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Results of the site-effects study in the village of Claut (N.E. Italy)

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Abstract - A magnitude 4.3 earthquake occurred in the Claut area (N.E. Italy) on April 13, 1996, causing damage to infrastructures which can be quantified as VI-VII on the MCS macroseismic intensity scale. Local geology and topographic features seem to have strongly affected the areal damage distribution. In particular, the buildings in the central area of the village, built on soft alluvial deposits, suffered the most severe damage. We presume that these unconsolidated, shallow deposits are at the origin of amplifications of the seismic ground motion. The sharp velocity contrast between the sedimentary cover and the underlying bedrock traps seismic energy within the incoherent deposits producing ground motion amplifications. The data used in this study consist of waveforms of about 45 earthquakes recorded by, at most, eight 3-component stations installed in the Claut area. All the records have been corrected for instrument response. We determined the response spectra for selected earthquakes. In addition, we present the results obtained from the analysis of spectral ratios computed with respect to a reference site. Moreover, for each site we computed the spectral ratios between the horizontal and the vertical components of motion both for earthquakes (receiver function) and for background noise (Nakamura's technique). Our results indicate that: i) the response spectra show a discrete variability of site amplification effects within the investigated area; ii) spectral ratios computed versus a reference site display remarkable differences in the amplifications of the ground motion for the different sites. Finally, we found that our results do not depend on the azimuthal distribution of the earthquakes used.

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1. Introduction

The seismic sequences that followed the April 13, 1996, $M_D = 4.3$ ($M_L = 4.5$, Tento, personal communication; VI-VII Mercalli-Cancani-Sieberg, MCS) main shock (Fig. 1) caused structural damage to simple stone masonry and light, non-structural damage to RC frame buildings in Claut (N.E. Italy, Pordenone Province), a village of about 1500 inhabitants about 6 km from the epicentre (Bernardis et al., 1997).

