THE 18TH JANUARY 2017 RIGOPIANO AVALANCHE DISASTER IN ITALY - ANALYSIS OF THE APPLIED FORENSIC FIELD INVESTIGATION TECHNIQUES

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ABSTRACT: The 18th January 2017 an avalanche destroyed the Rigopiano Hotel and SPA with 40 people caught and a death toll of 29 victims. Some of the authors were appointed as avalanche experts supporting the public prosecutors conducting criminal proceedings on the disaster. This paper describes the general meteorological scenario which produced such event and how field investigations were conducted and other multidisciplinary specialized geologic and engineering forensic techniques (aerial photo interpretation, dendrochronology, photogrammetry, geodesy, snow mechanics, structural engineering) were applied to provide insight on the avalanche dynamics and its interaction with the building. Detailed terrain features and damage evidences will be discussed allowing preliminary considerations on the avalanche frequency, its magnitude and dynamic.

KEYWORDS: Rigopiano disaster, forensic field investigation techniques, Central Apennines.

1. INTRODUCTION

The expert investigations activities aimed to reconstruct the events and dynamics of an avalanche disaster are characterized by a high complexity, by evident factors of temporal constraint, by the delicacy of the assignment and by the high profile of criminal and civil responsibility which the experts undertake to ward all the parties involved and ascertain, as far as possible and on the basis of the best science and technology, the objective truth following a multidisciplinary approach. The expert panel was appointed by the public prosecutor's office of the Pescara Court only 27th Jan. 2017 as, in the previous days, it was a priority to complete the complex search and rescue operations aimed at finding survivors to the Hotel collapse and recovering and identifying the 29 victims. The search and rescue operations lasted from the early hours of 19th until the afternoon of 27th Jan. employing, on average, 347 rescuers and technicians and several dozens of machineries necessary for excavating the ruins and debris.

The expert panel was asked to answer several questions but mainly to determine the most plausible scenarios for the avalanche event by analysing the three main zones of the avalanche path (the starting zone, the avalanche track and the runout zone) and to ascertain the building collapse dynamic and causes (see also Frigo et alii – this issue).

2. LOCATION

The Rigopiano place (Farindola Municipality – Pescara Province) is located in the valley named "Fosso Rigopiano" on the eastern slopes of Mount Siella (2,027 m asl) which is part of the NE sub-chain of the Gran Sasso d'Italia massif - Central Apennines - Italy.

3. WEATHER SCENARIO

For a synoptic and exhaustive description of the weather scenario between January 15th and 18th 2017 please refer to Chiambretti and Sofia (2018 - this issue). Unfortunately, continuous historical series of observation data, reliable and extended over time, or data referring to the period 15th-18th Jan. 2017 were not available for the Rigopiano

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area nor for either automatic or manual stations nearby (all managed by the Meteomont-Carabinieri Service). The expert panel was therefore forced to examine average data extrapolated from the synoptic meteorological models (NMM model – source MeteoBlue©). Despite all the uncertainties related to such method, those data proved to be consistent with records from other automatic or manual stations located in the Central Appennines. For the examined area only four historical precipitation events exceeded, between 1985 and 2017, the SWE 100 mm thresholds: in Nov. 2013, Feb. 2015, Mar. 2015 and Jan. 2017 respectively.

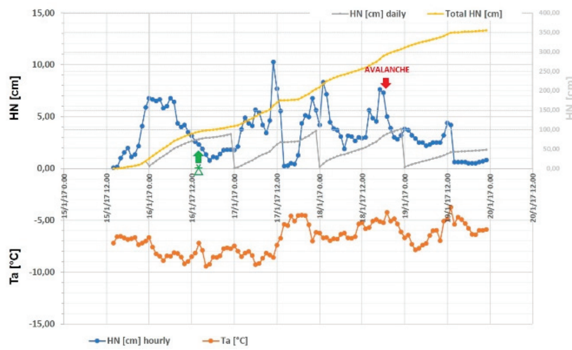

Fig. 1: HN [cm] hourly, daily, total values and Ta [°C] at 1.880 m asl in the avalanche starting area – period 15th – 19th Jan. 2018. All time values are in UTC. The red arrow marks the avalanche event. (NMM model - source MeteoBlue©).

