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Microzonation Study on the Western area of Napoli

Valeria Licata[a,c]*, Giovanni Forte[a], Anna d'Onofrio[a], Lorenza Evangelista[b], Fatemeh Jalayer[c], Antonio Santo[a], Francesco Silvestri[a]

[a]DICEA, Università degli Studi di Napoli Federico II, via Claudio 21, 80125 Napoli, Italy
[b]IAMC-CNR, Istituto per l'Ambiente Marino Costiero, Calata Porta di Massa, 80133 Napoli, Italy
[c]DIST, Università degli Studi di Napoli Federico II, via Claudio 21, 80125 Napoli, Italy

Abstract

A rational evaluation of the seismic risk of urban areas cannot neglect the variability of the ground motion due to site amplification and the induced effects, such as soil liquefaction and slope stability. In this framework, the microzonation maps certainly represent the most adequate tool to account for this element in the seismic risk and for planning mitigation strategies.
This study shows the preliminary results of a multidisciplinary research, which deals with the seismic microzonation of the Western area of Napoli. The selected case study is a challenging choice, as the seismic hazard is affected by both tectonic and volcanic seismicity, which in historical time differently affected the urban setting. The latter, in turn, results highly heterogeneous, as consisting of a mixing of both masonry and concrete structures.
The adopted approach followed the recommendations of both the National and International Guidelines, with reference to the multi-levels methods. The collection, homogenization and synthesis of a significant number of existing data permitted the development of reliable geological and geotechnical subsoil models, leading to Grade I and II seismic microzonation maps, characterized by different expected amplification of ground motion and instability due to the liquefaction. Such maps represent a key for a quantitative assessment of seismic performance of buildings and infrastructures, in view of the expected urban requalification of the area.

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Keywords: Geological model; Seismic microzonation; Ground types; Site Response Analysis, Soil Liquefaction.

* Corresponding author. Tel.: +39-338-8064138.
E-mail address: valeria.licata@unina.it

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1. Introduction

In recent years, several guidelines for rational approaches aimed at seismic microzonation (SM) have been proposed [1, 2, 3]. In particular, the scientific community agrees that the zonation detail is linked to the dimension of the area, while the scale of the maps is related to the availability of data, as well as to the degree of accuracy and complexity of the method adopted for the analysis. Nowadays, a well-established approach is the multi-level methodology currently shared by international [1] and national [2] guidelines: it is based on the adoption of mapping criteria with an increasing level of detail, as directly proportional to the completeness of the subsoil database, to the degree of definition of the reference seismic hazard, and to the complexity of the approach followed to describe the mechanical behavior of the soil.

According to the above mentioned guidelines, three levels of analyses can be defined. Grade I analysis consists of the collection and the elaboration of information needed to distinguish areas more or less affected by amplification of the seismic ground motion, as well as to identify those susceptible to liquefaction and slope instability. The resulting maps are typically based on historical data and geological surveys, and generally do not provide any engineering quantification of the expected effects. Grade II methods quantify both the ground motion and the related instability on the basis of shallow geophysical measurements and the application of semi-empirical methods. The performance of Grade III methods are based on the reliability of dynamic analyses, on an accurate seismic hazard assessment as well as on the complex geometry and the nonlinear stress-strain behavior of the geo materials.

It follows that the reliability of the predictions is proportional to the accuracy of seismological, geological and geotechnical models and therefore, a multidisciplinary approach is required in order to correctly assess the seismic performance of buildings and infrastructures.

This paper shows the results of Grade I and II SM of the Bagnoli-Fuorigrotta district, located in the Western part of Napoli. It represents an interesting case study, being the seismic hazard of the area affected by both tectonic (Fig. 1a) and volcanic (Fig. 1b) seismogenic sources, as shown by the damage induced by far-field (e.g. Irpinia 1980, [4]) and near-field (e.g. Phlegrean Fields, 1983-84) earthquakes. Furthermore, the area rests on a complex alluvial-volcanic geological setting, which can strongly affect the local seismic response, while the urban fabric is highly heterogeneous, since it is a mixing of masonry and RC structures of different ages. Recent territorial and site-specific studies [5] also highlighted a significant liquefaction susceptibility of the coastal area.

