Comparison between 1-D and 2-D site effects modeling in Thessaloniki

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ABSTRACT: The site effects in the city of Thessaloniki are estimated using synthetic seismograms obtained at different sites of well known geology. First, 1-D local soil profiles are used to construct strong motion synthetics based on modal summation method for frequencies up to 10 Hz. As input, four point sources are used, located at different distances and azimuths from the stations. Ratios of response spectra of the local 1-D over the regional 1-D seismograms are calculated and a theoretical mean amplification is estimated. To estimate the ground motion in the laterally heterogeneous part of the structural model we use different 2-D cross-sections modeling the subsurface beneath the receivers and compute synthetic accelerograms up to frequencies of 6 Hz both for P-SV and SH waves. For this purpose a hybrid method is applied which combines the modal summation and finite difference techniques. A comparison between the 2-D site effects with the mean site amplification estimated by the 1-D approach shows that in cases of complex geometries the use of at least 2-D geometries in site effects estimation is mandatory.

1 INTRODUCTION

Over the past few decades many urban areas have been hit by large destructive earthquakes, such as Mexico 1985, Loma Prieta 1989, Northridge 1994, Kobe 1995. The big amount of losses, has directed the scientific community's interest on estimation of seismic ground motion in such areas, before an earthquake occurs. This requires knowledge of both the sub-soil structures and the possible causative seismic sources, along with the availability of numerical techniques that allow us to map the expected ground motion. Detailed numerical simulations play an important role in the estimation of ground motion in regions of complex geology. They can provide synthetic signals for areas which lack recordings. Even when real time histories exist, the synthetics can be used for validation of the numerical method used by comparing them with the real recordings. Numerical simulations are, therefore, useful for the design of earthquake-resistant structures, in particular when seismic isolation techniques are applied. In fact the number of available strong motion recordings containing reliable information at periods of a few seconds is very small, and will not increase very rapidly, since strong earthquakes in densely instrumented areas are rare events.

It is necessary to proceed to pre-disaster surveys that can be usefully employed to mitigate the effects of the next earthquake, using all available technologies. As clearly indicated by the recent events in Northridge (1994) and Kobe (1995) we cannot only confine ourselves to using what has been learned from a catastrophe in the area in which it took place, but we must be also able to take preventive steps, extending, in a scientifically-acceptable way, results obtained to areas in which no direct experience has been gained. Therefore, in recent years many computational techniques have been proposed for the theoretical estimation of seismic motion at a specific site. According to Fäh et al. (1993) and Suhadolc (1997) the numerical methods that handle the wave propagation in two-dimensional media, can be devided into two classes: a numerical and an analytical one. According to the former the computational algorithm is based on an approximate mathematical method for solving the formal representation of the problem, while for the latter one the computational algorithm is based on an exact formal solution.

The numerical methods are capable of treating very complex structures; however they are restricted in the size of the models, which they can handle by computer memory limitations. Often the source cannot be included in the structural model, because its distance from the site of interest is too large; and the incoming wavefield is approximated by a planed polarized body wave. The advantage of the analytical methods is the possibility of treating realistic source models and extended structural models.

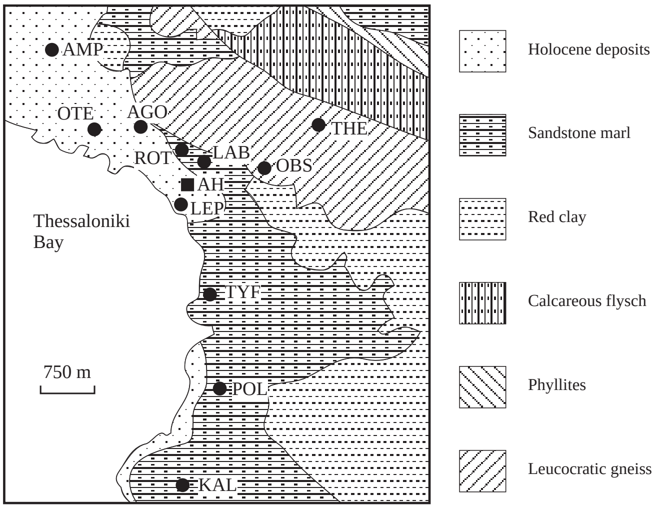

Figure 1. Map of the city of Thessaloniki showing the sites under examination (modified after Lachet et al. (1996)).

