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UPGRADING THE SIMPLIFIED ASSESSMENT OF THE LIQUEFACTION SUSCEPTIBILITY FOR THE CITY OF NAPLES, ITALY

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ABSTRACT

This paper presents a study of the liquefaction susceptibility for the city of Naples. This builds on previous work which showed that, based on conventional simplified procedures based on CPT and Vs measurements, the city the liquefaction potential for some parts of the city was very high. Here, an updating of the previous study is performed. This is because, in July 2009, a new comprehensive building code was adopted in Italy reducing the previously considered design peak ground accelerations. Furthermore, the available geotechnical database for the west part of the city has been improved though the acquisition of published CPT data and the realization of specific MASW tests. New analyses demonstrate that adopting a more careful evaluation of the hazard parameters for the city of Naples, a consistent reduction of the liquefaction susceptibility is observed, susceptibility that remains significant only in a limited portion of the city.

Keywords: Cone penetration test, Liquefaction, MASW, Seismic Codes, Seismic Zonation.

INTRODUCTION

During 2005-2006 a research project was carried out to assess the liquefaction susceptibility of the city of Naples, Italy, based on conventional simplified procedures following ISSMEGE-TC4 (1999) Grade-3 methods. The main results of the study were summarized in Santucci de Magistris & Evangelista (2007a, b).

Since then, some new data, information and constraints have arisen. Particularly, in July 2009, under the pressure of the recent destructive L'Aquila earthquake, a new comprehensive building code released in 2008 (NTC, 2008) was adopted in Italy. Guidelines for seismic zonation in Italy were also recently published (Vinale et al., 2008; WG MS, 2008). Further, design peak ground accelerations were modified with respect to the time when the previous work (Santucci de Magistris & Evangelista, 2007a) was written. A clearer seismological setting was drawn for the city of Naples, based on disaggregation procedures (Spallarossa & Barani, 2007; Convertito et al., 2009). Finally, the available geotechnical database for the west part of the city was enlarged, throughout the acquisition of published CPT data and the realization of specific MASW tests, directly performed by the Authors (Evangelista, 2010).

Therefore, in this paper a review of the previously published documents is done. An updated scheme of liquefaction potential for the city of Naples is presented and some specific comments for the comparison of the results of liquefaction resistance from CPT and MASW test are also given.

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A BRIEF SUMMARY OF PREVIOUS STUDIES

The attempt to analyze the liquefaction susceptibility for the city of Naples was motivated by the well-known disastrous consequences of this phenomenon on the natural environment and constructions (see for instance damage patterned observed from the events of Alaska, USA 1964; Niigata, Japan 1964; Loma Prieta, USA 1989; Northridge, USA 1994; Kobe, Japan 1995; Chi-chi, Taiwan 1999; Izmit, Turkey 1999 or those occurred in the recent 2010 Port-au-Prince, Haiti and Maule, Chile earthquakes).
Particularly, this specific city was selected due to:

- its big exposure, being the third large populated city in Italy, with one of the highest population density in Europe;
- its relatively elevated seismic hazard; and,
- the large knowledge of its subsoil, that was studied for some decades, starting from the landmark paper of Croce & Pellegrino (1967).

The analyses of the liquefaction hazard were carried out using two simplified procedures based on the knowledge of the cone penetration resistance and the shear wave velocity profiles. Both procedures derived from the classical Seed & Idriss (1971) approach based on the comparison between the shear stress producing liquefaction (or critical levels of deformation) and that induced from the earthquake. Formulas reported in Idriss & Boulanger (2004) were employed for detecting the liquefaction safety factor profiles, while, for each analyzed vertical, the Liquefaction Potential Index I_L (Iwasaki et al., 1982), was introduced to summarize the data.

At the time of writing the original papers, for the city of Naples a peak acceleration of 0.25 g on outcropping horizontal bedrock was introduced by the current building code for construction (OPCM, 2003). Even though the Authors were fully aware that design of new construction and microzonation are two independent process, this acceleration, corresponding to earthquakes having a returning period T_r= 475 years, was adopted for the analyses. For the same returning period a magnitude, equal to 6.85 was estimated using the Gutenberg-Richter recurrence law (Gutenberg & Ricther, 1956) for the seismogenic zone ZS927 (WG, 2004), which does not comprise directly the city of Naples, but included the epicenter of historical earthquakes of the greater intensity.

Geological and geotechnical setting

The city of Naples included an area of 117.27 km^2, whose morphology turns out irregular, with a maximum height of 454 m above sea level (a.s.l.). This morphologic complexity and the geologic context, derives from the consequences of various volcanic activities, produced from the Caldera of the Campi Flegrei on the west side and from the Somma-Vesuvio on the south-east.

