How obstacle geometry and snow properties influence avalanche impact pressure

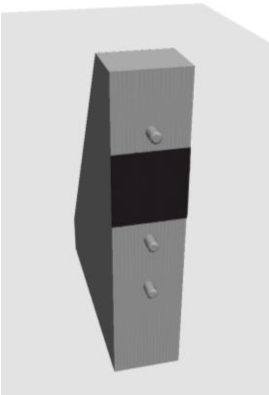
Michael L. Kyburz[1,2], Betty Sovilla[1], Johan Gaume[1,2], Christophe Ancey[2]

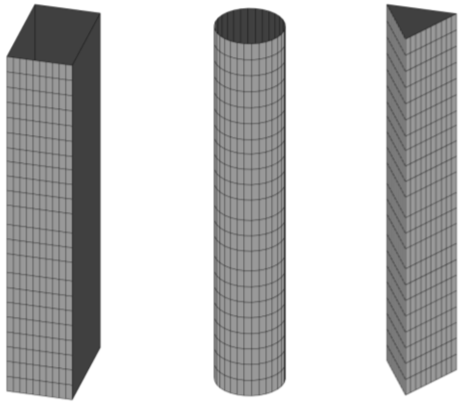
[1]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

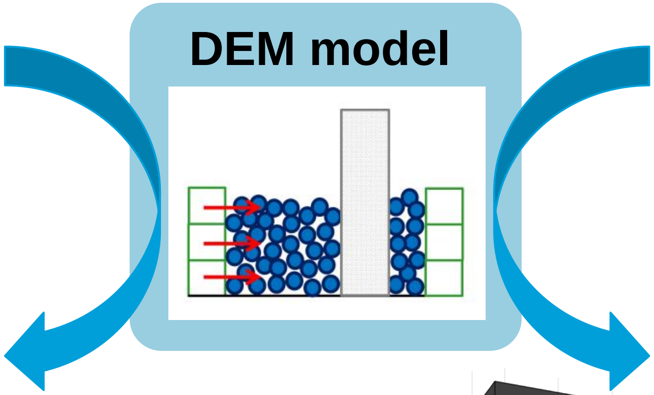
[2]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

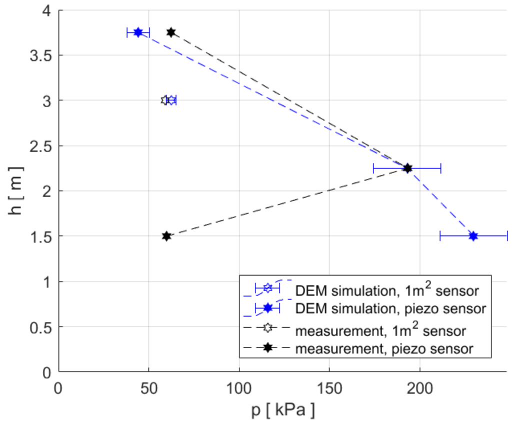
Contact:

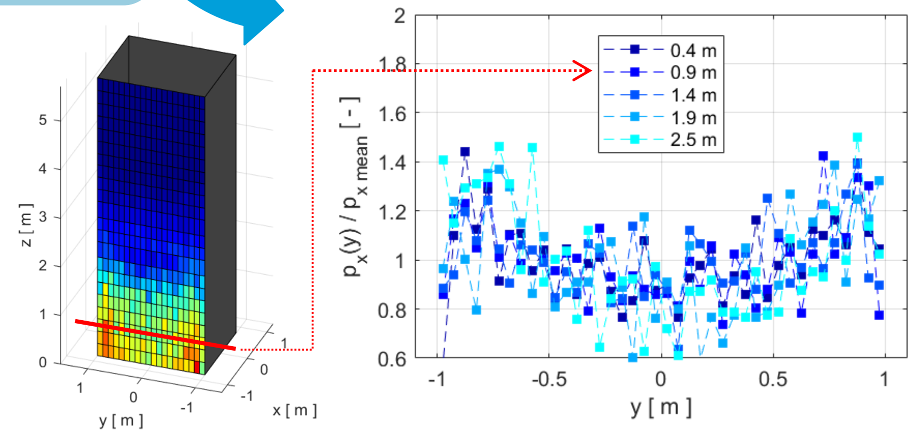
kyburz@slf.ch











How obstacle geometry and snow properties influence avalanche impact pressure

kyburz@slf.ch

Motivation

We aim to improve the estimation of impact pressure on structures which is usually estimated using empirical equations and coefficients.