These methods can be applied effectively to simple 2-dimensional geometries of sedimentary basins. In the present study we estimate the theoretical ground amplification at 11 selected sites with known subsurface geology within the city of Thessaloniki (Fig. 1) using for the 1-D models an analytical approach (mode summation) and for the 2-D models a hybrid approach (Fäh, 1992; Fäh et al., 1993) that couples mode summation and finite differences in such a way as to maximise the advantages of each technique.

2 1-D COMPUTATIONS

The data used in the theoretical 1-D and 2-D modeling come from detailed geotechnical information derived from cross-holes at each site (Lontzetidis, 1993; Raptakis, 1994).

Under the first km of depth each local site model is underlain by the regional velocity model, assumed to be the same as the one around Volvi basin (Papazachos, 1993).

For two of the sites that are located on bedrock (OBS and THE), the local site velocity model coincides with the regional model, whose velocity at 1 km depth is extended to the surface. Figure 2 shows the body waves velocities (V_p, V_s) at the first meters of depth at each station.

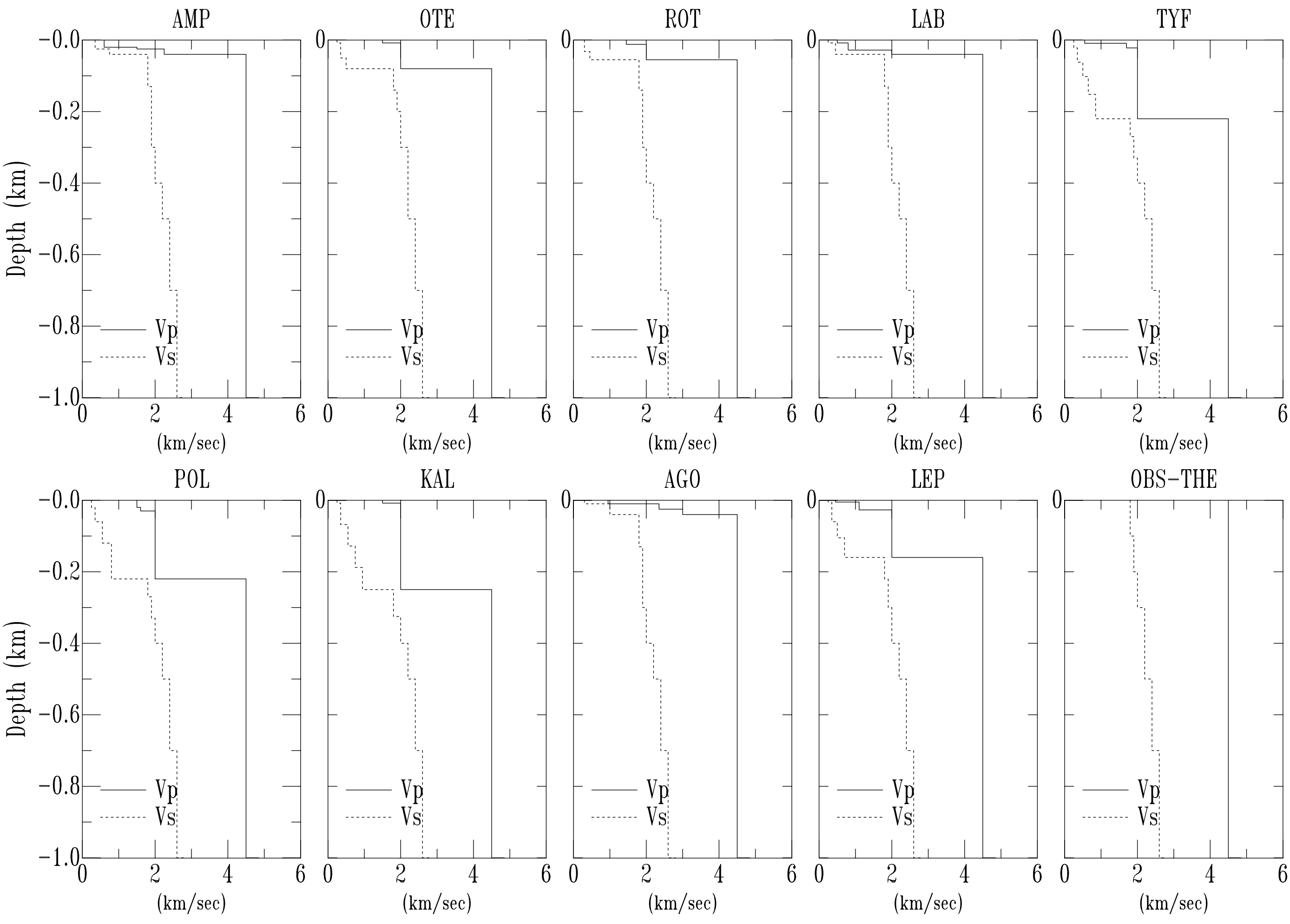

Figure 2: P-wave (V_p) and S-wave (V_s) velocities (continuous and dotted line respectively) at each station for the first km of depth.

