Third International Symposium on the Effects of Surface Geology on Seismic Motion
Grenoble, France, 30 August - 1 September 2006
Paper Number: 89

ESTIMATION OF SITE EFFECTS AT SOME STATIONS OF THE FRIULI (NE ITALY) ACCELEROMETRIC NETWORK (RAF)

Giovanni COSTA[1], Peter SUHADOLC[1], Andrea DELISE[1], Luca MORATTO[1], Eleonora FURLANETTO[1], Francesca FITZKO[2]
1 Dept. of Earth Sciences, University of Trieste, Italy
2 Protezione Civile della Regione Autonoma Friuli Venezia Giulia, Palmanova, Italy

ABSTRACT - The RAF accelerometric database is used to estimate site effects at several RAF stations. Different techniques are used, among them Fourier spectra applied to both HVSR and SSR. Moreover, noise measurements are performed in order to characterize the site response of some areas around the stations. In particular, station CARC in downtown Trieste, characterized by stratified soft sediments several tens of meters thick, evidences relevant source-independent amplifications in the frequency range around 2 Hz. Station GESC, located on the Gemona city alluvial fan, shows amplifications over a broader range, that seem to be source dependent. Gravimetric and noise measurements evidence a complicated 3D structure that might explain this site effect variability. Finally, the complete RAF database is used to obtain the PGA attenuation law for the Friuli Venezia Giulia (NE Italy) and neighboring region. The ratios between the average PGA values recorded at the RAF stations and the ones derived from the attenuation laws are computed to obtain the mean amplification factor at each site. As expected, a relevant amplification is obtained for the stations installed on soft soil but an amplification factor, up to 3, is obtained also for some stations installed on “rock”.

1. Introduction

The Friuli Accelerometric Network (RAF) has been installed by the Dipartimento di Scienze della Terra of the University of Trieste, DST, in the framework of national and international cooperation and projects in the years 1993-95, in the Friuli Venezia Giulia region (NE Italy). RAF is configured to record accelerations in several important sites in the seismic area of the junction Alps-Dinarides, that has experienced several damaging earthquakes in the past (e.g. Anderson and Jackson, 1987) allowing for an immediate estimate of peak ground acceleration. RAF data are used also for civil protection purposes, like the prompt estimate of damage after an earthquake and its extension, the emergency management, the reconstruction planning, the computation of shake-map and the validation and updating of seismic hazard maps.

Until recently, few reliable accelerometric data were available in the frequency range around and below 1 Hz due to the analog accelerometers used in the past, which had a pretty good frequency response, but a small dynamic range (less than 40 dB). Such instruments did not allow measurements of very low values of acceleration, normally present at low frequencies, that can however produce damage if amplified by particular site conditions. Today the RAF consists in 15 digital accelerometers, which have large frequency response (from dc to 80 Hz and over, at -3 dB) and high dynamic range (more than 120 dB), coupled with 18 and 24 bits acquisition systems (Fig. 1). All RAF stations are connected in real-time or “quasi” real-time with the DST datacenter.

