AVALANCHE PRESSURES AT THE VALLÉE DE LA SIONNE TEST SITE: INTERACTION OF AVALANCHES AND NARROW STRUCTURES STUDIED WITH DEM

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ABSTRACT: Recent advances in full-scale avalanche measurements have led to a better understanding of the avalanche flow dynamics. However, the processes involved in pressure build-up on obstacles in the various flow regimes are still elusive. From full-scale experiments it is well established, that in the inertial flow regime, which is mostly typical of fast and cold avalanches, the pressure is proportional to square velocity. The gravitational regime is often observed for warm/wet snow avalanches and features a linear pressure variation with flow depth. It is still unclear how to estimate the coefficients of proportionality, which are needed for the pressure calculation, namely the drag coefficient and the amplification factor in the inertial regime and in the gravitational regime, respectively. In order to investigate the origin of the amplification factor and the drag coefficient, we developed a model based on the Discrete Element Method (DEM), which allows us to simulate the interaction between a cohesive granular flow, such as an avalanche, and a structure. The DEM model is tested by comparing the simulation results to full-scale measurements from our "Vallée de la Sionne" test site. The results of the simulated pressure show that the newly developed model is able to capture both, the flow-depth and velocity-proportional pressure regime. Thus this model will be further improved to take into account more complex physical processes such as the snow compaction and granulation.

Keywords: Avalanche, Pressure, Obstacle, Avalanche dynamics, Discrete Element Method

1. INTRODUCTION

Today the identification and understanding of the processes, which are responsible for pressure build-up on obstacles, is still a challenge. Based on Voellmy's fundamental work in 1955, it has been accepted for a long time, that avalanches can be characterized by two main pressure regimes depending on flow dynamics and snow properties. In the inertial regime pressure is proportional to square velocity, while it is proportional to flow depth in the gravitational regime. With the advent of high-resolution measuring techniques it has been possible to gain increasing insight into the flow dynamics of avalanches. Current methods for calculating pressures still rely on empirical equations, where pressure depends on the choice drag coefficient in the inertial regime and the amplification factor in the gravitational regime. Today it is not clear yet how to choose suitable values for these proportionality factors based on physical considerations.

Therefore, we aim to improve the calculation of avalanche pressure on obstacles by understand-ing the processes involved in the interaction of avalanche flow and structures. In particular, we want to evaluate drag coefficients and amplification factors as a function of snow properties and avalanche flow regimes. To reach this goal a Discrete Element Method (DEM) model is developed to investigate the interaction between an avalanche flow and an obstacle. The DEM model is tested by comparing the simulated pressure to measurements collected at the *Vallée de la Sionne* (VdlS) full-scale avalanche test site, where the pressure, velocity, temperature and density of the avalanche are measured on a pylon-like structure.

2. METHOD

In order to simulate the avalanche-obstacle interaction, a new DEM model is developed using Itasca's PFC3D software, which is based on the soft-contact algorithm (Cundall and Strack, 1979). The snow is modelled in the form of spherical discrete elements, which interact with each other according to a *parallel-bond* contact model (Potyondy and Cundall, 2004). The bonds mimic the sintering of in the real snow, where the tensional and shear strengths of the bonds determine the cohesion. Because of limited computational power, to date, it is not possible to model individual ice grains as

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discrete elements in large avalanche events. Hence the spherical discrete elements correspond to agglomerations of snow in avalanches (Steinkogler et al., 2015) rather than individual ice grains, as illustrated in Figure 1 below.
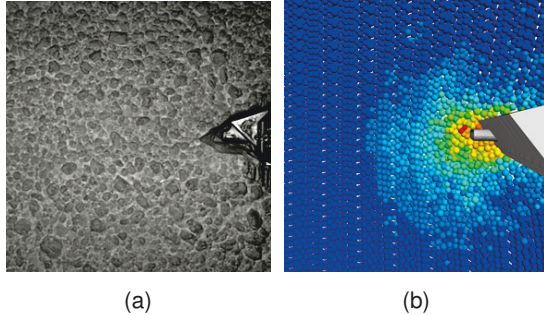

Figure 1: Example of snow granulation in a natural avalanche (panel (a)) and particle size in the DEM model (panel (b)).

