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Amplifications of the seismic ground motion in Gemona (NE-Italy) due to the 1998 Bovec-Krn earthquake

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Abstract - We look at site effects in Gemona (NE Italy) analyzing the waveforms recorded during the 1998 Bovec-Krn (Slovenia) earthquake at three different stations in the town in terms of normalized peak ground accelerations, Arias intensity and response spectra. Then, using a well established numerical approach and a simplified 2D structural model, we estimate site amplifications along a profile underlying Gemona. The simulations agree relatively well with the available observations and some discrepancies can be probably related to the inaccurate knowledge of the subsurface. The results of this study also confirm that our approach can be used for the estimate of site amplifications where the lack of recorded data prevents the evaluation of potential damage of buildings and manufacts.

1. Introduction

The estimate of local site effects from recorded data is of paramount importance for seismic hazard assessment purposes and different techniques can be employed to evaluate the local amplification generated, in a given area, by the geological or the topographical settings. Nevertheless, the necessary database of recorded data is not always available for all earthquake-prone areas due to lack of dense local arrays or to the relatively long return periods for strong earthquakes. In order to reduce damages and loss in such a situation it can be useful to predict the amplification of a certain area by adopting numerical modelling.

In this paper, we evaluate site effects in the city of Gemona (NE-Italy) both from the real accelerograms recorded in the town and from the simulations of the ground motion generated by the April 12, 1998 Bovec-Krn event (Slovenia, $M_L = 5.7$) along a profile 7 km long underlying the city Gemona (Fig. 1). The choice of Gemona as test area for site effects, together with the

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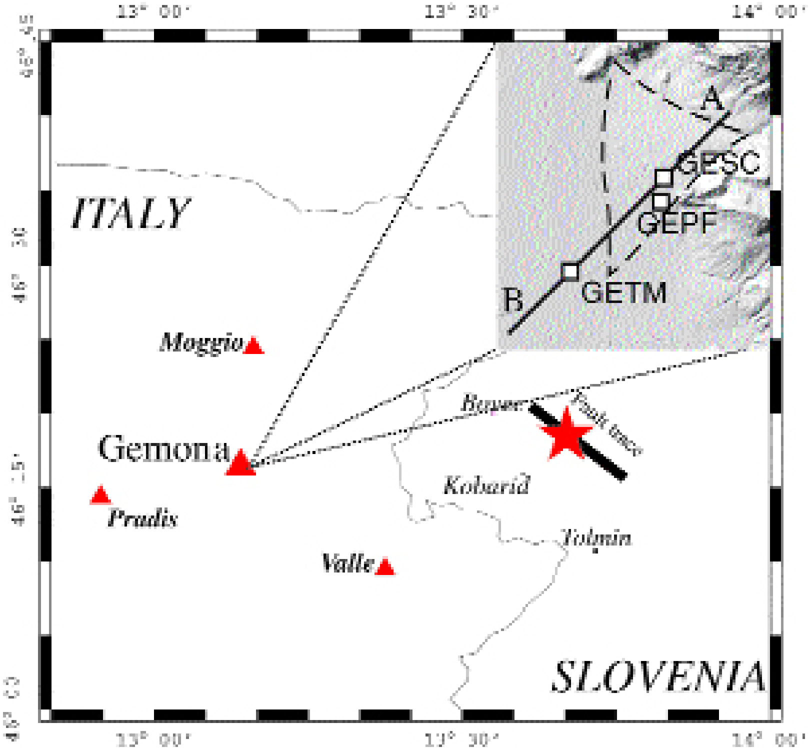
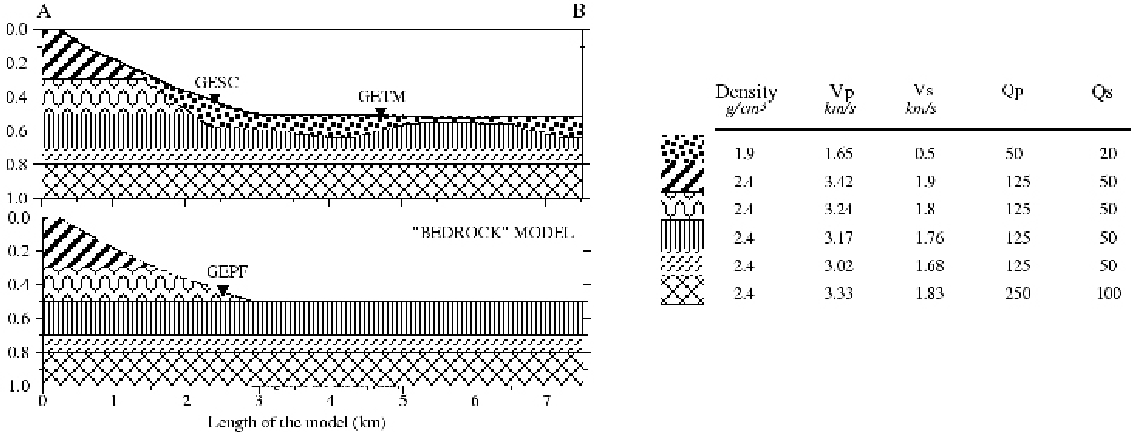


