The Seismic Microzonation of the City of Santa Venerina, Sicily (Italy)

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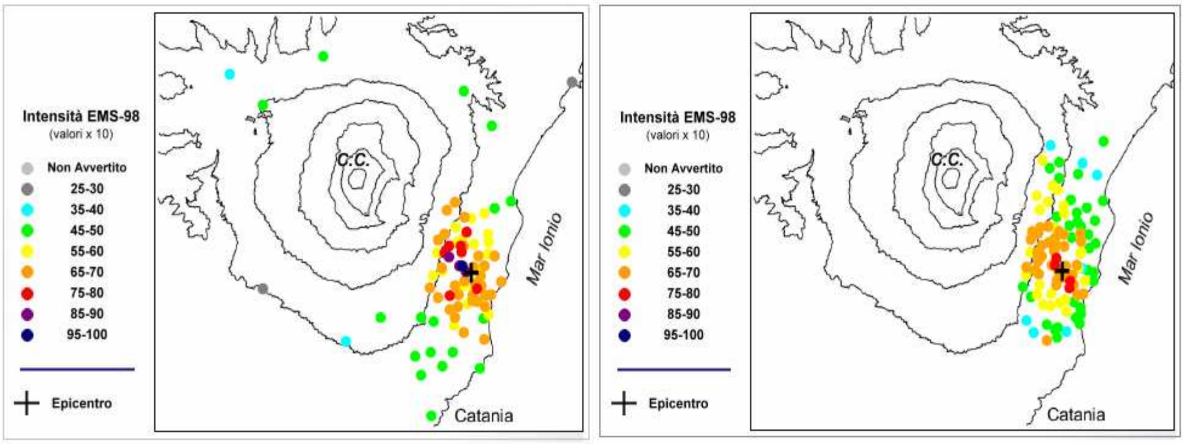
SUMMARY:
The geotechnical characterization of the subsoil of the city of Santa Venerina, municipality located about 20 km northeast of Catania (Italy), suggests a high vulnerability of the physical environment added to site amplification of the ground motion phenomena. Based on the seismic history of Santa Venerina, the 1914 and 1952 Linera earthquakes (M_L= 4.9) and the "Santa Venerina" earthquake of October 29, 2002 (M_L=4.4) have been considered as scenario events. On the basis of the seismic data it has been possible to obtain a detailed delineation of the spatial variability in seismic responses. The carried out procedure was to evaluate the design ground acceleration and after to evaluate the response spectra at the surface by the 1-D non-linear EERA code. Spatial variability of the spectral acceleration was determined. Ground-shaking maps for the urban area of the city of Santa Venerina were generated via GIS for the scenario earthquakes.

Keywords: Microzonation, seismic hazard, Santa Venerina, site effects, map.

