Web: www.witpress.com Email witpress@witpress.com
Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

Assessment of seismic potential in Southeastern Sicily

S. Gresta[(1)] & H. Langer[(2)]
[1]*Dipartimento di Scienze Geologiche, Università di Catania, Corso Italia 55, 95129 Catania, Italy*
[2]*Instituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Piazza Roma 2, 95123 Catania, Italy*

Abstract

Southeastern Sicily has been struck several times by large earthquakes (1169, 1542, 1693) each with MCS-Intensities of X-XI degrees (and estimated magnitudes around 6.5 to7). The area thus belongs to the zones with the highest seismic potential in Europe. Following probabilistic analyses, which were carried out on a national scale, estimated peak accelerations with a return period of 475 years here amount to ca. 20% of g. This is significantly less than reported for other active seismic zones in Italy, where comparable or even lower maximum intensities are reported. In this work GIS based electronic maps have been created for the county of Catania exploiting the rich material of seismic logs, which allows the identification of the characteristic lithological units in the sense of EC8-soil classes. The maps were constructed using empirical relations between peak ground acceleration and macroseismic intensities of each municipality within the county. Local geological conditions are accounted for by applying correction factors following a strategy similar to the U.S. Uniform Building Code. Finally thematic maps of pseudo acceleration were created for typical buildings of the area, with eigenfrequencies of 1 and 5 Hz, respectively. These analyses are backboned by synthetic site dependent strong ground motion simulations carried out for selected sites in several urban areas of the County. Various earthquake scenarios have been taken into account, which underscore the considerable damaging potential even of moderate sized local earthquakes. The higher level of seismic potential derived from the empirical and synthetic approaches is in better agreement with the observed damages caused by the

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

major earthquakes in Southeastern Sicily than the values obtained by the statistical approach mentioned above.

1. Introduction

The county of Catania extends over ca. 3500 km^2 in Eastern Sicily, one of the areas with the highest seismic potential in Europe. On the other hand, the coastal area between Messina and Syracuse belongs to the most populated zones in Sicily, and important industrial petrochemical facilities are situated between the cities of Catania and Syracuse. In recent years several studies on strong ground motion have been carried out on a national scale which were aimed at the reformulation of the seismic building code in the framework of the EC8 [1]. These analyses were carried out using statistical approaches similar to the technique proposed by Cornell [2]. Following these studies the county of Catania belongs to a zone with an expected peak ground acceleration of ca. 0.15-0.2 g for a return period of 475 years [3]. These levels are comparable to those reached in the zones of Belice (Sicily), Lago di Garda (Trentino region) or the western part of the Alpine Mountain belt, but far below the values of other important zones like Friuli or the Apennine chain (see Fig. 1).

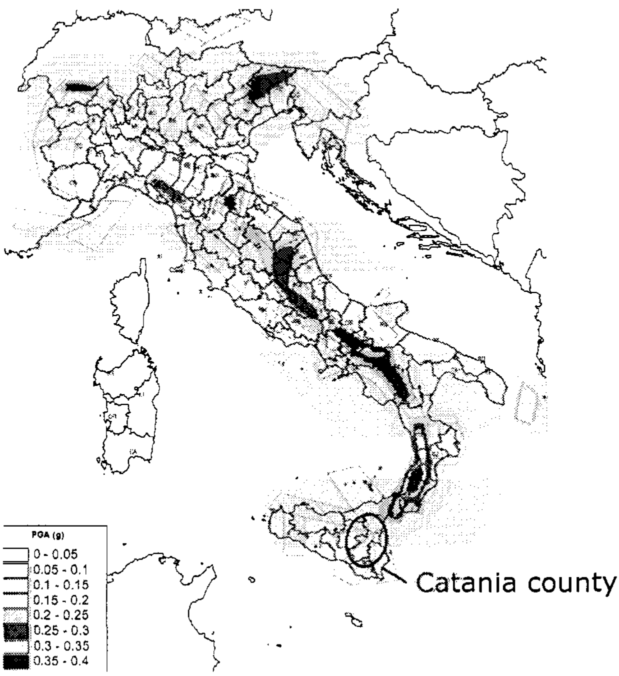


Figure 1. Statistically estimated peak ground acceleration for Italy [3].

