Attempt to combine few historical data from a 19th century avalanche and recent modelling capabilities for hazard zoning at Tignes Brévières

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ABSTRACT

As a popular ski resort, Tignes (French Alps) is under constant pressure to increase land use including new buildings. In this context, avalanche hazard zoning must be as precise as possible to ensure safety especially for expansion into new areas. One avalanche site, Les Brévières, experienced a remarkable event in 1881. The historical data clearly indicate that most of damages were due to a strong mixed flowing/powder avalanche coming from the Sache mountain. However, the data are sparse and there is the possibility, confirmed by some testimonies, that an avalanche from the opposite mountain side arrived at approximately the same time. To resolve these inconsistencies, a qualification and quantification process has been carried out based on classical expertise combined with numerical modelling approaches: we applied the extended RAMMS avalanche model. The goal is to understand the relative contributions of the dense and powder parts (from Sache side or possibly both sides) and to reconstruct the most realistic conditions to fit the available data and finally define a global hazard zoning consistent with implied hypotheses (including correspondence with pressure and load application height).

1. INTRODUCTION

In France, the main avalanche zoning regulation is based on defining an avalanche event with a 100-year return period. If the return period of the maximum known event is larger than 100-years, the 100-year scenario can be adjusted to include historical information. This implies, of course, that the event is well-documented. A progressive transition allows also to take into account passive protection structures, such as avalanche dams, provided they can be considered as permanent topographic changes.

In many places with little land development pressure or available safe space, qualitative approaches for hazard zoning are usually acceptable and accepted even with large safety margins. In more constrained territory, avalanche hazard requires a more precise and detailed understanding of the terrain and flows behaviour.

The Tignes ski resort in France is a good example of a region under huge land development pressure (amongst the highest real estate prices in France, approximately in the same range as Paris). It contains many confined zones that require careful hazard planning. In this paper we focus on the les Brévieres site which experienced a major avalanche in 1881. We address the problem of how to “manage’’ it, considering both partial historical data and numerical avalanche simulations.

2. TIGNES BREVIERES VILLAGE AND MAIN HISTORICAL AVALANCHE

The Tignes ski resort is consisting of 5 separate villages. Les Brévières is the oldest one and exists from 13th century. One hundred years ago, it was primarily a farming community. In the 1920's the first rumors of a hydro-electric dam appeared and became reality when the dam was built in 1952 becoming the tallest concrete wall in France. There was huge opposition as this project meant that one of the main settlements would be completely buried beneath the newly created lake, strongly reducing the available land near Brévières. However, the hydroelectric dam facilitated the overall development of the Tignes region, including the construction of a ski resort and new villages at higher altitudes.

The village of les Brévières is situated just below the dam at about 1560m asl with buildings mostly along and above the eastern ridge of the Isère river. To the west, it is dominated by the Mont Pourri (3797 m asl) glaciers with the Grande Parei (3350 m) secondary summit exactly opposite it. To the east, the terrain is a slightly gentler and reach la Davie (3000 m).

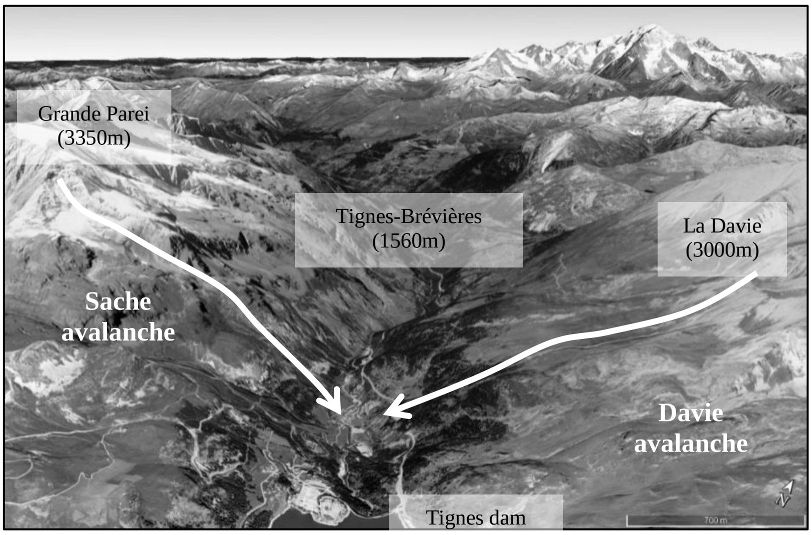

Figure 1 Tignes Brevières situation with the two main avalanches of la Sache (from the west) and la Davie (from the east) – Source: Google Earth

The village is located directly at the convergence of two large avalanche trajectories, la Sache from the west / Grand Parei and la Davie from the east (Fig.1). The final runout of la Davie avalanche was historically protected by a small "splitter" which was replaced and relocated when a road was moved during the construction of the hydroelectric dam. This protection has recently been reinforced and represents a reliable and massive deflective dam. The Sache avalanche trajectory is globally unchanged except a neglectable dam at the exit of the final deep gorge. This situation induced the current avalanche hazard zoning from 2006 (Fig.2): the darkest colours correspond to areas that cannot be developed (existing buildings cannot be modified). Buildings can be built in medium shaded colours zones provided that they respect architectural prescriptions and avalanche impact pressure tolerances.