Fig. 1 - Location map of the April 12, 1998 Bovec-Krn earthquake and recording accelerometric stations used for the source inversion study (Bajc et al., 2001). In the inset the DEM showing the conoid of Gemona (dashed line), the stations installed for site effect analysis and the projection of the section (AB), modelled in this study, are plotted.

deployment there of three accelerometers, is related to the fact that the 1976 Friuli earthquake destroyed the city. Moreover, Gemona is located in an area of terrigenous sediments (Flysch), covered locally by a thin Quaternary layer that forms an alluvial fan and a sedimentary basin responsible for local amplification of the seismic ground motion, as already shown by Fäh et al. (1994a). Even if the alluvial fan and its geometrical shape are not exactly defined, previous studies (Marrara, 1999) have validated a good approximation of a 2D model (Fig. 2) that we use to reproduce the level of amplifications generated by the 1998 Bovec-Krn earthquake.

In our modelling, the seismic wavefield is propagated from a scaled point source (Gusev, 1983), buried in a one-dimensional layered homogeneous and anelastic medium (1D model), through a structure with lateral heterogeneities (2D model) around the target area, using the hybrid method proposed by Fäh et al. (1990) and Fäh (1992). The hybrid method combines the modal summation (e.g. Panza 1985; Florsch et al., 1991; Panza et al., 2000) used to compute the wavefield generated from the source in the 1D model, with the finite differences (Virieux, 1984; 1986; Levander, 1988) employed to propagate, numerically, the time series obtained for the 1D model in the 2D model. This well tested method has been successfully applied to evaluate site effects of densely populated areas like Rome (Fäh et al., 1993), Mexico City (Fäh et al., 1994b), Naples (Nunziata et al., 1997), Benevento (Fäh and Suhadolc, 1994; Marrara and Suhadolc, 1998a), Beijing (Ding et al., 1998), Thessaloniki (Triantafyllidis et al., 1998), and the Volvi Basin in Greece (Marrara and Suhadolc, 1998b).



	Density *g/cm³*	Vp *km/s*	Vs *km/s*	Qp	Qs
▦	1.9	1.65	0.5	50	20
▨	2.4	3.42	1.9	125	50
⌒	2.4	3.24	1.8	125	50
▥	2.4	3.17	1.76	125	50
∽	2.4	3.02	1.68	125	50
⊠	2.4	3.33	1.83	250	100

Fig. 2 - 2D and 1D “bedrock” structural models used to compute site effects in the Gemona area.

2. The 1998 Bovec-Krn earthquake

The Bovec-Krn earthquake ($M_L = 5.7$) occurred on April 12, 1998 in Slovenia (Fig. 1) at a focal depth of 7.6 km (Bajc et al., 2001). The fault plane solution (strike = 315°; dip = 82°, rake = –171°) shows a strike-slip mechanism with a small tensile component on the NW-SE oriented plane. Inversion studies between 0.1-1 Hz of the waveforms recorded by the stations of Moggio (MOG), Gemona (GEPF), Pradis (GERC) and Valle (VALL), all located on bedrock sites and maintained by the Friuli accelerometric Network (Fig. 1), give insights into some main features of the rupture process. The process was characterized by two big patches of energy release on the fault in agreement with the geotectonic evidences and a rupture that propagated bilaterally on a fault less than 13 km long and 7 km wide (Bajc et al., 2001). This main feature connected to the rupture propagation direction is independent from the frequency investigated and enables us to use the scaled point source that does not take into account directivity effects, also for frequencies higher than 1 Hz.

