Applied Geophysics for Engineering

1st international conference

Messina, Italy

Osservatorio Sismologico

UNIVERSITÁ DEGLI STUDI DI MESSINA

Elaboration of GIS based multidisciplinary data for microzoning studies

By

Papadopoulos T.D., Voulgaris N. and Alexopoulos J.

Abstract

The elaboration of analytical microzoning studies involves a multidisciplinary approach comprising geological, geotechnical, seismological, geophysical and dynamic soil analysis data. In an attempt to incorporate the maximum available amount of information and in the view of the continuously expanding use of GIS, as a tool for analyzing and integrating data, a new software environment called AUTO-SEISMO-GEOTECH has been developed for handling these multi-parameter data. This user friendly package is presently implemented for the cities of Heraklion (Crete island) and Thiva (province of Beotia) in Greece.

The pilot methodologies applied in these urban areas, aimed also at determining a minimum package of tasks/methods needed for the elaboration of a microzoning study, are described and evaluated here. Next, a data bank with appropriate architecture was formed in order to handle all available geo-information for each city separately and produce thematic maps, such as geological, tectonic, hydrogeological, seismic hazard and microzonation ones. These maps can be easily reproduced, integrated and be used for building safer constructions contributing so to mitigation of earthquake consequences.

Geo-information obtained by a) existing regional seismicty maps and installation of local portable seismographic networks around in both cities, to monitor the microseismic activity and define possible active fault zones, b) geological mapping of the broader urban area in scale 1:5000, c) evaluation of existing geotechnical data as

well as new data coming from boreholes, d) geophysical data resulted from surface and borehole techniques, for Vp, Vs and dynamic elastic parameters estimation and e) consideration of historical seismological data for seismic hazard estimation, have been incorporated in this GIS based platform, to be easily handled for further use. The output of this information combined with the dynamic soil analysis produces detailed microzonation maps. Such maps are valuable in city planners and urban designers.

Introduction

During the last two decades microzoning studies in Greece have been considered as a primary tool towards seismic risk mitigation. Such studies were usually carried out in cities that had previously suffered severe damages as a result of a strong earthquake, or in areas that are characterized by high seismic risk. By definition microzonation studies require a multidisciplinary approach based on geological, geotechnical, seismological, geophysical dynamic soil analysis methodologies while the final product is usually expressed as a map or series of maps providing detailed information for strong motion amplification and frequency content in the investigated areas. However, the application of various methodologies from the different fields of geosciences, although required in order to guarantee a successful approach, is linked to a large volume of non-uniform data creating information management, analysis, integration and evaluation problems. Due to the inherent spatial attributes of the data a Geographical Information System (GIS) platform coupled with a user friendly environment represents the best possible solution to this problem. AUTO-SEISMO-GEOTECH represents such a multidisciplinary microzonation environment presently implemented for the cities of Heraklion (Crete island) and Thiva (Beotia) (figure 1). Designed with the characteristics of an open system AUTO-SEISMO-GEOTECH provides the possibility to integrate additional data as they become available, while already existing geoinformation can support additional environmental tasks in the same areas.

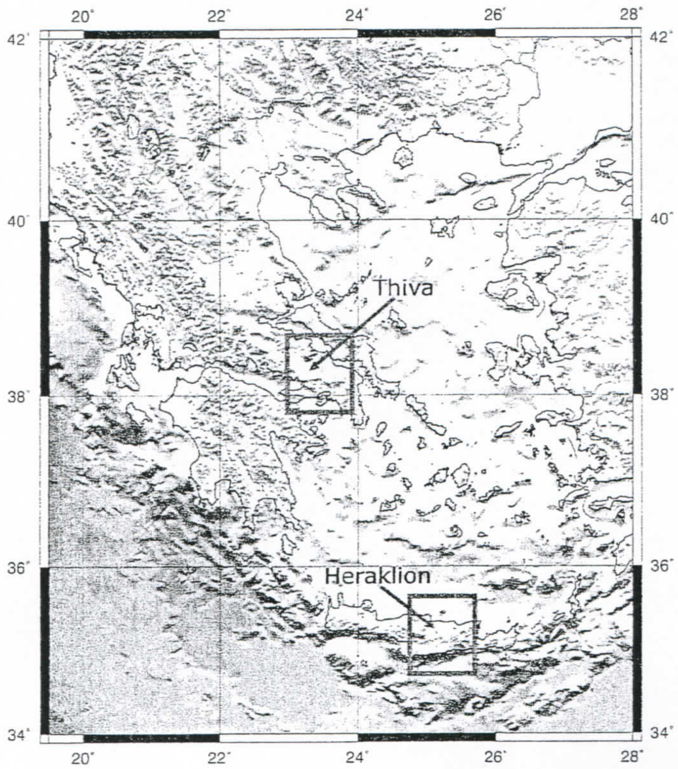


Figure 1. The two investigated areas.

System Architecture

The architecture of the AUTO-SEISMO-GEOTECH can be better understood if the system is examined from a GIS point of view in terms of layers, while several layers can also be combined in groups based on their common characteristics or origins. Processing and analysis of a given layer or layer combinations can produce new layers and so forth (figure 2).

