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Observations on the rotational seismic wavefield recorded in the Campi Flegrei volcanic area

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Summary. — The present work describes preliminary results of the analisys carried out on the signals provided by a rotational seismometer installed in the Campi Flegrei volcanic area. Starting from January 2021, a rotational seismometer (Lunitek Tellus R2) was installed in the area. The analyzed data consists of 20 local earthquakes occurred in Campi Flegrei from February 2021. The local seismicity is composed by low magnitude volcano tectonic earthquakes ($M_D max = 3.6$) located at depth between 0.3 and 4 km b.s.l. For the strongest earthquake, we observed a maximum rotational velocity equal to 6 mrad/s. The joint use of the rotational sensor and the accelerometer confirms the possibility of estimating the azimuth and the apparent velocity of the incoming wavefront and highlighted some more correlated phases in the coda of seismograms that could provide useful indications about the diffuse wave field recorded in the investigated area.

1. – Introduction

The rotational seismometers are sensors designed to record the rotational wave field in the three components of motion in addition to the translational wavefield recorded through seismometers and accelerometers. For this reason, over the last decades the joint use of classical translational seismometers (velocimeters or accelerometers) and rotational sensors has increased. The seismological applications present in the literature are multiple: studies on ground motion quantities and "point array" applications [1], site effects [2], seismic source analysis and volcano seismology [3].

Although many fields of investigation are still at an early stage, rotational seismology appears to provide useful information. For this reason a rotational sensor was installed in the volcanic area of Campi Flegrei with the aim of studying the rotational field induced by local seismicity in a volcanic complex. The Campi Flegrei caldera is an active volcanic field located in southern Italy and characterized by slow ground deformation and seismic activity. In the present work, some preliminary observations about rotational wavefield are shown for the signals generated by local earthquakes of medium-small magnitude ($M_D \leq 3.6$) and recorded in the central part of the caldera.

2. – Dataset

The Lunitek Tellus-R2 rotational seismometer is operating since January 2021. This sensor was installed in the Monte Olibano tunnel, beside a Guralp CMG40T broad band

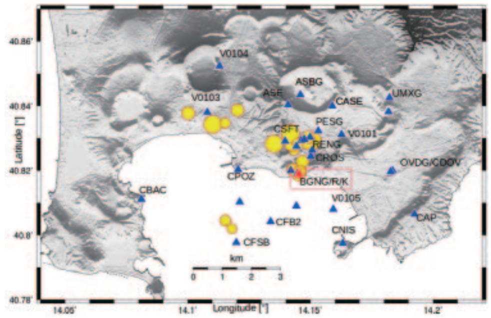

Fig. 1. – Map of Campi Flegrei monitoring seismic network (blue triangles). The red triangle shows the position of the rotational sensor (BGNR) close to broad band seismometer (BGNG) and accelerometer (BGNK). Yellow circles show the epicenters of selected earthquakes. The size of the circles is proportional to duration magnitude M_D.

seismometer and a Kinematrics FBA-EST episensor accelerometer already installed at the seismic station indicated with the acronym BGNG (fig. 1). The signals are sampled at 100 sps. The data set recorded over three years starting from 2021 is mainly composed of seismic noise, artificial transient signals and local earthquakes. Based on a magnitude threshold ($M_D \geq 1.5$), some of these seismic events were selected for the preliminary analyses carried out.

3. – Methods and preliminary results

The following analyses were carried out on the selected signals:

- estimation of peak rotational velocity for selected earthquakes (R_Z, R_N and R_E identify the three rotational components around Z, N-S and E-W directions);
- spectral analysis of selected earthquakes and noise recorded by the three sensors;
- correlation analysis of the wavefield recorded by rotational seismometer and accelerometer (A_Z, A_N and A_E are the three components of translational accelerometric motion).

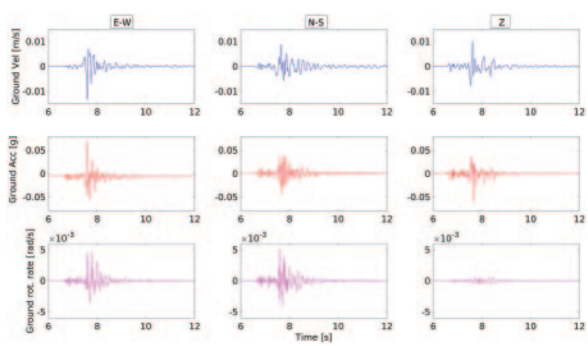

Fig. 2. – M_D3.6 20220329 17:40 earthquake recorded by broad band sensor (blue), accelerometer (red) and rotational sensor (magenta).

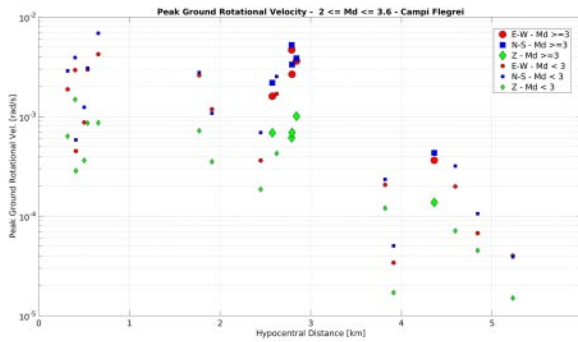

Fig. 3. – Peak ground rotational velocity observed for 20 local earthquakes ($1.5 \leq M_D \leq 3.6$) occurred in the Campi Flegrei volcanic area in the period 2021–2023.

