Thessaloniki-GREECE 2007

4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1491

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

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ABSTRACT

New seismic codes, recently introduced in Italy after the 2002 Molise earthquake, established a new seismic classification with higher level of peak ground acceleration. This caused some renewing interests for studying the liquefaction of saturated sands in Italy.
In this paper, the attention is concentrated on the city of Naples, which was subjected to an increase in the design seismic actions. Large number of data on its subsoil was also available.
Liquefaction analyses were performed using simplified methods, and particularly adopting the CPT-based procedure, proposed by Robertson and Write in 1998.
The results showed that in some area of the city of Naples the liquefaction susceptibility is very high.

Keywords: Liquefaction, seismic zonation, seismic codes, cone penetration test

INTRODUCTION

Liquefaction is considered one of the major threats for civil structures under seismic loads, as deduced from the damage surveys performed after some strong earthquakes (see for instance 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).

Sources of liquefaction in Italy for the years 1117÷1990 (Galli and Meloni, 1993, Galli et al., 1999) indicate the presence of 317 cases regarding 61 different earthquakes, always involving limited portion of the territory. The relative narrowness of the occurrence of this event, mainly ground fissuring and related phenomena (like water emission or sand boils), is due to the low to medium energy content of earthquakes and to the scarce susceptibility of Italian soil deposits (often clays, aged and stiff), near the main earthquake sources. For these reasons, it is a common opinion, in the Italian technical community that this phenomenon is of minor concern in our country.

However, after the 2002 Molise earthquake (M_w=5.78), a new seismic code, mainly inspired from Eurocode 8, was introduced in Italy, and the national territory was newly classified adopting more realistic and higher level of peak ground acceleration on outcropping rocks. The increment of the seismic category for many areas and the wide increase of the PGA made more attractive, in Italy, the study of the potential liquefaction of saturated sands.

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Particularly, this study was performed in the framework of the new guidelines of the Italian Geotechnical Society "Geotechnical Aspect of the Design in Seismic Areas" (AGI, 2005), and it is a development of what was previously reported in Santucci de Magistris (2006).

The city of Naples 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 movement from the third to the second category within the new seismic classification; and,
- the large knowledge of its subsoil, which was analyzed, from several decades, at the Department of Geotechnical Engineering, University of Naples, starting from the landmark paper of Croce and Pellegrino, 1967.

LIQUEFACTION ANALYSIS

As well known, according to TC4-ISSMGE, 1999, currently available methods for the assessment of the liquefaction hazard for saturated sandy soil in a given region can be divide into three grades of approaches, according to the dimensions of the investigating area and the relative availability of geological and geotechnical data. Grade-1 methods, that are valid for large areas, are based on compilation and interpretation of existing information available from historic documents, published reports and other accessible databases, having as a background the existing geologic and geomorphologic maps. Grade-2 methods, suggested for performing more detailed zonations, are improvements of the previous approaches, using for instance aerial photographs or specific field studies. For small areas, Grade-3 methods are recommended, to obtain quantitative data based on specific investigations and tests.

When the reference is made to a single construction, but the approaches are eventually extendible to a small area, the analysis methods, according to AGI 2005 and some other guidelines (i.e., PIANC, 2001), can be further subdivided in the following categories of a crescent level of complexity:
- simplified analyses;
- simplified dynamic analyses;
- advanced dynamic analyses.

All simplified analyses for liquefaction derive from the well-know Seed and Idriss (1971) procedure; in simplified dynamic procedures the seismic loading is evaluated trough a local site response analysis, thus requiring the knowledge of an appropriate accelerogram at the bedrock; in advanced dynamic analyses the liquefaction problem is included in the general analysis of the soil-foundation-structure system, using automatic computation codes and sophisticated soil models.

In the following, on the base of the available data, the analyses of the liquefaction hazard were carried out using two simplified procedures. The simplified analyses are based on the comparison between the shear stress producing liquefaction (or critical levels of deformation) and that induced from the earthquake. To this aim, the methods demand:

1. the evaluation of the main characteristics of the expected seismic event: PGA and magnitude.
2. the geotechnical characterization of the subsoil, by mean of field and laboratory tests aimed at determining:
   - the depth of the water-table;
   - the stratigraphic conditions;
   - some mechanical and physical property of the subsoil.

REGIONAL SEISMICITY FOR THE AREA OF NAPLES

Based on the historical records, several relevant earthquakes affected the city of Naples.
The intensity database of the damaging earthquakes in Italy (Monachesi and Stucchi, 1997), includes, for the years 1005-1980, 79 events having interested the area, being the most damaging the 1456 Molise earthquake, that had in Naples an estimated seismic intensity equal to VIII on the MCS scale (see Figure 1a).

