

## A procedure to estimate the seismic hazard in an urban area: an application to Acireale (Eastern Sicily)

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**Abstract** A “standard procedure” to characterize the seismic hazard of a given area was proposed. It is based on a multidisciplinary approach implying: (1) the knowledge of the seismic history of the area; (2) detailed geological surveys; (3) seismic noise measurements; (4) simulations of earthquake scenarios. The downtown of Acireale, a typical baroque town located on Eastern Sicily, was chosen as the “test area”. A catalog of the local seismogenic faults (able to generate earthquakes in historical times) has been compiled, as well as a seismic catalog for the effects of both local and regional earthquakes. The analysis of both catalogs allowed us to make the following conclusions: (1) the most important seismogenic faults affecting the Acireale municipality do not affect the downtown, while the related local earthquakes attenuate their energy (and intensity) in short (few km) distances; (2) the highest seismic intensity (degree *X*) experienced in Acireale downtown was caused by the 1693 regional earthquake; (3) over the last 140 years, the downtown has experienced the highest intensity value of VII only once, while six times the

intensity was VI. On the whole, this implies a moderate seismic hazard. The estimation of the seismic hazard has been also approached by the experimental method of recording seismic noise. Measurements have been performed at seven different sites, where drills gave detailed information on the shallow subsurface geology to obtain HV (horizontal/vertical) spectral ratios. On the whole, the highest site amplification factor was moderate (about 7). A further investigation based on synthetic seismograms (and spectra) produced by simulating two given earthquake scenarios was also performed. The two scenarios are, respectively, representative of the largest expected earthquake in the area (the 1693 shock) and of a moderate (magnitude ca. 5.5) local earthquake (as the 1818 one). Moderate to strong locally expected accelerations were evidenced.

**Keywords** Earthquake catalog · Seismogenic faults · Local site amplification · H/V spectral ratios · Earthquake scenario simulations · Seismic hazard

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### Introduction

The definition of “seismic hazard” needs an estimation of the ground motion. In the last decade, several studies on strong ground motion have been carried out in Italy. These analyses, at a national scale, were performed using statistical approaches similar to the technique proposed by Cornell (2000). Following these studies, Eastern Sicily belongs to a zone with an expected peak ground acceleration of ca. 0.2 g for a return period of 475 years (i.e., Giardini 1999). This result is in evident contrast with the distribution of maximum observed intensities, where Eastern Sicily is highlighted among the most hazardous

earthquake zones in Italy. Rather better results are obtained if the statistical approach is performed by considering a return period of 50 years (i.e., INGV 2006).

Moreover, the discrepancy underscores the problems arising when strong motion prediction from statistical approaches carried out on a large scale is applied to small areas like municipalities. For instance, questions arise from a suitable assessment of attenuation laws and their dependence on the geological structure; most of the intensity attenuation laws do not account for earthquake size. Other difficulties arise from the choice of the statistical model. 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 shocks.

In addition to the influence of the seismic sources, site conditions are widely recognized as an important factor in the distribution of earthquake damages. Efficient trapping of energy in basins and/or focusing of seismic waves by irregular interfaces leads to significant spatial variations of ground motion in both amplitude and duration. Among the many approaches to the site-effect estimate, an empirical trial is to use ambient seismic noise measurements.

Finally, the estimation of seismic ground motion can be performed by means of synthetic simulation of acceleration seismograms. Basically, a sufficient knowledge of the source parameters of the “expected” earthquake and of geotechnical parameters of both deep and shallow crust provides the elements for the simulations.

In the present study, we propose a procedure of investigation able to define the seismic hazard of inhabited areas, for which historical macroseismic data, detailed geological surveys and geotechnical parameters of the shallow subsoil are available. Our investigation will focus on the following five steps: (1) detailed knowledge of the seismic history of the area; in other words, the observed effects produced at different sites by the past earthquakes; (2) identification of the local faults able to generate earthquakes; (3) collection of geotechnical data from drillings and/or geophysical investigation to provide a detailed geological survey; (4) experimental seismic noise measurements to define the local site amplifications due to the layered structure of the subsoil; (5) computation of the expected ground shaking at different sites by simulating a given earthquake.

The above described procedure will be tested in Acireale (Eastern Sicily), more specifically on seven sites where subsurface geological data are validated by drills.