We applied an algorithm based on modal summation method (Panza, 1985; Panza & Suhadolc, 1987) to construct complete strong motion synthetics for all components of motion at each site for frequencies up to 10 Hz. The synthetic accelerograms are generated by four double-couple point sources, located at different distances and azimuths from the stations but in the same areas where there is observed seismicity (Fig. 3).

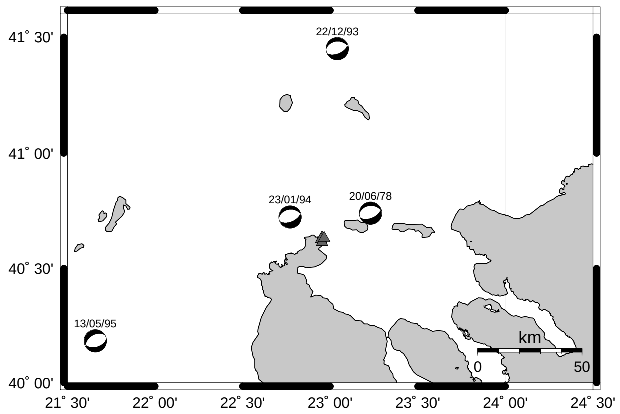

Figure 3: Distribution of the stations in the city of Thessaloniki (dark triangles) and the epicenters of the four sources used as input for the construction of the synthetics.

The location of one of these events (# 1, Table 1) corresponds to that of the destructive earthquake of June 20 (Ms=6.5) which hit Thessaloniki in 1978 (Papazachos, 1979; Soufleris et al., 1982). A second event (# 4, Table 1) is located in the area of the Kozani earthquake (Ms=6.6) of May 13,1995 (Hatzfeld et al., 1997). The remaining two locations are related to areas where the seismicity level is lower.

Table 1. Catalogue of earthquakes used for the construction of synthetics. φ stands for the strike, δ for the dip and λ for the rake of the earthquake.

I/N	Date	Lat N°	Lon E°	φ°	δ°	λ°
1.	780620	40.740	23.230	67	56	-100
2.	931222	41.450	23.040	67	56	-100
3.	940123	40.724	22.772	67	56	-100
4.	950513	40.183	21.660	240	45	-101

For all the four events we calculate the ratios of undamped response spectra of accelerograms obtained by the local 1-D over those obtained by the regional 1-D velocity model. Figure 4 shows the results obtained at four of the stations (ROT, LEP, TYF and at the station on bedrock, OBS), while the results obtained at the rest stations can be found in Triantafyllidis et al. (1998).

