FRENCH AVALANCHE RESEARCH : EXPERIMENTAL TEST SITES

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ABSTRACT: A variety of small-scale and full scale measurement instruments have been developed by Cemagref (ETNA research unit, Grenoble France) to study avalanche dynamics and define avalanche mitigation strategies. The avalanche site at the Lautaret pass is used since 1972. Two sides of the Chaillol mountain are operated at the experimental avalanche site located at the Lautaret pass (France). Three avalanche paths are used during the artificial releases by explosives. The avalanche paths n°1 and n°2 are equipped with structures supporting instrumentation which aims at measuring the thickness, the depth velocity profile and the pressure of avalanche flows. The snow chute at the Lac Blanc pass has been developed since 2000**.** At the Lac Blanc pass, located on the Alpe d'huez ski resort at 2800 m, the ETNA research unit has set up an experimental device which allows us to generate steady and uniform snow flows under entirely controlled conditions, and to measure the flow parameters: the mass flow rate, the flow thickness, the velocity profile, the shear and normal basal stresses. The instrumentation development in the Taconnaz avalanche path is in progress (2009). Taking the opportunity of the new design undertaken for the avalanche protection system at Taconnaz, the ETNA research unit has scheduled to equip two large retarding mounds recently built, located at the top of the run-out zone, with sensors to measure flows velocities and pressures, in the framework of the DYNAVAL Interreg III project.

KEYWORDS: Avalanche, experimental test site, full-scale, small-scale

1. INTRODUCTION

Each year hundreds of avalanches present serious risks in the French mountains for humans and constructions (including roads, bridges etc). From the point of view of fluid mechanics the flow of avalanches is a most complex phenomenon. One of the principal tasks of the research unit ETNA of the French institution Cemagref is to conceive and construct tools which may be applied to the reduction of natural hazards related to avalanches.

To this end a variety of *in-situ* measurement instruments have been developed. The flow channel from the Lac Blanc pass allows us to improve our understanding of the flow of dry snow under controlled flow conditions, which include the rate of flow and the corresponding flow angle.
In contrast, at the full-scale installation at the Lautaret pass, the avalanches are triggered artificially and are studied using instruments in the avalanche path.

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In particular the flow dynamics and the impact on constructions are studied in detail.

An other full-scale equipment is the operational protection site of Taconnaz which will shortly be used to study impact pressures for very violent flow dynamics.

2. THE AVALANCHE SITE OF THE LAUTARET PASS

2.1 *The site*

This site is used by the Cemagref since 1972. It is located on the Chaillol mountain between the Lautaret pass and the Galibier pass. The initial goal of this site was the study of snow avalanche dynamics and artificial release technology. It was chosen because it is close to Grenoble (90km) and the Grenoble-Briançon road is open all year long despite the pass elevation of 2068 m. Heavy snowfalls and severe storms can occur there and the site offers seven avalanche paths.

The starting altitudes varies between 2300 and 2600 m. The run-out zones are around 2100 m. The slopes of the flowing areas vary between 30° and 40°. The released avalanche volumes vary between 1000 and

10000 m^3. The covered distances are between 300 and 800 m. Various avalanche types are observed: wet and dense, dry and dense and mix. The involved snow is often new snow deposit under the crest. The snow height in the starting area varies between 0,50 and 2 m. The maximum observed velocities varies between 20 and 40 m/s. Today 3 paths are used, all crossing the Galibier road (Fig. 1).

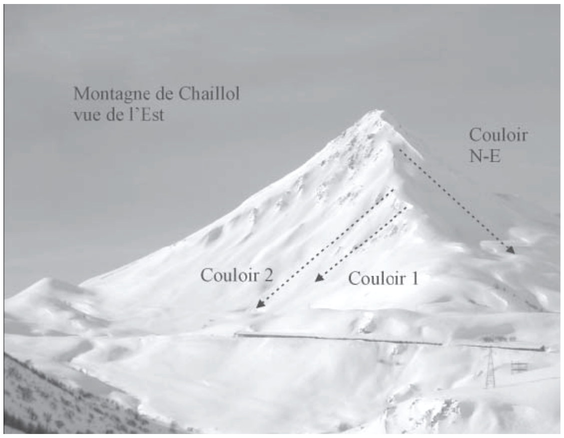

Figure 1: Avalanche Lautaret site

2.2 *The triggering*

After the first Catex (bomb-tram) used in France was tested here, now path n°1 is released by manual explosive (Fig. 2) with electric starting, and path n°2 is released with a Gazex remote system (gas explosive tube). The North-East path is released with an Avalhex (gas explosive balloon), a new system developed and tested by Cemagref and CEA in Lautaret site.