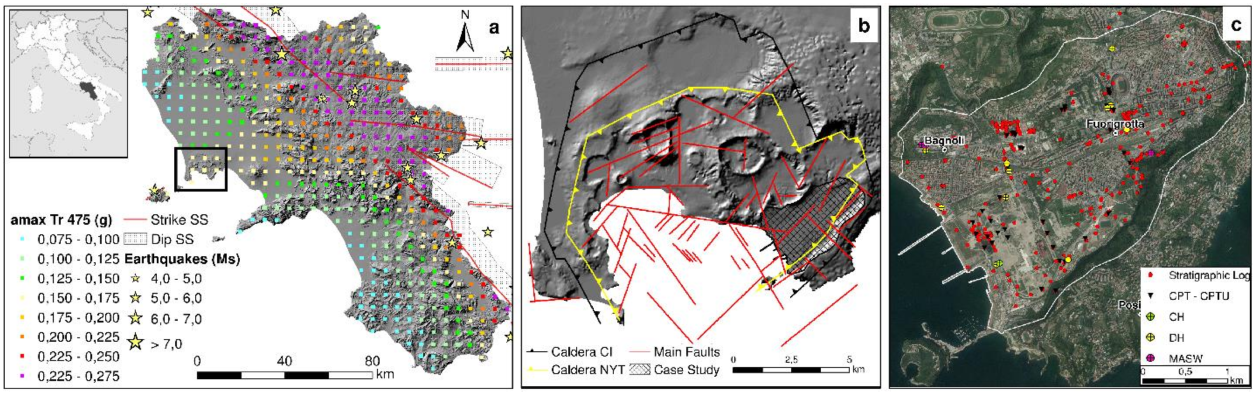

Fig. 1. (a) Apennines tectonic faults (diss.rm.ingv.it); (b) Phlaegrean Fields volcanic sources (mod. after [6]); (c) subsoil data in the study area.

2. Geological setting

The study area is part of a wider volcanic district known as Phlaegrean Fields (Fig. 1b). Its volcanic history is characterized by several eruptions, which mainly originated monogenic volcanoes, emplacing pyroclastic deposits and rare lava flows [7, 8]. The volcanic activity of Phlaegrean Fields can be divided into three periods, based on the identification of two relevant eruptions, namely the Campanian Ignimbrite (CI; 39 ky), which originated the Phlaegrean Caldera, and the Neapolitan Yellow Tuff (NYT, 12 ky). The recent phase completely occurred inside the

Caldera; this stage can be further divided into three epochs, based on stratigraphic markers constituted by two paleosoils. The first epoch followed the NYT eruption and consisted of nearly 37 explosive eruptions until 9.5 ky. The second occurred between 8.6 and 8.2 ky, with only 6 events in the Northern sector, while the third was constituted by 20 explosive and 3 effusive eruptions between 4.8 and 3.8 ky, with the strongest known as Agnano-Monte Spina (AMS; 4.1 ky). The last period was interrupted in historical times by the Monte Nuovo eruption (1538).

3. Subsoil model

The selected study area, shown in Fig. 1c, occupies a plain territory nearly 7.5 km^2 wide, located at the Southern margin of the Phlaegrean fields, in Bagnoli-Fuorigrotta coastal depression [9]. The geological and geotechnical subsoil model was built through the collection and analysis of a large number of stratigraphic logs, coupled with the geomorphological, structural and hydrogeological setting of the study area. In particular, the retrieved data consisted of nearly 330 stratigraphic logs (30 to 100 m deep), 39 cone penetration tests (CPT) and 15 geophysical tests (11 down-hole, DH, 1 cross-hole, CH, and 3 MASW tests).