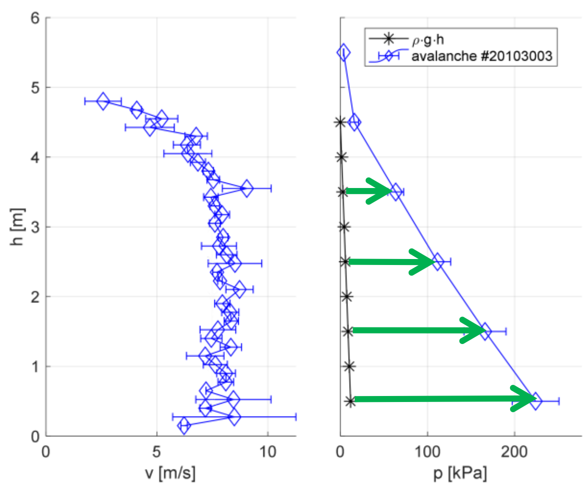
In practice the drag coefficient C_D and the amplification factor ζ vary in large ranges. Thus, for structure design it is often unclear how to choose suitable factors.

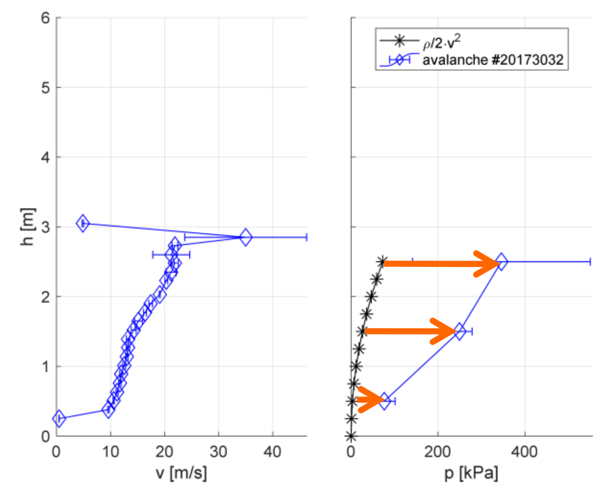
To identify the relevant physical processes involved in avalanche-structure interaction, we model dense snow avalanches as granular flows using the Discrete Element Method (DEM).

Gravitational regime

Inertial regime

$$p = \zeta \cdot \rho \cdot g \cdot H + C_D \cdot \frac{\rho}{2} \cdot v^2$$





$\zeta=[5,\ldots,10]$

[Sovilla et al. 2010]

$C_D=[2,\ldots,6,\ldots]$

[Norem 1990]
[Salm et al. 1990]