The rather moderate seismic potential inferred from the statistical analyses for the eastern coast of Sicily, is in evident contrast with the distribution of

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

maximum observed intensities in Italy, where Eastern Sicily is highlighted among the most hazardous earthquake zones in Italy. The discrepancy underscores the problems arising when strong motion prediction form statistical approaches carried out on a national scale is applied to small areas like municipalities or counties. The problems are indeed manifold, here we mention only some examples. Questions arise from a suitable assessment of attenuation laws and their dependence on the geological structure. Most intensity attenuation laws do not account for earthquake size. Other serious difficulties are given by the choice of the statistical model. It is often not clear how the extension of mesoseismic areas of large earthquakes is accounted for. Moreover, large earthquakes are typically rare events, with interval times of hundreds of years and it is far from guaranteed that they follow the same statistical model as the minor, but more frequent ones. Last but not least there's often considerable incertitude about the location of large historical earthquakes. For instance the location of 1693 M=7 earthquake has been indicated in the *Catalogo dei Forti Terremoti* (CFT [4]) ca. 10 km south of Catania, whereas other authors suggest an offshore location (see [5]), some 30 km distant from the CFT location.
In the light of the considerable uncertainties and discrepancies local governmental authorities have supported specific studies on the assessment of strong ground motion and the design of response spectra appropriate for their territories. In the present study we constructed site dependent response spectra using an empirical approach, deriving peak ground accelerations from intensities and accounting for the geological conditions as prescribed by the EC8 and the U.S. Uniform Building Code. Our empirical analyses are based on maximum intensities observed (i) in the last 50 years and (ii) the maximum intensities ever noticed. The first choice can be justified by the fact that data quality decisively improve after World War II. In the specific case of the county of Catania we observe rather frequently small, superficial earthquakes causing large damage on a very local scale. Maximum intensities of up to a degree of XI were observed during the 1693 M=7 earthquake, a similar earthquake is likely to have happened ca. 500 years earlier in 1169, and during the 1542 earthquake maximum intensities reached a degrees of X-XI on the MCS scale. It seems reasonable to assume that earthquakes of this size are likely to occur at intervals of some hundreds of years, matching the request of a return period of 475 years formulated in the EC8. All results derived from the empiric analyses have been represented in a GIS. Thematic maps were created showing the distribution of rock impedances, "50-year" and "475-year" peak ground accelerations and pseudo-accelerations at 1 and 5 Hz, with a damping of 5% of critical. In order to backbone our conclusions we carried out synthetic modelling for selected sites and for some realistic earthquake scenarios.

2. The seismic catalogue

The catalogue represents has been compiled by collecting and re-analysing published and unpublished macroseismic data for earthquakes felt in the area of the county of Catania with a MCS intensity IV or larger. It covers a time span from 1169 to 1996 with 2400 macroseismic observations of 420 earthquakes and

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

over 370 sites. Data were collected from various sources, such as bulletins, catalogues, maps and scientific papers. As the data sources showed discrepancies with respect formal aspects and geographical referencing we had to adjust the original data base correcting incorrect writing of localities, geographical coordinates, changes in the denomination of the localities and other. From these data we created the first thematic maps relative the distribution of maximum intensities in the last 50 and 475 years, respectively. The maps represent the maximum intensities felt within the borders of each of actual 58 municipalities of the county of Catania. This means that the maximum intensity felt somewhere in the area of a municipality is smeared across its entire territory. We have adopted this strategy as a compromise between scientific reasoning and practical needs. A "correct" way to extrapolate intensities over an area would require the assessment of attenuation laws on a local scale, which is unrealistic in the light of the available information with this respect.

3. The impedances

The geology of the county of Catania shows a very complex picture. To the north of the city of Catania volcanic rocks of Mt. Etna are predominant, while clastic sediments and sand prevail close to the sea and in the large alluvial plane south of Catania. Mostly limestone or marls are found in the hyblean platform and the nebrodian mountains north from Mt. Etna. In the southwestern part of the county one notes again volcanic units of the hyblean volcanism. Fortunately there's plenty of material available in the county of Catania, mostly from down-hole and cross-hole measurements which have been used for the creation of a database relating the single lithological units to the corresponding geotechnical parameters, in particular elastic moduli and density. For single units for which geotechnical data were lacking we used values from the literature [6]. Georeferencing the lithological units and cross-referencing them with the corresponding geotechnical parameters we can create the thematic maps for the distribution of seismic impedances (an example is given in Fig. 2a).