The DEM model which is proposed here allows us to accurately impose predefined profiles of relative velocity between the particles and a structure. This is achieved by considering a moving frame of reference, which is fixed to the mean flow of the avalanche instead of an earth- or obstacle-fixed one. In the model, the structure is therefore forced to move through a bed of resting particles, instead of the flowing particles impacting a static obstacle. Hence, the flow processes in the granular medium prior to the interaction are omitted. This also reduces the computational time for the simulations considerably.

As illustrated in Figure 2, the pylon is divided into vertical sections, which can move independently at different speeds in the horizontal direction. This allows us to impose arbitrary velocity profiles. The speeds of the sections are chosen to mimic velocity profiles measured in real avalanches with different flow regimes. Thus, to impose for example a shear flow with this setup, the structure is sheared instead of the granular medium (Figure 2b). This shearing of the obstacle also leads to a disintegration of the structure if the shear-rate is high. The shear-rate is therefore limited in order to achieve valid results.

Given that the particles are initially at rest, they move less relative to each other, compared to the particles in a shear flow. This applies particularly to agitated flows, shear flows and regions close to the free surface of the dense flow. In these situations the relative motion leads to dilation and therefore to a lower macroscopic density of the material, which may well affect the resulting pressure.

The geometry of the obstacle in the simulation is similar to the shape of the steel pylon at VdlS (Sovilla et al., 2014). The comparisons are performed for two typical flow configurations. The first is a
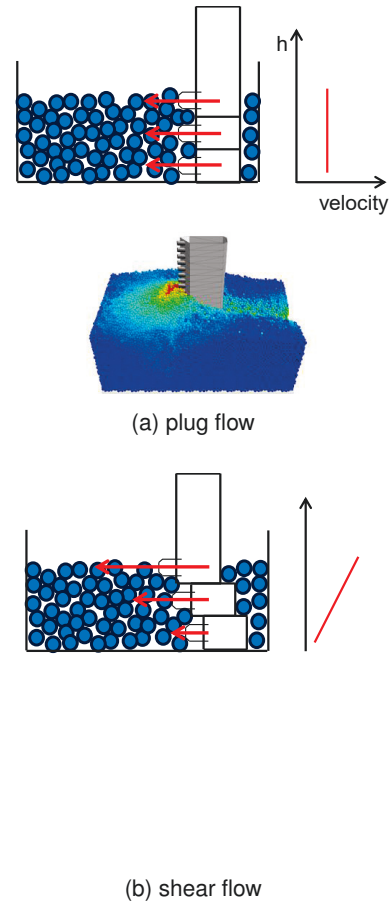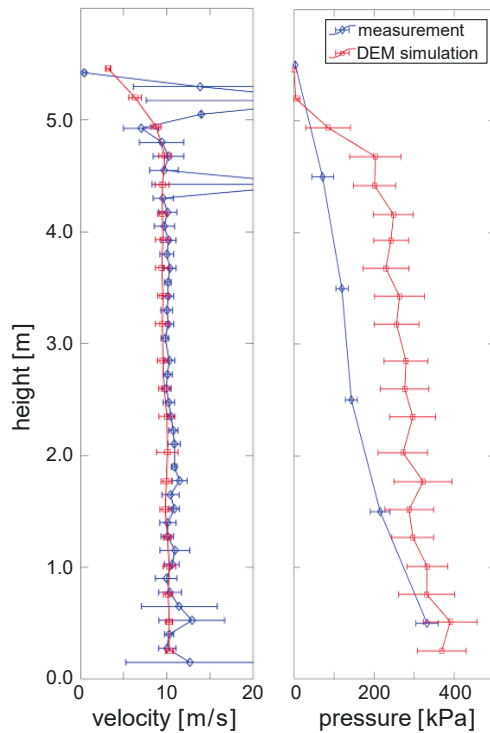

(a) plug flow

(b) shear flow

Figure 2: Schematic side view (top) and illustration (bottom) of the DEM model, where the structure moves through the particles (blue circles) with a plug (panel (a)) and a shear velocity profile (panel(b)).

gravitational flow with a constant velocity profile over the whole flow height, also referred to as plug flow (Figure 2a). The second is an inertial flow with a sheared velocity profile.

