ROBUSTNESS OFTHE VESUVIAN ROOFS UNDER THE COMBINED OVERLOAD AND HIGH TEMPERATURES DUE TO AIR FALLS

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Abstract

During an explosive eruption, a construction is hit by several actions, always associated to elevated temperatures, causing fires, possible explosions and reduction of the mechanical properties of the structural materials. In this paper, the attention is focused on the analysis of a specific volcanic event, the so-called air fall deposits, generally falling from the eruptive column due to gravity. In particular the robustness against the air fall deposit of the most common roofing structures, typically made of timber, steel and reinforced concrete, in the Vesuvian area is evaluated. Consequently, some protection systems for mitigating the effects of the combination of overloading and high temperatures are identified.

Keywords: explosive eruptions, Vesuvian roofs, ash fall deposits, high temperature, robustness evaluation, mitigation systems

INTRODUCTION

Explosive volcanoes, like Vesuvius (Naples, Italy), are extremely dangerous. They are characterized by the violent emission of the so-called eruptive column, formed by gas-solid dispersal, rising vertically from the vent, due to the initial high pressure of the magmatic gas.

An explosive eruption occurring close to an urban area generates several actions that possibly hit a construction: the volcanic earthquake; the additional gravity load on roofs produced by pyroclastic deposits; the horizontal dynamic pressures on façades due to pyroclastic flows and lahars; the impact produced by flying fragments (Mazzolani et al., 2009a,b). All these are associated to elevated temperatures, which either can trigger fires and explosions or induce degradation of the mechanical properties of the structural materials.

Down the century, the volcanic eruptions have produced many fatalities and economic losses all over the world. In Europe, the Vesuvius area is characterise dat highest risk: a probable eruption of Vesuvius menaces the surrounding urban zones, which are very much densely populated, with about 600,000 inhabitants. This hazard situation of the Neapolitan volcano motivated the core committee of European project COST Action C26 “Urban Habitat Constructions under Catastrophic Events” (2006-2010) to introduce the volcanic vulnerability assessment of the Vesuvius area as a case study within the research topics, with the twofold general objectives: the robustness evaluation of the urban environment towards a Vesuvian eruption and the identification of simple and economical mitigation interventions. In this context, the present paper specifically deals with the evaluation of the effects of the combination of overloading and high temperature due to pyroclastic deposits on roofing structures, consequently, leading to the identification of possible mitigation systems.

1 NATURE AND MODELLING OF AIR FALL DEPOSITS

The main products of an explosive eruptions are the pyroclasts, originated by the magma fragmentation. Their deposits are generically called tephra and divided in three basic types: air fall, pyroclastic flows and surges.

The air fall (or tephra fall) deposits are formed by the accretion of clasts, either falling by gravity from the eruptive column or throwing directly in surrounding areas from the crater, according to ballistic trajectories. Besides, the deposits of pyroclastic flows and surges are produced by gas-solid dispersions with high or low concentration of particles, respectively, which move along the volcano surface, following either the collapse of the eruptive column, or a directional explosion for the sliding of a volcano part, or a lateral explosion at the bottom of a lava dome (Nelson, 2010).

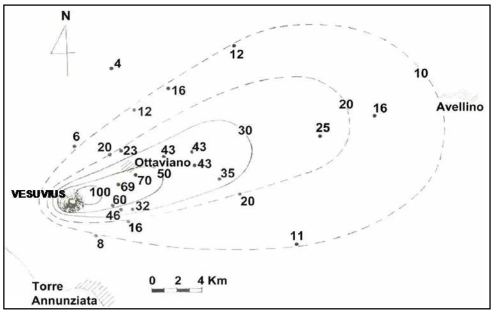
During violent explosive eruptions (Plinian and sub-Plinian), large deposits of tephra fall can cover an area of elliptical shape around the crater, reaching also large distances, according to the direction of stratospheric winds (INGV-OV, 2012). Contrary, moderately explosive eruptions can produce deposits of clasts, whose distribution is symmetrical around the crater, because the launches are not sufficiently high to be influenced by the wind. Generally, the thickness of air fall deposits decreases with the distance from the eruptive centre.

The air fall deposits action on the ground level can be considered as a gravitational distributed load, which can be estimated as it follows:

$$q_G = \rho \cdot g \cdot h \tag{1}$$

where g is the gravity acceleration (9.81ms^{-2}), $h$and ρ are the deposit thickness (m)and density (kNm^{-3}), respectively. The latter depends on the composition and compactness of pyroclasts and the deposit moisture, which is weather dependent. Therefore ρ, ranges, according to its compactness, from 4 to 16kNm^{-3}in dry conditions, from 8 to 20 kNm^{-3}in damp conditions (Spence et al., 2005).

