

THE JANUARY 18TH 2017 RIGOPIANO DISASTER IN ITALY – ANALYSIS OF THE AVALANCHE DYNAMICS

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ABSTRACT: On January 18th, 2017, a catastrophic avalanche released from Mount Siella (Gran Sasso Massif - Italy) after a 48-hour period of heavy snowfall. The avalanche started at 1900 m asl, flowed through a narrow canyon and then uprooted a beech forest, reaching the Rigopiano area as a "wood avalanche" (a mixing of snow, uprooted and crushed trees, rocks and other debris). The consequences were catastrophic: the avalanche completely destroyed the Hotel Rigopiano and 29 people died.

The Rigopiano avalanche presented many remarkable features of snow avalanches. These include how avalanches entrain snow and reach extremely long runout distances with little braking effect from mountain forests. This paper presents part of the simulations carried with the extended software **RAMMS**, developed by the WSL-SLF, to reconstruct the flow dynamics of Rigopiano event. Chiambretti et al. (these proceedings) describe the multidisciplinary approach to snow engineering and structural and geotechnical engineering, jointly with applied forensic field investigation techniques with different analyses which lead to the choice of the different inputs for the avalanche simulations. In particular, from the data gathered *in situ*, we observed that the avalanche was a fluidized dry snow avalanche which entrained a warmer snow cover along the path. From the simulations' results, it seems that the snow cover conditions had a significant effect on the avalanche dynamics (to simulate such long run-out distance), while the mix of wood and snow was the most important factor when analyzing the structural collapse of the hotel.

In conclusion, this paper presents the simulation of the catastrophic avalanches and highlights the importance of making correct specific assumptions when using avalanche dynamic models to reproduce real events. Such considerations must be taken into account and uncertainties have to be considered also when dealing with forensic investigations.

KEYWORDS: Rigopiano disaster, Wood avalanche, RAMMS, impact pressure, structural collapse.

1. INTRODUCTION

The snow emergency that occurred in Central and South Italy in mid-January 2017 is well known. Due to a low-pressure area trapped in the Western Mediterranean, Italy was affected by cold eastern currents that led to winter conditions with snowfalls accompanied by strong winds, even at low elevations. The most critical situations occurred in the Marche, Abruzzo and Molise regions where the recorded snow accumulations were extreme. An example is the Teramo area with 200 cm of snow fell in 48 hours at 500 m asl. (source: Neve Appennino). The situation was even more difficult for the mountain areas, starting from 800-900 m, where the snowpack easily exceeded 300-350 cm. The avalanche danger degree remained in the level "4-HIGH" for several days in the Central and Abruzzo Apennines. Especially in Abruzzo and Marche dramatic situations occurred: difficulties in the road clearing, absence of electricity for days

(100.000 users with no power in Abruzzo), no heating due to the blocking of boilers, isolated houses and municipalities due to the thickness of snowpack, etc. The social and economic costs of the snow event in the central Apennines was high, even without considering the Rigopiano tragedy. On January 18, 2017, the snowpack "*mostly unstable on all steep slopes*", consisting of "*layers of dry snow with low cohesion on weakly consolidated layers*", was overloaded by continuous and heavy snowfall that prevented the only road access to the hotel from the bottom of the valley. Two seismic $M > 5$ events occurred in the morning: they were distinctly felt also at Rigopiano Hotel, spreading panic among the residents. The avalanche released at approximately 17:40 from Mount Siella (2.027 m) on an open slope, meeting almost immediately the beech forest, then poured out inside the canyon, expanding at the plateau of the hotel, finally impacting and tearing the structure down completely.

2. THE HOTEL

Located in one of the most beautiful sites of Abruzzo, the Rigopiano Gran Sasso Resort & Wellness in Farindola was a 4-star hotel. In the heart of the Gran Sasso National Park, with a view of the sea, the hotel was standing at 1.200 m asl with its 1.200 mq surface, subdivided into 43 rooms, bar, congress center, "Il Vate" restaurant, and a 1.300 mq SPA and outdoor/indoor pool (Fig.1). Arranged in a radial form, the Hotel was essentially composed of 3 communicating bodies: the 4-levels main structure, the lower body (with 3 aboveground floors) including the original part, and the underground area, dedicated to the SPA.

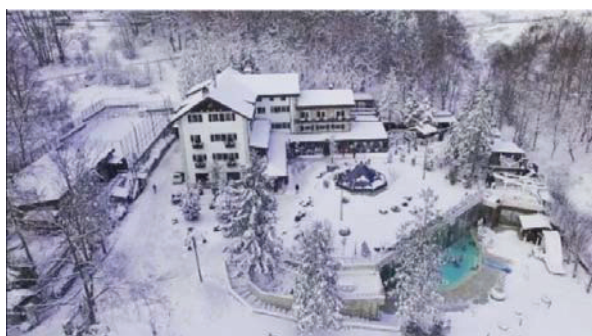


Figure 1: Winter aerial view of the Hotel Rigopiano in the 2000s (source: Internet).