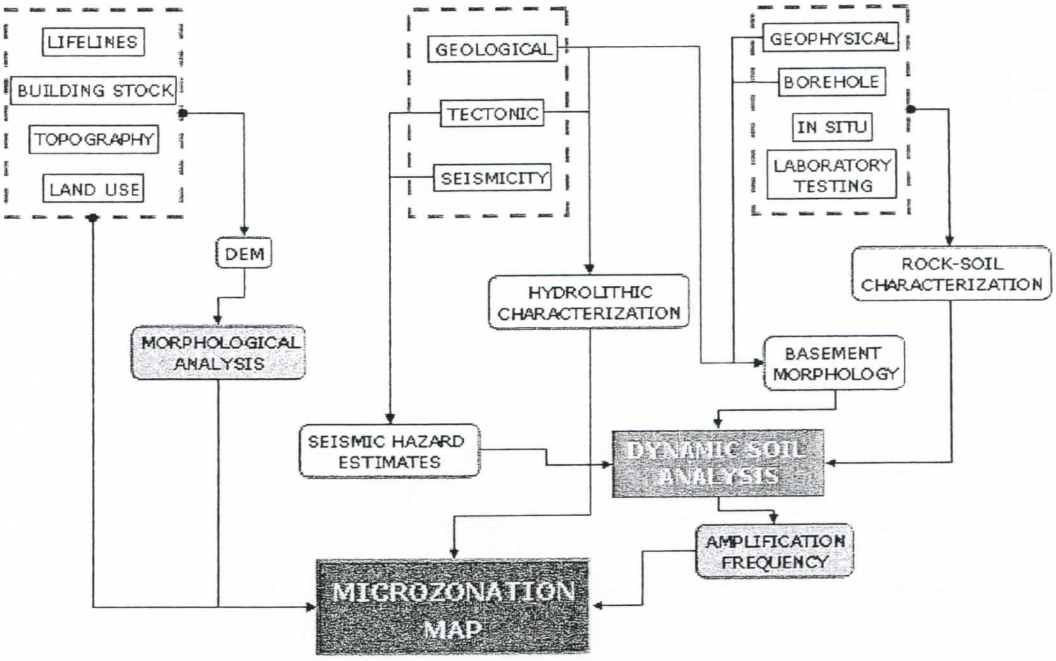


Figure 2. The AUTO-SEISMO-GEOTECH. GIS based architecture.

The first group is formed by all layers corresponding to the basic type of data that are expected to be available for the area under investigation such as topography, building stock, road and lifeline networks (using a scale of 1:5000). This initial group forms the basis of the system and must be therefore created beforehand. Morphological element analysis and Digital Elevation Models (DEM) could represent some of the resulting layers for this first group.

In the second group layers resulting from geological, tectonic, seismicity and seismic hazard studies are included. Hydrolithic, rock-soil characterization (borehole data and in situ measurements) and geotechnical mapping could be some of the resulting layers in this group.

The third and final group contains all these layers that are associated with extensive field work operations aiming at determining the basement morphology as well as the spatial and depth variations of rock properties and elastic constants (Young moduli etc) in the investigated areas. Furthermore, location map layers of geophysical measurements and boreholes "hot" linked to the actual data and interpretation logs could provide the most efficient method for organizing and archiving measurements. In this case these "location" layers should be considered as initial or main layers while basement morphology, or rock property represent resulting layers.

The three main layer groups with the corresponding resulting layers have been described above. However, for the next level of operations where dynamic soil analysis is carried out combination of data from the second and third group is required. The same applies for the compilation of the microzonation map with the required addition of layers also from the first group.

Multi-parameter data management

The system architecture described previously was the basis for developing the AUTO-SEISMO-GEOTECH platform for handling non graphical (tables, etc.) and graphical (maps, etc.) simultaneously. "Hotspot" definition techniques were used in order to provide the links necessary for displaying data and results obtained by the different studies while continuously operating within the GIS environment.

The actual development of the platform was carried out in parallel with field operations and research activities in Heraklion where initial testing was performed. Additional tests were carried out in Thiva area and the results were introduced in the basic environment that was already developed, thus providing an opportunity for evaluating the flexibility of the system and its adaptive capabilities.

A combined example for the first layer group including topographic relief, building stock and roads for the city of Heraklion is given in figure 3. As mentioned previously slope and aspect maps can be constructed based on this primary data layers.