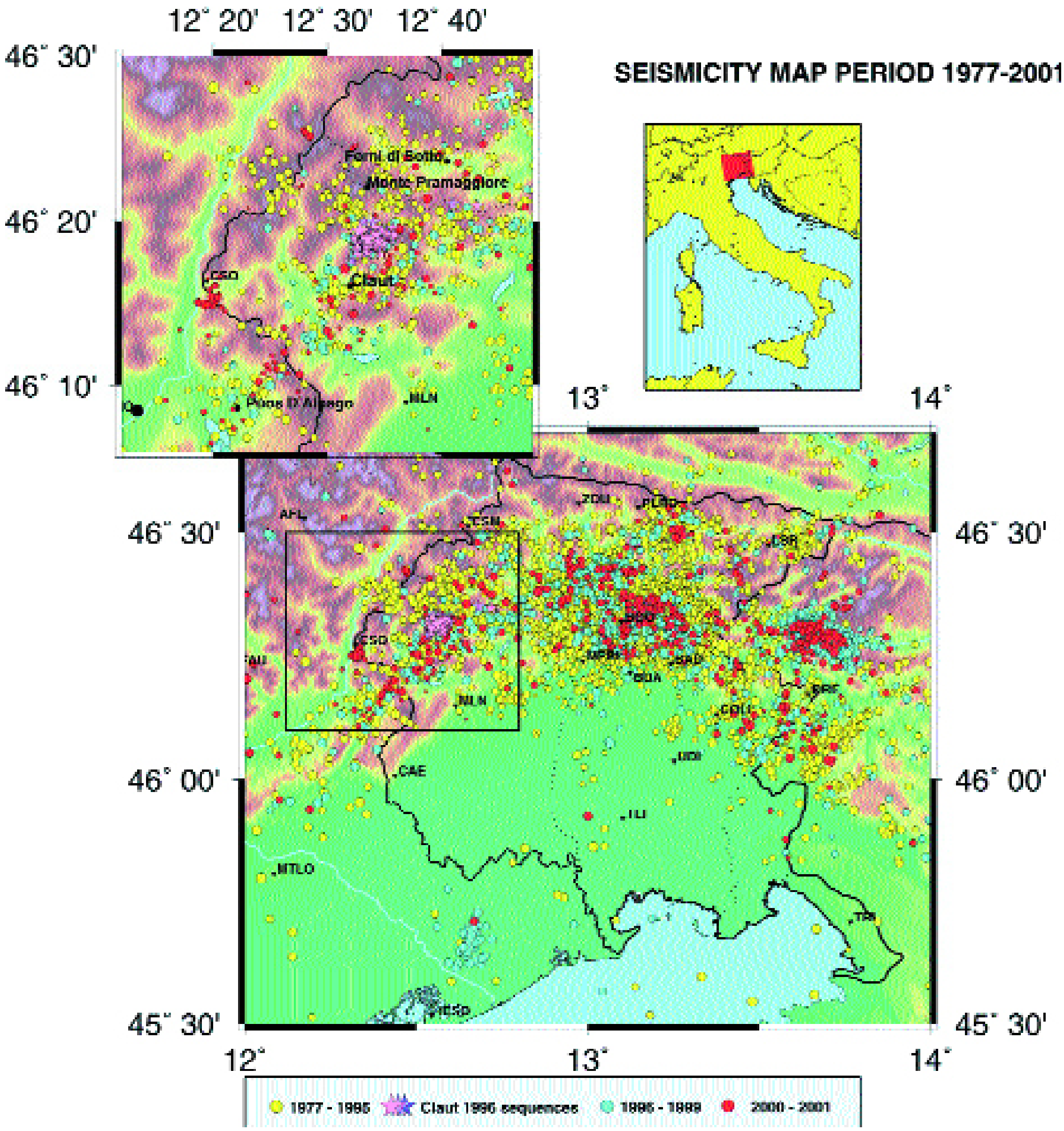

Fig. 1 - Friuli-Venezia Giulia Seismometric Network: map of 1977-2001 located earthquakes. The triangles indicate the seismometer stations.

The central part of the village lies on an area which, for both its stratigraphic and geomorphological features, is very suitable for a seismic amplification survey. Indeed, the buildings most seriously damaged by the 1996 seismic episodes are herein located. In addition, the proximity of the Cansiglio-Bellunese seismic zone which has been recognized by various authors (Barbano et al., 1986) as being the site of earthquakes with M_L 5.5 and above, makes the study of the local amplifications in Claut important for urban planning and building retrofitting.

2. Geological framework of the area

The epicentral area of the Claut sequences is located within the south-eastern Alpine domain. This is a chain-trench system of Neogene-Quaternary age whose geomorphological expression is constituted by the Alpine and pre-Alpine orogenic belts, that extend from Garda Lake to the west and to western Slovenia to the east, and to the Veneto-Friuli alluvial plains to the south. The village of Claut lies almost in the core of a broad syncline that strikes nearly E-W and is cut through by the River Cellina.

More in detail, the village of Claut is built upon a wide alluvial terrace extending for about 1.5 km in the E-W direction along the course of the river, upstream of the confluence of the Settimana Creek into the Cellina River itself (Fig. 2). This terrace is, furthermore, engraved by a NNE-SSW flowing right-bank tributary creek of the Cellina River (rio Chiadola), which carves a narrow, 25-30 m deep valley within the alluvial deposits.