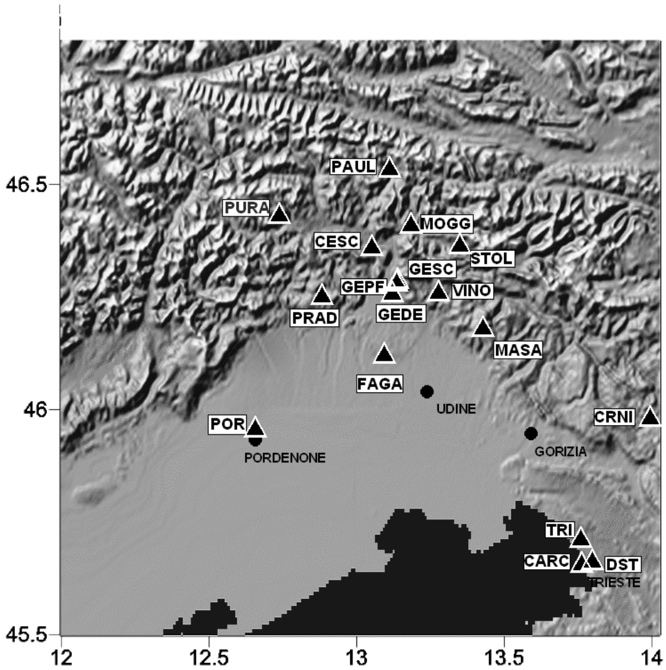


Figure 1. Location of RAF stations

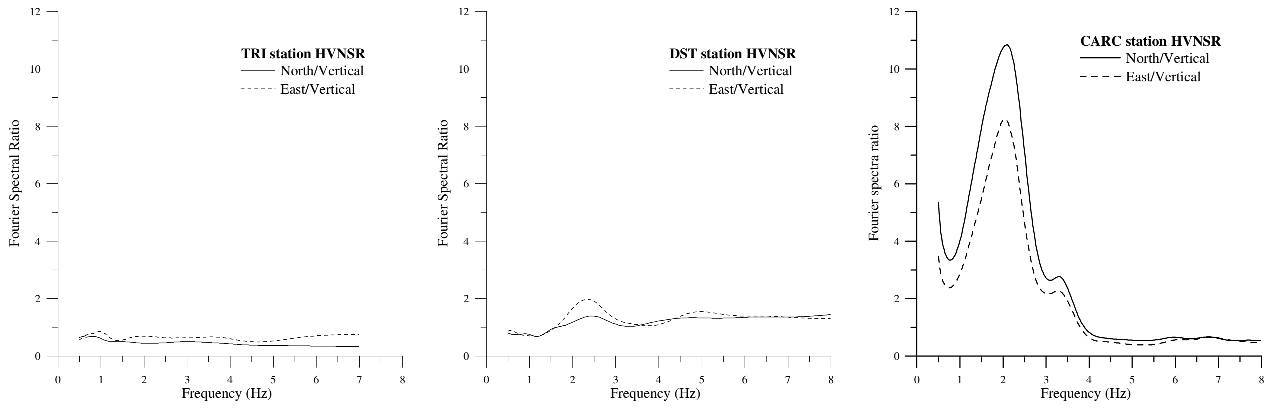
For site effects estimation purposes, some of the RAF accelerometric stations (GESC, GEDE, STOL, CARC) have been installed at sites characterized by peculiar quaternary geological features that produce different seismic signal amplifications. In particular, the station CARC is installed in downtown Trieste on a thick soft sedimentary layer, and the stations GESC, GETM and GEDE are installed in the city of Gemona del Friuli, two in a sedimentary basin and one on the alluvial fan. Site effects at these stations are studied using different techniques such as HVSR and SSR, and noise measurements are performed in order to characterize the site response also at several other stations.

Finally, the whole RAF accelero- metric database is used to check possible site effects at RAF stations by estimating acceleration attenuation laws in the area and comparing acceleration estimates at stations with recorded data.

2. Site effects estimates from microtremor measurements

Continuous microtremors measurements are also performed at some of the RAF stations. In order to estimate their site effects, 30 minute-signals are recorded during the night using broadband sensors and analyzed with the program J-Sesame (SESAME Project, 2001).

The results of the microtremors measurements (Fig. 2) confirm the very good quality of the sites located inside a natural or artificial cave (TRI, VINO and GEPF) and for the station DST installed in the basement of a house built on sandstone (Flysch). In fact, the amplification factor for these stations is on average less than 2 in the analyzed frequency range.



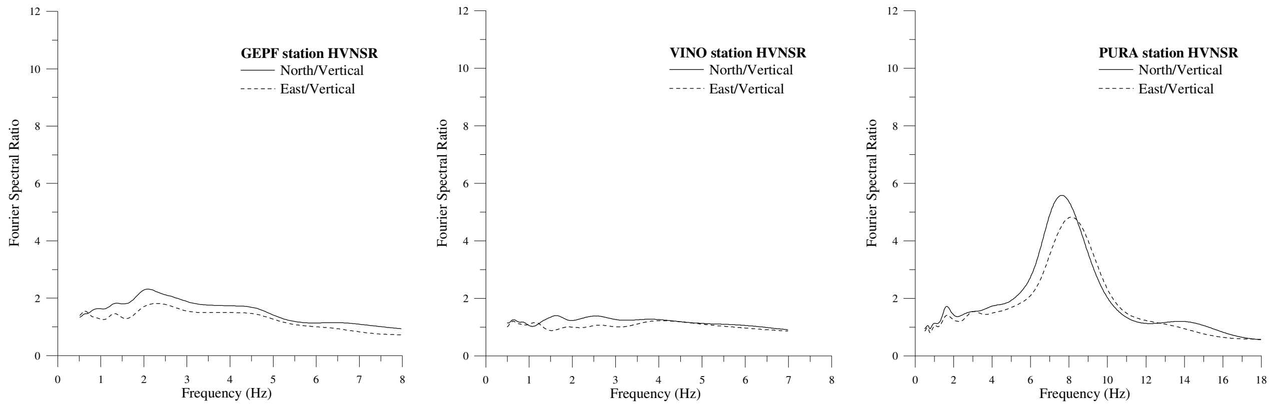


Figure 2. Fourier spectral ratio of microtremors (HVNSR) recorded at TRI, DST, CARC, GEPF, VINO and PURA stations. All the recordings were made using the resident instrument.

In figure 2 we observe a de-amplification with an average factor of about 1.5 at TRI station. This could be related to the large dimensions of the cave in which the station is located. In order to explain this effect on the signals (Amoruso et al., 1997) the records of five events, recorded both by a station installed at the surface just above TRI station (Gentile, personal communication) are compared with the related TRI records. The results are reported in Fig. 3, where the ratio of the average Fourier spectrum of the surface recorded signals and the average Fourier spectrum of the signals recorded on the bottom of the cave are shown. This result confirms the de-amplification effect of the cave for frequencies higher then 1.0 Hz.

