

PRELIMINARY ANALYSIS OF SITE EFFECTS IN THE ISCHIA ISLAND: NEW INSIGHTS FROM M_D 4.0 EARTHQUAKE OF 21 AUGUST 2017 AND SEISMIC NOISE DATA

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Introduction. On August 21, 2017, at 18:57 UTC, an earthquake of MD 4.0 occurred in Casamicciola, district of Ischia island. The damage caused by the earthquake was massive, with two victims and several buildings collapsed, and circumscribed to the areas of uptown Casamicciola, particularly in the Piazza Maio-La Rita area, and in a small area, called Fango, in Lacco Ameno. Medium and minor damages occurred in Piazza Bagni, in the area around the town hall of Casamicciola and in the Sentinella area (Zuccaro *et al.*, 2017). Even assuming the poor quality constructions and/or not in compliance with the anti-seismic regulations, such a level of damage has induced the scientific community to analyse the effects of local site amplifications, that usually are not negligible in volcanic areas (Galluzzo *et al.*, 2009; Tramelli *et al.*, 2010; Nardone and Maresca, 2011). As a matter of fact the seismic station IOCA (Fig.1), located very close to the high damage areas, recorded a peak ground acceleration (PGA) of 2.6 m/s^2 (red circle in Fig.3 top).

The island of Ischia is the emerged portion of a large volcanic active complex, part of the Phlegraean Volcanic District, which also includes the island of Procida and the Campi Flegrei caldera (Orsi *et al.*, 2003). Ischia is composed of volcanic rocks, epiclastic deposits and subordinate terrigenous sediments, reflecting a complex history of alternating constructive and destructive phases. The volcanic history of the island has been dominated by the large caldera-forming Mt. Epomeo Green Tuff (Brown *et al.*, 2008) eruption occurred ca. 55 ka (Vezzoli, 1988). The caldera depression was the site of marine sedimentation, with generation of a sequence of tuffite, sandstone and siltstone (Fig. 1).

The main morphostructural feature is the Mt. Epomeo resurgent block, delimited by two main trending fault systems (Acocella *et al.*, 2004), that has an asymmetrical profile, with the northwestern flank considerably steeper than the southeastern one as a result of an asymmetrical uplift. The surface expression of the volcano-tectonic features includes the north-northwest and southwest-facing steep flanks of Mt. Epomeo that are the gravitationally least stable slopes of the island. Mass movement deposits are widespread on the island and were generated by rock falls, slides, toppling, debris flows and debris avalanches (de Vita *et al.*, 2006).

In the past the island was affected by 12 earthquakes (Rovida *et al.*, 2016) with magnitude between ~ 3 and 4.3, the strongest occurred on July 28 1883. Common feature of all these earthquakes, largely concentrated in the north wester sector in the area between Casamicciola

