ACTIONS OF SNOW AVALANCHES ON A SNOW SHED

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ABSTRACT. The actions of snow avalanches on slightly inclined protection structures like snow sheds are a complex dynamic phenomenon. The impact stresses (normal and tangential) evolve not only in time but also in space. To better understand these actions so as to be able to design such structures, several studies have been conducted. Experimental measurements have been performed on a full-scale avalanche test site at Col du Lautaret (French Alps) where an instrumented plate with force sensors has been set up in an avalanche path. At each artificial release of an avalanche, the impact stresses and their temporal variations were measured. This real-scale approach is completed by a laboratory-scale experimental approach using granular flows in an inclined channel where normal and tangential forces on a basal plate are measured. The experimental results show that the impact effect is very important, particularly at the location of the rupture of slope formed by the shed. However, the stresses decrease rapidly when the distance to the rupture of slope increases. Finally, to assess the dynamic effect of the avalanche loading on the structure, dynamic simulations with a simplified multi-fiber model have been conducted. The results show that the dynamic effect is not negligible but is not critical for the structure.

KEYWORDS: experiments, snow avalanche, granular flow, impact stresses

1. INTRODUCTION

The current design of protection structures like snow sheds against snow avalanches have limitations related to an imperfect knowledge of the impact stresses. The impact stresses (normal and tangential) which are created by the slope change between the natural path (35° ~ 45°) and the snow shed roof (10° ~ 15°) evolve not only in time but also in space. To better understand these actions so as to be able to design such structures, experimental approaches have been conducted. A little inclined plate-senor was set up on a full-scale avalanche test site at Col du Lautaret (French Alps) to directly measure the snow avalanche loadings. These experiments, facing the difficulty of weather conditions, have not yielded many results. Consequently, a laboratory-scale experimental approach using granular flows in an inclined channel was realized to complete the results. Finally, a dynamic modelling based on a simplified 2D multi-fiber model of the snow shed was performed.

2. METHOD

2.1 Real scale experiments

Experiments are carried out at the Lautaret full-scale avalanche test site in the southern French Alps (45.033°N/6.404°E). This site owned by the Cemagref Research Institute has been extensively described in previous papers (Issler, 1999; Berthet-Rambaud and *al.*, 2008; Thibert *and al.*, 2008; Baroudi and Thibert, 2009), so only a short description is given here.

The avalanche path n°2 is used for this experiment (Fig. 1). Its length is 500-800 m with an average slope angle of 36° that reaches 40° in the starting zone. Small to medium avalanches occur at a sufficient frequency (up to 3 or 4 each winter). Avalanche flows are generally dense, wet or dry, with sometimes a small but fast powder cloud (or saltation layer). The dense part is usually less than one meter thick. Typical released volumes vary from 500 to 10000 m^3 and maximum front speed can reach 30 to 40 m/s (Meunier *et al.*, 2004). These characteristics make this site of particular interest for experiments on infrastructures and avalanche impacts. A reinforced-concrete shelter for data and acquisition is located at a distance of less than 20 m of the avalanche path.

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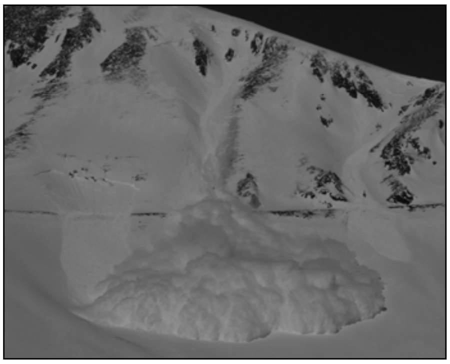

Fig.1: Avalanche artificially released on the 27 February 2007 in path n°2 where the instrumented snow shed is set up.

The instrumented snow shed is a double component balance designed measure the normal and tangential forces applied by the avalanche on the snow shed. A bottom frame is fixed in the ground with a variable orientation with respect to the horizontal plane [-20°, 0°] (Fig.2a). An upper frame is linked by 5 load cells and supports a 2 m^2 plate recovered by a concrete-like coating (Fig.2b).