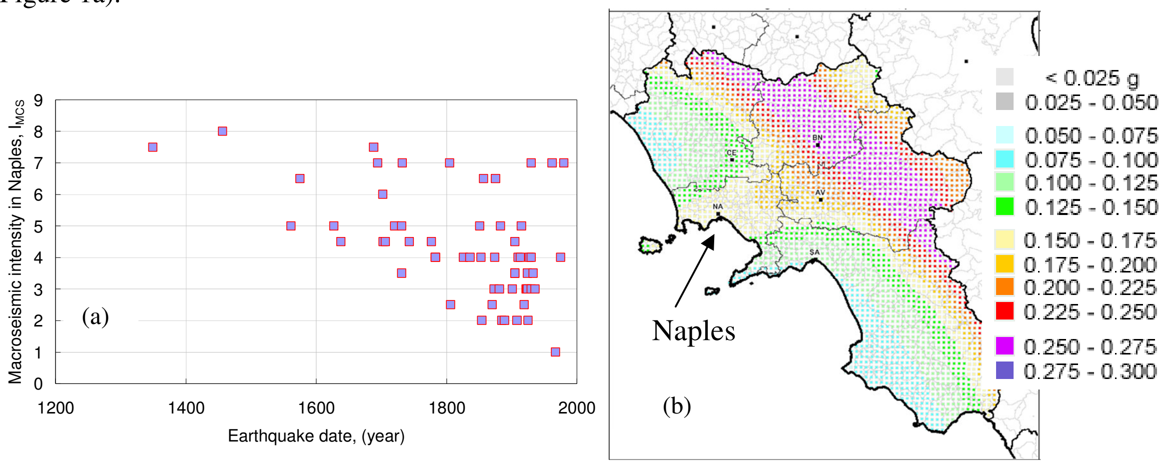


Figure 1 Seismic scenario in Naples: (a) Macroseismic intensity of earthquake (1005-1980) (data from Monachesi and Stucchi, 1997) and (b) PGA map for the Campania prefecture (modified after WG, 2004).

To analyze the seismic hazard for the city of Naples, the new seismogenic zonation ZS9 of the national territory (WG, 2004) was followed. The city of Naples is close to two main seismogenic 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. In the specific:
Zone 927 is characterized by the following parameters:

- Prevailing fault mechanism: normal;
- Average depth of earthquakes: from 8 to 12 kilometers;
- Maximum observed magnitude: M_{max}=7.06;

Zone 928 is characterized by the following parameters:

- Prevailing fault mechanism: normal;
- Average depth of earthquakes: from 1 to 5 kilometers;
- Maximum observed magnitude: M_{max}=5.91;

A value of the magnitude, equal to 6.85 for a return period of 475 years, has been achieved using the Gutenberg-Richter recurrence law (Gutenberg and Richter, 1956):

$$M = \ln(10.76 \cdot T_r)/1.2464 \quad (1)$$

These figures derive from earthquakes falling back in the seismogenic zone ZS927, which does not comprise directly the city of Naples, but included the epicenter of historical earthquakes of the greater intensity.

According to WG 2004, for the city of Naples it was estimated a PGA ranging from 0.15 to 0.175 g, for seismic events with a return period of 475 years, as can be seen from the map of Figure 1b. This lead to attribute at the communal territory a PGA equal to 0.25 g, according to the current seismic law. This value of acceleration has been used in all the analyses executed in this research.

SITE DESCRIPTION

The city of Naples included an area of 117.27 Km^2, whose morphology turns out irregular, with a maximum height of 454 m a.s.l. This morphologic complexity and the geologic context, dominated mainly from the presence of pyroclastic soil, were originated from the superimposition of various volcanic activities, produced from the Caldera of the Campi Flegrei and from the Somma-Vesuvio (see Figure 2).

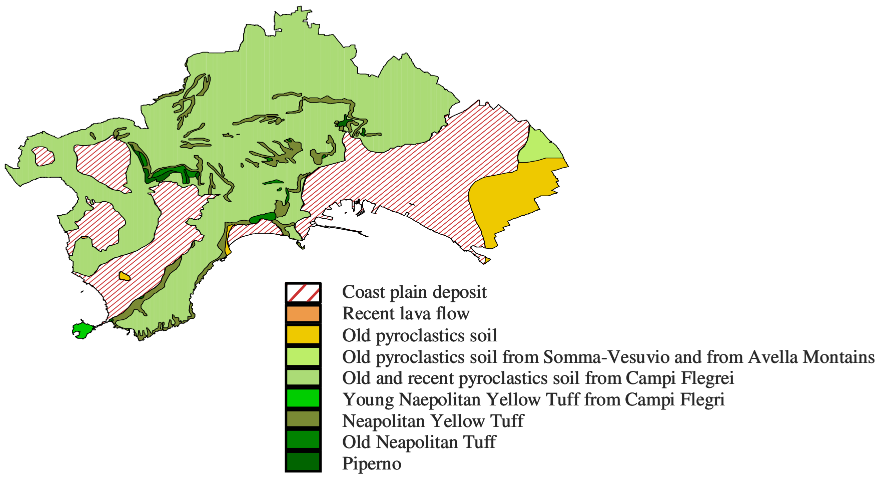


Figure 2 Geologic context of the city of Naples.

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 is present the pyroclastic sequence, constituted mainly by pozzolanic soil. The latter is the result of the primary volcanic deposition on the hill of the city, while it appears as alluvial sediments on the costal 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.

Figure 3 shows the water-table surface and, more specifically, its quota height above sea level. Hydrogeologic study has revealed a hydro-flow, moving from the hill areas to the sea.

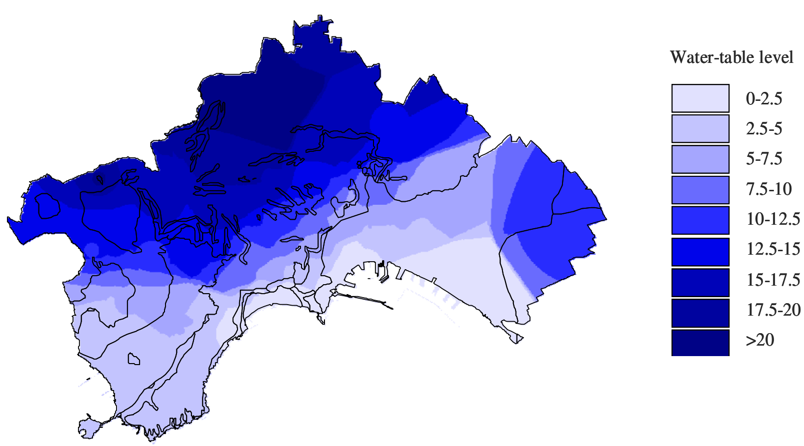


Figure 3 Water-table map for the city of Naples (heights in meters above the sea level).