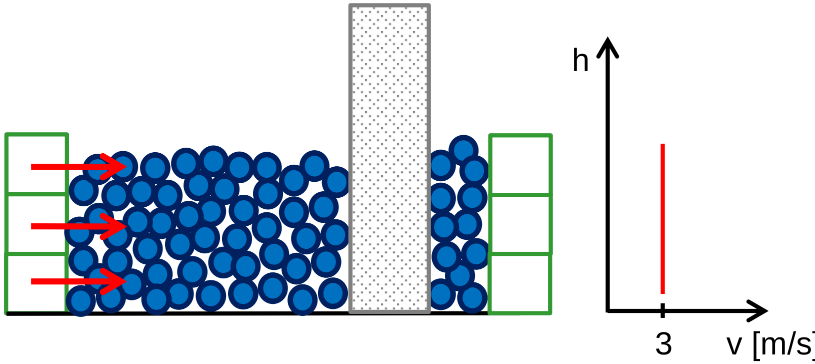
kyburz@slf.ch

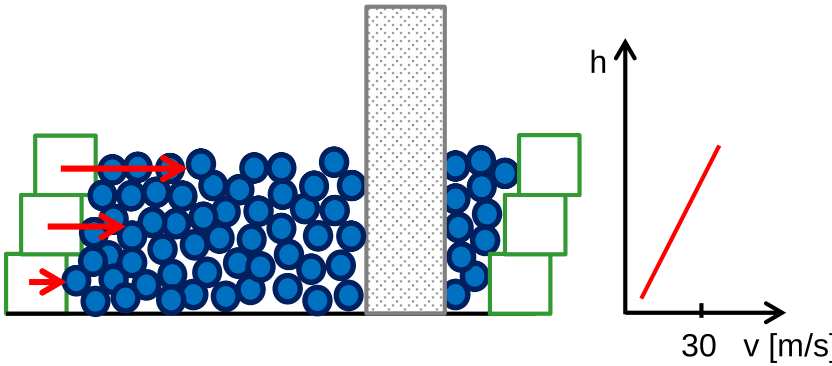
Discrete Element Method I

In nature the avalanche flow evolves along its path according to the topography and the snow properties. In our DEM model, the granular material is pushed past the structure by individually moveable boxes. This allows us to impose arbitrary velocity profiles, independently from the particle properties. The method is described in detail in [1].

We use four scenarios:

- Gravitational plug flow (top):
  - without cohesion (v=3m/s, c=0kPa)
  - with high cohesion (v=3m/s, c=10kPa)
- Inertial shear flow (bottom) :
  - without cohesion (v=30m/s, c=0kPa)
  - with high cohesion (v=30m/s, c=10kPa)





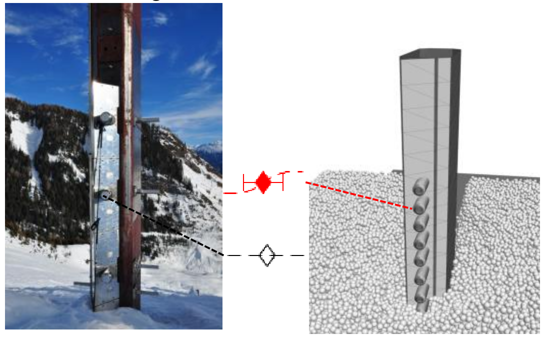
[1] Kyburz M. L., Sovilla B., Gaume J., Ancey C.; 2020

DEM model testing I

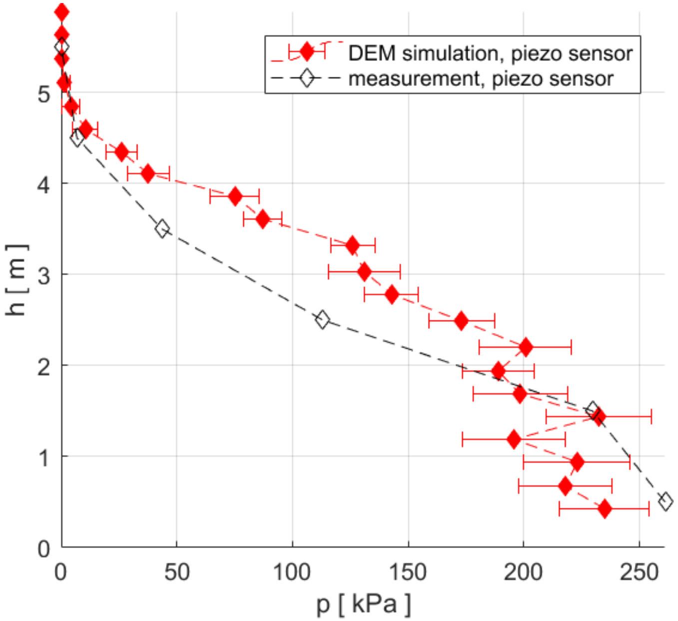
In our simulations we reproduce pressure measurements of the “Vallée de la Sionne” (VdlS) full-scale experimental site in Switzerland. The simulated pressures are compared to the measurements of the 0.6 m wide pylon (this slide) and the 1 m wide concrete wall (next slide).