The major damage caused by the earthquake was reported in the towns of Bovec, Kobarid and Tolmin (Živčić et al., 1999; Mucciarelli and Monachesi, 1999). Site amplifications were observed also in Gemona, about 40 km from the epicenter, where accelerations between 0.01 and 0.04 g were recorded on bedrock and on alluvium base, respectively (Costa et al., 1999).

3. Data

To study the source properties and the site effects in Gemona, three accelerometric stations equipped with Kinemetrics FBA-23 sensors have been installed since 1993 on a bedrock outcrop (station GEPF), in the lower part of the alluvial fan (station GESC) and in the sedimentary-basin part of the city (station GETM) (Fig. 1).

The response spectra (Fig. 3) of the seismograms recorded during the 1998 Bovec-Krn earthquake, confirm that site effects are present in the area. Indeed the spectra, computed with a

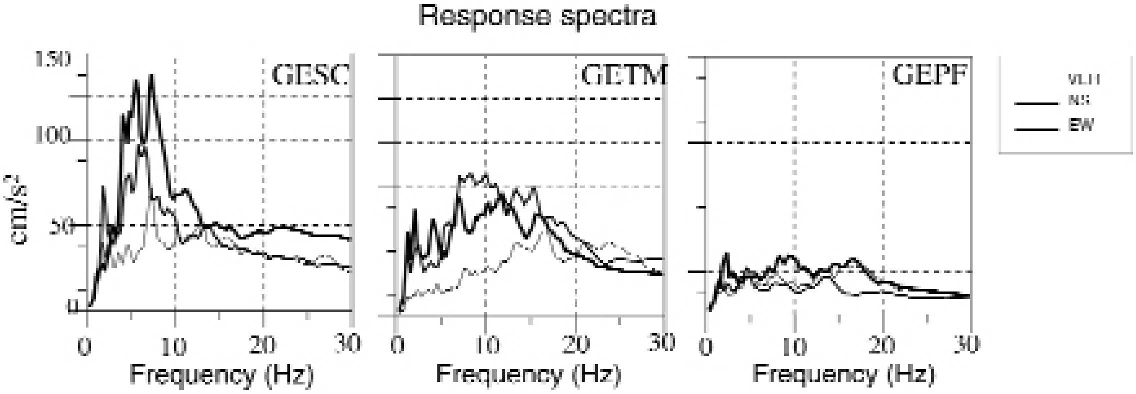


Fig. 3 - Response spectra of the recorded data computed with a damping factor of 5%.

damping factor of 5%, show a greater amplification within 10 Hz for GESC station with respect to GEPF and GETM, due to the presence of sediments.

4. Site effects modelled from synthetic strong motions

Using the scaled point source, we compute 76 synthetic accelerograms, regularly spaced (100 m) along the profile of the 2D model (Fig. 2), and only for the GEPF station, located on a bedrock outcrop, do we use the simplified 1D model. Since we are not interested in fitting the waveforms the related seismograms are not shown, whereas we show the results for all the components in terms of normalized peak ground acceleration (*AMAX*), normalized Arias intensity (*W*) and normalized response spectra (*Sa*). The normalized values are obtained dividing the values computed for the receiver sites with complex geology by the corresponding values obtained at GEPF on the simplified bedrock model (Suhadolc and Marrara, 1999).

In this study, the seismic response has been analysed in the frequency range from 0.2 Hz to 5 Hz. The maximum frequency depends on the knowledge of the structural model, but it is also selected to guarantee the stability condition of the finite difference scheme used in the numerical computations. Such a condition requires a grid spacing not exceeding 1/10 of the minimum wavelength in the 2D model (Fäh, 1992). In our case, we discretize the model by a grid sampled every 10 m that allows a maximum resolution of the wavefield up to 5 Hz with a minimum wavelength of 100 m for the shear-wave velocity value of the sediments (500 m/s).

