OCCURRENCE CONDITIONS OF TWO CATASTROPHIC AVALANCHES AT CHAMONIX, FRANCE

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ABSTRACT : In February 1999, in Chamonix, France, a large avalanche destroyed 14 houses and killed 12 people in a village called Montroc and another flowed through a large stopping system (Taconnaz avalanche path). After presenting historical and meteorological data, the paper focuses on describing the main effects (trajectories, destructions) of the dry-avalanche flows and the consequences in terms of hazard zoning or protective measures.
Depending of the chosen parameter (snow fall, snow height in the starting zone, runout distance), the return periods of these events ranged from 5 years to more than 100 years.
Although the point can be still debated, our opinion is that these two avalanches were dry-snow avalanches, with most of the mass near the ground. Using two different approximate dynamic models (Voellmy and powder snow) allowed us to compute different physical parameters (heights, speeds, pressures). The effects of the rising slopes (because of the opposite mountain side or of high catching dam) in the last course part are taken into account. In terms of mitigation measures, comparison of the two different methods, (new zoning for Montroc and extension of the protection system for Taconnaz) illustrates difficulties (technical, legal, and social) encountered by public officials.

KEYWORDS : avalanche, mitigation, Chamonix

1 INTRODUCTION

In recent European history, February 1999 was one of most catastrophic periods in terms of avalanche activity. Across the Alps, this occurred within two weeks resulting in the death of about 70 persons and extensive damage to forests and facilities : 12 people killed in the Montroc village (France, Haute-Savoie, Chamonix) on the 9th, 12 persons Switzerland on the 21th, 1 in Italy and 38 residents in Austria on the 23th. To find comparable death toll and damage extension, we have to come back to the terrific winters 1970 (95 people killed in France and Switzer-land), 1954 (143 persons killed in Austria), and 1951 (98 people killed in Switzerland). To better understand the origins of such catastrophic events, this paper focuses on the Montroc and Taconnaz avalanches occurring on February the 9th and 11th.

2 GEOGRAPHIC CONTEXT

In the French Alps, in the vicinity of the "Mont-Blanc" peak, the highest in Europe with 4,807 m, Montroc is a little village in the upper part of the Chamonix valley (see arrow in Figure 1) and Taconnaz is another one located in its middle.

These two sites are shown in the 2 following pictures :

Photo 1 : Montroc

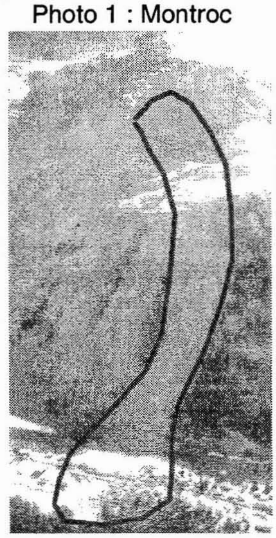
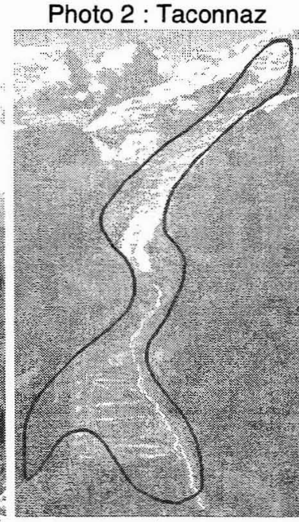


Photo 2 : Taconnaz



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The main characteristics of these sites are reported in table 1.

Table 1 : Main characteristics of the sites

		Montroc	Taconnaz
Direction from Chamonix		N-E	S-W
Altitude (average) in m	village	1350	1010
	top site	2450	4000
Starting zone	area (ha)	3,5	~180
	ground aspect	fallen rocks	glacier
	sun orientation	N-W	N
Track	cross section	Open	open then confined
	profile type	Irregular	regular
Runout zone	area (ha)	4	~30
	average slope	-(6° and 3°)	11,5°
Global	average slope	27°	26°

The average slope can be estimated as intermediate compared to usual avalanche areas. It is convenient to split the avalanche path into four distinctive zones for Montroc (see figure 2) and into six for Taconnaz (see figure 3). The lower limits of the starting zones are ill-defined and have been estimated arbitrarily.