The main base formation is the Neapolitan Tuff, formed from a process of solidification of loose pyroclastic soil erupted from Campi Flegrei. The Tuff is sometimes emerging or it is found at various depths from ground level. Above the tuff a pyroclastic sequence, constituted mainly by pozzolanic soil is present. The latter is the result of the primary volcanic deposition on the hill of the city, while it appears as alluvial sediments on the coastal zone, having continental or marine origin. The pozzolanic soil is present in all the territory with thickness of some tens of meters, underlying thin layers of a younger formation of pumices and lapilli, covered by volcanic fly ashes and remoulded soils, together with man-made grounds, including masonry blocks often used as filling materials. A sketch of the city of Naples from the 1:100000 geological map of Italy is reported in Figure 1.

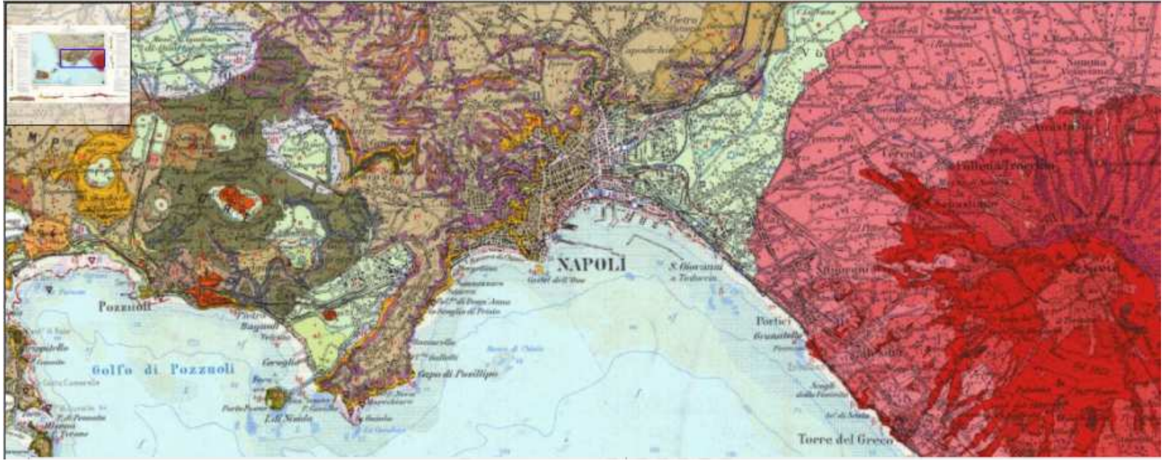


Figure 1. Geological setting of the city of Naples (*red: recent lava flow; light green: coastal plan deposits; okra: pyroclastic soils*) (http://www.apat.gov.it/Media/carta_geologica_italia/tavoletta.asp?foglio=183-184).

A geotechnical zonation of the city was proposed by Croce & Pellegrino (1967) (Figure 2). As specified in Santucci de Magistris & Evangelista (2007 a,b) analyzing the grading composition of the soils and the position of the water table (Figure 3), liquefaction might potentially occur in *Zone 3* (including a former industrial site where thick pyroclastic soils are sometime mixed with organic materials; the pyroclastic soils are sometime washed by old rivers and sometime deposited in a marine environment) in *Zone 5* (often a reclaimed land, filled with different man-made materials having several meters in thickness overlaying medium-fine grading alluvial soils, which covers, at a depth varying from 20 to 30 meters, the Neapolitan Yellow Tuff) and in the coastal part of *Zone 6* (constituted from the top by recent man-made ground placed to overwhelm ancient swamps plus layers of sands and peat characterize a fluvio-palustrine formation, with a whole thickness from around 15 to 20 meters overlaying, from a depth larger than 20 or 30 meters from the ground level, the Yellow Tuff formation constituted by uncemented or cemented pozzolanic material and the Yellow Tuff itself).