The validity of the scaled point source assumption is checked through a comparison of the synthetic seismograms with real data at the GEPF station. Looking at the displacement (Fig. 4a), we observe a good resemblance of the waveform in the first part of the seismogram. For the coda wave part, influenced more by complexities due to the wavefield propagation (e.g. scattering), our approximations are less efficient. The agreement for the amplitude values of the time series (Fig. 4a) and for the main frequency content of the signal is good (Fig. 4b). The frequency contents of both data and synthetics are essentially concentrated at frequencies below

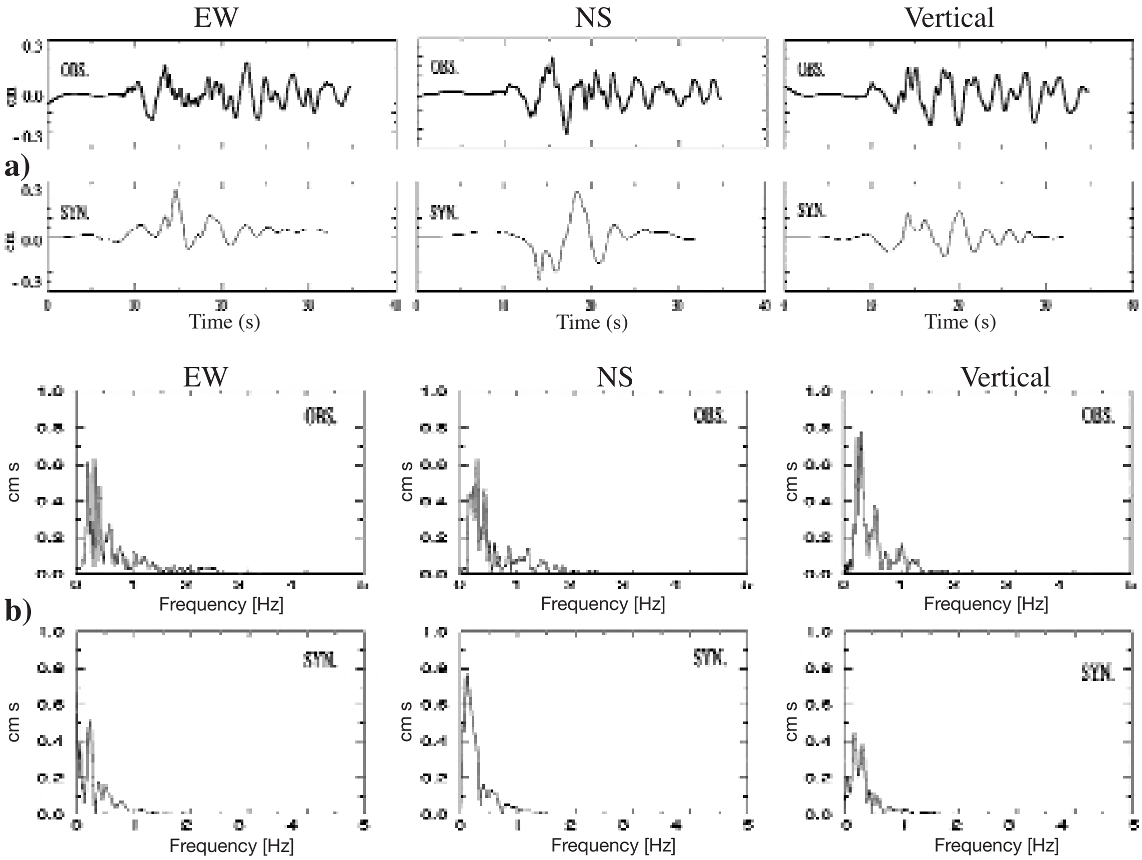


Fig. 4 - a) Comparison of the observed (OBS) and synthetic (SYN) displacements computed for a scaled point source at the GEPF station. b) Comparison of the observed (OBS) and synthetic (SYN) displacement spectra.

2 Hz (Fig. 4b). The comparison with the accelerograms, not shown here, is satisfactory in terms of amplifications, but the similarities of the waveforms is limited due to the complexities of the source that are more present in the acceleration time series. Contrary to the displacements, the accelerogram spectra are rich in frequencies up to 5 Hz.

The analysis of the normalized peak ground acceleration (Fig. 5) and normalized Arias intensities (Fig. 6) extracted from the P-SV and SH components confirms that the level of amplification in the basin is high, especially if we consider the normalized Arias intensity (Fig. 6). The amplification effects clearly depend on the thickness of the sedimentary layer (Fig. 2) and are stronger in correspondence to the alluvial fan (eastern part of the 2D model) for the E-W component. At the GETM station the observed amplification values for the transversal and vertical component of the motion are reproduced fairly well (Fig. 5), whereas at the GESC station we observe some discrepancies probably due to still unresolved structural features in the model. The uncertainties of the model in this part of the valley could be related to some 3D effects on the wavefield due to reflection or scattering phenomena from heterogeneities surrounding the 2D section. The amplifications are best seen on the ratios of response spectra vs. frequency plots (Fig. 7).

