MICROZONATION STUDY FOR AN INDUSTRIAL SITE IN SOUTHERN ITALY

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ABSTRACT :

A microzonation study for an industrial area located in Sicily (southern Italy) has been carried out through an integrated approach using GIS and modelling tools for subsurface geology, together with procedures for soil response estimation. The seismic input was provided by an updated seismic hazard analysis aimed at better defining and characterizing the seismogenic sources active in the region. The approach involved the development of a model of the subsurface geology through the interpretation of several borehole data coming from industrial or private wells records. The lithologies described in the borehole logs were reclassified according to main litotechnical units for which seismological properties were available from previous studies. The reclassified logs were then interpreted using the GSI3D software (Geological Surveying and Investigation in 3 Dimensions), which allows to draw and cross-correlate geological sections over the whole study area, to produce 3D surfaces which model the topography of each litotechnical unit at depth. The model was then imported into a GIS and linked to a customised version of SHAKE91 for the estimation of 1D soil response at a grid of points. Maps of amplification factors for different periods of engineering interest have been produced. The methodology used in this work has produced a dynamic tool which allows an easy update of the microzonation maps as new data become available, since both the subsurface model and the litotechnical units parameters can be quickly updated and new analyses run.

KEYWORDS: Seismic microzonation, local site response, Geographic Information Systems, noise measurements, seismic hazard

1. INTRODUCTION

This paper describes the microzonation study carried out for an area located on the south-eastern coast of Sicily (Italy), between the towns of Augusta and Siracusa. The purpose of the work was to provide acceleration and displacement response spectra at the surface, to be used by engineers as input for the vulnerability analysis of important industrial facilities located in the region. The industrial complex stretches along the coast of the Gulf of Augusta, covering an area of about 40 km^2. Given the large dimensions of the region and the large number of facilities to be analyzed, it was decided to develop an automated procedure for the calculation of soil response, which would allow to save the ground motion parameters of engineering interest in a spatial database covering the whole site. Such database could then be used by the engineers to extract the parameters required for the risk analysis. The implementation of such automated procedure required the development of a sub-surface geotechnical model and the definition of the seismic input on the rock outcrop for the whole study area, and the choice of a computer code which could be easily integrated with the spatial database so to be able at any location of interest to calculate the ground response parameters and save them for the given location.

2. GEOLOGICAL BACKGROUND

The geology of the study area is characterized by a carbonatic bedrock, of Oligocene to Miocene age, lying unconformably on volcanic and calcareous rocks dating from Cretaceous to Eocene. Over this sequence lie the Quaternary deposits, consisting of calcarenites and sands grading up to blue clays (Lower Pleistocene) with on top the biocalcarenites of middle Pleistocene separated from the blue clays by another unconformity (Carbone, 1985). Recent alluvial deposits of gravel, sands and clays of Olocene age close the stratigraphic sequence. All the layers of this stratigraphic sequence dip toward E or ENE at a low angle.

From the structural point of view the tectonic of the study area is characterized by a horst and graben style, with three main zones separated by normal faults with direction from E-W to ESE-WNW. The northernmost area, the Augusta graben, is filled with the largest thicknesses of Lower-Middle Quaternary deposits; the same deposits also fill a smaller graben with limited thicknesses in the central area, just south of the calcareous ridge called 'Costa di Gigia'. In the south of the study area only few meters of calcarenites can be found on top of the limestone bedrock. Part of the geological map showing the structures in the northern and central area is shown in figure 1.

3. SOIL RESPONSE CALCULATION

Several computer codes are available to model the propagation of seismic waves through a soil profile. When the deposits are horizontally stratified, site effects are well modeled with one-dimensional methods, while for more irregular configurations (basins, ridges), two or three dimensional effects can occur. In our case no topographic effects were expected, as the industrial site is mostly located along the coastal plain which has a very gentle slope (maximum 4%). Also the stratigraphic sequence can be assimilated to a horizontally layered deposit, as the strata and the surfaces of unconformity have very low dips, and the two grabens form shallow basins, where the sediment thickness and the layers geometry is uniform away from the edges. Therefore it was assumed that a one dimensional model would work well for most of the area, although some 2D effects could be expected near the edges of the graben.