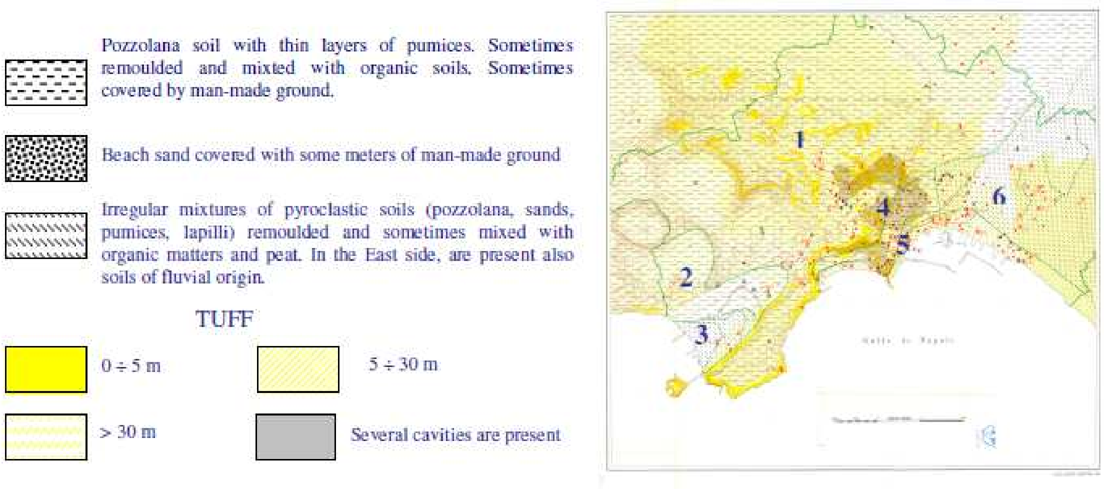


Figure 2. Geotechnical zonation of Naples (modified after Croce and Pellegrino, 1967).

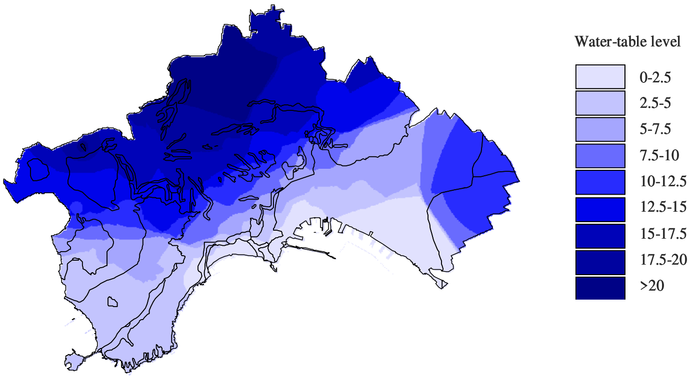


Figure 3. Water table level for the city of Naples (modified after Santucci de Magistris & Evangelista, 2007b).

Liquefaction potential

The analyses were executed in correspondence of 108 CPT and 4 Down-Hole tests available inside the selected area. The stratigraphic amplification was not considered (i.e., the soil amplification factor was fixed as S =1). The main result of the research indicated that in some part of the city the liquefaction potential was relevant as can be seen in the map of Figure 4.

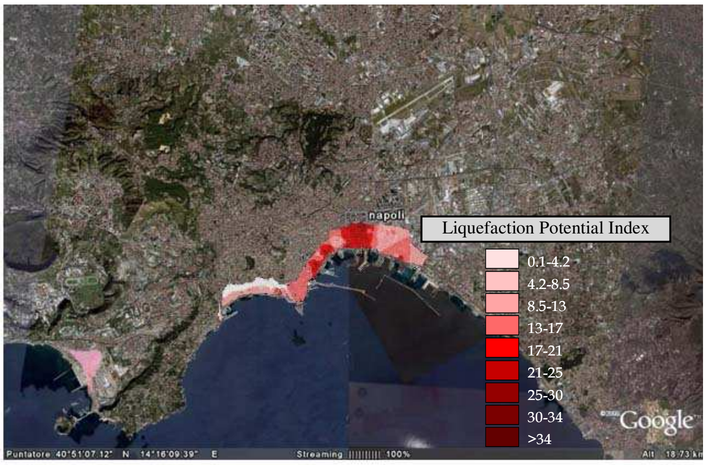


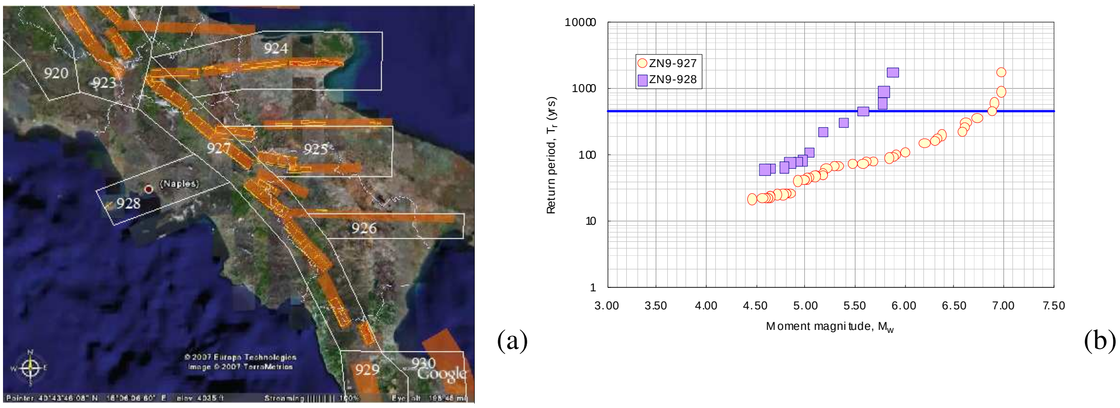
Figure 4. Map of the Liquefaction Potential Index for the city of Naples (modified after Santucci de Magistris & Evangelista, 2007b).