1. INTRODUCTION

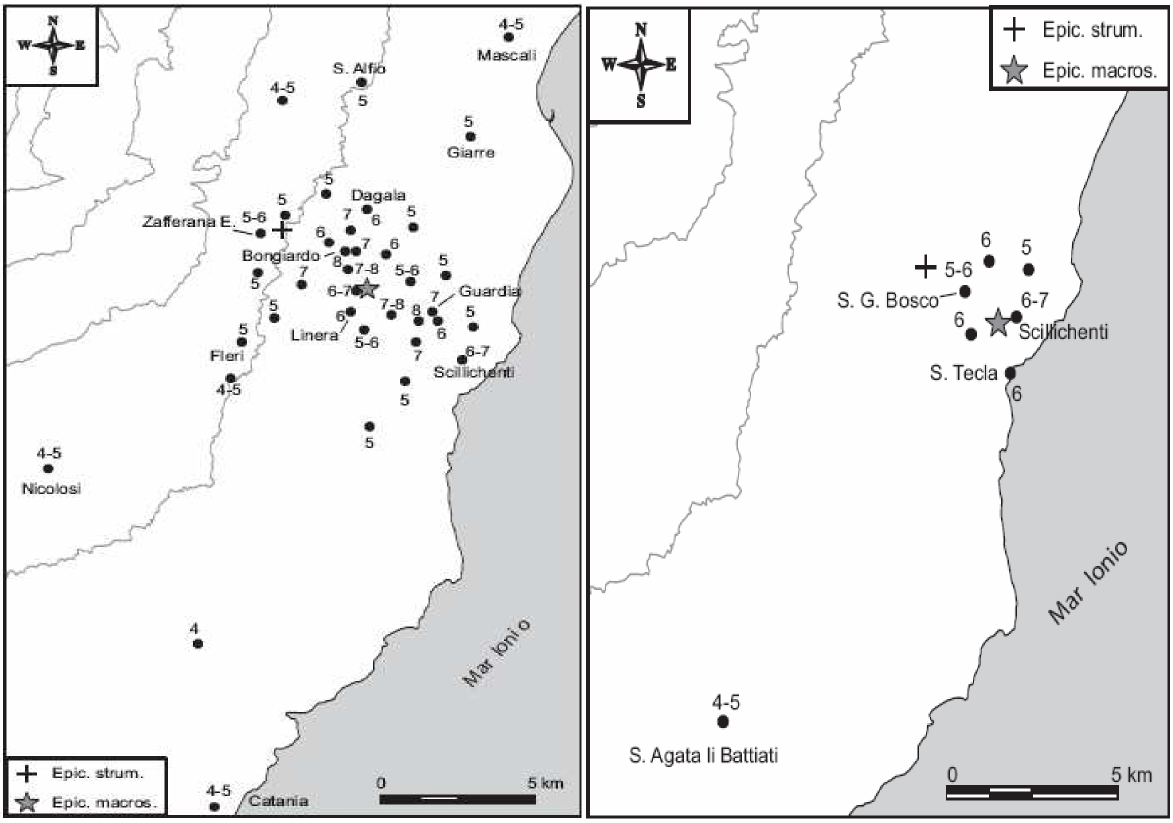
The geotechnical characterization of the subsoil of the city of Santa Venerina, municipality located about 20 km northeast of Catania, suggests a high vulnerability of the physical environment added to site amplification of the ground motion phenomena. These elements concur on the definition of the Seismic Geotechnical Hazard of the city of Santa Venerina in terms of amplification factors that should be correctly evaluated, through geo-settled seismic microzoning maps. Based on the seismic history of Santa Venerina, the following scenario events have been considered: the “Val di Noto” earthquake of January 11, 1693 (M=7.3), the “Etna” earthquake of February 20, 1818 (M=6.2), the 1914 and 1952 Linera earthquakes (M_L= 4.9), see Figure 1, and the “Santa Venerina” earthquake of October 29, 2002 (M_L=4.4), see Figure 2. The last one showed indeed surprisingly high spectral amplitudes at frequencies as low as 0.3 Hz, despite its moderate magnitude. On the eastern flank of Etna volcano, movements along the NNW–SSE trending normal faults of the Timpe system generate recurrent, low magnitude very shallow seismic events like those of October 29, 2002, that induce noteworthy ground surface effects (Figure 3).
The Timpe system is the on-land extension of the Hyblean–Malta fault system, which is the likely source of the 1693 earthquake. Frequent creep phenomena also occur both associated with seismic events and/or volcanic eruptions, and independent from them. These surface deformations are mainly confined in the eastern sector of the volcano apparatus and result from the interaction between regional tectonics and local volcano-tectonic processes.
In spite of its small local magnitude, the earthquake of October 29, 2002 caused significant damage to many buildings including reinforced concrete ones in an area that extends for about 4 km in a NNW-SSE direction and is centred around the villages of S. Venerina and Guardia. A long system of surface fractures originated along the damaged area. Other similar and even stronger events of the 2002 swarm in the northern zone did not cause diffuse damage since they occurred in a not densely urbanized area; however, they were highly destructive for the few sparse buildings close to the epicentres.



