AN EXAMPLE FOR STRONG GROUND MOTION MODELLING IN CONNECTION WITH VRANCEA EARTHQUAKES (CASE STUDY IN NE BULGARIA, RUSSE SITE)

Mihaela KOUTEVA[1], Giuliano F PANZA[2], [3] And Ivanka PASKALEVA[4]

SUMMARY

A powerful tool, capable of synthesising realistic ground motion from a basic understanding of fault mechanism and seismic wave propagation in the earth is illustrated in this study. Providing site response assessment simultaneously over the frequency and space domains, the applied procedure goes beyond the traditional engineering approach that discusses the site as an isolated point.

The territory of Bulgaria is situated in a seismically active region, the Mediterranean zone of the Alpine-Himalayan seismic belt. It suffers the seismicity of different seismic sources located in the area. In particular Northern Bulgaria is exposed to the hazard of strong ground motion from earthquakes in the Vrancea region in Romania. The wavefield radiated by the intermediate-depth (70 to 170 km) Vrancea earthquakes mainly at long periods (T>1s) attenuate less with distance compared to the earthquakes in other seismically active zones in Romania and Bulgaria. For these reasons a realistic modelling of the ground motion expected to occur at Russe due to a given Vrancea earthquake is carried out. The numerical experiments are performed by means of an analytical technique based on mode summation and mode coupling. The simulated ground motion is discussed in terms of acceleration time-histories (not only peak ground accelerations) as well as response spectra. A good agreement between the synthetic signals and the available strong ground motion accelerations recorded at Russe during the Vrancea earthquake of May 30, 1990 is observed. An estimation of the local site amplification in terms of spectral acceleration is illustrated. The procedure may be efficiently used to estimate the ground motion for different purposes - microzonation, urban planning, retrofitting or insurance of the built environment, etc. A natural extension of this work will be a parametric analysis to construct a proper earthquake scenario.

INTRODUCTION

The available strong ground motion database is too limited to accurately quantify the magnitude scaling and attenuation characteristics of large magnitude earthquakes at epicentral distances of engineering interest. Therefore the synthetic seismograms represent the best hope on design for the near future, when seismologists will be able to provide engineers with realistic time histories and response spectra for community- and site-specific situations. The best way of improving the understanding of these topics is to use recent earthquakes that have occurred during this century [Hays, 1998]. The main idea of this paper is to illustrate some results obtained by ground motion modelling, particularly for the case study of the town of Russe and its vicinity, NE Bulgaria, exposed to the Vrancea intermediate depth seismic sources. A suitable tool for the construction of synthetic signals, which is the modal summation technique [Panza, 1985; Panza & Suhadolc, 1987; Florsh, Fah, Suhadolc and Panza, 1991] and the mode coupling or the so-called analytical modal summation approach [Romanelli,

[1] *Central Lab. of Seismic Mechanics and Earthquake Eng.(CLSMEE), Acad.G.Bonchev str., bl.3, 1113 Sofia, Bulgaria*
[2] *DST, Univ. of Trieste, Via E.Weiss 4, 34127 Trieste, Italy, E-mail: panza@geosun0.univ.trieste.it, Fax: +39 040 6762111*
[3] *SAND Group, ICTP, Strada Costiera 11, 34014 Trieste, Italy*
[4] *CLSMEE, Fax: +359 2 9712407, E-mail: paskalev@geophys.bas.bg*

Bing, Vaccari and Panza, 1996; Vaccari, Gregersen, Furlan, and Panza 1989; Romanelli, Bekkevold and Panza, 1997] is applied in this study.

The Vrancea seismogenic zone, situated beneath the Eastern Carpathian Arc, is one of the responsible for the most destructive effects experienced in NE Bulgaria in the last years. In fact, this intermediate source can be considered as a regional danger, since large industrial areas can be seriously affected by the strong events originating in this seismogenic area. Vulnerable high risk constructions as NPP, lifelines, chemical plants, large dams as well as residential areas can be damaged or even demolished. Some investigations show that neglecting the Vrancea seismic source can cause severe underestimating of the expected intensity in comparison with the case, when only Bulgarian and regional seismicity is considered [Stanishkova & Slejko, 1991]. During the last century, twelve strong Vrancea events (Mw>6.4) have been reported. Vrancea earthquakes in 1940, 1977, 1986 and 1990 caused large damage in different parts of Europe. Due to these events, intensities up to IX (MSK-64) were observed in NE Bulgaria [AA.VV., Brankov, 1983]. During the last twenty years four major events were felt in NE Bulgaria, (e.g. Russe): March 4, 1977 (Mw=7.4); August 30, 1986 (Mw=7.1); May 30, 1990 (Mw=6.9) and May 31, 1990 (Mw=6.4).

