TAKING INTO ACCOUNT WET AVALANCHE LOAD FOR THE DESIGN OF TOWER-LIKE STRUCTURES

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ABSTRACT: Wet snow avalanches interact with infrastructures around the world but their significance on the structure design is frequently neglected due to the low velocity, which characterize the flow and thus the expected low impact pressures. Recent pressure measurements performed at the Swiss Vallée de la Sionne full-scale test site show that wet avalanche pressures, measured on a 20 m high tower, are considerably higher than those predicted by conventional avalanche engineering guidelines, thus potentially becoming relevant for the design of tower-like structures. In order to understand under which circumstances wet avalanches can become more relevant than their dry counter part and in order to establish simple rules to evaluate the pressure the avalanche exerts on a tower-like object, we analyse pressure and velocity data collected at the Vallée the la Sionne on obstacles of different shape and dimension.

KEYWORDS: avalanche impact pressure, wet-avalanches

1. INTRODUCTION

Wet avalanches are characterized by large flow depths, high density and slide directly on the ground similarly to gliding snow or on snow layers. Commonly, wet avalanches are considered irrelevant for the design of avalanche protection measures because of the low velocity of the flow, thus, the expected low impact pressures and the often short runout distance. However, recent full-scale measurements of wet avalanches have clearly shown that they can exert very large impact pressures depending on the depth of the incoming flow. Wet snow avalanches interact with finite size objects in a similar way and order of magnitude of forces as gliding snow (Sovilla et al., 2010). Thus they are potentially becoming relevant for the design of infrastructures.

At the Vallée de la Sionne (VDLS) (Sovilla et al., 2008a) impact pressures are measured on sensors mounted on finite-size obstacles, which resemble ski or chairlift towers. Sensors have various dimensions (Sovilla et al., 2008b; Schaer and Issler, 2001), with areas varying between 0.008 and 1 m^2. The highest pressures observed at the VDLS (Sovilla et al., 2010) were corresponding to measurements performed with the smallest cells of 0.10 m in diameter (Fig. **1**). However, it is not clear weather these large impact pressures are only an effect of the small sensor surface or they can be equally sensed on larger surfaces. Indeed, Baroudi et al., (2011) recently demonstrated that pressures recorded using sensors of similar area, but different shape show a dependence on the measurement shape, especially in the case of wet flow measurements. Differences in the case of wet avalanche flow were mainly attributed to the slow drag and bulk flow of this type of avalanche, leading to the formation and collapse of force-chain structures against the different surfaces of the sensors.

Thus, the first aim of this paper is to compare the pressure measured at the small cells (0.008 m^2) with the corresponding measurements performed at the largest pressure sensors of 1 m^2 (Fig. **2**) in order to investigate if the high pressures measured with small sensors are also occurring on design-relevant dimensions, such as skilift tower.

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With this a reduction coefficient from small to larger obstacles can quantitatively be determined.

Further, by comparing the dynamical characteristics of a wet/dry avalanche couple which has exerted similar pressures at the large obstacles, we will establish under which circumstances a slow, wet flow becomes more relevant that its dry counter part.

2. METHODS

At the Valleé de la Sionne impact pressure sensors are installed on multiple structures having different dimension and form (Sovilla et al., 2008b). In this paper we will compare measurements performed with the smallest and largest sensors.

2.1 Infrastructure and sensors

Small cells are installed on an oval-shaped steel tower, 20 m high, 0.6 m wide and 1.5 m long (Fig. 1). These High-frequency (7.5 kHz) pressure sensors of 0.10 m in diameters with an area of 0.008 m^2, are installed from 0.5 to 5.5 m above ground, so impacts in the different layers and turbulent eddies in the fluidized layer can be resolved. The tower is also equipped with optical sensors for the determination of speed profiles (between 0.5 and 6 m) (Dent et al., 1998; Tiefenbacher and Kern, 2004), capacitance probes for density measurements (at 3 and 6.5 m) (Louge et al., 1997) and flow depth sensors (toggles switches between 0.25 and 7.5 m).