At the wall the pressure is measured on a 1 m^2 square plate and on three piezoelectric sensors with a diameter of 10 cm. At the pylon the pressure is measured using the piezoelectric sensors.

Picture: P. Huguenin



measurement simulation



kyburz@slf.ch

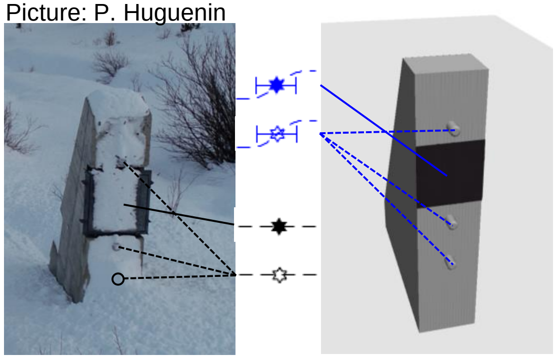
DEM model testing II

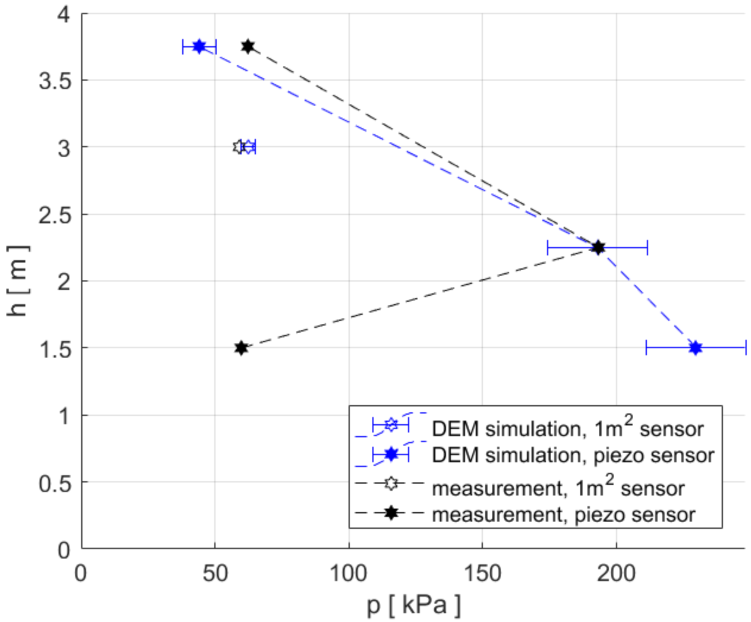
The measurement from a gravitational avalanche shows a significant difference between the pressure measurements by the different sensors.

The discrepancy between the simulated and measured pressures of the lowest piezo sensor may occur because the sensor is still in the resting snow cover or protected by the stagnating snow upstream of the wall.

We conclude that the numerical model is able to reproduce the pressure measured with both sensors of different size at the wall and two different structure geometries using the same simulation parameters.

