

**multi-Risk sciEnce for resilientT commUnities undeR a changiNg
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1. Technical references

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* PU = Public

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RE = Restricted to a group specified by the consortium (including the Commission Services)

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1.1.Document history

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2. Abstract

WP 4 is dedicated to the integration of Existing and new knowledge on earthquake monitoring, Earthquake Early Warning (EEW) and Rapid Response (RR). Within this context, Task 4.3 is dedicated to the development of time dependent hazard models based on Operational Earthquake Forecast (OEF) before the earthquake occurrence, EEW estimates and rapid response ground motion description to produce rapid assessment of the event impact.

Specific research activities of this task include:

- Development and testing of innovative and flexible OEF models which may be applied to different space-time scales and in different contexts to serve different end-users and purposes.
- Detection of local factors for earthquake generation and wave amplification.
- Nearly real-time risk mitigation for strong seismic events in the energy industry: the contribution of local seismic networks to UGS management.
- Advancements in operational earthquake loss forecasting.

A more detailed description of the progress of specific research activity is provided below, followed by a synthetic paragraph illustrating the main outcomes of the first year of the project.

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referenced study for the other labels). B) Moment-magnitude MWs available for the study area versus event-ML values obtained by Priolo et al., 2026 (redrawn from PEtA12026 Fig. 8); in blue and orange the dataset obtained by [6] and by [3], respectively. The dark, solid line and the equation above it indicate the linear best fit to the data obtained by orthogonal regression..... 11

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4. Introduction

Task 4.3 is dedicated to the development of time dependent hazard and risk models based on Operational Earthquake Forecast (OEF) before the earthquake occurrence, producing short-term forecasts, EEW estimates and rapid assessment of the event impact. OEF is usually based on Epidemic-Type Aftershock Sequence (ETAS) model to short-term and long-term earthquake forecasting. Traditional ETAS models are widely regarded as the most reliable tools for forecasting seismicity, but their practical use is hindered by the difficulty of estimating many interdependent parameters—an obstacle that is especially significant in regions with sparse or low-quality earthquake catalogs. One of the goals of this task is to develop a ETAS model, simpleETAS, that addresses this by fixing most ETAS parameters to globally consistent values and allowing only two region-specific parameters, the background seismicity rate and the aftershock productivity—to be calibrated from local data. This is connected to another important topic in probabilistic seismic hazard assessment (PSHA), that is the need to reduce the gap between operational probabilistic earthquake forecasting models (Operational Earthquake Forecasting, OEF; Jordan et al., 2011) and long-term hazard models. Traditional PSHA models represent seismicity as a Poisson process and are therefore time-independent; in contrast, OEF models explicitly describe the time-dependent nature of earthquake occurrence, incorporating the dynamics of sequences through triggering mechanisms (Ogata, 1988). The declustering required to obtain catalogs compatible with a Poisson model removes real events that contribute to ground shaking, with the risk of underestimating hazard. On the other hand, the most widely used OEF models (e.g., standard ETAS) treat events as point sources and do not yet systematically integrate the geometry of active faults, which instead plays a central role in PSHA. From a methodological standpoint, OEF requires rigorous prospective testing of the CSEP type (Jordan et al., 2011), as well as evaluations of potential ontological model errors (Marzocchi & Jordan, 2014). Here, this topic is dealt with by generating long-term catalogs using SimpleETAS, rejoining the two approaches.

OGS performs high-quality seismic monitoring for detecting potentially induced seismicity at some underground gas storages (UGS) facilities in Northern Italy. While the induced seismicity so far identified seems to be negligible in the studied cases, the strong tectonic earthquakes that occurred in the past suggest strengthening the efforts in the detection of micro-earthquakes, as signatures of potential impending major events. Here, we developed several efforts to introduce near-real-time signal processing in real case studies to improve micro-earthquakes in areas affected by induced seismicity.

As part of the WP4 activities, the ongoing seismic sequence in the Campi Flegrei volcanic area, where up to 5,000 earthquakes per km² have been recorded since 2014 with duration magnitude up to 4.6, has been studied. Operational Earthquake Forecasting (Marzocchi et al., 2014) tools, which allows one to obtain short-term estimates of seismicity, were employed to estimate the probability of observing (moment) magnitudes greater than 4.4—the reference value for the area—over the next thirty days (Iervolino et al., 2024). Using simplified structural models of masonry and reinforced-concrete buildings, nonlinear dynamic analyses were also conducted to assess the effects of the ongoing sequence on structures located both in Pozzuoli and Naples (Cito et al., 2025). These analyses can be used to enhance the Operational Earthquake Loss Forecasting system (Iervolino et al., 2015) for Italy, which provides weekly forecasts of seismic risk metrics, with specific focus on the Campi Flegrei area.