From a geotechnical viewpoint, some macro-areas can usually be distinguished, as can be seen in Figure 4 (Croce and Pellegrino, 1967):

Zone 1 includes the hill area that is characterized by uneven morphology and layers of made-man ground, pozzolana soil and pumices soils with a total thickness spanning from 10 to 30 meters. The basement is constituted by the Neapolitan Yellow Tuff. In the area the water table is very deep and soils are typically in a partially saturated condition.

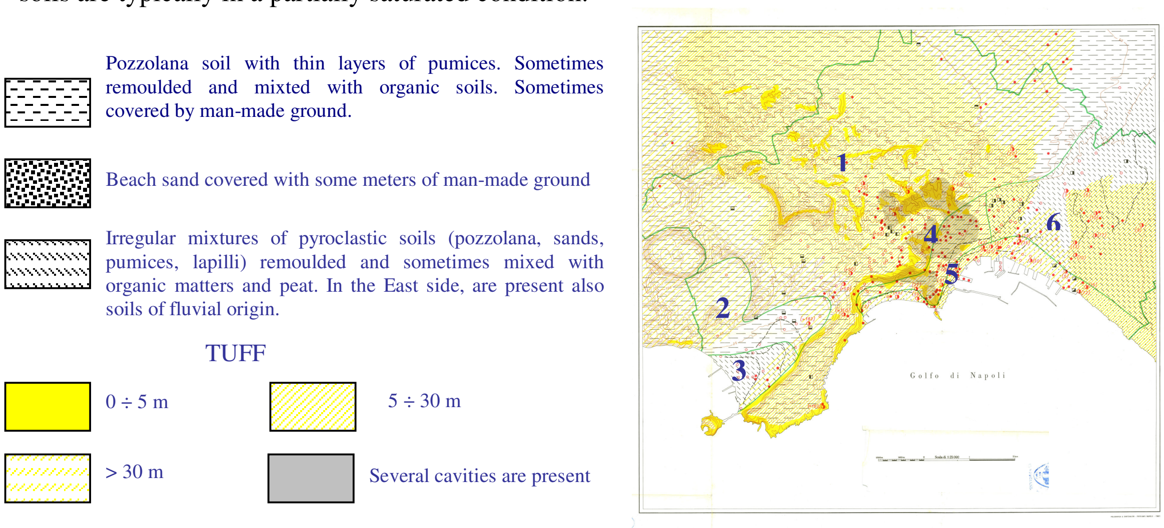


Figure 4 Geotechnical zonation of Naples (modified after Croce and Pellegrino, 1967).

Zone 2 is located in the western part of the city, where the subsoil is reasonably homogeneous and characterized by a thick cover (more than one hundred meter) of recent pyroclastic products on marine sands or occasionally, on Neapolitan Yellow Tuff.

Zone 3 is again in the west part of Naples and included a former industrial site. In this area, the thick pyroclastic soils (pozzolana, pumices and lapilli) are sometime mixed with organic materials. The pyroclastic soils are sometime washed by old rivers and sometime deposited in a marine environment. Water table is often very shallow.

Zone 4 is the downtown area that is constituted by some meters of man-made ground, followed by pozzolana and pumices soils. The Tuff is present at a depth varying from few to around 30 meters from the ground level. The water table spans from few to several meters from the ground level.

Zone 5 is the costal area that is often a reclaimed land, filled with different man-made materials having several meters in thickness. Such materials overlays medium-fine grading alluvial soils (with some thin pozzolanic layers), which covers, at a depth varying from 20 to 30 meters, the Neapolitan Yellow Tuff. Water table is close to the ground level.

Zone 6 is the eastern part of the city that is constituted from the top by recent man-made ground placed to overwhelm ancient swamps. Then, layers of sands and peat characterize a fluvio-palustrine formation, with a whole thickness from around 15 to 20 meters. Such material overlays, 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. Water table is at few meters from the ground level.

SELECTION OF THE INVESTIGATING AREAS

When the liquefaction hazard should be evaluated in a given area, some preliminary operations can be performed to select the portion of the territory where the liquefaction susceptibility is eventually negligible. In this research, we adopted the criteria introduced in a new proposal for the Italian geotechnical seismic code, which will be applied to civil structure. Such criteria are slightly different from those reported in Eurocode 8 (EN 1998-5, 2003) and will be shortly summarized here.

According to this proposal, the liquefaction analysis could be omitted, when at least one of the following conditions is found:

- Moment magnitude M_w of the expected earthquake lower than 5;
- Maximum horizontal acceleration at the ground level, in free-field conditions, lower than 0.1g;
- Average water table level deeper than 15 meters from ground level;
- Clean sand deposits having a normalized penetration resistance $(N_1)_{60}$>30 or q_{c1N} > 180.
- Soils with grading curves external to the threshold curves material established by Tsuchida, 1970.

