Open File Report Task5

Characterization of site effects for the Colfiorito, Città di Castello and Val d'Agri areas: predictability and site transfer functions.

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INTRODUCTION

The effect of local site amplification has been recognized as an important factor in ground motion assessment and is nowadays frequently studied. A common approach to evaluate ground shaking is to first estimate ground motion parameters at rock sites and then to correct them introducing site transfer functions derived from experimental data and from numerical modelling.

The site transfer functions to be used to modify ground motion evaluated at rock sites can be evaluated starting from strong motion, weak motion and microtremor data. According to the amount and quality of the available data the transfer functions are evaluated for specific sites, in order to be used as a punctual information, or as representative of an average local condition in selected areas. All the available geological and geotechnical data must be collected to put some constraints on the obtained results and to permit numerical modeling to be compared with experimental results.

The obtained transfer functions can be introduced in scenario studies convolving rock seismograms by the pulse response of the upper layers for different situations considered as representative of the geology of the studied areas.

The capability of describing local site effects is strongly affected by the amount of seismological, geophysical and geotechnical data available. This is particularly true if numerical modelling needs to be performed and if the contribution of non linear soil behaviour has to be taken into account.

For the three areas investigated in the framework of the project, the different amount of available data and information guided the performed studies and the obtained results.

For Colfiorito test site, the availability of strong motion data recorded during the largest events of the Umbria Marche sequence (1997-98) yields well constrained information for specific sites.

For Città di Castello the collection of weak motion and microtremor data allowed to reconstruct the geometry of the sedimentary basin underlying the city and to define zones with homogenous site response where to evaluate site transfer functions in a 1D approximation, including non linear behaviour.

For Val D'Agri area, the lack of seismic and geotechnical data did not allow to describe in detail the site response in the sedimentary basin. In this case some sample sites with a known uppermost geological structure were selected as representative of the seismic response of the basin. For them, microtremor data were collected to put some constraint on the transfer functions computed in a 1D approximation. In this case it was not possible to consider the non linear soil behaviour.

METHODS OF INVESTIGATION

Transfer function were evaluated using several methods proposed in literature and based, according to the available data, on strong motion, weak motion and microtremor data analysis.

The used approaches are based on conventional spectral ratios using a reference site for weak motions, receiver–function estimates for strong motion data, generalised inversion on strong motion data, numerical modelling based on geological and geotechnical information.

Conventional spectral ratio compares horizontal S waves spectrum at a soft site with the same spectrum recorded at a rock reference site in the hypothesis that source to site path can be considered as being the same for the two records. In this case the amplitude transfer function can be expressed as the spectral ratio as a function of frequency.

When a close rock reference site is not available, the receiver-function technique (Langston, 1979) provides a proxy of the empirical transfer function. The physical meaning of this technique is still controversial but the evidence of results comparable to those obtained by conventional spectral ratios in many studied cases allows its use when other approaches are not possible.

The generalised inversion is based on the concept that any accelerometric record at a station j is the product of source i, attenuation and site terms, as:

$$U_{ij}(f,R) = S_i(f)Z_j(f)A(f,R) \quad (1)$$

where: $U_{ij}(f,R)$ is the spectral amplitude of S waves; $S_i(f)$ is the spectral amplitude of source i_{th}; $A(f,R)$ is the attenuation function; $Z_j(f)$ is the j_{th} site transfer function; f is the frequency (Hz); R is the hypocentral distance (km). The spectral amplitude of S waves was inverted to evaluate the source functions, the site response and the attenuation function.

Theoretical modelling is performed using 1D linear (Haskell, 1953; Thomson, 1950) and non linear (Shake 91 linear-equivalent method) approaches. Also a 2D boundary elements modelling is applied.

RESULTS FOR THE ANALYSED TEST AREAS

The main purpose of this Task was the transfer function evaluation. The objective is reached with different methods and different resolution according to the level of knowledge available for any of the three studied areas. Following a discussion of the used approach, along with the obtained results is presented separately for Colfiorito, Città di Castello and Val d'Agri areas.