The air fall deposits action on the roofs can be modelled by similitude with the snow load (Faggiano et al. 2013), considering q_G as characteristic value of the tephra load. In particular with reference to the 1631 sub-PlinianVesuvian eruption, it being considered in the current Evacuation Plan by the Civil Protection, in Fig. 1 the isopaches of the air fall deposits, which give the distribution of the deposit thickness, are depicted. In the same figure, the air fall deposit loads on the ground (q_G) and on the roof (q_R), corresponding to C_E=1, ρ = 14 kNm^{-3}, different deposits thickness h and typical pitch angle α, according to the technical Italian code for the snow (M.D., 2008), are indicated. In addition to the relationship (2), the model of the air fall deposits action should be completed considering the high temperatures (200-400°C) of the clasts.



(a)

h	q_G	q_R			
		α=0°	α=20°	α=30°	α=45°
cm	kNm^{-2}	kNm^{-2}	kNm^{-2}	kNm^{-2}	kNm^{-2}
10	1.4	1.1	1.1	1.1	0.6
20	2.8	2.2	2.2	2.2	1.1
30	4.2	3.4	3.4	3.4	1.7
50	7.0	5.6	5.6	5.6	2.8
100	14.0	11.0	11.0	11.0	5.6

(b)

Fig. 1 Air fall deposits isopaches (cm) (a) and loads on the ground (q_G) and on the roof (q_R) (b), referred to the 1631 sub-PlinianVesuvian eruption

2 IN SITU SURVEY AT THE VESUVIAN URBAN AREA AND CASE STUDIES

The pilot area was identified in Torre del Greco, the most populous town in the volcanic area (about 90,600 inhabitants). Within the COST Action C26, two missions were organized, for investigating three different urbanized zones (De Gregorio et al., 2010), involving members of the partner countries, with the cooperation of the PLINIVS Centre (Hydrological, Volcanic and Seismic Engineering Centre, Naples, Italy; Mazzolani et al., 2010).

The most common constructive types of buildings in the Vesuvius area are masonry and reinforced concrete (RC). The main typologies of roofs are either horizontal (87%), made of timber (4%), steel (58%) and RC (25%) structures, or vaulted (13%).

The examined roof typologies are ventilated and not ventilated timber, steel and RC structures, whose features are represented in Fig. 2.

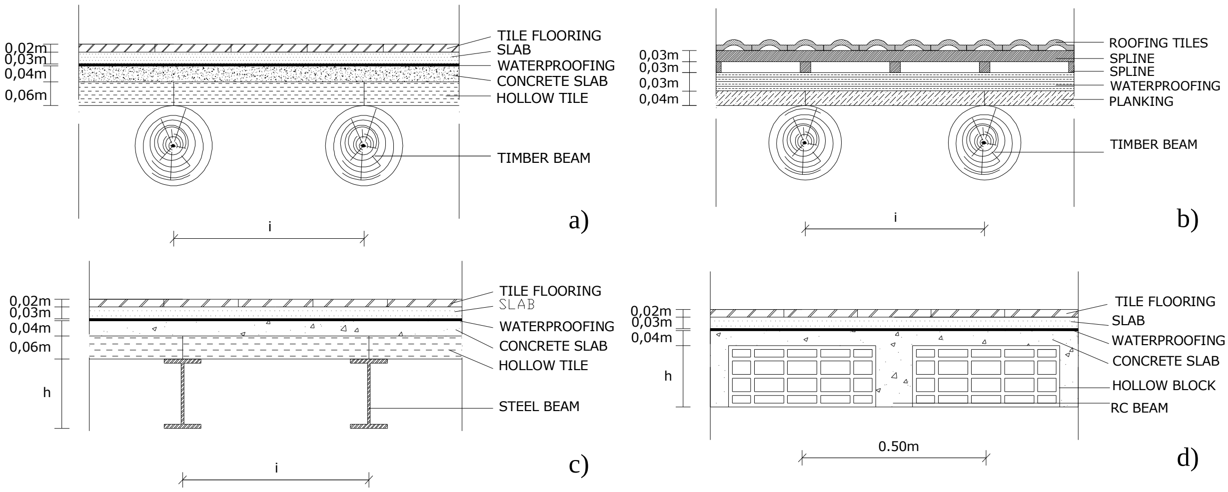
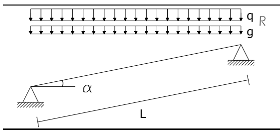