### The geophysical bases of the procedure

Seismic tremor, commonly called seismic “noise”, exists everywhere on the Earth’s surface. It is also called

*microtremor* because it involves very small oscillations [ $10^{-15}$  (m/s<sup>2</sup>) in acceleration], much smaller than those induced by earthquakes of any size in the near field. It mainly consists of surface waves, which are elastic waves produced by the constructive interference of the *P* and *S* waves in the layers near the surface. Seismic noise is mostly produced by wind and sea waves. Also, industries and vehicle traffic locally generate tremor, although essentially at high frequencies (some Hz), which are quickly attenuated. In areas without local noise sources, in the absence of wind and on flat rocky basements, the seismic noise spectrum decreases at high frequencies and has two peaks at 0.14 and 0.07 Hz. This is probably due to large ocean waves, which are only slightly attenuated even at thousands of kilometers from the ocean due to the wave guide-like properties of surface waves. Local effects due to anthropic and natural sources can add to this general trend. However, much more interesting is the fact that the background seismic noise acts as an excitation function for the local resonances of both subsoil and buildings.

Since the first empirical studies of Kanai and Tanaka (1961), the most popular method is the horizontal vertical spectral ratio (HVSr) technique, which consists of studying the ratio between the spectra of the horizontal components of motion and the vertical ones. This was widely divulged by Nakamura (1989). It is recognized that HVSr is able to provide a reliable estimate of the main resonance frequencies of subsoil. The theoretical bases of HVSr are relatively simple in an 1D-layered configuration. Let us consider a system where layers 1 and 2 differ in their density value ( $\rho_1$  and  $\rho_2$ ) and seismic wave propagation velocities ( $V_1$  and  $V_2$ ). A wave traveling across layer 1 is (partially) reflected at the transition with layer 2. The reflected wave will interfere with the incident waves to give a maximum amplitude (fundamental resonance frequency), when the wavelength of the incident wave ( $\lambda$ ) is four times (or odd multiples) the thickness  $h$  of the first layer. In other words, the fundamental resonance frequency ( $f_r$ ) of layer 1 for the *P* waves is:

$$f_r = V_{P1}/(4h) \quad (1)$$

while the fundamental resonance frequency for the *S* waves is:

$$f_r = V_{S1}/(4h). \quad (2)$$

Theoretically, this effect is addable so that the HVSr should show (as relative maxima) the resonance frequency of layers. This, together with an estimate of seismic velocities (which is generally available at least as a first approximation), allows one to predict the thickness  $h$  of the first (or more than one) layer. This information is mostly contained in the vertical component of motion. However, the idea of using the ratio of horizontal to

vertical spectra rather than the vertical spectrum alone derives from the fact that the ratio provides for an important normalization of the signal for (1) frequency content, (2) instrumental response and (3) overall signal amplitude if the recordings are taken at times of higher or lower noise levels. This normalization, which makes signal interpretation simpler, is at the basis of HVSR popularity (e.g., Mucciarelli 1998).

Ground motion estimation for the purpose of seismic hazard may be eventually carried out in some empirical way or on the basis of theoretical models. The empirical approaches essentially consist in the use of observed relations of strong ground motion parameters derived from various seismic zones. The difficulties of this strategy are quite well known: the empirical relations derived from records of other zones with differing seismotectonic setting, characteristics of wave propagation effects and subsurface site conditions can hardly be adjusted to the situation of actual interest. Given the large variety of possible earthquake scenarios with respect to source parameters, effects of wave propagation and site conditions, the choice of “suitable” example seismograms poses serious questions as to the significance of these approaches. Moreover, the use of some empirical strategy is certainly exacerbated in seismic zones with long quiescent periods as Eastern Sicily, where the return periods of large damaging earthquakes are up to hundreds of years.

A possible way out of these problems is the estimation of strong ground motion by means of synthetic simulation of acceleration seismograms. Synthetic simulation according to such concepts gives indeed a reasonable match of observed data, provided there is sufficient knowledge of the source and geotechnical parameters. The acceleration source time function was simulated here according to the procedure proposed by Boore (1983) and modified by Langer (1986). Its essence is the generation of a band-limited random sequence of random pulses. Global source parameters are accounted for by applying a band-pass filter to the Gaussian white noise, i.e.,

$$CM_0S(f, f_0)P(f, f_{\max}) \tag{3}$$

where  $C$  is a constant for geometrical spreading and radiation pattern,  $M_0$  the seismic moment of the event and  $f_0$  the corner frequency,

$$S(f, f_0) = f^2 / (1 + (f/f_0)^2) \tag{4}$$

$$P(f, f_{\max}) = (1 + (f/f_{\max})^{2q})^{-1/2} \tag{5}$$

$q$  is the parameter of the steepness of the high frequency decay (here  $q = 4$ ). The corner frequency  $f_0$  can be related to the size of the source (its radius  $r_0$ ) after Brune (1970) by:

$$f_0 = 0.37v/r_0 \tag{6}$$

where  $v$  is the shear-wave velocity. Finally, the seismic stress drop is given by:

$$\Delta\sigma = 7M_0/16r_0^3. \tag{7}$$

Results can be seriously affected by wave propagation effects caused by absorption, reflection and refraction at the boundaries of the geological structures. In particular, the subsurface geological structure is of principal importance in this context. Since there is no simple way to account for wave propagation effects, we have calculated the transfer function of the propagation medium using Haskell’s (1960) matrices for an 1D model.