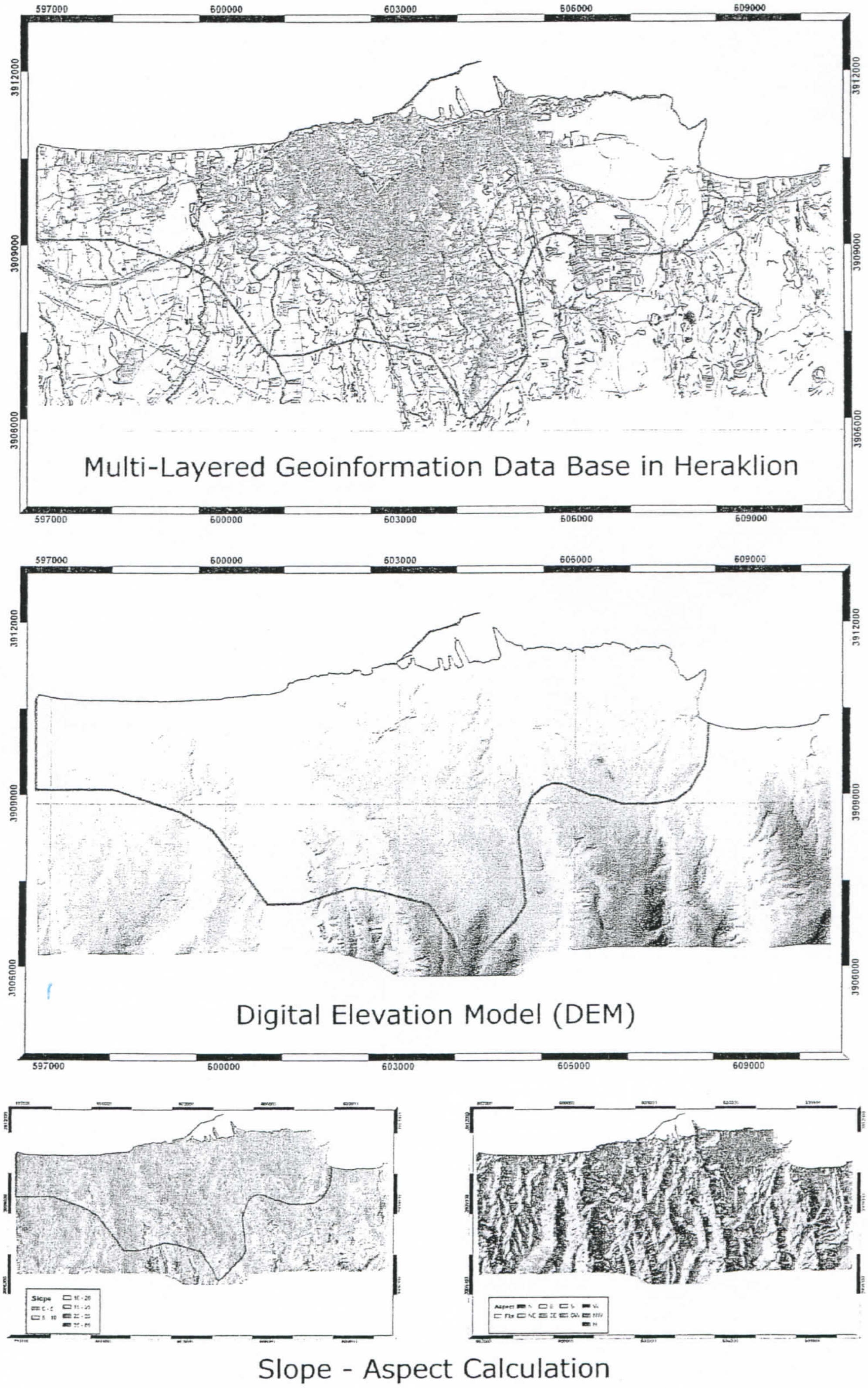
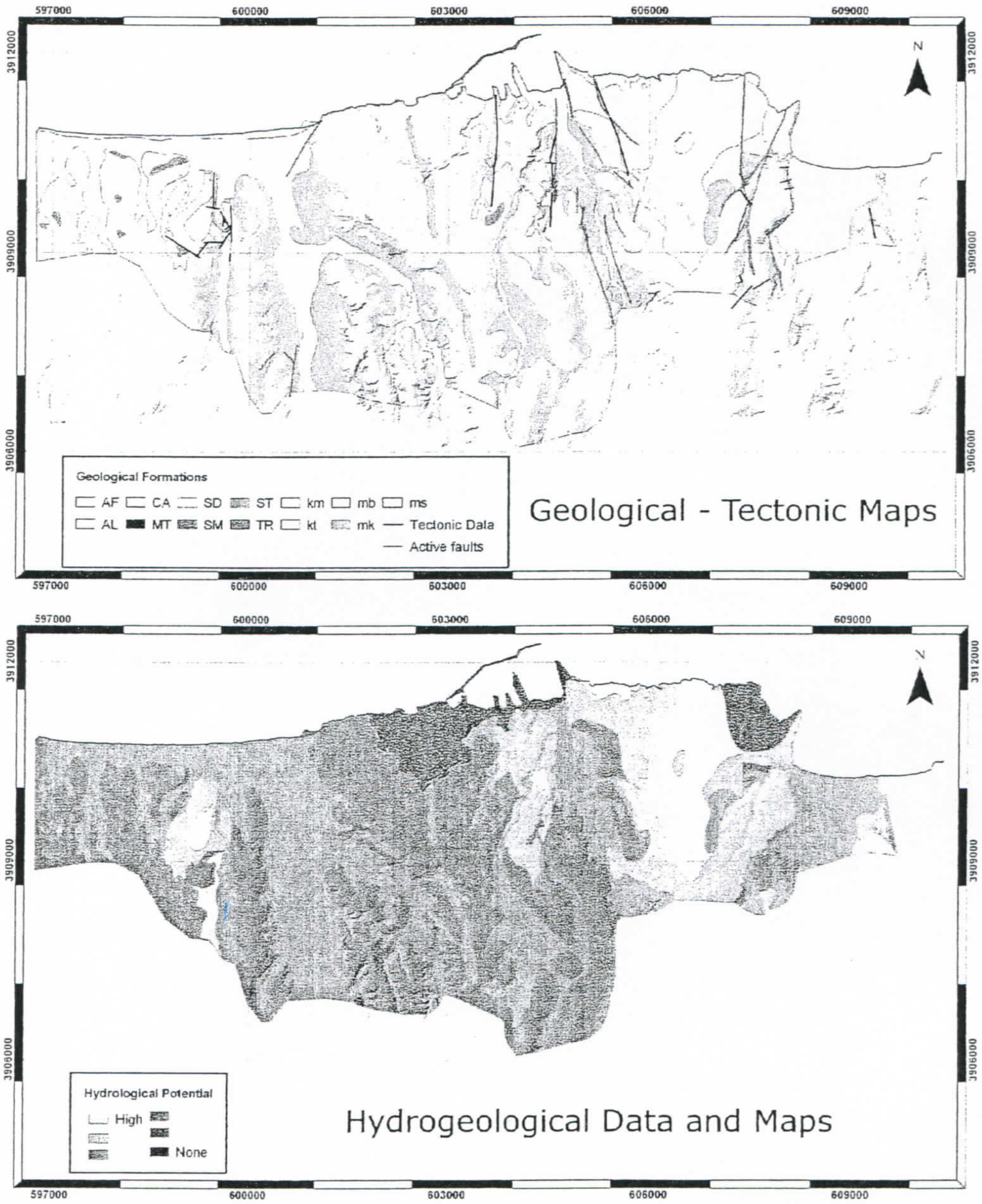