Between 15th-19th Jan. HN daily cumulate values over 24h, at 1.880 m asl, exceeded 70-80 cm of fresh snow while the HN total cumulate value was close to 356 cm without contemplating wind action (Fig. 1). Following Fig.1, the snowfall started on the afternoon of Jan. 15th and rapidly increased its rates with short breaks during the 16th Jan. late morning and 17th Jan. early afternoon. The snowfall was accompanied by low air temperatures (Ta: <-6° C, with negative peaks of -9° C) and was therefore characterized by a low density (by the Apennine standards). In the early afternoon of Jan. 16th, a temporary rise of Ta (from -9° C to about -7 ° C) favoured the deposition of a graupel (PPgp) layer During the 17th Jan. afternoon the snowfall was characterized by a higher density as it occurred with Ta more similar to those usual for the Apennine's winter precipitations. During the 17th Jan. night, the Ta lowered again rapidly and kept close to -7°/-6° C until late morning of 18th Jan. thus producing a snowfall characterized by a low density. Subsequently Ta return to increase slightly, although they remain negative, during the day and were accompanied by a new increase in snowfall rates in the afternoon.

The major phases of erosion, transport and wind deposition of fresh snow took place on the morning of 16th Jan., the night between 16th and 17th Jan. and the following morning, part of the afternoon and night of 17th Jan. and the full day of 18th Jan.. The wind provenance was initially from NW-NNW (15th-16th Jan.), then from N and NNE on 17th Jan. and finally from NNE-NE on 18th Jan.

4. FIELD INVESTIGATIONS

The priority for the expert panel was to collect, as soon as possible, the largest amount of objective data resulted from observations, measures and subjective expert evaluations before the traces left by the avalanche dynamics were altered excessively or cancelled due to the passing time and the snowpack metamorphism and melting processes. Being official investigations, the expert panel had to ensure also the reliability (quality and traceability) of all information collection conditions as all observations and measures could be used as trial evidences.

The most complex data to gather were in the release area as the considerable time spent from the event and the snowpack alteration phenomena had made it difficult to ascertain the avalanche's main characteristics like: triggering conditions, physical properties of released snowpack as well as the exact shape and area of the starting zone.

One of the experts had the unique opportunity to start such activities two days in advance of the official appointment being well aware of such difficulties in gathering a factual description of the event (observation, testimonies from other technicians and expert which operated during the first phases of the search and rescue activities, measurements, photos and videos).

Field equipment used for this study included: a mapping GPS, a laser distance meter, a clinometer and compass, an altimeter, a fibreglass measuring tape and a folding double meter stick and an increment borer. Other equipment included standard field data recording materials (notebooks, pencils, water resistant markers and colour spry cans, one HD camera and one action camera able to save GPS metadata, radio and standard safety equipment). Detailed field studies were conducted both with and without snowcover along the whole avalanche site.

The whole perimeter of the avalanche was immediately surveyed and mapped using a GPS (both in track logging – 1 point/sec - and waypoint acquisition mode with a horizontal average accuracy of ± 3-5 m on GPS-GLONASS signal), a laser distance meter (with an average accuracy of ± 1 mm/m) and a measuring tape. Only the topmost and steepest part of the starting zone was not measured immediately as the residual avalanche danger was considered still too significant thus impending the safety of technicians. Typically, measured segments varied between 5 m and 15 m in slope length. The position of the extreme avalanche runout was deduced from trimline, deposit and debris distribution as well as discernible and specific types of vegetation damage left by the flow. Both the dense and the powder component of the flow left clear traces of the snow and entrained debris impacting onto trees and shrubs along the avalanche path allowing the opportunity to record useful data about the direction and approximate depth of each component of flow and to derive elements about the avalanche impact pressure and local speed. Almost all the types of vegetation disturbance due to an avalanche were observed and: tilting, scarring, growth curvature or stem indentations, stem cracking or breakage, upslope or side branch trimming (flagging) or breakage, tree burial or root exposure, tree removal and trunk grinded (Fig. 2). Flagged trees and bark scares were used to approximate the depth of the dense flow component since the lower limit of the height of the undisturbed branches from the ground were a reliable indicator.

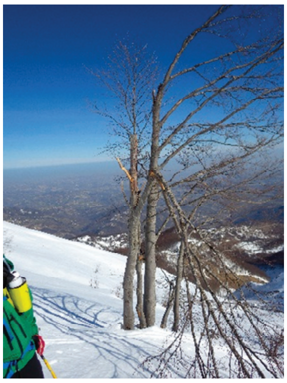

Fig. 2: vegetation damages left by the avalanche flow on a beech tree at the base of the starting zone. (photo Chiambretti).