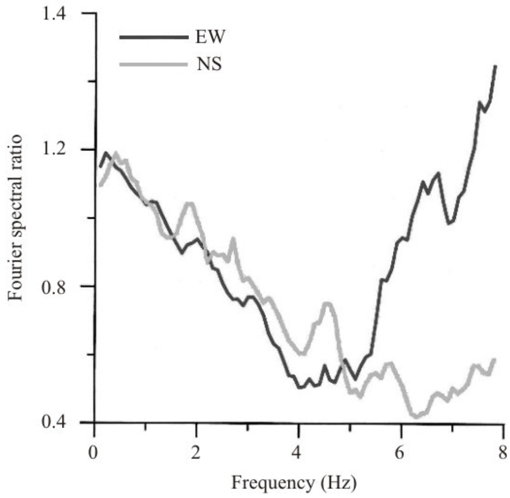


Fig. 3. De-amplification effect for the station TRI (see text).

For the station PURA, due to high signal amplification around 8 Hz, the analysis is extended to 18 Hz. The 8 Hz amplification factor, visible on the HVNSR, is due to the presence of a very soft soil (peat) just underneath the sensor, temporarily installed inside a small house. Due to these results the PURA station will be moved to a new nearby site on hard-rock.

We discuss the results of site effects at the stations installed on sediments in Trieste and Gemona del Friuli in the next sections.

3. Estimation of site effects in downtown Trieste

Trieste, even if not strongly affected by major earthquakes in its recent past, is located close to several active faults (Aoudia, 1998; Fitzko et al., 2004). Most of its old city center is built near the sea on thick soft sediments, which can significantly amplify the earthquake ground motion in case of a local or regional earthquake. An accelerometric station (CARC) has been recently (November 2002) set up in a historical building (Palazzo Carciotti) in the old city center. As results from borehole data, Palazzo Carciotti is built in the place of a former salina, on a 27-meter thick sedimentary cover composed by made ground, sands and silts washed by the ancient course of the stream that runs (covered today) through the city.

Seven regional small-to-moderate events recorded at CARC station are used to study the site effects at this location. The related records are compared to those obtained at two nearby stations, TRI and DST, located respectively on limestone and sandstone (Flysch) bedrock. Fourier and response spectra are computed for all components and both the reference station and H/V ratio techniques are used to assess site effects (Fitzko et al., 2006).

To analyze the local response of CARC we first derive the transfer function of CARC relative to the reference station TRI, located 5 km N of CARC inside a natural cave within Mesozoic limestones, at about 100 meters depth. The five regional events used are reported in Table 1 and the computed Fourier SSRs are shown in figure 4. The SSRs show a clear and strong amplification for all analyzed events at 2 Hz on both the east and north components.

Table I. Regional events recorded by the stations operating in Trieste (CARC, TRI).

Date (dd/mm/yy)	M (Agency)	Epicentral Area	Distance, (km)	Azimuth	Data source
30/08/03 09:10:51	3.8 M_l (CSEM)	Friuli (I)	112	317°	CARC
14/09/03 21:42:53	5.0 M_l (CSEM)	Appennines (I)	240	230°	CARC
23/05/04 15:19:09	4.9 M_b (CSEM)	Bosnia (BiH)	381	132°	CARC-TRI
12/07/04 13:04:02	5.1 M_b (CSEM)	Bovec (SLO)	73	350°	CARC-TRI
14/09/04 18:09:26	4.5 M_b (CSEM)	Rijeka (HR)	76	120°	CARC-TRI
24/11/04 22:59:39	5.3 M_b (CSEM)	Garda (I)	246	268°	CARC-TRI
25/11/04 06:21:18	5.2 M_b (CSEM)	Adriatic Sea	301	158°	CARC-TRI

Subsequently, we compute the H/V spectral ratios at CARC station using weak motion data (Tab. 1). The basic assumption in using H/V spectra ratio for site effects estimation is that the vertical component is free from local amplifications. This fact is not always true, especially at sites located near sub-vertical discontinuities of lithologic or tectonic origin which affect the vertical motion in the same proportion as the horizontal one. Anyway it is mainly observed at higher frequencies where ellipticity variations with frequency can cause also strong de-amplification of the vertical component (e.g. Triantafyllidis et al., 2001). HVSR at CARC are shown in figure 5. There is a good agreement with SSR results at low frequencies, in particular as regards the 2 Hz frequency amplification, although the amplification factor is smaller in this case.

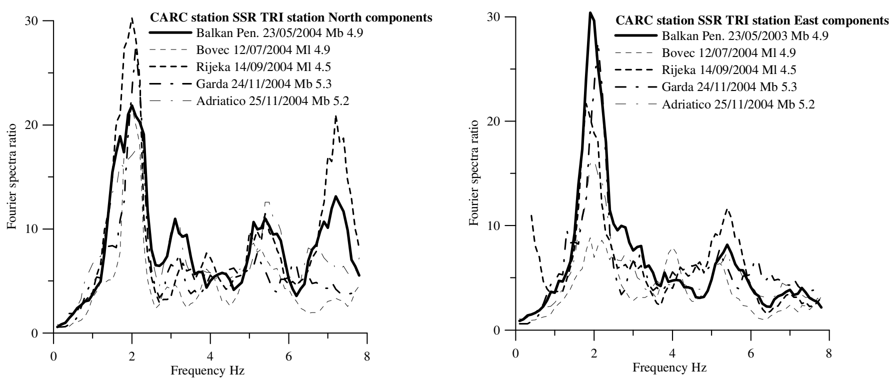


Figure 4. Fourier spectra ratio SSR of the regional events recorded at CARC and TRI (Tab. 1). East components on the left, North components on the right.