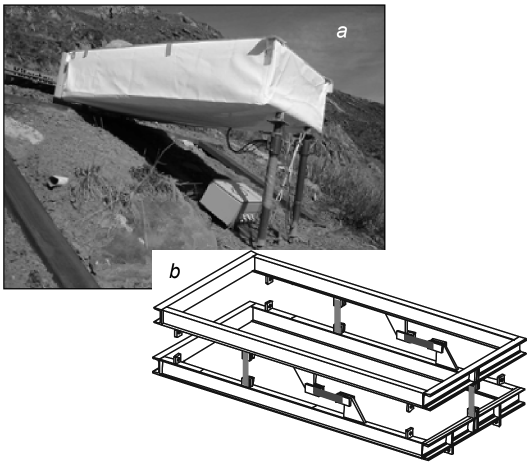

Fig.2: a. Instrumented snow shed structure set up in path n°2. b. Structure of the snow shed with the 3 normal and 2 tangential load cells.

The structure is designed for nominal avalanches at path n°2: velocity of 25 m/s, density of 250 kg/m^3 and height around 1 m which yields to a normal load of 30 kN and a tangential load of 12 kN for the 2 m^2 of surface of the structure (Salm *et al.*, 1990). Forces are measured with precision strain gauge load cells. The data-logger is a National Instrument PXI-SCXI system. Sampling rate for data acquisition is set at 3000 Hz to record dynamic effects. The 0-200 mV range signals of the load cells are amplified to a 0-10 V range before being conveyed along the 40 m long wires. Signals are filtered with a cut-off frequency of 1000 Hz to ensure a bandwidth without aliasing. Load tests have shown a transverse sensitivity of the instrumented structure of 7% between normal and tangential forces.

2.2 Laboratory experiments

The laboratory channel consists of two parts: the upper and lower channels. The upper channel has a total length of 6 m, a height of 20 cm, a width of 50 cm and an inclination set to 43° of horizontal. The lower part has the same section and is 15° inclined. The Froude numbers obtained in this granular flow experiments are within the same order of magnitude as a real-scale snow avalanche, i.e., 5–10. A gauge sensor is located at the bottom of the channel. The position of the sensor can be changed by moving a supporting plate. Both normal and tangential forces are measured by the sensor.

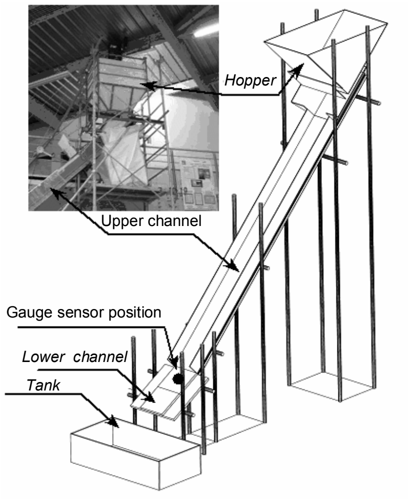

Fig.3: Granular flow experiment set-up.

Glass beads are used as the granular material. To avoid electrostatic phenomenon and the influence of friction of the sidewall at the center of the flow, grain size was chosen between 350 and 850 μm. The material density ρ_s is 2348 kg/m^3 and the bulk density ρ_b is 1637 kg/m^3. The natural slope angle is 28.8°. A layer of sandpaper was placed on the bottom of the channel. The grains on the sandpaper were similar in size to the glass beads. The basal friction is considered equal to the material's internal friction.

3. RESULTS: AVALANCHE IMPACT PRESSURE RECONSTRUCTION

3.1 Real scale experiments results

The results are exploited for two winter seasons 2005-2006 and 2006-2007. In total, five avalanches have been released in path n°2. The characteristics of these five avalanches are listed in Table 1. Except that of 21 February 2006 which is a small dense type, most avalanches are mixed avalanches, including a dense core and a saltation layer. All avalanches involve cold and dry ice particles. The mean front speed at the position of the sensor-plate is about 25 m/s.

Table 1. Characteristics of released avalanches.