The computer code chosen for the calculation was SHAKE91, a widely used 1D code which achieves good results using a linear equivalent analysis (Schnabel, 1972; Harraz et al, 2007). To automate the procedure for the ground response calculation the source code was modified so as to be able to interact with a Geographic Information System (GIS). The subsurface model was stored in the form of georeferenced surfaces representing the elevation of the different soil layers. A program written in Visual Basic running within the GIS would read the values from these surfaces to obtain the stratigraphy at a grid of points and save it to a database file. SHAKE91 was then called by the program and the different values needed for the calculations were passed to it as parameters, rather than read from an input file. In this way the code would run for each point of the grid covering the study area, calculating the ground response parameters for different ground shaking return periods, and saving the response spectra for each point into the database.

4. GEOTECHNICAL MODEL

4.1. Subsurface Geotechnical Model

The subsurface geotechnical model was constructed using the GSI3D software (Geological Surveying and Investigation in 3 Dimensions), developed by H.G. Sobisch of the University of Cologne (Hinze et al. 1999; Kessler et al. 2004). With this software the user can combine Digital Terrain Model (DTM), geological surface maps and borehole data to create regularly spaced cross-sections which show the outcrop of the geology at surface and the lithology at depth. The geological interpretation is then hand drawn on these cross-sections, by connecting the units found in the boreholes with the limits displayed by the surface geology. As the interpretation proceeds, automatic cross-correlation between sections allow the geologist to check the integrity of the stratigraphic model throughout the study area. Once the interpretation is completed the software can interpolate the nodes along the sections to produce triangulated surfaces for each geological unit.

For our work we used a 1:50000 geological map and about 200 deep boreholes (>200m), integrated with shallow ones (<20m). We decided to reclassify the formations of the geological map according to 5 main litotechnical units, for which estimates of the shear wave velocities (Vs) were available (L. Tortorici 2000).The geotechnical units are: recent alluvial deposits (a), Upper Calcarenites (Qp), Blue Clays (Qa), Lower Calcarenites (Qc), Bedrock (PEOMc). The geotechnical model was then constructed by interpreting the borehole logs accordingly, and interpolating the three-dimensional surfaces of these 5 units. An example of the interpretation and of the boreholes coding is shown in figure 1.