Colfiorito Area

The seismic sequence started in Colfiorito area in November 1997 is very well studied and characterised regarding both the spatial and temporal distribution of the events (Chiaraluce et alii, 2004) and the source characteristics of the main shocks (Zollo et alii, 1999). This features makes the area very interesting for testing the more recent ground motion modelling techniques. In this framework the possibility of measuring with detail local site effects becomes very important to define earthquake scenarios which evaluate the characteristics of ground motion as a function of rupture distribution and evolution along the fault plane. The most direct approach to evaluate site effects, including also possible non linear effects, is based on the analysis of strong motion records. The Umbria Marche sequence triggered several strong motion instruments, figure 1, in the epicentral area (S.S.N., 2002).

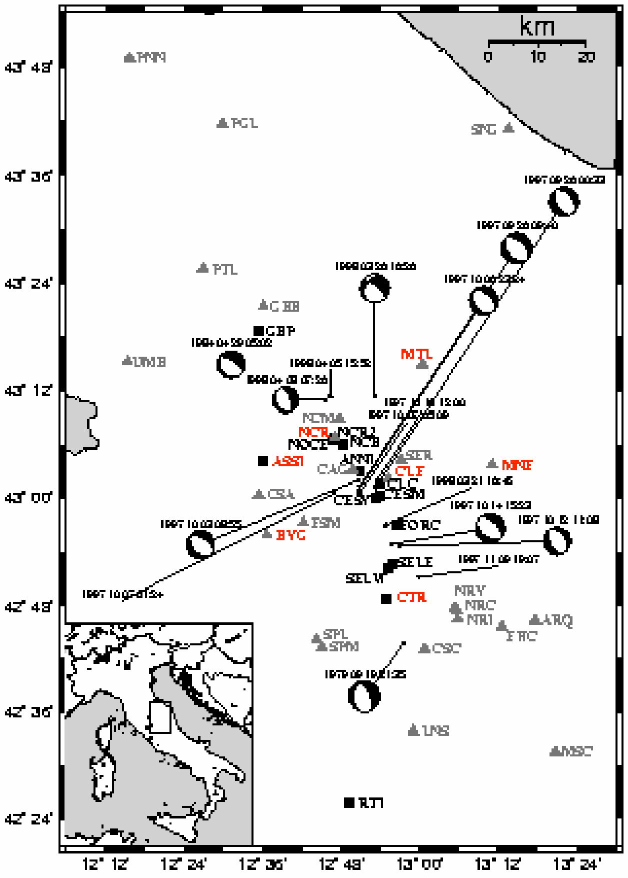


Figure 1) Umbria-Marche 1997-98 major events distribution. Triangles represent the triggered analogical strong motion analogical stations, squares the triggered digital strong motion station. The stations plotted in red are the ones analysed in this work. CTR and MNF stations are located on rock and their transfer function is assumed unitary.

The seismic sequence was characterized by many events with magnitude higher than 4.5 that activated the strong motion stations and enlarged the instrumental strong motion dataset.

The studied area is quite wide and it is not possible to divide it in zones with homogeneous site response, due to this fact transfer functions were evaluated for some particular sites and can not be extended to other areas.

Starting from the strong motion data set site transfer function was evaluated for the accelerometric sites located at Nocera Umbra, Assisi, Colfiorito, Bevagna and Matelica, the selected sites are among the sites used to test all the ground motion simulation techniques applied in the framework of the project. In a first stage also the stations of Borgo Cerreto torre and Monte Fiegni were taken into account, but, since they are installed on rock their transfer function were assumed unitary.

The three stations Colfiorito, Bevagna and Matelica were classified as soft sites (S.S.N., 2002 and unpublished geotechnical information of the civil protection department) and their response was evaluated through two experimental techniques (H/V ratio and generalised inversion) and a theoretical model (1D response of soil columns, Shake91, Idriss 1991).

Nocera Umbra and Assisi have been classified as rock sites, but their gelogical and geomorphological setting is very complex, so that they give rise to amplification effects (Marra et al., 2000; Castro, 2001). Experimental techniques (H/V ratio and generalised inversion) were used to quantify the amount of amplification, as well as theoretical models (1D response of soil columns, Shake91, Idriss 1991) and 2D boundary element technique).

Although papers in the literature indicate that the ground motion amplification at several stations can be ascribed to a 2D or 3D effect (Nocera Umbra and Colfiorito in particular), we verified whether the main features of the sites could be quantified with mono-dimensional approximation.

As final step a comparison between the different approach is made in order to select the most reliable results, this process brings to the following results also shown in figure 2.