Fig. 2 Main Vesuvian roof types: a) not ventilated timber; b) ventilated timber; c) steel; d) RC

3 ROBUSTNESS EVALUATION OF THE VESUVIAN ROOF STRUCTURE

The behaviour of the study roof structures struck by the air fall deposits is evaluated in two steps (Faggiano et al., 2013), considering the combination of the twofold action, such as the additional gravity load and high temperatures. The first one consists in the assessment of the ultimate vertical load which the structure is able to sustain, in addition to permanent design load. In particular, the study is extended to roofs having different geometries and design live loads (0.6 and 2.0 kNm^{-2}). The second one is the thermal analysis of the roofs, which aims at evaluating the mechanical degradation due to high temperatures.

The considered static scheme is a simple beam supported at both ends (Fig. 3), subjected to dead load g and live load q_R due to the air fall deposits.



Spans:
L = 3, 4, 5, 6, 7m
Pitch angles:
α = 0, 20, 30, 45 °

Interaxes:	Timber and steel beams:	i = 0.80, 1.00m
	RC beams:	i = 0.50m

BEAM SIZES:

Timber		Steel	RC
(chestnut)		FeB360	
Circular (ϕ)	Rectangular (BxH)	IPE	
[cm]	[cm]		
10	12×20	100	Materials, height of beam and reinforcement bars variable according to the different Italian technical codes (RD 1939, MD 1972, MD 1996 and MD 2008), in function of two assumed design live loads equal to 0.6 and 2.0kNm^{-2}
12	12×24	120	
14	12×26	140	
16	14×20	160	
18	16×20	180	
20	16×22	200	
22	16×24	220	
24	18×22	240	
26	18×24	270	
28	20×24		
30	20×26		

Fig. 3 Static scheme and geometrical features of the roofs

The mechanical thermal degradation of structural materials (Eurocodes 2, 3 and 5, Parts 1.2) is considered at four temperatures, such as 20, 200, 300 and 400°C, they being assumed as uniformly distributed within the cross section. Thermal analyses are carried out by ABAQUS v. 6.5 nonlinear calculation program (Hibbitt et al., 2010). The FEM model of a 1.50 m x 1.00 m roof area with 16cm depth beams for timber and steel roofs and 12 cm depth beams for RC ones, all of them having a 80cm interaxis, is set up (Fig. 4). The different roof layers (tile, slab, waterproofing), which the thermal properties of the constitutive material (density, conductivity and specific heat) are assigned to, are modelled through *3D heat transfer* elements. With the purpose of increasing the heat transfer time from extrados to intrados of the roof, a layer of a thermal insulator, constituted by a 3cm thick rock wool with a conductivity coefficient of0.04Wm^{-1}K^{-1}, which is considerably smaller than those of timber (0.1204Wm^{-1}K^{-1}), steel (53.3004 Wm^{-1}K^{-1}) and concrete (1.9104Wm^{-1}K^{-1}), is also considered.

For each roof types, the ultimate residual live load *q* is determined, at different pitch angles α (0-45°) and temperatures T (20-400°C). In particular, for the sake of example in Fig. 5 for steel roofs the diagrams of *q*vs*L*, they referring to ambient temperature (20°C) with variable pitch angle (Fig. 5a), and to a 0° pitch angle (plane roof) with variable temperatures (Fig. 5b), and the thermal trend (Fig.5 c)are illustrated.

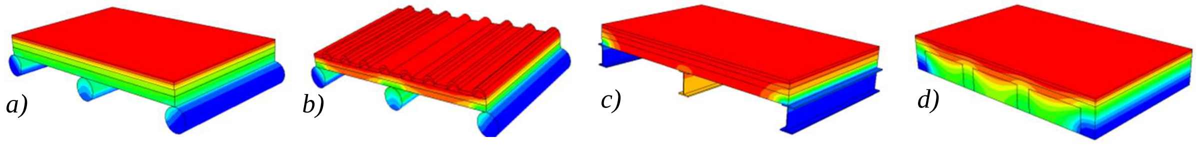


Fig. 4 Portions of roof considered in the thermal analyses: a) not ventilated timber; b) ventilated timber; c) steel; d) RC

