Post-Emergency, Multi-Hazard Health Risk Assessment in Chemical Disasters
PEC

Deliverable D.A.2

Hazard identification for earthquakes

ECHO/SUB/2015-713844-PREV11 - PEC: Post-Emergency, multi-hazard health risk assessment in Chemical disasters
Project co-funded by ECHO - Humanitarian Aid and Civil Protection

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1. INTRODUCTION

The seismic hazard of an area is, in probabilistic terms, the probability of occurrence of a certain severity of the shaking. This type of assessment therefore considers only the seismic characteristics of an area and assess the ground shaking without considering the structures that insist on the territory.

The seismic hazard analyses have improved considerably in recent years due to the development of sophisticated computer codes, which, together with the multiplied capacity of calculation of the processors now available, make these evaluations possible in a very short time and thus enable to develop models with a high degree of complexity.

In Italy, there is a reference map of seismic hazard for the entire national territory. The National Institute of Geophysics and Volcanology, on behalf of the Major Risks Commission of the Department of Civil Protection, produced it. In 2008 the map has become the reference for the definition of the elastic response spectra that determine the seismic action to consider in the structural design according to the "Technical Standards for Construction" (NTC08, DM 14/01/2008). This document was produced at national level, and, therefore, with a detail that is sometime not enough in relation of area with high exposure like the one here considered.

This study aimed to perform probabilistic estimates of acceleration response spectra at the bedrock, along with hazard maps that describe the expected peak ground acceleration (PGA) for 4 return periods of engineering interest (30, 50, 475 and 975 years) to be used as input for the calculation of the ground shaking a the soil surface. A microzonation study was carried out to define the amplified surface spectra, which account for soil amplification effects. Once the spectra for selected return periods (30, 50, 475 and 975 years old) are known, the hazard curve required to calculate unconditional risk for selected time windows can be defined. The unconditional risk is in fact given by the convolution of the vulnerability, which will be expressed by means of fragility curves, and the seismic hazard that will be expressed by means of the hazard curves obtained from the spectra described in this deliverable.

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2. SEISMIC HAZARD

An ad hoc probabilistic seismic hazard was undertaken by INGV, who was partner of EUCENTRE in a project undertaken on the selected area. Therefore, PEC will have access to an ad hoc probabilistic seismic hazard, situation that is quite rare in Italy where the reference is quite always the national seismic hazard.

The probabilistic evaluation of acceleration response spectra was performed using the 2007 release of CRISIS software, an open source and freely distributed code developed by the Autonomous University of Mexico (Ordaz et al., 1999). The code is essentially based on the standard approach of the probabilistic assessment of seismic hazard (Cornell, 1968). It allows to use two different models of seismic hazard: the “Poisson” (i.e. the events are independent with each other and the release mode is constant in time) and the “characteristic” pattern (which is applied to seismogenic faults for which the release of energy through earthquakes of predetermined magnitude and return period is known).

In this type of analysis the input elements are: a seismogenetic model where each zone has a rate of seismicity, a catalog of earthquakes from which completeness intervals are defined, an attenuation relationship that gives the ground shaking as a function of magnitude and epicentral distance.

A well-established standard at international level for the estimation of the seismic hazard (SSHAC, 1997) based on a logical tree approach was followed to consider all possible alternatives in the selection of models. The epistemic uncertainties in the estimates produced from the selection of each option are assessed. Particular attention was paid to the selection of the alternative source models, in order to take into consideration the most recent and reliable research results in the field of seismotectonic. 4 alternative models have been considered (Figure 2-1). The boundary conditions are described by the ZS9 model (Meletti et al., 2008), i.e. 6 source areas (929, 930, 932, 933, 934 and 936), each defined by geometry, seismicity rate and prevalent fault mechanism. The differences between the 4 models are related to the seismotectonic characterization of eastern Sicily according to the following scheme:

1. ZS9: in this case the seismicity of eastern Sicily is described by a single source zone (935), exactly as assumed for the construction of the reference seismic hazard map (MPS04, Working Group MPS, 2004);
2. ZS4: In this case, the source zones have been modified (Meletti et al., 2000). including two independent zones: a first zone (401), parallel to the Ionian coastline, which includes all the most disastrous earthquakes structures, recognized to be source of the most disastrous historical earthquakes, with failure mechanisms mostly normal; a second area (402), corresponding approximately with the Ibleo front. This structure is characterized by low energy earthquakes with predominant reverse failure mechanism;
3. ZS9+Monte Lauro: the source area 935 of the model ZS9 is considered together with the compressive structure of Monte Lauro, indicated by the seismogenic sources database DISS (Basili et al. , 2008) as being responsible for the maximum expected earthquake in the area (the earthquake of the 11th of January 1693);
4. ZS9+Malta Slope: this model is similar to that described above, by the slope of Malta is considered instead of the Monte Lauro as being responsible for the most destructive earthquake, including the 11th of January 1693. Malta slope is a well-known structure, which dissects the seabed of the Ionian coast (Azzaro and Barbano, 2000).

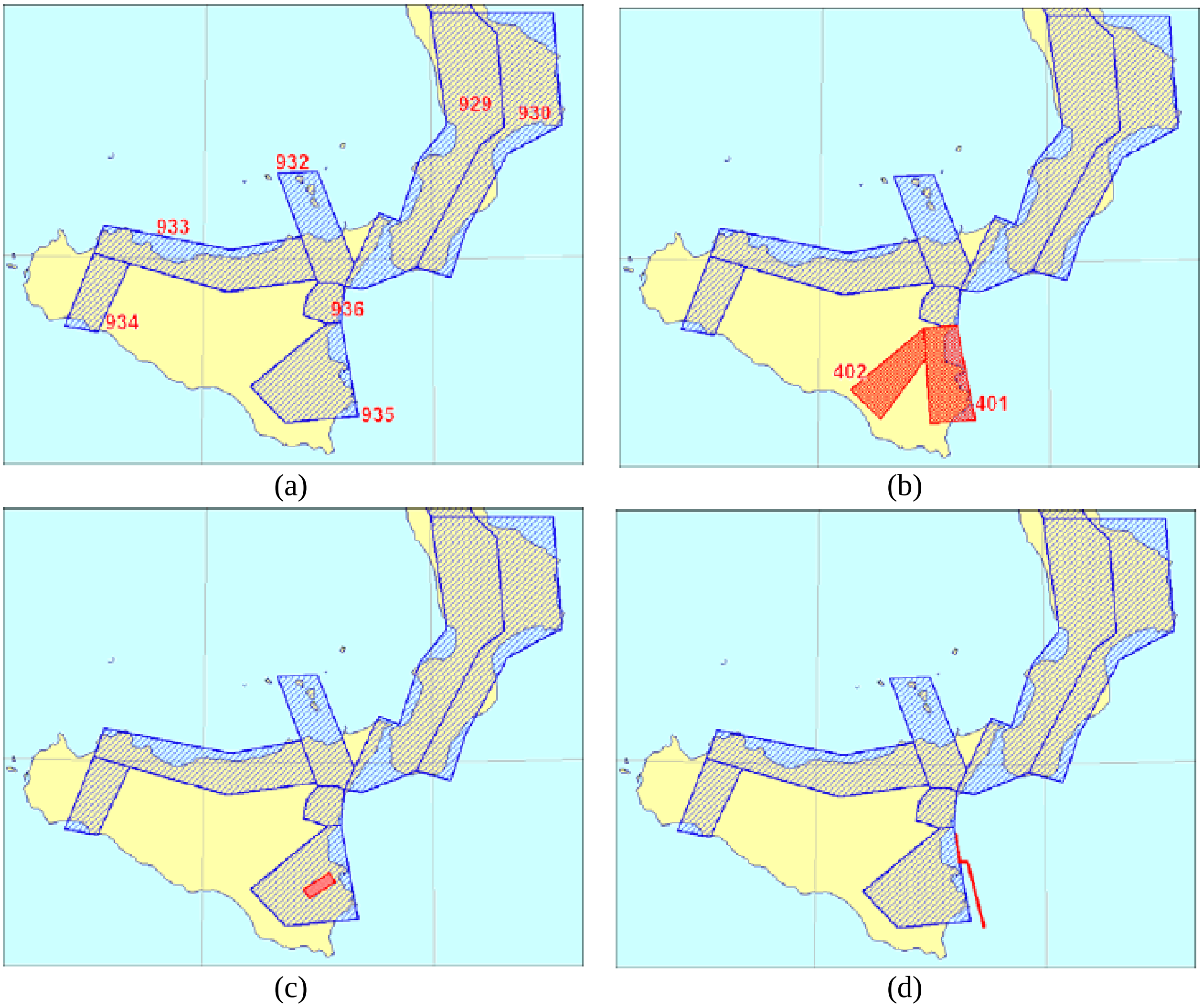


Figure 2-1: The 4 alternative models of source areas adopted in this study: (a) ZS9, (b) ZS4, (c) ZS9+Monte Lauro and (d) ZS9+Malta Slope.

The seismicity rates and the expected maximum magnitude to associate to each individual source were estimated based on the earthquakes parameters catalog CPTI04 (Working Group CPTI, 2004). In this catalog all events above the threshold of the damage occurred in Italy from 217 A.C. up to 2002 are documented. Only the catalog portions considered complete are used. Two completeness criteria have been adopted: the first is based historical criterion, i.e. the catalog is considered complete if the historical source is complete. The second is based on statistic criterion, i.e. the catalog is considered complete on the bases of the stability of the number of earthquakes in the time.

The last input element in the seismic hazard evaluation with the standard approach of Cornell (1968) is the attenuation relationship of ground motions as a function of magnitude and distance from the hypocenter (GMPE, Ground Motion Prediction Equation). In this study, we chose 3 different GMPE. The GMPE used in this study are Akkar and Bommer (2007) and Boore and Atkinson (2008) that are based on data from global datasets; Cauzzi and Faccioli (2008), which mainly use European and Japanese data.

All the different choices described above were used to build the logical tree of possible options, in order to realize all possible combinations of input elements (Figure 2-2). The combination of 4 source models, 2 criteria of completeness of the catalog and 3 GMPE lead to a tree of 24 possible alternatives A weight was assigned to each possible alternative choice.