- ASSISI – The different techniques provide similar results. The transfer function proposed is the result obtained from the non parametric inversion method. Only the amplitudes are available.
- BEVAGNA – The theoretical approach underestimates observations probably due to 2- and 3-D effects. In contrast, the inversion result is extremely high. Lacking other independent information, we propose 2 different solutions: a lower boundary corresponding to H/V spectral ratios and upper boundary corresponding to non parametric inversion method. Only the amplitudes are available.
- COLFIORITO – The availability of a conventional spectral ratio based on an abundant weak-motion analysis indicates that 1D (Haskell) modeling is suitable to fit the local conditions. The proposed transfer function for strong motion computation is the result of linear modeling. Amplitudes and phases are available.
- MATELICA - The data available for this site are limited in number. Also in this case, a linear model is proposed, so that amplitudes and phases are available.

- NOCERA UMBRA – The complexity of this site has been well investigated in many papers. The H/V spectral ratios (separately for NS and EW components) represent an empirical but adequate estimate of the local effect to be used in simulations. Only amplitudes are available.

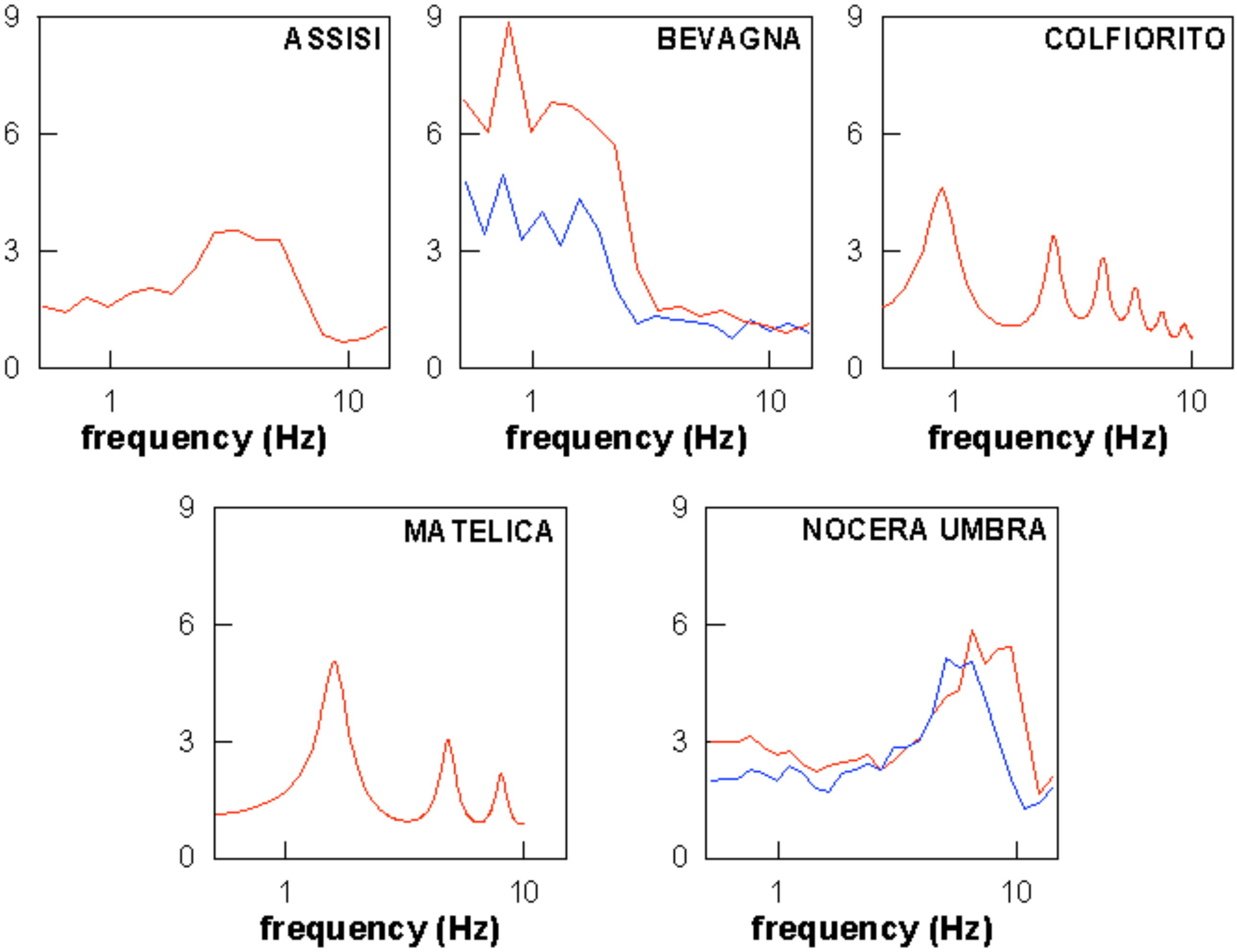


Figure 2) Transfer function for the investigated sites. For Bevagna station an upper and lower bounds are proposed using non parametric inversion (red line) and receiver-function method (blue line). For Nocera Umbra station the receiver-function method is proposed for the North component (red line) and for the East component (blue line) separately.

Città di Castello Area

Città di Castello is an ancient urban settlement with monumental buildings of historical and architectural importance located in the Valtiberina valley, central Italy (Figure 3). The valley is a continental basin developed during the extensional tectonic regime which affected the central Apennines during the Pliocene-Pleistocene. The sedimentary sequence that fills the basin consists of Plio-Quaternary continental fluvial and lacustrine deposits. The valley width is about 3500 m, along the WSW-ENE direction, whereas the maximum sediment depth is about 250 m, that gives a h/l ratio of 0.15 (where h is the depth and l is the valley halfwidth).

There were not strong motion records available for the area so it was necessary to collect some weak motion and microtremor data during a field experiment performed in 2001, data were collected in the same area also by Regione Umbria as shown in the map.