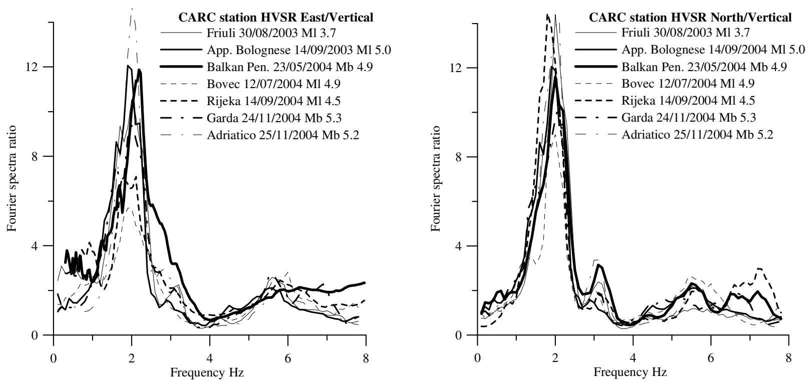


Figure 5. Fourier spectra ratio HVSR of the regional events recorded at CARC (Tab. 1). East/Vertical components on the left, North/Vertical components on the right.

These results are also supported by continuous microtremors measurements, acquired in a time period of 24 hours, performed on the basement (CARC station) of Palazzo Carciotti. The H/V noise spectral ratios (HVNSR) at CARC clearly evidences the 2 Hz peak (Fig. 2), with an amplification factor being comparable to that resulting from HVSR using weak motion data.

All the site effect analyses used evidence a relevant amplification for frequencies around 2 Hz, consistent with the resonance frequency of the soft sedimentary cover, obtained using a simple 1-D model: $\boldsymbol{f = v_s/4H}$ (where $\boldsymbol{v_s}$ is the S-wave velocity and $\boldsymbol{H}$ the thickness of sediments). If we consider the known thickness of sediments and the resonant frequency of 2 Hz and we apply the 1D model, we obtain a $\boldsymbol{v_s}$ of about 220 m/s compatible with the geotechnical characteristics of the soil beneath the station (Tagliapietra, 2003).

4. Estimation of site effects in Gemona del Friuli

Gemona is a city located in Friuli (NE Italy) built mainly on an alluvial fan and partly on a sedimentary basin. The area is seismically active and it is characterized by a N-S compressional tectonic regime related to the interaction between the Eurasian and Adriatic microplates. In the past it experienced several events of moderate-high intensity. The most recent destructive events were the Friuli earthquakes in May and September 1976, which almost totally destroyed the city.

Three RAF accelerometric stations are set in Gemona for site effects estimation purposes. Station GESC is located on the alluvial fan sediments, the stations GETM and GEDE on a sedimentary basin. The station GETM was operating from 1994 to 1999, and afterwards it was moved to a new location (GEDE). All three locations are close to the bedrock station GEPF installed in a tunnel on bedrock and it is considered as the reference station for the analyzed events. The site effects of the stations placed on sediments are related to both the lithology of the quaternary sedimentary deposits and their thickness.

Site effects in Gemona were first analyzed by Marrara et al. (2001) using the recordings of the Bovec, Slovenia, 1998 event. Their 2-D modeling evidenced the strong influence of the unknown subsoil geometry and its elastic and anelastic properties on the seismic response at different sites, but the fit with the observed records related to a single event posed the question on the general validity of the obtained results.

In this paper we use weak motion data of six events of small-to-moderate intensity, recorded at the Gemona accelerometric stations (Tab. 2). We use the waveform data to estimate site effects using both the reference site technique and the H/V spectral ratio.

Table II. Strong and recent events recorded by the stations operating in Gemona (GESC, GETM, GEDE, GEPF)

Date (dd/mm/yy)	M (Agency)	Epicentral Area	Distance, km	Azimuth	Data source
12/04/1998 10:55:31	5.7 M_s (OGS)	Bovec-Krn (SLO)	40	84°	GESC - GETM - GEPF
14/ 02/2002 03:18:02	4.9 M_d (OGS)	Carnia (I)	15	352°	GESC - GEPF
02/01/2005 11:56:15	2.5 M_d (OGS)	Bordano (I)	8	328°	GESC - GEDE - GEPF
08/02/2005 20:06:11	2.3 M_l (DST)	Venzone (I)	7	339°	GESC - GEDE - GEPF
31/08/2005 21:55:33	3.1 M_l (DST)	Bovec (SLO)	30	77°	GESC - GEDE - GEPF
12/12/2005 16:35:51	3.3 M_l (DST)	Pontebba (I)	29	36°	GESC - GEDE - GEPF

We first compute the transfer function related to the reference station GEPF. The related Fourier SSRs for GESC station are shown in Fig. 6. We also compute the H/V spectral ratios using the same weak motion data of Tab 2 and HVSR are shown in Fig. 7 at GESC.