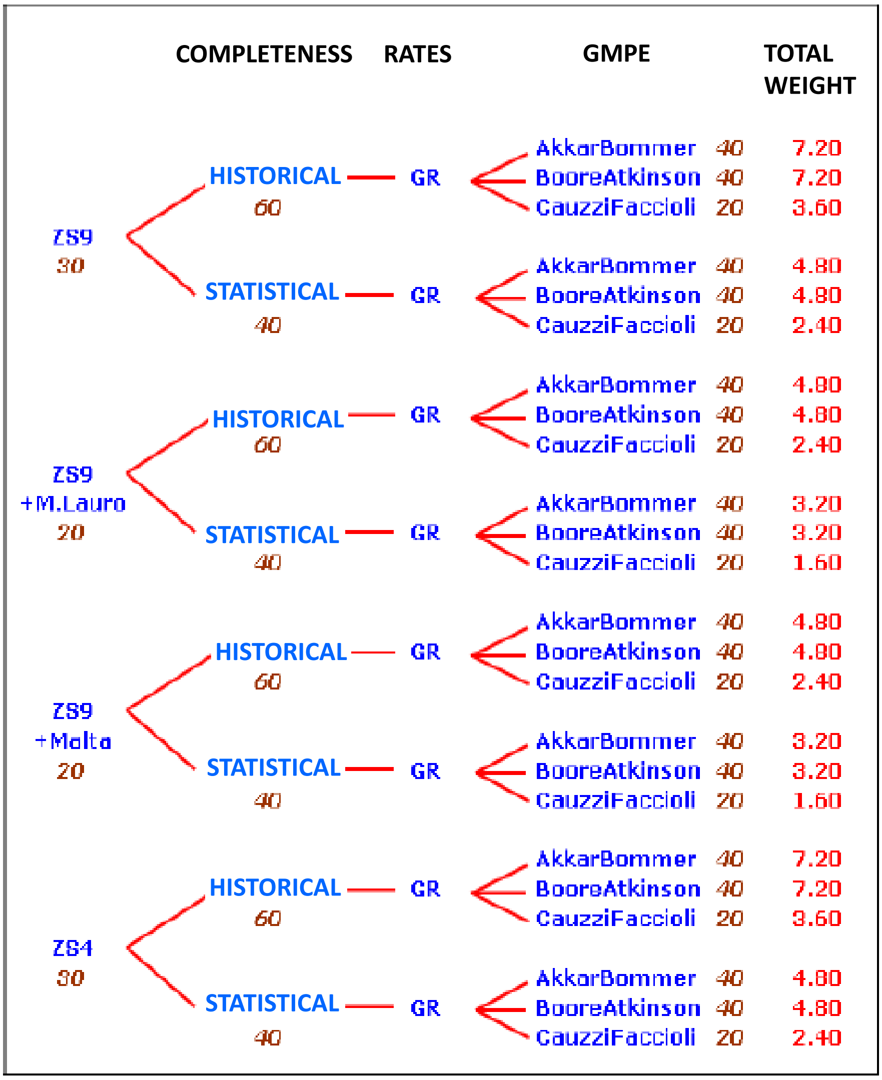