Picture: P. Huguenin





kyburz@slf.ch

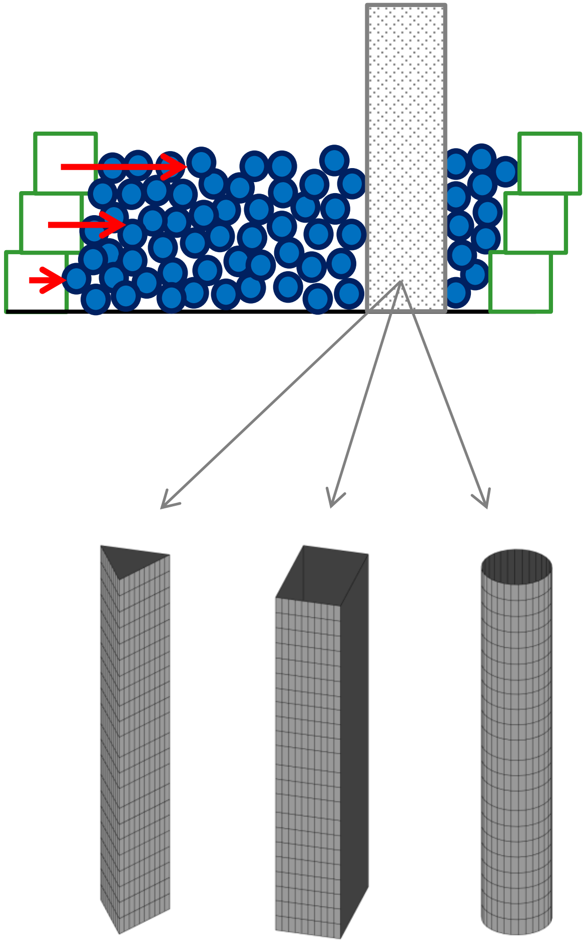
Discrete Element Method II

Apart from the structures at the field site, we also implement generic structures with triangular, rectangular and circular cross sections.

Structures with these geometries are relevant in practice as they are found in the shape of houses, dams, cable car posts, protective wedges or other infrastructure in avalanche prone terrain.

We vary the structure size to study the influence on the impact pressure.

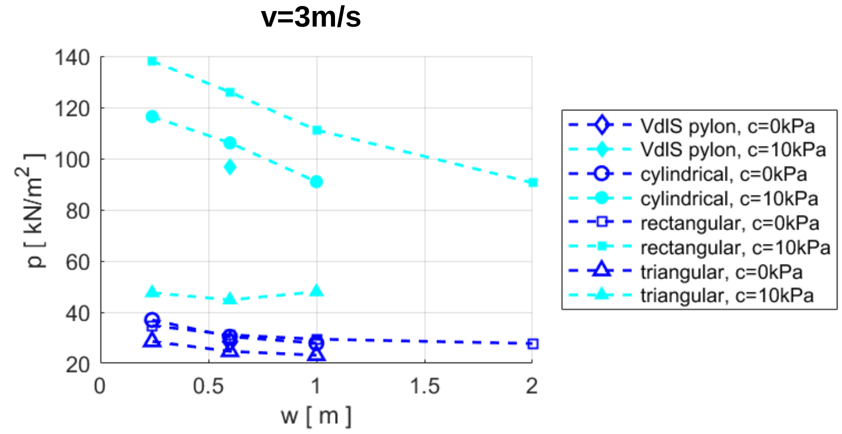
Furthermore, the structure surfaces facing the flow are divided into smaller areas to analyse the impact pressure distribution in these areas.

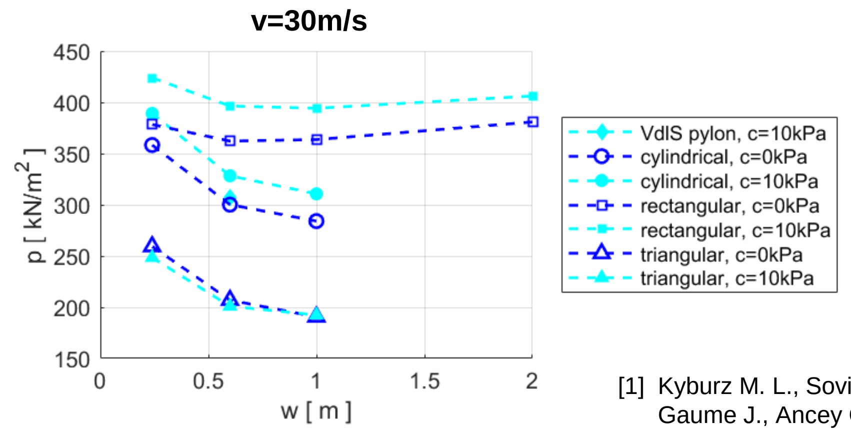


kyburz@slf.ch

Impact pressure influences

In agreement with other studies we find that narrow structures are more affected by gravitational flows, as the mean pressure *p* on the structure increases for decreasing sizes (width *w*). This behaviour is most pronounced for the rectangular and cylindrical structures. The size dependency is especially strong for cohesive flows.