Figure 3. Basic GIS layers of the first group and corresponding derived or calculated layers.

The second layer group was created following field work operations like geological and tectonic mapping, in situ measurements and laboratory testing, including layers resulting from this group like hydrolithic maps (figure 4).

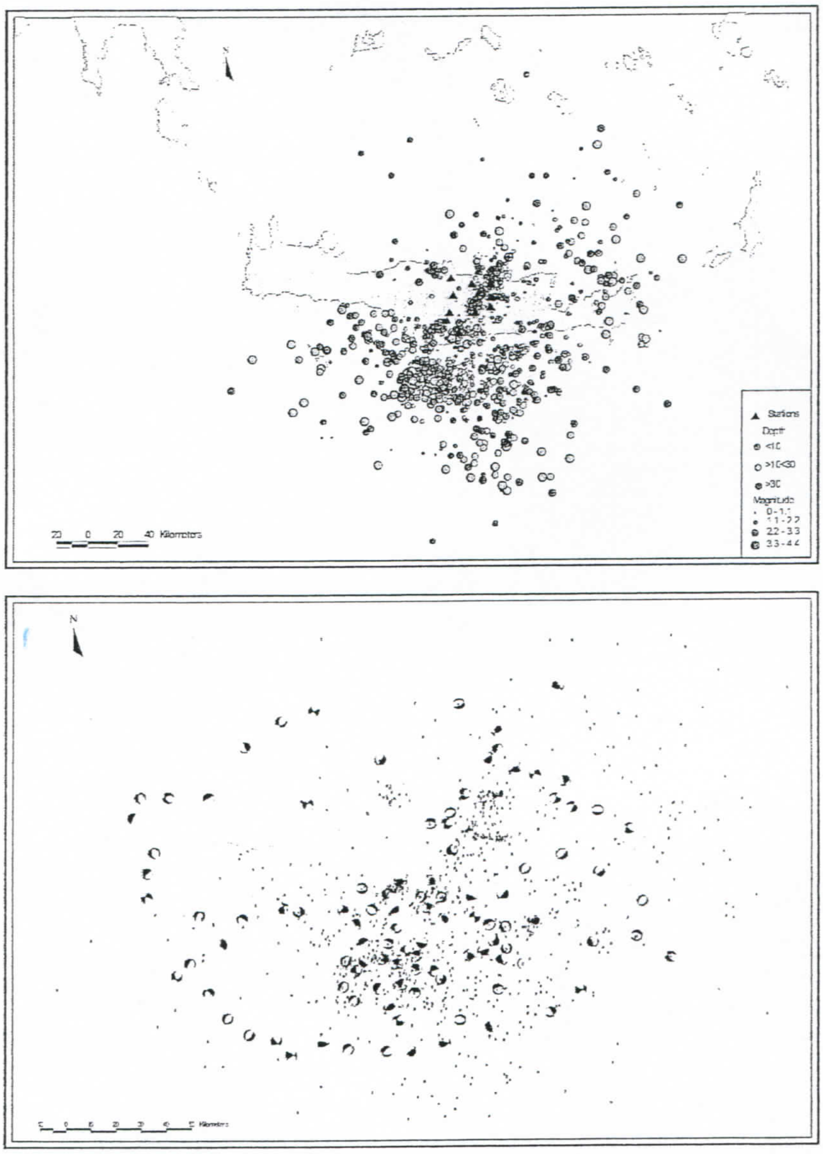


(a)

(b)

Figure 4. Combined geology and tectonic map (a) obtained following field work. GIS supported operations may be used in order to obtain additional information layers (b).

Additional information linked to geological and tectonic layers includes stratigraphic columns and geological sections. In the same group of layers all the data related to seismological research and seismic hazard assessment are also included. Both historical and old instrumental seismological data available for the investigated areas, as well as the results obtained from detailed microseismicity surveys are incorporated in this group (figure 5). In figure 5 the seismicity and fault plane solutions for events recorded during the six month period of network operation are shown.