The French avalanche inventory (known as CLPA - Fig.2) shows two converging and partly superimposed zones corresponding to the Sache and Davie avalanches. The first one appears as a unique zone going far beyond the river (180 m farther and 35 m higher on the opposite valley side) with a possible powder avalanche blast zone. The Davie avalanche stays on the eastern side and shows several branches clearly due to the passive protections. For instance, the south-eastern zone comes from a remarkable event during the XXst century, after the protection improvement whereas the oldest known trajectory is only the northern one.

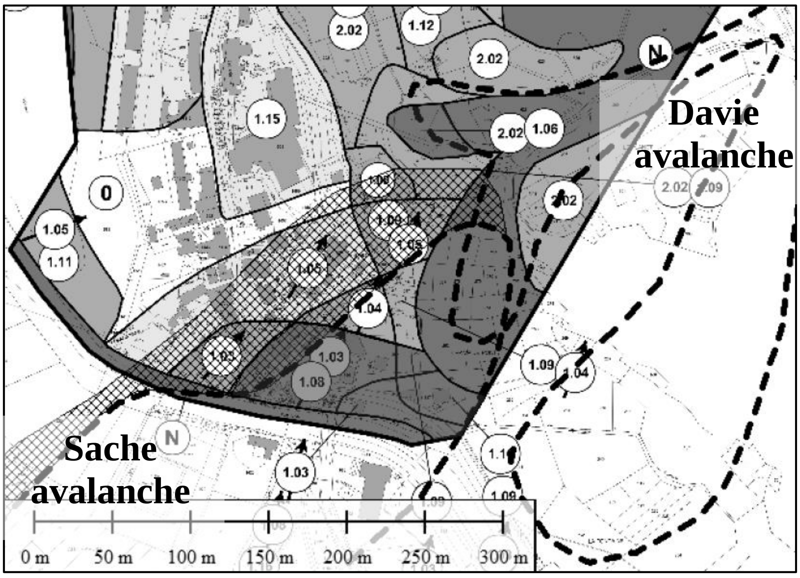

Figure 2 Tignes Brevières avalanche zoning (2006) superimposed with the avalanche inventory limits (flowing part in black dash, powder influence in cross-hatch)

An extreme avalanche event occurred on February 12th 1881: "Catastrophe of the village of Brévières, engulfed by a formidable avalanche descended from Mt Pourri", "The snow depth accumulated on Brévières is estimated at 20 m", "We could not reach the unfortunate buried only by wells and tunnels dug in the hardened snow where the work was difficult and long." as stated some days after by the regional newspaper le Courrier des Alpes.

The avalanche released spontaneously at 6 o'clock in the morning from the ridge of Grande Parei, the avalanche damaged 14 houses on the southern part of the village, buried 37 people and killed 9 of them. At the same time, a few testimonies also indicate that the Davie avalanche occurred in the same days.

Some photos exist, by Paul Mougin which were probably taken a few days after the avalanche: On several of them (Fig. 3), a set of landmarks can be clearly identified to locate and orient these pictures. It confirms the interaction limit near the southern center of the village. A first row of houses were "filled" with snow without being collapsed or carried away. Cottages in the background appear not to seem affected. The Sache final gorge was also clearly overpassed revealing a powerful powder part coming with this avalanche.

However, these pictures do not allow to correctly draw most eastern limits whereas doubts clearly exist about a possible contribution of Davie avalanche. And as this last one is now strongly protected by a reliable deflecting dam (which could allow now to modify/open corresponding zoning where about 20 houses are in the red zone), it is important to clarify what was the exact extension of the Sache avalanche including respective contributions of the pure flowing part and of the powder cloud.