4. Assessment of strong ground motion parameters in the framework of the EC8

4.1 The seismic code EC8

As many other standard codes the EC8 has been developed in order to create a frame for a simplified seismic loading estimation. The reaction of a building to an incoming seismic wave is described using the model of an oscillator with a single degree of freedom. Though being questioned in recent years this method is still widely used because of its simplicity. Standard spectra are created using essentially two parameters. The former is the reference value a_g, i.e., the value of the pseudo-acceleration response spectrum at high frequencies (typically 33 Hz) which corresponds to the free field acceleration. The latter important parameter is the shape of the spectrum which is supposed to depend on the geological conditions of the site.

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

The EC8 standard response spectrum with 5% damping in terms of pseudo-acceleration is given by:

$$S_e(T_n) = a_g\, S\, \{1+T_n/T_B(\upsilon\, \varsigma_0 - 1)\} \qquad 0 < T_n < T_B,\ T_n = 1/f_n \qquad (1.1a)$$

$$S_e(T_n) = a_g\, S\, \upsilon\, \varsigma_0 \qquad T_B < T_n < T_C \qquad (1.1b)$$

$$S_e(T_n) = a_g\, S\, \upsilon\, \varsigma_0\, T_C/T_n \qquad T_C < T_n < T_D \qquad (1.1c)$$

$$S_e(T_n) = a_g\, S\, \upsilon\, \varsigma_0\, T_C/T_D\, (T_D/T_n)^2 \qquad T_D < T_n < T_\infty \qquad (1.1d)$$

Here $T_n = 1/f_n$ is the natural period of the building, ς_0 is the amplification of the response spectrum with respect to peak acceleration (or reference value a_g) with a proposed value of 2.5. υ depends on the damping β_0 and is unity for β_0=5%. T_B, T_C and T_D are corner periods which control the shape of the response spectrum and assume the values given in Table 1.

Table 1. Parameters of the EC8 standard response spectrum. S factors in brackets indicate the values used in this study.

Soil class	*Soil parameter S*	*T_B[s]*	*T_C[s]*	*T_D[s]*
A	*1.0 (0.7)*	*0.10*	*0.4*	*3.0*
B	*1.0 (1.0)*	*0.15*	*0.6*	*3.0*
C	*0.9 (1.4)*	*0.20*	*0.8*	*3.0*

The U.S. Building Code differs form the EC8 in particular with respect to the choice of the soil factor S. It becomes 2.0 for a soft soil (soil class C in EC8 terminology), assumes values between 1.2 and 1.5 for a soil class B and is set to 1.0 for a hard rock soil (class A in the EC8). In the US Building Code philosophy it is assumed that estimate for the reference value (or free field peak ground accelerations) are given with respect to a hard rock situation, whereas in the EC8 soil amplification of the free field peak ground acceleration is already accounted for in a_g. For our specific purposes the U.S. Code philosophy is more appropriate, as we have only one intensity (and thus peak ground estimation) for each municipality. We thus assumed that the medium soil condition in the county of Catania corresponds to a class B and set the corresponding soil factor S to unity. Consequently, the factor S for a soil classes A and C becomes 0.7 and 1.4, respectively.

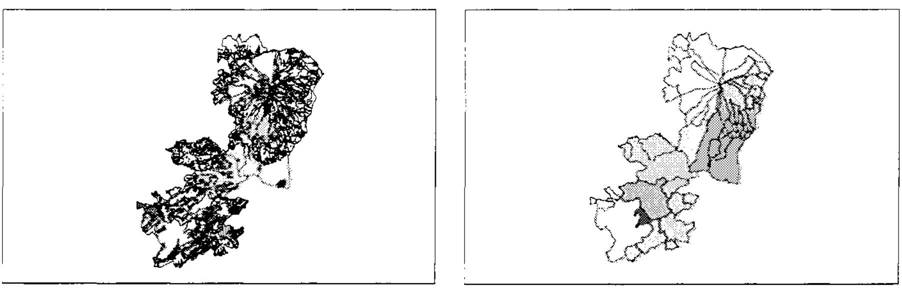


Figure 2: Impedances (left) and reference accelerations (right) deduced for the municipalities of the county of Catania. Dark grey represents high, light grey low values.