Thirty meters downstream from the tower a small concrete wall, 1 m wide, 4.5 m high and 3.5 m long supports a 1 m^2 pressure plate, which is mounted with its centre at a height of 3 m above ground surface (Fig. 2). The pressure plate is supported by four strain-gauged pins. The set-up makes it possible to measure normal and tangential forces along the horizontal and vertical directions with a sampling frequency of 2 kHz.

2.2 Criteria for data comparison

The tower and the plate are approximately 30 m apart. This implies that an avalanche can interact with the obstacles with different intensity and depth depending on the incoming flow direction and dimension thus, potentially invalidating the comparison. To compare set of data we have followed the following criteria:

Fig. 1: The 20 m high tower is instrumented with high-frequency load cells, optical sensors for velocity measurements, capacitance probe for density measurements and flow depth sensors.

Fig. 2: The small concrete wall supports a 1x1 m^2 pressure plate.

- We have used picture and videos to qualitatively identify avalanches, which have interacted with both infrastructures in a similar manner. Avalanches characterized by a large width in the run-out zone are better suited since they extend over large area with similar features. Only signals comparable in duration have been included in the analysis.

- Given that the 1 m^2 plate is mounted with its center 3 m above the ground and spans from 2.5 to 3.5 m, we compare this data with the average impact pressure measured at the tower with the 0.008 m^2 sensors positioned at 2.5 m and 3.5 m above ground, assuming that the sliding surface is the same at the location of the plate and at the tower.

- The time offset between tower and wall are corrected in function of the average front velocity.

- Pressure is strongly correlated to the flow regime, with wet dense flow, dry dense flow, and dilute flow characterized by completely different obstacle/avalanche interactions (Sovilla et al., 2008a; Baroudi et al., 2011). Thus data need to be classified in these (at least three) categories. Difficulty arises when many flow regimes are present in one single avalanche. Two criteria to differentiate between measurements are: (1) looking at pressure signals fluctuations (Sovilla et al., 2010) and (2) looking at the velocity profile and their fluctuations to distinguish between plug flow (warm snow, granules, stick-slip phenomena), sheared flow (cold snow) and turbulent zones of the signal.

3. DATA

Measurements at both plate and tower have been performed since the winter season 2004/05. In this period, we have recorded impact pressure of about 20 avalanches of varying dimension and typology, which have interacted with both infrastructures. As an example, in this paper we show measurements corresponding to two large avalanches, a wet one and a dry one, which have exerted similar impact pressures at the large pressure sensors.

3.1 Avalanche #7226

On 21 January 2005 at 15:00 h, an avalanche naturally released at the VDLS test site (Fig. 3). Moderate snowfall over several days had added ~15 cm of new snow to the ~1m thick snow cover in the release zone. Temperatures at release were measured to be about −4°C after a significant temperature rise from −14°C, which also affected the snow cover: snow surface temperatures had been rising from −25 to −4°C.

The temperatures in the run-out zone were ~0°C. The recorded data indicate a dry-flowing avalanche that may be characterized by two parts: a high-speed, fluidized head in which velocity variations and considerable shear were present, and a low-speed flow tail. Densities strongly fluctuated from head to tail with values up to around 300 kg/m^3. Further description of this avalanche can be found in Kern et al. (2009) and in Sovilla et al. (2008b).

Impact pressures measured at the tower with the small cells and at the concrete wall with the 1m^2 plate are shown in Fig. 4. Data shows a fair temporal agreement and an overall similarity in the signal variations. Measurements performed at the small sensors are considerably larger in magnitude, however. Fig. 5 shows average velocities measured by sensors close to the pressure location and flow depths. The faster part of this avalanche reached velocities of the order of 45 m/s and maximum flow depths of about 5 m. The high avalanche velocity and large pressure fluctuation underscore, that most parts of this avalanche, 3 m above ground, was probably dilute and turbulent.