(a) (b)

Figure 1. Localization and EMS-98 Intensity (values x 10) of Linera historical earthquakes: a) earthquake of May 8, 1914; b) earthquake of March 19, 1952. Data from macroseismic catalogue of etnean earthquakes of INGV (Azzaro et al., 2000).

The sequence was well recorded by the Broad Band Station of Antillo (Mednet Network), the most energetic events also triggered the Strong Motion Stations of Bronte (BRNT) and Catania (CATA). The latest part of the sequence (2005-2006) was recorded by the local micronetwork installed in Santa Venerina (SVN).



(a) (b)

Figure 2. Localization with macroseismic intensities of October 29, 2002 Santa Venerina earthquakes: a) earthquake of 11.02 a.m.; b) earthquake of 5.39 p.m. After Azzaro et al. (2006).

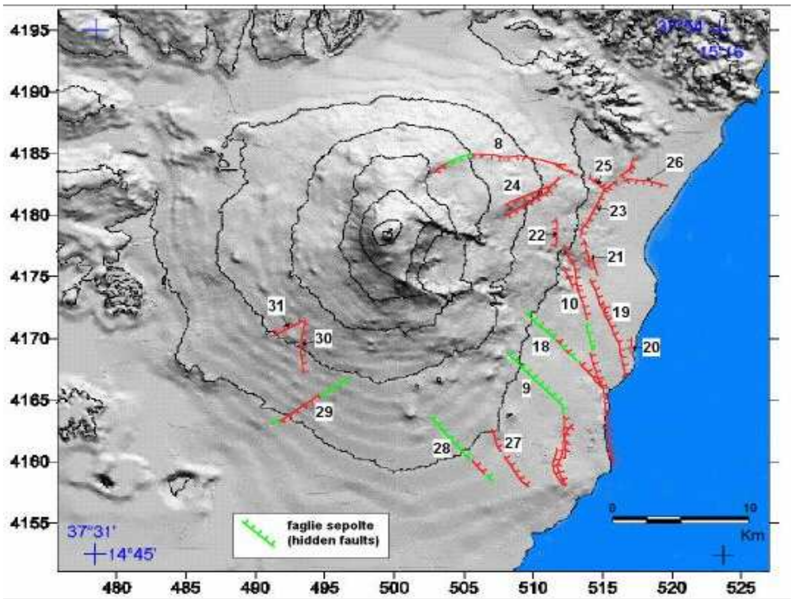


Figure 3. Surface faulting at Mount Etna volcano (Sicily) and active tectonics. From Azzaro (1997; 1999)

2. THE GEOTECHNICAL MODEL FOR THE CITY OF SANTA VENERINA

One of the most important input information for the ground response analysis is a subsurface model that represents the variation in thickness of the upper 30 m soil layers. This model should at least contain information on the depth of the conventional bedrock (Vs = 800 m/s), or on the depth where the shear wave velocities approach a value that is comparable to rock. The data largely consist of the stratigraphic log of borings, characterised by variable degrees of accuracy; some are accompanied by in situ and/or laboratory tests. In total, the database assembled for the project includes 32 boring locations, with a density distribution of the investigation points highly varying from site to site. Processing of this information has resulted in the via GIS geo-settled map of borings, shown in sketch in Figure 4.

Borehole

Figure 4. Map of borings location in the city centre of the city of Santa Venerina.