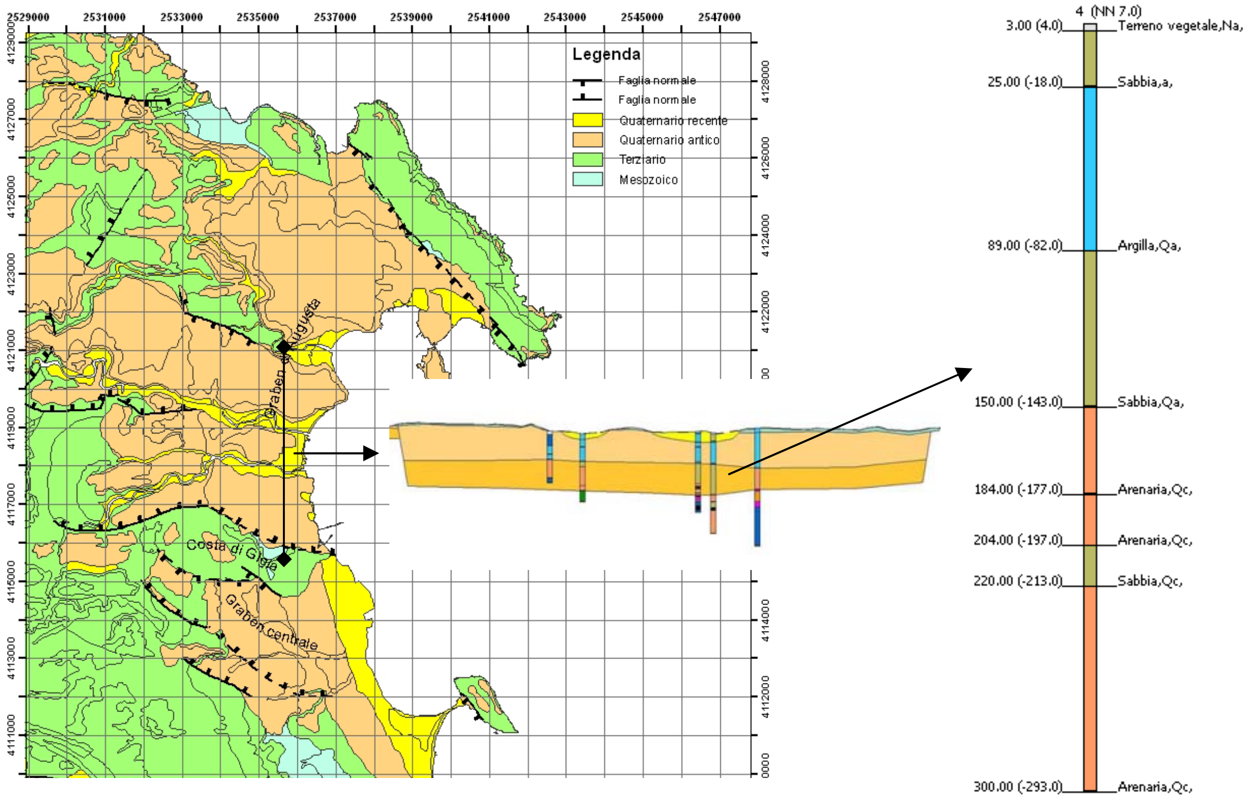

Figure 1. Sketch of the geological map detailing the northern area, with one interpretative cross-sections. The borehole log shows the lithologies and their reclassification in geotechnical units (a, Qa, Qc).

4.2. Noise Measurements and Validation

The depth of seismic bedrock has been validated using the data collected during a campaign of noise measurements. The measures of environmental noise provide the resonant frequency of a soil deposit (f0) and give indications about the average shear wave velocity and thickness of the deposits, since the resonant frequency is equal to the soil S-wave velocity over four times the deposit thickness. The data were collected using Lennartz LE3D-5sec sensors, coupled with a 24 bit Reftek 130-01 acquisition system. For each measure a 30 minute signal was recorded, with a sample frequency of 100 Hz. The points of measure were selected so that different lithologies and soil profiles could be sampled, choosing locations at or close to good quality borehole logs. This allowed us to verify the units which could amplify the reference input motion and to check the estimate of average S-wave velocities obtained from the literature. Using these values we also checked the geometry of the subsurface model in locations where the interpretation was more uncertain because of a lack of deep borehole data.

The preliminary results of the noise measurements campaign are shown in figure 2, where the sample points and an automatic interpolation of the f0 are shown. The data confirm the presence of deep deposits in the northern area (low values of f0), reaching up to 200 m of thickness, and a deepening trend of the series toward the ENE. The most important litotechnical unit in terms of soil response seems to be the blue clays, with an average shear wave velocity of 600 m/s, while the upper and low calcarenites, which in the literature had S-wave velocity of 350-400 m/s, appear to behave as bedrock.

