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# Simulating earthquakes effects: the SHAKYGROUND simulation tool

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**Abstract:** In this paper we describe SHAKYGROUND, a software tool that has been designed with the aim of providing the user a friendly environment allowing the simulation of strong ground motion by means of synthetic simulation of acceleration seismograms and the estimation of seismic load in a given area.

**Keywords:** Earthquake effects, simulation code, seismic code, ground motion, wave propagation, urban planning.

## 1. INTRODUCTION

In a classical sense, earthquakes originate from the rapid release of elastic energy caused by the rupture of rock in the earth. Damaging effects due to an earthquake arise (i) from a source outcropping directly at the earth's surface, (ii) from the radiated seismic waves. In practice the second effect is the most important. It occurs more frequently and the area shattered by seismic waves is by far larger than the zone which could be hit by an outcropping source.

Strong ground motion is seriously affected by wave propagation effects caused by changes due to 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 (1953) matrices for a 1D-model.

SHAKYGROUND has been created with the scope to provide a reliable, easy to use, and versatile tool for the estimation of seismic strong ground motion. It forms the seismological base for the design of earthquake-resistant buildings and for land use planning. Moreover, it allows the identification of sites where the expected ground shaking is severe; this can be useful for emergency planning, as well as for enhancing earthquake awareness.

The bespoke software tool incorporates concepts of the seismic source process and wave propagation effects which are well confirmed by numerous scientific studies and practical applications. The problem of seismic load estimation is approached by means of synthetic simulation of acceleration seismograms, that gives the possibility to account for the specific geological site conditions and the characteristics of the seismotectonic zone.

The user's experience is exploited for establishing the model parameters rather than for the search of a "suitable" experimental example seismogram. The mentioned simulation tool allows to vary the geotechnical and source parameters randomly disclosing the possibility to evaluate the stability of the results statistically.

Finally the program produces a report of important simulated engineering seismological signal parameters together with response spectra which can be directly compared to standard seismic codes (for ex. EC8, US Building Code).

SHAKYGROUND is a software that runs on Microsoft Windows operating systems (95, 98, NT, 2000, XP, VISTA), and a database engine for the models and results storage. The user interface allows to enter the input parameters on “sheets”. There are sheets related to the seismic source parameters, others concern the geotechnical parameters, the calculation of response spectra and some general information concerning the operation of program and its output. This system protects the user from errors due to misspellings and the use of improper parameters.

Accessing inputs from an external data base is a special feature that facilitates the use of the application in seismic zoning projects where a large number of sites and different seismic scenarios have to be considered. Earthquake parameters and typical sets of geotechnical parameters (called “stratigraphies”) can be stored and accessed in “catalogs”. The models (either derived or not from this catalogs) can be saved with the simulations results and they can be used by different users in a network and can be easily exported on the Internet/Intranet. It is possible to pass the afore mentioned sheets to the data base and to recombine them creating a new model and new sheets. This makes the setup of a model easy and fast, and avoids many errors occurring during the creation of suitable input parameters.

The results of the software tool are both numerical and graphical: response spectra, the simulated seismograms allow the user an immediate evaluation.

## 2. STRONG GROUND MOTION SIMULATION

Ground motion estimation for the purpose of seismic hazard and loading analysis may be eventually carried out in some empirical manner 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 earthquake zones. In a more refined manner the analyst tries to cull from a vast data set of strong ground motion records those accelerograms which duplicate the source, travel path and local site conditions. The difficulties coming along with this strategy are quite well-known: the empirical relations derived from records of other earthquake 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 severe questions as to the significance of these approaches. The drawbacks of the use of some empirical strategy is certainly exacerbated in earthquake zones with long quiescent periods as, e. g., Italy where the return periods of large damaging earthquakes range from tens to hundreds of years.

A possible way out of these problems, which was adopted for SHAKYGROUND, is the estimation of strong ground motion by means of synthetic simulation of acceleration seismograms. As shown for various earthquake zones and sites, synthetic simulation according to such concepts gives indeed a reasonable match of observed data, provided there is a sufficient knowledge of the source and geotechnical parameters (see, e. g., Langer et al., 1999; Gresta et al., 2004).