The results of both SSR and H/V show that the same event produces different resonant frequencies at GESC. Also different events cause different resonance frequencies observed at the same site.

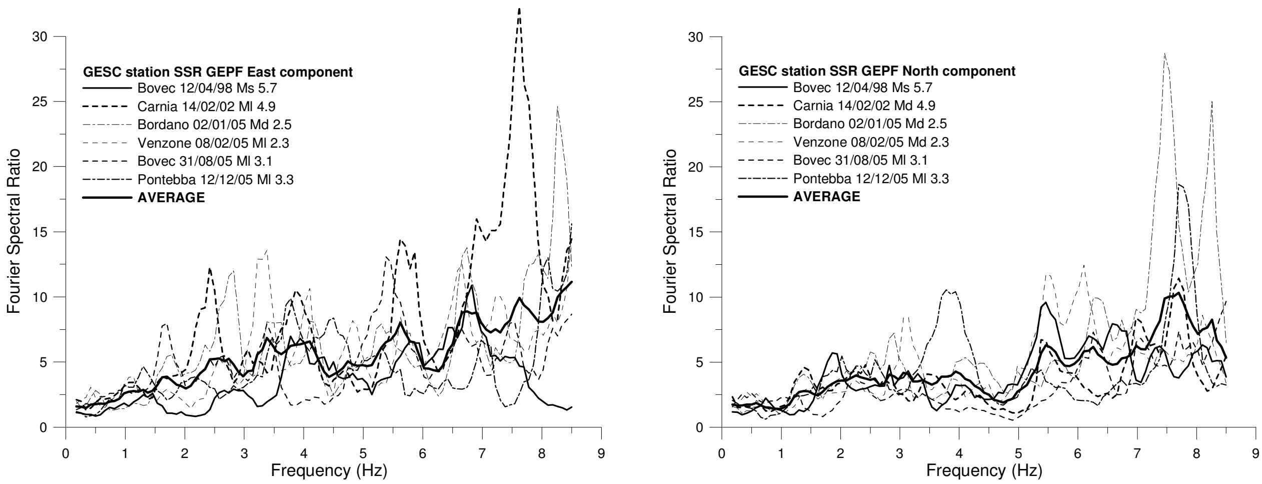


Figure 6. Fourier spectra ratio, SSR, of the events recorded at GESC, alluvial fan, and GEPF (Tab. 2). Horizontal components.

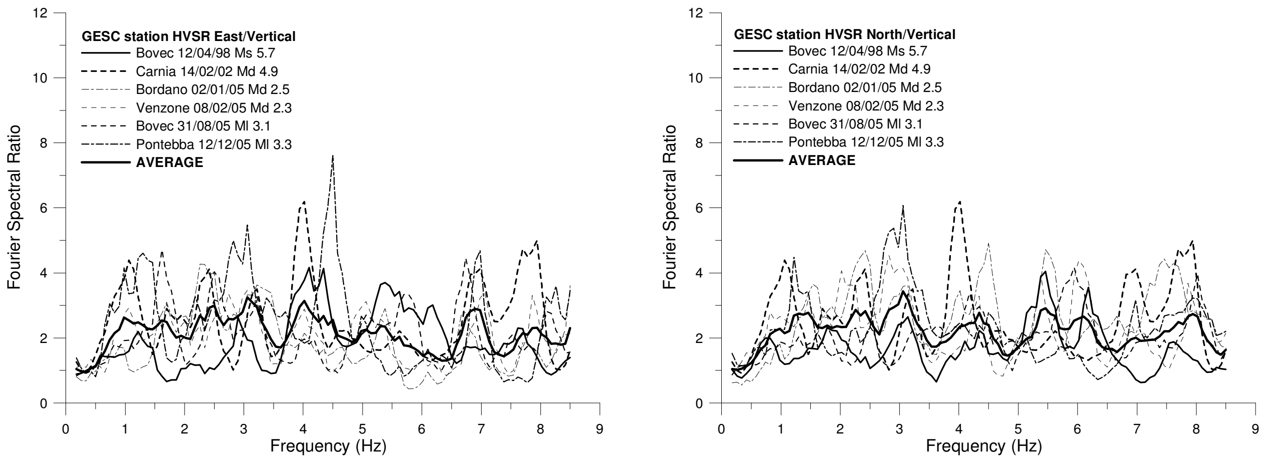


Figure 7. Fourier spectra ratio HVSR of the events recorded at GESC (Tab. 2). East/Vertical components on the left, North/Vertical components on the right.

This can only be explained with complex subsurface structures under the sites that produce interference of seismic waves, as already proposed by Triantafyllidis et al. (2004) when studying site effects in the city of Thessaloniki (Greece). Therefore, a detailed characterization of the local subsoil structures is necessary in order to allow theoretical modeling and thorough understanding of such effects, the most important data to retrieved being the depth of the sediment-bedrock contact.