Because of their relevance on the estimation of local ground shaking and site effects, data from in-hole geophysical surveys (Down- and Cross-Hole measurements) have been examined with special attention, particularly for S wave velocity measurements. Down-Hole data were available from previous investigations at several different test sites, in the urban area and in the surroundings. They include measurements in different lava flows, tuffs, sandy and marly clays and alluvial fine-grained deposits. For the specific purpose of the work, three new borings have been recently executed to the depth of 90 m in the central city area, with Down-Hole tests and sample recovery. The boring data have been summarised according to a simple lithological description, through the choice of few fundamental classes. The denominations of the fundamental classes are consistent with the definitions of the Italian Geotechnical Association (AGI, 1977): peats, clays, silts, sands, gravels and pebbles are defined with the first letter of the name (in Italian T, A, L, S, G, C), while their percentages are expressed with simple notations (conjunction, comma or parenthesis).
It must be noted that the shear waves velocity V_s was also evaluated by the results obtained by the three Seismic Dilatometer Marchetti Tests (SDMTs) of Figure 5 for the soil properties characterisation. The SDMT provides also the shear wave velocity (V_s) measurements to supplement conventional inflation readings (p_0 and p_1). Soil stratigraphy and soil parameters are evaluated from the pressure readings while the small strain stiffness (G_0) is obtained from in situ V_s profile.
Source waves are generated by striking a horizontal plank at the surface that is oriented parallel to the axis of a geophone connects by a co-axial cable with an oscilloscope.
The test is conceptually similar to the seismic cone (SCPT). First introduced by Hepton (1988), the SDMT was subsequently improved at Georgia Tech, Atlanta, USA (Martin & Mayne 1997, 1998, Mayne et al. 1999). The measured arrival times at successive depths provide pseudo interval Vs profiles for horizontally polarized vertically propagating shear waves.
Shear modulus G and damping ratio D of formation were obtained in the laboratory from Resonant Column tests (RCT), see Figure 6.
In these test sites, in addition to the boreholes and routine laboratory tests, the following tests have been carried out: Down-Hole (D-H) tests, Seismic Dilatometer Marchetti Tests (SDMT), Resonant Column Tests (RCT).