SIMULATION METOD

The particle motion including the inertia, body and surface forces is described by a linear system of three partial differential equations, with parameters that are dependent on the space variables. It is not always possible to find an exact analytical solution for the equations describing wave propagation in anelastic laterally heterogeneous media. In general there are two main classes of methods to solve the equations of motion, analytical and numerical methods. Analytical methods should be preferred when dealing with models whose dimensions are several orders of magnitude larger than the representative wavelengths of the computed signal, because of the limitations in the dimensions of the model that affect the numerical techniques. Among the methods that try to solve the equations of motion in flat laterally heterogeneous media with numerical techniques applied to analytical solutions, two main complementary classes can be distinguished: methods based on ray theory and methods based on mode coupling. The arrivals associated with surface waves (fundamental and higher modes) represent the dominant part of the seismogram and they supply the data with the most favourable signal/noise ratio and for seismic hazard studies, with engineering implications. Surface waves cannot be modelled easily with methods based on ray theory, because of computational problems: it is not theoretical, but a practical limitation. On the other end the modal summation is a natural technique for modelling the dominant part of the seismic ground motion. The key point of the technique is the description of the wavefield as a linear combination of given base functions, the normal modes characteristic of the medium.

In this study it is illustrated the application of the analytical mode summation method based on modal summation and mode coupling approach [Romanelli, Bing, Vaccari and Panza, 1996; Vaccari, Gregersen, Furlan, and Panza 1989; Romanelli, Bekkevold and Panza, 1997], for simulating the ground motion at Russe. The technique shares the idea that the unknown wavefield generated by the lateral heterogeneties is written as a linear combination of base functions representing the normal modes (Love and Rayleigh) of the considered structure, therefore the problem reduces to the computation of the coefficients of their expansion. The basic model is formed by two different quarter-spaces in welded contact. The main difficulty here is the fact that the horizontal boundary conditions are no longer valid, so some diffracted waves at the contact are neglected and energy considerations must be used to check if the approximation can be accepted [Vaccari, Gregersen, Furlan, and Panza, 1989].

INPUT DATA

All the existing assessments of the seismic hazard of the Bulgarian territory are based on the evaluation of regional seismicity, geological and tectonic situation and earthquake source characteristics. The tectonic characteristics of the Balkans are described by different authors: [e.g. Bonchev 1982, Dachev 1988, Dabovski, 1991, T.van Eck & T. Stoyanov, 1995]. According to the tectonic map of Bulgaria presented by Stanishkova & Slejko, [1991, 1994], just few buried faults are present at Russe site. In fact, three kinds of input parameters are required: (1) source seismic tensor, (2) travelled path mechanical characteristics and (3) local site conditions.

The input data for the ground motion simulation at Russe due to Vrancea intermediate depth seismic events consist of two structural models (bedrock and local structure) which are shown in figure 1 and of the seismic source tensor. To include the free vibration periods of different types of construction frequency range up to 1Hz is considered in these computations.