To derive a 3D model of the alluvial fan under the city of Gemona, gravimetrical measurements have been performed along five selected profiles to estimate the thickness of sediments (Furlanetto, 2004). Even if density stratification within the sedimentary layer cannot be excluded, the adopted model consists of a single homogeneous layer of mean density 1.8 kg/m^3, compatible with the geotechnical characteristics of the fan soil (Carulli et al., 1982). The results show strong lateral variations in the thickness of sediments along a NS directed profile as well as a general decrease in the mean thickness of sediments from the bottom to the top of the alluvial fan (Fig. 8), confirming that the alluvial fan cannot be modeled appropriately with a simple 1D structure.

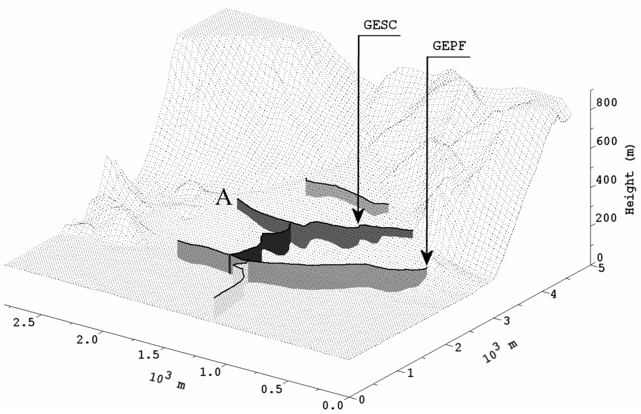


Figure 8. Model of the sedimentary layer along the selected profiles on the fan. Are marked the locations of the two seismological station GESC and GEPF.

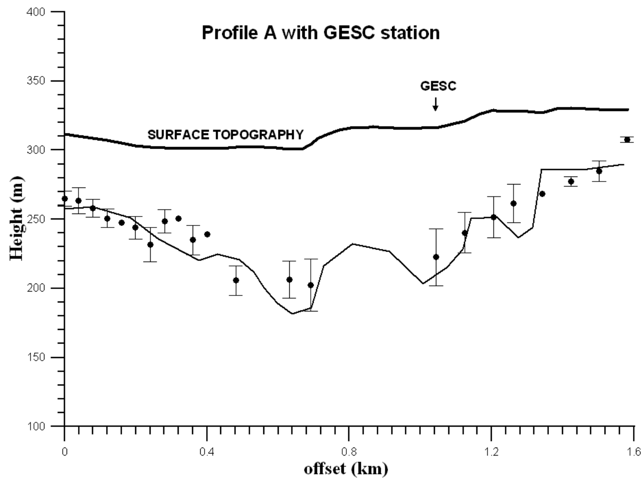


Figure 9. Surface topography (thick line) on top; gravimetric (thin line) and noise (dots) bedrock topography on bottom.

The gravimetric results are also supported by microtremor measurements performed at the location of the GESC station and at other 27 sites used in the gravimetrical campaign. The HVNSR at these sites show a variation in resonant frequencies across the alluvial fan suggesting a thickening of the sediments. Assuming an average shear-wave speed of 500 m/s (Marrara et al., 2001) in the sediments, we can estimate the thickness of the sedimentary layer across the fan. The obtained results are in good agreement with the gravimetric ones (Fig. 9) and a future extension of the noise measurements all over the fan could result in a 3D model to be used to explain the observed site effects in terms of wave propagation in laterally heterogeneous media.

5. Site effects at strong motion stations estimated through attenuation laws

5.1 Data

The attenuation laws are computed using the RAF (RAF, 1996-2005) and the ESD databases (Ambraseys et al., 2002). We select 123 earthquakes and about 900 PGA data in the areas of NE Italy (Friuli – Venezia Giulia and Veneto) and in Slovenia, fixing magnitude (3.0-6.5) and epicentral distance ranges (1-100 km). No selection criteria are applied on the PGA values. The soil types of the recording stations are divided in two simple categories (rock and soil) because we do not have detailed information about the geology at all the considered recording stations.

All seismic signals are filtered with a high-pass filter (cut-off frequency ranging from 0.1 Hz to 0.25 Hz) and, successively, with a low-pass filter (cut-off frequency ranging from 25 Hz to 30 Hz). The locations and magnitudes are selected from the OGS catalogue (OGS, 1995-2002), otherwise ESD (Ambraseys et al., 2002) or DST databases (DST, 1996-2005) are used.

5.2 Analysis techniques

In this work attenuation laws are estimated for PVA and for two different types of PHA (largest component and vectorial addition). The following model is adopted (Moratto et al., 2006):

$$\log_{10}(PGA) = c_0 + c_1 \cdot M + c_2 \cdot M^2 + (c_3 + c_4 \cdot M) \cdot \log_{10}(\sqrt{d^2 + h^2}) + c_S \cdot S \pm \sigma \qquad (1)$$

Equation (1) is not linear, thus the method applied for the regression procedure is as follows: a grid for h parameter is defined (h ranges from 0 to 20 km and the increase step is 0.1 km) and the R^2 computed for each value; the least R^2 fixes the h value and the parameters for the ground motion estimates are derived applying the one-step least squares method in the regression technique.