Fig. 3: Deposition zone of avalanche #7226 at the Vallée de la Sionne test site. The arrow indicates the position of the tower and small concrete wall.

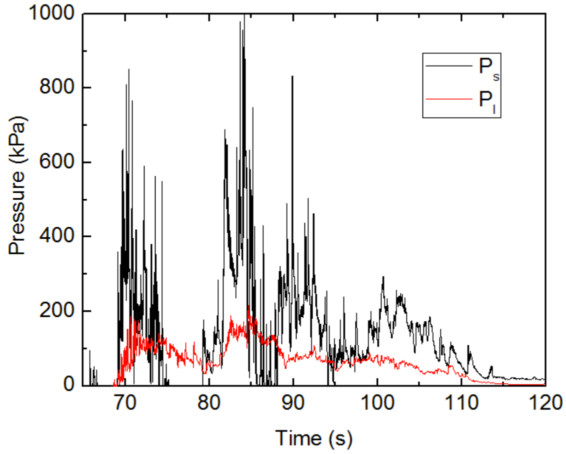

Fig. 4: Avalanche #7226: Comparison between impact pressures measured at the tower (black line, average between small sensors at 2.5 and 3.5 m above ground) and impact pressure measured at the small concrete wall with the 1 m^2 plate (red line).

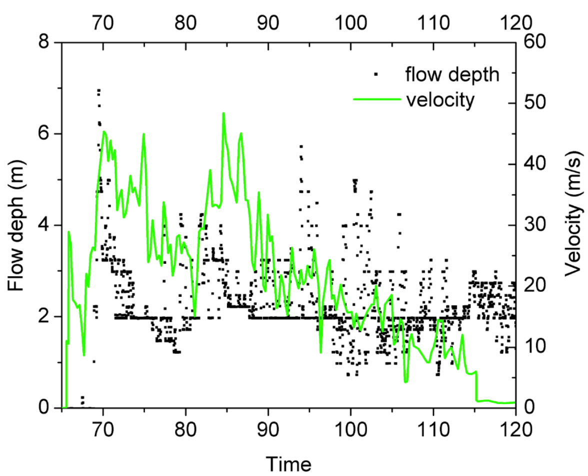

Fig. 5: Avalanche #7226: Average velocity corresponding to measurements performed at 2, 3, 4 m above ground (green line) and flow depth measured at the tower (black line).

3.2 Avalanche #20103003

Avalanche #20103003 released naturally on 30 December 2009 at 13:30 (Fig. **6**). At the time of release, ca. 0.20 m of new snow has fallen in the preceding 24 h on a snow cover of 1.80 m. A snow temperature of -5 °C at a snow height of 1.0 m and an air temperature of -1.5 °C. Air temperature in the release zone was -4 °C. This would indicate that, at a lower altitude, close to the deposition zone, the snow precipitation could have evolved into rain. According to measurements performed at the tower, in the runout zone the avalanche was characterized by two main flow regimes (Fig. 4).

Fig. 6: Deposition zone of the wet avalanche #20103003. The arrow indicates the position of the tower and small concrete wall.

Fig. 8 shows that the avalanche was characterized by a fast-diluted front followed by slow large dense core moving at about 10 m/s. Undulations in velocity and flow depth indicate that the flow was characterized by successive surges. This large avalanche had maximum flow depths up to 6 m at the pylon. Thus, the avalanche had a large powder component in the first part of the path but had evolved into a high-density flow (around 450 kg/m^3) as the avalanche entrained wet snow at lower altitudes. This avalanche is also described in Kogelnig et al. (2011).