### The application to Acireale

The Acireale municipality (more than 50,000 inhabitants) is located on the southeastern flank of Mt. Etna volcano (Eastern Sicily). It covers an area of about 40 km<sup>2</sup> that is affected by several faults able to generate local earthquakes. The origin of the city dates back to Greek colonization, but during its history the town was destroyed many times by earthquakes or invasions. Actually, Acireale has a huge cultural heritage represented by several churches and buildings, many of which are in the typical Sicilian baroque.

### The framework of the investigation

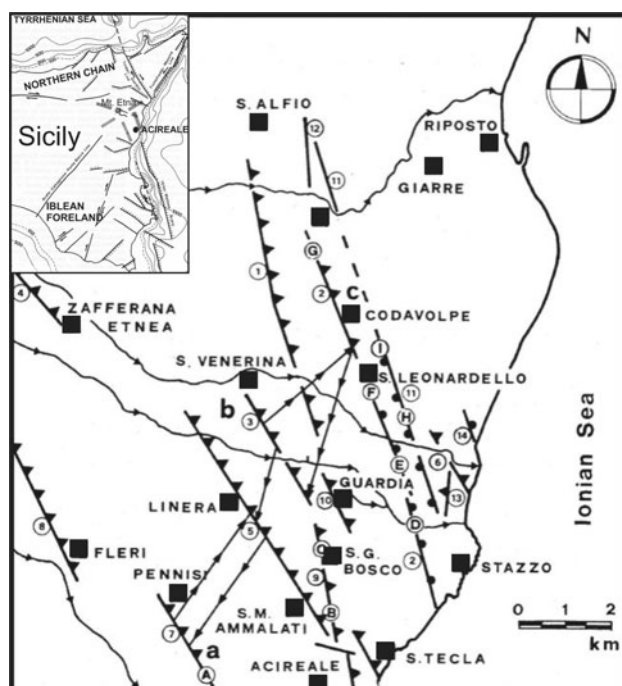
The seismicity of Eastern Sicily relates to the development of moderate to large earthquakes, the magnitudes of which may reach values up to 7. The major examples are the two destructive shocks that occurred in 1693 (Gulf of Catania,  $I_0 = XI - MSC$  scale) and in 1908 (Messina Strait,  $I_0 = XI$ ). More recently, the 13 December 1990 earthquake has caused severe damages, despite its moderate magnitude ( $M = 5.5$ ). In particular, this event cleared up that seismic hazard does not refer only to largest (but very rare) earthquakes.

The local earthquake activity on the eastern flank of Mt. Etna has a tectonic origin, due to dislocations along regional and/or local faults. However, earthquakes are generally extremely shallow ( $h < 2$  km) and characterized by low energy release ( $M_{\max} = 5.0$ ) for most events (Gresta et al. 1998).

The main faults affecting the area are characterized by lengths of some kilometers and by vertical dislocations up to some hundred meters. In detail, a network array of fault escarpments (locally named “Timpe”) is remarkable. These structures sharply downthrow to east the gently inclined coastal flank and produce a step-fault system that

culminates with a small graben, named “San Leonardello”. They define a highly seismogenic area (Fig. 1), located among Acireale, Zafferana Etnea and Riposto (Gresta et al. 1997).

Concerning the local seismogenic faults, we studied in detail the area located among Acireale, Fleri, Zafferana Etnea, S. Alfio and Riposto (see Fig. 1). This area is



**Fig. 1** Structural map of part of the eastern flank of Mt. Etna, with the main seismogenic faults (see text for details). In the upper left corner, a sketch map of Eastern Sicily; the main structural units and the location of Mt. Etna volcano and Acireale are shown

characterized by faults having a remarkable development on the ground surface. This allowed us to perform accurate field survey. Moreover, this area has been densely inhabited since a long time and a large amount of bibliographic information on local seismic phenomena, covering at least the last two centuries, is available. Identification and mapping of the tectonic structures have been performed through repeated field surveys, analysis of stereo pairs (scale 1:33.000 by I.G.M.) and collection of both unpublished reports and recent bibliography. Fourteen main alignments have been recognized and classified. Their direction, length, morphologic evidence, displacement and downthrow side are reported in Table 1.