A preliminary screening of the available investigation reports permitted to discard the redundant information, selecting the most reliable data, which were georeferenced and stored in a GIS database. The uniform interpretation and analysis of the stratigraphic logs in the framework of the volcanic and geologic evolution of the Bagnoli-Fuorigrotta coastal plain allowed to detect 11 geolithological complexes, mainly made of the well identified eruptions of the III epoch or coming from coastal and alluvial processes.

A reference geological cross-section of the area is reported in Fig. 2a. The most continuous complexes are represented by the Ancient Agnano Pyroclastic Deposits (APD; 4.8 ky) made of silty sandy ash and pumices; Monte Sant'Angelo Tephra (MST; 4.1 ky) made of silty sandy ash; Agnano-Monte Spina Deposits (AMS; 4.1 ky) made of ashes and pumices and the Recent Astroni Pyroclastic Deposits (RAPD; 3.9 ky) made of silty grey ash. Those soils are locally overlain by quaternary silty sands, reworked in alluvial and marshy context (ARD) by the Arena S. Antonio stream, and near the coast by Aeolian sand dunes (AS). Furthermore, at several stratigraphic heights several lenses of peat (P) can be found, while the succession is capped by a thick layer of infillings (I), coming from the remediation works carried out in historical times. At the center of the plain, a post-NYT Tephra locally crops out, constituting the remnants of the ancient Santa Teresa volcano (STT). The overall succession rests on pyroclastic marine sands (MS) which, in turn, in the Southern sector lie atop of the NYT, cropping out in the Posillipo hill. This latter can be found either in a lithic facies or as soil, and it is locally underlain by pre-NYT pyroclastic deposits.

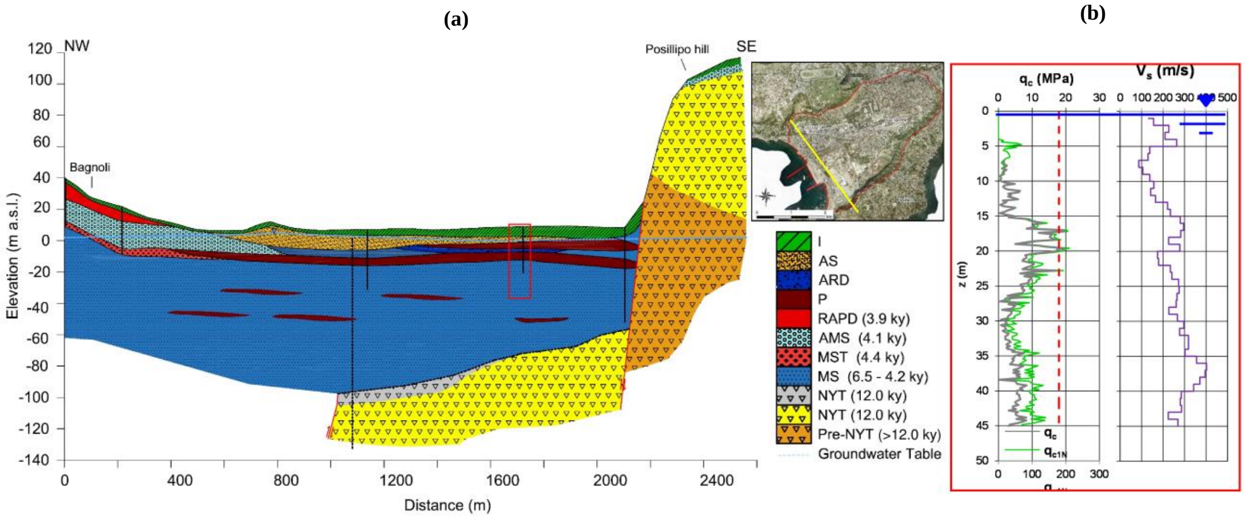

Fig. 2. (a) Geologic cross-section of the case study; NYT depth inferred from stratigraphic logs and the depth reported offshore in [10]; (b) V_S and q_c profiles at the site marked with the red frame along the section.