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

4.2 The estimate of reference (free field) accelerations.

Due to the lack of sufficient strong ground motion recordings the reference ground acceleration maps have to be created using empirical relations between peak ground acceleration and macroseimsic intensity. The relation shown in Fig.3 has been derived from Chiaruttini & Siro [7]. From the Friuli, 1976, earthquake series these authors obtained two relations, one for soils corresponding to thick alluvial deposits or hard-rock, the other one for sites with alluvial like layers whose thickness is less than 20 m. As we have no information to which soil type our maximum intensities in the single municipalities correspond, we used the average of two relations. As we shall point out below, the individual soil conditions of the single lithological units is accounted for later, when we construct the response spectra applying the shape parameters and correct the reference acceleration by applying the soil factors S.

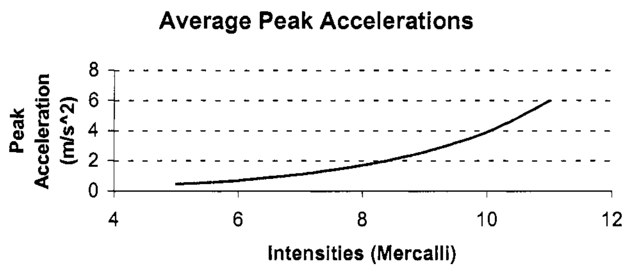


Figure 3. Empirical relation used for the estimation of peak ground acceleration.

Clearly, the peak ground acceleration estimated using the relation inferred from the Friuli earthquake sequence is affected by considerable uncertainties. First of all, it is not clear whether a relation of an other region can be used for the county of Catania. For instance, the relations found for the zone of Ancona or the Alpine mountains differ significantly from the ones found for Friuli earthquakes [7]. Furthermore, in the Friuli data set the observed maximum intensities, for which a corresponding peak ground acceleration is available, do not exceed 8.5, in the subset of the Alpine mountains the maximum value covered by observed data is I=7. Consequently, the higher values are obtained by extrapolation. One may suspect that the peak accelerations estimated for the higher intensities are overestimated as the macroseismic intensity, in other words, the damage of an earthquake, depends not only on peak ground acceleration but also on factors like the duration of ground shaking. It is known and easy to explain that peak ground acceleration tends to saturate with increasing earthquake magnitude, whereas the duration of ground shaking continues to augment in a considerable way. It can be speculated that the high intensities encountered for large earthquake reflect the increased signal duration rather than peak ground acceleration. However, reference ground acceleration maps have been created

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

following the above discussed steps. As an example, see the 475 year map in Fig. 2b.

4.3 The construction of site dependent standard response spectra

We now have all elements for the construction of the standard EC8 response spectra. The reference values a_g are obtained using the empirical relation shown in Figure 3, for each municipality. The soil classification of the sites is carried out on the basis of the thematic map of the impedance. Note that the impedance pattern is controlled essentially by the shear wave velocities, whereas the densities scatter in a much minor degree. The following maps are constructed for ca. 900 graphical objects which are obtained from the intersection of the borderlines of the municipalities with the lithological units. Finally we apply the formulas 1.1a-c using the appropriate soil factors S and corner periods T_B, T_C and T_D and choosing the natural frequencies of 1 Hz and 5 Hz. The natural frequencies of 1 and 5 Hz correspond to buildings whose height H can be estimated using a formula give in the EC8:

$$T_n = 1/f_n = C_t * H^{0.75} \tag{1.2}$$

where C_t is a factor between 0.05 and 0.085 depending of the make up of the structure. Thus a natural frequency of 1 Hz corresponds to a ten to twenty store building, whereas 5 Hz correspond to houses with one or two floors. In reality, the values obtained for 5 Hz cover a wider range of buildings because the EC8 standard spectrum is flat around this value. The acceleration responses calculated for 1 and 5 Hz covers thus a great deal of typical buildings present in the area and may be of considerable practical use for land-use planning purposes and civil protection. The maps shown in Figures 4a and 4b were obtained using maximum computed accelerations for the last 475 years. Particularly high values (sometime over 2 g) are obtained for small buildings constructed on soft soil, as present in the zone close to the sea or in the river valley of Simeto. From the map shown for a natural frequency of 1 Hz a high degree of seismic loading should be expected also for higher buildings, particularly in the zones of the Catania plane.