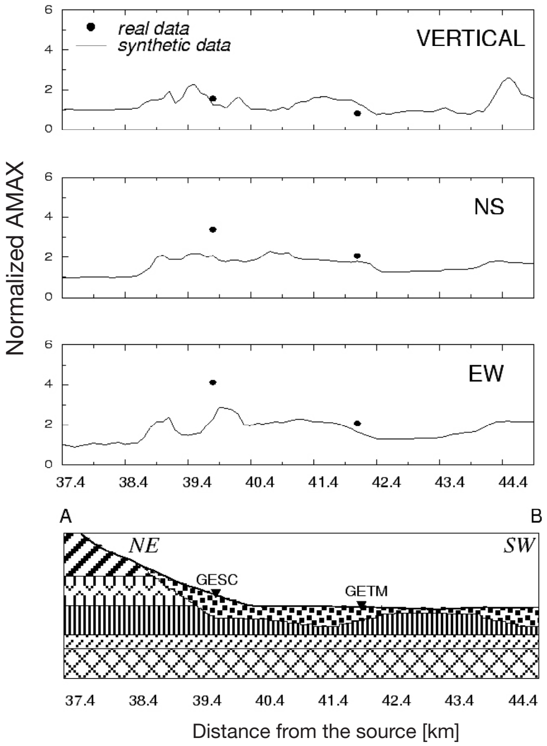


Fig. 5 - Normalized peak ground acceleration (*AMAX*) observed (black dots) and computed (continuous line) in the Gemona area. The normalized *AMAX* is obtained dividing the *AMAX* of each time series by the *AMAX* of GEPF (site on bedrock).

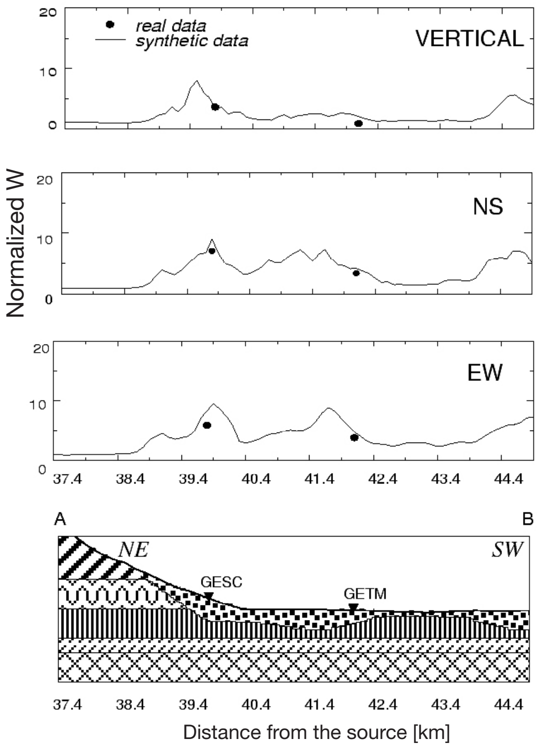


Fig. 6 - Normalized Arias intensity (*W*) observed (black dots) and computed (continuous line) in the Gemona area. The normalized *W* is obtained dividing the *W* of each time series by the *W* of GEPF (site on bedrock).

Even if the absolute values of the response spectra show some discrepancies, the ratios GESC/GEPF and GETM/GEPF between the amplifications obtained from both observations and theoretical modelling is, generally, within a factor of two. This represents an acceptable condition to validate amplification estimates using numerical techniques (e.g. Riepl, 1997). The lack of fitting of some resonance frequencies and the difference in the level of amplification below 2.5 Hz for the EW component at the GESC station, can be due either to unresolved geometrical and parametric features at the related scales wavelength, or to possible 3D effects, or to an inaccurate estimation of the thickness of the sedimentary layer at the scale of the related wavelengths. Possible source effects could be also present but are surely less important than the structural ones, since we do not observe the same discrepancy in the spectra fit at the other station.