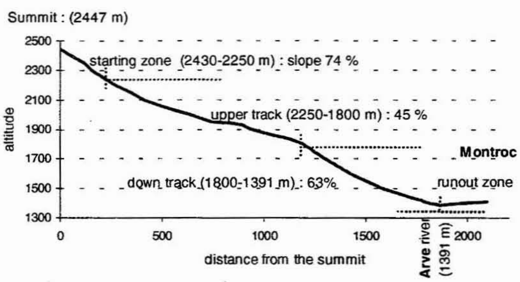
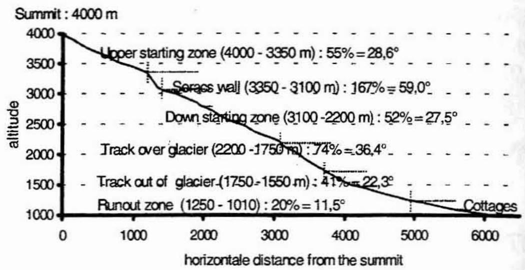


Figure 2 : Montroc lenghtwise profile

A key feature in the Montroc lengthwise profile, is the low slope angle, close to 36% (20°), over a 700-m distance at the end of the upper track. It is sufficiently low to cause the deposition of most avalanches. If an avalanche can flow through this area, then, below an altitude of approxima-tely 1800 m, it benefits from a substantial increase in the slope, ranging from 100% (45°) at the beginning to 22% (12°) near the river. Before the accident, this section of the avalanche path was mainly occupied by dwarf alders and surrounded by a scattered larch forest. Then the runout zone is located in the opposite south-facing slope. It is negative and gentle, with a slope ranging from 5% and 10% (from 3° to 6°). After 1945, a few chalets have been built in this area, mainly along the road.

In the Taconnaz lengthwise profile, there is a serac wall in the middle of two large potential starting zones. A large part of the track is also over the glacier. The down part of the track (down to the beginning of the deposition area at 1250 m) is confined by a high moraine.
Different cottages (Taconnaz, Vers-le-Nant, La Côte-du-Mont) are built on the alluvial fane at approximately 1050 m. At these locations the slope angle is still pronounced (17% = 9,6°) and positive.



Closing the runout zone, the Taconnaz stopping

Figure 3 : Taconnaz lenghtwise profile

system stretches from 1250 m to 1180 m and includes 11 deflecting concrete walls, 14 braking mounds, 3 platforms and 5 different big dams. The main catching dam rises up to 14 m height. All these elements were built in 1990.

Table 2 : Main significant aspects

		Montroc	Taconnaz
Avalanche path size		usual	(very) big
Runout zone	location	opposite side	regular
Avalanche activity		unknown from the top	known

3 METEOROLOGICAL CONDITIONS PRECEDING THE AVALANCHES

At the beginning of January, the snowcover in the northern Alps was shallow scarcely reaching 50 cm in north-facing slope at 2000 m of altitude, At the end of January, 150 cm of fresh snow within 4 days were measured at Le Tour (altitude 1470 m), the village closest to Montroc. After several sunny, windy and cold days, a new stream struck the Alps on February the 6th. The temperature was particularly cold (-10°C isotherm at 2500 m) all along. Especially in the Mont-Blanc valley, huge amounts of snow were recorded. In Le Tour, from the 6th to 10th February, the snowfalls reached 225 cm. In this location, the return period of such snowfall was estimated at 4 years, that is relatively usual. In the same time, in the Chamonix center (altitude 1050 m) with 140 cm of fresh snow, the corresponding period of return was evaluated at 40 years. The deviation in frequency is mainly due to the difference of elevation between the two stations.

The snowpack structure has been evaluated:
- a great quantity of cold recent snow with low cohesion, settling under its own weight (mean density close to 110 kg/m³) ;
- a weak layer probably existing at the base of this recent snow in spite of the strong winds which preceded the episode from the 6th to 10th ;
- deep layers made up mainly of plane faces or depth hoar.

The avalanche risk was announced by the local meteorological centre as very extreme (level maximum : 5) from the Sunday afternoon to Wednesday the 10th (where it decreased to 4/5). It reached its paroxysm Tuesday the 9th. Thus in 3 days, 17 major avalanches reached down the bottom of the Chamonix valley. Among them, 8 were characterized by a runout distance larger than those previously known (as reported on the local avalanche registration map, in its 1991 edition). The avalanche of Montroc occurred on Tuesday the 9th, around 2h40 p.m. Taconnaz arose two days later on Thursday the 11th, approximately at 4h a.m. and was the last of this avalanche series.