The main direction of the faults is about N20W in the eastern part of the area, and ca. N40W (structures no. 4, 5, 7, 8) in the southwestern part (Fig. 1). The fault length varies between 0.4 km (Praiola fault) and 8–9 km (S. Leonardello fault and Macchia-Stazzo fault). Morphologic evidences consist of both fault escarpments and flexures due to the superposition of lava flows on the fault escarpments. The observed vertical dislocations range from 5 to 200 m (southernmost segment of structure no. 5); a downthrow side generally eastward is observed. Only faults no. 11 and 13 show western downthrow side. Few evidences of horizontal dislocations have been detected. The correlation between ground cracks and active faults might not be always significant; however, the use of ground cracks to identify faults in the investigated area is largely justified by the shallowness of the considered earthquakes (e.g., Lo Giudice and Rasà 1992). Only 11 structures, among the 14 ones reported in Table 1, have been recognized as responsible for earthquakes with  $I_0 > VI$ , during the last 145 years. Some of

**Table 1** Features and parameters of the main faults located on the southeastern flank of Mount Etna

No.	Fault name	Direction	Length (km)	Morphologic evidence	Downthrow side	Activity in the last 130 years
1	Moscarello	N 20W	5.05	Escarpment	East	Earthquakes
2	S. Leonardello	N 20W	8.00	Escarpment	East	Earthquakes and creep
3	S. Venerina	N 30W	3.00	Flexure	East	Earthquakes
4	Zafferana Etnea	N 45W	3.00	Flexure	East	Earthquakes
5	S. Manria Ammalati-Linera	N 40W	5.00	Flexure	East	Earthquakes and creep
6	Pozzillo-T. Fago	N 30W	1.00	Escarpment	East	Earthquakes
7	Fiandaca	N 45W	3.00	Flexure	East	Earthquakes
8	Fleri	N 45W	3.00	Flexure	East	Earthquakes
9	S. G. Bosco	N 13W	2.00	Flexure	East	Earthquakes and creep
10	Guardia	N 25W	1.02	Flexure	East	Earthquakes and creep
11	Macchia-Stazzo	N 20W	9.00	Escarpment	West	Creep
12	S. Giovanni	N 7W	1.05	Escarpment	West	No activity
13	Pozzillo-C. se Carpinati	N 7E	1.05	Escarpment	West	Earthquakes and creep
14	Praiola	N 10W	0.04	Escarpment	East	Creep

Numbers refer to Fig. 3

them are also characterized by creep phenomena (see Table 1). The faults no. 11 and no. 14 are affected only by aseismic creep, whereas the S. Giovanni fault (no. 12) is solely the not active one. The most important result of our investigation is that seismogenic structures affecting the territory of the Acireale municipality do not affect its downtown.

#### The seismic history

The analysis of all available seismic catalogs (Baratta 1901; Postpischl 1985; Azzaro et al. 1989; Boschi et al. 1995; Patanè and Imposa 1995, among the others), of coeval sources and of papers referring to single earthquakes was performed for the time period 1865–2005. The values of the maximum intensity ( $I_0$ ) were compared among the differing bibliographic sources. Moreover, the reported effects on structures, objects and people were re-interpreted in terms of the MCS intensity scale; sometimes, the original  $I_0$  value was discounted. The resulting catalog includes 93 local earthquakes. To avoid the effects of the interpolation, only the intensity values effectively obtained by the reports were attributed at each of the 64 different localities identified inside the Acireale municipality area.

The visual analysis for the completeness of catalog allowed to define the threshold as  $I_0 > VI$  for the whole considered period. The resulting catalog contains 51 earthquakes. For each of these, the date of occurrence, maximum intensity, responsible seismogenic fault and the related bibliographic references are reported. For most of the major local earthquakes, ground fractures were quoted. Considering both regional and local earthquakes, the highest seismic intensity (X in the MCS scale) in Acireale downtown was felt during the 1693 regional earthquake.

Figure 2 shows the distribution of the observed intensity values, referring to the 8 May 1914 destructive local earthquake. In the epicentral area, the intensity was IX, while damages included the total collapse of many buildings and several people killed and injured. In spite of the short distance (6–7 km), the downtown of Acireale has experienced an intensity value of V, meaning no damages. This is just an example of the high attenuation of the seismic energy with increasing distance from the epicentral area.

The main consequence of this behavior is that over the last 140 years, Acireale downtown has experienced an intensity  $I = VII$  only once, while the value  $I = VI$  was observed only six times. This fact, associated with the above reported absence of faults in the downtown, allowed us to consider the seismic hazard induced by local faults on the Acireale urban area as very low.

