# Effects of flow regime and sensor geometry on snow avalanche impact pressure

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## 1. Introduction

The impact pressure exerted by an avalanche on a structure is of fundamental importance in avalanche engineering. Nevertheless, impact pressure is very difficult to measure because a loading is the result of complex interactions between the structure and the snow avalanche.

To verify if different methodologies and installation methods may have an influence on the measured loads, we compare impact pressure data from piezo-electric load cells and small steel cantilever beams equipped with high precision strain gages.

We analyze both sensor responses for 2 very different dense avalanches : fast dry and slow wet.

## 2. Site and experimental set-up

Measurements are performed at the Vallée de la Sionne experimental site (Fig. 1)

Fig. 1

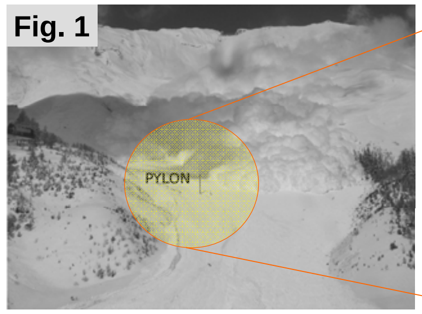
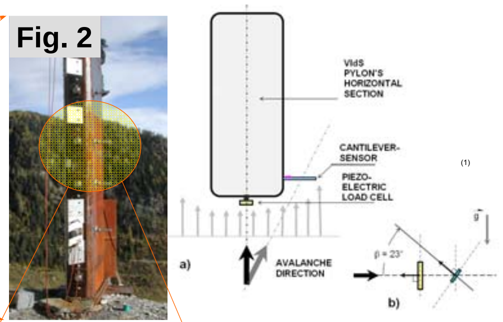



Fig. 2




The impact pressure has been measured using two different type of sensors. Sensors are installed pairwise on a 20 m high steel pylon (Fig. 2), from 0.5 to 5.5 m above ground, with a vertical spacing of 1 m.

**Piezo-sensor:**

1) 6 piezo-electric load cells with charge accumulators (for static pressure)

2) Installed on pylon hillside

3) Diameter of 10 cm

4) Acquisition frequency 7.5 kHz and bandwidth 2.5 kHz

**Cantilever sensor:**

1) 6 stainless steel cantilevers strain gages. Sensors have been developed by Cemagref. Force is obtained *via* deconvolution of measured strains (Fig. 3). The method is validated in laboratory and in-situ (Baroudi et al., 2011).

2) Installed on the pylon lateral side and extend into the avalanche flow.

3) Dimensions 5 x 25 cm$^2$

4) Acquisition frequency is 2 kHz (bandwidth 0–500 Hz after regularization for the data analyzed here).

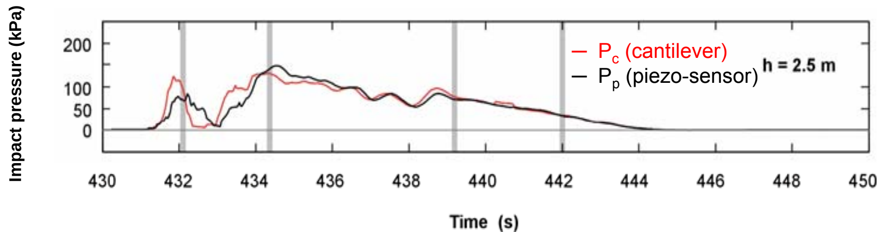
## 3. Fast dry snow avalanche

### Data: avalanche 2009-003

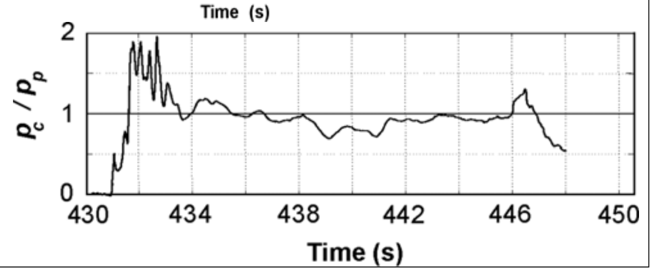
- Medium-sized dry dense avalanche released on 4 December 2008
- Avalanche velocity: up to 20 m/s
- Maximum flow depth at the pylon: 2.5–3.0 m (Kern et al., 2009)
- Froude number: between 2 and 4
- Avalanche duration: 17 s

### Results

- **Very good agreement** in the time-description of the pressure of this dry-dense avalanche: less than 10% of discrepancy for 80 % of the record
- Good agreement of the frequency response in the 0-100 Hz range (main energy content)
- 70% of common variance for 60% of the recorded pressure




$$\frac{P_c \text{ (cantilever)}}{P_p \text{ (piezo-sensor)}} \approx 1 \pm 0.1$$