The original nucleus (Fig. 2) was a mountain hut built just below and subsequently to the Tito Acerbo shelter (inaugurated in 1933), transformed into a hotel at the end of the 60s, with a wellness structure added at the beginning of the 2000s. Inspired by the aestheticism of Gabriele d'Annunzio, the hotel hosted some international celebrities, earning the nickname of "VIP hotel".

3. THE EVIDENCE OF AVALANCHE DYNAMICS

From the field evidence and from the analysis of the silent witnesses, the Rigopiano event on January 18th, 2017, consisted in a dry snow avalanche with preponderant (and more destructive) flowing part. The most important peculiarities of the event were:

1. the prevalence of the flowing part, highly fluidized due to the medium-high density and dry snow, weak internal friction and very high velocity (similar to a saltation layer);
2. the entrainment of the beech trees in the snow that transformed the avalanche into a composite snow/wood mixture, dragging the trunks, rocks and other debris downstream.

Due to the high speed of the snow flow, the wood was not able to slow it down. On the contrary, the entrainment of wooden material increased the density of the avalanche body. From the on-site evidence (confirmed by the simulation), the velocities of snow at the altitude of Rigopiano Hotel, reached the maximum at the Hotel not yet in the run-out zone. Most probably, at the altitude of the hotel the avalanche was no longer accelerating, but still maintained a high speed increasing its density due to the entrainment of wood, rocks and debris: these conditions provided a huge impact force of the avalanche flow against the reinforced concrete structure. The steady state was probably helped by the local topography which produced along the track, from the fan apex and down to the hotel, some hydraulic jumps. The avalanche hit the hotel, razing it to the ground and shifting it about 35 mt. The avalanche was so fast and fluid that it did not stop after the impact against the building passing through, dragging concrete elements, furnishings, lives and hopes for the future for hundred meters downhill.



Figure 2: Historical image of the original Rigopiano hut in 1958 (source: www.quotidiano.net).

4. THE CHOICE OF THE NUMERICAL MODEL

The physical complexity of the Rigopiano phenomenon affects the choice of the model to better reproduce its behavior. The distinctive dynamics of the event, with a starting zone outside the woods and a track zone in a strongly canalized beech forest, turning the snow avalanche into a mixed snow/wood flow, led us to choose the **RAMMS** model for the simulation of the dynamics of rapid movements in 3D alpine terrain. **RAMMS** can model, although in a parametric way, the effects of the interaction between the avalanche and the wooden area in terms of erosion of the snowpack, loss of energy and mass variation of the flow, by varying the dynamic parameters (Feistl et al.,

2014; Teich et al., 2014). Developed by the Swiss Federal Institute for the Study of Snow and Avalanches, Davos (CH), the commercial version of **RAMMS** (*Operational*) is dedicated to professionals (www.ramms.slf.ch). However, the model is continually under development. An extended version allows the simulation of fluidized mixed flowing/powder avalanches (Bartelt et al., 2016), wet snow avalanches (Vera Valero et al., 2015, 2018) with or without forests (Feistl et al., 2014, 2016).

An important part of the extended **RAMMS** model is the treatment of snow entrainment. The **RAMMS** entrainment model considers both the thermal and random energy fluxes associated with the avalanche-snowcover interaction (see Bartelt et al., in these proceedings). Entrainment of dry, cold snow will contribute to the fluidization of the avalanche core, including the development of disperse flow regimes that include particle splashing (saltation fronts) and the formation of powder clouds. Entrainment of warm snow can damp these processes leading to heavy, dense flowing avalanches. The avalanche flow regime depends on the temperature of the release and entrained snow. Significant meltwater can be generated which leads to lubricated shear surfaces and therefore a reduction of the flow friction (long runout). The extended version of **RAMMS**, like the operational version, applies a Voellmy rheology to model flow friction. In the operational version, the friction parameters (Coulomb friction μ and turbulent friction ξ) are constants, defined by calibration and avalanche return period (Christen et al., 2010). In the extended version the parameters change dynamically with the degree of fluidization (bulk flow density). This change is controlled by snow temperature as well as by the entrainment mechanism (Bartelt et al., in this issue). Another feature of the extended **RAMMS** software is the ability to include mountain forests in the simulations (Feistl et al., 2014; 2015). Forests are included by first defining forested areas within the simulation domain. The forests can vary with respect to the tree species, age (stem diameter and tree height) as well as stand density. These parameters define the breaking stress needed to fracture or uproot trees. If the trees are broken, they offer little resistance, other than energy required to accelerate the woody debris to the speed of the avalanche. If the trees do not break, they offer a more effective protection. Avalanche mass piles-up behind tree stems, removing snow from the avalanche. The removal of mass, detrainment, causes the avalanche to decrease in speed, limiting both the runout and lateral spread of the ava-

lanche. The loss of the momentum and of the mass (detrainment) due to the resistance of trees to avalanche flow, is therefore considered, although in a parametric way.