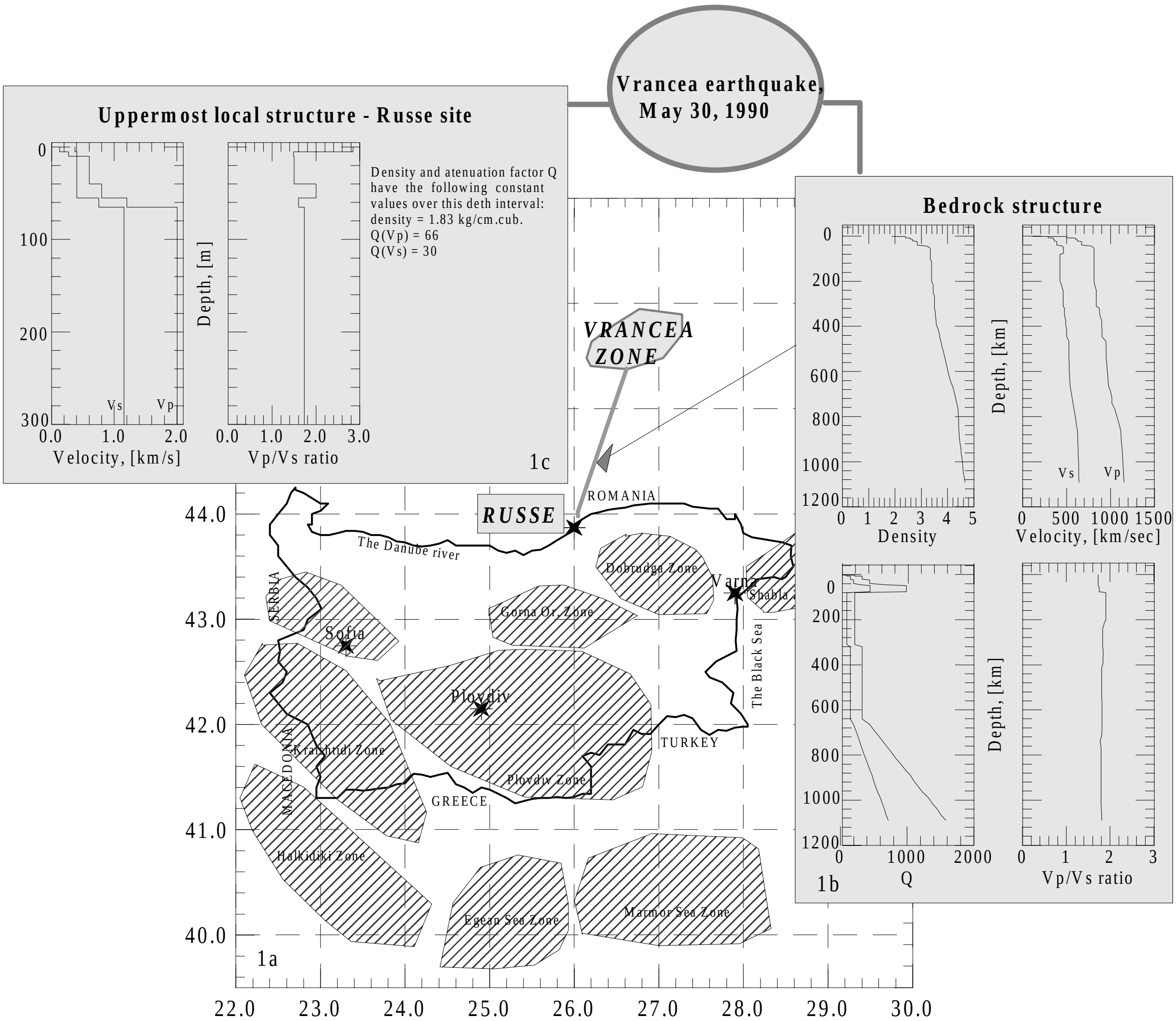


Figure 1. Ground motion modelling. (1a) Seismogenic areas (shadowed zones) influencing the territory of Bulgaria according Glavcheva and Samardgieva, [Todorovska, M., Paskaleva I., Glavcheva R. , 1995]; (1b) Bedrock structure and (1c) Uppermost part of the local model, below 300m the both structures have the same geotechnical characteristics

The structural information is organised in I-Data format [Du, Michelini and Panza, 1998] and represents the structure of the seismic wave propagation path from Vrancea to the site of Russe (bedrock), about 270 km away, and the local sedimentary layered structure of Russe site. The bedrock structure shown in figure 1b has been chosen from a comparative analysis of the available structures [Paskaleva, Ranguelov, Shanov, Matova and Kouteva, 1996; Radulian, Vaccari, Mandrescu, Panza and Moldoveanu, 1998].