Minor and topmost branch breakages were used to approximate the height of the powder component or of the air blasts associated with the dense flow. However, each individual data has always been used only in conjunction with all other observations and measurements after appropriate cross-checking, particularly along the flow sections, in order to establish their significance and coherence. Trimlines were also carefully considered as indicators of flow margins but only when associated with other evidences as some parts of the forest were subject to periodic logging. The accurate survey of orientation and direction of logs, branches or other flowed debris provided useful evidence about the avalanche dynamic. Corrasion or impact traces left on rock outcrops or on soil were also surveyed.

5. FORENSIC TECHNIQUES

Starting from these preliminary field investigations other multidisciplinary specialized geologic and engineering forensic techniques were applied to provide insight on the avalanche dynamics and its interaction with the building applying all the most advanced knowledge on snow mechanics and structural engineering.
The field data were compared with the results obtained from the morphometric and geomorphologic analysis derived from the GIS elaboration of the DTM with 10 m resolution and with 50 cm resolution (UAV and helicopter photogrammetry), from a laser-scanner and from the stereoscopic photo-interpretation of aerial photos and high-resolution satellite images of different periods, suitably georeferenced and orthorectified. The perimeter of the starting zone was completed through a comparison between field measurements and georeferenced and orthorectified photos taken from an helicopter fly three days after the event when the avalanche crown was still quite visible. Geodesy, geophysics, core sampling and geotechnical analysis were used to investigate the micromorphological and subsoil characteristics of the Hotel area. The dendrochronological and dendromorphological analysis of trees was limited by available time and budget problems. The time interval covered by this analysis was 99 years (from 1918 to 2016). The average age of the trees sampled is 65,5 years, with a minimum age of 32 and a maximum of 99 years. The expert panel evaluated to not rely onto this data as trial evidence for the following reasons:

- the sample analysed was to small and characterized by low correspondence;
- field evidence suggested that the size of the avalanche could probably have eliminated almost all the specimens which could have recorded the effects of previous events with a magnitude similar or slightly smaller than Jan. 2017 event.

It is interesting to note that the beeches growing in the Rigopiano area show an almost double growth rate compared to other sectors of the Apennine chain (2,29 mm/year against 1,11 mm/year) and the expert panel is confident that a more extensive and detailed sampling, in the context of a scientific research work that, however, goes beyond the assigned tasks, would provide interesting elements on the site's avalanche history.

6. THE AVALANCHE

The avalanche basin is set on limestones, locally outcropping only on crests and rock bars, largely masked by undifferentiated cryo-nival or moraine deposits and debris-colluvial deposits mostly covered by long-stem grass and small shrubs (Fig. 3). At lower altitudes the basin is covered by broad-leaved woods [prevailing beeches (*Fagus sylvatica sp.*)]. The fan area and the bottom of the valley named "Fosso Rigopiano", have reduced limestones and conglomerate outcrops and are mainly covered by largely grassy or vegetated undifferentiated cryo-nival and moraine deposits or debris-colluvial deposits often quite thick.

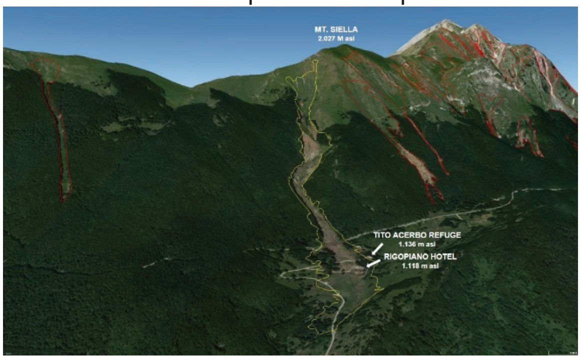

Fig. 3: 3D image of the Rigopiano Avalanche. The yellow line is the perimeter of the 18th Jan. avalanche which hit the Hotel. The red lines shows the perimeters of other coeval avalanche events. (source Google Earth Pro – images Jul. 2017).

Such deposits are often dissected and partially altered by a widespread anthropic remodelling. In the flattest part of the valley there is a peat bog surrounded by meadow-pastures, and sparse thorn bushes.

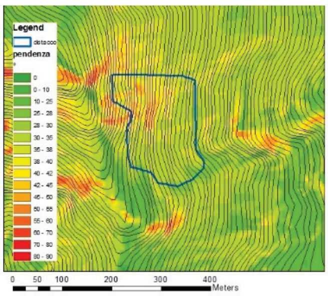

Fig. 4: starting zone slope analysis from DTM.