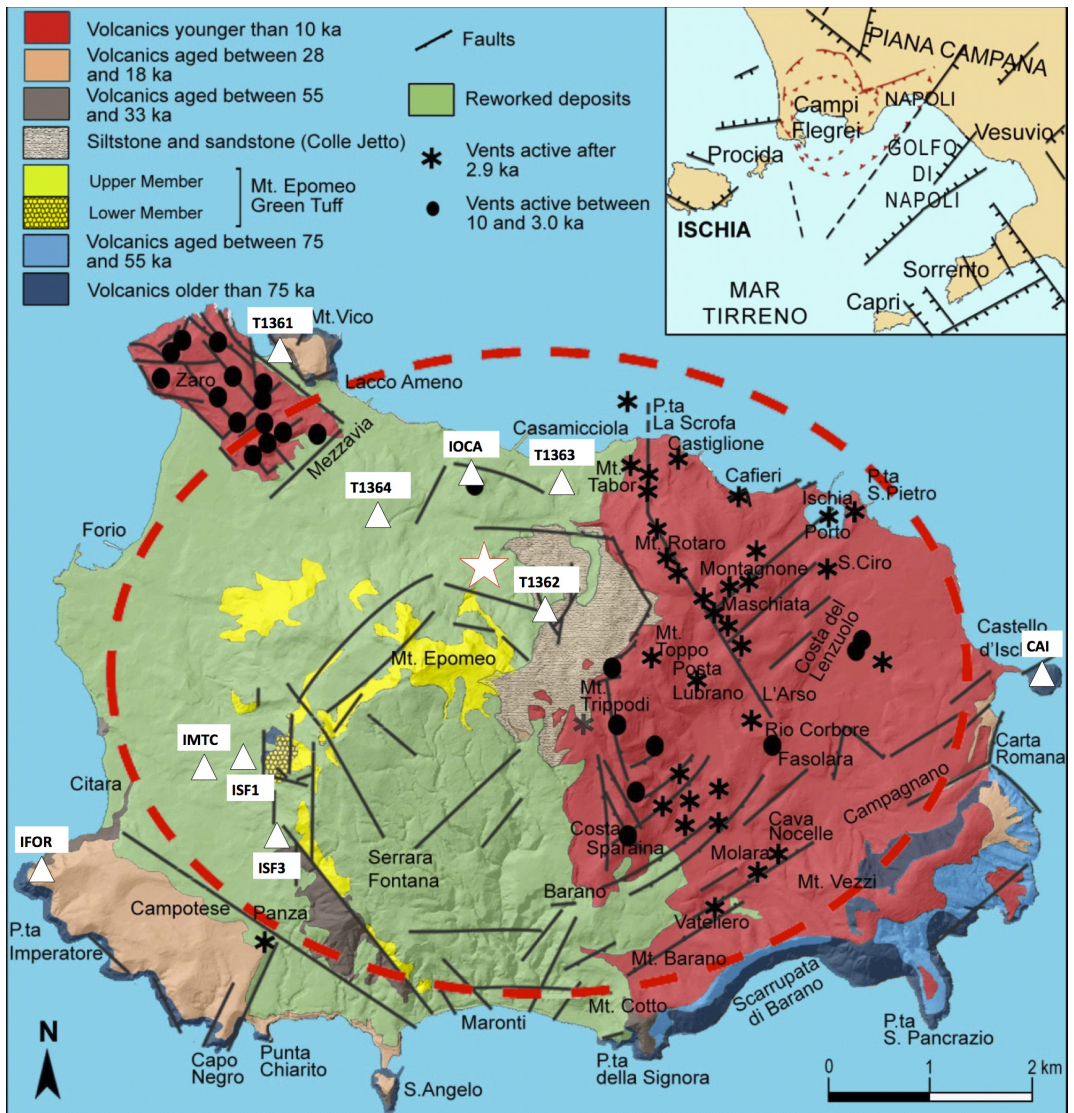


Fig. 1 - Geological map of Ischia Island. The red dotted line indicates, presumably, the Mt. Epomeo Green Tuff Caldera (modified after de Vita *et al.*, 2010 and Della Seta *et al.*, 2012). The white triangles indicate the seismic stations. The white star is the epicentre of the MD 4.0 earthquake.

and Lacco Ameno, is that rather modest magnitude estimates (maximum Mw is 4.3) correspond to very high and destructive macroseismic intensity effects (X MCS in 1883 in Casamicciola, Guidoboni *et al.*, 2007).

This paper is aimed to study the possible site amplification in the areas heavily affected by the August 21 earthquake in order to better understand the causes of these macroseismic effects and high damage levels already observed in the past.

Dataset and methodology. After the MD 4.0 earthquake hit Casamicciola on August 21, four seismic stations of the mobile network (T1361, T1362, T1363 and T1364) were installed on the island in addition to the four stations of the permanent network (CAI, IFOR, IMTC and IOCA). All the mobile network stations acquire locally and are equipped with short period sensors and one accelerometer, whereas permanent network stations, equipped with broad