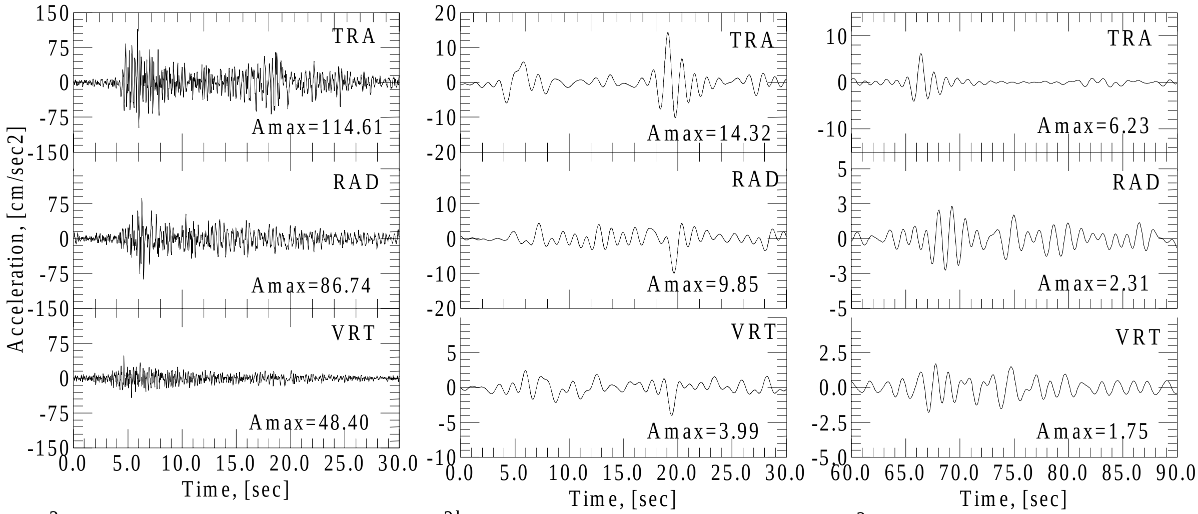
Detailed geological and geotechnical data available for a surface layer, about 100m thick in Russe are used to define the uppermost part of the local model (figure 1c) along a cross section oriented NE 42 SW.

The seismic source is described as a buried double-couple point. The focal mechanism used here corresponds to the May 30, 1990 Vrancea earthquake, Mw=6.9 [Dziewonsky, Ekstrom, Woodhouse and Zwart, 1991].

NUMERICAL EXPERIMENTS AND DISCUSSION OF THE RESULTS

The available observation in Russe is the three-component accelerogram, shown in figure 2a. The same data low-pass filtered at 1Hz are shown in figure 2b and the computed accelerograms in figure 2c. The comparison between the response spectra for the three components of the ground motion is shown in figure 2d. The results shown in figure 2 have been obtained without any data fitting, but simply using the information available in the literature. The existing strong motion database is rather limited and it is therefore encouraging the quite good agreement obtained for the transversal component. In addition we may quote that a similar approach has led to a good agreement between the synthetics and observation at Magurele, Bucharest [Moldoveanu & Panza, 1999].

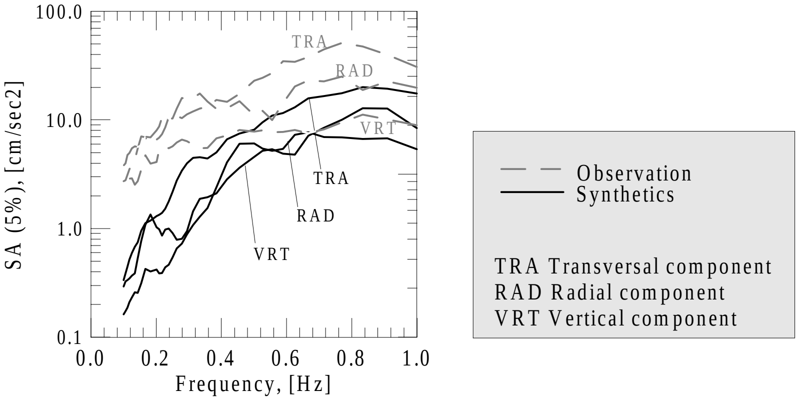
To improve the general correspondence between the synthetics and the observed signals, different numerical experiments have been carried out varying (1) the source parameters (dip, rake, strike, depth and distance) and (2) the velocity model of the uppermost 500m of the surface layer of the local model [Mammo, Vuan, Costa and Panza, 1995].