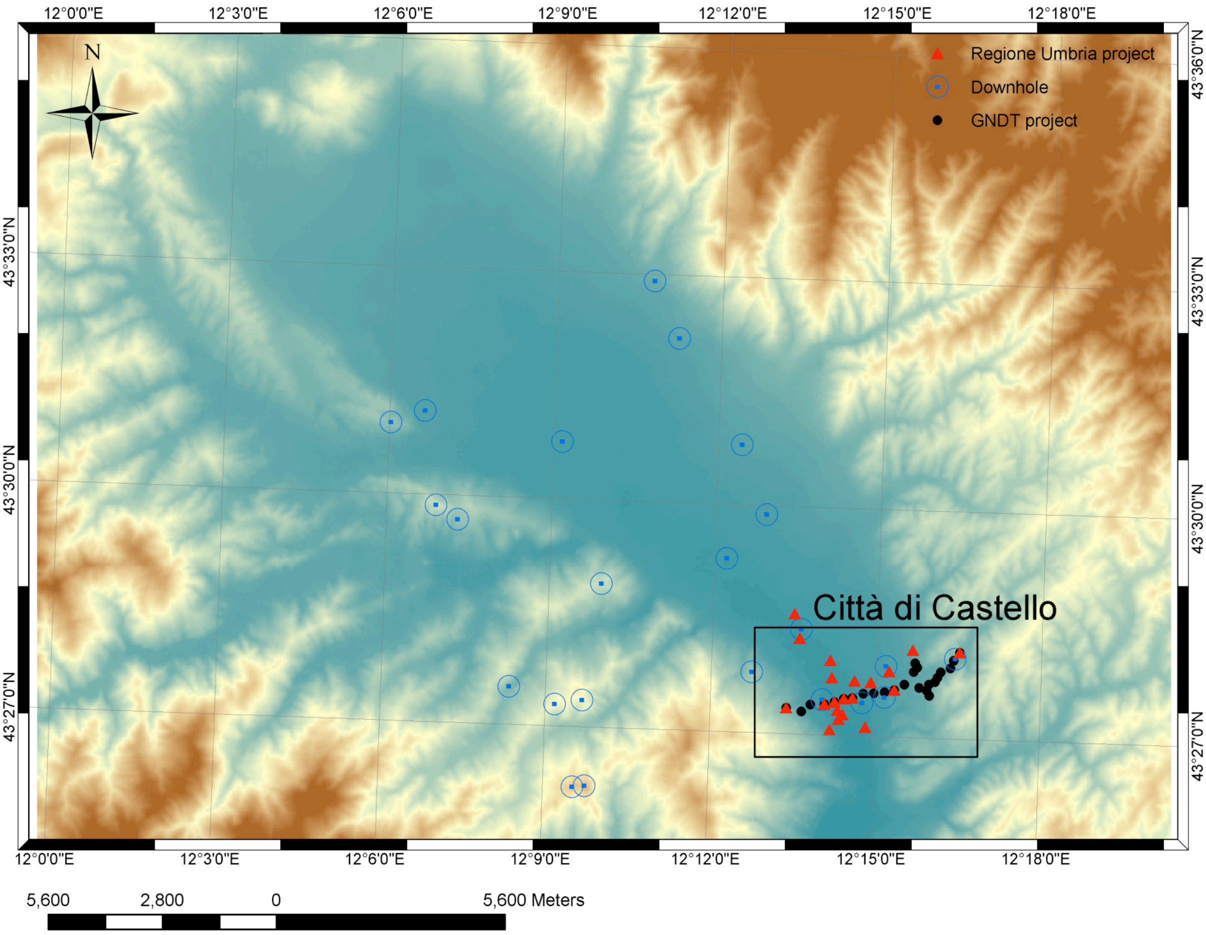


Figure 3) Overview of the Valtiberina Valley and location of the study area.

The stations deployed along the profile elongated in the East West direction, that crosses the basin in correspondence of Città di Castello historical centre, recorded both microtremor and earthquake data for a period of about 10 days in 2001. Both westernmost and easternmost stations along the profile are settled on outcropping rock so the profile follows the changes in the geometry of the basin in W-E direction. Other recording points are spread out all along the area and are used only for microtremor measurements. In this case microtremor data are related to short time windows and sometimes are affected by a high noise level due to anthropic activities. The map also shows the boreholes (Crespellani et Al., 2002) used to get information about the depth of the basin and the shear_wave velocities of the sediments that fill in it.

The analysis of these data allows to define the geometry of the Città di Castello basin (figure 4). The objective is achieved using direct S waves travel times delay at seismic stations deployed along a the profile (Bordoni et al. 2003). The delay is converted in bedrock depth using, as a constraint, data from a deep borehole that intercepts the basement at a depth of about 145 m in the western part of the basin. The shear wave velocities are compared with those derived from shallow geotechnical measurements and extrapolated in depth. H/V spectral ratios calculated on ambient noise data permit to detect the fundamental frequency of resonance of the basin and to observe its variation along the profile.