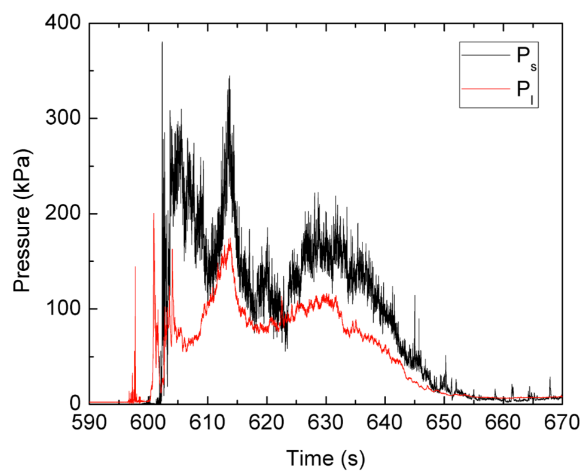

Fig. 7: Avalanche #20103003: Comparison between impact pressures measured at the tower (black line, average between small sensors at 2.5 and 3.5 m above ground) and impact pressure measured at the small concrete wall with the 1 m^2 plate (red line).

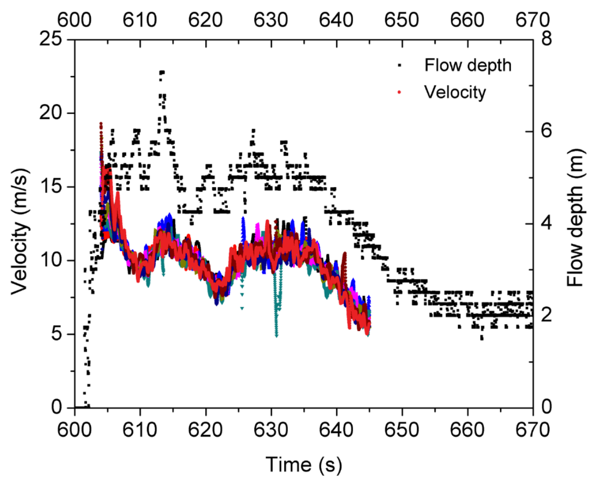

Fig. 8: Avalanche #20103003: Flow depth (black dots) and average velocities (colored dots) measured at the tower between 2.5 and 3.5 m above ground.

4. RESULTS

Fig. 4 and Fig. 7 show a comparison between impact pressures measured at the tower with small sensors (red lines) and impact pressures measured at the small concrete wall with the1 m^2 plate (black lines). In spite the very different avalanche dynamics of the wet and dry avalanches, pressures at the 1m^2 plate are similar in magnitude with maximum values around 150 kPa. On the contrary, pressure measured by the small pressure cells shows relevant differences, with the largest pressures reached by the dry dense avalanche, with maximum values up to 1000 kPa.

The ratio between the pressure measured with the small cells, P_s, and the pressure measured with the 1 m^2 plate, P_l, are shown in Fig. 9 and Fig. 10. The horizontal lines represent the average ratio calculated in continuous segment of signals corresponding to wet and dry flows, according to a signal fluctuation analysis as in Sovilla et al. (2010).

In particular for the wet avalanche #20103003, the dilute head has been excluded from the analysis. The average ratio in the wet-dense part is 1.7.

In case of the dry avalanche #7226, the ratio has been determined with the average impact pressure measured at the tower with sensors positioned at 2.5/3.5 m (black dots in Fig. 9) and 1.5/2.5 m (red dots in Fig. 9) above ground, since the hypothesis that the sliding surface was the same at the plate and at the tower was not completely true in this case. The average ratio in continuous parts of the signal is ranging between 2.5 (black line) up to 4.3 (upper red line).

5. DISCUSSION AND CONCLUSIONS

By comparing impact pressure measurements performed at the VDLS using two types of sensors of small dimensions (0.008 and 0.0125 m^2), Baroudi et al. (2011) concluded that avalanche impact-pressure measurements in slow, wet avalanche flow are affected by the shape and size of sensors while in dry avalanches the effect is negligible. Our simple comparison shows that this is true only when the sensors are small and have comparable dimension but does not hold when the dimension of the sensor is much bigger than the diameter of snow granules.