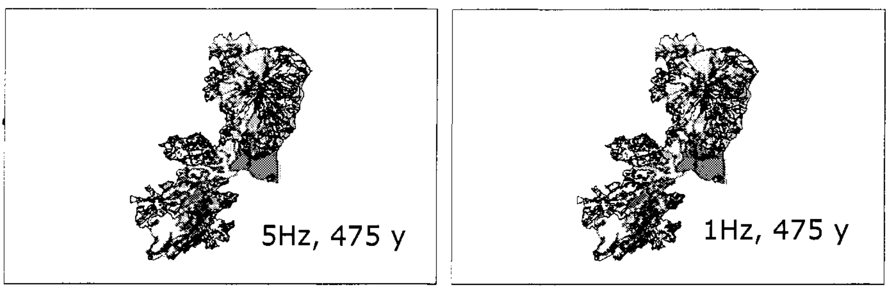


Figure 4. Pseudoaccelerations at 475 years, for small (5 Hz) and high (1 Hz) buildings. Dark to light grey represents high to low values.

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

Here maps show acceleration responses exceeding 1.5 g even for 1 Hz buildings. The situation is considerably less severe in the northern-western part of Mt. Etna, which offers, on average, more favourable soil conditions and is characterized by lower observed intensity values (because the distance from important earthquake sources.

5. Strong ground motion simulation for selected sites

The technique used for the creation of the maps shown above is based on empirical relations for the estimate of strong ground motion. In order to verify our results we have carried out strong ground motion simulations at sites for which detailed geo-stratigraphic data are available. We used the stochastic source model by Boore [8] and, following Langer [9], propagated the wave-field from the source to the surface with Haskell matrices [10]. Some different earthquake scenarios have been considered. Among the several selected sites in some urban areas of the County, we report the results of simulations for the sites of Giarre and Adrano downtown, using the parameters of the 1693 earthquake ($M=7$; $M_0= 2.5*10^{19}$ Nm; stess drop = 100 bars). The city of Giarre is located at the coast of the Ionian sea and is dominated by B and C-soils, whereas Adrano is situated on the southwestern slope of Mt. Etna where A-type soils prevail. The geotechnical parameters of subsurface and deeper underground layers are given in Tables 3a and 3b, respectively.

Table 3a. Geotechnical parameters for the subsurface and deeper underground at Giarre downtown.

Layer	*Thickness (m)*	*c (m/s)*	*Density* (kg/m^3)	*Q*
Sands	10	500	1800	20
Sands, pebble	200	600	2000	30
Claystone	500	1500	2100	70
Marls	300	1700	2200	100
Limestone	5000	2600	2500	150
Basement	∞	3500	2800	300

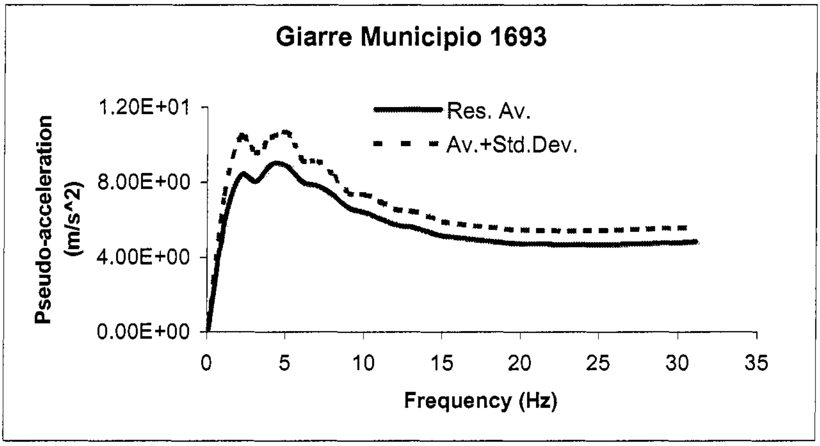
Table 3b. Geotechnical parameters for the subsurface and deeper underground at Adrano downtown.

Layer	*Thickness (m)*	*c (m/s)*	*Density* (kg/m^3)	*Q*
Lavas	10	800	2000	20
Lavas	40	1000	2200	40
Clay	200	600	2100	30
Claystone	500	1500	2100	70
Marls	300	1700	2200	100
Limestone	5000	2600	2500	150
Basement	∞	3500	2800	300

The strong ground motion simulations show that the peak ground accelerations estimated from the intensities could to be overestimated. For the downtown area

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

of Giarre the peak ground acceleration with a value of ca. 4 m/s^2 for a magnitude 7 earthquake at a distance of 20 km reaches approximately the level predicted by the relation shown in Fig. 3 for an intensity X. The 5 Hz response spectral values obtained from the simulation are close to those shown in the maps for B-soils.