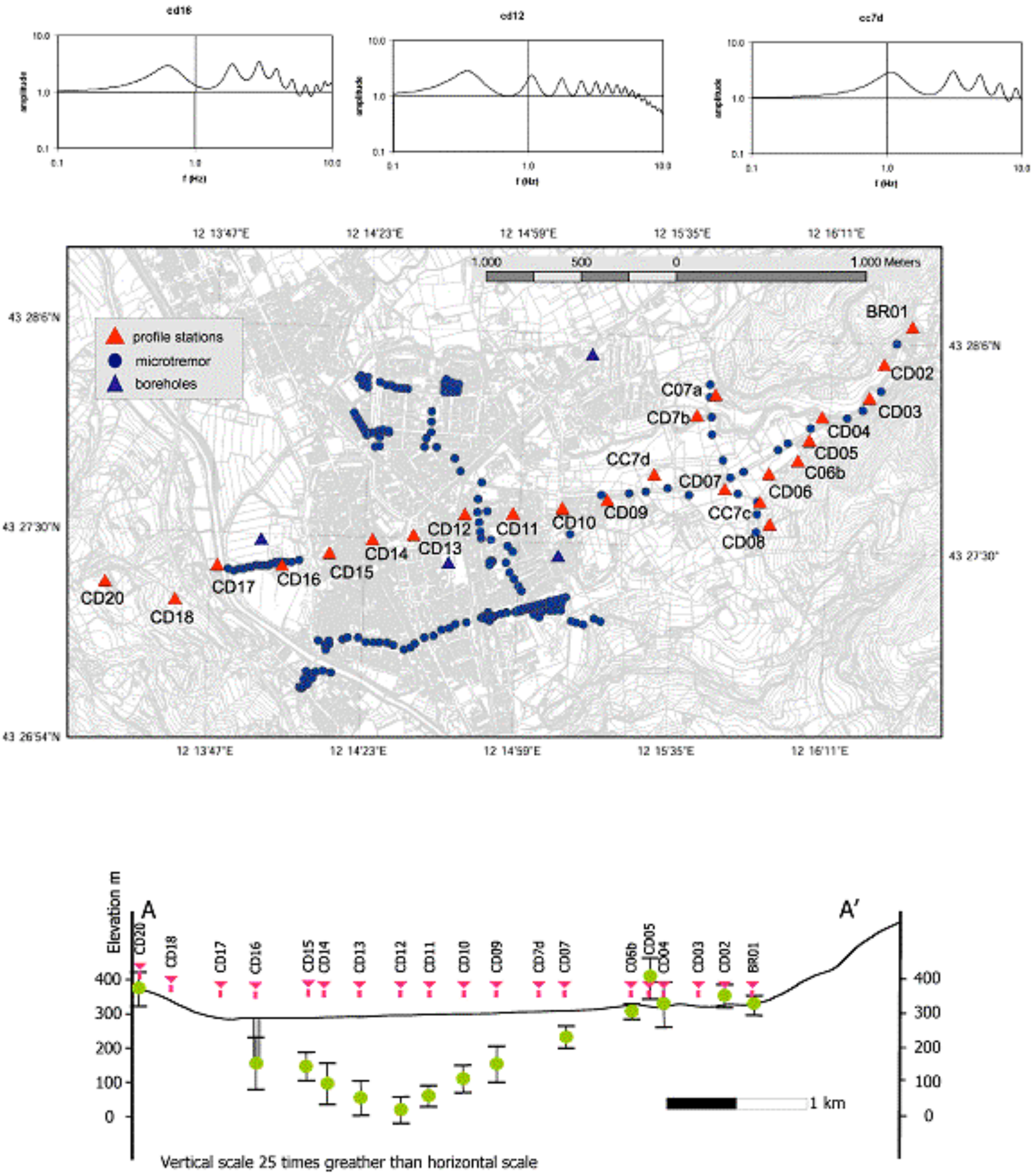


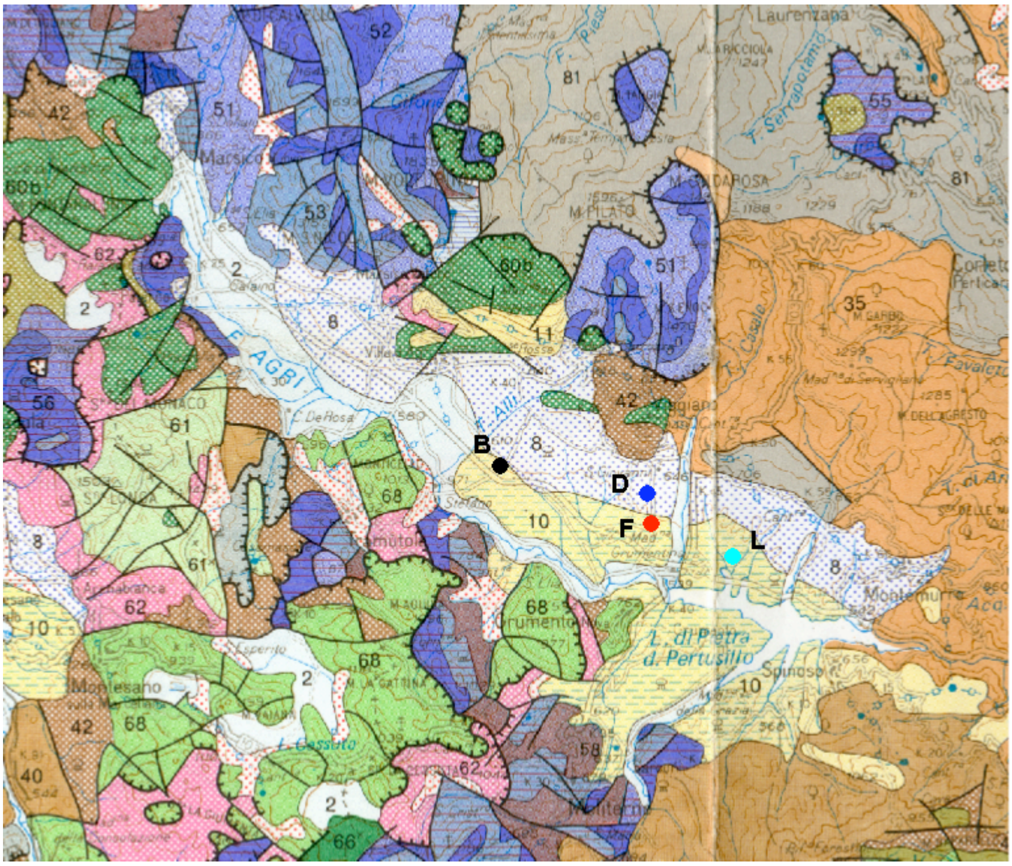
Figure 4) Geometry of Città di Castello basin, as derived from S waves delays along with temporary seismic stations deployment. Panels on the top represent the theoretical transfer functions evaluated for the sites CD16, Cd12 and CD7d.

