Engineering Structures 92 (2015) 15–28

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

# Impact of snow avalanche on buildings: Forces estimation from structural back-analyses

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ARTICLE INFO

*Article history:*
Received 20 April 2014
Revised 20 February 2015
Accepted 2 March 2015
Available online 18 March 2015

*Keywords:*
Snow avalanche
Impact pressure
Structural back-analysis

ABSTRACT

Snow avalanches, debris-flow and landslides are the major hazards in mountain areas. These phenomena involve high energies and the interaction with urbanized areas often implies large destruction. This is what happened in Italian Alps on December 2008: an avalanche totally destroyed several houses and cut-off the infrastructures (roads, power and telephone lines) for many days.

The usual approach to the study of such phenomena considers, first, the setup of a dynamic analysis of the snow avalanche in order to estimate the interaction forces. Following that, the collapse mechanisms are defined and computed. In an opposite way, we herein present a structural back-analysis of the failures of some constructions in order to deduce physical features of the avalanche, most importantly the impact pressures. The need of assumptions on snow characteristics is a great disadvantage for the analysis, meaning that, in the future, accurate measurements on nivological parameters are required.



## 1. Introduction

The effect of avalanche interference with constructions is still one of the main issues in mountain areas even if the response of structures under avalanche loads has been largely reported and studied in the past [19]. In addition to measurements at instrumented experimental-sites [21,3], back-analysis of real events is a tool to better understand the avalanche/structure impacts [33]. The analyses of damages and the understanding of the collapse mechanisms generated by snow avalanches can be very valuable to improve the knowledge of avalanche dynamics [6] and of imposed overloads on structures [22]. It can lead to a better evaluation of the risk [14] and, moreover, it can teach how to build in avalanche areas [13]. Simple models are shown to be effective for the estimation of single parameters in complex natural phenomena [11].

In engineering terms, the interaction between snow avalanche and constructions is evaluated in term of impact pressure, i.e. a dynamic pressure proportional to the square of flow velocity. The usual approach is based on the creation of a numerical model of the phenomenon. Flow dynamics models give and estimate of flow velocity and, thus, impact pressure. In the last calculation, the density of the snow composing the body of the avalanche has to be known, since there is direct proportionality between dynamic pressure and flow density. Once the dynamic actions of the avalanche on the construction are known, the common structural engineering approaches would serve as a guidance to the evaluation of the structural safety in such hazardous scenario.

This paper wants to investigate the possibilities of studying the dynamical properties of snow avalanches through the back-analysis of the effects of real avalanche events on real structures. In this sense, two main issues are herein addressed and discussed. The first obviously relates to the strategy for obtaining useful information from building failures. The latter intends to define the parameters to be measured in order to get reasonable results, i.e. to limit the incertitude of the final values.

Avalanche impact pressure are notoriously high and snow flow is capable of large destructions, as surveyed in this event. In order to overcome the problem of getting the correct values of the impact pressures of *Les Thoules* snow avalanche from simulations the damages on four constructions (both partially damaged, and totally collapsed) are analyzed under a structural framework following forensic approaches [27,1] and surveys onsite. Following the practice commonly used in failure engineering, the analyses are performed formulating *ad hoc* hypotheses on collapse mechanisms. Forensic engineering is devoted to the study of causes of damage and the modalities of crisis, rather than the physics of the event. Despite the original cause of damage is herein known, uncertainty on the ways the buildings collapsed is still large.

For the purposes of the analysis, advanced aspects linked with the complex interaction between the flow and the construction,

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http://dx.doi.org/10.1016/j.engstruct.2015.03.004
0141-0296/

such as short-lived peaks and fluctuations of impact forces on moving boundaries (the construction that collapses), are not considered. As detailed in the following, the lack of precise measurements of snow characteristics is the major source of variability of the back-analyzed dynamic parameters.

The paper is organized as follows. Section 2 describes the injurious event. The description of the damaged constructions, the calculations and the estimated dynamic parameters are reported in Section 3 (further details are in Appendix A). The analyses are made trying to limit to the maximum the number of assumptions, which are described in detail in Section 3.1. The discussion of the results and the conclusions are reported in Sections 4 and 5.

## 2. The "Les Thoules" snow avalanche event

Snow avalanche is a rapid movement of snow down a mountain slope. Density, velocity and depth of the flow are extremely variable, depending on various parameters such as topography, snow characteristics, vegetation [23]. Fig. 1 shows the avalanche path that released from the slope named *La Tour* on December 15th 2008 at about 1 pm. The south-west oriented slope is located at an altitude of about 2300–2500 m a.s.l. with a slope inclination of 45–55° and covered by grass and rocks of small size.

The release volume was estimated 50,000 $m^3$ compacted in a slab with a maximum width of 350 m and a thickness up to 1.50 m. The release zone descends into a steep slope over Les Thoules village. The released thick soft-slab induced 3 avalanches: n.039 *La Frange*; n.082 *Pro-Lombard nord*, which arrested before the alluvial fan; n.083 *Pro-Lombard sud*, which hit the valley floor and interrupted the regional road at a length of 80 m and stopped in the Torrent Savara [4,28].