2a.
Corrected recorded signal

2b.
Corrected recorded signal, filtered by low-pass filter with cut-off freq. at 1Hz

2c.
Synthetic accelerogram

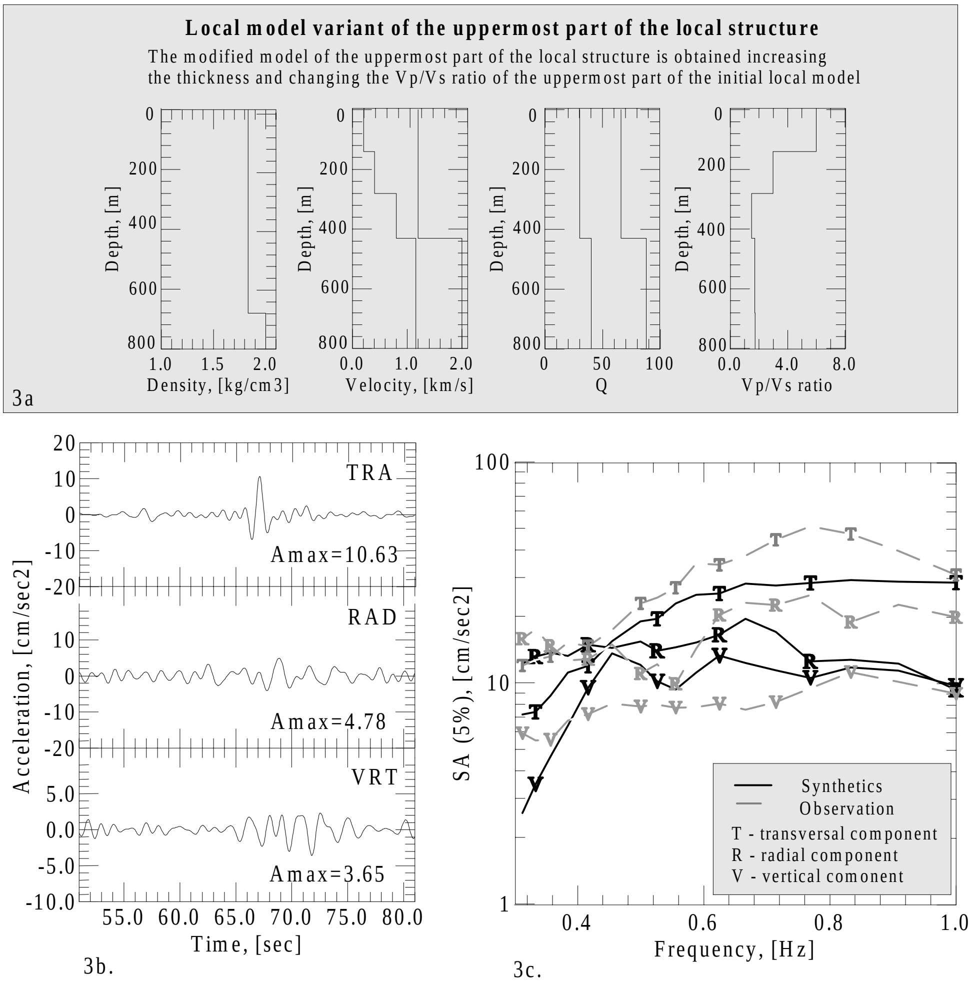


2d
Synthetic and observed response spectra, 5% damping

Figure 2. Ground motion modelling. Accelerations at Russe site, due to Vrancea event of May 30, 1990: (2a) corrected recorded signal (CRS), origin time coincides with time triggering of the recording instrument; (2b) low-pass filtered CRS with cut-off frequency at 1Hz; (2c) synthetic signal and (2d) synthetic and observed response spectra

Among the selected source parameters the source depth is especially important for the modelling of the all components of the ground motion, while the space orientation of the movement at the source, expressed by rake, dip and strike, influences much more the radial and vertical components than the transverse one. The same conclusion is drawn out also for Magurele site, Bucharest [Moldoveanu & Panza, 1999]. Varying the characteristics of the uppermost part of the local model causes obvious changes in the shape of the signals and their peak amplitudes for all of the three components. The synthetic signals shown in figure 3b and 3c have been obtained considering the local model variant shown in figure 3a.

