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Impact of dense avalanches on civil engineering structures: demarcating depth-dependent from velocity-squared impact forces

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Recent well-documented measurements on full-scale snow avalanches impacting civil engineering structures have identified an impact force regime for which the pressure exerted on the obstacle is depth-dependent, rather than being controlled by the square of the avalanche speed. In addition, these measurements have shown that the depth-dependent force could be many times greater than the hydrostatic force associated with the thickness of the incoming avalanche-flow. The present paper proposes a general analytic form for the impact force of dense avalanches on any kind of structure, with the help of the depth-averaged hydrodynamics applied to a control-volume surrounding the influence zone of the obstacle. This form extends the recently established force models for wall-like and pylon-like obstacles impacted by flows of dry granular materials. A criterion to distinguish between the depth-dependent force regime and the velocity-square force regime is derived. It is demonstrated that the size of the influence zone of the obstacle, relative to the dimension of the obstacle and/or the avalanche thickness, is a key ingredient---in addition to the traditional Froude number---to demarcate the depth-dependent from velocity-square impact forces. There is still a need for further developments to unravel the size and shape of the influence zone of any kind obstacle for any type of flowing snow, and then being able to hone this criterion as well as to predict the force amplification in the depth-dependent regime. However the present study takes a step forward for a better understanding of granular avalanche impact force on civil engineering structures.