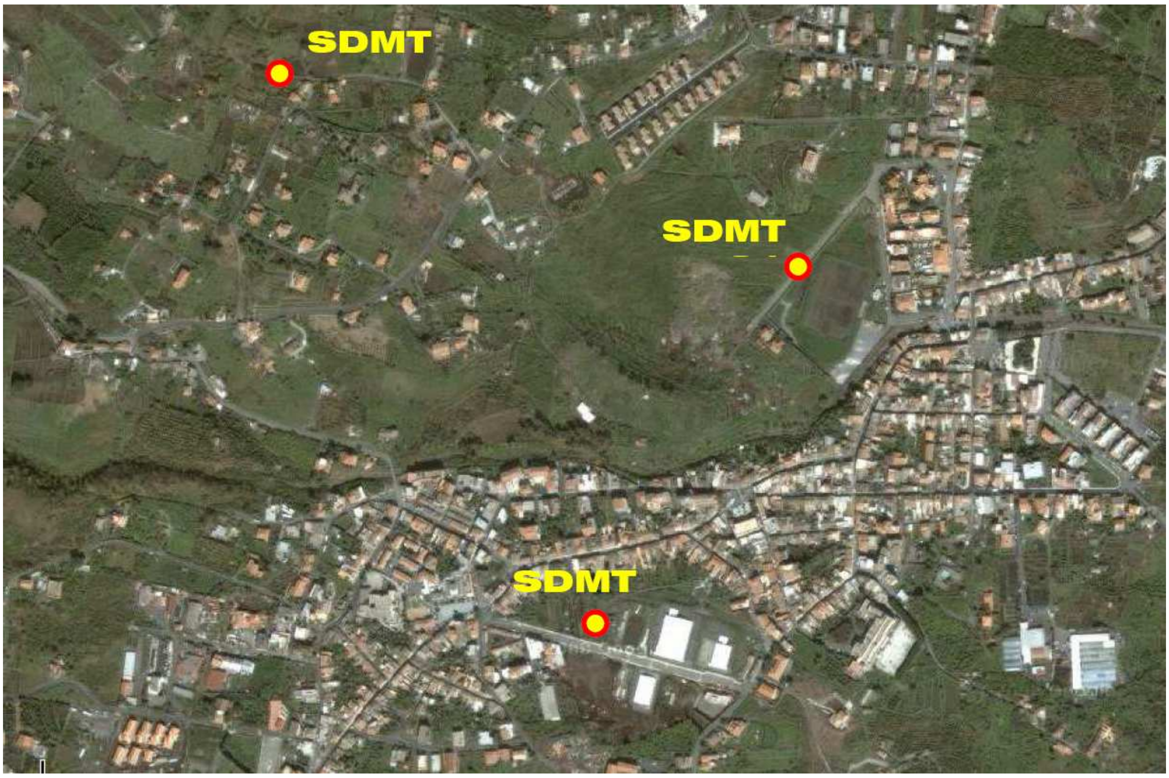
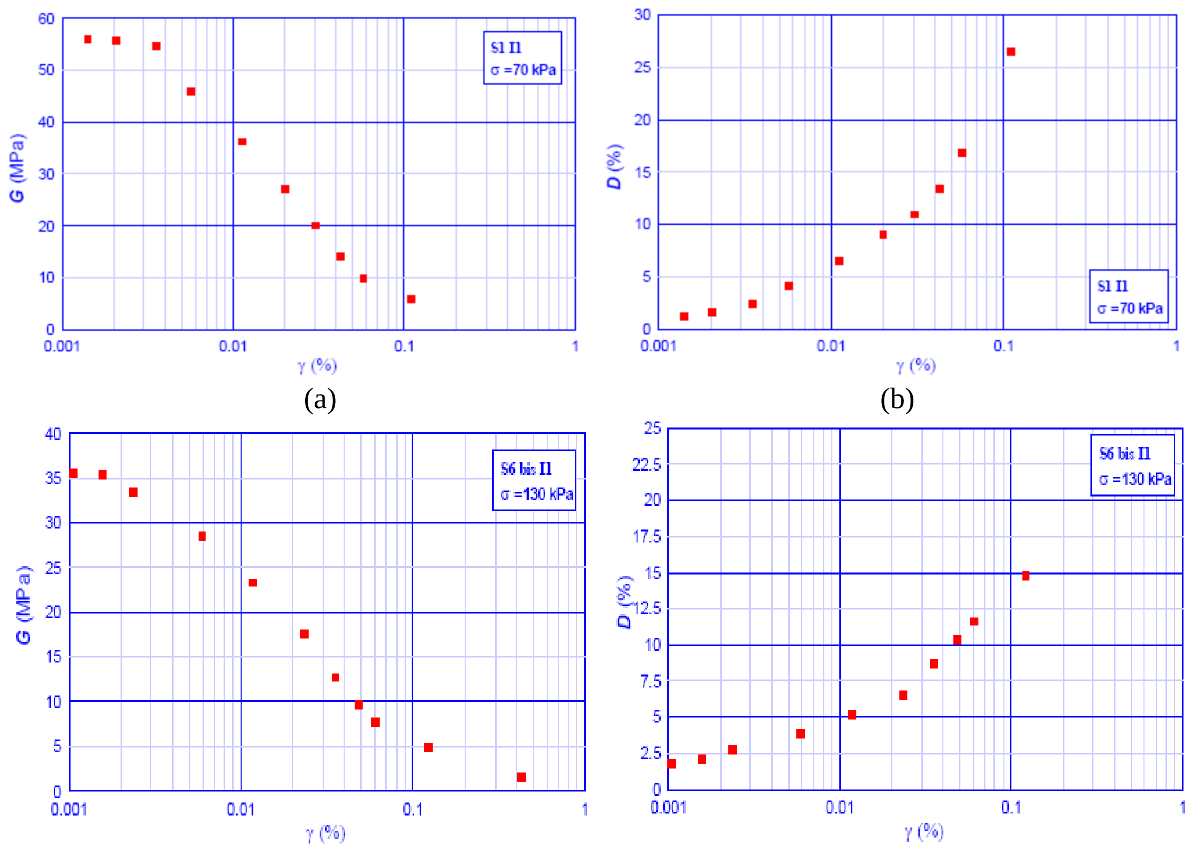


Figure 5. Location of the Seismic Dilatometer Marchetti Tests (SDMTs) in the city centre.