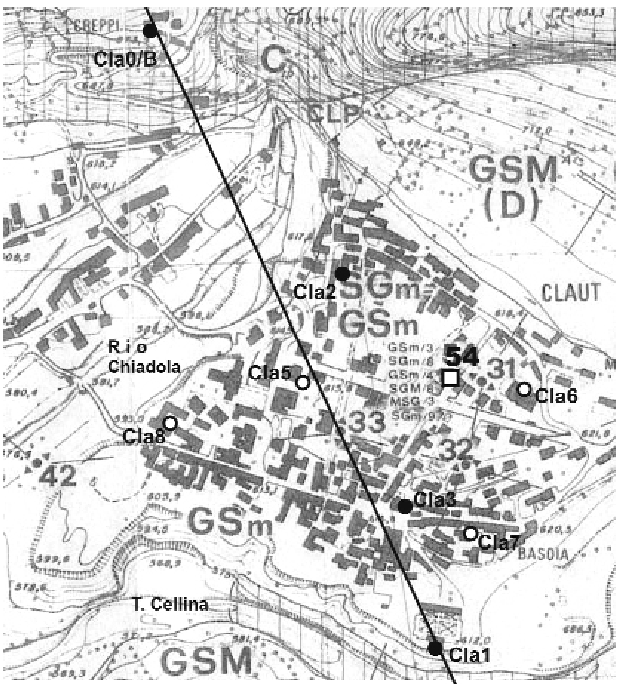

Fig. 2 - Map of Claut village: open square (54) geomechanical survey and correspondent litostatigraphic column found; (31-32-33-42) V.E.S.; Lennartz MarsLite data loggers (black circle); Nanometrics Orion data loggers (open circles).

All the buildings badly damaged during the 1996 sequences belong to the main and most ancient nucleus of Claut, lying on the easternmost sector of the terrace, which reaches its top width (~ 600 m) at this point, and faces the bed of the Cellina River with a steep, 30-40 m deep, scarp. At its foot, and for at least more 10 m, the turbidites of the Claut Flysch formation outcrop, showing a sub-vertical stratification and intense folding.

In the past, the same area was the target of four vertical electrical surveys (V.E.S.; Fig. 2) which evidenced a low-resistivity bedrock (interpreted as the Claut Flysch formation) whose surface is shaped by two E-W striking depressions (about 40 m depth). These structural lows are interspaced by a horst-like feature overlaid by a 25 m thick sedimentary cover (Fig. 3). The rocky bedrock is also abruptly excavated just in correspondence with the course of Rio Chiadola, as the progressively more shallow depths reveal as one moves towards the western sector of the terrace (only a few metres from field-level).

The geomechanical drilling (54) extracted a continuous core down to a depth of 35 m from field-level and provides a stratigraphic description of the more recent deposits which have smoothed the bedrock palaeomorphology. They are mainly constituted by medium-to-coarse grained and cobbled sands, including two sandy gravel layers and some thinner layers of sandy clays with cobbles and silts. The silty-clay matrix content is always very variable; cobbles are mainly of carbonate composition and reflect a poor selection.

The interpretation of such data, accompanied by field observations and examined in the context of the late-Pleistocene/Holocene geomorphological setting of the area, suggests that these incoherent deposits represent the filling sequence of the proximal sector of a short-lasting lake. The two E-W bedrock depressions may be the traces of palaeo beds of the Cellina River, while this seems the obvious origin of the deeper NNE-SSW striking one in correspondence with Rio Chiadola (Fig. 3).

3. Seismological features of the area

Historical seismicity in the area features events reaching, at most, a macroseismic intensity equal to a VI-VII MCS degree (Bernardis et al., 1997). Starting from May 6, 1977 a monitoring seismic network was installed covering the whole of the Friuli area. In 1998, the network coverage was improved with deployment of two new stations in Casso (CSO), and Malnisio

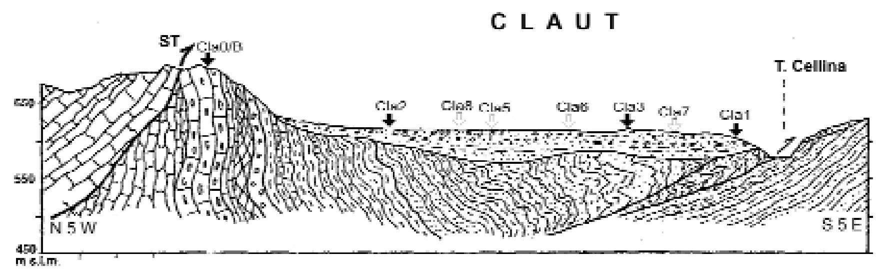

Fig. 3 - Geological cross-section striking through the village of Claut. Location of seismic stations: Lennartz MarsLite data loggers (Black arrows); Nanometrics Orion data loggers (white arrows).