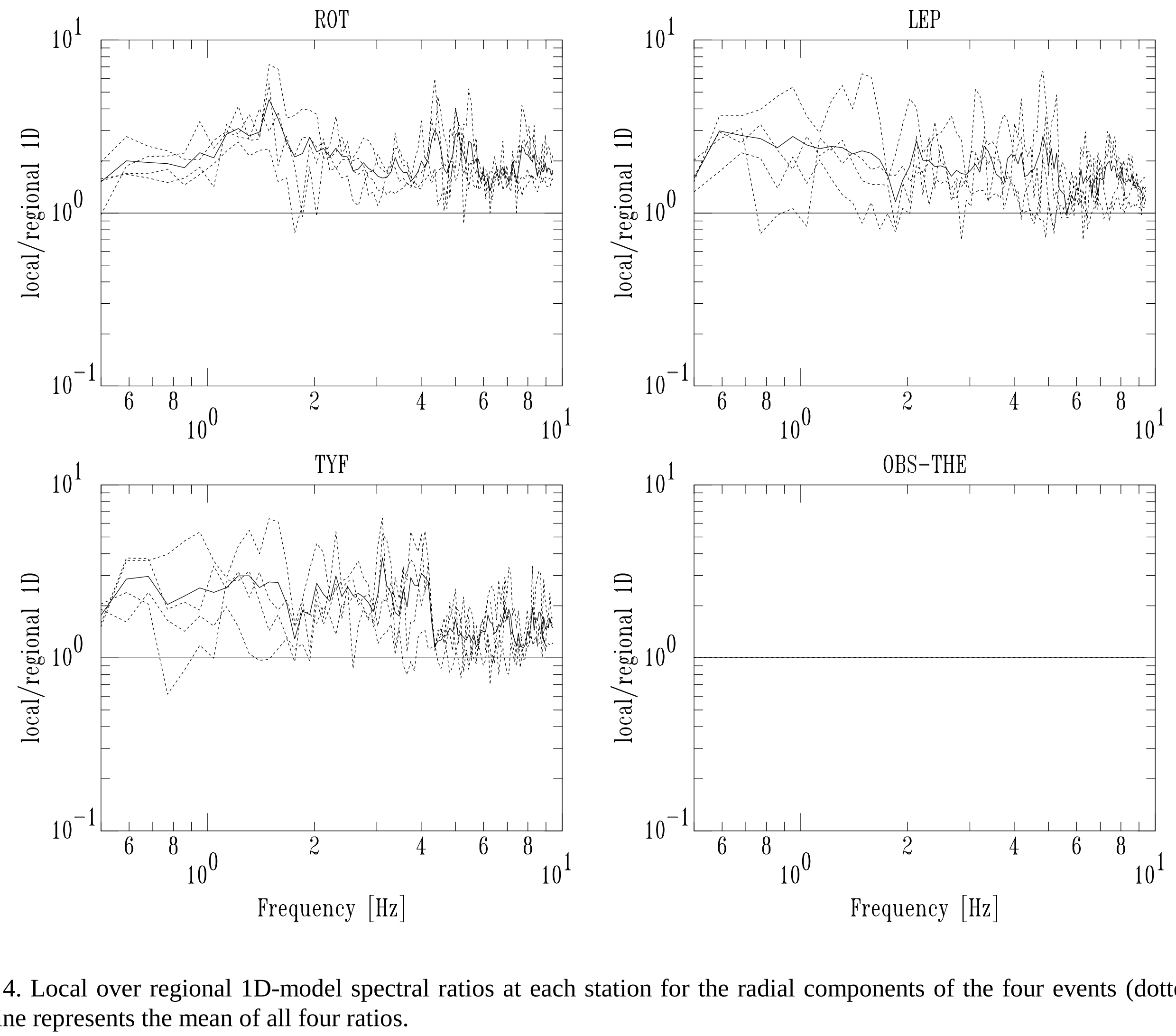

Figure 4. Local over regional 1D-model spectral ratios at each station for the radial components of the four events (dotted lines). Solid line represents the mean of all four ratios.

In order to check the validity of the reference station technique we have computed for each station also the ratios of response spectra of the local 1-D accelerograms over the response spectra of the reference station (OBS) 1-D accelerogram for all the components. The two kinds of ratios at each site, were almost similar in terms of spectral shape, although the amplitude level of local-over-reference station ratios was different, in particular for the local events. In order to correct the local-over-reference station ratios of the local events for the source and radiation pattern effects, we have multiplied the spectra by a correction factor.

We also calculated the ratios of undamped response spectra of accelerograms of the horizontal and the vertical component of motion.

3 2D-COMPUTATIONS

In order to estimate the ground motion taking into account also the lateral heterogeneities of the structural model, we used two different 2-D cross sections modeling the subsurface beneath the receivers at the area of interest. Therefore, we constructed synthetic seismograms for a maximum frequency of 6 Hz both for P-SV and SH waves. The hybrid technique employed (Fäh, 1992) couples the modal summation and the finite difference methods. The former one allows us to take into account the path from source position to the target area, while the latter permits the modeling of wave propagation in complicated and rapidly varying velocity structures, as is required when dealing with sedimentary basins, like that in Thessaloniki.

Before going into 2-D computations, we first compared the results of modal summation and the finite difference technique for the simple case of the 1-D structural model. This comparison is necessary each time the hybrid technique is applied in a new region.