5. Real-time hazard assessment

5.1. Time-dependent hazard model developments including Operational Earthquake Forecast, EEW and rapid response approaches (Resp. OGS)

5.1.1. Reports and open codes of innovative OEF models and their testing

5.1.1.1. Activity goals

Development and testing of innovative and flexible OEF models which may be applied to different space-time scales and in different contexts to serve for different end-users and purposes.

5.1.1.2. Main results achieved

This work introduces simpliETAS, a streamlined framework for applying the Epidemic-Type Aftershock Sequence (ETAS) model to short-term and long-term earthquake forecasting. Traditional ETAS models are widely regarded as the most reliable tools for forecasting seismicity, but their practical use is hindered by the difficulty of estimating many interdependent parameters—an obstacle that is especially significant in regions with sparse or low-quality earthquake catalogs. The simpliETAS approach addresses this by fixing most ETAS parameters to globally consistent values and allowing only two region-specific parameters—the background seismicity rate and the aftershock productivity—to be calibrated from local data. This reduces model complexity while retaining the ability to represent earthquake occurrence in space, time, and magnitude. The model was calibrated for the Italian mainland and tested against both instrumental and historical seismicity over intermediate (50-year) and long (~400-year) periods. Despite its simplified structure, simpliETAS performed well in reproducing observed rates of medium-to-large earthquakes and showed competitive skill when retrospectively forecasting M4+ events during the 2016–17 Central Italy sequence. Its consistent performance suggests that the model can be applied operationally with minimal effort, including in regions with limited data. It also offers a practical benchmark for evaluating more complex models in formal forecasting experiments such as those organized by CSEP. Because simpliETAS can efficiently generate synthetic catalogs over various time scales, it may be particularly valuable for engineering applications that require realistic, non-Poissonian representations of seismic hazard. The model's parameter-estimation and simulation codes are publicly available on GitHub (<https://github.com/smancini2/simpliETAS>), and simpliETAS will soon undergo fully prospective testing in the upcoming CSEP-Italy experiment. Future work will explore its performance in diverse tectonic settings, with planned applications in Türkiye, Southern California, and the Phlegraean Fields of Italy.

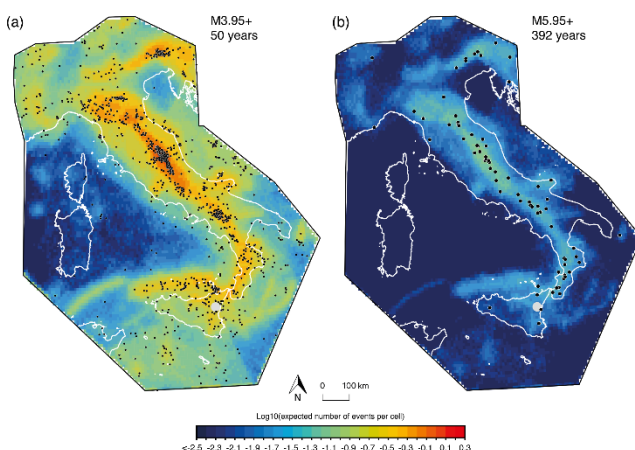


Figure 1: SimpliETAS forecast maps. (a) 50-year model aimed at reproducing the spatial distribution of the M3.95+ seismicity; black circles represent the 1972-2021 observations from the HORUS catalog above the target magnitude threshold. (b) 392-year model targeting the M5.95+ events; black circles indicate the location of the 1630-2021 M5.95+ earthquakes of the historical CPTI catalog. In both panels, the area around Mt Etna (light gray circle) is excluded from the analysis.

5.1.2. Filling the gap between OEF models and models used for long-term probabilistic seismic hazard models.

5.1.2.1. Activity goals

Filling the gap between OEF models and models used for long-term probabilistic seismic hazard assessment

5.1.2.2. Main results achieved

A central issue in probabilistic seismic hazard assessment (PSHA) concerns the need to reduce the gap between operational probabilistic earthquake forecasting models (Operational Earthquake Forecasting, OEF; Jordan et al., 2011) and long-term hazard models. Traditional PSHA models represent seismicity as a Poisson process and are therefore time-independent; in contrast, OEF models explicitly describe the time-dependent nature of earthquake occurrence, incorporating the dynamics of sequences through triggering mechanisms (Ogata, 1988). The declustering required to obtain catalogs compatible with a Poisson model removes real events that contribute to ground shaking, with the risk of underestimating hazard. On the other hand, the most widely used OEF models (e.g., standard ETAS) treat events as point sources and do not yet systematically integrate the geometry of active faults, which instead plays a central role in PSHA. From a methodological standpoint, OEF requires rigorous prospective testing of the CSEP type (Jordan et al., 2011), as well as evaluations of potential ontological model errors (Marzocchi & Jordan, 2014). Traditional PSHA, however, is often validated through weaker or retrospective comparisons.