The complex geological setting is also evidenced by the results of the CPT and seismic in situ tests, which were compared with the local stratigraphy, as showed in Fig. 2b in terms of tip penetration resistance (q_c) and shear wave velocity profiles (V_S). Although the geological cross-section reaches more than 100 m of depth, the in situ tests only allowed for characterizing the first 45m, showing a highly inhomogeneous subsoil, often marked by variable strength and stiffness inversions with depth.

A typical V_S profile is shown in Fig 2b together with the result a cone penetration test. Below the anthropic ground layer, V_S gradually increases up to 250 m/s in the Aeolian sands (AS), as well as in the deep Alluvial/Marine sands deposit (MS), where V_S reaches 300 m/s. Two velocity inversions are detected, corresponding to as many Peat layers. The same trend is detectable for the entire depth along the CPT profile, showing low values of tip resistance, q_c (grey line in Fig. 2b), representing a recurrent feature of the deposits of the area. The same figure reports the normalized tip resistance, q_{C1N} (green line in Fig. 2b), showing values always lower than 180 below the groundwater level, which according to the Technical Code [11], highlights that the site could be prone to liquefaction.

The Neapolitan Yellow Tuff (NYT) is considered the seismic bedrock in the whole area; being its depth and morphology of outmost importance for the seismic site amplification, an accurate reconstruction of its buried setting was attempted by interpolating the depths in the logs and reported offshore in [10]. The roof of the tuff formation is displayed as isolines in Fig. 3a, which update and expand the former reconstruction [12]. The bedrock shows a complex geometry; it crops out at the NE side, at the toe of Posillipo hill, and it is lowered by fault systems in the central area of the plain, down to more than 120 m below sea level. Along the NW side, the NYT is present with an un-lithified facies (grey shaded in Fig. 2a) even at great depth. The same figure also reports the isolines of groundwater table, showing an elevation from 7 to 0.5 m a.s.l. along the coast.

A geolithological map was also defined as shown in Fig. 3b. In particular, 7 geolithological zones characterized by homogenous stratigraphic sequences of pyroclastic deposits were identified. They were distinguished based on the presence of dune sands, peat layers and depth of the top of the tuff formation (NYT).

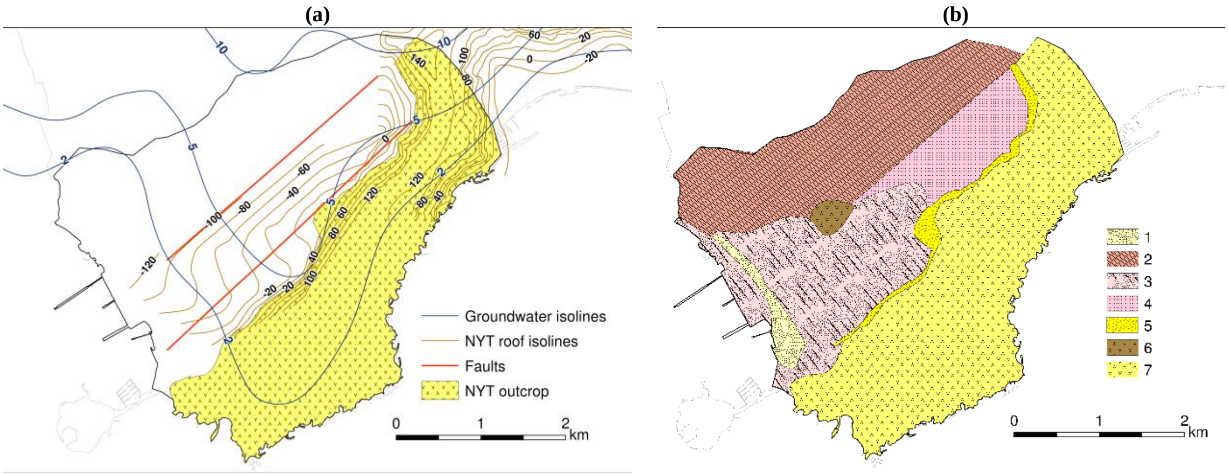

Fig. 3. (a) Isolines of the outcropping and buried tuff and groundwater table elevation; (b) Geolithologic map of the study area: 1) pyroclastic soils below dune sands; 2) pyroclastic soils on unlithified NYT; 3) pyroclastic and marine soils with peats on NYT (z> 20m); 4) pyroclastic soils on NYT (z> 20m); 5) pyroclastic soils on NYT (z< 20m); 6) pyroclastic soils below STT; 7) NYT outcrop.