5. THE MODEL INPUTS

Due to the snow and weather conditions, it was not safe to make field work and to collect data immediately after the avalanche event. The hazard level remained high for the following days. Only on Jan 20th and 21st two snow profiles could be carried out. Later, both during the winter and the subsequent spring/summer seasons, several filed surveys were made to collect data along the track, like, e.g., avalanche path, forest damage and structural collapse. Therefore, some uncertainties are present in the model (e.g. exact fracture depth and snow cover conditions). In the following, the most important inputs of the simulation are reported.

5.1 The release zone

Since the release zone was not accessible immediately after the event, the release area, the fracture depth and the snow temperature/density of the slab were not directly measured but were determined with a cross analyses of the data gathered on field in the following days. The release area was observed for the first time from a helicopter fly three days after the event. The release area used for the simulation was determined on the basis of the few traces of slab fractures observed on the slope integrated with assumptions taken from specific literature about potential avalanche release areas (e.g. Maggioni et al. 2003; Schweizer et al. 2003). The release area developed from 1.890 to 1.760 m asl with a mean slope angle of 32°. The fracture depth was determined from the combined analyses of the data gathered from the snow profiles dig at the altitude of the hotel (1.120 m asl) and a bit higher up in the surrounding (Chiambretti et al, in this issue) applying an altitude gradient equal to 5 cm / 100 m altitude rise, as used in other parts of Italy (Barbolini et al., 2005) and in Switzerland (SLF, 1999) and other corrections (Barbolini et al., 2005; SLF, 1999) to take into account the mean altitude and slope angle of the release area plus the additional load due to snow drift caused by intense wind blowing during the snowfall and immediately after. Finally, the input value for the fracture depth was calculated equal to 2 m, leading to a total snow release volume of ca. 77.000 m³. The average snow density of the slab was taken equal to 250 kg/m³. This value was determined combining the measure-

ments of the snow gathered from the snow profiles together with the most probable densification due to snow drift. The total release mass was therefore equal to 19.255 Mg.

5.2 The forest characteristics

The avalanche run within a wooden area made of beeches (*Fagus sylvatica*), whose characteristics were determined through aerial photo analyses and field work. Two forested areas have been identified: a large area from about 1.600 m to 1.160 m asl made of younger beeches of 25 cm diameter and high canopy coverage and a smaller one closer to the hotel (below the road at 1.160 m asl) made of beeches of 70 cm diameter with medium canopy coverage.

5.3 The snowcover and erosion parameters

On the basis of the snow profiles interpretation, the erodible snow cover, one of the inputs in the model, was considered made of two layers: a superficial one of 1.5 m thickness with a density of 200 kg/m³ and a mean temperature of -3 °C. Beneath this layer we specified layer of 0.8 m thickness with a density of 250 kg/m³ and a temperature of -2 °C. According to the assumption, the upper layer was considered more erodible than the bottom one varying two model parameters related to erosion processes. The first parameter defines the erodibility, the second parameter defines the elasticity of the snow (Bartelt et al., in this issue). The erodible snow height within the forested areas was considered variable according to the characteristics of the trees, in particular to the canopy cover and forest density which determined the capacity of snowfall interception by trees.

5.4 The avalanche density

We assumed a high deposition density of 450 kg/m³ as the avalanche was finally a mix of snow and trees (the density of the wood was about 700 kg/m³). This density represents the ultimate compaction density of the flowing mass. When the avalanche fluidizes, the bulk avalanche flow density can decrease to values less than 200 kg/m³. As it can easily be intended, such high value well explains the huge pressures attained at impact against the structure.

6. THE MODEL OUTPUTS

Outlines of the deposition field (Fig. 3) provided the most reliable guide to back-calculate the Rigopiano avalanche event. The spatial extent of the deposition areas could only be simulated by correctly choosing the temperature of the snowcover.

Only by selecting sub-zero temperatures in the release zone ($T = -3^{\circ}\text{C}$), as well as warmer temperatures in the entrainment zone (T between -3 and -1°C), dissipative heating led to meltwater production, providing the lubrication necessary to model the extreme runout of the avalanche. The avalanche stopped at an elevation of 1.080 m asl. Because of the colder temperatures in the upper-track region, the simulated avalanche reaches a high peak velocity along the track (44 m/s), at about 1.450 m asl before the first sharp turn to the right (Fig. 4).