As explained by Santucci de Magistris, 2006, the first condition derives from the analysis of databases of the observed liquefaction phenomena. The second condition was detected evaluating the peak acceleration at the ground level in correspondence to the minimum value of the cyclic resistance ratio *CRR* in the conventional verification charts. The forth condition derives from the vertical asymptote existing in the same charts for the simplified verification methods. Then, a further threshold could be introduced if the normalized shear wave velocity is available (V_{s1}> 215 m/s for clean sand).

The criteria based on the expected peak ground acceleration or on the expected magnitude cannot exclude that liquefaction might interest the city of Naples.

Some physical and mechanical properties of Neapolitan volcanic soils are reported in Pellegrino (1967). Referring to the pozzolana soil, no macroscopic differences, in properties, are found in the city. Figure 5a shows the variability of the grading curves of such material, compared with the grading curves limits to exclude liquefaction phenomena. It clearly appears that, from the grading distribution viewpoint only, the pozzolana might have elevated liquefaction potential. Also the material does not have relevant clay fraction. Grading curves of pumices are plotted in Figure 5b together with the bonding curves for liquefaction. In this case, the material should not be subjected to liquefaction, due its coarse nature. Finally grading curves of alluvial materials are plotted in Figure 5c. In this case, the data are those reported by Croce and Pellegrino (1967). From the figure it appears that such materials are potentially liquefiable, even tough their grading curves are very variable.

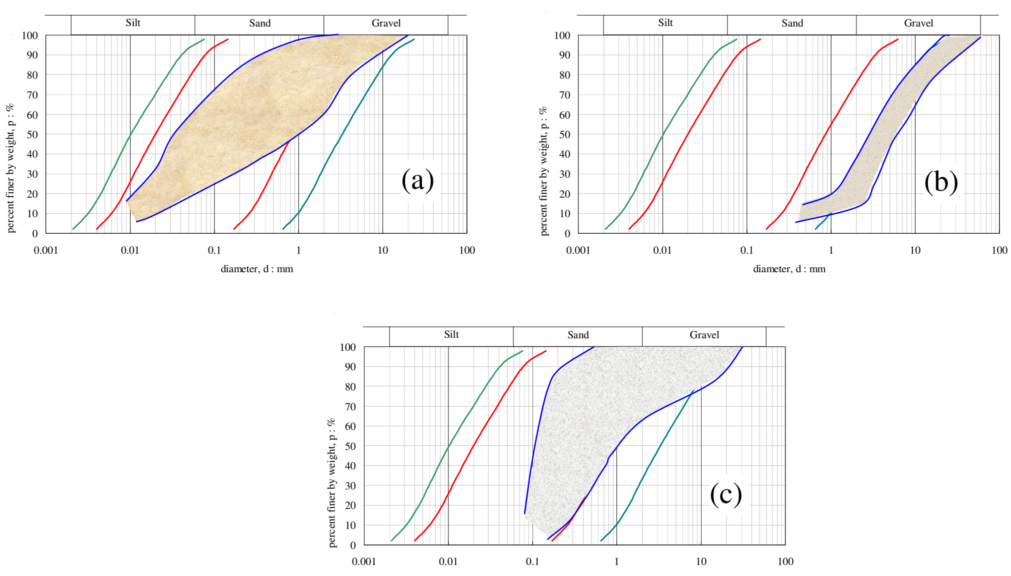


Figure 5 Grading curves for: (a) pozzolana, (b) pumices and (c) alluvial material in Naples, compared with the limit curves for liquefaction susceptibility.

On the whole, it appears that for all materials that constitute the Neapolitan subsoil the clay fraction is always negligible.

Based of what is reported above, the key variable to select the areas potentially interested to liquefaction phenomena is the depth of the water table, together with the penetration resistance.

Combining the map of water table (Figure 3) with an elevation map of Naples it was possible to select the portion of the communal territory in which the water level is less than 15 meters depth from the ground level. In this zone it is necessary to carry out studies of liquefaction. In other parts of the city liquefaction susceptibility should be negligible. The attention was then concentrated in shadowed areas of Figure 6, that include the western region of the city (Zone 3 of Figure 4) and the costal zone that is Zone 5. The latter zone, based on the values of cone penetration resistance, is further divided in four sub-zones, following what was reported in Grosso, 2002.

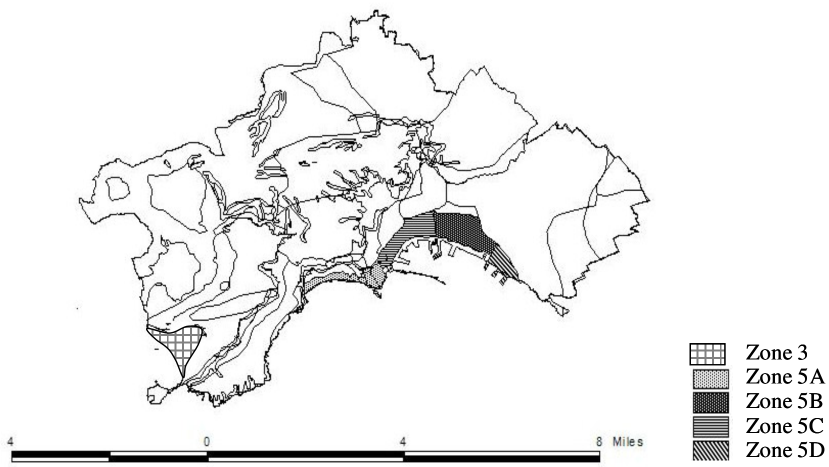


Figure 6 Investigated zone of the city for liquefaction susceptibility.