(MNL). Further, in 1995, the Casera Razzo station was moved to the Casera Mimoias (CSM) site at a distance of 27 km from the village of Claut. During the period 1977-2001, the Friuli-Venezia Giulia Seismometric Network determined 524 hypocenters of events with M_D between 1.0 and 4.3 within a radius of about 20 km around the centre of Claut (46° 10' - 46° 30' N, 12° 20' - 12° 40 E). 59 of these earthquakes have $M_D \geq 3$, and display hypocentral depths between 2 and 16 km. It is noteworthy that the seismic activity was sporadic in this area until 1995. Between January and April 1996, 3 significant seismic sequences occurred, with main shocks having magnitudes M_D 3.7, 4.0 and 4.3. Since then a persistent seismic activity has been observed (Fig. 1).

4. Data acquisition

Along a profile stretching in a NNW-SSE direction, transverse to the Cellina River valley, and passing through the village of Claut, eight monitoring sites were selected (Fig. 2). Station Cla0/B was installed on a bedrock outcrop of the Vajont limestones, and thus constitutes the reference site in our study. The remaining Cla1, Cla2, Cla3, Cla5, Cla6, Cla7 and Cla8 receivers were deployed on the alluvial terrace overlying the Claut Flysch Formation, at points of different sedimentary cover thickness (Table 1).

Table 1 - Location of seismic stations.

Place	Name	Site geology information	Lat. N (°)	Lon. E (°)	Elevation (m)
Claut (Lorenzi's house)	Cla0	Vajont Limestones	46,272	12,513	670
Claut (Lorenzi's house)	ClaB	Vajont Limestones	46,272	12,513	672
Claut (cemetery)	Cla1	Quaternary cover (20m) on top of Claut Flysch	46,266	12,517	612
Claut (Bellitto's house)	Cla2	Quaternary cover (20m) on top of Claut Flysch	46,269	12,516	618
Claut (parish house)	Cla3	Quaternary cover (30m) on top of Claut Flysch	46,267	12,517	617
Claut (surgery)	Cla5	Quaternary cover (>35m) on top of Claut Flysch	46,268	12,515	617
Claut (grammar school)	Cla6	Quaternary cover (>35m) on top of Claut Flysch	46,268	12,519	617
Claut (Valentina's house)	Cla7	Quaternary cover (>30m) on top of Claut Flysch	46,267	12,518	617
Claut (Frattino's house)	Cla8	Quaternary cover (>20m) on top of Claut Flysch	46,268	12,513	617

Cla0 MarsLite - Lorenzi's house, stopped recording sometimes in first half of March 2001
ClaB MarsLite - Agnese Lorenzi's house, registration start on 18/04/01
Cla1 MarsLite - Claut cemetery, registration start in 1999
Cla2 MarsLite - Bellitto's house, registration start in August 2000
Cla3 MarsLite - Parish house, registration start in September 2000
Cla5 Orion - Surgery, registration start on 15/06/01
Cla6 Orion - Grammar school, registration start on 15/06/01
Cla7 Orion - Valentina's house, registration start on 15/06/01
Cla8 Orion - Frattino's house, registration start on 15/06/01

The data were sampled at 125 sps and Le3Dlite, 1 Hz, 3-component geophones were employed together with Lennartz MarsLite and Nanometrics Orion data loggers. The first two stations (Cla0 and Cla1) were deployed in October-December 1999. The data recorded between January 2000 and August 2001 were used in this study. To summarize, stations Cla0 e Cla1 recorded for the whole time; in August 2000 two additional stations (Cla2 and Cla3) were deployed. Finally, four stations (Cla5, Cla6, Cla7 and Cla8) took recording between June 15, 2001 and September 12, 2001.