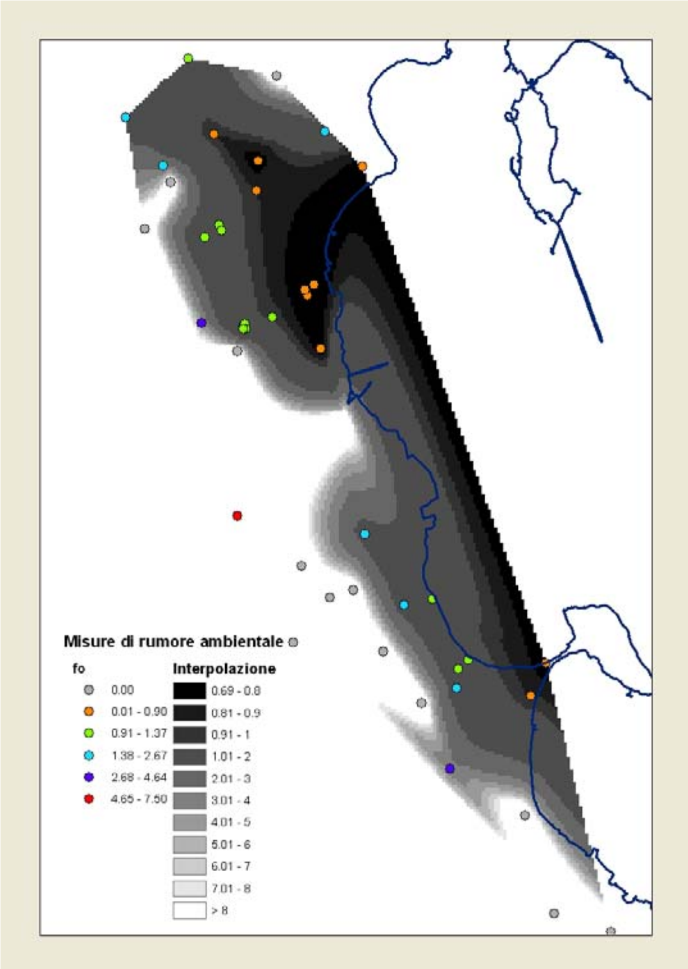

Figure 2 Preliminary results of the noise measurements campaign. The depth of seismic bedrock is inversely proportional to the fundamental frequencies f0. A value of f0 = 0 indicates rock at outcrop.

5. SEISMIC HAZARD

A detailed probabilistic seismic hazard analysis (PSHA) was carried out based on the most updated data available in the literature, particularly concerning the characterization of regional seismic sources and ground-motion attenuation properties. The aim of the analysis was to provide acceleration and displacement response spectra on rock together with hazard maps for peak values of ground motion (PGA and PGV) for 4 different return periods (30, 50, 475, 975 years) to be used as input for soil response calculation.

Computations were performed by using the 2007's version of CRISIS an Open Source code (Ordaz et al., 1999), essentially based on the standard Cornell's approach to PSHA, which admits two types of seismicity models: Poissonian or characteristic. The input elements required for the analysis are: a source zone model with each zone characterized in terms of seismicity rates, an earthquake catalog with relevant completeness time-intervals, a ground-motion predictive equation as function of source energy and distance. According to current international conventions for PSHA (SSHAC, 1997), a logic-tree approach was followed to consider and evaluate the epistemic uncertainties which affect hazard estimates and derive from different possible choices of the input elements.

Special care was devoted to define alternative source zone models to take into account the most recent evidences on regional seismotectonic setting. In particular, the following 4 alternative models (figure 3) were considered, which share the 6 zones (geometry, seismicity rates, predominant style of faulting) defining the boundary conditions of the study area and deriving from the ZS9 source zone model (Meletti et al., 2008), while differ one from each other in the seismotectonic characterization of the south-eastern Sicily area:

1. ZS9: the same source zone (935) defined for the present reference seismic hazard map of Italy (MPS04: MPS Working Group, 2004) is assumed;
2. ZS4: 2 separate zones (401, 402) are considered (modified from Meletti et al., 2000), the former along the Ionian coast of Sicily, which includes the largest mainly normal-fault earthquakes of the area and the latter, roughly corresponding to the Iblean front, which is characterized by less energetic mainly reverse-fault events;
3. ZS9+Monte Lauro fault: zone 935 of model 1 is retained but, according to the DISS database of seismogenic faults (Basili et al., 2008, also available at http://www.ingv.it/DISS), the earthquake of 11 January 1693, which is the largest event (Mw=7.41 in CPTI Working Group, 2004) known to be occurred in the area (and in whole Italy too), is assumed to be related to the Monte Lauro compressional fault;
4. ZS9+Malta Escarpment fault zone: the same as model 3 but, in this case, the 1693 earthquake is attributed to the larger offshore estensional tectonic structure known as Malta Escarpment (Azzaro et al., 2000).