Location	Date	21-feb-06	07-mar-06	14-mar-06	15-feb-07	27-feb-07
Release zone	Atmosphere temperature (°C)	-	-4.2	-	-1	-1.5
	Altitude (m)	2380	2380	2380	2380	2380
	Type	Dense	Mixed	Mixed	Mixed	Mixed
	Thickness (m)	0.15	0.2	0.2	0.5	0 ~ 0.7
	Density (kg/m³)	100	160	160	80 ~ 160	120
	Snow temperature (°C)	-2.2	-7.4	-4	-2	-2
Sensor-plate	Avalanche velocity (m/s)	13.6	25	19.3	25	28-30
	Deposite volume on the plate (m³)	0.4	0.37	0.31	-	0.6
	Deposite density (kg/m³)	250	300	340	320	220-260
Run-out zone	Low altitude (m)	2271	2100	2135	2100	2100
	Run-out distance (m)	355	500	430	510	510
	Density (kg/m³)	260	340	340	320 ~ 340	320
	Thickness (m)	0.15	-	0.5	0.3	0.3
	Snow temperature (°C)	-2.1	-4	-4	-0.8	-0.8 ~ -1.2

Fig.4a shows the normal impact pressures over time for 4 typical avalanches. According to different avalanches, the maximum value of normal pressure ranges from about 1 kPa to 15 kPa. The loadings of the instrumented snow shed are very different. Some have a remarkable peak corresponding to a very short period (avalanches of 7 March, 14 March 2006), some have a "peak" spread corresponding to a period of decade seconds (avalanches of 15 February and 27 February 2007 (not shown here)). The loading can also be almost constant in time (avalanche of 21 February 2006). The great variability of the impact loads is due to the great variability of the snow flows, speed, height and density between the different avalanches. It is therefore difficult to make a general conclusion from only five avalanches.

The ratio between the tangential and normal pressures (Pt/Pn) over time is shown in Fig.4b. The value of the ratio varies mainly between 0.2 and 0.6 throughout the avalanche. It is more important than the range commonly used by the French avalanche experts (between 0.2 and 0.4) and close to the experimental values obtained by K. Plazter (2006) on mixed avalanches in an inclined channel. Due to the fixed position of the sensor-plate, the spatial changes of impact pressures and ratio of Pt/Pn is not accessible for the real scale experiments. On the other hand, it can investigate by our laboratory experiments.

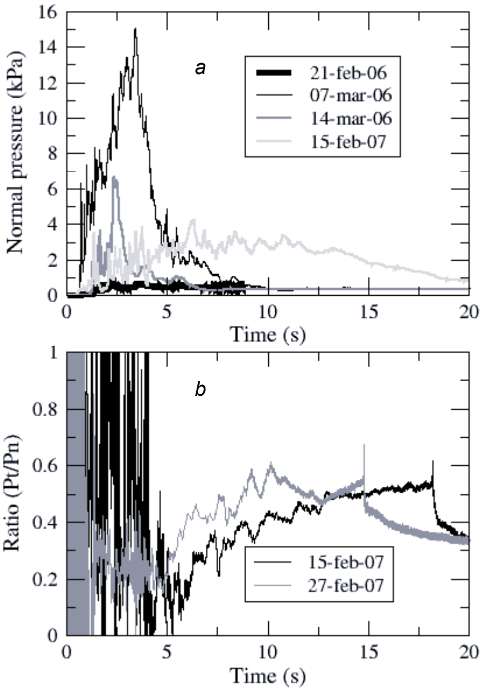

Fig.4: a. Normal stresses for four avalanches. b. Ratio Pt/Pn.

3.2 Laboratory experiments results

The temporal evolutions of the normal pressures exerted by the flow with an initial opening of 20 cm measured at 4 different positions are shown in Fig.5.a. According to the curves, remarkable peak at the beginning of the flow can be found for the measurement positions 0 cm and 5 cm. It almost disappears for a measurement position greater than 15 cm. The values of the normal pressures decrease quickly with the position and the ratio between the maximum and minimum peak value is about 7. Fig.5a highlights that the impact effect is very important at the position just after the change in slope and it decreases according to the distance.