(c) (d)

Figure 6. Dynamic characterization of the test sites: a) Shear modulus G (MPa) of a specimen retrieved in the city area (depth =4.0m); b) Damping ratio D (%) of a specimen in the city area (depth =4.0m); c) Shear modulus G (MPa) of a specimen retrieved in the city area (depth =7.0m); d) Damping ratio D (%) of a specimen in the city area (depth =7.0m).

The undisturbed specimens were isotropically re-consolidated to the best estimation of the in situ mean effective stress. The size of solid cylindrical specimens are Radius = 25 mm and Height = 100 mm.

The experimental results of specimens from Santa Venerina formation were used to determine the empirical parameters of the equation proposed by Yokota et al. (1981) to describe the shear modulus decay with shear strain level:

$$\frac{G(\gamma)}{G_o} = \frac{1}{1+\alpha\gamma^{\beta}} \tag{2.1}$$

in which:

$G(\gamma)$ = strain dependent shear modulus;

γ [%] = shear strain;

α, β = soil constants.

The expression (2.1) allows the complete shear modulus degradation to be considered with strain level.

As suggested by Yokota et al. (1981), the inverse variation of damping ratio with respect to the normalized shear modulus has an exponential form as that reported in Figure 5 for the Santa Venerina formation:

$$D(\gamma) = \eta \cdot \exp\left[-\lambda \cdot \frac{G(\gamma)}{G_o}\right] \tag{2.2}$$

in which:
D(γ) [%] = strain dependent damping ratio;
γ = shear strain;
η, λ = soil constants.
The equation (2.2) assume maximum value Dmax = 8 % for $G(\gamma)/G_0$ = 0 and minimum value Dmin = 0.87 % for $G(\gamma)/G_0$ = 1.

3. GROUND RESPONSE ANALYSIS

The use of advanced methods capable of using accelerograms from local earthquakes can give a valuable insight into the evaluation of a seismic ground motion scenario. This approach has been brought in the present work with the aim of defining the ground motion at the bedrock. The reference events have been the accelerogram of the earthquake of October 29, 2002 (M_L = 4.4) recorded in the city of Catania 31 km far from the epicentre scaled to the site and the accelerogram of October 21, 2005 (M_L = 3.2) recorded in the city of Santa Venerina at the epicentre (see Figure 7).

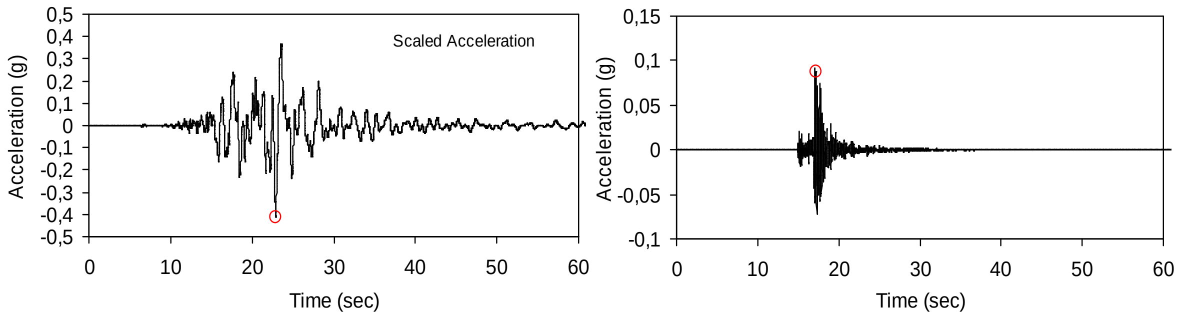


Figure 7. Ground motion at the bedrock: a) accelerogram of the earthquake of October 29, 2002 (M_L = 4.4) recorded in the city of Catania 31 km far from the epicentre scaled to the site; b) accelerogram of October 21, 2005 (M_L = 3.2) recorded in the city of Santa Venerina at the epicentre.