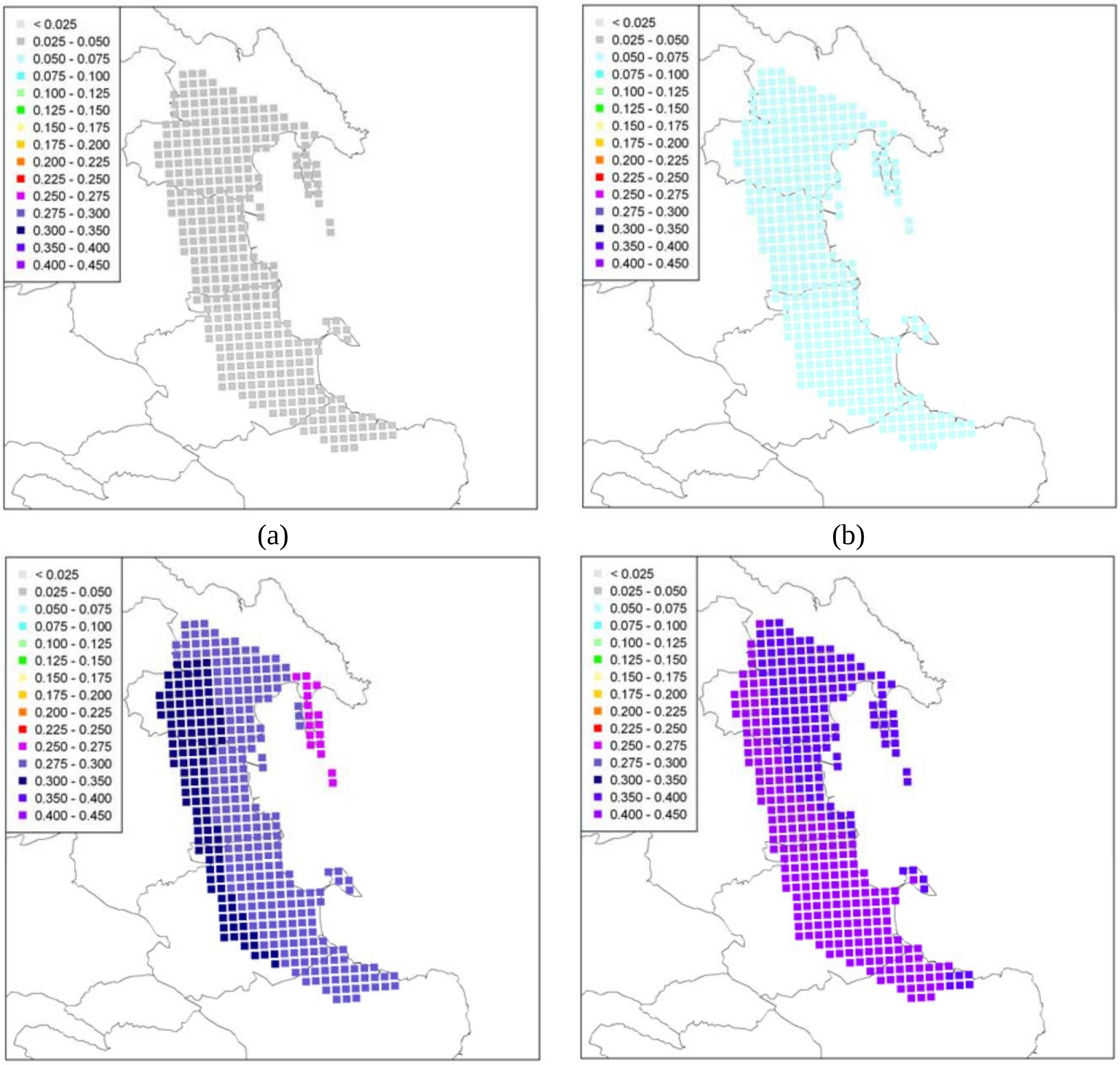