Figure 5b shows the time changes of the ratio between the tangential and normal pressures. Firstly, the value of the ratio increases with distance and reaches a constant value of about 0.5 ~ 0.6 when the measurement position is greater than 15 cm. Then, at the position of 0 cm, the ratio varies over time between 0 and 0.35. And there are almost no changes over time for the other positions.

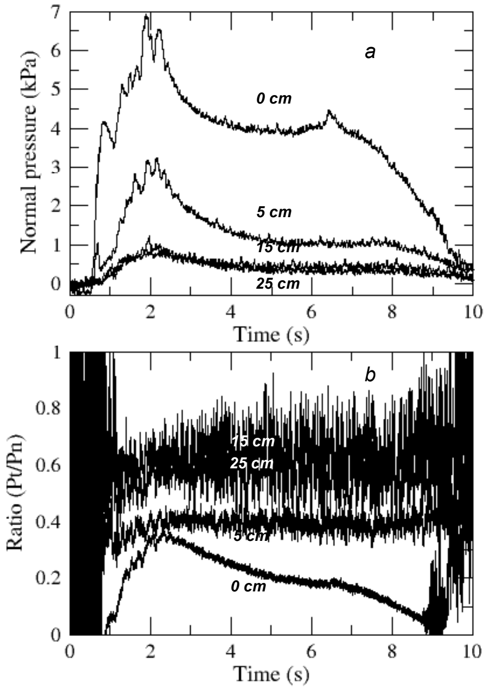

Fig.5: a. Spatiotemporal changes of the pressure. b. Spatiotemporal changes of the ratio averaged over time.

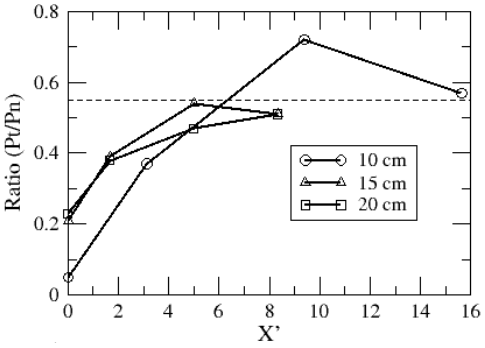

Fig.6: Spatial changes of the mean ratio.

We now compare the spatial changes in the ratio (mean value over time) for different flows. A more representative, characteristic is the undimensional parameter x′ defined as the ratio of the real position of the sensor from the change in slope to the characteristic height of the flow before the change in slope is used. For the three types of granular flow (10, 15 and 20 cm gate opening) we took the values of the characteristic height of 3 cm for the 15- and 20-cm gate opening tests, while 1.6 cm for the 10-cm gate opening tests. The results are shown in Fig.6. For all types of tests, we found that when x′> 5, the ratio values remained around 0.5 (except for one value due to the low values of Pn and Pt). These values are close to the material's internal friction coefficient, equal to 0.55. Our results confirm the findings of (Platzer, K., 2006).

4. DYNAMIC SIMULATIONS

The goal of simulations is to determine the existence of a dynamic effect due to the snow avalanche on the structure.

4.1 Model

To be able to apply a complex avalanche loading (varying in time and space), a simplified 2D model based on a multi-fiber beam, inspired from a reinforced concrete snow shed of Montaulever (Savoie, France), was used. It is a homogenized beam consisting of the entire slab, longitudinal and transversal beams (Fig.7). The beam has a length of 14.4 m, a height of 0.35 m and a width of 1 m. A state of plane deformation has been assumed in width. The liaison with the upper stream pole is simplified as a ball joint and the one with the downstream pole is a simple support. A damage law of La Borderie for concrete and a model of Menegotto Pinto for steel are used respectively. The numerical studies were conducted with the finite element software Fedeaslab.