#### The local geology

The geology of the city of Acireale (Fig. 3) is the result of the combined effects related to (1) the volcanic and tectonic processes, (2) the Late Quaternary sea-level changes and (3) human activity. The backbone of the urban area is represented by a sedimentary slope. This substratum consists mainly of marls and claystones with a thickness of up to 800 m. Such a heterogeneous sedimentary substratum is dissected by lava flows, which form the most representative rocks cropping out in the city. The lava flows consist mainly of basalts. For the sake of convenience, we may divide our model into two levels, one related to the subsurface geology and another one to the deeper units. The subsurface geology varies from site to site, whereas the parameters of deeper units are supposed to be almost constant across the downtown. The shallow geological stratigraphy at the seven sites is reported in Fig. 4.

The parameters of the deeper units, formed by lavas, claystones, marls and limestone, are reported in Table 2. After all, the total thickness of the layer stack overlying the crystalline basement reaches about 6,000 m.

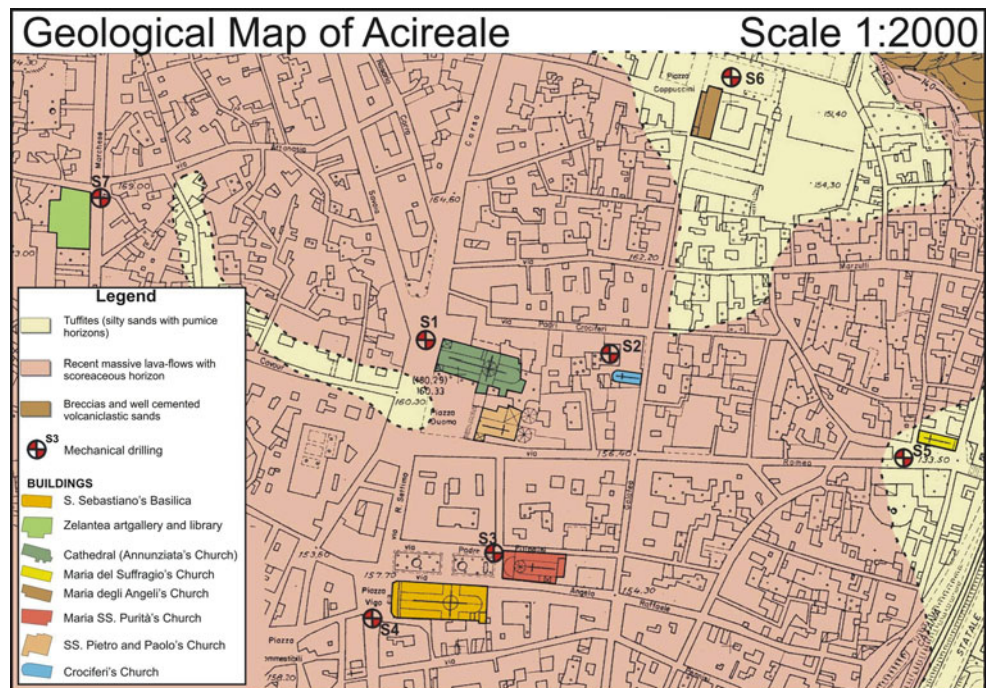
#### Microtremor data analysis

Microtremor measurements were carried out at the ground surface at the seven sites as in Figs. 3 and 4. Seismic signals were recorded with a digital tromometer (Tromino<sup>TM</sup>), which is an instrument specifically designed to accomplish this task. Tromino relies on a patent pending design, which optimizes the measurement of seismic tremor in the range 0.1–200 Hz. It is a highly portable all-in-one device (dimensions 10 × 7 × 14 cm, weight 1 kg) equipped with three orthogonal velocimeters, powered by two 1.5 V AA batteries, which includes an internal GPS antenna and does not have any external cable. The ground motion is amplified, converted into digital form, organized, transferred to a Compact Flash card and then to the PC, where the storage, analysis and review of the data are performed through a proprietary software.