The site response analysis was made by 1-D approach. The code implements a one-dimensional simplified, hysteretic model for the linear equivalent soil response. The S-wave propagation obtained by D-H and SDMT occurs on a 1-D column having shear behaviour. The column is subdivided in several, horizontal, homogeneous and isotropic layers characterized by a non-liner spring stiffness G(γ), a dashpot damping D(γ) and a soil mass density ρ. Moreover, to take into account the soil non-linearity, laws of shear modulus and damping ratio against strain of Figure 6 have been inserted in the code. The 1-D columns have a height of 30 m and of 70 m and are excited at the base by accelerograms obtained from the recording of the local earthquakes (see Figure 7). The analysis provides the time-history response in terms of displacements, velocity and acceleration at the surface. Using this time history, response spectra concerning the investigated site have been deduced. The soil response at the surface was modeled using the linear equivalent computer code EERA (Bardet et al., 2000) for calculus of amplitude ratios and spectral acceleration.

4. MICROZONATION OF THE GROUND MOTION

With the aim to providing ground shaking scenarios as an input for large-scale damage evaluations, an engineering approach based on the use of attenuation relationships was also adopted in the present work. For this method of hazard estimation only the zero period spectral acceleration has been used. Herein, an attenuation relation has been tested; The relations is SJL99 (Spudich. et al., 1999), herein chosen for the simpler treatment of site conditions, simply accounted for through the rock (S = 0) and soil (S = 1) classes. It is calibrated on 142 strong-motion records (26 from Italy) of events in the 5.0 - 7.7 moment magnitude range and 0 - 70 km distance range, and is appropriate for extensional tectonic regimes, such as that predominating in South-eastern Sicily. It makes use of the fault distance, defined as the shortest distance from the surface projection of the fault rupture. As to SEA99, it is a revised predictive relation for geometric mean horizontal peak ground acceleration and 5%-damped pseudo-velocity response spectrum, appropriate for estimating earthquake ground motions in extensional tectonic regimes.

A ground-shaking map for the urban area of the city of Santa Venerina was generated via GIS for the local earthquake scenarios. The shaking description is given in terms of amplification ratio (FA) at the frequency of 5 Hz. Ground shaking scenario has been constructed in terms of FA, to satisfy the demand by the method used to obtain a Grade-3 map of the seismic geotechnical hazard for the city of Santa Venerina, according to the Manual for Zonation on Seismic Geotechnical Hazards (ISSMGE, 1999).

The desired ground motion parameters were computed via GIS at all points of the study area through the appropriate attenuation relation, with a pixel resolution of 120x120 m. In Figure 8 is presented the ground shaking map in terms of predicted FA values for the urban area of the city of Santa Venerina at the frequency value of 5Hz, generated via GIS for the local earthquake scenario by soil response evaluation at borehole sites.