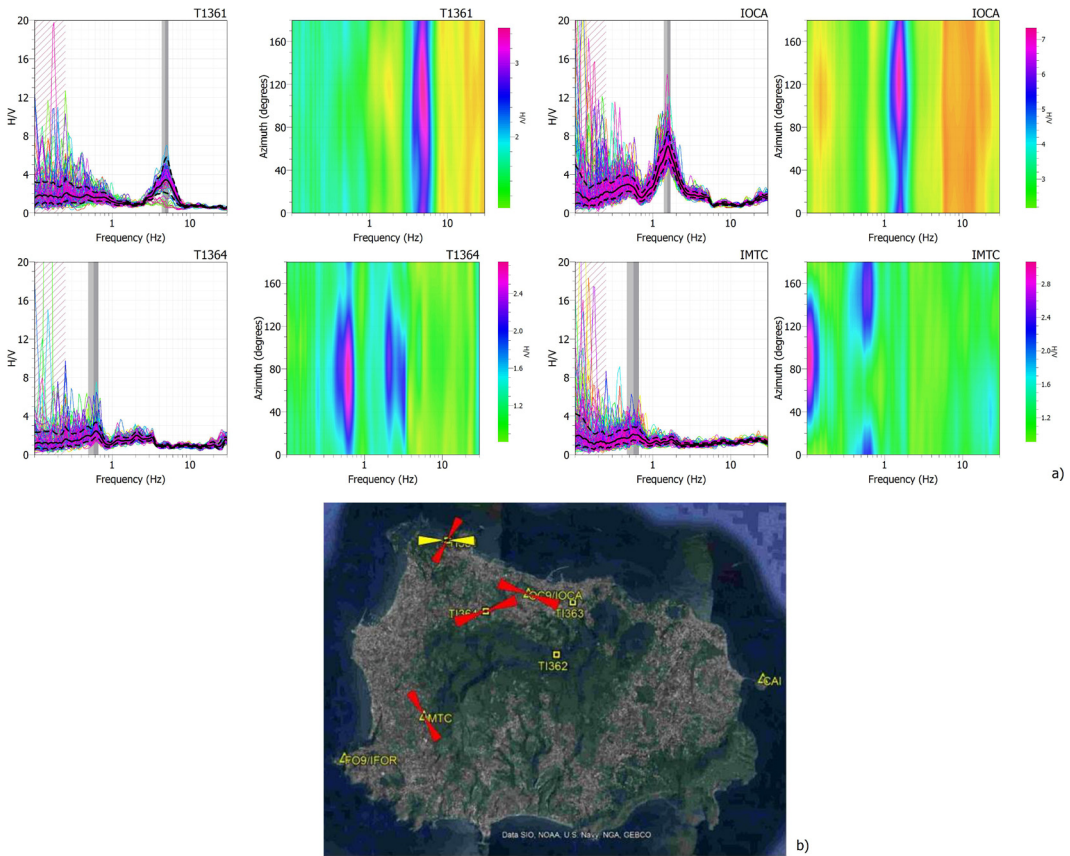


Fig. 2 - a) Noise H/V ratios (first and third column) as a function of frequency and directivity of the H/V ratio obtained rotating the horizontal components with a step of 10 degrees at four seismic stations (second and fourth column). The coloured curves on the H/V vs frequency graphs represent the H/V ratios calculated on each time-window. b) In red the rose diagrams in the 1-5 Hz ranges. In yellow the rose diagram in 3-7 Hz range for the station T1361.

band, accelerometer and short period sensors, transmit the seismic signals in real-time for seismic surveillance purposes. The eight stations currently installed on the island have different technical characteristics and their positions are shown in Fig. 1. Moreover, we have analysed seismic noise data acquired in 2002 by the stations ISF1 and ISF3 installed temporarily in the southwestern area of the island, close to IMTC station.

Spectral analysis. Horizontal to vertical spectral ratios (H/V) are computed from seismic noise data using the GEOPSY package (Wathelet *et al.*, 2004). We selected at least one hour of noise signals, preferably at night hours, and we calculated, on 40s moving time windows with 30% overlap, the spectral ratios, their stationarity and directivity showed in Fig. 2 a. Stationarity refers to the stability of the H/V ratios throughout the analysis: which means that the H/V ratios performed on each time-window should be as similar as possible among them, especially with respect to the amplitude peak frequency. The directivity of the H/V ratio is a function of the direction of the signal source on the horizontal plane, which can help to detect any signal polarization along a specific direction. The continuous black curves represent the average H/V ratio, while the dashed black curves are representative of the standard deviation. The grey bands identify the frequency peak, or f_0 , with the relatively standard deviation bandwidth. The dashed red area in the left part of the graphs indicates an uncertain confidence zone; this is caused by the fact that the dimensions of the time windows used for the data processing are not big enough to goodly resolve the ratios at low frequencies.

Polarization analysis. We investigated the polarization properties of seismic noise by applying the covariance matrix method (Montalbetti and Kanasevich, 1970) to the three-component seismograms, which allows to obtain the rectilinearity, the azimuth and the incident angle of the polarization vector through a diagonalization procedure. 1-hour-long samples of seismic noise recorded in September 2017 were band-pass filtered in the 1-5 Hz frequency range. Moreover, data recorded by T1361 were also analysed in the 3-7 Hz frequency band, over which the H/V ratio has the maximum amplitude. The polarization parameters were estimated using sliding time-windows containing two wave cycles, with an overlap of 50%. Narrow azimuthal distributions of the polarization vector were obtained: the overall pattern is shown in the rose plots of Fig. 2b.

Data analysis and results. *Sesimic noise.* In this paper we show only four representative station: IOCA and IMTC of the permanent network, T1361 and T1364 of the mobile network (Fig. 2). Clear and stationary amplitude peaks are evident in the H/V ratios of IOCA and T1361.

The station T1361 shows a peak centred at 5 Hz and has the maximum in the directivity diagram around the nearly E-W direction. Looking at the polarization analysis we observe that the direction of the polarization changes from a nearly NS direction, in the 1-5 Hz frequency range, to the E-W direction in the 3-7 Hz frequency range (yellow rose diagram in Fig. 2b). The higher frequency interval analysis covers the same range in which the H/V ratio reaches its maximum in the directivity analysis and highlights the same polarization direction.