5. Conclusions

The strong ground motions recorded at Gemona during the 1998 Bovec-Krn earthquake confirms the presence of site effects in the area. The maximum peak ground accelerations, the Arias intensity and the response spectra show a significant amplification, especially for

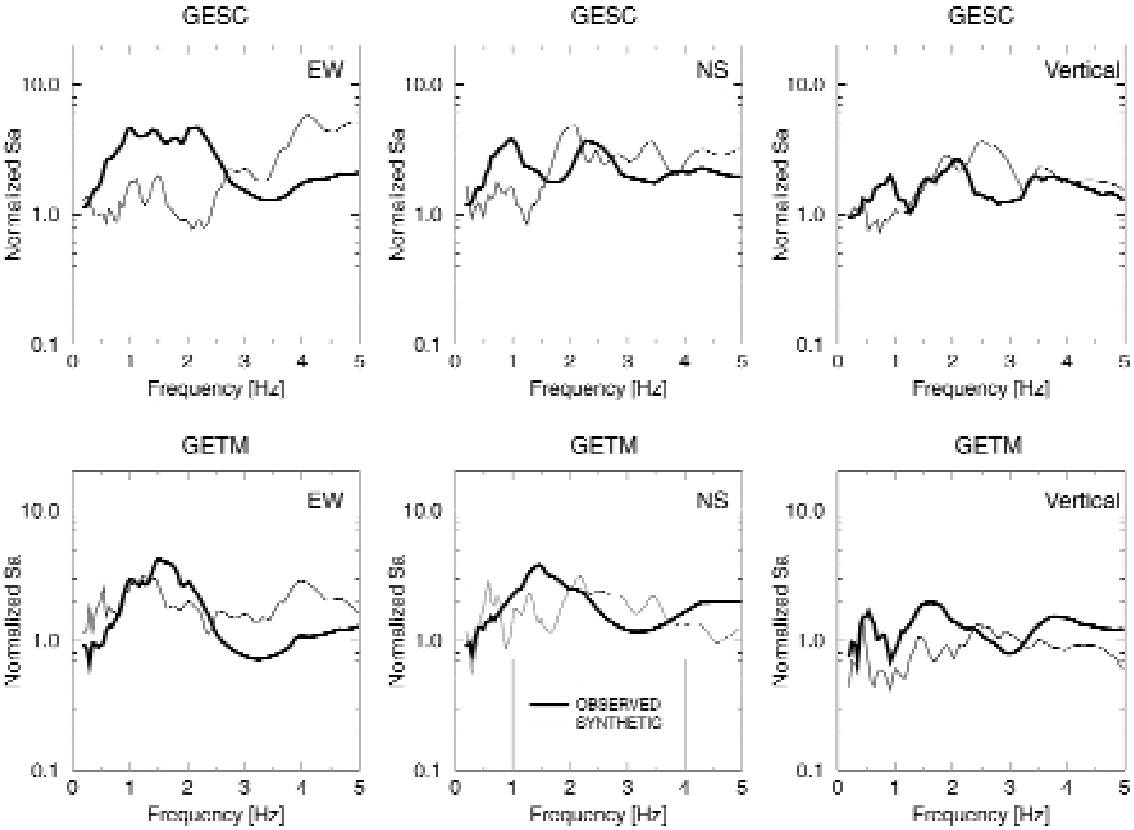


Fig. 7 - Normalized response spectra (*Sa*) with 5% damping at GESC and GETM stations from the EW, NS and Vertical components of the observed (thick line) and synthetic (thin line) accelerograms. The normalized *Sa* are obtained dividing the absolute *Sa* by the *Sa* of GEPF (bedrock site).

the GESC station, due to the presence of alluvial fan sediments under the station. In order to evaluate site amplifications along a 7 km profile underlying the town, where data are lacking, we modelled strong ground motions taking as scenario the 1998 Bovec-Krn earthquake. We generally obtain a satisfactory fit between the few data recorded in the town and the computed strong motions with some discrepancies, possibly related to unresolved structural modelling. More accurate geological and geotechnical investigations along with a detailed modelling of the rupture process by an extended source can certainly help to improve the fit of the resonance frequencies. Nevertheless, in our case the source effects are less important than the structural ones, since we do not observe the same discrepancy in the spectra fit at different sites.

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