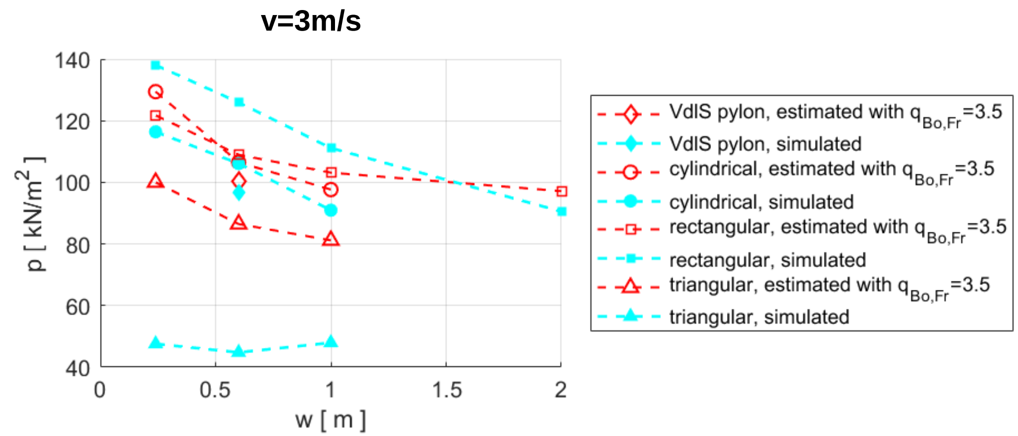
[1] Kyburz M. L., Sovilla B., Gaume J., Ancey C.; 2020

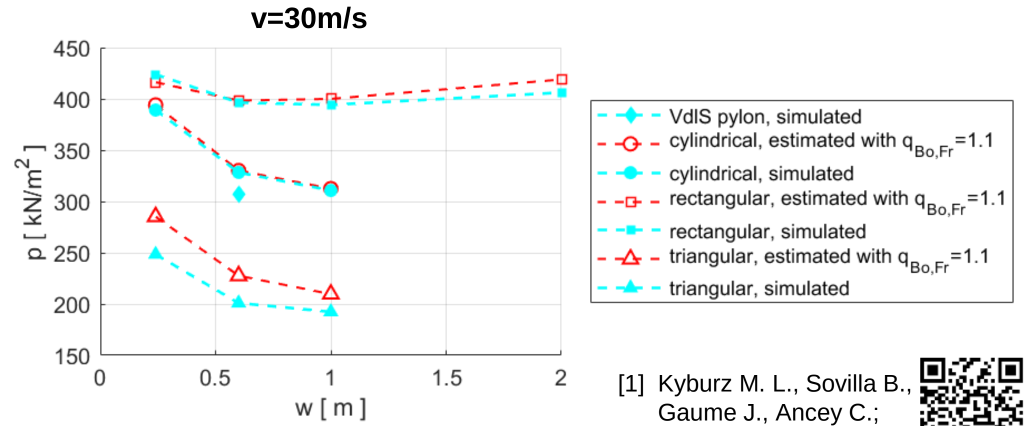
How obstacle geometry and snow properties influence avalanche impact pressure

kyburz@slf.ch

Impact pressure influences

In [1] we identify a pressure amplification factor $q_{Bo,Fr}$ relating the pressure of cohesive flows to the impact pressure of cohesion-less flows for the VdlS pylon. Here, we estimate the impact pressure of cohesive flows by multiplying the pressure of the cohesion-less simulations with $q_{Bo,Fr}$ for all geometries.
The estimated and simulated pressures agree well even for other geometries, except the triangular structure. The estimated values fit best for the data of the cylindrical geometry, which has also the closest absolute pressure compared to the pylon. The factor $q_{Bo,Fr}$ is most accurate for the 0.6 m wide structures, which corresponds to the width of the VdlS pylon.
These results highlight that the underlying physical processes depend on geometry and flow regime, and behave not linearly with the structure width.