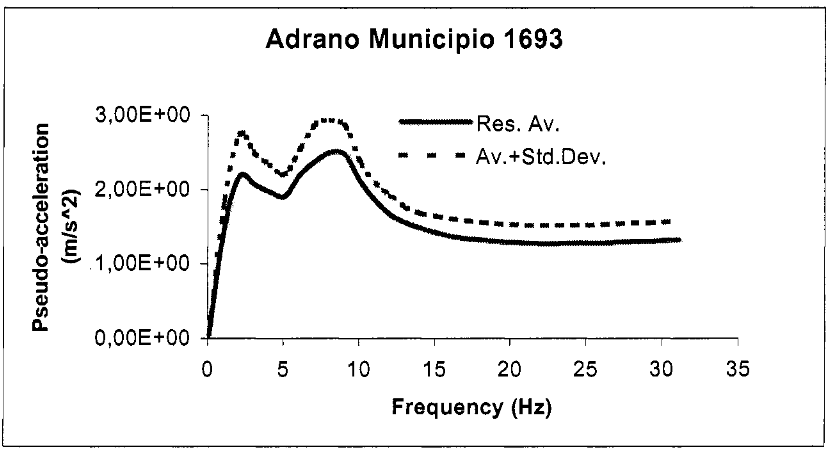


Fig. 5. Simulated 5% response spectra at the two selected sites, for the 1693 earthquake scenario.

Similar to the patterns in the maps, where we obtain a lower degree of seismic loading in the areas to the west of Mt. Etna, the response spectra of the site Adrano are considerably lower than those of Giarre, as Adrano is more distant from the epicenter of the 1693 earthquake and the subsurface conditions are more favorable as at Giarre.

Paper from: *Risk Analysis III*, CA Brebbia (Editor).
ISBN 1-85312-915-1

Acknowledgements

This work is part of a project funded by the County of Catania in the framework of the plan of Civil Defence against natural risks. We wish to thank Dr. Nello Musumeci, President of the County of Catania, for having strongly supported the project.

References

[1] Romeo, R. & Pugliese, A., *Analisi probalistica della scuotibilità del territorio italiano.* Ingegneria Sismica, **14**, 68-76, 1997.
[2] Cornell, C.A., *Engineering seismic risk analysis.* Bull. Seism. Soc. Am., **58**, 1583-1606, 2000.
[3] Giardini, D. (editor), *The Global Seismic Hazard Assessment Program (GSHAP) 1992-1999.* Ann. Geofis., **42**, pp. 957-1230, 1999.
[4] Boschi, E., Guidoboni, E. & Mariotti, D., *Seismic effects of the strongest historical earthquakes in the Syracuse area.* Ann. Geofis., **38**, 223-253, 1995.
[5] Azzaro, R. & Barbano, M.S., *Analysis of the seismicity of Southeastern Sicily: a proposed tectonic interpretation.* Ann. Geofis., **43**, 171-199, 2000.
[6] Schön, J., *Petrophysik.* Akademie-Verlag Berlin, 1983.
[7] Chiaruttini, C. & Siro L., *The correlation of peak ground horizontal acceleration with magnitude, distance, and seismic intensity for Friuli, Ancona and the Alpide Belt.* Bull. Seism. Soc. Am., **71**, 1993-2009, 1981.
[8] [8] Boore, D.M., *Stochastic simulation of high frequency strong ground motion based on seismological models of the radiated spectra.* Bull. Seism. Soc. Am., **73**, 1865-1894, 1983.
[9] Langer, H. *Seismotektonische Herdparameter und Ausbreitungs-effekte bei Mikroerdbeben im Bereich der westlichen Schwäbischen Alb.* Berichte Institut für Geophysik, Univ. Stuttgart, **2**, 113 pp., 1986.
[10] Haskell, N.A., *Crustal reflection of plane SH-waves.* J. Geophys. Res., **65**, pp. 4147-4150, 1960.
[11] Di Bona, M., Cocco, M., Rovelli, A., Berardi, R. & Boschi, E., *Analysis of strong-motion data of the 1990 Eastern Sicily earthquake.* Ann. Geofis., **38**, 283-300, 1995.