Global source parameters are accounted for by applying a band-pass filter to the Gaussian white noise, i.e.  $C M_0 S(f, f_0) P(f, fmax)$  where  $C$  is a constant for geometrical spreading and radiation pattern,  $M_0$  the seismic moment of the event,  $f_0$  the corner frequency,  $S(f, f_0) = f^2 / (1 + (f/f_0)^2)$ ,  $P(f, fmax) = (1 + (f/fmax)^{2q})^{-1/2}$ ,  $q$  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:  $f_0 = 0.372 c/r_0$ , where  $c$  is the shear-wave velocity. Finally the seismic stress drop is computed as  $7M_0/(16r_0^3)$ .

The strength of the synthetic approach resides in the possibility to account for the specific geological site conditions, the effects of wave propagation and the characteristics

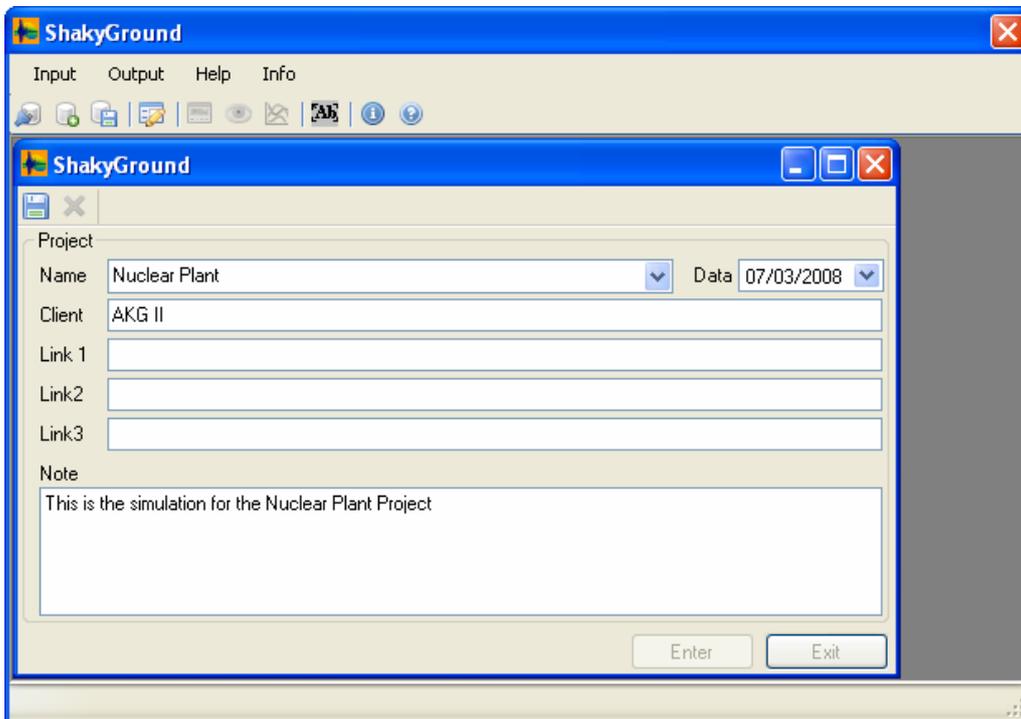
of the seismotectonic zone. According to the strategy chosen in SHAKYGROUND the user's experience is exploited for establishing the model parameters rather than for searching of a suitable, experimental example seismogram. Given the stochastic nature of the source model, The program performs a number of simulations and calculates average, standard deviations and peak hold values of engineering seismological parameters.

Furthermore, it allows to randomly change the geotechnical and source parameters, thus enabling the statistical evaluation of the stability of the results. Finally SHAKYGROUND produces a report of relevant simulated engineering parameters of seismological signal together with response spectra which can be directly compared to standard seismic codes.

### 3. HOW IT WORKS

#### 3.1 Data Input

The users can start a project typing in its name and, if needed, the customer's name (see figure 1).