Figure 2-2: Logic tree adopted in this study to evaluate the various alternative options and the epistemic uncertainty of seismic hazard assessment. In brown there is the weight assigned to each option, in red the total weight of each individual branch.

For each branch of the tree, seismic hazard calculation was performed for the points of a regular grid of 382 nodes distributed on the area. For each node of the grid 24 estimates are available. These are combined together according to the given weight. This process led to the evaluation of the median value that represents the final hazard estimation. The estimation of the 16th and 84th percentile represent the uncertainty of the estimation. Overall, for each node of the grid a very large number of seismic hazard indicators, i.e. PGA, spectral ordinates for different return periods, were calculated.

Moreover, for the PGA values a disaggregation analysis, that is the evaluation of the contribution of each possible pair of magnitude and distance values, was performed.

Figure 2-3 shows the PGA values at the bedrock for 4 different return periods. The estimated maximum PGA ranges from 0.05 g (return period of 30 years) and 0.42 g (return period of 975 years).



(a) (b)

(c) (d)

Figure 2-3: Expected values of PGA (in g) for return periods of 30 years (a), 50 years (b), 475 years (c) and 975 years (d).

For each node, the elastic acceleration and displacement response spectra have been produced. 14 spectral periods between 0.05 and 10 seconds have been considered. Figure 2-4 and Figure 2-5 show

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an example of acceleration and displacement spectra for two selected sites, corresponding approximately to the municipality of Augusta and Priolo.