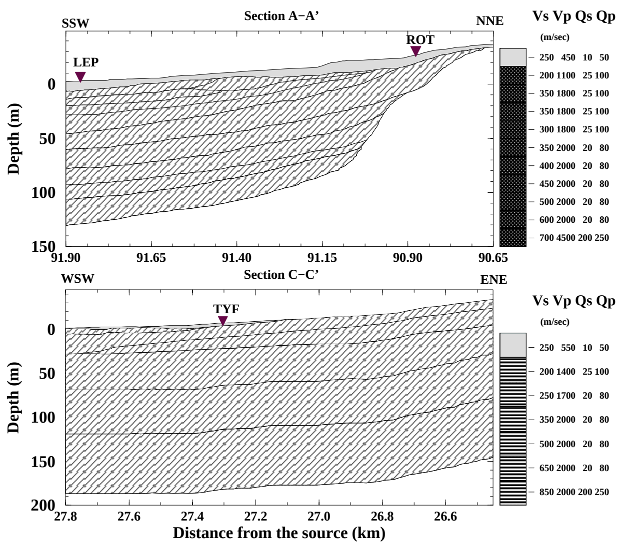

Figure 5. The two sections, A-A’ (up) and C-C’ (down), and their characteristics used in 2-D computations.

The comparison allows us to establish control over the accuracy of the finite difference part of computations, relative to: (1) the efficiency of the absorbing, artificial boundaries, (2) the correct discretization of the structural model in space, (3) the presence of all phases in the seismograms, and (4) the treatment of anelasticity. The comparison is performed for the layered structural model, which describes the path from the source to the region where the finite difference method is applied.

For the construction of the synthetics we simulated two events at almost the same direction with the two profiles; for section (A-A') (Fig. 5, up) we used the focal mechanism of 1978 earthquake (# 1, Table 1) while for the second (C-C') (Fig. 5, down) we used the average focal mechanism at the area of northern Greece (Papazachos & Kiratzi, 1996) in a distance around 90 km from the city (# 2, Table 1).

For A-A' the mesh size in the finite difference computation is 3.5 by 3.5 m in the upper part of the model and 3.5 by 21 m in the lower part, resulting in a model size of 1300 by 5075 m. The dimensions of the second profile (C-C') were 1350 by 6320 m while the mesh size was 3 by 3 m in the upper part and 3 by 30 m in the lower part.

One of the ground motion related quantities that can be extracted from the synthetic accelerograms obtained from our numerical modeling is the spectral amplification, Sa(2D). In order to remove as much as possible the effects of the radiation pattern and of the regional propagation, and to estimate the amplification due to lateral heterogeneities the above quantity is normalized with respect to the corresponding quantity Sa(1D), computed in the reference bedrock model at the given source-receiver distance.

4 COMPARISON BETWEEN THE METHODS

The mean spectral amplifications obtained at each site from the theoretical 1-D and 2-D are compared for all the components of motion with those derived from experimental techniques, such as of Standard Spectral Ratio (SSR) and Horizontal-over-Vertical Spectral Ratio (HVSR), which had been applied to a set of observed accelerograms recorded at the same stations (Triantafyllidis et al., 1998). The comparison (Fig. 6) shows that the results are not too different from each other and that most of the peaks coincide. This means that the geophysical and geotechnical surveys done in the area have permitted to define a relatively good model. Also it is evident that in some cases, especially when the subsurface geometry is complicated, a single 1-D local modeling is not sufficient and the use of 2-D numerical simulations is required in order to produce reliable estimates of the site effect amplification. Obviously, there are some discrepancies, that one cannot eliminate completely even when studying a 2-D model