In spite of the relatively simple models used for the source and the medium, the synthetic ground motion reproduces qualitatively the observed data quite well for the purposes of seismic engineering. The peak values of the synthetic and observed time-histories for the transversal and vertical components are in a very good agreement, while for the radial component the observed peak value is twice the synthetic one.



3b.
Synthetic accelerogram, obtained increasing the Vp/Vs ratio of the surface layer of sediments

3c.
Response spectra, 5% damping.
Synthetic and observed response spectra

Figure 3. Ground motion modelling. Accelerations at Russe site, due to Vrancea event of May 30, 1990: (3a) local model variant of the uppermost part of the local structure (3b) synthetic signal obtained considering the Vp/Vs ratio in the range of 3 to 5 in the uppermost part of the local model and (3b) synthetic and observed response spectra

Relying on the reached good agreement between the synthetics and the observation, we can investigate the behaviour of the so called "site effect" even if the heterogeneous model is rather simple. A practical definition of the site effect, that combines the purposes of the engineering and seismological communities, is proposed by Field [1996]: "the unique behaviour of a site, relative to other sites, that persists given all (or most) of the potential sources of earthquake ground motion in the region." Such a definition implicitly reveals the difficulties connected with the correct site response estimation, i.e. the identification of the different ingredients that are involved in the resulting ground motion signal: source, path (including the presence of lateral heterogeneities) and local soil effect. Due to the simple model considered, the use of classical methods will allow to identify a single site effect along the entire model. In reality the situation is quite different, as can be seen from figure 4a and 4b, where some site effects in terms of response spectra amplitudes ratio, for 5% damping, are shown. The site amplification is defined as the ratio between the values obtained considering the structure of the local site and the values obtained considering only the bedrock structures. Transversal, radial and vertical components are shown.