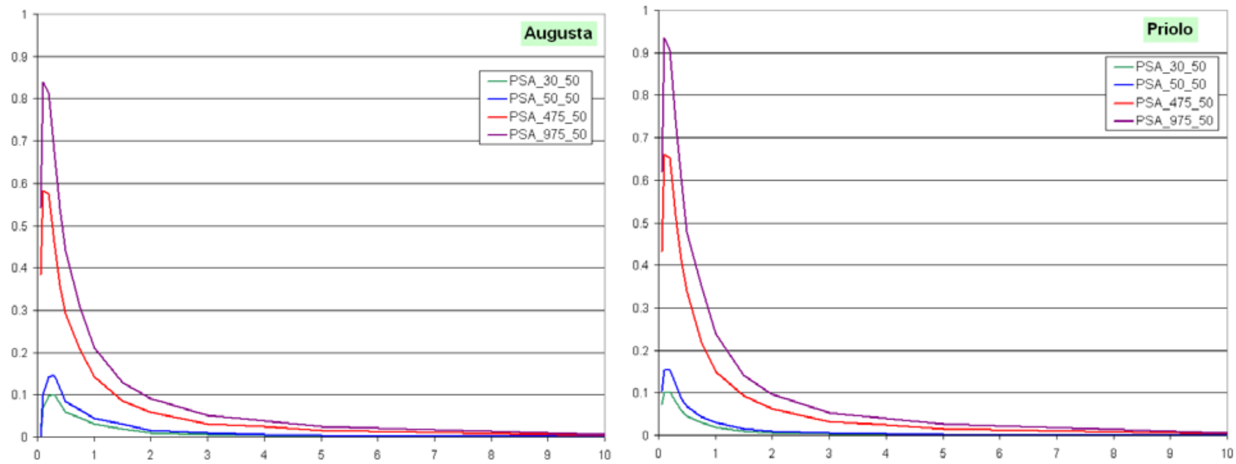


Figure 2-4: Uniform hazard acceleration spectrum for Augusta and Priolo for different return periods. In x the periods (in s), in y the acceleration values (in g).

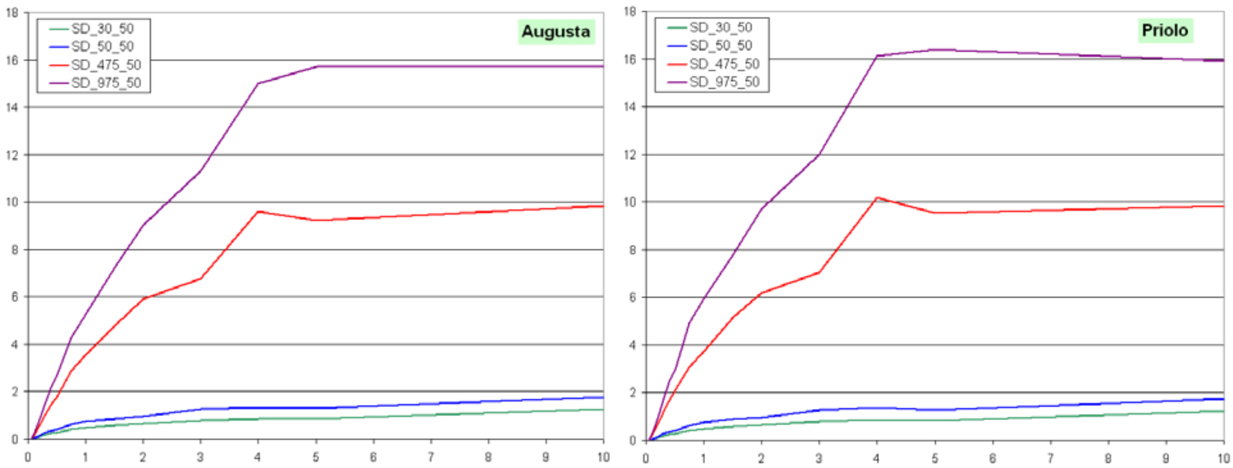


Figure 2-5: Uniform hazard displacement spectrum for Augusta and Priolo for different return periods. In x the periods (in s), in y the displacement values (in cm).

The seismic hazard analysis of the target area of this project is completed with the disaggregation analysis. The contribution of all the possible seismogenic sources to the hazard of a certain site is then considered. Selected a site (i.e. a single node of the grid) and a return period, the exedance probability of the event (magnitude and epicenter) that mostly contribute to the hazard of the site is quantified. The aim of this type of assessment is to evaluate the most probable reference event for a site, in order to search natural accelerograms (or calculate synthetic ones) that match the characteristics defined by the disaggregation.