4 THE METHODOLOGY

As avalanches are complex phenomena and current knowledge limited, it is still difficult to give a faithful description of what exactly happened. To study these two avalanches in the most confidently way, recourse has been made to various sources of information and methods :
- gathered testimonies: because of poor visibility (snow was falling the 9th) or night (for Taconnaz), no direct observation was possible ; Some people reported blast effects, window vibrations, muffled noise, indicating that the airborne component of the avalanche (the so-called powder avalanche) struck their own chalets ;
- many visits were carried out the days after and during spring ; Interpretation of snow deposits, runout zone extensions, chalet displacements, damages, visible stream lines on the avalanche debris, etc. could give an approximate picture of the avalanches in their terminal phases ; Aerial photographs gave us also an interesting general view ; The different clues were compared and criticized ;
- using numerical models helped us in quantifying the avalanche effects more accurately. But, in fact, our actual knowledge is relatively poor about the physical mechanisms involved in such avalanches. For instance, rheological properties or boundary conditions can only be roughly estimated, with a weak level of confidence. This is mainly due to the great variety of snow properties and avalanche morphology. To simplify, it is helpful to consider that avalanche flows can be represented by two basic classes : powder avalanches and flowing avalanches. To model powder avalanches, we used the model proposed in France by Beghin. For the flowing part of the avalanches, we used the VSG procedure as explained in the Swiss guideline of 1990. Both models are empirical, they are based on simplified equations of fluid mechanics. Their parameters have been fitted either from laboratory experiments (Beghin's model) or field data (VSG model). In the Montroc event, we used also the model developed in our Institute by Naaim. This model deals with the transition from flowing avalanche to aerosol. As far we know, it is the first model, in which the avalanche type (powder/ flowing) does not need to be specified since it is determined by computation.

5 THE MONTROC AVALANCHE DESCRIPTION

In the following reconstitution, some characteristics of the avalanche can be still discussed, even if there is a global agreement within our team. In the starting zone, the upper part of the snow cover naturally broke down as a result of its own weight. The slab was 1 to 2 m deep and about 250 m in width. The moving volume was approximately 90 000 m³. Quickly the avalanche reached a significant speed (>25 m/s), then slowed down a little because of the slope decrease. It kept on incorporating fresh snow from the snowcover (about 60 000 m³). Then, it spread out (400 m in width) with a separation in two branches : the main branch (~2/3) in direction of Montroc, the other one (~1/3) in the usual direction of Le Tour. The flow was like a tablecloth with 4 to 5 m in depth, topped by a small plume without any particular dynamic role.

In the lower part of the track, the avalanche experienced several transformations, including strong incorporation of air, transformation into an airborne, and substantial acceleration, significant snow entrainment from the snowcover. The speed reached 40∀10 m/s. The dense part of the avalanche was 2 to 5 m high, and approximately 150 m in width.

Table 3 : Main characteristics of the Montroc avalanche

Charac-teristic: / Phase:	Width/ Height (m)	Volume (m^3)	Average speed (m/s)	density (kg/m^3)
Starting zone	250 / ~2	90000	25 à 30	100 à 150
Upper track	350 / 4 - 5 + plume	+ 150 000 x 2/3 ≡ 160 000	20	100 à 150
Down track	150 / ≡ 2 à 5 (flowing p.) ≡ >25 (powder p.)	+ 90 000 ≡ 250 000	40∀10	100∀50
Runout zone	150 - 200 / ~ 4 (déposit)	150 000 (déposit)	20 à 25	100 à 250

Close to the river, the avalanche widened out clearly (about 200 m) as a result of the decrease in slope while keeping a significant speed (more than 25 m/s). The dense part of the avalanche easily went up the opposite side. A few seconds before, the airborne part which probably caused no significant damage, was felt by the residents as a blast effect. On the other hand, the dense part of the avalanche was far more destructive. Approximately 3 m in depth, it exerted a pressure higher than 50 kPa on the ground floors of the first country cottages (mainly built with wood), which were pulverised. Progressively with the slope, the avalanche lost its strength, in particular above the road. The deposit had 250 m in length, 150 m broad, and approximately 4 m of average depth.