SEISMIC HAZARD FOR THE CITY OF NAPLES

Grade-3 zonation methods require an appropriate knowledge of the seismic hazard for the area in hand, throughout sets of acceleration time histories or some derived parameters, according to the adopted computational methods. The seismic hazard for the city of Naples was analyzed based on the seismogenic zonation ZS9 of the national territory (WG, 2004). The city of Naples is close to two main zones: Zone

SZ927 (Sannio-Irpinia-Basilicata) which runs parallel to the Apennine chain and included all the sources that had given tectonic earthquakes in the past, and Zone SZ928 (Ischia-Vesuvius) which runs perpendicular to the previous zone and includes the earthquakes generated by the Neapolitan volcanic areas (Figure 5a). Based on data reported in WG-CPTI (2004), for the two above mentioned seismogenic zones, in Figure 5b the recurrence laws, that are the relationships between the moment magnitude and the return period of earthquake (i.e., the reciprocal of the mean annual rate of exceedance λ_m, that is the number of exceedance of each magnitude divided by the length of the time period) are plotted.

An open question in performing Grade-3 zonation analyses is fixing a returning period for earthquakes. In WIDRM (2004) it is specified that a returning period of 100 years need to be selected, not correspond to the returning period of the Turkish Building Code. In WG MS (2008) it is specified, instead, that seismic hazard analysis need to be congruent with the current building code for Italy. In this case, a selection of a proper returning period for hazard analyses is rather controversial since, according to the codes, for each type of building and for each limit state a different returning period needs to be considered. Then, a unique answer for an urban area cannot be properly found if not adopting a conventional value.



(a) (b)

Figure 5. Seismogenic zonation ZS9 for the Centre-South Italy (modified after Meletti & Valenzise, 2004) (a) and recurrence law for zone 927 and 928 (b).

Being the seismic actions for life-safety limit state of ordinary constructions computed considering a returning period of T_r=475 years, this value is employed here. Notice that WG MS (2008) suggests employing the maximum ever estimated magnitude for each seismogenic zone located close to the area of interest. This statement is not consistent with the indication related to the choice of the maximum acceleration.

At T_r= 475 years corresponds an approximate value of the moment magnitude equal to 6.8 using the Gutenberg-Richter recurrence law for zone ZS927 and 5.5 for ZS928. According to WG 2004, for the city of Naples a PGA of 0.168 g was estimated, referring again for seismic events with a return period of 475 years. This acceleration, lower than the previous indicated value of 0.25 g, needs to be employed according to the current building code (NTC, 2008) for Ultimate State for new constructions.

This value of peak acceleration is substantially determined from the contribution of ZS928, as can be deduced from Figure 6 in which a desegregation graph for PGA for the city of Naples is reported (Spallarossa & Barani, 2007). More specifically, for the city of Naples, the disaggregating analysis for the PGA gives a mean value of magnitude equal to 5.02 for a mean distance of 9.41 km.

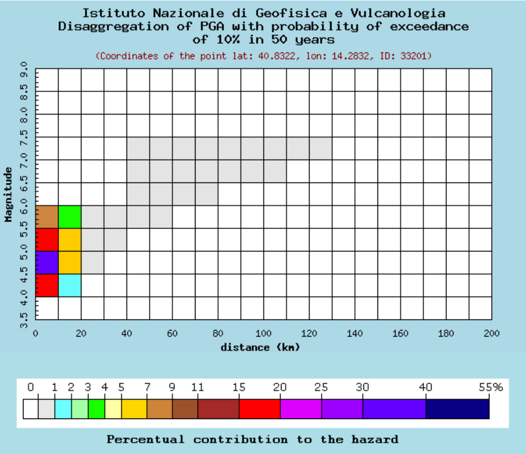


Figure 6. Disaggregation of PGA for a return period of 475 years for the city of Naples (modified after Spallarossa & Barani, 2007).

Therefore, we can conclude that the seismic hazard for the city of Naples is mainly due to earthquake of moderate magnitude having close and shallow epicentral distance. Such earthquakes are mainly due to the volcanic activities generating in Campi Flegrei and Vesuvius, rather than earthquakes of tectonic origin. Furthermore, Convertito et al. (2009) performed a disaggregation analysis for a specific location in the East part of Naples to analyze the contribution of the seismogenic faults not only on the PGA (i.e., the spectral ordinate having a period T= 0 s) but also on the spectral ordinate having T= 1 s, using again a return period of 475 years. In this case, the seismic hazard is "bimodal" controlled by zone 928, but the contribution of design earthquake located in the zone 927 at a distance of 41.50 km having a magnitude 7.0 that is very close to the maximum magnitude expected for that zone cannot be neglected.

