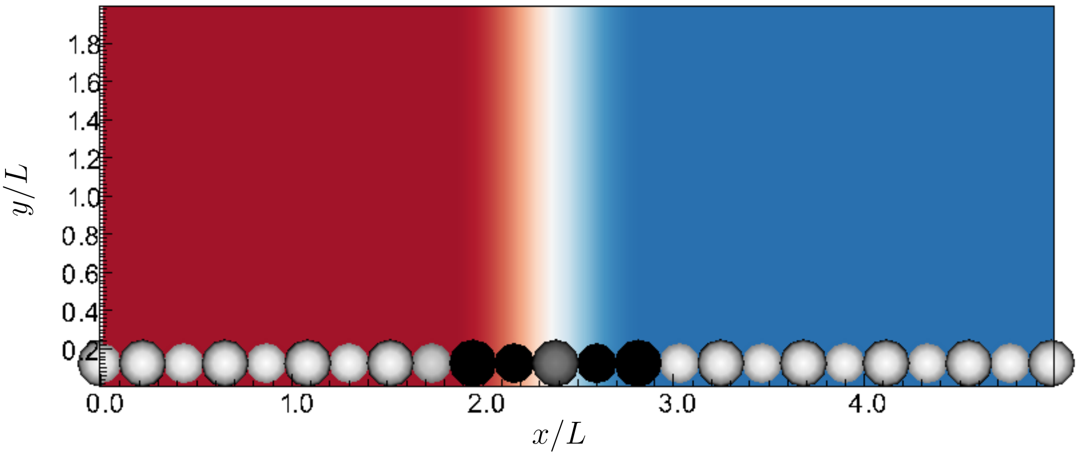

Figure 1: *Side view of a pressure pulse propgating through an open channel. Contor colored by pressure (red: high; blue: low), particles colored by magnitude of hydrodynamic force vector.*

the particles in the sediment bed. The results presented are of particular importance for the erosive potential of turbidity currents and can help to explain their long runout distances recorded in the ocean.