[1] Kyburz M. L., Sovilla B., Gaume J., Ancey C.; 2020

How obstacle geometry and snow properties influence avalanche impact pressure

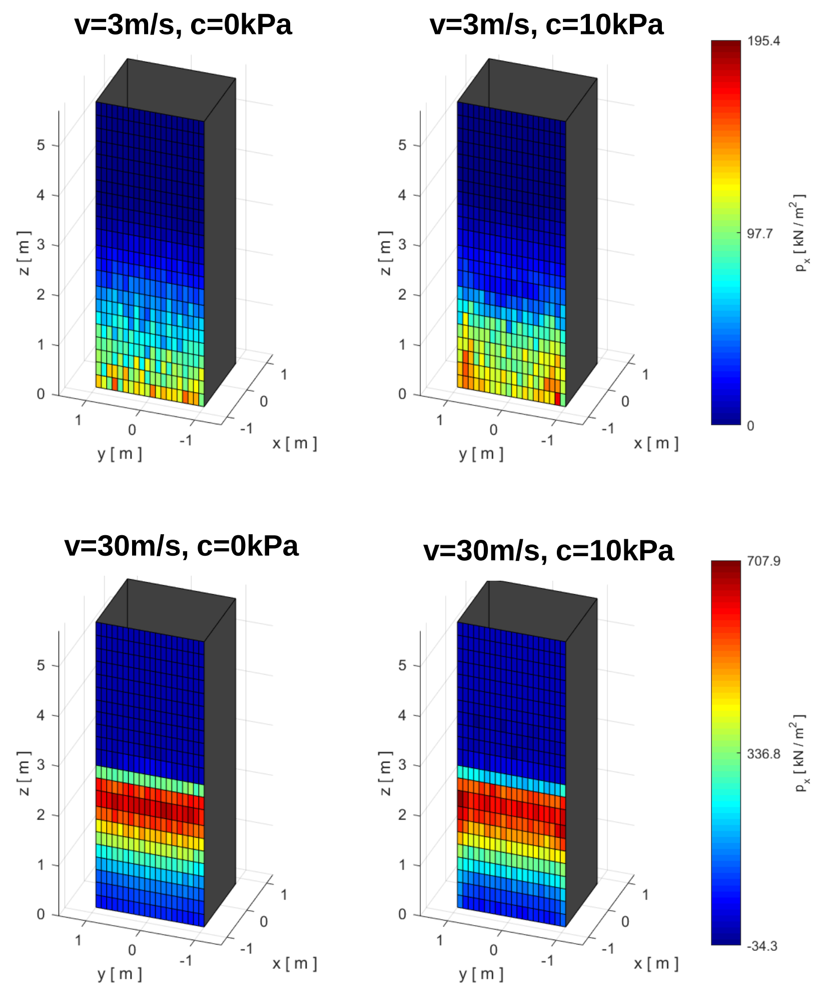
kyburz@slf.ch

Pressure distribution I

As an example we analyse the impact pressure distribution for a structure with rectangular cross section and a width of 2m.

In the vertical direction the pressure distributions show well established patterns.
For the gravitational plug flow (top) the pressure is linearly increasing with flow depth.
For the inertial shear (bottom) flow the pressure is proportional to the square of the velocity and is therefore highest near the flow surface.

In the horizontal direction the pressure distributions reveal that for low cohesion the pressure is evenly distributed across the width (left), while for high cohesion the pressure is concentrated near the edges at the side (right).