2.3 *The Avalanche path n°1*

Its length is 500 m with an average slope angle of 36° that reaches 40° in the starting zone. An instrumented structure is set up to measure avalanche impact pressure. It consists of a one square-meter plate supported by a 3.5 m high steel cantilever, facing the avalanche, and fixed in a strong concrete foundation (Fig. 3). The plate can be moved along the beam to be located exactly at the surface of the initial snow-cover prior to avalanche release. It represents a large obstacle in comparison to the flow height and therefore integrates the effects of flow heterogeneities. Strains are measured at the bottom of the beam with precision strain gages placed in the maximum bending moment area. Sampling rate for data acquisition is set at 3000 Hz to record dynamic effects. Signals are filtered with a cut-off frequency of 1000 Hz to ensure a bandwidth without aliasing. This system has provided new results in avalanche impact pressure quantification (Berthet-Rambaud et al., 2008; Thibert et al., 2008; Baroudi et Thibert, 2009).


Figure 2: Avalanche artificially released on the 15 February 2007 in path n°1.


Figure 3: Instrumented structure set up in path n°1. The 1 m^2 plate can be moved along the beam to be located exactly at the surface of the snow-cover.

2.4 *The Avalanche path n°2*

A little bit longer than the n°1 but with similar slope angles, path n°2 is consecrated to the study of flow dynamic (Fig. 4). To this end a sensor support (a steel tripod) is equipped with sensors able to measure the flow velocity of the avalanche and the pressure each 20 cm over a vertical height of 3.5 m. The pressure sensors are commercially constructed and are set up on a mast facing the flow. The velocity sensors, developed in our laboratory, are located on arms attached on the left side of the mast (Fig 5). An accelerometer measures the vibration of the tripod to check the boundary conditions of the pressure sensors. Electronic signals are conveyed to the measurement bunker situated between the two avalanches paths. Preliminary results will be shortly published.

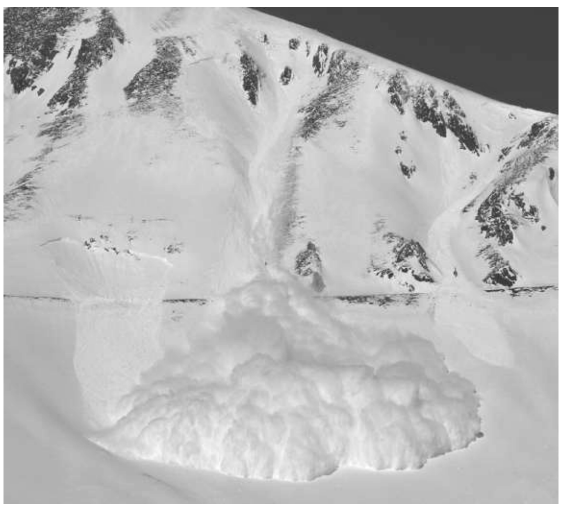

Figure 4: Avalanche artificially released on the 27 February 2007 in path n°2.

Figure 5: Pressure (right) and velocity (left) sensors set up on the tripod at path n°2.

3 THE SNOW CHANNEL AT THE LAC BLANC PASS

3.1 *The site*

The principle here is to build a "laboratory-like" flow experiment using natural snow particles. This implies being able to control the flow and reproduce it easily in a flow channel. As our research unit is not equipped with cold rooms, the instrument has to be located in the filed at a high enough altitude so that snow can be directly brought from the ground to the experiment after a snow-fall. Such a device was built during the winter of 2000– 2001, near the Alpe d'Huez ski resort at 2800m elevation.