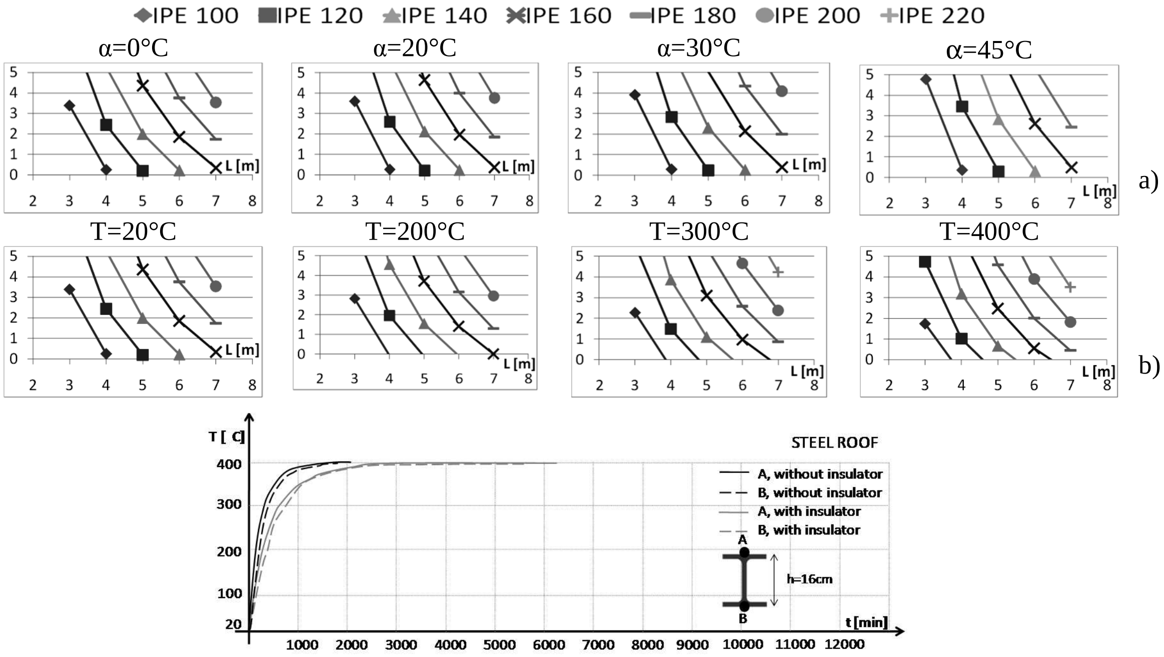


Fig. 5 Steel roofs: air fall deposit collapse loads with different pitch angles (a) and temperatures (b); thermal trend (c)

Results show that the ultimate residual load *q* has an increment of about 30-40% as far as the pitch angle α varies from 0 to 45°. Contrary, high temperatures produce a decrease of the collapse vertical load due to the thermal degradation of the materials, which, as an average, can be quantified as 30% at 200°C and 50% at 300°C; when the clasts temperature reaches 400°C, for most of the considered sections, any additional load cannot be resisted and the collapse occurs already for permanent loads.

Tab.1 Collapse times with or without an insulator layer

	T_{cr}	Time without insulator	Time with insulator
	°C	s	s
Timber roof	100	180	430
Ventilated timber roof	100	120	360
Steel roof	400	2000	6200
RC roof	400	2900	12950

Finally, the maximum collapse time for each roof typology is determined, as reported in Tab. 1, where the beneficial effect of the insulator layer, especially for RCroof structures is apparent (Faggiano et al., 2013).

4 PROPOSED VULNERABILITY CHARTS

In Fig. 6 some vulnerability charts are proposed. With reference to the 1631 Vesuvius eruption, the isopaches corresponding to deposit thicknesses at certain distances from the crater, together with the roof types ($L=6m$, $C_E=1$ and $\rho=14kNm^{-3}$) and the related collapse times are represented, in the case either of a pitch angle α equal to 0°without insulator layer (Fig. 6a) or pitch angle α equal to 0°, 20°, 30° and 45° and with the insulator layer (Figs. 6b-e).

