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Impact of explosive eruption scenarios at Vesuvius

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Abstract

In the paper the first attempt at the definition of a model to assess the impact of a range of different volcanic hazards on the building structures is presented. This theoretical approach has been achieved within the activities of the EXPLORIS Project supported by the EU. A time history for Sub-Plinian I eruptive scenario of the Vesuvius is assumed by taking advantage of interpretation of historical reports of volcanic crises of the past [Carafa, G. 1632. In opusculum de novissima Vesuvij conflagratione, epistola isagogica, 2ª ed. Napoli, Naples; Mascolo, G.B., 1634. De incendio Vesuvii excitato xvij. Kal. Ianuar. anno trigesimo primo sæculi Decimiseptimi libri X. Cum Chronologia superiorum incendiorum; & Ephemeride ultimi. Napoli; Varrone, S., 1634. Vesuviani incendii historiae libri tres. Napoli], numerical simulations [Neri, A., Esposti Ongaro, T., Macedonio, G., Gidaspow, D., 2003. Multiparticle simulation of collapsing volcanic columns and pyroclastic flows. J. Geophys. Res. Lett. 108, 2202. doi:10.1029/2001 JB000508; Macedonio, G., Costa, A., Longo, A., 2005. HAZMAP: a computer model for volcanic ash fallout and assessment of subsequent hazard. Comput. Geosci. 31,837–845; Costa, A., Macedonio, G., Folch, A., 2006. A three-dimensional Eulerian model for transport and deposition of volcanic ashes. Earth Planet. Sci. Lett. 241,634–647] and experts' elicitations [Aspinall, W.P., 2006. Structured elicitation of expert judgment for probabilistic hazard and risk assessment in volcanic eruptions. In: Mader, H.M. Coles, S.G. Connor, C.B. Connor, L.J. (Eds), Statistics in Volcanology. Geological Society of London on behalf of IAVCEI, pp.15–30; Woo, G., 1999. The Mathematics of Natural Catastrophes. Imperial College Press, London] from which the impact on the building structures is derived. This is achieved by an original definition of vulnerability functions for multi-hazard input and a dynamic cumulative damage model. Factors affecting the variability of the final scenario are highlighted. The results show the high sensitivity of hazard combinations in time and space distribution and address how to mitigate building vulnerability to subsequent eruptive phenomena [Baxter, P., Spence, R., Zuccaro, G., 2008-this issue. Risk mitigation and emergency measures at Vesuvius].

The first part of the work describes the numerical modelling and the methodology adopted to evaluate the resistance of buildings under the combined action of volcanic phenomena. Those considered here for this multi-hazard approach are limited to the following: earthquakes, pyroclastic flows and ash falls. Because of the lack of a systematic and extensive database of building damages observed after eruptions of such intensity of the past, approaches to this work must take a hybrid form of stochastic and deterministic analyses, taking into account written histories of volcanic eruptions and expertise from field geologists to build up a semi-deterministic model of the possible combinations of the above hazards that are situated both in time and space. Once a range of possible scenarios has been determined, a full stochastic method can be applied to find a sub-set of permutations and combinations of possible effects. This preliminary study of identification of the possible combination of the phenomena, subdividing them into those which are discrete and those which are continuous in time and space, enables consideration the vulnerability functions of the combinations to be feasible.

In previous works [Spence, R., Brichieri-Colombi, N., Holdsworth, F., Baxter, P., Zuccaro, G., 2004a. Vesuvius: building vulnerability and human casualty estimation for a pyroclastic flow (25 pages). J. Volcanol. Geotherm. Res. 133, 321–343. ISSN 0377-0273; Spence, R., Zuccaro, G., Petrazzuoli, S., Baxter, P.J., 2004b. The resistance of buildings to pyroclastic flows: theoretical and experimental studies in relation to Vesuvius, ASCE Nat. Hazards Rev. 5, 48–50. ISSN 1527–6988; Spence, R., Kelman, I., Petrazzuoli, S., Zuccaro, G., 2005. Residential Buildings and Occupant Vulnerability to Tephra Fall. Nat. Hazards Earth Syst. Sci. vol. 5. European Geosciences Union, pp.1–18; Baxter, P.J., Cole, P.D., Spence, R., Zuccaro, G., Boyd, R., Neri, A., 2005. The impacts of pyroclastic density currents on buildings during the eruption of the Soufrière hills volcano, Montserrat. Bull. Volcanol. vol. 67,292–313] the authors investigated, by means of experimental and analytical methods, the limiting resistance of masonry and reinforced concrete buildings assuming each action separately. In this work the first attempt to estimate the response of the buildings to the volcanic seismic action or to the lateral dynamic pressure due to pyroclastic flow combined with an extra vertical