A first step toward reducing this gap consists in introducing the structure of seismic sequences directly into long-term hazard assessment. This can be achieved using synthetic catalogs generated with Epidemic-Type Aftershock Sequence (ETAS; Ogata, 1988) models and, in particular, with the simplified SimpleTAS version (Mancini & Marzocchi, 2024). These catalogs realistically reproduce the statistics of observed seismicity and ensure good levels of consistency across a wide range of return periods. Each simulated event can be associated with a plausible seismogenic source, from which geometric parameters and site-to-source distances can be derived for ground-motion calculations using GMPEs. In this framework, the probability of exceeding a given intensity level is obtained from the fraction of catalogs in which the threshold is exceeded at least once, replacing the Poisson model with a fully empirical and time-dependent approach. This methodology can be applied to site-specific hazard assessment over predefined time horizons, to comparisons with official Poisson-based models to quantify the effect of removed events, or to the construction of risk scenarios for engineering applications. The systematic use of simulated catalogs within a time-dependent framework therefore represents an important step toward a more realistic PSHA, capable of incorporating the effects of sequences without resorting to either declustering or assumptions of stationarity.

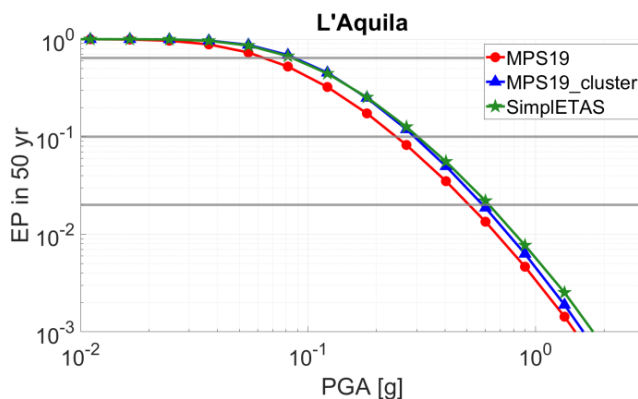


Figure 2: Comparison of 50-year seismic hazard curves for the L'Aquila site calculated using three different approaches: MPS19 (official Poissonian model), MPS19_cluster (the same model with declustering correction), and SimpleTAS-based (time-dependent approach based on synthetic catalogs). The comparison shows that traditional declustering underestimates hazard, while the SimpleTAS approach provides estimates consistent with MPS19_cluster.

5.2. Nearly real-time risk mitigation for strong seismic events in the energy industry: the contribution of local seismic networks to UGS management

5.2.1. State of the art and innovative elements introduced within the RETURN project

OGS performs high-quality seismic monitoring for detecting potentially induced seismicity at three underground gas storages (UGS) facilities in Northern Italy, namely Collalto Storage (in province of Treviso, seismic monitoring since 2012 [1], <http://rete-collalto.crs.inogs.it/>), Cornegliano Laudense (in province of Lodi, seismic and geodetic monitoring since 2017 [2], <http://rete-cornegliano.crs.inogs.it/>), and San Potito e Cotignola (in province of Ravenna, monitoring started in 2025, <https://rete-sanpotito.ogs.it/>).

While the induced seismicity so far identified seems to be negligible in the longest monitored UGSs, the strong tectonic earthquakes occurred in the past suggest deepening the analyses of micro-earthquakes, as signatures of potential impending major events.

The innovative elements introduced within the RETURN project aimed at strengthening and standardizing the seismological procedures of detection, location, and characterization of microearthquake sequences, thus providing new methodologies and datasets that enhance the earthquake catalogues.

5.2.2. Research objectives

The processing of seismological data acquired by the dedicated, industrial networks of Collalto and Cornegliano Laudense is based on standard automatic procedures, further revised by manual, time-costly efforts. In the past, thanks to an extremely productive microearthquake sequence occurred in the Collalto area [3], some automatic phase detectors and association algorithms have been tested [4]. The main research objectives of RETURN project were the betterment of geophysical models at depth, new methodologies for populating the catalogue of micro-events, and the calibration of local magnitude equations which consistently account for the energy release at short and regional distances.