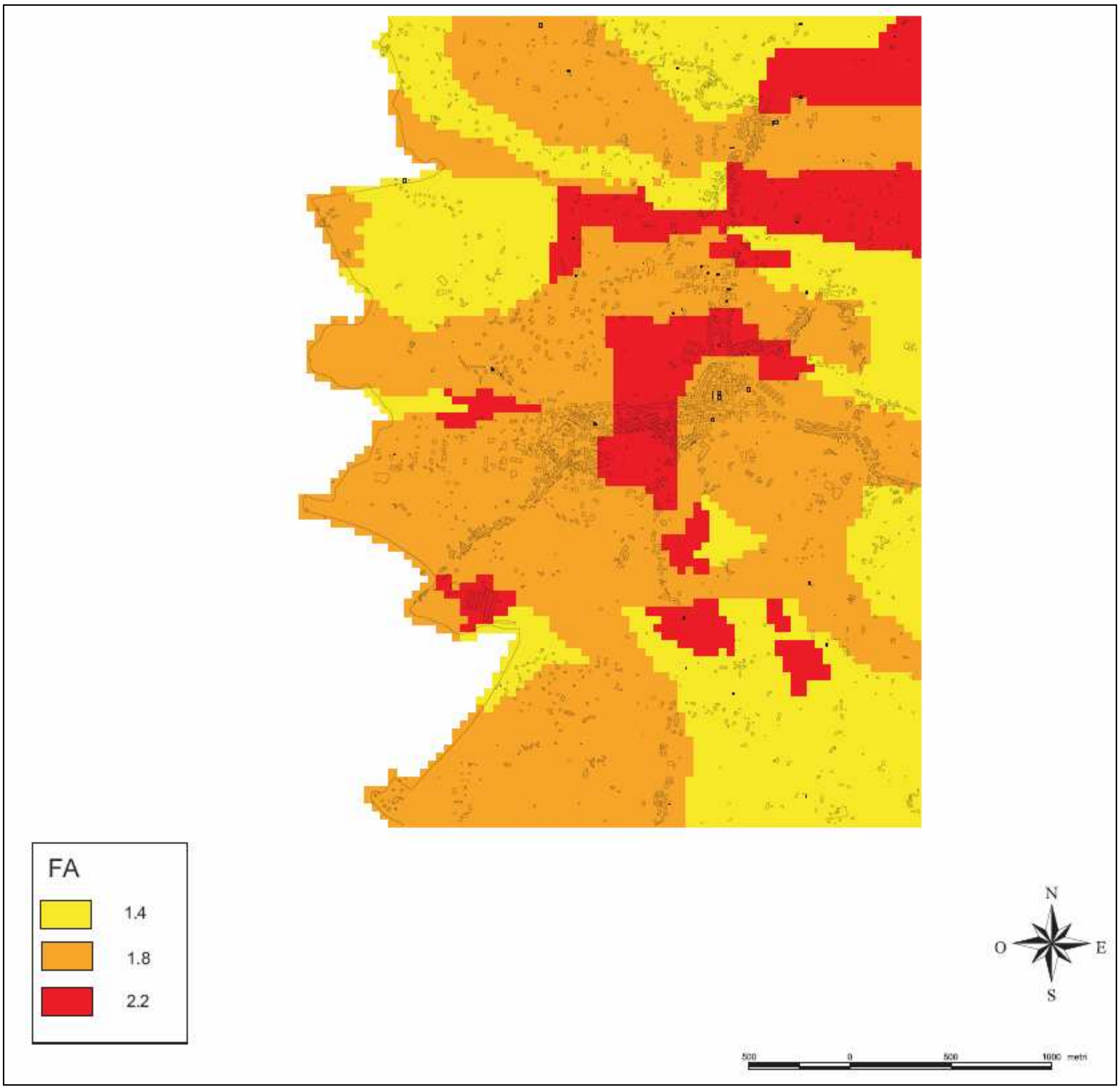


Figure 8. Microzoning map for the urban area of the city of Santa Venerina in terms of amplification ratio (FA) at the frequency of 5Hz generated via GIS for the local earthquake scenario.

5. CONCLUSIONS

On the basis of the proposed method it has been possible to obtain a detailed delineation of the spatial variability in seismic responses, which can be used as an improved basis for seismic microzonation mapping. This method has a clear advantage above the "traditional" way of microzonation because it incorporates any a-priori geological and geotechnical knowledge into the model and can yield microzonation. The spatial variability of the amplification ratio was determined. A ground-shaking map for the urban area of the city of Santa Venerina was generated via GIS for the local earthquake scenario.

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