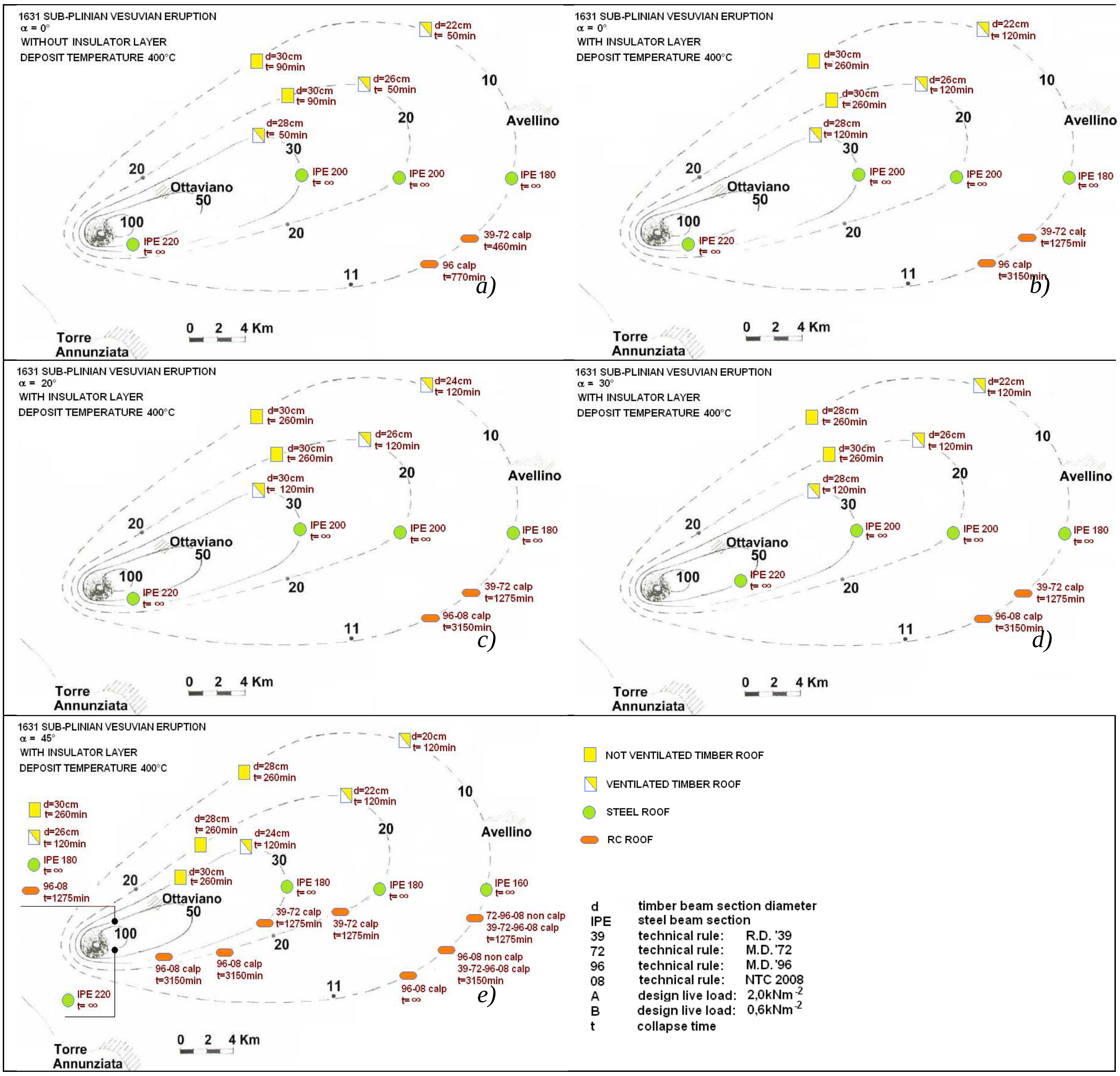


Fig. 6 Maximum collapse time produced by air fall deposits relating to 1631 Vesuvian eruption for roofs without insulator and α=0° (a) and with insulator and α=0° (b), 20° (c), 30° (d) and 45° (e)

5 CONCLUSIVE REMARKS AND POSSIBLE MITIGATION SYSTEMS

With reference to the Vesuvius area, roofs designed to resist ordinary vertical loads (0.60 and 2.00 kNm^{-2}) collapse when subjected to air fall deposits due to a sub-Plinian eruption, as the 1631 one. As it appears, the roofs behaviour under air fall deposits is influenced by two main factors: the materials thermal degradation and the roof pitch angle. The former one is due to the high clasts temperatures (150-400°C). It can be mitigated through the use of a thermal insulator with a conductivity coefficient of 0.04W/mK, able to triple the collapse time of timber, steel and concrete roofs. Besides, as far as the pitch angle is large, the load on the roof due to the air fall deposits decreases and the ultimate residual vertical load increases; so, in the areas at risk of pyroclastic deposits, a minimum slope of the roofs, such as 30°, should be required. In particular, for the existing plane roofs, a pitch angle can be obtained through the realization of over-structures made of light materials and provided with an adequate thermal insulation.

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