5.2.3. Methods, algorithms, data analysis

Two UGS monitored by OGS represent kind of endmembers in terms of natural background seismicity, with an average of 110 earthquakes/year located within about 13 km distance from the reservoir boundaries in Collalto Storage, versus the less than 40 events in 8 years (on average, 0.5 earthquakes/year) in the same distance range, at Cornegliano Laudense site. Anthropogenic noise, and crustal velocity profiles are extremely different too, and require to be properly accounted for.

Several techniques have been preliminarily applied to characterize microseismicity and swarm activity, to analyze the diffusivity of clustered seismicity to better understand spatio-temporal migration processes, and to refine the geophysical model at depth (Sugan et al., 2024; Romano et al. 2024; Cipressi et al., 2024; Guidarelli et al., 2024; Romano et al., 2024a; Fusco et al., 2025).

Methodological developments include the comparison between machine learning-based and manual earthquake location procedures using the LOC-FLOW framework. Additional research applies advanced analysis techniques to microseismic sequences in industrial environments, improving event characterization and operational monitoring. Another contribution focuses on calibrating local magnitude (M_L) at short distances to enhance magnitude reliability for dense local networks (Priolo et al., 2026, see Fig. 1).

5.2.4. Results, validation, and/or applications

Overall, the studies aimed to improve detection, location accuracy, magnitude estimation, and physical interpretation of small-magnitude seismicity. The results support better monitoring of natural and induced seismic processes, and potential benefits concerns operational safety and hazard assessment in energy-related infrastructures.

5.2.5. Impact of the research according to the objectives of RETURN and WP4 in particular

The work done in TK4.3.3 combines observational datasets, methodological innovation, and case studies. Together, these contributions strengthen the understanding of microseismic processes and enhance monitoring capabilities in seismically active and industrially influenced areas.

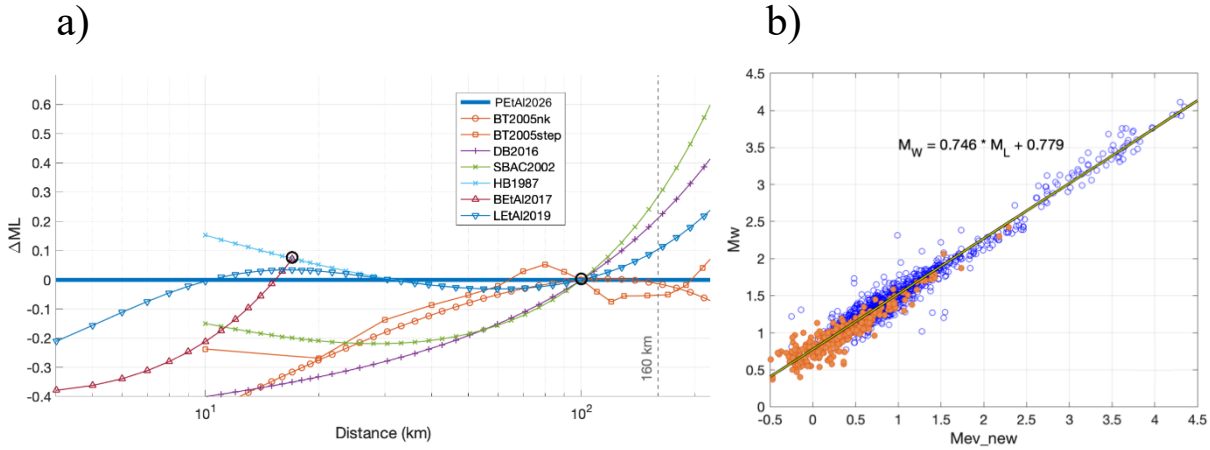


Figure 3: Local Magnitude comparisons. A) Differences between the M_L of Priolo et al., 2026 (PEtAl2026), and the M_L s of various formulas (redrawn from PEtAl2026 Fig. 10). Note the departure of the newly calibrated law from the worldwide used HB1987 formula at distances less than about 15 km, and greater than 160 km (HB1987 refers to [5] and this curve is overlapped by LEtAl2019 above 30 km distance: see in the referenced study for the other labels). B) Moment-magnitude M_w s available for the study area versus event- M_L values obtained by Priolo et al., 2026 (redrawn from PEtAl2026 Fig. 8); in blue and orange the dataset obtained by [6] and by [3], respectively. The dark, solid line and the equation above it indicate the linear best fit to the data obtained by orthogonal regression.