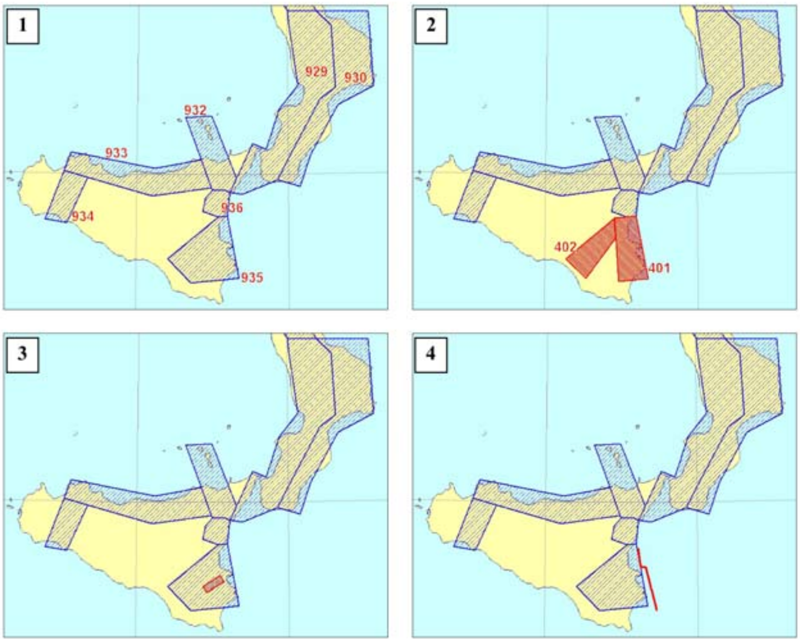

Figure 3 The 4 alternative source zone models considered for PSHA.

For models 3 and 4, a characteristic behavior was assumed for the two faults considered; seismicity rates of zone 935 were thus reassessed with respect to the original values of the MPS04 reference hazard map (here adopted in model 1), since highest magnitude events (like that of 1693) are linked to one of the two faults.

Seismicity rates and maximum magnitude values to be associated to each source zone were assessed from the CPTI04 catalog (CPTI Working Group, 2004), which lists the damaging events (M≥4) occurred in Italy since 217 B.C. up to 2002. Only those portions of the catalog which resulted complete for different magnitude ranges were considered. To this purpose, 2 alternative sets of completeness time-intervals (one assessed from historical considerations and one from statistical analysis) were used, which are those derived for the MPS04 hazard map.

As concerns the last input element, i.e. ground-motion predictive equations, 3 recent alternative models were taken into account: Akkar and Bommer (2007a,b), Boore and Atkinson (2008), Cauzzi and Faccioli (2008). The 3 models were defined from different strong-motion data sets (European and Middle East for the former model, World for the other two) and predict different shaking parameters: peak values of ground acceleration and velocity (PGA, PGV) and response spectra in acceleration or displacement (PSA or SD) for different spectral periods. All models use moment magnitude and source distance (Joyner-Boore distance for the first two models, focal distance for the latter) as explanatory variables together with style-of-faulting and site class. For all models, only rock-site condition was considered in this phase.

All the above computational choices were used to build the logic-tree structure. Thus the alternative input elements were combined into a logic tree made of 24 branches, each characterized by a weight representing the reliability of relevant choice. Seismic hazard was computed for each branch; resulting median value represents the reference hazard estimate and relevant uncertainty is quantified through the 16th and 84th percentiles. Figure 4 shows the PGA and PGV values on rock with exceedance probability of 10% in 50 years (475-year return period) computed at 382 nodes of a regular grid covering the study area. The estimates vary in the range 0.26-0.31 g for PGA and 15-19 cm/s for PGV.