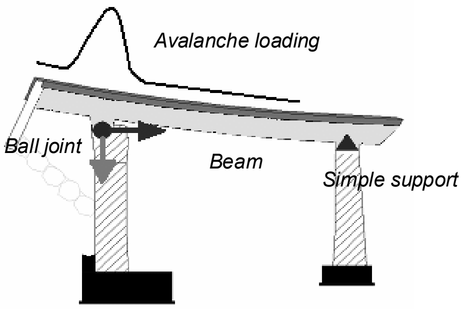

Fig.7: Simplified model.

4.2 Applied loading and numeric results

We firstly performed a modal analysis of the structure. The first frequency of the structure is 5.11 Hz, which is close to that obtained with a global model (Martinez Granados 2007). We assumed that the avalanche loading period was the period corresponding to the largest peak of loading. The loading frequency can then be calculated. For five avalanche loadings of Lautaret, the frequencies vary between 0.05 Hz to 1 Hz (see Fig.5.a), and they are much smaller than the first structure frequency. A priori, the snow avalanche loading on the snow shed can be considered as a slow impact loading. It means that the dynamic effect should not be very important. The loading of 14 March 2006 with a frequency (1 Hz) closer to the structure one has been applied. To accurately take into account the flow displacement on the slab with time, we also shifted the effort applied longitudinally on it.

The static loading simulation has been conducted to quantify the dynamic part. The results show that to get the same response of the structure in term of damage, the value of static loading must be 1.5-1.7 times larger than the maximum value of the dynamic loading. In other words, the dynamic effect is not negligible but is not critical as safety coefficients are also generally around 2.

5: CONCLUSION

This paper shows the research works on the snow avalanche loadings against the snow shed. Two aspects have been envisaged: impact effect due to the change of slope and dynamic effect of the avalanche loading on the structure.

For the first one, we have realized two experiments based on the real snow avalanches and a synthetic material (glass beads). The results of the real scale experiment show that the impact loadings have a transient state and can be very variable (value, duration etc.) according to the different flow conditions of the avalanches. The ratio Pt/Pn ranges from 0.2 to 0.6 throughout the avalanches. The spatial changes of stresses were measured by the laboratory experiment. According to the experimental results, the pressures have a very high value just after the change of the slope and decrease to the hydrostatic pressures when $x' > 5$. The impact pressures can be 7 ~ 10 times greater than the hydrostatic one, so that the impact effect is very important. The ratio Pt/Pn increases with distance, and when $x' > 5$, the value of the ratio is close to the basal static friction coefficient.

Regarding the dynamic character of the loading, simulations based on a simplified structure have been performed. The dynamic effect was quantified in comparing the dynamic and static results. Our conclusion is that the dynamic effect is not negligible but is not critical for the structure. But this part is quite crude and it deserves a deeper study.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Baroudi, D., Thibert, E., 2009. An instrumented structure to measure avalanche impact pressure. Cold Regions Science and Technology 58, doi:10.1016/j.coldregions. 2009.05.010.

Berthet-Rambaud P., Baroudi D., A. Limam, E. Thibert, Taillandier J.-M., 2008. Characterization of avalanche loading on impacted structures: a new approach based on inverses analysis. J. Glaciology, 54(185), 324-332.

Issler, D., 1999. European Avalanche test sites. Overview and analysis in view of coordinated experiments. Issler, D. (Ed.)., Eidg. Inst. SLF, Mitt. 59.

Meunier, M., Ancey, C., Taillandier, J.M., 2004. Fitting avalanche-dynamics models with documented events from the Col du Lautaret site (France) using the conceptual approach. Cold regions science and technology, 39 (1) 55-66.

Platzer, K., 2006. Experimental investigation of avalanche forces acting on snow sheds. University of Natural Resources and Applied Life Sciences Vienna, Thesis.

Thibert, E., Baroudi, D., Limam, A., Berthet-Rambaud, P., 2008. Avalanche impact pressure on an instrumented structure. Cold Regions Science and Technology. doi: 10.1016/j. coldregions .2008.01.005

Tiefenbacher, F., Kern M.A., 2003. Experimental devices to determine snow avalanche basal friction and velocity profiles. Cold regions science and technology Vol. 38, p17-30.