5.3 Results

The obtained coefficients for both PVA and two different types of PHA (the largest component and the vectorial addition) are presented in Table 3. The horizontal component computed using the vectorial addition has always a smaller standard deviation than the largest horizontal component.

Table 3. Coefficients of regression computed using PVA, PHA larger component and PHA vectorial addiction data.

Data	c_0	c_1	c_2	c_3	c_4	c_S	h	σ
PVA	-3.464	0.958	-0.053	-2.224	0.147	0.330	6.1	0.3137
PHA (lc)	-3.879	1.178	-0.068	-2.063	0.102	0.411	7.8	0.3448
PHA (va)	-3.401	1.140	-0.070	-2.356	0.150	0.415	8.2	0.3415

Considering that the geographic area is the same, the comparison between our regression results with laws proposed by Bragato and Slejko (2005) shows that the models and the coefficients are very similar, even if different ground motion data have been selected in the two studies. In all studies made with NE Italy recordings (Costa et al., 1998; Bragato and Slejko, 2005; this work) a stronger attenuation for small seismic events and a steeper curve slope for distances greater than 20 km, with respect to Sabetta and Pugliese (1996) and Ambraseys et al. (1996), is quite evident.

The mean ratio between recorded and computed (applying Eq.1 model) PHA are shown in Figure 10 for every station with a meaningful number of recordings. Generally the use of vectorial addition produces lower mean ratios than the use of the larger component PHA. Black circles indicate stations where site effects have been considered in computing attenuation laws (S=1); the site amplification factor in our model is about 2.5 and its use gives us a good site effects estimation at CARC and GESC but not at STOL where PGA recorded strong motions are twice the computed ones.

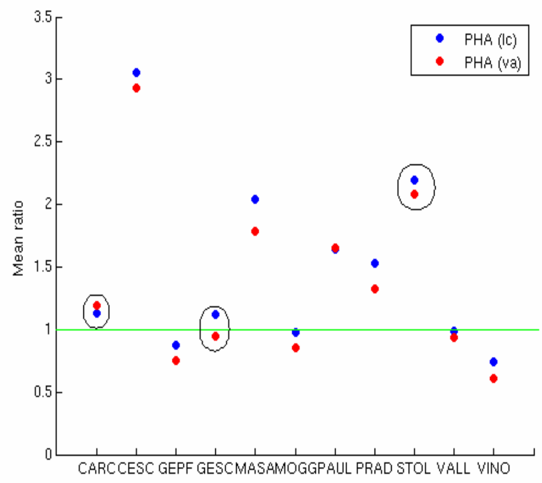


Figure 10. Mean ratio between observed and computed PHA (blue points=largest component; red points=vectorial addition); black circles indicate stations where PGA has been computed considering a site effects term (S=1) in the attenuation law.

Bedrock stations have very similar recorded and computed PGA (GEPF, MOGG, VALL, VINO, PRAD and PAUL); MASA station recorded PGA are twice the estimated one from attenuation laws. The most interesting result we find for CESC: this is a bedrock station placed inside an artificial cave in a mountain area, but the mean ratio indicates that there is an amplification factor of three on the recordings with respect to our estimates from derived attenuation laws.

On the other hand CESC recorded very few data (six registrations only) of earthquakes with magnitudes bigger than 3.0 and this could have resulted in a strong bias.

6. Conclusions

A variety of techniques have been applied to estimate site effects at stations of the RAF strong motion network (NE Italy). At some stations in Trieste and Gemona del Friuli placed on quaternary cover on purpose to study site effects, we use Fourier spectra with both HVSR and SSR techniques, the latter one with a reference station. Microtremor measurements are also made at several stations allowing HVNSR technique to be used. Finally, site effects are detected from the comparison of attenuation laws estimates with observed recordings.

The results confirm the “bedrock” nature of several stations, such as TRI, DST, GEPF and VINO. For TRI a strong de-amplification effect is found between 1 Hz and 6 Hz related to the dimensions of the cave in which the instrument is placed.

We derive detailed site amplifications at stations placed on quaternary sediments such as CARC and GESC. The strong source-independent amplification in the frequency range around 2 Hz of CARC with respect to TRI is partly caused by the TRI station de-amplification, thus the SSR and HVSR results are compatible. Some of the observed amplifications (CARC) can be explained by a simple 1-D local soil profile, at other sites (GESC) a clear 3-D subsoil geometry, estimated from gravimetric and noise measurement data, seems to be responsible for the observed source-dependent site response.

Finally, the comparison of recorded data with estimates derived from attenuation laws permits to detect unexpected amplifications at some stations. The reasons for the amplification of CESC station, placed on bedrock, has still to be discovered, but the scarcity of records might bias our results. PURA station temporary location is probably lying on a thin peat layer and the station will have to be moved to a nearby rock outcrop.