(a)

(b)

Figure 5. Seismicity (a) and fault plane solutions (b) for events recorded during the six month period of the portable seismic network operation.

In a first step towards seismic hazard estimation, purely statistical methodologies were used to define maximum expected earthquake magnitudes. Next, by combining seismological data layers with the available tectonic information, the seismic sources which are expected to contribute to the seismic hazard of each area were defined and their seismic potential was calculated. Since a variety of seismic hazard assessment methodologies are usually applied requiring different parameterization of these sources (linear, area or dipping) a number of source model GIS layers can be created. Applying the different seismic hazard estimation algorithms (Cornell 1968, Mortgat and Shah 1989, McGuire 1976, McGuire, 1978) for two return periods of 475 and 949 years, several seismic hazard maps displaying maximum expected peak ground acceleration and velocity values at the bedrock were created and introduced into the system (Stavrakakis et al., 1997). The final maximum expected PGA and PGV maps which were used later to create the microzonation map were derived through map algebra from the previous layers.

Finally, the third layer group encompasses all the data related to the geophysical surveys and borehole geological and geotechnical data. A first objective for geophysical and drilling data is to assist the delineation of basement morphology and character in relation to the surface geology already described in the previous layer group (figure 6c). This task was accomplished using surface seismic methods (reflection – refraction) and geolectrical methods (VES methods). Interpretation was assisted by geophysical measurements within boreholes which were used for calibration purposes (figure 6b).

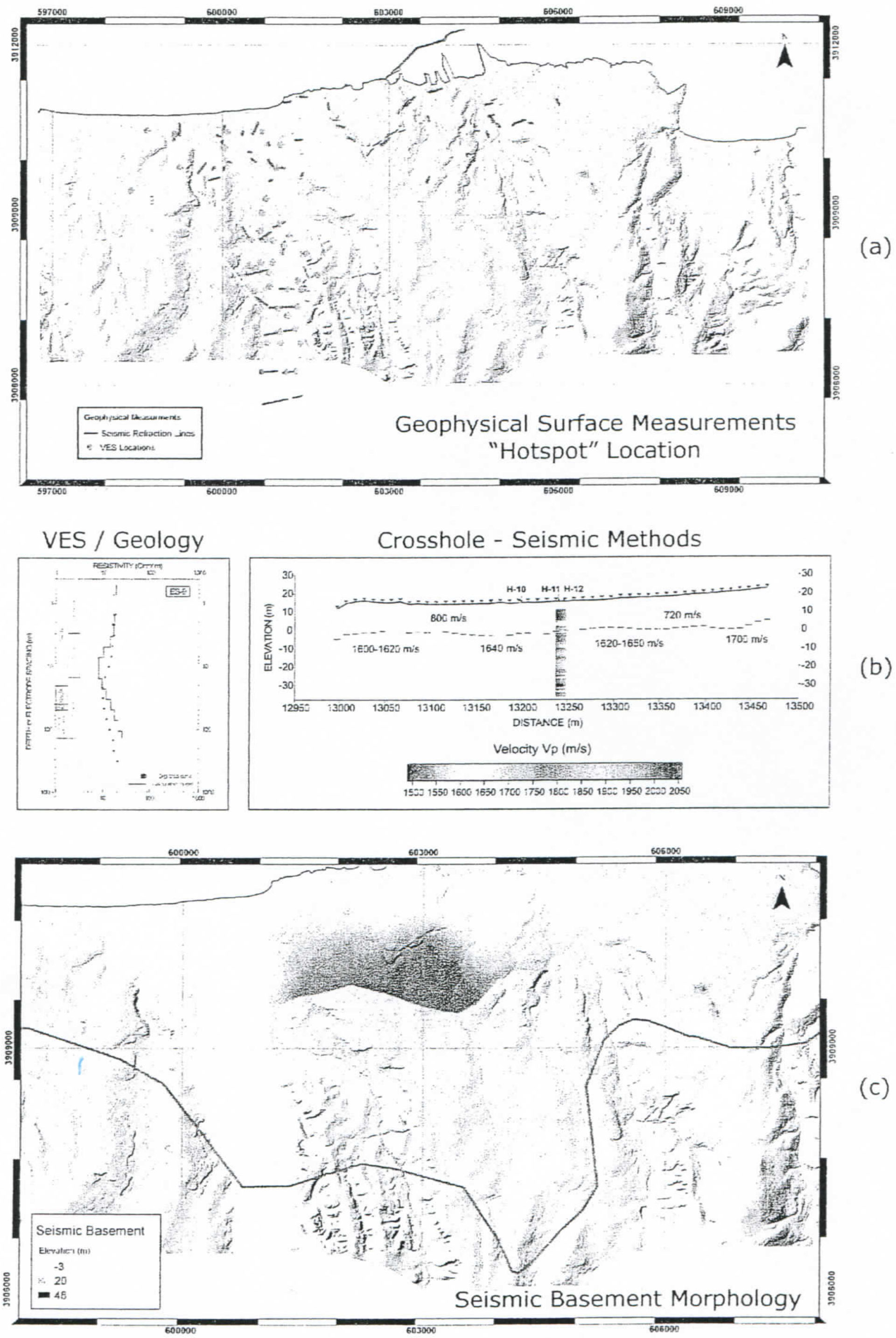


Figure 6. Geophysical measurements location and results.