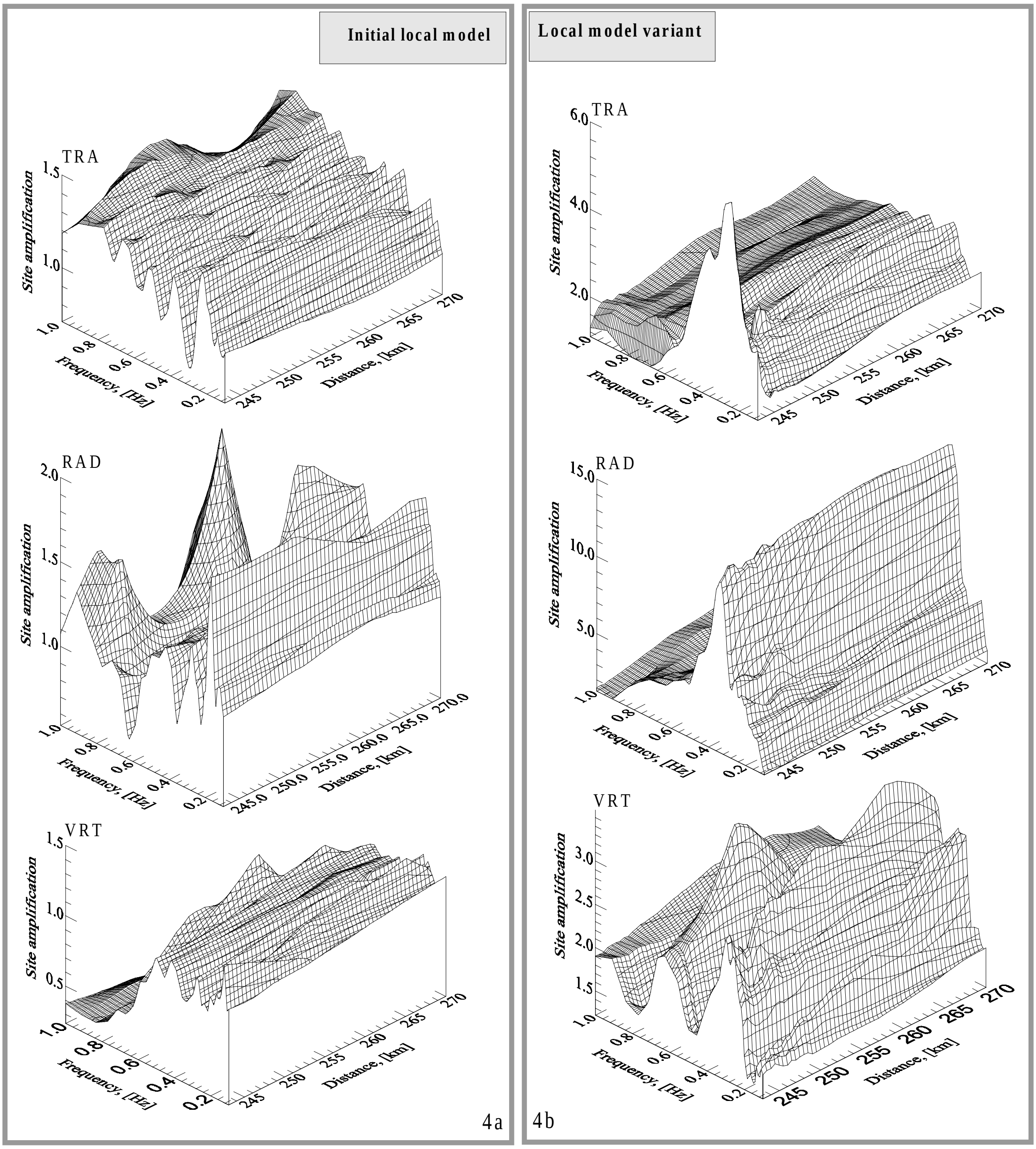


Figure 4. Ground motion modelling. Analytical mode summation approach. An estimation of the local site effects at Russe in terms of spectral accelerations, Vrancea, May 30, 1990 earthquake, (4a) initial local model and (4b) new local model, obtained by increasing the thickness and Vp/Vs ratio of the uppermost part of the local structure.

The results obtained using the local model variant shown in figure 1c show that the maximum amplifications for the vertical component occur at frequencies below 0.5 Hz, while for the radial component there are several peaks, distributed over the entire considered frequency range. The pattern for the transversal component is similar to the one of the radial, but generally smoother. Varying the characteristics of the uppermost part of the local model, increasing its thickness and Vp/Vs ratio keeping Vs fixed causes significant changes in the absolute values and in the general pattern of the site effects. For the transversal and radial components there is a clear shift of the peaks of site amplification to lower frequencies. For the vertical component, a redistribution of the amplification over the whole frequency range considered is observed. The radial component gives the most significant contribution to the site amplification for both local models, while the vertical is less affected by the local soil conditions. Therefore to estimate properly the site effects it is necessary to incorporate in the direct modelling of the wavefield all the factors controlling the ground motion at the site: the source tensor, the lateral heterogeneities of the media and their relative positions. It is not sufficient to consider only the structural models as it is done in the usual practice for the most engineering applications. The performed study shows how difficult it can be to define “pure site effect” caused only by the local geological settings. Even in a situation with quite simple geological settings, as in the example presented in this paper, it is obvious the irregular trend of the site amplification over the frequency and space domain due to the mutual interaction between the wavefield and the lateral heterogeneties. To obtain realistic and reliable seismic hazard assessment it is therefore necessary a detailed parametric study to define the different ground shaking scenarios corresponding to the relevant seismogenic zones affecting a given site.

CONCLUSION

1. The illustrated approach is capable of synthesising realistic strong ground motion records from a basic understanding of fault mechanism and seismic wave propagation in the earth. Rather good agreement between the synthetic and observed signals is obtained using quite simple source and structural models.

2. The approach used in this study is suitable to compute a wide set of time histories and spectral information corresponding to possible seismotectonic scenarios for different source parameters and structural models and to provide a definition of realistic seismic input, necessary for different purposes of earthquake engineering. Therefore, it is very useful for the engineering practice both, from the economically and scientific point of view.

3. An advantage of this approach, in comparison with the traditional engineering methods [Lysmer, Udaka, Tsai and Seed, 1975] is the possibility to obtain the site response simultaneously over the frequency domain and as spatial distribution. The obtained results - site amplification distribution over frequency and space - suggest that even at sites with rather simple local geological settings the traditional method can produce very misleading result.

4. To perform an accurate assessment of the site effects, it is necessary to make a parametric study that takes into account the complex combination of the seismic source parameters and the laterally varying characteristics of the seismic wave propagation media.

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