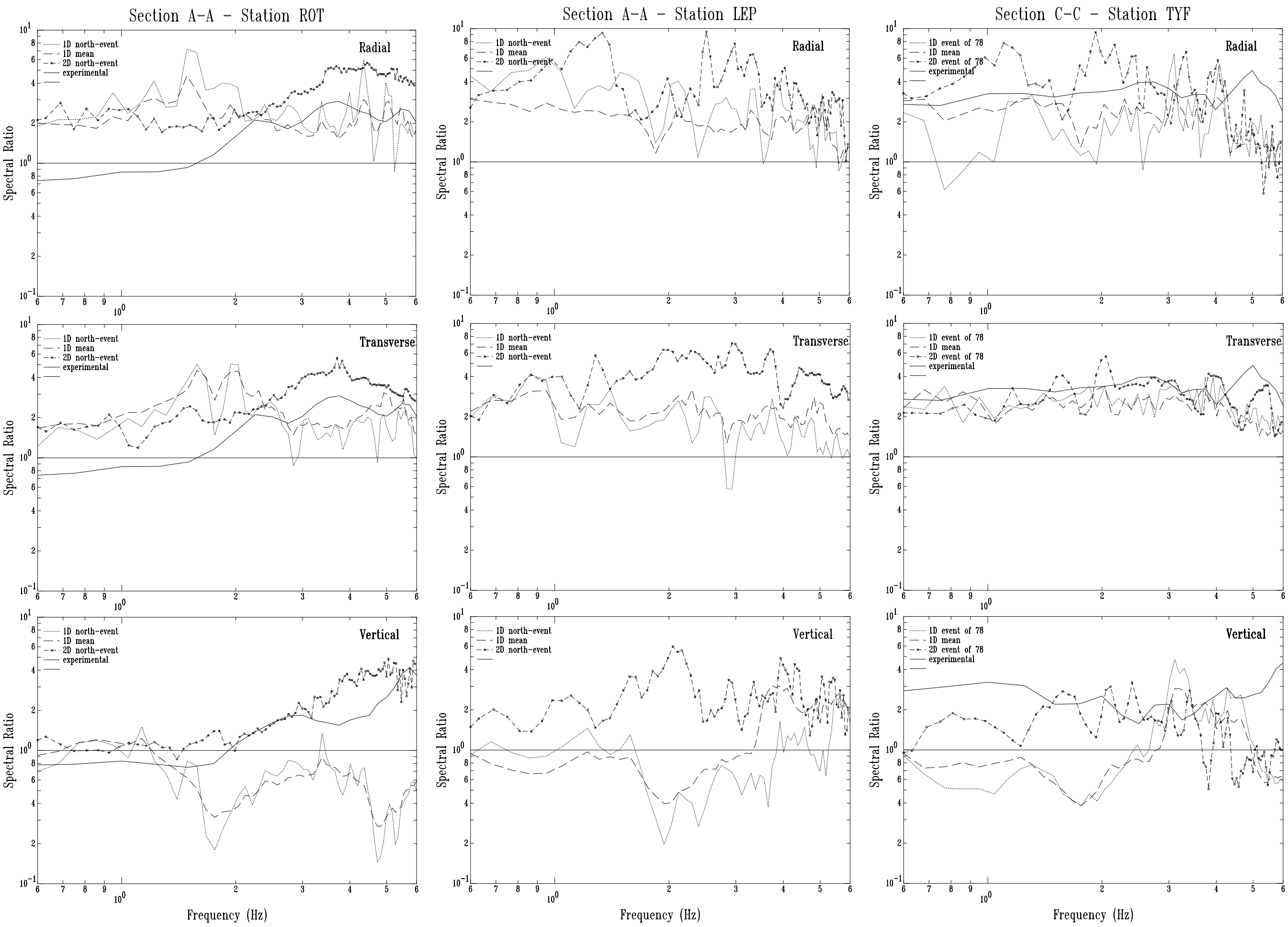

Figure 6. Comparison between the mean amplification obtained by 1-D modeling (with dashed line the mean of all the events, while with dotted line only of the event simulated for each 2-D section), 2-D modelling (dot-dashed line) and the experimental data (solid line) for station ROT (a), LEP (b) and TYF (c). At LEP there were no experimental data available for comparison.

with the hybrid method. In fact, to obtain a correct numerical simulation a very big number of parameters has to be very well known in the input stage. So, for example, a small inaccuracy in the definition of a few 2-D model parameters is sufficient to obtain waveforms that do not resemble the observations. Also another cause of errors is the positions of real receivers with respect to those of the corresponding synthetic ones. In fact, the actual receivers are not aligned perfectly and therefore the positions of the real and synthetic receivers do not always coincide and the geological situations below them can be different from the assumed ones. We have also to mention that the experimental curve is a mean of ratios related to 34 real events, while the 1-D and 2-D ones are ratios of only one event.

5 CONCLUSIONS

As final conclusion we can state that the proposed 2-D models based on the geotechnical and geophysical investigations explain quite well the main amplification features at the area of interest, demonstrating that such knowledge can be sufficient, within the proper frequency range, to estimate with a high degree of accuracy, for engineering purposes, the effects of seismic waves in the city from a future earthquake. In addition, further investigation along other well-known 2-D sections is planned in order we construct a three dimensional model of the city by inter-extrapolating the present geotechnical information. In that case all the limits described before will be minimized and we will be able to define different more realistic scenarios to be used in any kind of decision making related to seismic hazard mitigation.

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