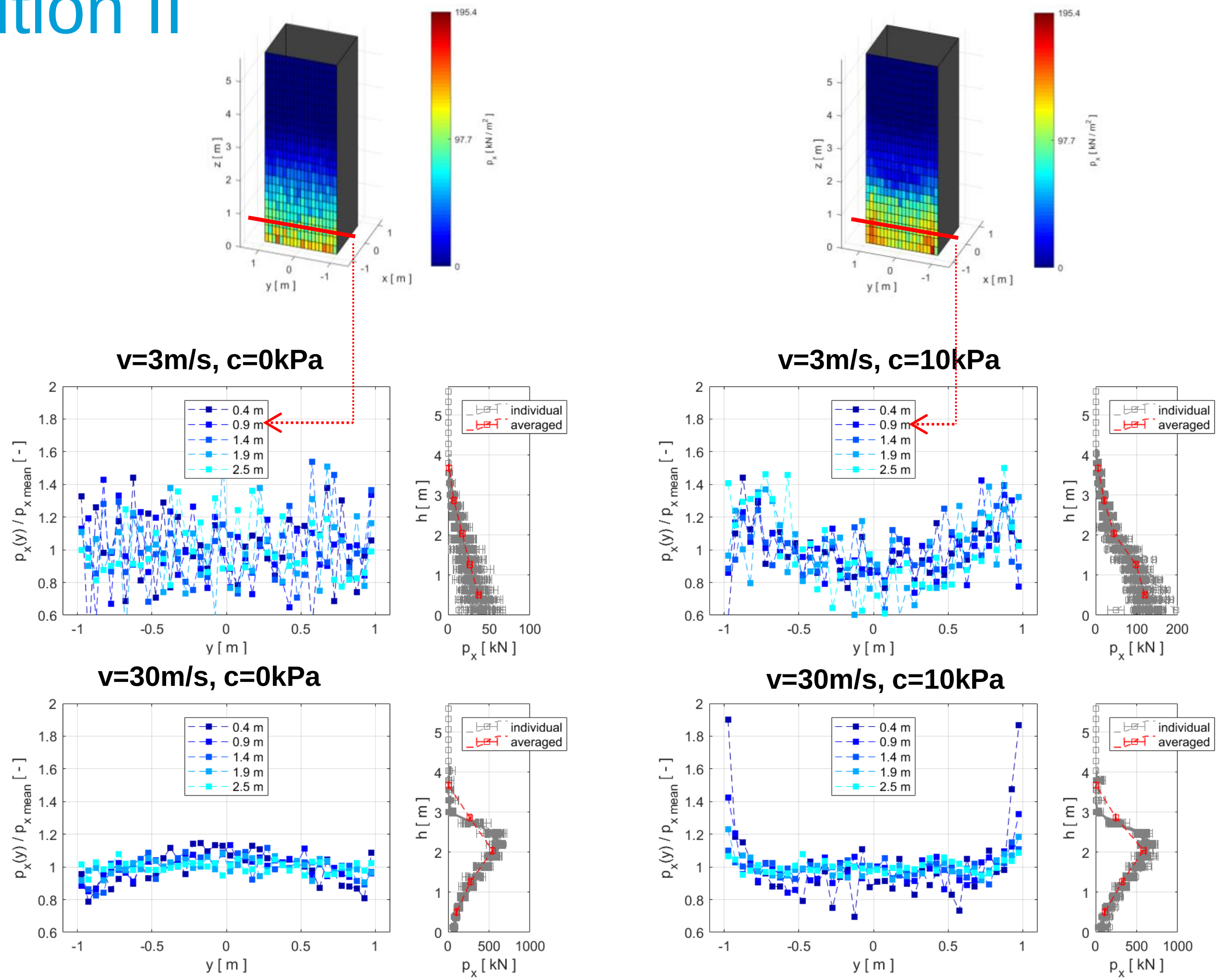
How obstacle geometry and snow properties influence avalanche impact pressure

kyburz@slf.ch

Pressure distribution II

Here, we show horizontal pressure profiles at different heights above ground normalized by the average pressure at that height.
The analysis reveals that the pressure is locally amplified up to 1.5 - 2 times the mean pressure.

In the vertical pressure profiles, the pressure on elementary areas of the impacted surface is shown individually (grey). By averaging the values of the divided surfaces we mimic the pressure experienced by sensors with a larger area (red).
This demonstrates the importance of the sensor size and placement to capture local pressure concentrations.



kyburz@slf.ch

Conclusions

- The presented model correctly reproduces the pressure on sensors of different sizes and structure geometries.
- Regime dependent local pressure variations and concentrations may play a critical role when measuring or estimating pressures.
- In most configurations the mean impact pressure decreases significantly for obstacles of increasing width. This behaviour is most pronounced for rectangular and cylindrical structures in gravitational cohesive avalanche flows.