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# Laboratory measurements of impact forces of granular flow against mast-like obstacles

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Impact forces by snow avalanches on narrow obstacles are important for the design of many constructions in avalanche prone terrain, such as masts of electrical power lines, ski lifts and cable cars. An important question in connection with such impact forces is how the total force exerted on the obstacle depends on the run-up of the avalanche on the obstacle, for high obstacles that extend through the flow. Widely used engineering guidelines imply that a significant fraction of the dynamic pressure of the avalanche impacts the obstacle simultaneously over the full height range corresponding to the run-up of the avalanche. A series of laboratory experiments was conducted in a 6 m long and 0.35 m wide chute in order to investigate impact forces on narrow rectangular and cylindrical obstacles for supercritical granular flow. Obstacle heights varied from about twice the flow depth to more than 20 times the flow depth, which was higher than the observed run-up, and the width of the obstacles varied from about twice the flow depth to about 7 times the flow depth. It was found that the total force on the obstacle did not depend much on the obstacle height for heights that exceeded about 3 flow depths, which is much lower than the run-up on the highest obstacles. For a wide range of obstacle heights exceeding about 3 flow depths, the total force on the rectangular obstacles was of similar magnitude as the dynamic pressure, $\frac{1}{2}\rho u^2$, acting over an area corresponding to the width of the obstacle and the upstream depth of the flow. The total force was about 30% lower for cylindrical compared with rectangular obstacles. Impact forces of natural snow avalanches on obstacles are observed to be characterised by some important features that were not analysed in the laboratory experiments described here. In particular, high peaks in the loading are believed to be

caused by the impact of large snow clods on the obstacles and even higher impacts may be caused by impacts of rocks, tree trunks and other debris that is advected with the snow in many avalanches. In spite of this, the experiments provide information about the nature of granular flow around obstacles, which may be useful for engineering applications.