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load on the roof due to ash fall is performed. The results show that up to a certain limit of ash fall deposit, the increment of structure weight increases the resistance of a building to pyroclastic flow action while it reduces its seismic resistance. In particular the collapse of the top storey of R.C. buildings having large roofs could occur by accumulation of ash and a strong earthquake. Seismic and pyroclastic flow vulnerability of tall R.C. and masonry buildings with rigid floors is less sensitive to ash fall load combination. The model allows any sequence of events (earthquake, ash fall, pyroclastic flow) to be assumed and evaluates the spatial distribution of the cumulative impact at a given time. Single impact scenarios have been derived and mapped on a suitable grid into which the territory around Vesuvius has been subdivided. The buildings have been classified according to the constructional characteristics that mostly affect their response under the action of the phenomena; hence the vulnerability distribution of the buildings are assigned to each cell of the grid and by taking advantage from the combined vulnerability functions the impact is derived at time *t*.

In the paper the following impact simulations are presented:

- single cases of selected seismic sequence during the unrest phase (Sub-Plinian I)
- ash fall damage distribution compatible to a Sub-Plinian I eruption
- pyroclastic flow cumulative damage scenarios for selected cases (Sub-Plinian I).

The model also allows either Monte Carlo simulation to evaluate the most probable final scenario or maximisation of some parameter sensitive to Civil Protection preparedness. The analysis of the results derived for a Sub-Plinian I-like eruption has shown the importance of the seismic intensities released during the unrest phase that could interfere with the evacuation of the area and the huge number of partial collapses (roofs) due to ash fall.

Keywords: Sub-Plinian I eruption; cumulative damage; impact scenarios; probabilistic model

1. Introduction

The evaluation of the possible effects due to a volcanic eruption in an urbanised region, such as the realization of a credible impact scenario, represents a very complex problem and a quite unexplored field of interest. The damage impact scenario in fact can be quite different depending on the type of eruption, both because of the development over time of the different phenomena that characterize it and because of the urbanistic and typological–structural characteristics of the buildings and of the infrastructures in the study area.

A volcanic eruption is characterized by a series of successive physical phenomena, so the damage impact due to a volcanic eruption depends upon several disastrous events, different even though tightly connected, each of which contributes in different way to the final scenario.

Within the EXPLORIS Project three of these phenomena have been studied: earthquakes (EQ), ash falls (AF) and pyroclastic flows (PF).

The impact on building structures deriving from the combination of different volcanic actions has been rarely studied. Extensive statistical databases on such damage are not available from previous cases, except some information that could be derived from recent eruptions around the world (Rabaul, Montserrat, etc.) and by interpreting historical reports of volcanic crises of the past. In the EXPLORIS Project, some historic manuscripts describing the 1631 eruption have been translated from Latin and ancient Italian, and these have supplied useful information to validate the assumptions and the results of this work.

The goal is to develop a dynamic model, here presented, that simulates the whole eruptive process, from the first precursory seismic events up to the final pyroclastic flows, evaluating at every step of the process, the damage accumulated on the buildings and the distribution of the damage on the territory.

It is considered, in fact, that the sequence of events during the eruption causes a progressive diminution of the resistance characteristics of the buildings, depending on the evolution of the damaging process.

Therefore an important starting point is represented by the event tree (ET) (Aspinall et al. 2008-this issue) developed in EXPLORIS (Fig. 1) that estimates the probabilities of occurrence for each of the possible eruptive scenarios, or rather of the possible typologies of eruptive process.

The model for damage evaluation has been tested for a “Sub-Plinian I” style of eruption, with the creation of maps that describe the impact of the eruption on the region and the evaluations of the losses, either in terms of building damage (number of collapses, heavy damaged etc.) or in terms of casualties (people killed, people seriously injured and homeless).

The model has been tested also for a violent Strombolian type eruption, for which only preliminary results are reported elsewhere in this volume (Baxter et al., 2008-this issue).

2. Event definition

The combination of the three volcanic phenomena can increase damage on buildings by comparison with the effects of each one acting separately. The real impact resulting from the load combination is dependant on the possible eruptive scenario assumed. The dynamic evolution of the eruption will impose the real loading combination at a specific time in the evolution of the eruptive event. Therefore, in order to simplify such a complex task and considering the great uncertainty in the definition of the load history derived from different eruptive