For the entire urban area of Città di Castello conventional spectral ratios on weak motion earthquakes data are also calculated using a reference station on a nearby limestone outcrop. Starting from the geological profile the area is dived in zones characterized by the same average thickness of sediments, and for each zone the 1D theoretical transfer function is derived using both linear (Haskell, 1953; Thomson, 1950) and non linear (Shake 91 linear-equivalent method) approaches. The curves of shear modulus and damping ratio versus strain are taken from literature data and from Crespellani et al. (2002).
Both weak motion and microtremor data recorded during the project in the study area are analyzed.
Unfortunately signal to noise ratio for the recorded events does not permit to detect frequencies lower than 0.8-1 Hz, and to investigate the part of the spectrum that contains information about the resonance frequency of the basin. In our explanation the amplification found using earthquake data at frequencies between 1 and 10 Hz can be related to higher mode excitation. In contrast, microtremor data seem to be quite reliable and can be used to detect the fundamental resonance frequency that in some area is lower than 0.5 Hz. 1D modelling reproduces quite well microtremor results in the deepest part of the valley and can be used for evaluating the transfer function to be used in the scenario studies. A confirmation of the microtremor results comes from few strong motion records of higher magnitude events that show the presence of a low frequency peak in the HVSR amplification function. In the areas closer to the edges of the basin, the observed amplification functions are quite complex and the available geological and geotechnical information does not consent to model them.
As result of the performed analysis we propose three transfer functions to be applied to areas characterized by different thickness of the sedimentary layer. Figure 4 shows the cross section of the basin as inferred from S wave delay along with the distribution of seismic stations deployed in the project along with the position of the available boreholes. The figures also show the three proposed transfer functions including non linear effects.

Val d’Agri Area

The Agri River valley (figure 5) is a complex intermontane basin formed in southern Apennines during Quaternary times. The area has been studied in the past and recent studies based on seismic and electrical profiling trying to define the geometry of the basin and the seismic velocity distribution. Up to now a detailed description of geotechnical characteristics of the sedimentary layer is still missing. Among the available data useful to reconstruct the main features of the basin it is possible to consider many deep drill well distributed along the basin. They reach depths as large as 200 meters and, in some case, intercept the bedrock.
From seismological point of view there are not earthquake data recorded in the basin at the moment, since all the seismic stations operating in the area in the last few years for microseismicity studies are deployed in rock sites located out of the basin.
The lack of seismic data does not consent to apply any data based technique in the area, and it makes necessary to find a different approach to evaluate site transfer

functions. In this conditions the only seismic data to collect are microtremor data, that can be used to evaluate the Nakamura H/V spectral ratios.



From Geological Map
of Southern Apennines
Bonardi et al., 1988

Quaternary Deposits
in the Map are indicated
by Units 2,8,10,11

Figure 5) Geological map of Val D'Agri area. Four microtremor recording points, characterized by a similar H/V ratio are also indicated.

The H/V approach on microtremor (Nakamura, 1989; Bard,1999) is able do detect the frequency of resonance of the sedimentary layer when a strong velocity contrast is present at the contact with underlying bedrock. Using in a combined way thickness information derived from deep drilling and resonance frequency from H/V, it is possible to infer information about the velocity of soft sedimentary layer in the basin. We then performed microtremor measurements in correspondence to the drilling points and applied H/V technique on the recorded data. In particular microtremor data were collected in 23 sites located in the sedimentary basin and distributed along longitudinal and transverse profiles.