3.2 *The feeding system*

The feeding system (hopper + Archimedean screw) is commonly used in industry and is known for providing constant flow discharges. The screw is 4 m long with a 0.6 m diameter. It has a slightly increasing thread lead to limit compaction and metamorphism of the snow during operation. It is set in motion with a diesel engine linked to the screw by a hydraulic engine. This enables to set a constant rate at any value below 220 m^3 /hr. Since the storage capacity of the hopper is around 5 m^3, the flow can last from one to several minutes. However, to avoid the snow compacting too much, the hopper is filled up to only one third of its capacity, providing flows lasting roughly 20–30 s (Fig 6).

Figure 6: The feeding system and the channel

Figure 7: The avalanche path of Taconnaz : avalanche protection system designed in 1991

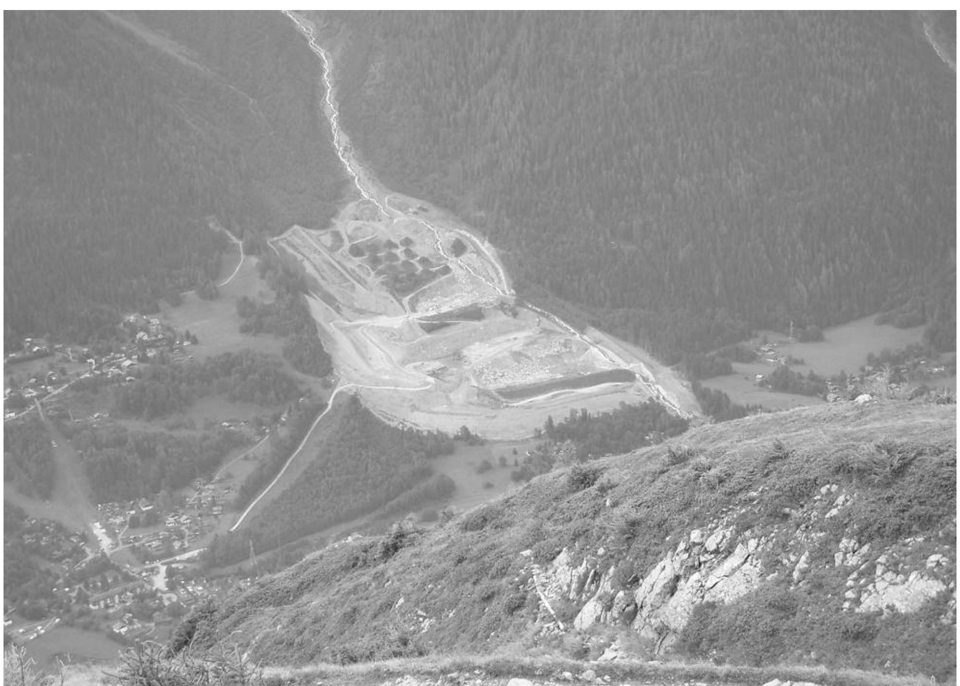

Figure 8: The avalanche path of Taconnaz in 2010 (by the courtesy of Roland Burnet): new avalanche protection system under construction

3.3 *The flow channel*

The channel is clamped to a beam with adjustable inclination. Therefore, the channel slope can be set from 27° to 45° at increments of 2°. The channel length is 10 m, its width is 0.2 m and its height is 0.2 m. Since it is narrower than the screw, a funnel-shaped slide links the end of the screw to the beginning of the channel. The bottom of the channel was covered with sand paper to create a high shear rate. Underneath, it has a double bottom where the electronic systems required for the sensors are installed (fig 6).

This equipment has provided new results in snow particles rheology and constitutive relation of snow flow (Bouchet et al., 2004; Rognon et al., 2007).

4 THE TACONNAZ AVALANCHE PATH

4.1 *The site*

The Taconnaz avalanche path in the Chamonix valley is an exceptional channel overlooked by the Taconnaz glacier (Fig 7). The total length exceeds 7500 m with a mean slope of 46%. The corridor width varies between 200m and 400m. There are several potential starting sites at approximately 4000m on Taconnaz glacier. The run out is located at 1100m in the valley.

4.2 *Triggering*

Triggering occurs naturally, sometimes in relation to serac downfalls from the ice fall located at 3400 m. An historical revue of the avalanche activity has revealed the existence of 75 events over the 20th century.