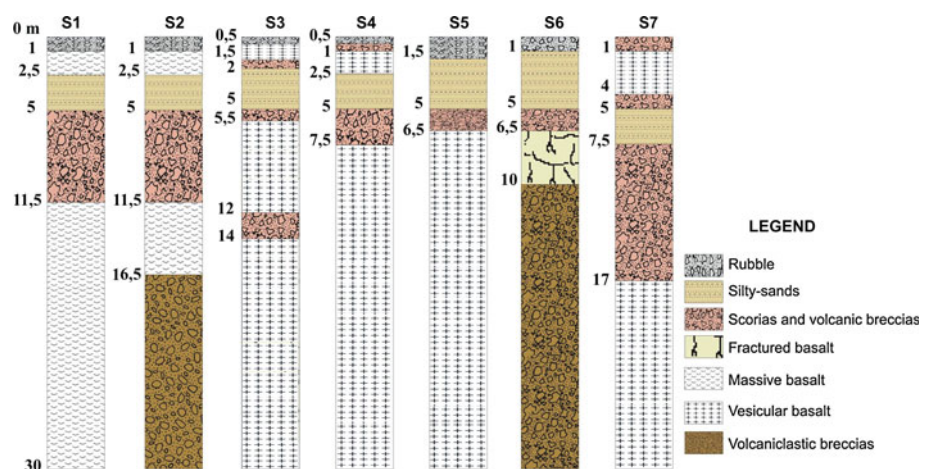
HVSR values larger than 2 have been considered as significant values of amplification. In Fig. 5, the amplification functions over the whole frequency band 0.1–50 Hz are reported for all the seven investigated sites, while the largest values of amplification at each site are reported in Table 3. Sites S1, S6 and S7 show significant amplifications (from 4 to 6) in the frequency band 1–4 Hz. This is probably due to the layered structure of the shallow subsoil at the sites (see Fig. 4). The largest value of amplification (about 7) is observed at site S5 (Fig. 5, Table 3). Sites S2, S3 and S4 evidence very low amplification (about 3). On the whole, amplification can be considered as low to moderate.



**Fig. 3** Geological map of the Acireale downtown, with the location of the seven drills providing subsurface data



**Fig. 4** Stratigraphic section of the subsoil at the seven drills for which data from drillings are available



**Table 2** Geotechnical parameters for the area of Acireale, estimated in a conservative way from Casadio and Elmi (1995) and unpublished reports

Layer	Thickness	<i>C</i> (m/s)	Density (kg/m <sup>3</sup> )	<i>Q</i>
Lava	100 m	1,500	2,200	50
Claystone	500 m	1,500	2,100	50
Marls	300 m	1,700	2,200	100
Limestone	5,000 m	2,600	2,500	150
Basement	∞	3,500	2,300	300

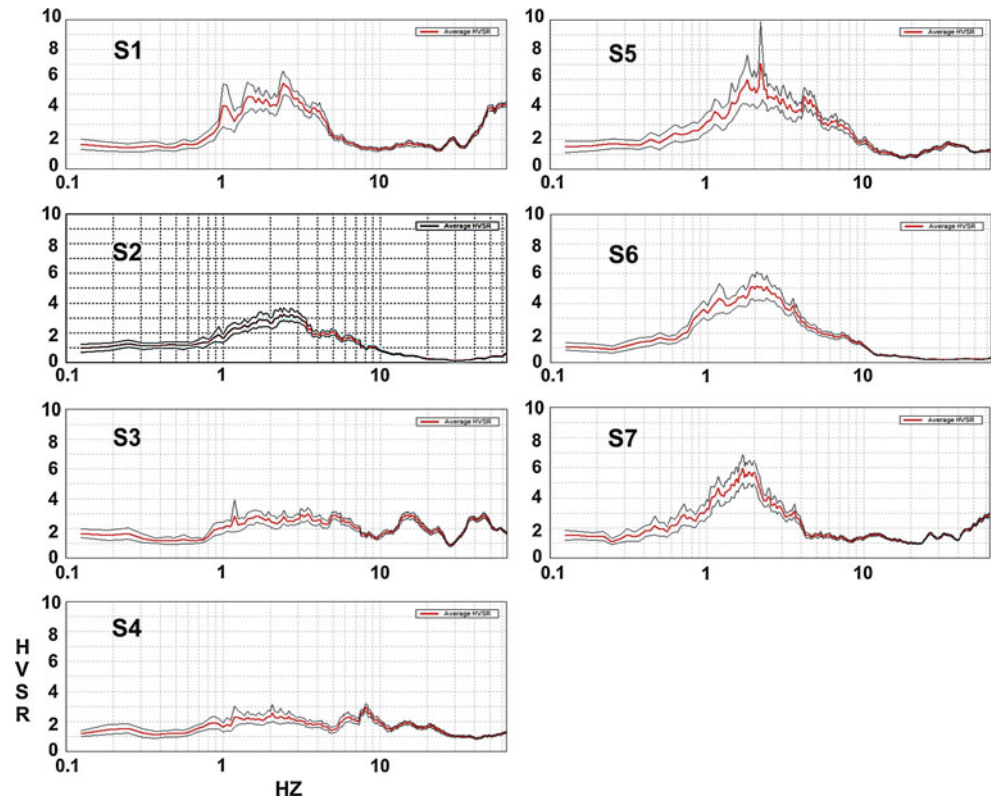
Simulation for earthquake scenarios

To represent the seismic loading, we chose the peak ground acceleration as inferred from the synthetic spectra obtained by considering two different scenarios.

