ON LIQUEFACTION MICROZONING STRATEGY AT LEVEL 2/3 FOR IMPROVING RESILIENCE OF URBAN AREAS

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**Introduction.** Microzoning studies have been developed and conceived as a profitable strategy to tackle seismic hazard estimation at local scale. Microzoning activity in Italy has recently been promoted according to three working levels: level 1 – geological susceptibility;
level 2 – simplified analyses and level 3 – in-depth quantitative analyses. The first level aims at defining areas that may suffer ground motion amplifications and/or susceptibility to instabilities (i.e. significant permanent deformations): due to active and capable faults, liquefaction phenomena, landslides. The second and third levels are related to quantitative estimations of co-seismic effects through simplified (level 2) or advanced (level 3) analyses. This work presents the case study of the Sulmona intramontane basin located in the Central-Northern sector of the Apennine chain, in the Abruzzi Region. The basin infill consists of a thick lacustrine succession passing to different orders of terraced alluvial deposits (Fig. 1). Here areas susceptible/not susceptible to liquefaction phenomena have been investigated through an analytical simplified approach (level 2) where the first level studies identified potential liquefiable areas.
Results from the first level of the seismic microzoning Sulmona urban area. According to the GdL MS (2008), the objective of the first level of microzoning activity is to identify portions of territory that are characterized by a homogeneous seismic behaviour (MOPS) based on geological and geotechnical data gained by past investigations supported by local administrations that appointed local professionals and new quick investigations (for example noise measurements). Past investigation campaigns have been generally undertaken for other purpose than the seismic microzonation. These characterization campaigns are commonly used to get information of the lithotypes and stratigraphic succession near the surface although they were commonly performed for other purposes than to collect physical and mechanical dataset of soil properties useful for dynamic characterization. This is the main reason why, at level 1, a few data are available of physical and mechanical values of soil properties to estimate the liquefaction susceptibility of soils. Concerning the level 1 microzoning at the intramontane Sulmona basin, based on past in field data, high local seismic amplifications are expected due to the presence of complex geological, geomorphological and tectonic features. In fact, it shows an asymmetric half-graben-like geometry (Fig. 1c). The deepest available borehole passes through a 435 m of continental deposits but not reaching the carbonate bedrock. The continental

Fig. 2 – Simplified stratigraphic logs of the two investigated wells (S1 and S2; see Fig. 1 for their locations). a) S1 is deepened to the valley floor and intercepts the water table. It passes through recent fine grained alluvial deposits laying above mud and clays lacustrine deposits, in an area identified as a liquefaction prone area, near the railway station. b) S2 is located in the historic center of the Sulmona town in alluvial deposits constituted by gravels and sands passing to lacustrine deposits. This passage always shows a velocity value inversion. The code spectrum related to the SLV ultimate limit state is overpassed over the whole interesting range of periods (0.1-1 s) by the median of the spectra calculated through the numerical simulations of local seismic responses. c) The profile of the factor of safety against liquefaction (FSL) calculated at S1 site. The calculations performed here, based on preliminary analyses, show that site S1 is not susceptible to liquefaction.
stratigraphic succession of the Sulmona basin is made up of gravelly sand, with silty clay intercalations, terraced alluvial deposits (Late Pleistocene-Holocene) overlying fine silty-clay and sandy-silt lacustrine sediments with local intercalations of gravel and conglomerate (Early-Middle Pleistocene) (Fig. 1). Accordingly, data from down holes DHs and cross holes CHs generally show a clear decreasing in the velocity values at 20-30m where the boundary between the gravelly alluvial unit and the silty-clay lacustrine one is found (Fig. 2). Furthermore, the carbonate ridges at the boundary of the basin show complex lithostratigraphic and morphological settings due to clastic supply from slope and alluvial fans (Fig. 1c). The superimposition of different geological units that can be subdivided according to their geophysical and geotechnical properties defined several “Stable Zones Susceptible for Local Amplification” in the MOPS map (Fig. 1b). “Unstable Zones” have been also mapped to highlight the presence of possible instability phenomena that have to be analyzed in the level 2/3 of microzoning (Fig. 1b).

**Local seismic response.** Comparing the seismic intensities suffered from Sulmona city center with its suburbs during several historical earthquakes (e.g., 1349, 1456, 1706, 1915, 1933, 1984 and 2009) it can be pointed out that, in some cases, the city center showed the heaviest damages (DBMI11 database, http://emidius.mi.ingv.it/DBMI11/). This suggests that, for this city, site effects could be relevant. Four permanent strong motion stations are installed in Sulmona district area by the Italian Civil Protection Office (Fig. 1b). One of them is installed on the outcropping bedrock, the other two in the center of the plain and the last one nearby the Morrone slope. The acceleration tracks recorded at these seismic stations (Fig. 3) highlight that the Sulmona plain may suffer remarkable amplifications. As a matter of fact, the seismic stations placed in the Sulmona plain recorded velocity and displacement peaks about 6 times higher than those at the rock site. The study of the local seismic response performed with STRATA (https://nees.org/resurces/strata) on two profiles available in the Sulmona area (S1 and S2 in Fig. 1) highlights, in fact, that the calculated spectra through 1D site response analyses by using as input motion accelerograms compatible with 475 years response spectra at outcropping rock conditions are higher than the ones related to the design code NTC08 (2008) for the corresponding subsoil class. The amplifications shown by those spectra fall in the period range