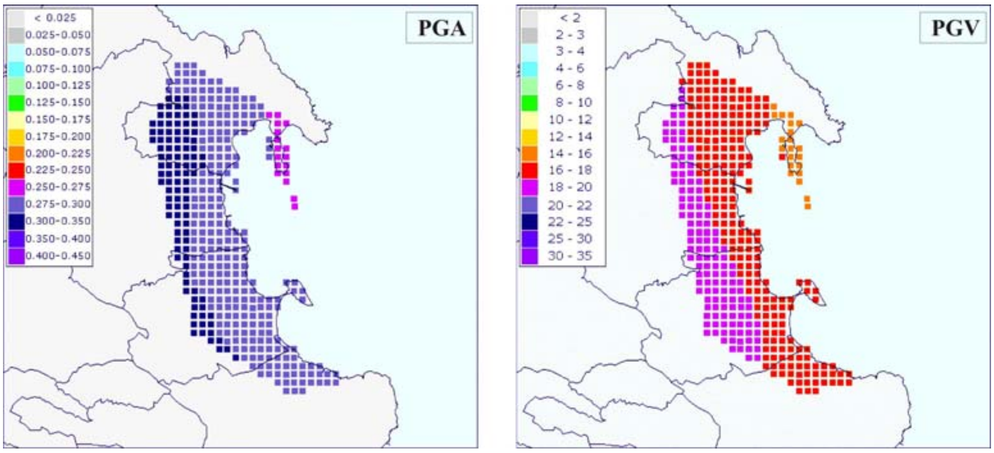

Figure 4 Expected values of PGA (g) and PGV (cm/s) for return period of 475 years.

At each site of the computational grid, response spectra in acceleration and displacement at rock-site condition were then computed in the range 0.05-10 seconds (for 14 spectral periods) for the 4 return periods considered. Figure 5 displays an example of resulting uniform hazard spectra for the site of Priolo.

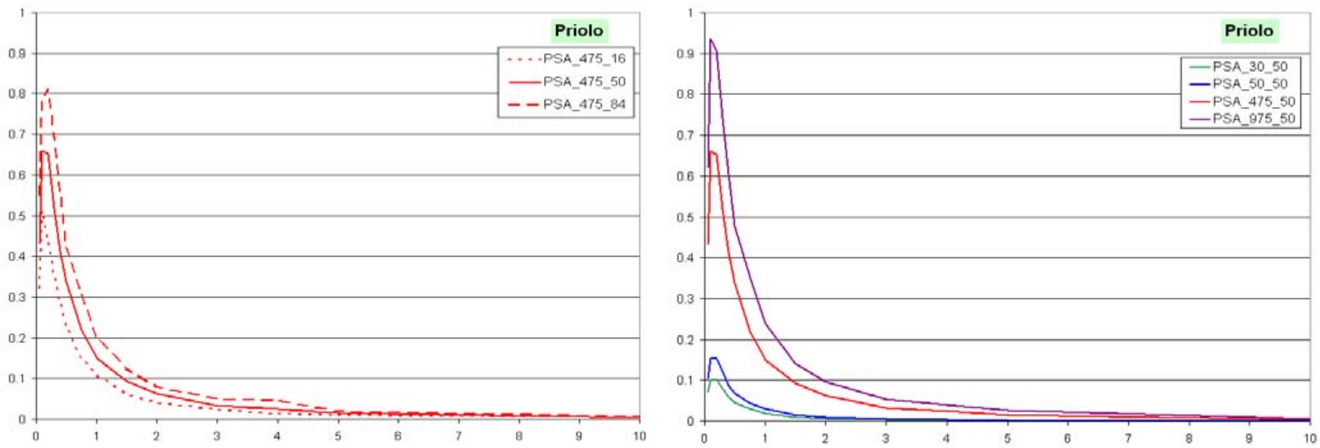

Figure 5 Acceleration response spectra on the rock outcrop (g). 16th, 50th, 84th percentiles for 475-year return period (left) and median spectra for the 4 return periods (right).

6. DISCUSSION AND CONCLUSIONS

We have developed an automated procedure to obtain the transfer functions and 5% damped acceleration and displacement response spectra at surface for a large industrial area using SHAKE91 within a GIS. The implemented system is able to read the soil profile at each point of a grid with a 100 meter spacing from a subsurface geotechnical model stored in the GIS in the form of surfaces representing the elevation of the different litotechnical units. The code uses as seismic input seven accelerograms compatible with the uniform hazard spectra calculated on the rock outcrop for different return periods. An example of the output obtained is shown in figure 6.