The station IOCA has the maximum amplitude peak centred at 1.5 Hz and it also has a maximum in the directivity diagram around the E-SE direction (~ N120). This is in agreement with the polarization direction (Fig. 2b) and with the prevalent geological structures in the northern island.

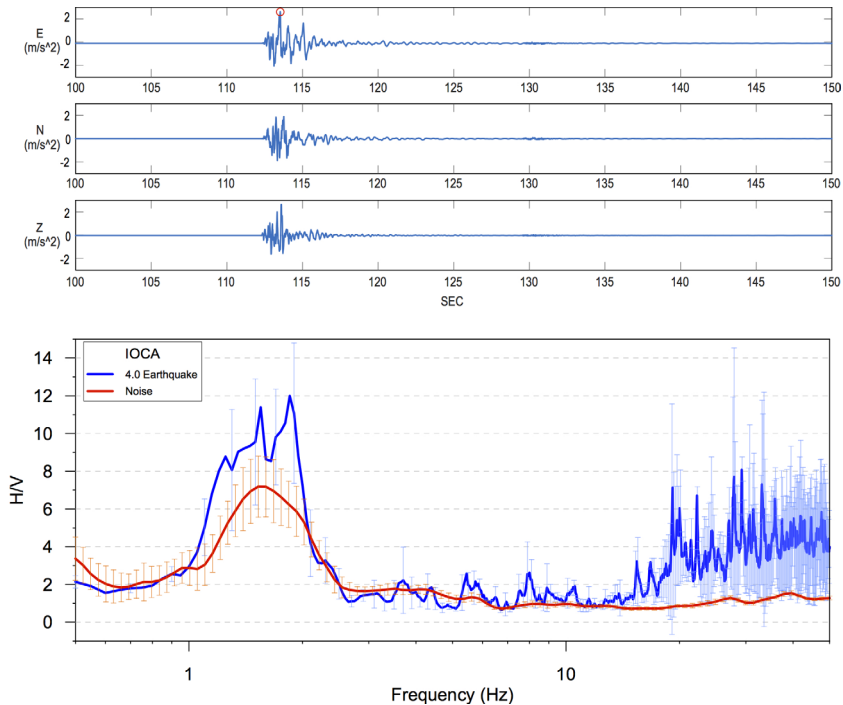


Fig. 3 - Top: MD 4.0 earthquake accelerograms for the three components of motion recorded at IOCA station. The red circle identifies the maximum acceleration value equal to 2.6 m/s². Bottom: H/V ratio obtained for the MD 4.0 earthquake (in blue) and H/V ratio obtained for seismic noise (in red) at the station IOCA. The vertical bars indicate the standard deviations.

The station T1364 shows a H/V peak centred at 0.6 Hz with an amplitude of 2.6 in the E-NE direction (\sim N70) of the directivity plot in agreement with the polarization direction. This matches the prevalent geological structural features of the northwestern portion of the island.

In the station IMTC we do not recognize properly an amplitude peak of the H/V, nevertheless at a 0.6 Hz there is a maximum of the ratio which assume a value of 2.1. This maximum is in the SW-NE direction (\sim N150) of the directivity plot according to polarization direction and to the prevalent trend of the geological structures.

Earthquake MD 4.0. During the earthquake the velocimeters of the permanent seismic stations network saturated and only the station IOCA, that is equipped also with an accelerometer, recorded entirely the earthquake (Fig. 3 top). We calculated the earthquake H/V ratios and compare it with the one obtained using the seismic noise (Fig. 3 bottom). We observe that both have a peak centred at 1.5 Hz, but the earthquake H/V peak reaches a value of 12, significantly higher than the noise H/V peak, that has an amplitude of 7. Furthermore at high frequencies, after 20 Hz, H/V earthquake ratio is more than three times higher than the seismic noise one.

Conclusions. The H/V analyses performed with the noise data show that the analysed sites have two response behaviours, one almost flat in the entire frequency range and the other with a predominant amplitude peak well centred at a specific frequency.

The results indicate that there is a good agreement between the H/V peak directivity and the polarization direction of the noise, which observing the geological map coincides with the main structural features of the island.

We are confident that the sites that exhibit H/V amplification peaks are characterized by high seismic impedance contrast between the shallow reworked volcanic deposits and the underlying lavas. Further investigations are in progress.

The comparison of the two ratios performed for the station IOCA highlights that the noise H/V ratio has strong similarities with the earthquake H/V, therefore we can assert that the seismic noise analysis identifies perfectly the resonant site frequency, even if with a lower amplitude value.

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