The avalanche n.039 was split into two branches just in front of the regional regional road because of the topography of the run-out zone and impacted several buildings of Les Thoules village. Seven houses, phone and power lines (many masts and an high voltage pylon), and portions of forest were destroyed. In addition, five buildings and one hydroelectric power-plant were damaged and the regional and the communal roads were interrupted. Ten animals were killed.

The natural snow cover depth in the proximity of the village of Les Thoules was about 1.30 m, as reported in RAVA [28].

## 3. Structural back-analysis

This section describes the procedures and the results of a detailed structural back-analysis of the event on December 15, 2008. The outputs of the calculations herein presented are: (i) the evaluation of the manner the buildings collapsed and (ii) the estimation of avalanche flow parameters, i.e., the impact pressure. Referring to the avalanche, all the data available on the event were brought together, i.e. snow characteristics, historical avalanches in the area and meteorological conditions. In reference to the constructions, the original drawings and, if present, the design reports were collected; plan and sections views were found. Since few drawings were not dated, further investigations were performed on historical maps and at the National Building Registry. For this avalanche event, a rich photographical archive is available among the Authorities. The pictures taken few days after the event catch the main characteristics of the avalanche (size, triggering, running and deposition zones). On the other hand, the detailed views of the main structural components of the damaged buildings were taken in the months following the event and after spring snowmelt.

Debris position was mapped and a first topographical survey was made. After a preliminary data elaboration, a first hypothesis on the failures was made: a more detailed "structural" investigation on materials and geometry of the remaining parts of the constructions was performed with the purpose to prove or to confute the suppositions. Bovet et al. [6] considered the effects of the mutual positions of the constructions and modeled numerically the flow around the constructions. Finally, the rupture modes were supposed based on the real mechanical capacities of the structural elements.

The back-analysis of each construction is treated in detail in the following paragraphs. A preliminary description of the damages is presented, then the collapse modes are illustrated. In most of the simulations of collapses presented, the rupture mechanisms analyzed presupposes that each part composing the construction is infinitely stiff, i.e., rigid body. In this sense, the inverse analysis

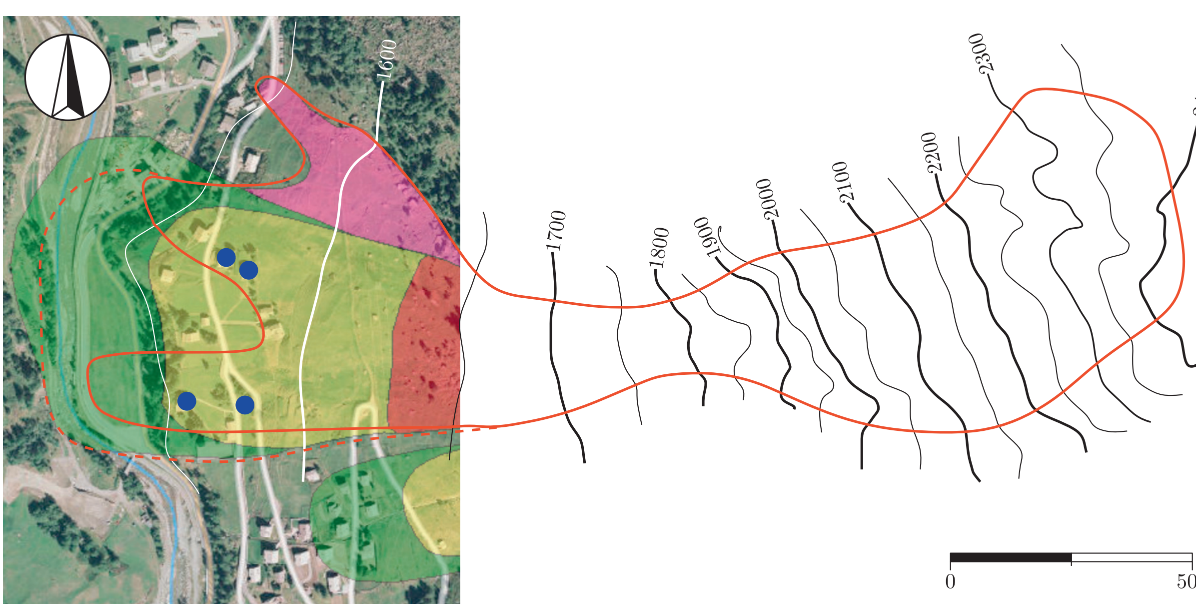


**Fig. 1.** Path of *La Frange* avalanche on December 15, 2008 (n.039). The aerial view is centered on the run-out zone; it includes the avalanche hazards land zoning (green, yellow, red) reported by the Authorities after the installation of snow umbrellas in the starting zone [4]. The red plain line marks the limits of the dense component of the avalanche while the dashed line relates to the limits of the airborne component. The location of the four buildings that are analyzed in this paper are indicated by blue circles [28]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)