The slope map shows that the starting area is a steep slope (30° to 35° with an average value of 32°) characterized by two regular and planar sub-basins with apex sections very steep (up to 40°) or extremely steep (>40°) partly channelized (Fig. 4). The two sub-basins are merging, towards the bottom and near the tree-line, in a single wide and uniform area characterized by steep grassy slope, weakly concave and progressively more channelled. At the foot of this sector there is a minor mixed fan which is suspended and which represents a temporary run-out area for the smallest and more frequent avalanches or debris flows. The track area is channelled, weakly sinuous and is characterized by the presence of some important rocky steep sections. At the junction between the track area and the main valley two mixed coalescent fans are present characterized by a series of escarpments and slight ridges whose genesis refers to slope gravity processes (debris flows, avalanches, colluvium and rockfalls).

The analysis of some old aerial photographs, spanning a 68 years period, shows that the fan was also characterized by an elongated depressed area (interpretable as an inactive channel - where the Hotel Rigopiano was built), by alignments (with a radial pattern) of coarse-size deposits, by very thin scree deposits covering small meadows (locally reorganized in artificial piles of removed debris) and by radial rows of trees and bushes all interpretable as clear indications of the repeated passage of gravity flows (avalanches and/or debris flows). All such features were progressively masked by trees growth during the last 30-40 years. Such comparative analysis demonstrate that the Rigopiano area was subject to high magnitude avalanche events but with a medium-low frequency.

Field surveys show how the avalanche event already had, at the base of the starting area, a high speed and impact force able to seriously damage the isolated beeches present at the tree-line (see Fig. 2). From this point and along the entire track area the fast moving avalanche developed as a bipartite flow (dense and powder component) characterized by an important saltation layer. The avalanche was able to erode the snowpack present along the track, entraining it, thus increasing the volume and mass in a self-feeding process which produced a further increase in momentum allowing to eradicate and grind almost all the trees together with a considerable amount of rocky debris and soil (Fig. 5). In this sector the measured flow heights reach 3-4 m from the ground and up to 6-7 m. Along the track area the two flow components followed, often, different trajectories which allowed the powder component to climb up, in a parabolic trajectory, the valley sides up to 18-25 m of elevation thus promoting the corrasion and entrainment of the altered rocky substratum and portions of soil.

Moreover, the sudden slope changes favoured the formation in the flow of several "hydraulic jumps" with a consequent increase in whirling motions, turbulence and destructive power.

Fig. 5: beeches damaged by the avalanche in the upper track zone. (photo Chiambretti).

Fig. 6: beeches uprooted and finely splintered along the track zone. (photo Chiambretti).

The intermediate section of the channel was significantly enlarged compared to the pre-event situation thanks to the intense deforestation process operated by the avalanche. The beeches present in the center of the channel were uprooted and the stems incusing their root system (a bulb up to 1-2 m^3) were transported downslope and often finely splintered (Fig. 6). In this sector the height of the dense flow was between 2,5 and 5 m while the powder flow component reached 6-7 m.

At the fan apex, the presence of a series of relevant road embankments favoured the formation of new hydraulic jumps (Fig 7). The analysis of the damage heights on the trees allows to estimate, in this area, that the dense flow reached approximately a 3-4 m height, while the powder flow component reached a 7-8 m one. From this sector the flow dense component expanded laterally and vertically to occupy almost the entire section available and without excessively losing speed (Fig. 7). The interaction of the avalanche with the Hotel Rigopiano complex of buildings provoked a deviation (post impact) of the flow while the rest of the flow expanded laterally with its less dense flow components.

Fig. 7: HD satellite image of the Rigopiano Avalanche. The denser part of the deposit is clearly visible. (source Google Earth Pro – images Jul. 2017).

Some lateral deviations of the flow assumed a divergent trajectory (with respect to the axis of the fan) opening penetrating traces within the beech forest and inside the pinewood present, respectively, in the area upstream of the parking lots and near the camping area and the Tito Acerbo Refuge. Downstream of the Tito Acerbo Refuge the height of the dense flow reached approximately between 3-4 m while the powder flow component reached 9-14 m.

The avalanche injected material into the Hotel Rigopiano structure since the very first post-impact moments and continued to mix the material during the whole phase of structural collapse and deposited the whole structure some tens of meters further downstream. Furnishing components, parts of the fence and the lighting system of the Hotel were projected further downstream (up to 50-350 meters away) together with some of the vehicles present in the parking area and limestone boulders weighing up to about 4000 kg.

conclusion

Until today, the trial about this disaster is still underway and the authors have been able to illustrate only briefly the techniques used in the forensic investigations. The hope is that as soon as possible it will become possible to share all data with the scientific community because from such tragedies we can draw useful elements to learn best practices.

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