As for soil properties in the selected areas, in Figure 7 (a) and (b) representative cone penetration tests CPT and shear wave velocity measured with down-hole tests DH are reported. For zone 3, CPT shows poor mechanical characteristics between the ground level and a depth of approximately 11 meters, while an increment of resistance can be observed for the remaining investigated portion. Mechanical resistance is poor maybe because the material has medium porosity and copious inclusions of organic material.

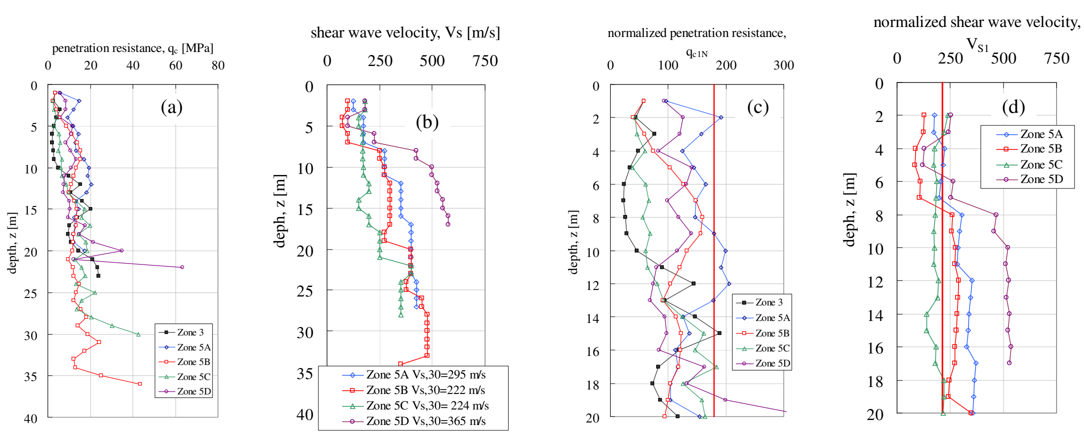


Figure 7 Mechanical characteristics of subsoil in Naples: (a) CPT profile; (b) Shear wave velocity profile; (c) normalized penetration resistance and (d) normalized shear wave profile.

For zone 5, penetration resistance grows in the first meters from the ground level and then remains constant until around 20 meters of depth. In this interval the resistance is always lower than 20 MPa.

Shear wave velocity profile, for all zones, are more dispersed and apparently there is not a clear relationship between q_c and V_s data. It should be also noticed that always shear wave velocity is above 200 m/s, except for the first few meters of the all analyzed subsoils. No shear wave velocity profiles are available for Zone 3.

In Figure 7 (c) and (d) the profiles of the normalized penetration resistance q_{c1N} and the normalized shear wave velocity V_{S1} are reported. To normalize data we referred to the suggestions reported in Idriss and Boulanger, 2004. In the same figures, the threshold values to exclude the liquefaction possibility are also indicated. It can be see that for the selected areas, q_{c1N} values are not so large to exclude, a priori, the occurrence of liquefaction related phenomena. The same result can be obtained looking at the normalized shear wave velocity profile. However, in the latter case, excluding the data for zone 5C all data overtake the threshold value at a depth larger than 7 meters from the ground level.

SIMPLIFIED METHODS

For estimating the liquefaction hazard in the selected areas of the city of Naples, two simplified procedures were used. The first is the CPT-based procedure proposed by Robertson and Write in 1998, currently considered one of the most accurate and complete methodology for the determination of the cyclic resistance profile (Youd et al., 2001); while the second procedure, by Andrus and Stokoe (2000), uses the shear wave velocity. Both CPT-based and V_s-based methods were reviewed by Idriss and Boulanger (2004) and in this research we referred to the formulation reported in this specific paper.

As well known, both methods allow defining a liquefaction safety factor *LSF* expressed by the ratio between the capacity of the soil to resist to the liquefaction, and the demand of seismic resistance of the deposit:

$$LSF = \frac{CRR}{CSR} = \left(\frac{CRR_{7.5}}{CSR}\right) \cdot MSF = \left(\frac{CRR_{7.5}}{CSR}\right) \cdot \frac{1}{MWF} \qquad (2)$$

In Equation (2) $CRR_{7.5}$ represents the cyclic resistance ratio for an earthquake of magnitude 7.5, *CSR* is the cyclic stress ratio, *MSF* is the "Magnitude Scaling Factor", while *MWF* is the "Magnitude Weighting Factor".

The cyclic stress ratio is determined, for the two procedures, by the same relation proposed by Seed and Idriss (1971), while the cyclic resistance ratio is calculated with different formulations.

Cyclic stress ratio, at one defined depth, is estimated by the following expression:

$$CSR = \frac{\tau_{average}}{\sigma'_{v0}} = 0.65 \frac{a_{\max s}}{g} \frac{\sigma_v}{\sigma'_v} r_d \qquad (3)$$

where $a_{max,s}$ is the peak ground acceleration at the soil surface; g is the gravitational acceleration, σ_v and σ_v' are, respectively, the total and effective vertical overburden stresses; r_d is a reductive coefficient of the seismic action that accounts for the deformability of the soil.