3. MICROZONATION STUDY

The microzonation study is focused on the analysis of the seismic response in order to amplify the spectra from the bedrock to the ground surface. The first phase was the retrieval of the available data on area, such as geological maps, boreholes data with the stratigraphic profile and previous studies. These have enabled us to frame the geology of the area and to make a first assessment on the site effects that could be of interest in the considered area.

A qualitative preliminary zoning was made by reclassifying the geological map based on lithology and age of different formations. A qualitative zonation map, which shows the level of susceptibility of the stratigraphic amplification, was thus produced. This preliminary zonation is the base for the selection of a mono or two-dimensional model for the numerical amplification analyzes. Other site effects, such as topographic amplification and liquefaction were considered negligible.

Geological model

A three-dimensional model of the subsurface geology is built. The preliminary model was defined considering five Lithological Units Techniques (ULT). The input for the 3D model are borehole stratigraphic profiles that Eucentre collected.

A campaign of seismic environmental noise is available and this data have been used in order to validate the results obtained with the preliminary model. Nakamura technique (Nakamura, 1989; Nogoshi and Igarashi, 1971) was selected to identify the fundamental vibration frequencies of the soil using the relationship between the horizontal component of the spectra and the shake vertical component (HVSR, Horizontal to Vertical Spectral Ratio). The data from this campaign, which was undertaken during a project run by Eucentre in 2007, has allowed identifying the most important ULT for the seismic response, validating the interpretation of the borehole stratigraphy and the seismic bedrock depth.

The frequency f_0 of the HVSR peak is related to the pair of parameters Vs (velocity of the S seismic waves) and H (the thickness of the sediment), according to the relation:

$$f_0 = Vs / 4H \qquad (3.1)$$

Using Equation 3.1 an estimation of the average Vs for the measuring points was made obtaining values of Vs close to 600 m/s. The value Vs of 600 m/s was then used to update the deposits thickness for the measuring points of the NSA and the updated geological interpretation using both the lithology of the boreholes and the depth constraint given by the noise measures. In the North area, the preliminary model was generally confirmed with minor modifications. In the southern area, where deep boreholes were missing in the coastal area, the depth of the bedrock obtained from the noise measurements made possible to update the model with important changes.

Numerical analysis

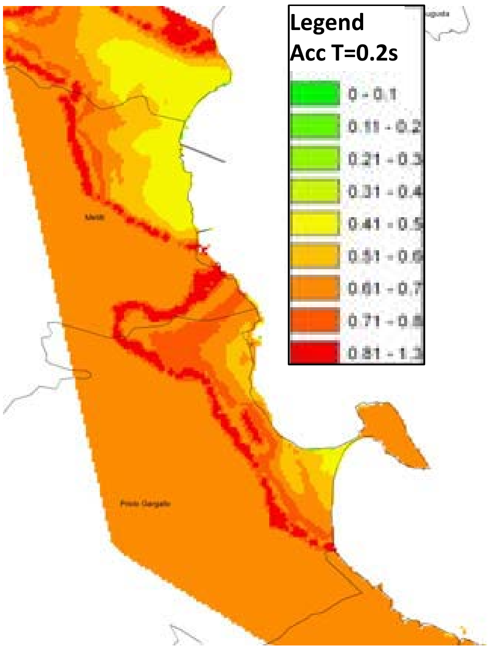
Numerical analysis consist in modeling the real system through reconstruct of geometry, physical and mechanic characteristics of the soil. In this study two calculation codes for the numerical analysis were chosen, the first is one-dimensional and the second is bi-dimensional. The 1D code SHAKE91 (Schnabel 1972) has been used to evaluate the soil stratigraphic amplification for the whole area. The use of 1D model was possible since the topographic amplification effects are negligible or absent and the subsurface geology is quite regular such that soil layers can be treated as a system of plane-parallel layers, especially in areas distant from the faults and the edges of the graben. The 2D code has been used to validate the 1D amplification where the presence of the graben has been a concern for potential 2 D effects.