5.3. Earthquake engineering issues for operational earthquake loss forecasting: the case of bradyseism at Campi Flegrei

5.3.1. State of the art and research objectives

Recent seismic activity in the Campi Flegrei volcanic area, near the city of Naples in southern Italy, has continued into 2025, which is attributed to the ongoing bradyseism. The zone experiencing uplift—approximately a 5 km radius area around Rione Terra, the downtown of Pozzuoli—is shown in Figure 4a, although earthquakes are mostly occurring within 3 km from Rione Terra. Ground motion records for most of the $M_d \geq 2.5$ earthquakes recorded at Campi Flegrei are made available by the *Rete Accelerometrica Nazionale* (RAN) portal (<https://ran.protezionecivile.it>). The engineering analyses presented in the following were conducted using the records of all earthquakes with $M_d \geq 2.5$ and depth not exceeding 4 km, recorded from March 2022 to September 2025, available on the RAN portal. For six events that occurred between May 13th and September 1st, 2025, recordings provided by *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) were used instead.

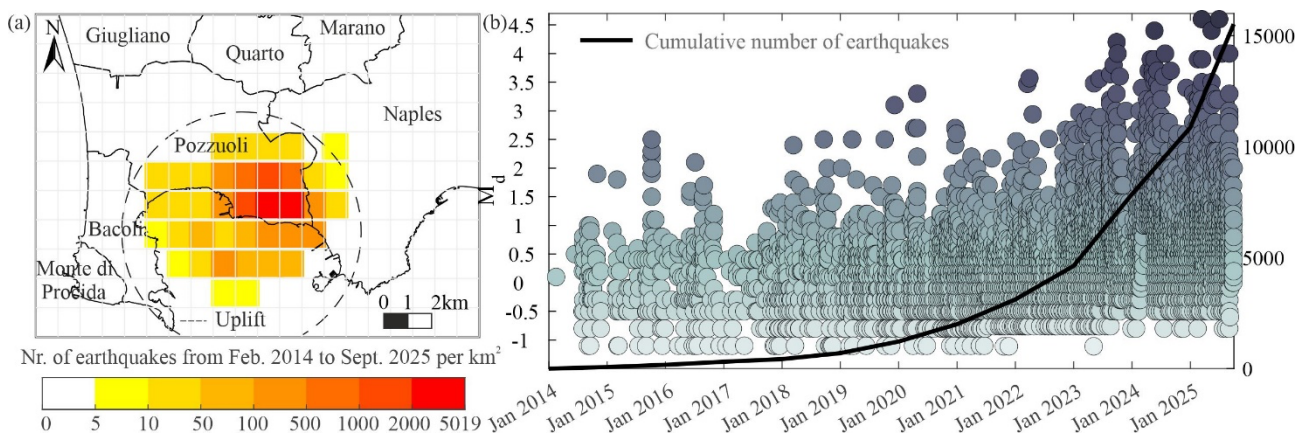


Figure 4: (a) Number of earthquakes per square kilometer recorded between February 2014 and September 2025 and uplift area with 5 km radius (dashed circle). (b) Occurrence date, duration magnitude and cumulative No. of recorded earthquakes (b).

The level of shaking recorded after December 2024, in both Pozzuoli and Naples, highlights the importance of assessing the structural engineering implications of the earthquakes recorded in 2025 at Campi Flegrei. This includes the analysis of the structural response of nonlinear single degree-of-freedom systems equivalent to code-conforming residential masonry and reinforced concrete buildings at Pozzuoli, when subjected to records from the whole $M_d \geq 2.5$ sequence, as recorded at four stations close to the epicenters of the largest magnitude events and in the Fuorigrotta district of Naples. Some final remarks close the study.

5.3.2. Data analysis and results (structural response of code-conforming buildings)

Nonlinear dynamic analyses discussed in Cito et al. (2025) showed that, among the $M_d \geq 2.5$ earthquakes recorded between August 2023 and December 2024, only the largest one had a non-negligible structural impact. However, the ground motion analysis of the 2025 earthquakes, presented in the previous sections, suggests the need to update those analyses. This is because not only the seismic actions recorded in 2025 are stronger than those in 2024, even for the same magnitude and epicentral distance, but also because some earthquakes recorded in 2025 have produced significant shaking, at short vibration periods, even at locations not necessarily within 1 km from the epicenter, something that does not emerge when considering only the events that occurred up to the end of 2024.