Fig. 3 – Acceleration, velocity and displacement values recorded by the seismic stations installed on the bedrock (SUL) and at the Sulmona plain (SULA). These latter recorded velocity and displacement peaks are about 6 times higher than those on the rock site: these data suggest that the Sulmona plain may suffer remarkable amplifications.
0.1-1s at S2 site whereas it is limited within 0.5-0.8s at S1 site (Fig. 2). Comparing Fig. 1b and Fig. 2 it can be drawn that the local amplification due to the soil deposits involves a large range of periods and can affect a broad range of structures. At S1 site, where a liquefaction prone area is evidenced at level 1, a spectral acceleration peak of 0.9g has been calculated. This value can be used to calculate the liquefaction instability of this zone through a simplified approach based on the Factor of Safety FSL.

**Liquefaction instability.** The high seismic hazard associated to the activity of the Sulmona fault system suggests the possible occurrence of high magnitude earthquakes exceeding acceleration threshold for liquefaction phenomena. Moreover, during the 2009 L’Aquila earthquake liquefaction phenomena occurred within the Holocene alluvial deposits in the Sulmona plain near the Vittorito village even if they affected limited areas. The first level of microzoning studies defined liquefaction prone areas according to the following predisposing conditions (NTC08): (1) the presence of sandy deposits (some quantitative limits on granulometric composition are provided), (2) the presence of the water table at depth higher than 15 m, (3) the expected magnitude Mw > 5, (5) the expected peak ground acceleration (a_max) at surface > 0.1g. These conditions are all matched at Sulmona city center. The identified prone areas to liquefaction are located nearby the railway station and along the main arterial road to the city. These sites are characterized by Late Pleistocene-Holocene alluvial deposits that host a water table at depth higher than 15 m. These deposits are mainly composed of fine loose sandy-silt deposits, falling in the grain size range of susceptible soils to liquefaction (S1 in Fig. 2a). Conversely, the older alluvial deposits that show 20-30m elevation over the valley floor are composed of gravelly soil deposits (S2 in Fig. 2a). However, due to the scarce data available and the high variability in soil properties and grain sizes characterizing these deposits, the liquefaction susceptibility must be evaluated in several points, at least with simplified methods, to be correctly assessed.

**Analytical methods to estimate the factor of safety against liquefaction.** Only at the S1 site, where some physical and mechanical soil properties were available, the Factor of Safety against Liquefaction (FSL) has been calculated (Fig. 2c). For this calculation the following equations have been used (Youd and Idriss, 2001):

\[
CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} - \frac{50}{[10 \cdot (N_1)_{60}+45]^2} - \frac{1}{200}
\]

\[
CSR = \frac{\tau_{av}}{\sigma_{vo}} = 0.65 \left( \frac{a_{max}}{g} \right) \left( \frac{\sigma_{vo}}{\sigma_{vr}} \right) r_d
\]

\[
FSL = \frac{R}{L} = \frac{CRR}{CSR}
\]

where a_{max} is the peak ground acceleration calculated through 1D seismic local response at S1 and S2 sites by site response analyses. The CRR_{7.5} is referred to a 7.5 M earthquake. In order to scale to the actual value of the earthquakes at Sulmona site, the following equation is used:

\[
CRR_{M,\sigma_{tv}} = CRR_{M=7.5,\sigma_{tv}=1atm} \cdot MSF \cdot K_o
\]

where MSF is the magnitude scaling factor and K_o is factor of the effective overburden stress.

Results from these calculations, that are simplified studies of level 2 microzoning activity, S1 site shows not to be susceptible to liquefaction.

**Conclusions.** Microzoning studies are divided into three levels of details. Passing from the 1st to the 3rd level those areas that are highlighted and bordered within MOPS as unstable to liquefaction must be studied through analytical and numerical methods. The present study shows a liquefaction analysis at level 2 carried out at Sulmona urban area. Here, due to the variability of physical and mechanical properties of recent alluvial deposits several boreholes have been performed to characterize the deposits. Starting from two available stratigraphic
profiles, S1 and S2, the factor of safety against liquefaction have been calculated. In doing this, surface peak ground acceleration values from local seismic responses undertaken at S1 and S2 have been used. Results from the present study enable the authors to exclude the liquefaction susceptibility at the studied sites. However, more a representative number of sites must be investigated and characterized to undertake these simplified analytical calculations at a number of sites representative of the heterogeneity of the soil deposits at Sulmona intra-montane basin to undertake further simplified analytical calculations in order to exclude the occurrence of liquefaction phenomena.

References
GdL MS; 2008: Indirizzi e criteri per la microzonazione sismica. Conferenza delle Regioni e Province autonome – Dipartimento della Protezione Civile, Roma.