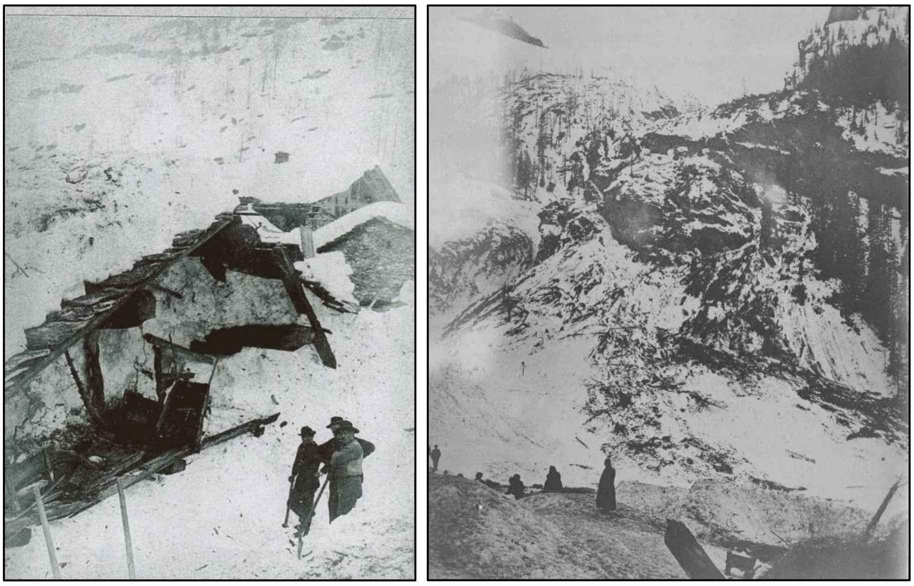

Figure 3 Photos by Paul Mougin of February 12th 1881 avalanche at les Brévières

3. FIRST ATTEMPT WITH RAMMS

From the zoning point of view, the existence of the historical event of 1881 is a crucial point as it constitutes the reference. Of course, its current representativity could be discussed with the climate evolution and including some changes of topography (strong decrease of the top glacier and the corresponding starting zone). But the main point is to better understand how the avalanche run out at that time to fit at best limits with regulation requirements.

A first attempt was carried out with the "all-users version'' 1.7.20 of RAMMS (Christen et al., 2010) following the usual protocol (statistical assessment of the reference snowdepth in the starting zone considering a 300 years return period scenario, definition of the potential starting zones along the overall trajectory to accumulate them progressively) and including some additional hypotheses: the DEM was manually modify to rub out the modern road platform and the deflecting dam.

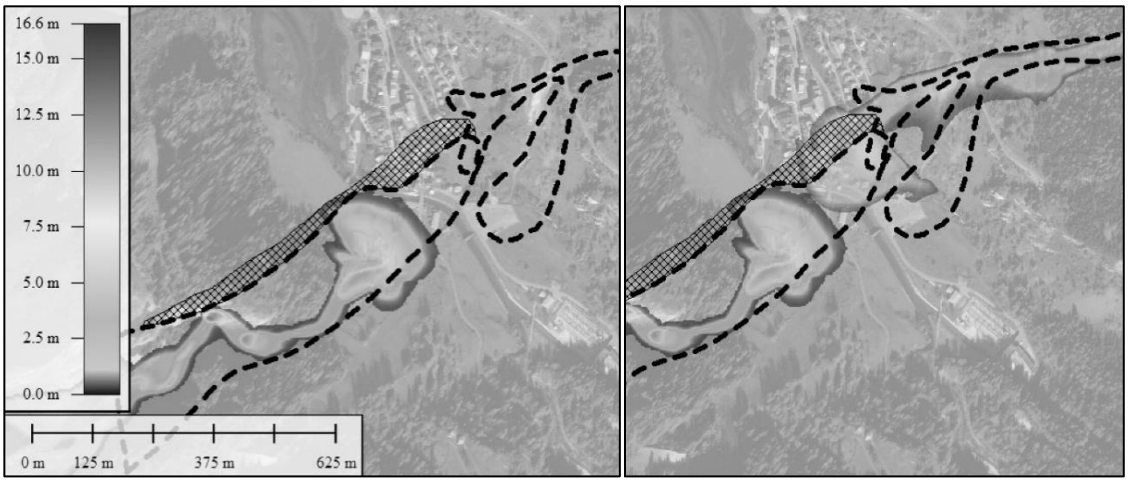

Figure 3 Results (maximum height) with the basic version of RAMMS for the Sache avalanche (left) and including the Davie avalanche (right)

Due to the highly mixed characteristics of the 1881 event, results could be but partial and could not lead to a clear conclusion regarding the respective contributions of the Sache or Davie avalanches. The CLPA avalanche map limits could even be better reproduced introducing the conjunction of both avalanches than in the case of the only Sache avalanche. The operational version of RAMMS cannot properly reproduce this kind of phenomena and therefore could lead to erroneous conclusions if wrongly applied.

4. SECOND ATTEMPT WITH EXTENDED: RAMMS

A second solution could have consisted in "tuning" RAMMS parameters to best-fit one scenario or another. However, the problem with this approach is that it initially chooses indirectly one of the two possible solutions. By doing that, it might even be possible to obtain a sufficiently convincing demonstration for both of the scenarios but finally, not distinguishing between them. This method, that clearly exists in engineering practice, is obviously wrong as it better tries to reproduce the expert opinion by modelling instead of confronting it with unbiased numerical results to reinforce the conclusion.