**Figure 1.** The Project Screen

After saving the data, the project is created and the user can start the data entry. Each project can be made by many different "models". In SHAKYGROUND, "models" are made up of a series of "sheets", and each of them is related to a specific item of the model, e.g. the seismic source, the geological structure, the response spectra and the general conditions for the calculus. A further sheet supports the configuration of the results. Such "sheets" concept has been adopted to provide a safe input, to avoid either misspellings or the use of incorrect parameters. The sheets can be stored in the program catalog and re-used for the creation of new models.

The first sheet focuses on the seismic source parameters and their position with respect to the receiver. The random fluctuation of the parameters may also be specified. The user can re-use a previously defined source by scrolling the sources presented in the catalog ("Sources in Catalog" box) and accessing the corresponding source parameters. Otherwise one can specify a new name in the box "Source Name:", enter a new set of parameters, and finally save the new source in the catalog.

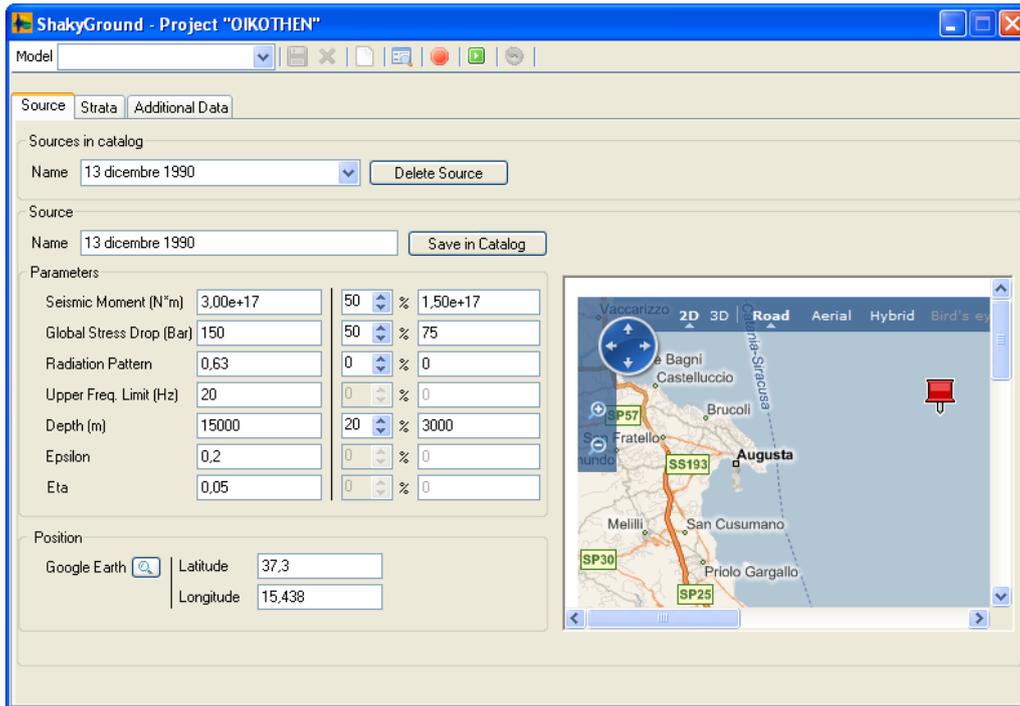


Figure 2. The Source Sheet

The software works together with Google Earth to allow for an easy location of an earthquake. The map of the event is presented in a browser screen on the right hand part of the “Source Sheet” window.