The variation in the resonance frequency indicates changes in bedrock depth moving along the sedimentary basin from North to South and from West to East. For the sites with lower geological complexities, which are distributed in the central part of the valley H/V the resonance frequency is quite stable (figure 6), indicating a constant depth of the bedrock.

In this case 1D modelling can be performed using a linear (Haskell, 1953; Thomson, 1950) approach, the non linear behaviour can not be considered because of the lack of data.

The experimental data can be reproduced with a 1D model with a bedrock 200 meters deep and an average shear waves velocity of about 500 m/s as shown in figure 7.

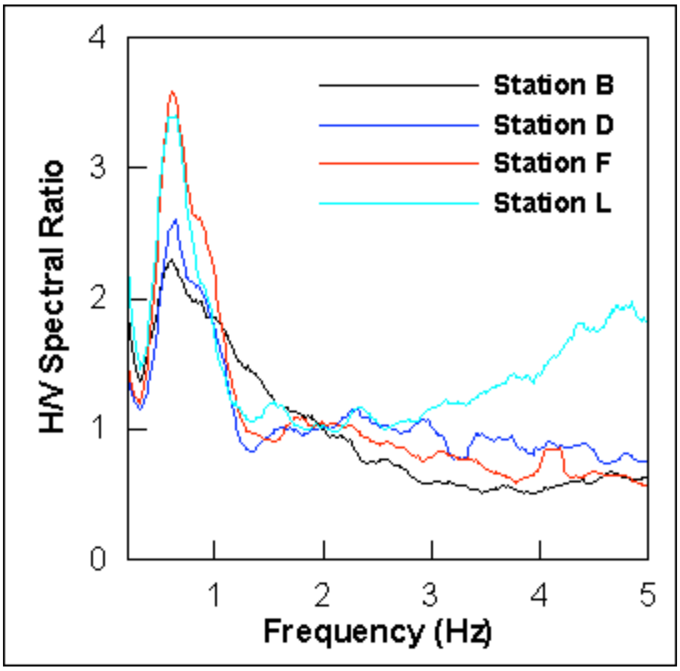


Figure 6) H/V spectral ratio for the microtremor recording site B,D,F,L.

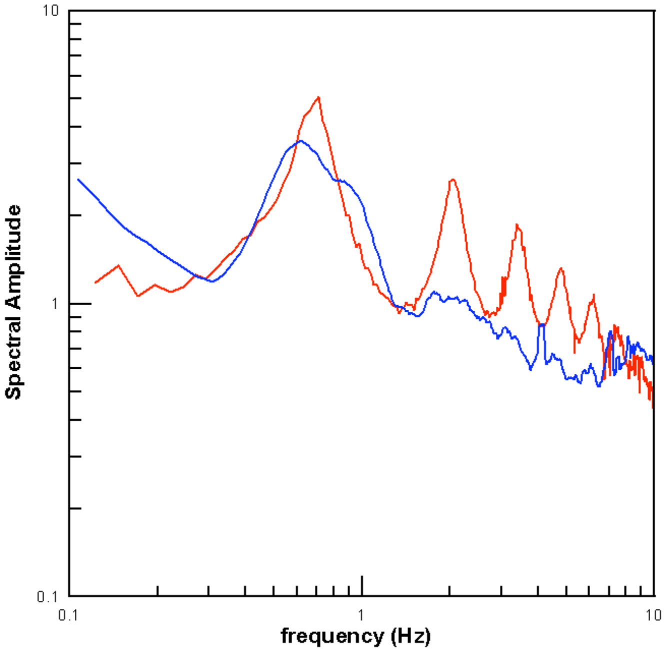


Figure 7) Comparison from H/V spectral ratio (blue line) and theoretical 1D linear modeling.

CONCLUSIONS

Site effect evaluation is a very important step in ground motion estimation since site transfer function can strongly modify the characteristics of motion predicted by the synthetic approaches used in scenario studies.
Unfortunately the high variability of surface conditions makes the site effect evaluation particularly critical in absence of good quality geological, geotechnical and seismological data.
In this study it is clear how, also for sites with a quite good amount of data, results can be not always too clear.
As final remark we recommend to put more strength in the future in seismic and geotechnical data acquisition for those area were strong site effects can be predicted from geological studies. Also a multidisciplinary approach is always necessary since simple approaches can not be suitable of furnishing convincing results.

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