The analyses of liquefaction are then conducted here for these two magnitude levels and values of PGA:

1) M=5.02 and PGA=0.168 g (thus, following the prescription of the Italian Building code for life-safety limit state);
2) M=7.0 and PGA=0.12 g (from the seismic hazard for the city of Naples, taking account the contribution of the seismogenic faults of ZS927, see Figure 7).

As a matter of fact, in Figure 7 the decay laws for the PGA adopting the Sabetta & Pugliese (1987) relationship (still employed for seismic hazard analysis in Italy, WG, 2004) are plotted, with reference to the two above mentioned magnitudes. Note that the value of maximum horizontal peak acceleration provides by an earthquake located in the zone 927 at a distance of 40 km (the minimum value between Naples and ZS927) it is equal to the PGA generates by a seismic event in ZS928 at a distance of 10 km.

GEOTECHNICAL CHARACTERIZATION AT THE WEST PART OF NAPLES

As specified before, new data are available for the west part of the city - Bagnoli district, a former industrial area - allowing a clearer understanding of the geotechnical models for Zone 3 of Figure 2. Previous analyses showed a low liquefaction risk, probably because of the presence of non-negligible fine fractions in the soil. To perform a more accurate study in this zone, a relatively large database, comparing to the extension of the area, has been collected, including boreholes and CPT measurements at 9 different locations. MASW tests provide shear wave velocities profiles inside the same area.

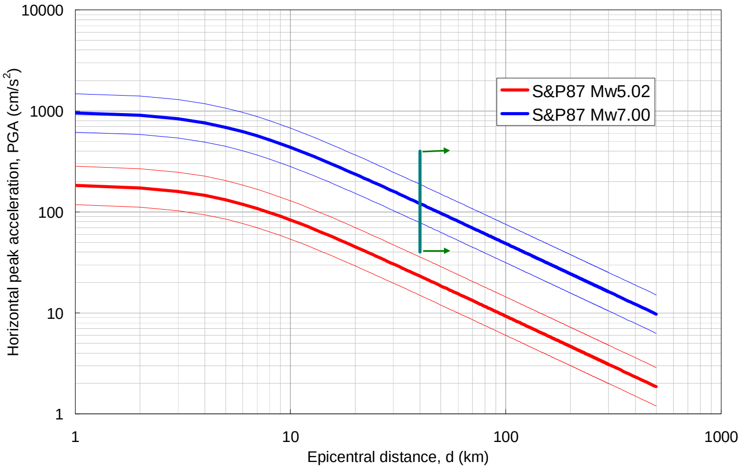


Figure 7. Sabetta & Pugliese (1987) decay law for PGA for ZS928 (Mw=5.02) and ZS927 (Mw=7.0)

Bagnoli district was generated by a huge volcanic-tectonic collapse at the Phlegrean caldera. Since then, its evolution has been controlled by the recurrent volcanic and tectonic events which occurred throughout the Phlegrean Fields as well as by sea-level rise. In particular, the tephra ejected from the Agnano area modeled the depression by aggrading its bottom and shifting the coastline seaward. The depression fill consists of sub-aerial tephra and marine deposits with intercalations of paleosoils and transitional alluvial and lacustrine-palustrine sediments. The subsoil is constituted by four main materials. From top to the bottom: anthropogenic debris and pyroclastic remolded soil, having a thickness ranging from 3 to 11 m; pyroclastic cineritic (4÷10 m thick) followed by approximately 30 m of various very coarse and medium sands formations, overlayering a bench cineritic silty sand which is found around 40 m depth. Along the coastline, the pyroclastic soils are sometime mixed with organic materials and sometime washed by old rivers and sometime deposited in a marine environment.

CPT tests show a substantial mechanical homogeneity of the lithologic horizons (Figure 8). From the profiles it turns out poor mechanical characteristics for the first ten meters of soils, due to the medium porosity and the presence of copious inclusions of organic material, while an increment of resistance can be observed at deeper levels. In Figure 8 previous data (red curves) have been integrated with new available investigations (blue lines). Comparing the two databases, the tip resistance is similar in all the area, while the sleeve friction is higher in the previous CPT tests. This aspect could be due to the presence of peat material and a higher fine friction in the relative subsoil profile interjected the sand formation. It is possible, therefore, to point the attention on the rule of the sleeve friction on the liquefaction analysis and how it influences the results, reducing the occurrence of the liquefaction.

Apart from previous existing Down-Hole tests two new MASW tests have been executed in the area. Experimental procedures and specs for these two tests are reported in Evangelista (2010). Figure 9 shows the obtained results.

The available DH tests showed a high level of uncertainty, being the shear wave velocity profiles either normally or inversely disperse. These results could be explained by the presence of organic material in the coastal sector of the area. On the other hand, carefully executed MASW tests show a regular variation of V_S with depth. In both cases, however, the velocity values are not dissimilar by the maximum limits proposed by the DH. From the surface to deep layer, the first thickness ranging from 3 to 11 m, consisting of anthropogenic debris and remolded pyroclastic soils are characterized by V_S of around 200-250 m/s, while the following horizons has a shear wave velocity varying between 350 and 400 m/s.