7. Acknowledgments

This study was financially supported by contracts “Contratto tra Dipartimento di Scienze della Terra e Regione Autonoma FVG, Direzione Regionale della Protezione Civile per la gestione della Rete Accelerometrica del Friuli Venezia Giulia (Contratto 6/06, Delibera Giunta Regionale 3425, dd 29/12/05)”, Progetti di ricerca di particolare interesse per il Dipartimento della Protezione Civile - convenzione ProCiv-INGV 2004-06: Progetto esecutivo S4 "Stima dello scuotimento in tempo reale o quasi reale per terremoti significativi in territorio nazionale", INTERREG IIIB Alpine Space Project "Sismovalp: Seismic risk in alpine valleys" and Interreg III A Italia-Austria 2000-2006 "Reti sismologiche senza frontiere nelle Alpi sud-orientali". We thank Franco Gentile of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) for providing us the data of the broadband surface station TRI and Franco Palmieri of OGS for the help in the acquisition and processing of the gravimetric data.

8. References

Ambraseys, N., Smit, P., Douglas, J., Margaris, B., Sigbjørnsson, R., Olafsson, S., Suhadolc, P. and Costa, G., 2004. Internet Site for European Strong-Motion Data. *Boll. Geof. Teor. Appl.*, 45, n. 3, 113-129.

Ambraseys, N.N., K.A. Simpson and J.J. Bommer (1996). Prediction of horizontal response spectra in Europe. *Earthquake Eng. Struct. Dyn. 25, 371-400.*

Amoruso, A., L. Crescentini, G. De Luca, R. Scarpa, M. Abril, and A.Cirella (1997). Underground earth strain and seismic radiation measurements with a laser interferometer and a dense small-aperture seismic array. *Annali di Geofisica, 40, 995-1005.*

Anderson H. and J. Jackson (1987). Active Tectonics of the Adriatic Region. *Geophys. J. Roy. Astr. Soc., vol.91, pp. 937-983.*

Aoudia, A. (1998). Active Faulting and Seismological Studies for Earthquake Hazard Assessment, *Ph.D. Thesis, University of Trieste, 152 pp.*

Bragato, P.L. and D. Slejko (2005). Empirical ground-motion relationship for the Eastern Alps in the magnitude range 2.5-6.3. *Bull. Seism. Soc. Am. 95-1, 252-276.*

Carulli G.B., F. Giorgetti, R. Nicolich and D. Slejko (1982). Friuli zona sismica: sintesi di dati sismologici, strutturali e geofisici. *Guide geol. reg. Soc.Geol.Ital., pp. 361-370 Bologna*

Costa G., P. Suhadolc and G.F. Panza (1998). The Friuli (NE Italy) accelerometric networks: analysis of low-magnitude high-quality digital accelerometric data for seismological and engineering applications. *6th U.S. National Conference on Earthquake Engineering.*

Fitzko F., P. Suhadolc and G. Costa (2004). Realistic strong ground motion scenarios for seismic hazard assessment studies at the Alps-Dinarides junction. In: Earthquake: Hazard, Risk, and Strong Ground Motion, Y.T.Chen, G.F.Panza and Z.L.Wu (eds.), *Seismological Press, Beijing, 361-377.*

Fitzko F., G. Costa, A. Delise and P. Suhadolc (2006, in press). Site effects analyses in the old city center of Trieste (NE Italy) using accelerometric data. *Journal of Earthquake Engineering.*

Furlanetto E. (2004). Indagini geofisiche per caratterizzare al struttura del sottosuolo del conoide di Gemona del Friuli. *Graduate Thesis, University of Trieste, 190 pp.*

Marrara F., A. Saraò and P. Suhadolc (2001) Amplification of the seismic ground motion in Gemona (NE-Italy) due to the 1998 Bovec-Krn earhquake. *Boll. Geof. Teor. Appl. vol. 42, n. 3-4, pp. 209-217*

Moratto L., G. Costa and P. Suhadolc (2006, in preparation). Attenuation of peak ground acceleration from strong motion data in the Friuli area (NE Italy).

OGS (1995-2000). Bollettino della Rete Sismometrica del Friuli-Venezia Giulia e del Veneto. *Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Dipartimento Centro Ricerche Sismologiche, Udine, Italy.*

RAF (1996-2005). Rete Accelerometrica del Friuli-Venezia Giulia Rapporto. *Dipartimento di Scienze della Terra dell'Università di Trieste, Trieste, Italy.*

Sabetta F. and A. Pugliese (1996). Estimation of response spectra and simulation of nonstationary earthquake ground motions. *Bull. Seism. Soc. Am. 86-2, 337-352.*

Site EffectS assessment using AMbient Excitations SESAME (2001) *European Commission, nr. EVG1-CT-2000-00026.*

Tagliapietra G., (2003). Caratterizzazione geologica della stazione accelerometrica di palazzo Carciotti e relative stime di effetti di sito. *Tesina di laurea in Sc. Geol., Dip. Sc.Terra, University of Trieste, 24 pp.*

Triantafyllidis, P.A., P.M. Hatzidimitriou and P. Suhadolc (2001). 1-D theoretical modeling for site effect estimations in Thessaloniki - Comparison with observations. *Pageoph, 158, 12, 2333-2347.*

Triantafyllidis, P., P. Suhadolc and D. Hatzidimitriou (2002). Influence of source on 2-D site effects. *Geophys. Res. Lett.*, 29, 6, 13, 1-4.