The former takes into account the largest earthquake, which had shaken the urban area of Acireale (*X* degree for the observed intensity) that occurred on 11 January 1693 in the Gulf of Catania. Its magnitude was estimated by various authors to be  $M \cong 7$ , which corresponds to a seismic moment of about  $2 \times 10^{19}$  Nm. The epicentral distance from Acireale was about 25 km. By assuming a seismic stress drop of 200 bars for this event, which corresponds to the lower value estimated for the 1990 earthquake, a source area of about 200 km<sup>2</sup> is obtained (values of the parameters, from Langer et al. 1999).

The latter scenario corresponds to a local earthquake having a magnitude of  $M \cong 5.5$ , comparable with the local shock that occurred on 20 February 1818. The observed intensity in Acireale was VIII. The source parameters for

**Fig. 5** Horizontal to vertical spectral ratios by microtremor measurements at the seven sites (the average spectra in red, while the gray line represents the standard deviation)



**Table 3** Values of the highest amplification and of the related frequency for each of the seven sites

Site	Highest amplification	Frequency (Hz)
S1	5.8	2.4
S2	3.0	2.4
S3	3.0	3.4
S4	3.0	8.1
S5	7.0	2.2
S6	5.0	2.0
S7	6.0	1.7

the simulation are the same as estimated for the 1990 earthquake. The epicenter is supposed to be located about 5 km southward the downtown. The focal depth of both earthquakes was fixed at 15 km.

The synthetic spectra for the above two earthquake scenarios have been computed at each of the seven sites of Figs. 3 and 4. All spectra are shown in Fig. 6.

Generally, the highest values of the acceleration are observed in the frequency band 1–5 Hz for spectra referring to the 1693 scenario. Nevertheless, at site 6 the two spectra amplitude are comparable (Fig. 6). This is somewhat surprising since the earthquake of 11 January 1693 is the largest one that occurred in the region, and one commonly refers to it for hazard evaluation. However, the relative vicinity of the source of the 1818 shock,

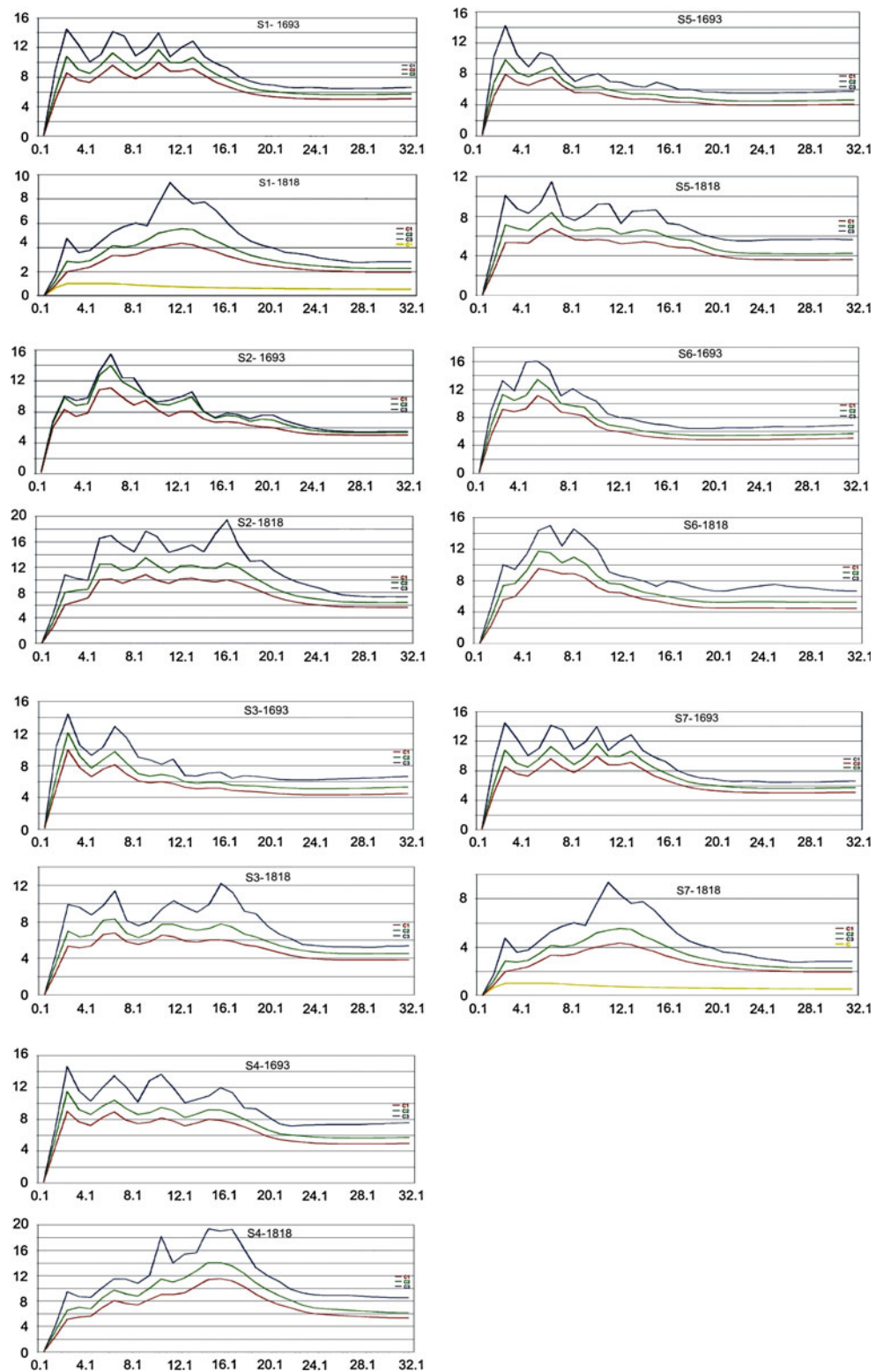
coupled with the particular layered shallow crust at site S6, may produce this effect. In any case, the 1818 local earthquake represents a rare event, like the 1693 one. Then, the seismic loading in Acireale downtown, as estimated by simulations, may be qualitatively defined as moderate.