4.3 *Avalanche protection system*

The avalanche protection system which was completed in 1991 was designed to contain up to 800 000m^3 of dense wet snow. Recently, passive structures had to be improved (Naaim et al., 2010). A new statistical analysis of historical data combined with numerical modeling of dense avalanche allows characterization of 100 year return period events : Centennial values are 3.58 for the Froude number and 1.6Mm^3 for the volume. Physical and numerical models of dense avalanches interacting with defence structures are combined in order to design the most effective passive structure able to contain the reference scenarios and works are in progress (Fig. 8).

4.3 *Measuring equipment*

At the same time, Cemagref set up sensors on braking mounds constructed at the entry of the run-out zone and which are expected to resist a 72t/m^2. Three mounds, approximately 7 meters high, have been equipped with two pressure sensors and two velocity sensors. The same technology of sensors as those set up at Lautaret is used but adapted to the highest velocity and pressure values expected here. It aims at better understanding the dynamics of avalanche flow over and around breaking mounds, estimating the run-out distance reduction, and determining impact forces (particularly dynamic drag coefficients) at large scale for natural avalanches. These measurements are complementary to those conducted on the Lautaret avalanche test site (France / Cemagref) at intermediate scale.

Figure 9: Reinforced concrete shear wall's building specially designed for supporting sensors and for withstanding flowing avalanche

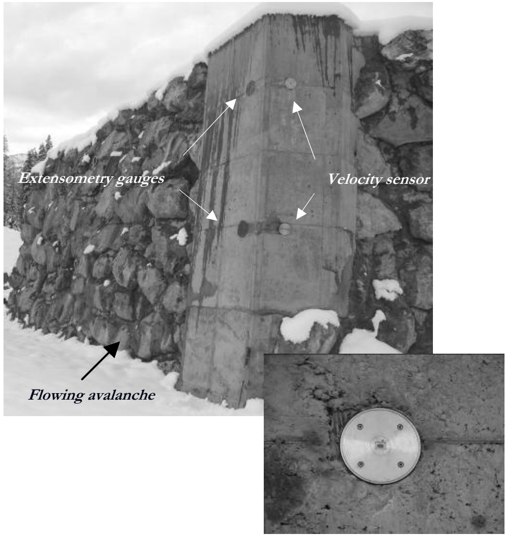

Figure 10 : Breaking mound equipped with pressure and velocity sensors

Figure 11 : Protective chamber for data logger at the foot of the breaking mounds

Figure 12 : First avalanche impacting the measurement device, February 2010

Taconnaz avalanche path's equipment was done in the framework of the European project DYNAVAL (INTERREG ALCOTRA) with a cofinancing from General Council Haute-Savoie.

5 CONCLUSION

This short presentation of the French avalanche experimentations shows the three scales of the experimental approaches. The decametric scale with the Lac Blanc channel has shown its potential with two PhD theses that used this set-up (Bouchet et al., 2004; Rognon et al., 2007). The medium scale is accessible at the oldest French avalanche test-site at the Lautaret pass, who after lot of result regain a new life with new equipments in relation to new research projects. At the end, the extreme scale with Taconnaz who promised interesting results in perspective of the Alcotra Interreg III research project.

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7. REFERENCES

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.

Bouchet, A., Naaim, M., Ousset, F., Bellot, H., Cauvard, D. - 2003. Experimental determination of constitutive equations for dense and dry avalanches: presentation of the set-up and first results. *Surveys in geophysics* 24: 525-541.

Bouchet, A., Naaim, M., Bellot, H., Ousset, F., - 2004. Experimental study of dense snow avalanches : velocity profiles in steady and fully developed flows. *Annals of Glaciology*, vol. 38, p. 30 – 34.

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

Naaim, M., Faug, T., Naaim, F., Eckert, N., 2010, Return period calculation and passive structure design at Taconnaz avalanche path, France. *Annals of Glaciology 51(54)*, p. 89-97.

Rognon P., Chevoir F., Bellot H, Ousset F, Naaim M ., Coussot P., 2008. Rheology of dense snow flows: Inferences from steady state chute-flow experiments. Journal of Rheology 52(3): 729-748.

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