They were twenty country cottages concerned : 14 were destroyed and 6 were more or less damaged. 12 people died. In terms of occurrence the period of return of this event exceeds several dozens. Using statistical simulations of the avalanches in the Montroc site, we arrived at periods of return ranging between 150 and 300 years according to the variable chosen as the key parameter of the avalanche (energy, power of impact, dimension reached, runout distance etc).

6 THE TACONNAZ AVALANCHE DESCRIPTION

The Taconnaz avalanche started on a glacier. In the avalanche debris, the ice part was estimated at 30% in volume. A large serac was broken along the ice cliff (elevation 3200 m). Due to the high slopes and the fresh snow all along, the speed increased very quickly and should exceed 80 m/s. The avalanche turned left along the moraine, grasping all the snow cover and rocks. It went up the opposite side of the moraine over more than 90 m in elevation. Then the impact against the deflecting walls was very violent : two were partially damaged. Computations have estimated that the impact pressure should exceed 500 kPa during a few second for the concrete walls to break.

A part of the avalanche jumped over a lateral dam, 10 m high. No snow deposit was observed at the dam base, although a large volume, estimated at 80 000 m^3 and including ice blocks as large as one cubic meter in diameter, had flowed over the dam. The main part of the avalanche was nearly stopped by the catching dam event though 220 000 m^3 of snow jumped over it. This is to be compared with the volume stocked inside the protection system (measured at 530 000 m^3). This large extent shows that the avalanche had been partially under control. Parts of the forest were destroyed in three locations, a few houses were damaged, but fortunately nobody was injured. The return periods are approximately 40 years for the snow fall, 100 years for the runout distance, and only 10 years for the avalanche debris.

Specifying the 100 year return period avalanche is a key process in designing a mitigation system. In the present, this was extremely complex due to the size of the path and the various triggering mechanisms. It was necessary to consider different avalanche types with various characteristics (see table n°6).

Table n°6 : Taconnaz avalanche design, just before the mitigations measures

	Powder snow	Flowing dry	Flowing wet
Height (m)	90 - 130	12 - 18	8 - 13
Width (m)	200-250	90 - 130	70 - 90
Volume (m^3)	25.10^6 - 50.10^6	$1,4.10^6$- $2,8.10^6$	$0,8.10^6$ - $1,6.10^6$
Mass (t)	300.10^3 - 400.10^3	400.10^3 - 550.10^3	350.10^3 - 500.10^3
Speed (m/s)	70 - 100	35 - 60	15 - 25
Average density (kg/m^3)	80 - 120	200 - 300	300 - 450
Impact pressure (kPa)	25 - 40	100 - 250	40 - 100

It is worth noticing in the table above that the mass of the avalanche is almost identical for the three types considered here. The similar values after the effect of the actual system and after the future stopping system is more difficult to determine.

7 COMMENTS AND CONCLUSION

These two avalanches are complex and not very ordinary phenomena. Several factors contributed to their extents. First of all, the snowfalls by very cold temperatures allowed the establishment of a significant layer of dry snow, which was subsequently easily entrained by the avalanches.

The gap between the period of return of precipitations and the exceptional character of the damages caused by the avalanches is worth noticing. That naturally raises the following question : will we able to avoid similar catastrophes ? The answer is in half-tone. In the current state of the French procedure, the answer would be rather negative. Indeed, in the spirit of the current zoning maps (for risks prevention), only historical events are considered. Obviously, in some cases, such a method leads to the "strange" implication : there is no danger beyond the known historical event.

Another aspect raised by such avalanches regards zoning methods, especially because few country cottages located in white zone were destroyed in Montroc. But the white zone is not synonymous with area without any risk. This short cut is dangerous because it induces on the one hand that a zero risk exists and on the other hand, evaluation of the zero risk being at the very least subjective ; the people in charge of the zoning are entirely responsible of any mistake.

At the end huge avalanche are still a mistery. Where an avalanche was (has ?) gone another one will go again, and another one will go further !

BIBLIOGRAPHY

Experimental and theoretical study of the dynamics of powder snow avalanches, P. Beghin and X. Olagne, Cold Regions Science and Technology, 19 (1991) 317-326

The avalanche handbook, D. McClung and P. Schaerer, The Mountaineers, 1993, ISBN 0-89886-364-3