4. Seismic Microzonation maps

According to the National Guidelines for SM [2], Grade I maps for seismic ground motion should identify the zones susceptible to stratigraphic amplification among those classified as not prone to slope instability. To this aim, the synthetic geolithological map in Fig. 3b was coupled with in-situ measurements of V_S and q_c. Figure 4 shows the simplified envelopes of V_S (a) and q_c (b) profiles and the geotechnical zonation (c, d) obtained from the relevant results.

The overall envelopes of V_S and q_c highlight low values of mechanical properties, in terms of both stiffness and strength in the first 30m depth (Figs. 4a-b). In particular, in the first 10m depth, weak soils are recognized between the infill (I), the RAPD and the peat layer. The coastal area is characterized by inversions of V_S and q_c below 20-25 m, due to the presence of peat (P) and alluvial layers (ARD).

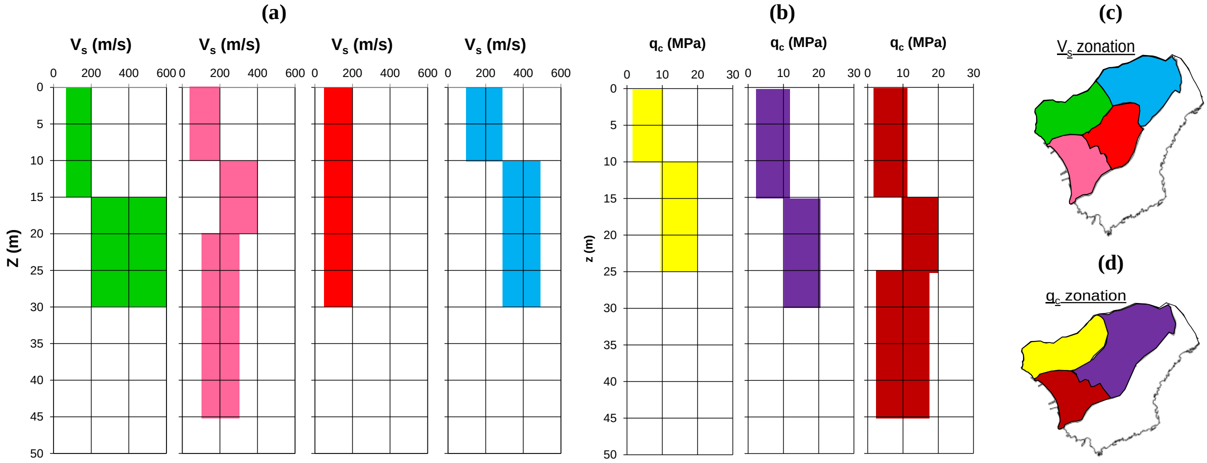

Fig. 4. Enveloped profiles of (a) shear wave velocity and (b) tip resistance; zonations in terms of (c) V_S and (d) q_c.

Following the guidelines [1, 2], the integration of the hydrogeological and geomorphological settings (Fig. 3a) with the geolithological map (Fig. 3b) permitted to define the Grade I SM maps of ground motion amplification (Fig. 5a) and instability due to liquefaction (Fig. 5b).

The SM map for ground motion amplification, reported in Fig. 5a show that, except for the East zone, where the NYT is outcropping, the entire Bagnoli-Fuorigrotta district is covered by soft soils, at least down to the maximum investigated depth (z = 45m), which may be interested by stratigraphic amplification phenomena. In particular, three different amplification zones can be distinguished: SA1, where the depth of the tuff bedrock is between 20 and 150 m; SA2, with tuff bedrock depth lower than 20m; SA3, where soft soils are present and the underlying tuff is not lithified. Instead, the East zone where the NYT outcrops is characterized by slope gradients such that significant topographic amplification should be expected; thus, it was indicated with TA in the Grade I map. No topographic amplification and significant slope instability is expected for the SA1-2-3 areas of interest, being the slopes less than 15° (i<15°) [2].