Although the existing building stock in Campi Flegrei is mainly composed of residential buildings built with obsolete or absent seismic provisions (Iervolino et al., 2024), this section evaluates the structural impact of the recorded ground motions on buildings designed according to the seismic code currently enforced. Two cases are analyzed: an unreinforced masonry (URM) structure, and a reinforced concrete (RC) moment-resisting frame. These typologies together represent nearly 90% of the stock in Pozzuoli.

The URM structure is a two-story building, regular in plan and elevation, while the RC structure is a three-story bare frame. The structural models were developed within the RINTC project (RINTC-Workgroup 2018). Design was carried out assuming that the structures are located in Naples on C-type site conditions according to EC8. Each structure was modelled as an equivalent single-degree-of-freedom (ESDoF) system (Suzuki and Iervolino 2021). The equivalent vibration period is $T = 0.07$ s for the URM ESDoF system and $T = 0.93$ for the RC one. The backbone curves, and their parameters, for the two ESDoF systems are shown in Cito et al. (2025). It results that the yielding spectral acceleration for the URM and RC structure are $S_{a,y,URM}(T = 0.07 \text{ s}) = 0.52 \text{ g}$ and $S_{a,y,RC}(T = 0.93 \text{ s}) = 0.31 \text{ g}$, respectively. For both systems, hysteretic behavior is pinched peak-oriented (Lowes et al., 2004) with no degradation for both systems, and equivalent viscous damping factor is 5%.

The two structural models were virtually placed at the sites of stations POZS, POZT, CSOB, and NAFG, and analyzed using as input the records at the considered sites. More specifically, each ESDoF system was subjected to four sequences of records, each constructed by appending all signals from the 82 earthquakes with $M_d \geq 2.5$ (those considered for the envelope of the shaking maps) recorded at the selected stations. The sequence at a site can differ between the analyses for the URM and RC systems, because, for each earthquake, the horizontal component with the largest spectral ordinate at the period of the considered ESDoF system was selected. Moreover, the time between two earthquake-specific records, during which the ESDoF system is in free vibrations, was set equal to ten times the ESDoF period.

The results of the analyses, in terms hysteretic response are shown in **Errore. L'origine riferimento non è stata trovata.**5. The RC system never exhibits plastic behavior engagement, with the residual displacement (cyan marker) being zero at all the four sites of the stations considered. This indicates that seismic activity recorded so far at Campi Flegrei has effects that can be deemed negligible for this building typology, even in Pozzuoli, within 1 km from the epicenters of the events. The same conclusion cannot be drawn for the URM system, which exhibits engagement of nonlinear behavior at three out of the four stations, including CSOB, POZS and NAFG in western Naples. The largest structural impact is observed at CSOB, as expected. The ground motion records at this station produce a maximum transient displacement (blue marker) approaching to 0.3 cm, more than five times the yield displacement, while the residual displacement is approximately 0.2 cm.

Figure 5 shows that the structural impact of the $M_d \geq 2.5$ earthquakes is less severe at POZS compared to CSOB, and it further decreases from CSOB to NAFG. To deepen this issue, the earthquakes that induce plastic excursion at each station were identified. They are those with the record at the station, which has been used in the dynamic analysis, having. It is observed that the five earthquakes causing the URM ESDoF system exhibiting inelastic behavior at CSOB occurred between January and June 2025, all with epicentral distances smaller than 1.1 km. At POZS, plastic excursion happens due to seven earthquakes with magnitude

between 3.1 and 4.4, all with from 0.2 km to 1.6 km. Earthquake depths are between 2.2 km and 2.9 km and hypocentral distance varies from 2.3 km to 3.0 km. Five out of seven earthquakes occurred in 2025, while the others are the largest magnitude event of May 2024 and one occurred in March 2022. At NAFG, nonlinear behavior is seen only for the March 2025 event.