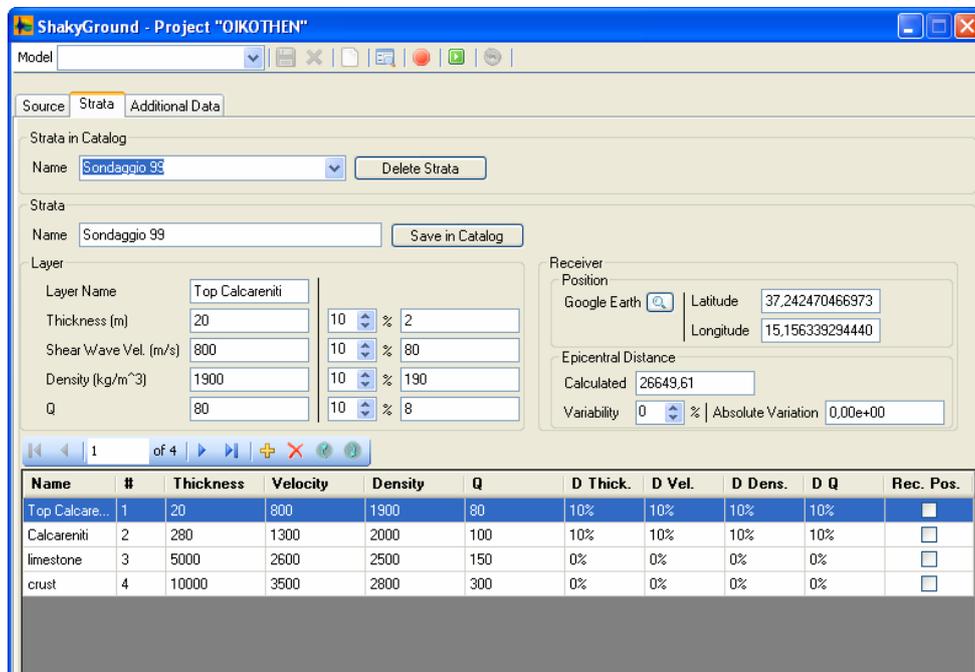


Figure 3. The Strata Sheet

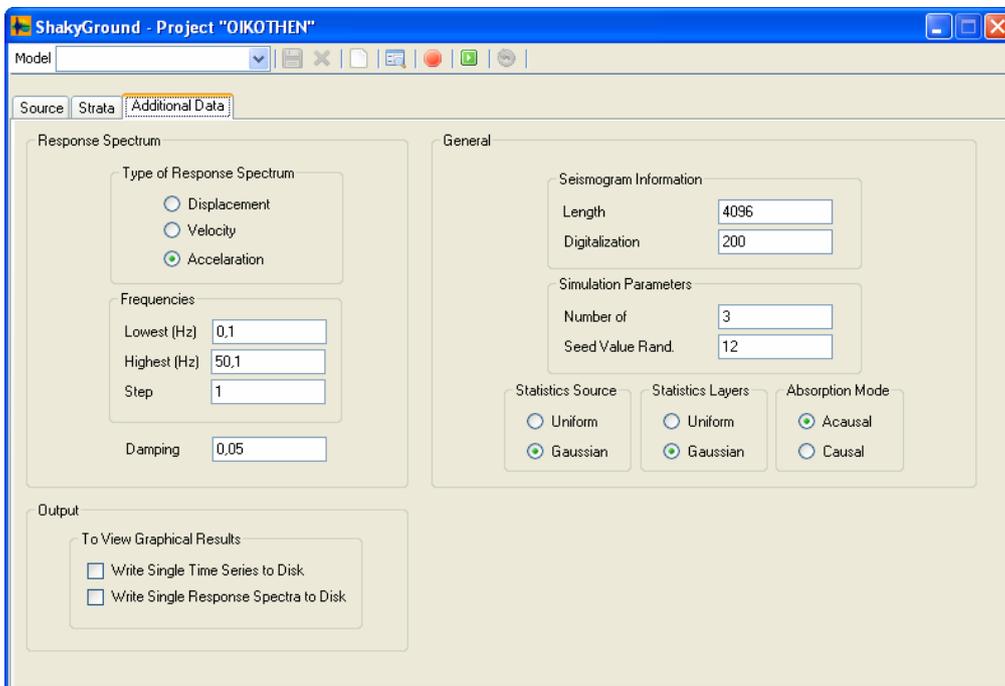
The “Strata” sheet (Figure 3) is made up of two levels. In the box “Stratigraphy” one can select an already existing geological model consisting of a number of layers. The user can

define a new layer by using the box “Layer name” or the table below. A already explained for the source parameter sheet, the user can here specify the random fluctuation of the layer parameters. By clicking on the “Insert” button, the new layer is inserted in the layer stack. Any layers can be moved within the layer stack by selecting it in the box at the bottom and using the “Up” and “Down” buttons.