3. RESULTS

To assess the performance of the proposed DEM model, we compare the results of the simulated pressure to the real-scale measurements of the VdlS test site. Figure 3 compares full-scale measurements and DEM simulations of a plug flow (Figure 3a) and a shear flow (Figure 3b). In both pressure regimes the simulations capture the qualitative trends of the measured pressures. In the left panel (Figure 3a), the pressure of the real-scale experiment increases with flow-depth at a higher rate than the simulated pressure. For the sheared velocity profile in the right panel (Figure 3b), the measured and simulated pressure show good agreement. There are two places for which agreement is less good: at the bottom, the simulated pressure exhibits a moderately higher pressure; in the upper

half the simulated pressure increases more with increasing flow-height.

(a) plug flow
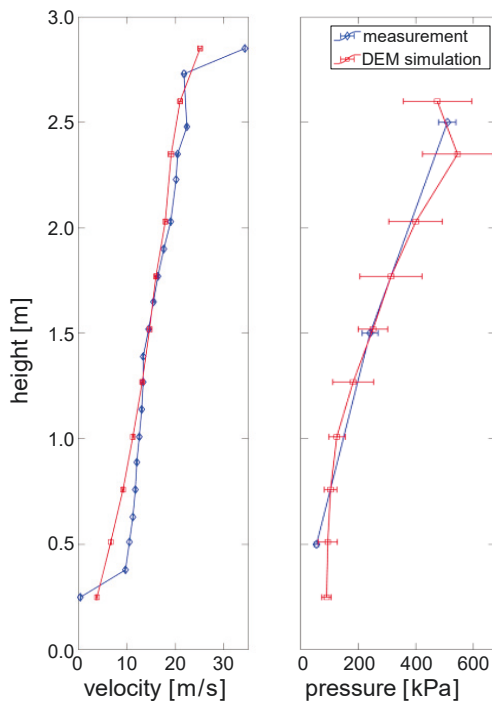
(b) shear flow

Figure 3: Comparison of pressure and velocity profiles between full-scale measurements at VdlS and DEM simulations.

4. DISCUSSION AND CONCLUSIONS

The comparison of measurements and simulations shows that this simple DEM model is able to reproduce the fundamental proportionality of the pressure with flow-depth and with square speed, in the gravitational and inertial regime, respectively. In the plug flow regime a difference of the pressure increase with flow-depth is observed. One reason why the simulated pressure increases less with flow-depth might be that the contact model is not able to capture the compressive behaviour of the snow in the lower layers of the avalanche under its own load. This demonstrates the need for a more physics-based contact model, which takes the plastic deformation and compaction of snow into account.

Towards the bottom of the pressure curve in the inertial regime, a slightly higher pressure is observed in the simulation compared to the measurement. The reason for this probably originates from the features of the model setup. Because the particles are not sheared in the bottom layer, there is no, or little dilation. Thus the macroscopic density is higher, which leads to larger pressures. Although the model is highly simplified, the discrepancies between the simulations and the measurements remain relatively small.

In order to gain a better understanding of the processes involved in avalanche-obstacle interaction, this DEM model will be extended by including among other things snow compaction and granulation as well as different flow regimes. Finally, it will be used to simulate the interaction of avalanches of different flow regimes with structures of different shape and dimensions.

REFERENCES

Cundall, P. A. and Strack, O. D. L. (1979). A discrete numerical model for granular assemblies. *Géotechnique*, 29(1):47–65.

Potyondy, D. and Cundall, P. (2004). A bonded-particle model for rock. *International Journal of Rock Mechanics and Mining Sciences*, 41(8):1329 – 1364. Rock Mechanics Results from the Underground Research Laboratory, Canada.

Sovilla, B., Margreth, S., Schaer, M., and Ancey, C. (2014). Taking into account wet avalanche load for the design of pylon-like structures. *Proceedings of International Snow Science - Montana State University library*, pages 727–732.

Steinkogler, W., Gaume, J., Löwe, H., Sovilla, B., and Lehning, M. (2015). Granulation of snow: From tumbler experiments to discrete element simulations. *Journal of Geophysical Research: Earth Surface*, 120(6):1107–1126. 2014JF003294.