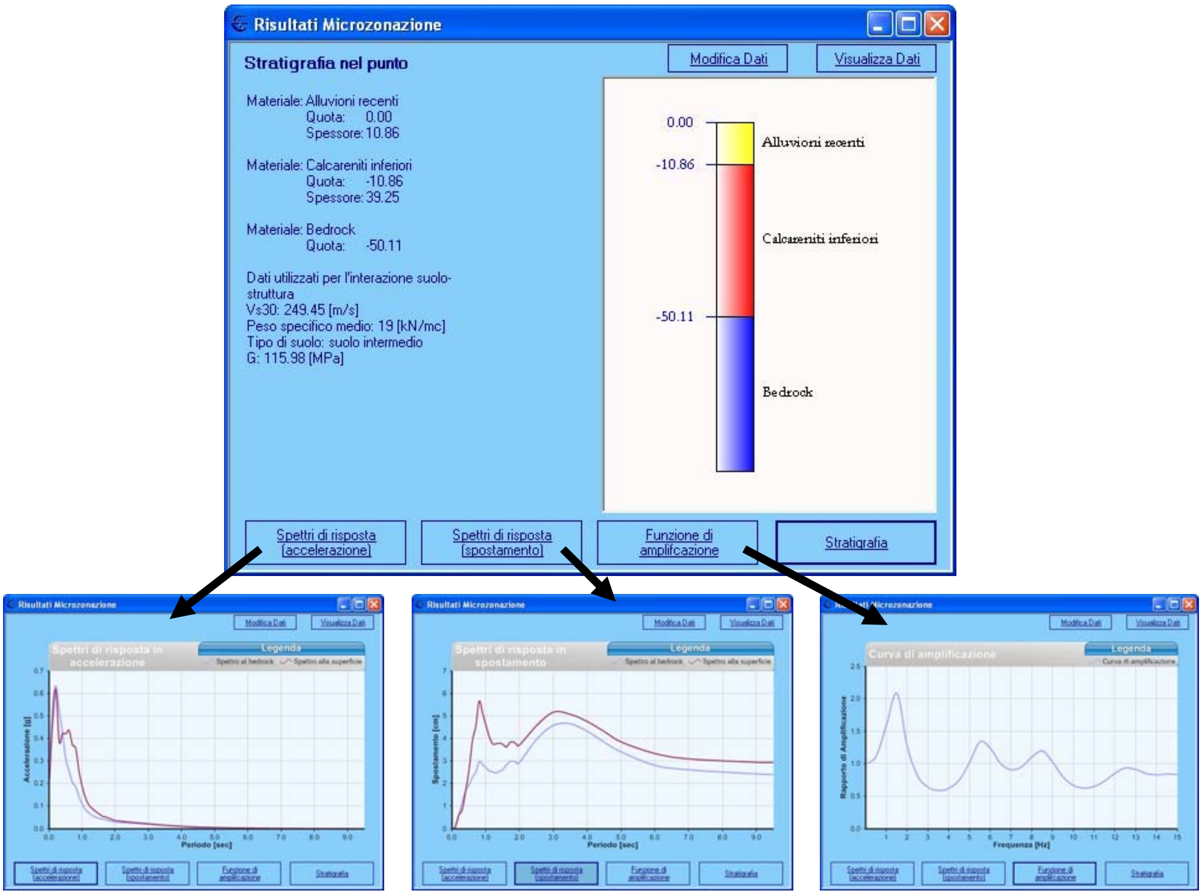

Figure 6. Example of output from the GIS, showing the soil profile, the response spectra in acceleration and displacement and the soil transfer function.

The probabilistic seismic hazard study which has provided the seismic input for this work has taken into account new research on the faults affecting the seismicity of eastern Sicily, in particular the Malta escarpment, and has used ground motion prediction equations specific for this area. Further work is in progress to produce a deterministic shaking scenario modelling the great earthquake of 1693, one of the most destructive earthquakes that occurred in this region, whose source is thought to be the Malta fault. The geotechnical model has been created using a software for geological interpretation in 3 dimensions, integrating data from surface geology, boreholes and geophysical investigations. As new data on the seismic input or on the soil model become available the spatial database can be easily updated and the whole calculation can be run again, updating the risk maps for the industrial facilities.

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