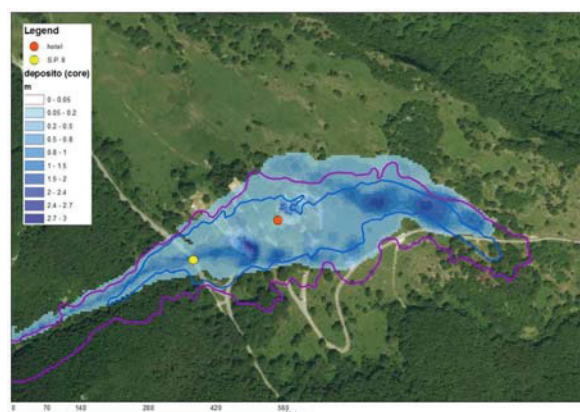


Figure 3. Simulated deposition height. The blue and violet lines represent the outline of the dense and powder parts of the avalanche, as determined from field work.

When the avalanche reaches the hotel (68 seconds after release), it is travelling with a speed of 30 m/s, with warmed avalanche temperature ($T = -1.1^{\circ}\text{C}$) and high flow densities. The calculated impact pressures reached very high values along the track (Fig. 4), and in the area closed to the hotel, the avalanche showed pressures above 300 kPa. At the hotel the peak of the impact pressure was 393 kPa. Considering the hotel damage, these impact pressures are considered reasonable. In the runout zone the snow thickness on the ground consists of both the snowcover and avalanche deposits. At the hotel level the snow thickness was 1,83 m. The avalanche entrained 103.000 m³ of snow, obtaining a grow index of 2.3.

7. CONCLUSIONS

Speaking about avalanche risk, taking into account magnitude and potential damage caused by events, a final evaluation can be performed thanks to the "Intensity scale for avalanche risk" by Rapin (2002). Divided into 5 degrees (from 1 - very low,

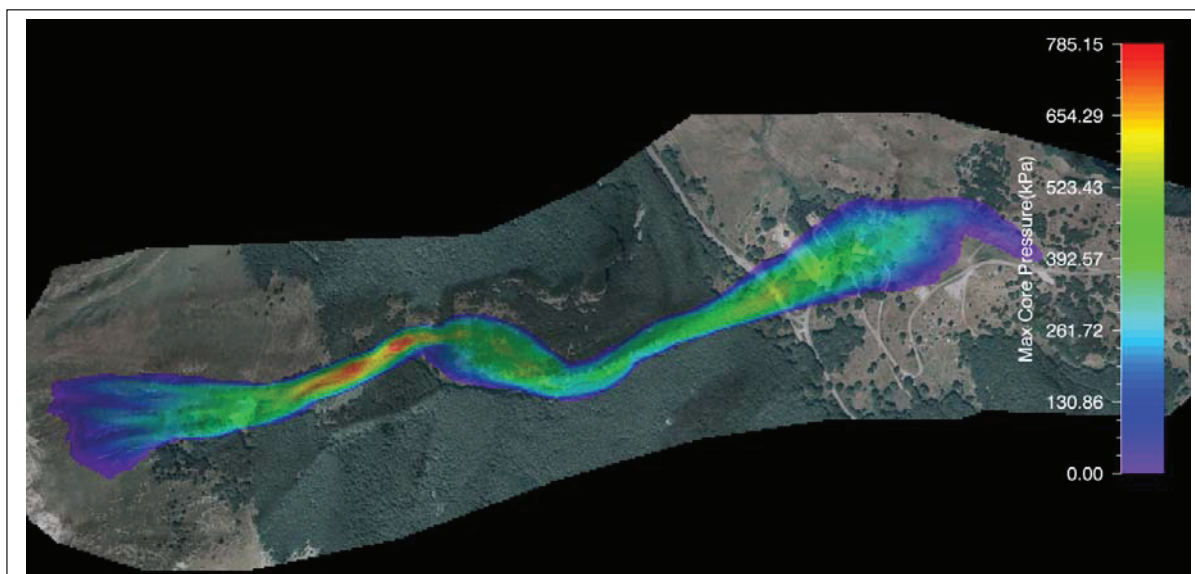


Figure 4. Modeled impact pressure of the core along the track.

to 5 - very high), the scale is defined on the basis of physical parameters (such as: the surface affected by the event, the average thickness detachment, the deposited volume, the impact pressure) that define a grade of magnitude of the event and the foreseeable effects on: people, buildings, infrastructures and defense structures, etc., potentially imposed by the avalanche phenomenon. Based on this scale of risk, the event of January 18th, 2017 in Rigopiano would be placed among the grades: 4 - HIGH and 5 - VERY HIGH.

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