As an example of rotational signal, we show in fig. 2 the M_D 3.6 20220329 17:40 UTC local earthquake recorded by the three sensors. For this earthquake we have observed a peak ground rotational velocity equal to 4.7, 5.2 and 0.6 mrad/s on east-west, north-south and vertical components respectively. In time domain, peak ground rotation along the three axes were estimated for all the 20 selected earthquakes (fig. 3). The largest rotational rate values (6.9 mrad/s around the N-S component) were observed for M_D 2.4 occurred at a hypocentral distance equal to 0.7 km.

Some other observations were performed in frequency domain. In fig. 4 we show the spectral amplitude of the previous signals shown in fig. 2. The results highlighted that broadband spectra show that most energetic frequency content is in the range 1–20 Hz, the Episensor amplitude spectra (red) are richer in high frequencies in the range 2–20 Hz and similarly rotational sensor spectra are in the range 3–20 Hz with main energy content in the range 4–8 Hz.

By taking into account the spectral features previously observed, we have performed a directional analysis by considering simultaneously rotational and accelerometer waveforms [2]. In particular, considering the local earthquake signals filtered in the 4–8 Hz band, a cross-correlation calculation was carried out between R_z and the rotated horizontal A_N and A_E components. We show the results of this analysis in fig. 5, for the earthquake shown in fig. 2. In the first three panels of fig. 5, R_Z, A_N and A_E filtered signals are shown. The fourth panel shows the rms evaluated on translational compo-

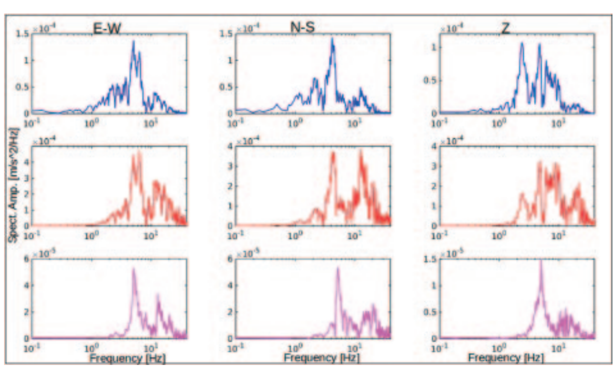

Fig. 4. – Spectral amplitude of seismic signals shown in fig. 2.

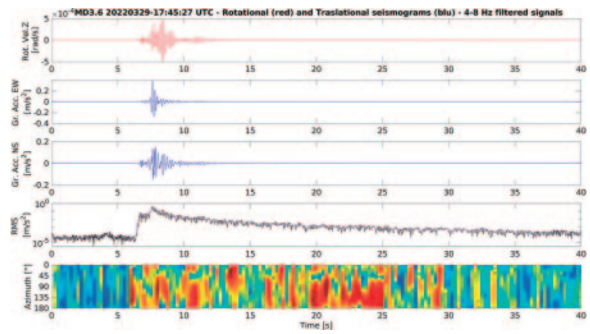

Fig. 5. – Cross-correlation analysis between the rotational component R_Z and the rotated horizontal component A_N and A_E. The first three panels show the filtered 4–8 Hz R_Z, A_N and A_E components of motion. The fourth and five panels show the rms of acceleration *vs.* time and the cross-correlogram versus time respectively. The color scale indicatate the cross-correlatoin values. The azimuth on the vertical axis is the rotation angle used for the horizontal components A_N and A_E.

nents A_N and A_E. The fifth panel contains a correlogram between the R_Z and the transverse component of translational motion obtained for different azimuth (Y-axis). The maximum cross-correlation value (dark red in the fifth panel of the fig. 5) at a time equal to 8 s starting from the beginning of the seismograms indicated the azimuth of the incoming S-wave (65°–70° clockwise from north, which is in a good agreement with the source-station direction).

4. – Discussion and conclusions

The selected data set was composed by 20 local earthquakes occurred in Campi Flegrei volcanic area ($1.5 \leq M_D \leq 3.6$, depth < 3 km b.s.l, hypocentral distance < 6 km). Peak rotational rate showed a maximum value equal to 6 mrad/s. The rotational peak values around horizontal components are always greater than the rotational rate along vertical axis. Spectral content of analyzed local earthquakes indicate that the suitable frequency range is 3–15 Hz which are very similar to the frequency content recorded by the accelerometer. Most of energy is concentrated in the frequency band 4–8 Hz.

Propagation azimuth has been estimated by applying cross-correlation approach and results are in good agreement with the source azimuth estimated from the epicenter taken from the catalogue. Furthermore, cross-correlation analysis has shown well correlated phases observed along the coda that could be used to analyze seismic scattering.

The observations and results obtained in the present work show that rotational signals are recorded with a good signal-to-noise ratio for small earthquakes ($M_D < 2$) at hypocentral distance of about 5 km. The directional analysis shows results in agreement with the source-receiver direction and could be used to improve localization procedures in the case of very close seismicity or in case of few available seismic stations and large location gap.

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