For those familiar to Eurocode 8, $a_{max,s}$ can be obtained by the product of the design ground acceleration a_g for stiff type A ground and a soil factor S, which depends from the subsoil stiffness, often synthesized by an equivalent shear wave velocity $V_{S,30}$ (EN 1998-1, 2003). The current version of Eurocode, however, is somehow contradictory, since does not give any *S* value for S_2 ground type, which is constituted by deposits of liquefiable soils. Actually, according to the suggestions of Youd et al., 2001, it should first be assumed that the soil deposit is not subjected to liquefaction and a proper *S* should be estimate. Then, if the soil liquefies, specific studies are required for the definition of the seismic action on structures. It should be observed also that Eurocode do not directly allow classifying a site, and then defining the soil factor *S*, if only cone penetration tests are available. This point will be touch later in the paper.

It can be observed that *LSF* is computed to one determined depth, while to define the liquefaction susceptibility of a site it could be necessary to associate a unique numerical value at the whole *LSF* profile. Therefore, a synthetic representative index of the liquefaction for a single profile was used in this study. This index, that was introduced by Iwasaki et al., 1978, is the Liquefaction Potential Index I_L, defined as:

$$I_L = \int_0^{20} F(z) \cdot w(z) \cdot dz \qquad (4)$$

in which z is the depth from ground level, measured in meters, F(z) is a linear function of the safety factor, that is equal to zero for $LSF>1$ and its complement to 1 for $LFS<1$, and $w(z)=10-0.5z$ is a linear function of z, that decreases with the depth. The values of I_L vary in an interval from 0 to 100, but the authors suggest that if:

- $I_L \leq 5$ liquefaction risk is low;
- $I_L \leq 5 \leq 15$ liquefaction risk is elevated;
- $I_L \geq 15$ liquefaction risk is extremely elevated.

ANALYSIS OF THE RESULTS

The analyses were executed in correspondence of 108 CPT and 4 Down-Hole tests available inside the selected area. The CPT profiles derive from a large database that was collected at the Department of Geotechnical Engineering, University of Naples, covering the whole urban territory, and that was updated until 2004. The only 4 Down-Hole tests in the studied zones, available to the Authors, were collected by Nunziata, 2005.

As for example, two analyses, carried out in correspondence of a static penetrometric test and Down-Hole test nearby, are presented here (see Figure 8). The aim was to show the adopted evaluation procedures and to make a comparison between the analyses performed starting from two types of in-situ tests.

All the liquefaction analyses were executed considering different soil factors *S*, particularly equal to 1; 1.25 and 1.35, even tough, for this specific example, the $V_{S,30}$ values were available and then proper soil factors could have been easily defined. This was not possible in the other analyzed cases, due to the aforementioned difficulties in classifying a site without direct measurement of shear wave velocities.

Results show that in some strata of the deposit, the liquefaction safety factor, *LSF* is below the unit while in some other liquefaction should not occur. In Figures 8, a line corresponding to a safety factor 1.25 separates point which are or are not safe, according to the limit provision of Eurocode 8.

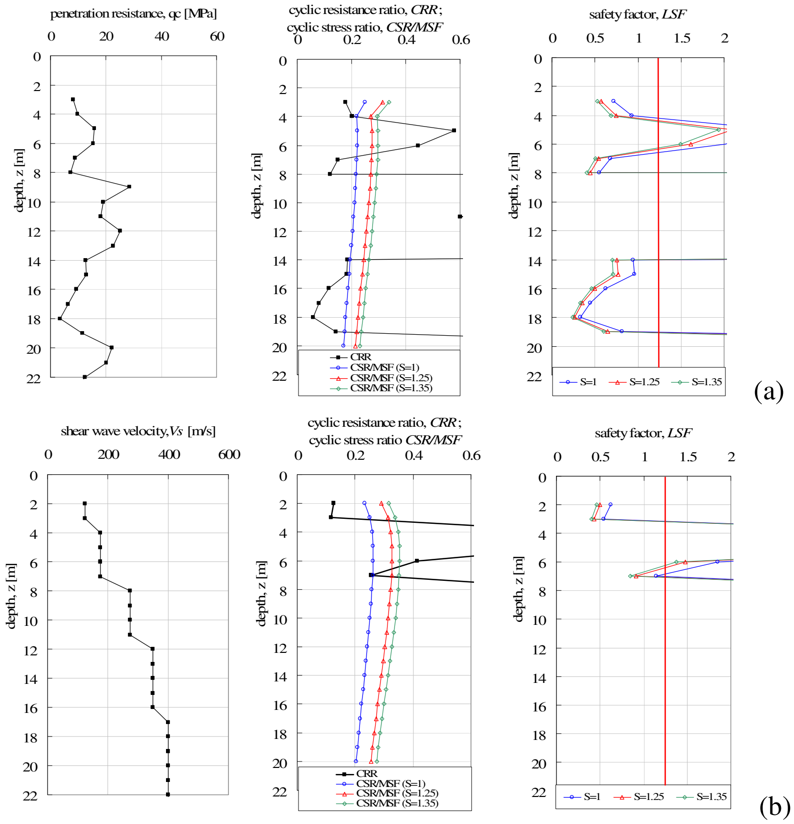
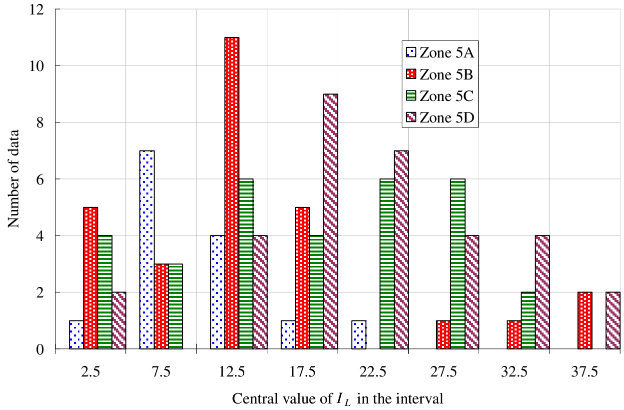


Figure 8 Example of liquefaction analyses: (a) CPT-based procedure; (b) V_S-based procedure.