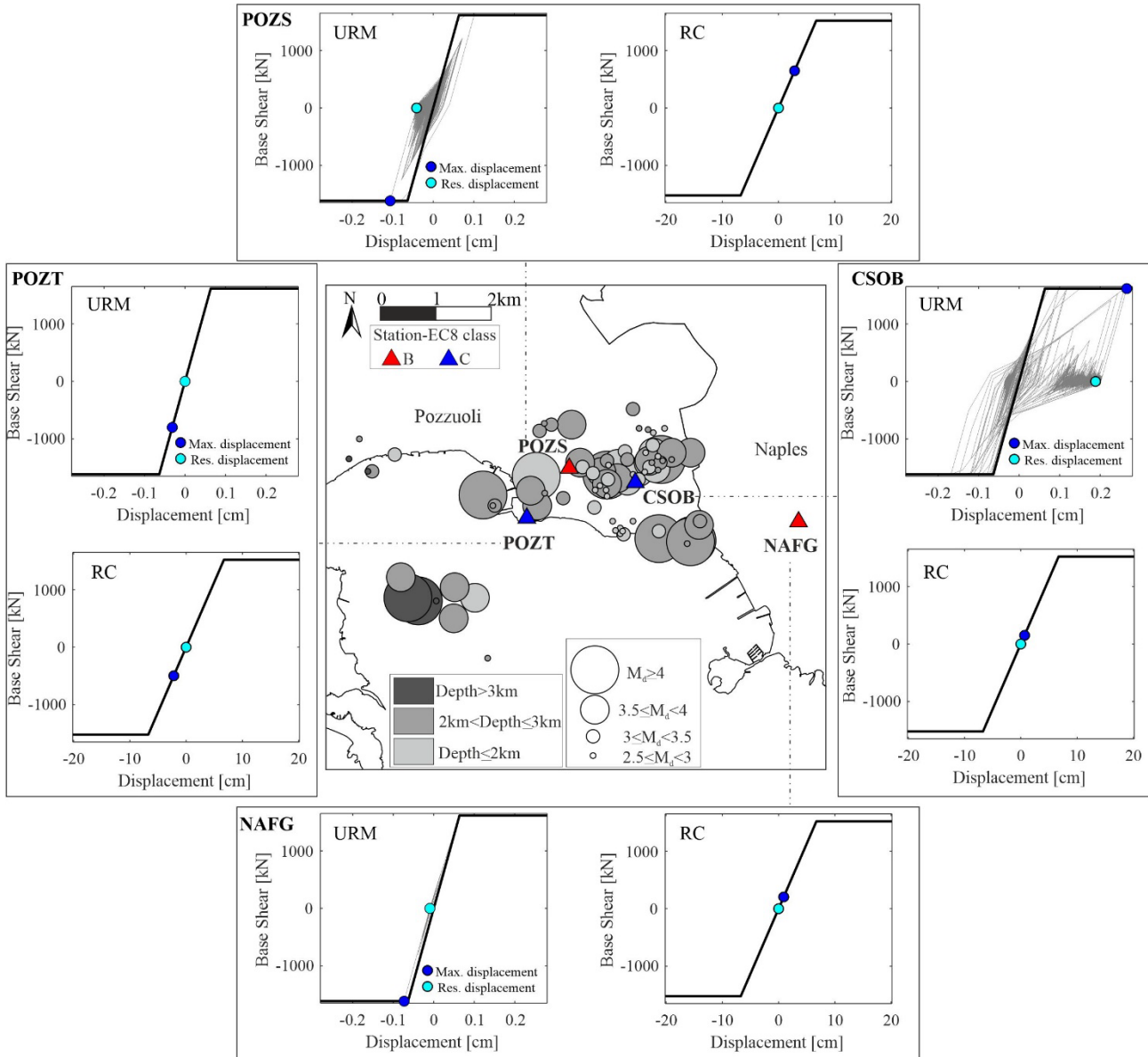


Figure 5: Results of nonlinear dynamic analysis for the unreinforced masonry (URM) and reinforced concrete (RC) ESDoF systems subjected to records from earthquakes with recorded at CSOB (right), POZS (top), POZT (left) and NAFG (bottom). Station sites and earthquake magnitude, depth and epicenters are shown in the central panel.

5.3.3. Final remarks

Since 2014, approximately 15,000 earthquakes, with duration magnitude ranging from -1.6 to 4.6 , have been recorded in the Campi Flegrei area, which is currently undergoing slow uplift due to volcano dynamics named bradyseism. So far, largest bradyseism-induced seismic actions were recorded during the $M_d = 4.6$ of March 2025, close to its epicenter.

The code-conforming URM structure examined engages inelastic behaviour due to ten earthquakes with $3 \leq M_d \leq 4.6$ recorded from January 2025 to July 2025, the $M_d = 4.4$ of May 2024 and the $M_d = 3.5$ of March 2022. Plastic excursion is observed at an epicentral distance of about 1.5 km at most for almost all events, and at 2.5 km, in western Naples, for the $M_d = 4.6$ of March 2025. The number of equivalent cycles shows that, for the latter event, the hysteretic energy dissipated by the URM structure increases by one order of

magnitude as its epicentral distance decreases from 2.5 km to 1.1 km. The structural impact on the considered code-conforming RC structure can be deemed negligible, for each of the considered $M_d \geq 2.5$ events and even in proximity of their epicenters.