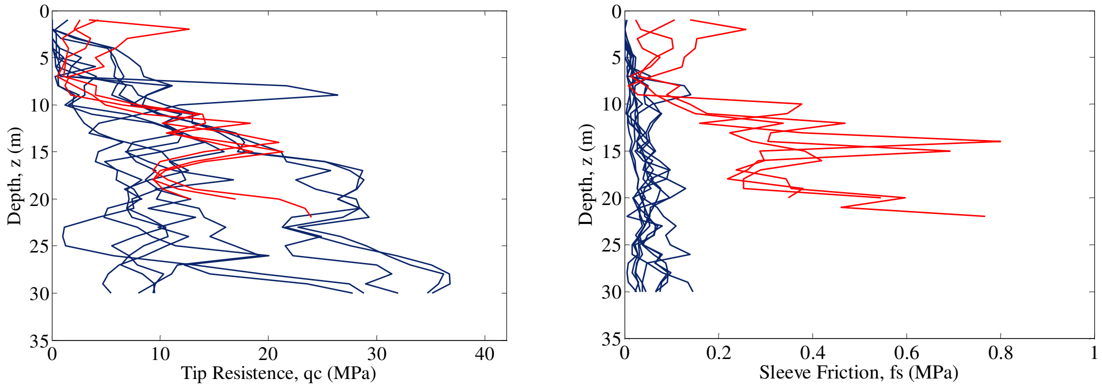
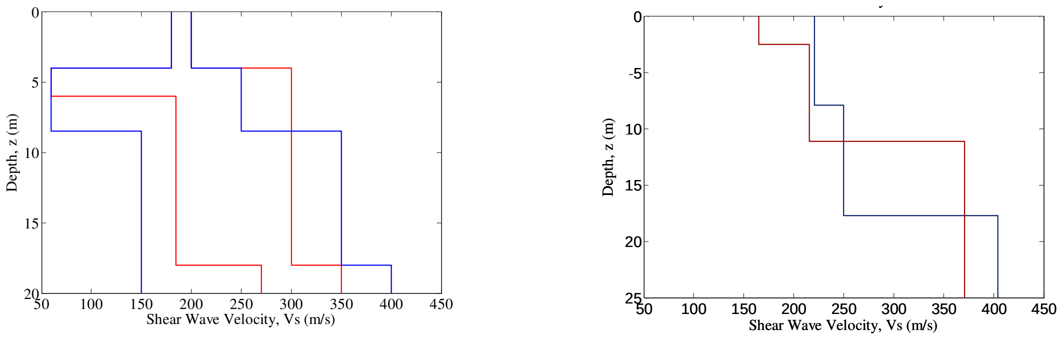


Figure 8. A collection of CPT results tip resistance and sleeve friction for the area of Bagnoli, Naples (red previous database; blue new database).



(a) (b)

Figure 9. Shear wave velocity profile from: (a) DH tests (minimum and maximum Vs profiles) (Nunziata, 2006); (b) MASW tests (Evangelista, 2010).

NEW LIQUEFACTION ANALYSES

As specify in Santucci de Magistris and Evangelista (2007) liquefaction analyses are executed in the previous indicated area 3 and area 5 of Figure 2. In the following, initial screening criteria for liquefaction, specifically applied for the new data in the west part of the city (Bagnoli district) and comments on overall results are given.

Initial screening criteria in liquefaction analysis

To identify boreholes for which liquefaction susceptibility could be eventually negligible, in these new analyses, the criteria introduced in NTC (2008), which will be applied to civil structure, are adopted. Such criteria are slightly different from those reported in Eurocode 8 (EN 1998-5, 2003) and will be shortly summarized here: 1) Moment magnitude M_w of the expected earthquake lower than 5; 2) Maximum horizontal acceleration at the ground level, in free-field, lower than 0.1g; 3) Average water table level deeper than 15 meters from ground level; 4) Clean sand deposits having a normalized penetration resistance $(N_1)_{60}$>30 or q_{c1N} > 180; 5) Soils with grading curves external to the threshold curves material established by Tsuchida, 1970.

Based on data diffusely discussed in the previous section, the criteria based on the expected peak ground acceleration or on the expected magnitude do not allow excluding the occurrence of liquefaction.The physical and mechanical properties of Neapolitan volcanic soils are summarized in Santucci de Magistris & Evangelista (2007a, b). Relating to material of the west area of Napoli, the results of the grading curve analysis, on 12 specimens sampled at different depths, along the subsoil profile, until 25 m, are shown in Figure 10 and compared with the grading curves limits to exclude liquefaction phenomena. The materials show similar grading curve: they does not have relevant clay fraction and it is evident the presence of sand around the 50% dry weight, with a high percentage of gravel. Their grain size distributions curves are within the suggested range of possibility of liquefaction, therefore these soils seem to be susceptible to liquefaction in terms of their grain size.