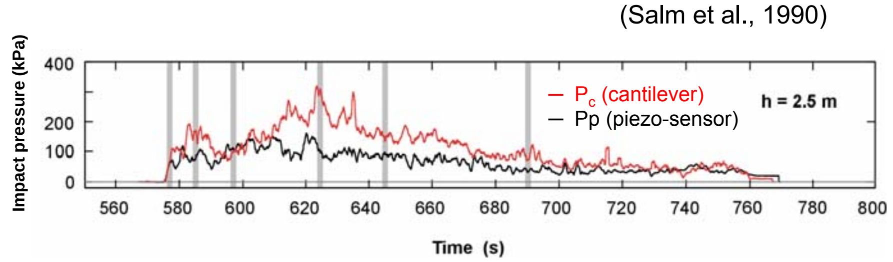

## 4. Slow wet snow avalanche

### Data: avalanche 8448

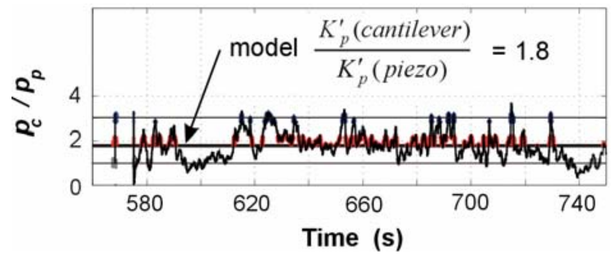
- Wet dense avalanche released on 1 March 2007
- Avalanche velocity: in the range 1-3 m/s, plug flow with small shear rate
- Maximum flow depth at the pylon: 3.5 m (Kern et al., 2009)
- Froude number: less than 1
- Avalanche duration: 200 s

### Results

- **Cantilever and piezo-sensor pressure generally diverge**: by a factor 2 (72% of the data), by a factor of 3 for 2 % of the data
- Poor correlation with 15% of the recorded pressure having more than 40 % of common variance
- Pressures are ~10–20 times that expected from the drag formulation (Salm et al., 1990)



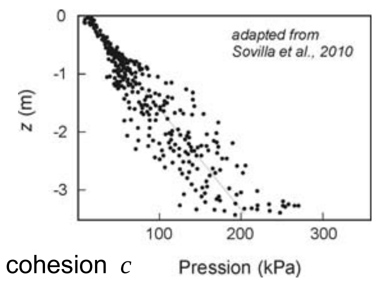

$$\frac{P_c \text{ (cantilever)}}{P_p \text{ (piezo-sensor)}} \approx 2$$




## 5. Macroscopic interpretation of the discrepancy

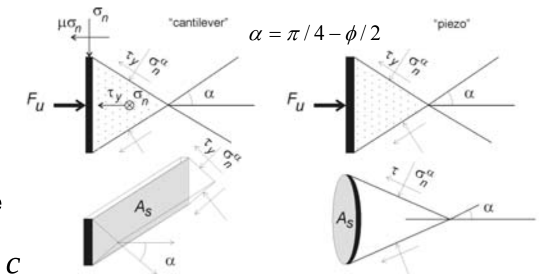
### from the data

- Impact-pressure are linear with respect to the avalanche depth $z$
  $p(z) = \xi \rho g z$ , with $\xi$ = 7.2 and 12 for piezo and cantilever sensors




### Model

- The pressure-depth linearity is consistent with a Mohr-Coulomb shear failure criteria $\tau \equiv \sigma_t \le \tau_y = c + \sigma_n \cdot \tan(\phi)$ , internal friction $\Phi$, cohesion $c$
- Shear failure occurs in the snow jamming around the sensors
- Dead zones of different shapes form on each sensor
- A normal balance of forces acting on such failure surfaces that delimit the dead zone can explain the observed differences in impact-pressure measurement




-Pressure = ultimate load expressed as local horizontal passive earth pressure

$$\frac{F_u}{A_s} \equiv p = \sigma_h = K'_p \cdot \sigma_v + K'_{pc} \cdot c$$

- The sensor specific $K'_p$ explain the observed $\xi$ factors and the differences between recorded pressures

## 6. Conclusion

- Sensor geometry effects on impact-pressure measurements were not observed in dry dense avalanche flow
- Avalanche impact-pressure measurements in slow, wet avalanche flow are affected by the shape and the size of the sensors
- A macroscopic approach is proposed and states that a shear failure occurs in the snow jamming around the sensors
- A Mohr-Coulomb shear failure criteria is consistent with the observed pressure-depth linearity
- The model interprets impact pressure in a wet cohesive avalanche as a limit load
- The model can be used to calculate snow forces exerted on structures of different geometry, offering possible improvements in engineering design calculations.

– Baroudi et al., *J. Glaciol.,* 2011. – Kern et al., *J. Glaciol.,* 2009. – Sovilla et al., *J. Glaciol.,* 2010.