## Conclusions

Some pioneer studies on the urban areas of Catania (Langer et al. 1999; Giampiccolo et al. 2001) and Ragusa-Ibla (Gresta et al. 2004) had suggested that the combined use of: (1) seismic history of the area, (2) detailed geo-structural survey, (3) experimental measurements of seismic noise and (4) strong ground motion simulations can be a powerful tool for the estimation of the ground shaking of a given site. This allows us to use a “standard procedure” to characterize the seismic hazard of a given site. On the whole, the collection of information is as follows:

1. the seismic history of the area (town and/or locality): basically, a seismic catalog including the observed effects produced at different sites by the past earthquakes (both local and regional);
2. the identification and characterization of the local seismogenic faults;

**Fig. 6** Spectra obtained by simulating the occurrence of the two chosen earthquake scenarios at the seven sites. *Red line* represents the average spectrum, *green line* the standard deviation, and the *blue* one the peak hold. In *yellow* the Eurocode 8 spectrum, based on the soil class B is shown. Note the different vertical scale



3. a detailed geological survey, based on the collection of available geotechnical data from drillings and/or geophysical investigation;
4. seismic noise measurements, in order to define the local site amplification due to the layered structure of the subsoil;
5. the definition of one (or more) earthquake scenario, on the basis of which the expected ground shaking spectrum may be computed. Each simulation is based on the detailed knowledge of the subsoil at the site.

Following this “procedure”, each investigated site might be characterized in terms of seismic loading. This can be helpful for urban projects, such as the planning of the use of a given area and/or the retrofit and restoring of buildings.

One of the advantages of our approach is a more detailed knowledge of possible local effects in the framework of a given area. A comparison among: (1) the local intensity of past earthquakes, (2) local amplification evidenced from noise measurements, and (3) ground motion spectra from scenario simulations can be done.

These results are much more accurate than those from statistical and/or empirical approaches. The former may give an estimation of the seismic hazard at a national or regional scale. The latter, mainly based on a rough classification of soils into three categories depending on their average hardness, are too often locally disobeyed, because of the complex shallow geology.

The main disadvantage of our approach is that it needs a large amount of data. However, when urban areas are considered, most of the geological and geotechnical data had been already acquired (and are available) by the public offices devoted to planning and controlling urban development and/or by companies devoted to utilities (i.e., water, gas, electric power).

The results obtained following our procedure and considering the downtown of Acireale (southeastern side of Mt. Etna volcano) as a test site are intriguing.

On one hand, the most important seismogenic structures affecting the lower southern flank of Mt. Etna do not affect the Acireale downtown. This fact, associated with the evidence that the local earthquakes highly attenuate their energy in short (few km) distances, allowed that during the last 140 years the seismic intensity by local earthquakes in Acireale downtown reached the value of VII only once. This induced us to choose two earthquake scenarios, the largest regional earthquake (1693, magnitude 7) and the large local 1818 earthquake (magnitude ca. 5.5). The simulated spectra have evidenced a slightly larger value for the acceleration due to the smaller (but closer) earthquake. The complex structure of the shallow subsoil at the site is responsible for the moderately high peak ground acceleration values obtained by applying the two earthquakes scenario parameters.

Finally, microtremor measurements at the chosen seven sites have evidenced only moderate site amplification factors (from 3 to 7). In conclusion, the seismic hazard for the Acireale downtown can be defined as ranging from low to moderate.

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