The 1D amplification analysis was performed on the entire area of interest using SHAKE91, a popular 1D code that allows to get good results through an equivalent linear analysis (Schnabel, 1972; Harraz et al., 2007). The calculations were performed on all the points of a grid with 100 meters step that covers the whole area of interest. For each point from the 3D geological model the stratigraphy and the mechanical properties of the soil layers has been defined. Hence, the 1D amplification analysis has been performed with SHAKE.

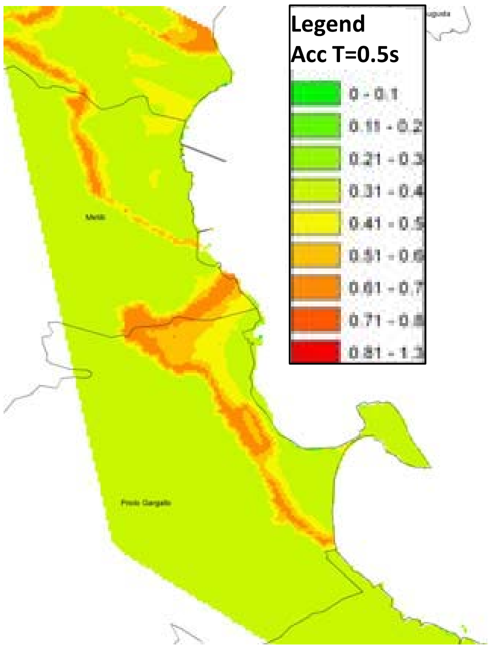
By the numerical simulations is evident that for short return periods (TR=30 and 50 years), these deposits give moderate amplifications at high frequencies, with amplification factors of the order of 1.1 ÷ 1.3, while on the low frequencies the amplification factors reach the value of 2. For long return periods (TR=475 and 1000 years) the highly thick deposits cause de-amplification of the motion at high frequencies, with amplification factors less than 0.8 (for T=0.2s) where deposits have thicknesses greater than 150 meters, whereas at low frequencies the amplification factors increase reaching values between 1.6 and 2 for spectral ordinates between 0.5s and 1s.

Based on the results of the 1D analysis, at high frequencies, strong shaking values are achieved in this area because of the high seismic hazard of the eastern Sicily and potential amplification effects are not a concern, while in the low frequency the amplification effects appear to be dominant.

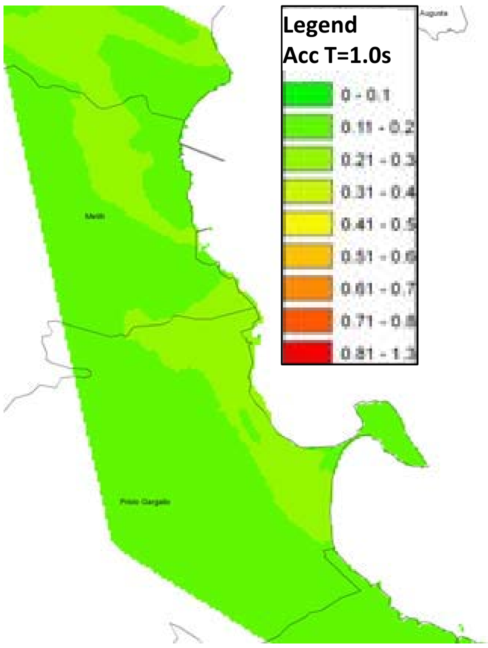
The 2D analysis performed in correspondence of a section of the northern graben substantially confirmed these results. Moderate difference between the 2D and 1D models have been recorded. Hence, the use of 1D model leads to reliable results for the whole area. Figure 3-1 shows an example of the results obtained for the return period of 475 years in terms of spectral acceleration.



(a)



(b)



(c)

Figure 3-1: Maps for return period of 475 years: spectral accelerations in g for T=0.2s (a), T=0.5s (b) and T=1s (c). The higher acceleration values are in correspondence of the higher frequencies, i.e. lower period T (T=1/f).

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