The geophysical measurements within boreholes served also to achieve a second objective, the determination of the elastic parameters to be used in order to describe the dynamic behavior of the local soil and rock formations overlying the seismic basement. Among the applied geophysical methods cross-hole seismic tomography tests conducted at selected sites in the cities of Thiva and Heraklion proved successful in determining P-wave and S-wave velocities at 2-meter depth interval (figure 7b), as well as the dynamic elastic parameters including Young's modulus, Ed, rigidity modulus, Go and Poisson ratio, σ, (figure 7c).

An additional advantage of cross-hole measurements is related to the possibility to carry out such measurements in populated areas exploring the subsurface structure between boreholes with sufficient accuracy (Papadopoulos et al., 1997). A cross-hole test between two boreholes spaced 100 meters apart conducted in the Heraklion. Alluvial environment represents a successful application of the method (figure 7a). Geotechnical core sample testing also contributed towards the same goal.

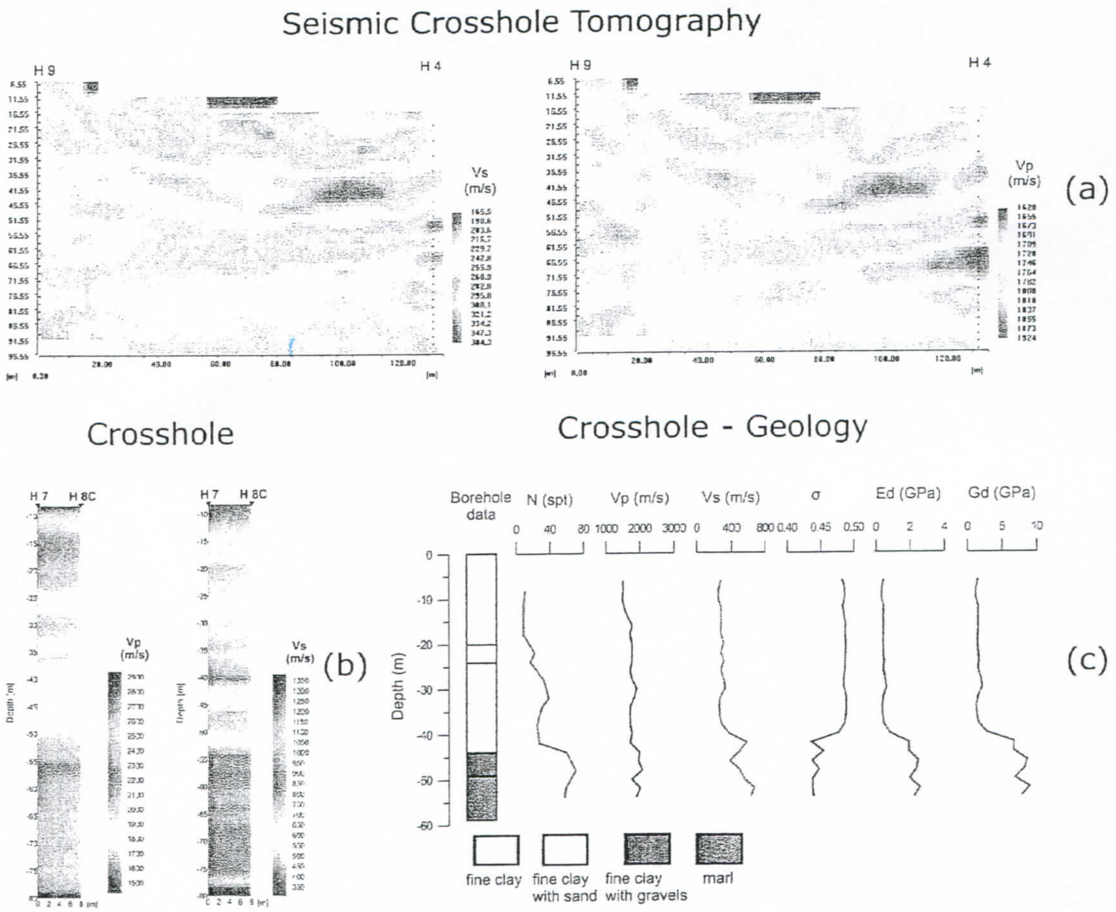


Figure 7. Geophysical cross-hole method interpretation and results.

The GIS platform on which the application was based proved indispensable during the procedure of defining the hard rock basement, by combining all the above mentioned data types and results in a user friendly environment. All available data (electrical soundings, cross-sections, tomographic images, electric/seismic-bedrock maps, general information maps, tables, etc.) could be accessed independently or in combined interpretations by clicking on predefined "hotspots" located on the main map (figure 6a).