We could observe, that on a 1 m^2 surface, the pressure exerted by a dry-dilute avalanche can be up to factor 4 smaller in respect to the measurements performed on a 0.008 m^2 surface, but only factor 1.7 smaller in case of wet flow.

It is to note that the reduction coefficients presented in this paper are only referring to two events and thus need to be considered as order of magnitude, only. Nevertheless, a preliminary analysis of the 20 avalanches recorded at the VDLS shows a similar tendency. This means that pressures measured with small cells need to be treated carefully for the extrapolation to larger obstacles and thus for the design of tower-like structures.

Further, it is interesting to note that a wet flow avalanche with a depth of 6 m moving at 10 m/s can exert the same pressure magnitude as a 40m/s fast dilute layer. This is possible because of the different mechanics of impact as shown by Sovilla et al., (2010) and Baroudi et al. (2011). In particular, Sovilla et al. (2010) observed that, for wet snow avalanches moving in a plug flow regime, the impact pressure on a pylon increases linearly with flow depth and that the pressure is independent of the avalanche velocity. Thus, in the future, the challenging task will be to properly simulate the correct flow depth rather than a correct velocity for this kind of flow. This is particularly difficult since wet flow is frequently randomly confined as a result of old deposit distributions or levees formation.

In synthesis, our analysis indicates that wet avalanches can become decisive for the design especially if characterized by large depths and the obstacle is large.

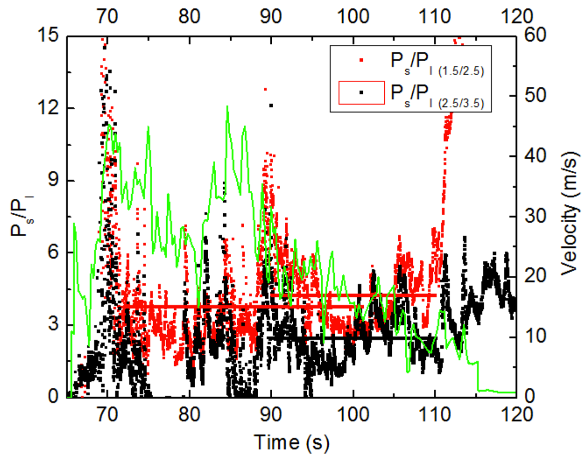

Fig. 9: Avalanche #7226: Ratio P_s/P_l between pressure measured at the small sensors, P_s, and pressure measured at the large plate, P_l. The average ratio in continuous parts of the signal is ranging between 2.5 (black line) up to 4.3 (upper red line). Velocity, in green, is superimposed for easy comparison.

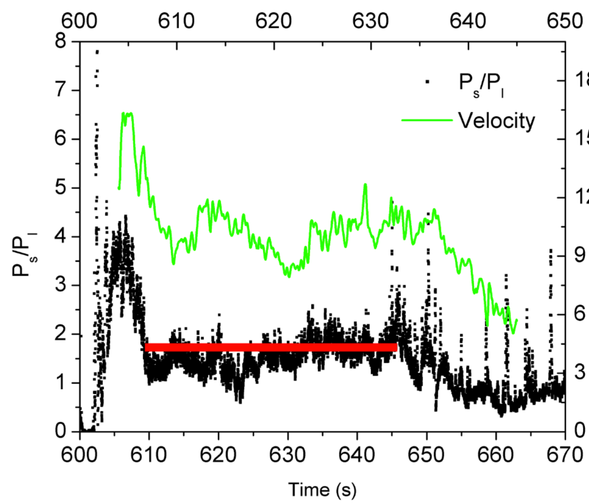

Fig. 10: Avalanche #20103003: Ratio P_s/P_l between pressure measured at the small sensors, P_s, and pressure measured at the large plate, P_l. The ratio in the wet-dense part is 1.7. Velocity, in green, is superimposed for easy comparison.

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