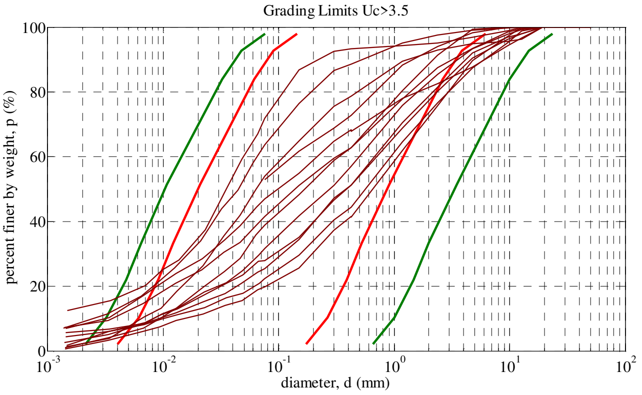


Figure 10. Grading Curves of pyroclastic material in Bagnoli area compared with the limit curves for liquefaction susceptibility

Results

All the liquefaction analyses were executed without considering the possible soil amplification; please notice that, unless using correlation with CPT data, in this specific example the $V_{s,30}$ values are available and then a proper soil factor could be defined only for the west area (from MASW tests, $V_{s,30}$ is equal to 270m/s and 221m/s), while this is not possible in the other analyzed cases, due to the aforementioned lack of measurement of wave velocities.

The difficulty of the judgment of the liquefaction inside the deposit in term of the liquefaction safety factor, *LSF,* suggests to express the assessment of the liquefaction risk with the Liquefaction Potential Index that provide a more objective evaluation of the liquefaction susceptibility for a single vertical.

In Figure 11, all the results, derived by CPT tests, are summarized through the frequency distribution of the liquefaction potential index for the different seismic scenario defined for the city of Naples. In particular, in Figure 11a there is a map of the analyzed areas that derives from a further refinement of the geotechnical zonation of the city of Naples compared with the map reported here in Figure 2.

Figure 11b-d show the results of the analysis in terms of the liquefaction potential index I_L, divided in five classes at different liquefaction risk: 1) liquefaction risk is null (I_L=0); 2) low (0<I_L<5); 3) medium (5<I_L<10); 4) high (10<I_L<15) and 5) very high liquefaction risk ($_{IL}$>15).

Data in Figure 11 b pertains to the analyses executed using the seismological parameters adopted in Santucci de Magistris & Evangelista (2007). Those in Figure 11 c refer to Mw=5.02 and PGA=0.168 g while Figure 11 d was obtained using Mw=7.0 and PGA=0.12 g.