The created geological model can be saved in the catalog with a new name or overwriting an existing one. For zoning projects, the strategy of using pre-defined stratigraphies is particularly effective and safe, since with little effort the user can recombine typical geological conditions at the surface and in the structure underneath.

SHAKYGROUND allows to place the receiver either at the surface or at some interface within the layer stack. With this option the tool allows analysing the case of a building whose base is supposed to be situated at some depth. The default position is set at the ground surface.

The “Additional Data” sheet (Figure 4) contains three different areas: Response Spectrum, General and Output.



**Figure 4.** The “Additional Data” Sheet

In the “response spectrum” section the user can specify some settings used by the model for calculating the response spectra (type of the response spectrum, frequency bounds and resolution). The default response spectrum is “Acceleration” as required by most seismic regulations, but when needed velocity or displacement response spectra can be selected. The default value for the damping is set to 0.05, i.e., 5% of the critical damping. This damping value is usually considered in standard seismic regulations, but occasionally damping values of 1%, 2%, or 10% have also to be used.

The “General” section of the sheet contains basic information about how to perform the calculations. In the box “Seismogram Information” the user must specify the length of the seismogram and the sampling frequency. In the box “Simulation Parameters” the user selects the number of simulations carried out for the model and the seed value for the generator of the pseudo random numbers. Two further items (box “Statistics Source” and “Statistics Layers”) concern the mode how the program varies the model parameters randomly within the ranges selected in the source parameter and layer sheets. It is possible

to configure the model to calculate source and geotechnical parameters according to a uniform or a Gaussian distribution.

The “Output” section is used to specify how SHAKYGROUND should handle the output. Usually a short output, with a report about calculated signal parameters and response spectra, is sufficient. By ticking on “Write single Time series to disk”, the program is configured to write each single synthetic seismogram on the computer hard disk: such dataset and can be visualized at the end of the run. The same applies for the Response spectra. These features enable the user to access the single time series and response spectra, thus verifying the good choice of the parameters and the performances of the model. Since the time series and response spectra are recorded as plane ASCII files, they can be easily imported by other sophisticated data processing and visualization packages.

### 3.2 Data Output

SHAKYGROUND offers several levels of output which enable the user to immediately check and evaluate the results of a simulation. After completing the numerical processing, the standard output is generated (example displayed in Figure 5).