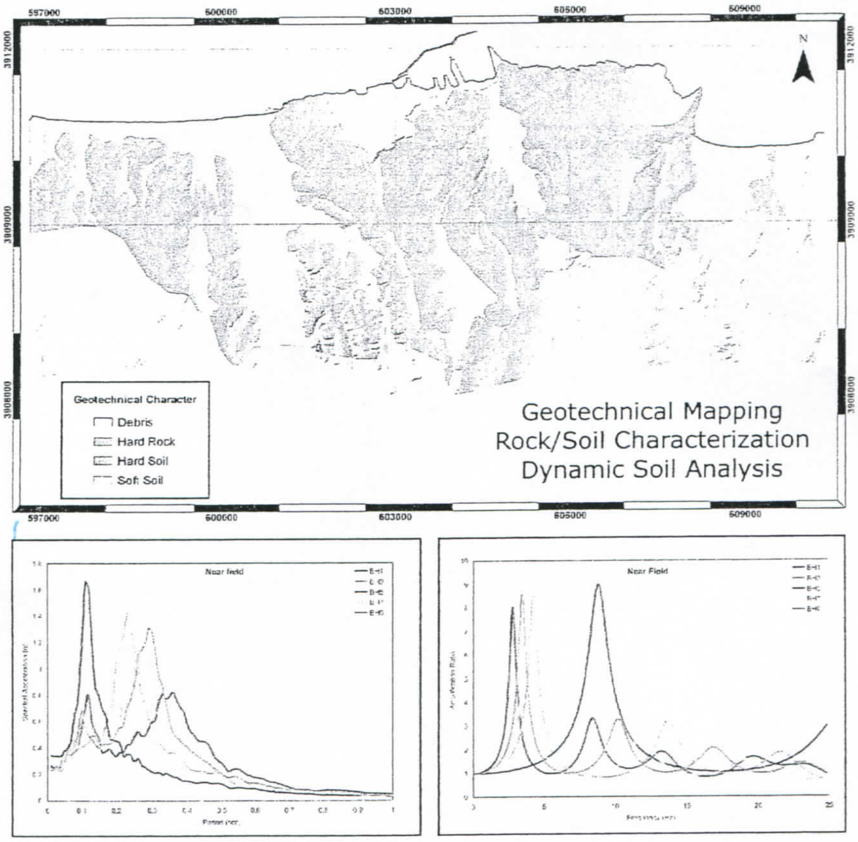


Figure 8. Dynamic soil analysis results obtained by combining all available information.

The geoinformation organized in the three layer groups described above, serves as the basis for generating the next informational layer related to dynamic soil analysis (figure 8). The main components contributing to the calculations required for this generation process are those related to the geological, geophysical, geotechnical and seismic hazard assessment, which can provide bedrock to surface amplification estimates through well known algorithms such as the SHAKE program proposed by Idriss and Sun (1992). Following the application of such analysis procedures at selected representative test sites within the investigated areas and by combining the obtained results with the available surface and basement morphology and geological information, the final microzonation map for each area has been compiled based on the various norms as defined by the Aseismic Building Code of Greece or the Eurocode 8 of the EU (figure 9).

All these layers introduced into the GIS spatial database system, using a predefined logical design in order to support automatic processing, can be readily examined by the user who can also make comparisons and evaluation of the results according to his specific needs. Furthermore, since this platform provides an open spatial database system alternative or additional data, calculations and results can be introduced at any time.

Discussion - Future Plans

As mentioned previously the aim for developing the AUTO-SEISMO-GEOTECH platform was to provide an environment in order to support microzonation related research activities. Presently the platform has been installed and is operational in the municipalities of Heraklion and Thiva for five years. Feedback obtained from the users revealed that several lines of action could contribute significantly to the improvement and the usefulness of this platform. A first task appears to be related to the necessity of automatic or semi-automatic database and map updates as new information becomes available during additional surveys, including revision of microzonation maps. In addition, improvement could also be made in the direction of incorporating new advances emerging in each discipline involved, such as new, more efficient methodologies with improved accuracy which could be incorporated in the platform.