Referring to the comparison between the analyses, it was previously evidenced a disagreement between V_s 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 V_s. 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 for *S* varying from 1 to 1.35, while for the case of shear wave velocity I_L varies from 7.2 to 11.0 again for *S* varying from 1 to 1.35. Please notice that there is a linear correlation between I_L and the soil factor *S*. It is not clear to the Authors whether differences in the analyses are due: (a) to the soil heterogeneity; (b) errors in measurements, (c) limits in the simplified calculation procedures, that were created adopting no Italian case-histories or (d) to the fact that cone tip resistance might underestimate the liquefaction resistance for volcanic soils, because of their grain crushability. Unfortunately, it was not possible to extend the comparison in all the investigated area, due to the limited number of the down-hole tests available.

Referring to the CPT based procedure only and fixing the soil factor *S* to 1, all the data were summarized in the following for the city of Naples, using the Potential Liquefaction Index.

First, in Figure 9 a statistical analysis is presented, drawing for each sub-zone a histogram probability of I_L and reporting the significant data in the nearby table. It can be seen that the average I_L increases from zone 5A to zone 5D, i.e. zone 5D has the highest susceptibility to liquefaction. It can be notice also that the standard deviation of I_L is lower for zone 5A. Data of zone 3 were not included in the histogram plot because of the limited number of cone resistance profiles available there.



	Zone				
	3	*5A*	*5B*	*5C*	*5D*
Average	3.38	10.25	13.92	17.40	21.36
Standard Error	1.02	1.27	1.77	1.66	1.59
Median	4.15	9.18	12.60	18.76	20.38
Standard Dev.	1.78	4.75	9.37	9.22	8.97
Kurtosis	-	1.24	1.33	-1.07	0.15
Asymmetry	-1.58	0.59	1.14	-0.25	-0.11
Num. of data	3	14	28	31	32
Greatest value	4.64	21.00	38.58	32.14	38.02
Smallest value	1.35	1.65	1.63	0.30	0.85

Figure 9 Distribution of I_L for different sub-zones and some statistical parameters.

Then, in Figure 10 the aerial distribution of the Liquefaction Potential Index for the city of Naples was drawn. The map was created interpolating single I_L values using an IDW algorithm. In some part of the city the liquefaction potential is very high, exceeding sometime the value of 15, indicating an elevated risk, especially in the eastern areas. In other part of the coastline zone, the liquefaction cannot be excluded, even though the susceptibility is moderate. For the western area of Naples, the few available data show low liquefaction risk, probably due to the presence of non-negligible fine fractions.

As expected from the geological nature of the Neapolitan subsoil, i.e., its volcanic origin, the distribution of the Liquefaction Potential Index in the investigated area is relatively scattered.

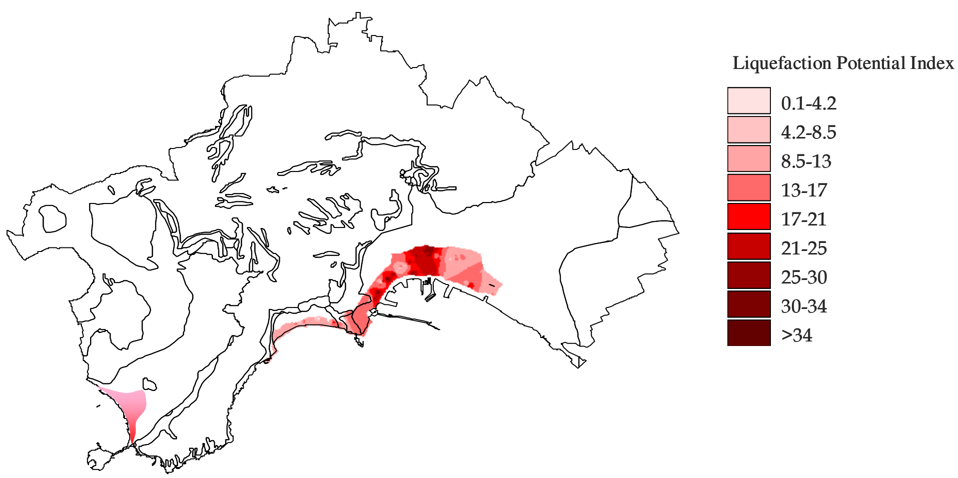


Figure 10 Liquefaction hazard map of Naples.

CONCLUSIONS

In this paper an attempt to evaluate the liquefaction susceptibility for the city of Naples is made, using the simplified Seed and Idriss (1971) methods and a large number of cone penetration tests.

Reference was made to earthquakes having a return period of 475 years. In this case, hazard studies indicate expected acceleration on outcropping bedrock in the order of 0.150÷0.175 g. However, to perform the analyses this value was raised to 0.25 *g*, to accomplish for the indication reported in the current seismic code for Italy.

Some preliminary criteria were proposed to delimitate the areas where liquefaction can occur. It was demonstrated that some areas of Naples can be interested by the liquefaction phenomenon, even if the variability of the subsoils does not allow expressing a simple picture of the problem.