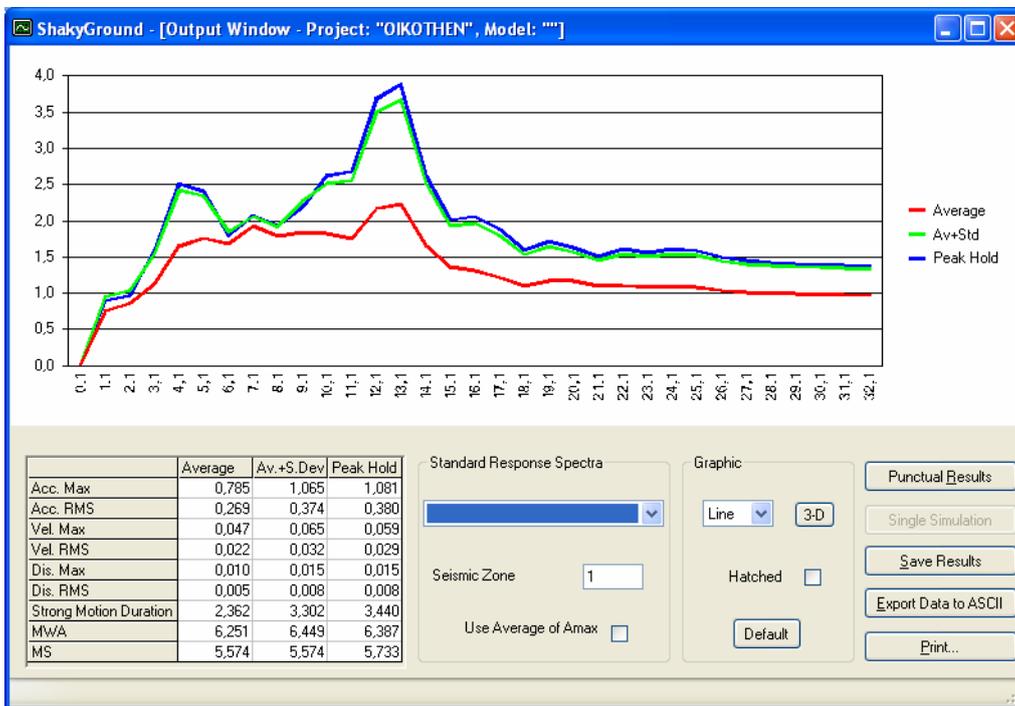


Figure 5. Output Window for SHAKYGROUND

It consists of a plot of the response spectra and their statistical variation, and of a table with important signal parameters, i.e., peak ground acceleration, velocity and displacement, RMS-values of the three types of signal, the duration of strong ground motion (calculated following the concept of HUSID-plots), finally corresponding magnitude values (MS deduced from the seismic moment, MWA as obtained from the simulated signals). All these results can be saved to a georeferenced data base, where they can be easily accessed for further processing with GIS-applications.

By choosing “View Results” the program generates a screen displaying the graphical visualization of the single simulated seismograms and response spectra (Figure 6), where the user can scroll the recorded seismograms and response spectra one by one. The accelerograms can be visualized together with velocity, displacement and WOOD-ANDERSON seismograms, as shown in the figure. By choosing a seismogram length different than the one proposed as default, plots can be visualized in their total length or be zoomed.

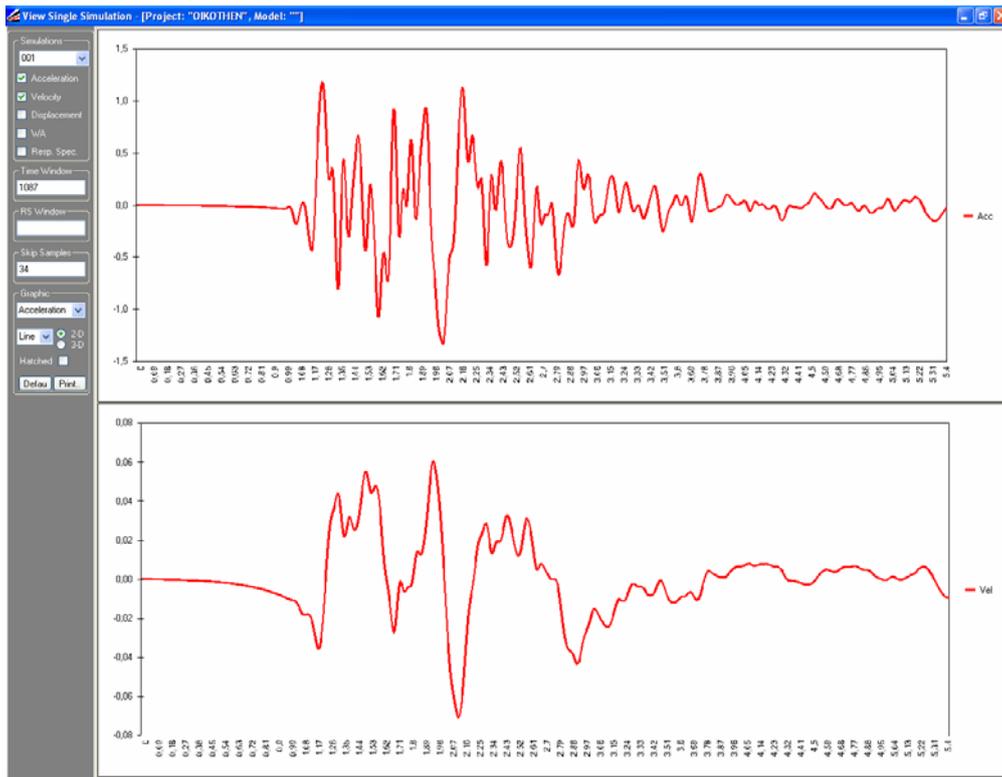


Figure 6. Single Results

The user may decide which signal types are shown by ticking on/off the selection boxes on left-hand side. The graphical interface allows the editing of the figures so that they can be easily imported in other documents, an extremely useful feature for the preparation of publications and reports.