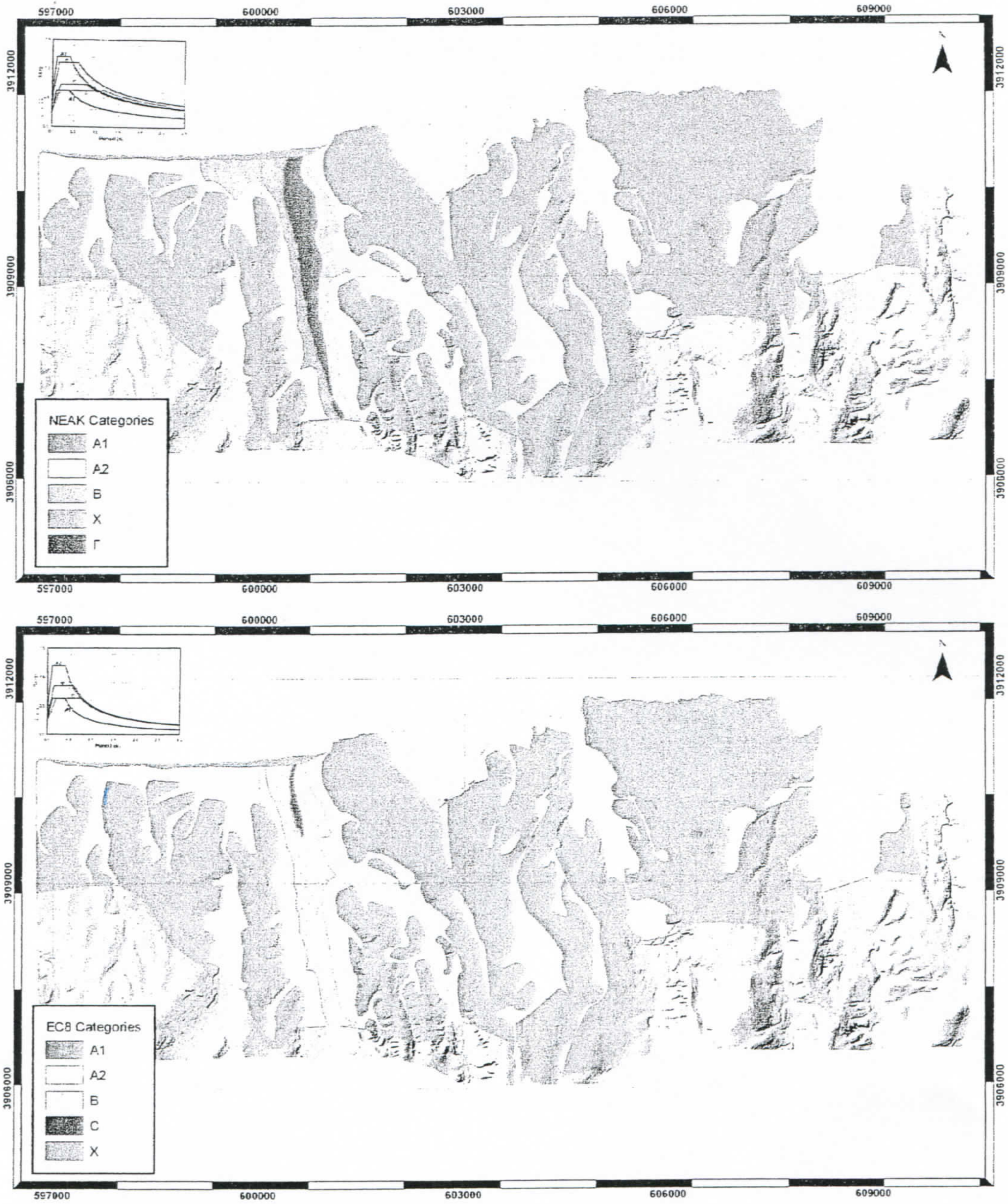


Figure 9. Final microzonation maps compiled by adopting two norms defined by the Aseismic Building Code of Greece (NEAK) and Eurocode 8 (EC8).

Presently, the final output of the platform can be summarised in terms of a microzonation map, expressing a detail image of seismic hazard variations within the two areas it has been implemented until now. This represents a very important task towards seismic risk mitigation mainly related to pre-disaster policies and actions. However, a further extension of the platform in order to include seismic risk assessment related databases and map layers would further enhance its contribution towards seismic risk mitigation by supporting retrofitting and emergency planning during the pre-earthquake phase and emergency response and reconstruction activities during the short and long term following a destructive earthquake. Before such a task can be realised it would be necessary to create a detailed database of the existing building stock for the two areas including specific information regarding the characteristics required for calculating the vulnerability and the economic value of each unit. Once these two additional layers are created a detailed seismic risk map could be derived by using simple or complex map algebra.

Finally, a last possible course of system improvement, which appears to be related to the capabilities incorporated into it as a result of the open architecture provided by the supporting GIS platform, would be to provide the necessary structures and extensions for its application in additional aspects of municipal management. Such aspects, dominated by the spatial character of their attributes and the necessity to use data already available by the system, could include, land use, hydrological resource management, environmental and urban planning.

References

1. Connell, C.A. (1986). Engineering seismic risk analysis, Bull. Seism. Soc. Am. 58, 1583-1606.

2. Idriss, I.M. and Sun, H.I. (1992). SHAKE91 A computer program for conducting equivalent linear seismic response analyses on horizontally layered soil deposits. Center for Geotechnical Modelling Department of Civil and Environmental Engineering, University of California, Davis, California, November, 1992, 20p.
3. McGuire, R.K. (1976). Fortran computer program for seismic risk analysis, U.S. Geol. Survey, Open-File Rep. 67-76.
4. McGuire, R.K. (1978). FRISK: Computer program for seismic risk analysis using faults as earthquake sources, U.S. Geol. Survey, Open-File Rep. 78-1007.
5. Mortgat, C.P. and Shah H.C. (1979). A Bayesian model foe seismic hazard mapping, Bull. Seism. Soc. Am. 69, 1237-1251.
6. Papadopoulos, T.D., Stavrakakis, G.N., Alexopoulos, J.D., Kambouris, P.J. & Voulgaris, N.S. (1997). Combined geophysical methods for subsurface characterization in the framework of microzoning studies. Proc. of the IAEG Intern. Symp. on Engineering Geology and the Environment, Vol 2, pp. 1419-1424, P.G. Marinos, G.C. Koukis, G.C. Tsiambaos and G.C. Stournaras eds., A.A. Balkema, 1997.
7. Stavrakakis, G.N., Papadopoulos, T.D., Voulgaris, N.S. and Drakopoulos, J.K. (1997). Seismic hazard estimation in the framework of microzonation studies. Proc. of the IAEG Intern. Symp. on Engineering Geology and the Environment, Vol 2, pp.1493-1498, P.G. Marinos, G.C. Koukis, G.C. Tsiambaos and G.C. Stournaras eds, A.A. Balkema, 1997.