Figure 5b reports the liquefaction susceptibility map, based on a screening of soil grading within the first 15m. Two zones were defined: high liquefaction potential (HLP), where the poor-graded Aeolian sands (AS) are detected at shallow depth, and medium liquefaction potential (MLP), characterized by silty sands with non-plastic fines.

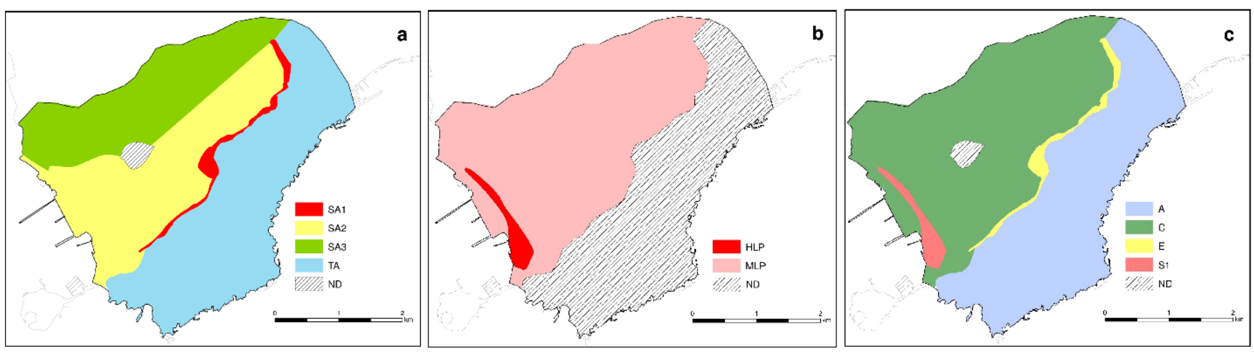

Fig. 5. Grade I seismic microzonation maps for (a) ground motion amplification; (b) stability against liquefaction; (c) Grade II microzonation map in terms of ground types.

Based on the simplified V_S profiles (Fig. 4a), it was finally possible to assign values of the equivalent shear wave velocity, V_{S30}, to each geolithological complex in Fig. 3b, and to classify them according to the ground types specified by the National Technical Code for seismic design [11, 13]. The resulting Grade II zonation map is reported in Fig. 5c. In detail, the outcropping tuff along the South – East sector was classified as ground type A ($V_{S,30}$>800 m/s), whereas the main part of the plain area was classified as ground type C ($V_{S,30}$ = 180 – 360 m/s, bedrock depth higher than 20m). The narrow transition between these two zones, characterized by $V_{S,30}$ ranging again between 180 and 360 m/s, but with a relatively shallow (z<20 m) NYT depth, was classified as E type soil. Also, the deposits below the dune sands, with a mean $V_{S,30}$ between 180 and 360 m/s but highly susceptible to liquefaction, were classified as ground type S1; finally, the pyroclastic soils below STT were not classified, since the stratigraphic profile is characterized by significant inversions of the V_S with the depth.

5. Conclusions and perspectives

This paper shows the preliminary results of the SM study performed on a strategic area located West of Napoli. The study was carried out with reference to Grade I and II criteria, based on the recommendations of National and International Guidelines. The results rely on the definition of an accurate geological and geotechnical model, inferred from a wide collection of pre-existing logs, surface and in-hole geophysical tests. The SM maps permitted to define the ground types with different degrees of ground motion amplification and to identify the zones most susceptible to soil liquefaction. Being the area of interest in a plain, no slope instability map was required. Further developments will be specific field and laboratory investigations on representative sites, aimed at the characterization of cyclic stress-strain and strength properties, required to perform dynamic site response and liquefaction analyses.

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