#### 4. SHAKYGROUND USERS

##### **Public Agencies (local, regional, national) interested to territory planning, emergency planning and seismic microzoning**

Public Agencies may use SHAKYGROUND to identify critical points in a territory, spotting where damages would be greater if an earthquake should occur. The model can help the identification of areas and sites where severe ground shaking is expected, so that competent public authorities can adjust their territory planning (emergency, territorial, microzoning etc.).

The program is designed to support seismic microzoning project with many earthquakes and sites examples as input. It has been positively used in seismic microzoning projects for the cities of Catania, Ragusa, Sarno, Nocera (Italy).

##### **Civil, mechanical and electrical engineers, geologic and geotechnical consultants**

These users may use SHAKYGROUND to obtain numerical data of earthquake ground motion at the level of the foundation of a building.

At the same time they can obtain the prevision of the seismic impact in a specific site where a building is planned to be erected or reconstructed or reinforced. Moreover they can insert the schemes of the synthetic seismogram resulted by the run of the simulations as input for their calculations.

##### **Civil Protection**

The necessities of these users are the same of those of the Public Agencies. The critical sites location allows the territorial planning and the emergency planning optimization. It will be possible to identify zones where earthquake damages will be particularly serious.

People living in these areas will have greater need of aid, and at the same time these areas would not have to be chosen for the deployment of first aid structures.

### **Insurance and re-insurance Companies**

Companies that want to propose insurances contracts covering damages to buildings caused by earthquake, can use SHAKYGROUND to classify all sites on the basis of the estimated effects for several earthquake scenarios. The so obtained results of the seismic zoning would help the insurance companies to develop a specific marketing strategy for each of these areas.

### **CONCLUSIONS**

Based on sound and proven methodologies, SHAKYGROUND provides the user with a user friendly interface for tackling the complex problem of the assessment of seismic hazard. The program has already been used in many projects in Italy, Germany, USA, Japan, Corea and has proven to be a reliable and useful software for estimating strong ground motion. More information on SHAKYGROUND can be found at [www.shakyground.biz](http://www.shakyground.biz).

### **REFERENCES**

- Aki, K., Characterization of barriers on an earthquake fault. *Journal of Geophysical Research*, 84, 4160-4168, 1979.
- Boore, D.M., Stochastic simulation of high frequency strong ground motion based on seismological models of the radiated spectra. *Bulletin of the Seismology Society of America*, 73, 1865-1894, 1983.
- Brune, J., Tectonic stress and the spectra of seismic shear waves from earthquakes. *Journal of Geophysical Research*, 75, 4997-5009, 1970.
- Gresta S., Langer H., Mucciarelli M., Gallipoli M.R., Imposa S., Lettica J., Monaco C. (2004). The site response in the city of Ragusa-Ibla (Sicily) by using microtremors and strong ground motion simulations. In: Risk Analysis IV (C.A. Brebbia ed.), WIT Press, Southampton, pp. 93-101.
- Haskell N.A., The dispersion of surface waves in layered media. *Bulletin of the Seismology Society of America*, 43, 17-34, 1953
- Langer H., Catalano S., Cristaldi M., De Guidi G., Gresta S., Monaco C., Tortorici L., 1999. Strong ground motion simulation in the urban area of Catania on the basis of a detailed geological survey. Proc. 2nd Int. Sympos. Earthquake Resistant Engineering Structures, Catania, Italy, June 15-17, 1999, pp. 343-352, ISBN 1-85312-689-6