The "extended" RAMMS model was subsequently applied (Bartelt et al., 2016, Bartelt et al., 2018). At the time of this writing, the extended RAMMS model was being utilized to back-calculate powder avalanche events from a 30-year avalanche cycle that struck Switzerland in early January 2019. Avalanche release conditions and entrainment depths were documented. Because of the immediacy of the events, it was also possible to approximate absolute snowcover temperatures and temperature gradients with altitude. These recent events, and many historical avalanches, have been used to calibrate the RAMMS extended model.

So, the extended model was applied to simulate the historical Sache event by using the calibrated snow parameters of the recent events but assuming (1) more extreme snowcover depths (d0 = 1.5 m) (2) cold snowcover temperatures (T = –7°C) which facilitate the formation of the powder cloud and (3) high snowcover erodibility. The last condition ensured that snow was entrained by the avalanche from initiation to runout. The extreme avalanche had a starting volume of 250'000 m^3 and a total deposition volume of 620'000 m^3. The growth index (by mass) reached 5.5; 14% of the total mass was suspended in the powder cloud. The avalanche increased in mean temperature by approximately 5°C (Vera Valero, 2015).

Fig. 4a depicts the inundation area of the avalanche core (velocity); Fig. 4b the map of the powder air-blast. Unlike the operational RAMMS model, we find the modelled mixed flowing/powder avalanche penetrates deeply into the runout zone. The 3 kPa pressure line is in good agreement with the mapped destruction in the village. The width of the inundation area is larger than the corresponding CLPA zone. This is clearly due to the overflowing of a ridge above the village of les Brévières which permits the formation of a second flow arm which is registered also as a possible trajectory. Here the deposit region clearly mixes with the opposite avalanche trajectory of la Davie. The calculations indicate that an extreme avalanche could descend from the Sache track and accurately represent the documented destruction pattern.

The primary difficulty in modelling the destruction of the village is overcoming a 50 m high gully wall. This cliff deflects the avalanche away from the village; however, there are model scenarios where the fluidized avalanche core can overcome this wall and directly impact the village. It is unlikely that the DEM model of today, accurately represents the terrain of 1881. Changing terrain clearly makes the investigation of historical events a problem.

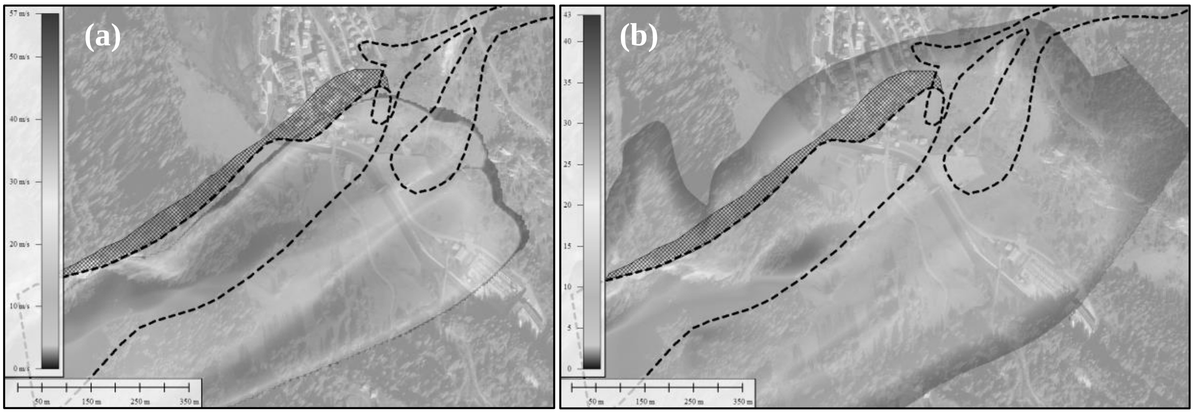

Figure 4 Extended RAMMS results: avalanche core velocity (a) and powder air blast (b)

5. CONCLUSIONS

Beyond controversy, this example shows the usefulness of such advanced tools in engineering practices not to replace but to feed engineers conclusions: for that, the community needs to develop a consistent methodology to account for entrainment, including thermal energy fluxes, in mixed flowing/powder avalanche dynamics models. This includes methods to define snowcover depth (including spatial variation and changes in altitude), erodibility and temperature for 10, 30, 100 and 300-year avalanche events. Efforts in Switzerland are presently directed at modifying calculation procedures used to define avalanche release depths. That is, historical data from measurement stations will be used to define the entrainment conditions. However, there is little information on how to constrain snowcover temperature. Progress in this area would be helpful for avalanche practice.

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