A comparison between simplified analysis using CPT and DH tests was attempted and some differences in results were observed: liquefaction susceptibility appears higher if computed using the cone resistance rather than the shear wave velocity. Such differences, maybe, could happen because cone penetration resistance might underestimate the resistance for volcanic soils, because of their grain crushability. This point should be investigated with more attention in the near future.

The liquefaction analyses were summarized by the Liquefaction Potential Index that was very high in some zones of Naples. The Authors, however, wander why available historical data does not report relevant cases of liquefaction in the city. This contradiction might be due to some difficulties in detecting liquefaction related phenomena from past documents and to the urban development of the city that only recently (compared with the return period of the design earthquakes) has interested the area where the liquefaction potential is higher.

Finally we can conclude that the finding in this paper, unfortunately contribute to rise the seismic risk for the city of Naples that was already estimated to be very high, due to its high exposure and its high vulnerability of the constructions.

ACKNOWLEDGMENTS

The Authors wish to thank Massimo Ramondini for his help in providing the cone penetration test for the city of Naples, Daniela Ducci for some data on the hydrogeology of the city and Concettina Nunziata for the shear wave velocity profiles.

REFERENCES

Andrus DR and Stokoe KH II "Liquefaction Resistance of Soils from Shear-Wave Velocity," ASCE, Journal of Geotechnical and Geoenvironmental Engineering, 126, Issue 11, 1015-1025, 2000.

Associazione Geotecnica Italiana (AGI). Geotechnical Aspect of the Design in Seismic Areas, Patron Editore, Bologna, 416 p., 2005 (in Italian).

Croce A. and Pellegrino A. "The subsoil of the city of Naples. Geotechnical characterization of the urban area", Proc. of the 8th AGI National Conference, Cagliari, 233-253, 1967 (in Italian).

(pr)EN 1998-1. Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, CEN European Committee for Standardization, Bruxelles, Belgium, 2003.

(pr)EN 1998-5. Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects, CEN European Committee for Standardization, Bruxelles, Belgium, 2003.

Galli P. and Meloni F. "Historical liquefaction. A National Catalogue", Il Quaternario - Italian Journal of Quaternary Sciences, 6, 271–292, 1993 (in Italian).

Galli P., Meloni F. and Rossi A. "Historical liquefaction in Italy: relationship between epicentral distance and seismic parameters", European Geophysical Society XXIIII General Assembly Natural Hazards NH3, The Hague, Netherlands, 1993.

Grosso V. Geotechnical characterization of the subsoil of the city of Naples using static penetration tests, Master Thesis, University of Naples Federico II, 2002 (in Italian).

Gutenberg B. and Richter CF. "Earthquake magnitude, intensity, energy and acceleration", Bulletin of

the Seismological Society of America, 46, 105-145, 1956.
Idriss IM and Boulanger RW. “Semi- Empirical Procedures for Evaluating Liquefaction Potential During Earthquakes”, Proceedings of the 11th ICSDEE & 3rd ICEGE, (Doolin et al. Eds.), Berkeley, CA, USA, 1, 32-56, 2004.
Technical Committee for Earthquake Geotechnical Engineering, ISSMGE-TC4. Manual for zonation on seismic geotechnical hazards, The Japanese Society of Soil Mechanics and Foundation Engineering, 1999 (http://www.civil.tohoku-gakuin.ac.jp/yoshida/tc4/tc4manual/zonation.pdf).
Iwasaki T., Tokida K., Tatsuoka F., Yasuda S. and Sato H. “Microzonation for soil liquefaction potential using simplified methods” Proceedings of the 3rd Int. Conf. on Microzonation, Seattle, 3, 1319-1330, 1982.
Monachesi G. and Stucchi M. DOM4.1, an intensity database of damaging earthquakes in the Italian area, 1997. (http://emidius.mi.ingv.it/DOM/home.html).
Nunziata C. Personal Communication, 2005.
Pellegrino A. “Physical and mechanical properties of volcanic soils in Naples”, Proc. of the 8th Geotechnical National Conference, Cagliari, 113-145, 1967 (in Italian).
PIANC. Seismic Design Guidelines for Port Structures Working Group no. 34 of the Maritime Navigation Commission, International Navigation Association, 474 p., Balkema, Lisse, 2001.
Robertson PK and Wride CE. ‘‘Evaluating cyclic liquefaction potential using the cone penetration test.’’ Canandian Geotechnical Journal, 35, Issue 3, 442–459, 1998.
Santucci de Magistris F. “Liquefaction: a contribution to the Eurocode from the Italian Guideline “Geotechnical Aspects of the Design in Seismic Areas” ISSMGE ETC-12 workshop, NTUA Athens, Greece, 2006 (http://users.civil.ntua.gr/gbouck/gr/etc12/papers/paper8.pdf).
Seed HB and Idriss IM. “Simplified procedure for evaluating soil liquefaction potential”, ASCE Journal of Soil Mechanics and Foundations Division, 97, Issue 9, 1249- 1273, 1971.
Tsuchida H. “Prediction and countermeasure against the liquefaction in sand deposit”, Abstract of the seminar, Port and Harbour Research Institute, Yokusuka, Japan, 1970 (in Japanese).
Working Group (WG). Redaction of the map of the seismic hazard, following the Ordinanza PCM 3274 of March 20, 2003, Final Report for Department of Civil Protection, INGV, Milano-Roma, p. 65 + 5 annexes, 2004 (in Italian).
Youd TL et al. “Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils”, ASCE Journal of Geotechnical and Geoenvironmental Engineering, 127, Issue 10, 817-833, 2001.