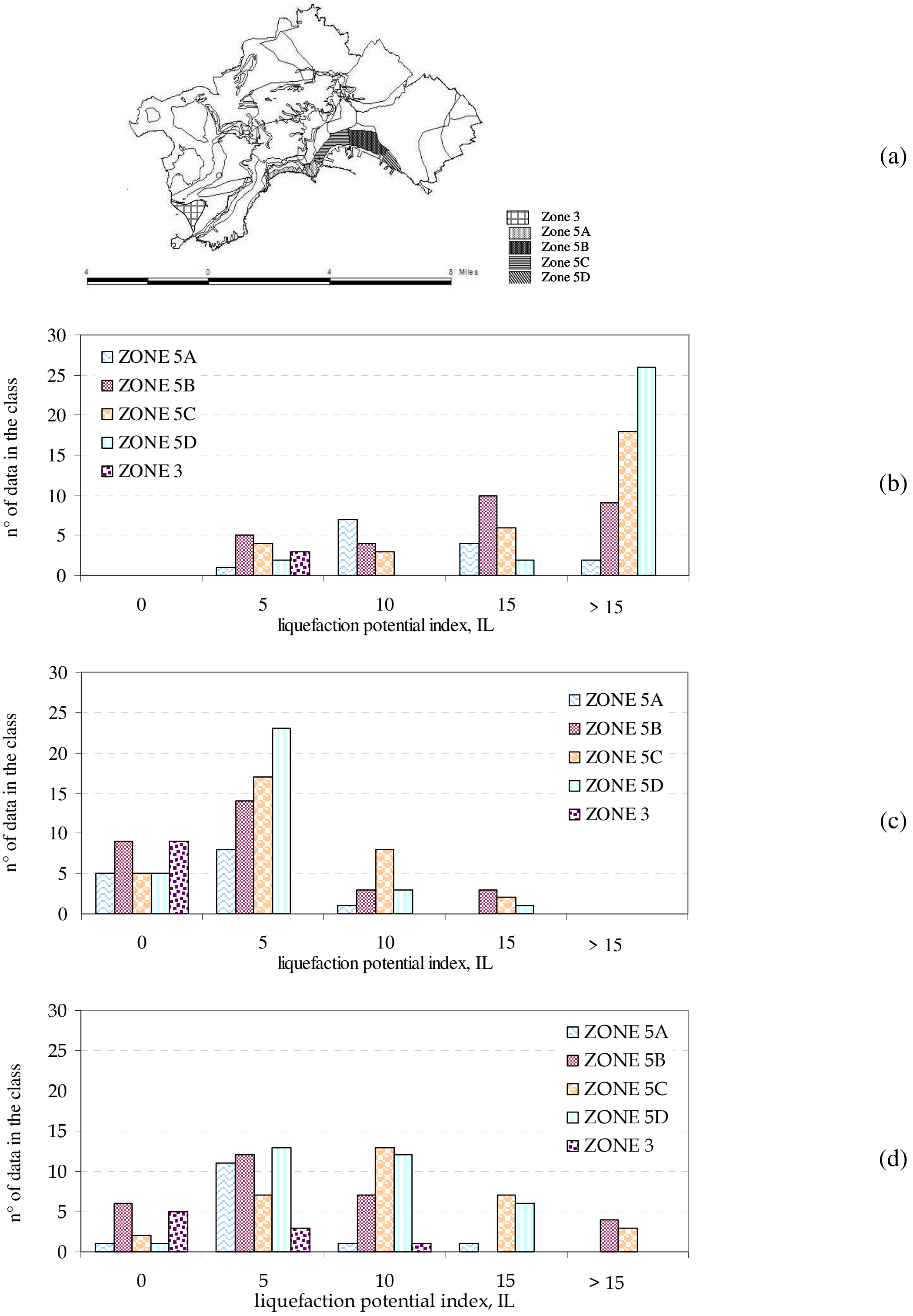


Figure 11. Map of subzones in the city of Naples (a) and distribution of liquefaction potential index for the analysis with: (b) M=5.85 and PGA=0.25 g (data of Santucci de Magistris & Evangelista, 2007) ; (c) M=5.02 and PGA=0.168 g and (d) M=7 and PGA=0.12 g

Looking at diagrams of Figure 11, the previously increasing of the average I_L from zone 5A to zone 5D (Figure 11b) is not marked in the new analyses. Zone 5D has always the highest susceptibility to liquefaction, but the risk of liquefaction is not very high considering the different seismic actions; in particular I_L reaches value of 10 only for event of magnitude equal to 7. Statistical analyses performed in Bagnoli, with the new elaboration becomes more consistent, therefore liquefaction risk is low there.

In Bagnoli site, previously analysis have evidenced a disagreement between Vs, derived from DH test and the cone penetrometric resistance measures. Such disagreement is reflected in the LSF profiles that show lower values if computed from q_c rather than from Vs. Analyzing the calculations, in terms of Potential Liquefaction Index, for the case of cone penetration tests I_L varies from 10.3 to 17.9, while for the case of shear wave velocity I_L varies from 7.2 to 11.0.

The analysis with MASW tests rejected the liquefaction risk due to the values of normalized shear wave velocity that are always larger than 215 m/s, that is the threshold for liquefaction occurrence (Andrus & Stokoe, 2000). It is not clear to the Authors whether differences in the analyses are due: (a) to the soil heterogeneity; (b) limits in the simplified calculation procedures, that were created adopting no Italian case-histories or (c) to the fact that cone tip resistance underestimates the liquefaction resistance for volcanic soils, because of their grain crushability. Moreover, it was not possible to extend the comparison in all the investigated area, due to the limited number of the down-hole tests available.

CONCLUSIONS

The paper presents a study of the liquefaction susceptibility for the city of Naples. The background of this work is a similar paper presented by the Authors at the 4ICEGE (Santucci de Magistris & Evangelista, 2007b) where, based on conventional simplified procedures, it was demonstrated that in some part of the city the liquefaction potential was very high. Here, an updating of the previous study is performed.

First of all, a new comprehensive building code adopted in Italy on July 2009 (NTC, 2008) revised the design acceleration for new constructions. Specific hazard analysis is provided for each location on the national territory that, beforehand was divided in four overall large macrozones. Liquefaction analyses were run again having in mind this background seismological work embedded in the current building code (see also http://esse1.mi.ingv.it/). Moreover, a specific investigation campaign was performed in the west part of the city in a former industrial area that includes the collection of geological data the acquisition of published CPT data and the realization of specific MASW tests. These new information are presented here.

New analyses demonstrate that adopting a more careful evaluation of the hazard parameters for the city of Naples, a consisted reduction of the liquefaction susceptibility is observed, susceptibility that remains significant only in limited portion (zone 5D) of the city.

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