6. Conclusions

The present document summarizes the state of advancement of research activities carried on within WP4 – Task 3.

- Short-term estimates of seismicity were employed to estimate the probability of observing (moment) magnitudes greater than 4.4—the reference value for the area—over the next thirty days (Iervolino et al., 2024). Moreover, the University of Naples' School of Engineering main building was equipped with a structural monitoring system to study its dynamic response to bradyseism-induced earthquakes. Using simplified structural models of masonry and reinforced-concrete buildings, nonlinear dynamic analyses were also conducted to assess the effects of the ongoing sequence on structures located both in Pozzuoli and Naples (Cito et al., 2025). These analyses can be used to enhance the Operational Earthquake Loss Forecasting system (Iervolino et al., 2015) for Italy, which provides weekly forecasts of seismic risk metrics, with specific focus on the Campi Flegrei area.
- While the induced seismicity so far identified seems to be negligible in the studied cases, the strong tectonic earthquakes that occurred in the past suggest strengthening the efforts in the detection of micro-earthquakes, as signatures of potential impending major events. For the Collalto UGS (Treviso, storage managed initially by Edison Stoccaggio and now by Stogit Adriatica), some automatic phase detectors and association algorithms have been tested and tuned on the existing dataset of microseismic sequences, and a local magnitude law for short distances and microearthquakes has been calibrated. At the Cornegliano Laudense UGS (Lodi, concession holder Italgas Storage), several methodologies have been applied to enhance the earthquake catalogue, and to refine the geophysical model at depth. The monitoring at San Potito e Cotignola UGS (Ravenna, Stogit Adriatica the concession holder) started in 2025 with custom procedures that are still under testing.
- The simpleTAS approach addresses this by fixing most ETAS parameters to globally consistent values and allowing only two region-specific parameters—the background seismicity rate and the aftershock productivity—to be calibrated from local data, reducing model complexity while retaining the ability to represent earthquake occurrence in space, time, and magnitude. The model was calibrated for the Italian mainland and tested against both instrumental and historical seismicity over intermediate (50-year) and long (~400-year) periods. Its consistent performance suggests that the model can be applied operationally with minimal effort, including in regions with limited data. It also offers a practical benchmark for evaluating more complex models in formal forecasting experiments such as those organized by CSEP.
- A first step toward reducing the gap between long- and short-term hazard analyses consists in introducing the structure of seismic sequences directly into long-term hazard assessment. This can be achieved using synthetic catalogs generated with SimpleTAS, realistically reproducing the statistics of observed seismicity and ensuring good levels of consistency across a wide range of return periods. The systematic use of simulated catalogs within a time-dependent framework represents an important step toward a more realistic PSHA, capable of incorporating the effects of sequences without resorting to either declustering or assumptions of stationarity.

- Overall, the activities carried out within WP4 – Task 3 provide relevant scientific, technological and socio-economic contributions to the objectives of the RETURN project, particularly in the development of advanced tools for seismic monitoring, forecasting and rapid response. From a scientific perspective, the research improves the understanding of seismic processes across different contexts, ranging from volcanic seismicity at Campi Flegrei to microseismic monitoring associated with underground gas storage facilities and time-dependent earthquake occurrence models. The development and testing of simplified yet robust forecasting approaches, such as the simpleTAS framework, contributes to bridging the gap between short-term earthquake forecasting and long-term seismic hazard assessment, enabling more realistic representations of earthquake sequences and their implications for hazard and risk analysis. From a technological and methodological standpoint, the project delivers improved monitoring procedures, automatic detection and association algorithms, refined magnitude calibration laws, and enhanced earthquake catalogues derived from local seismic networks. These developments strengthen the capability to detect and characterize micro-seismicity, support operational monitoring of industrial infrastructures, and provide reliable datasets for hazard modelling and operational earthquake forecasting. In addition, the integration of structural response analyses and monitoring systems contributes to the advancement of operational earthquake forecasting frameworks, particularly in complex environments such as the Campi Flegrei caldera. The socio-economic impact of the research lies in its potential to improve risk mitigation and emergency preparedness. By supporting the development of operational forecasting tools, enhanced monitoring networks and impact-oriented analyses, the outcomes of WP4 – Task 3 provide scientific and technical bases for more informed decision-making by civil protection authorities, infrastructure operators and local administrations. These advances contribute to strengthening resilience in densely populated and industrially relevant areas exposed to seismic and volcanic hazards, in line with the broader goals of the RETURN program.

7. References

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