In April 2001, the reference station Cla0 was moved to a different, nearby site, ClaB, some ten meters to the north, but on the same bedrock outcrop.

This useful data set (Table 2) consists of 45 events: 32 of them were recorded by two stations, 7 by three, 4 by seven and 2 events by all eight stations deployed. Such events occurred mostly within an area spanning 30 km at most around the centre of Claut, and have M_D values ranging between 1.0 and 3.1. Only two events at a larger distance were included in the analysis: the July 17, 2001, $M_D = 5.2$ earthquake located 120 km from Claut, in the Merano area (BZ) and the December 28, 2000, $M_D = 3.1$, event that occurred in nearby Slovenia at about 150 km distance.

5. Processing and interpretation of data

In our analysis of site effects, we processed seismometric recordings of both seismic events and environmental noise. Four different analysis methods (Fourier and response spectra, Spectral ratios, Nakamura method and Receiver function method) were employed with the purpose of evidencing correlations between our instrumental data of ground motion and the information coming from the available geological sections across the area. One of our aims is to provide indications to local planner authorities which can be used for an effective seismic zoning of the area.

Reference site spectral ratios were computed separately on two subsets of data. The first one included 39 events recorded in the year 2000 by, at most, 3 MarsLite stations each. The second one included 6 events recorded in the year 2001 by these same stations plus the additional 4 Orion stations installed in the last phase of the recording experiment. The good match between the results obtained with the two different data subsets for stations Cla1, Cla2 and Cla3 constitutes proof of the robustness of the analysis performed. Similarly, this also indicates that the results obtained for Cla5, Cla6, Cla7 and Cla8, though based on a limited number of records, are likely to be trusted.

5.1. Fourier spectra - response spectra

For each site and each component we calculated the maximum value of the Fourier amplitude spectrum and the 5% damping response spectrum with the corresponding peak frequencies. This has allowed us to provide a rough estimate of the seismic amplifications at

Table 2 - Listing of records used in the analysis

Date	Time	Lat°N	Lon°E	Depth	Md	Recording Stations							
						Cla0/B	Cla1	Cla2	Cla3	Cla5	Cla6	Cla7	Cla8
Subset 1													
2000/01/05	17:59:09.29	46.419	12.475	10.9	2.6	X	X						
2000/01/14	01:40:29.73	46.390	13.040	15.2	2.4	X	X						
2000/01/17	21:10:26.60	46.330	12.637	13.0	1.9	X	X						
2000/01/19	18:05:43.58	46.369	12.464	17.6	1.4	X	X						
2000/01/28	18:10:22.75	46.290	12.589	9.8	2.5	X	X						
2000/02/07	03:46:23.37	46.307	12.694	13.8	2.3	X	X						
2000/02/11	16:10:23.08	46.157	12.391	13.9	1.9	X	X						
2000/02/14	05:37:21.11	46.282	12.583	10.2	2.1	X	X						
2000/02/22	02:07:08.65	46.191	12.845	19.5	2.4	X	X						
2000/02/22	03:33:37.57	46.318	12.583	11.1	2.5	X	X						
2000/02/26	02:29:24.06	45.925	13.002	12.9	2.8	X	X						
2000/03/17	07:49:18.34	45.959	12.101	12.4	2.3	X	X						
2000/03/20	07:17:20.49	46.423	12.468	8.2	2.4	X	X						
2000/03/29	16:57:02.32	46.325	12.605	7.5	3.1	X	X						
2000/03/29	21:42:35.89	46.285	12.525	8.5	3.0	X	X						
2000/04/22	06:33:06.91	46.254	12.490	9.3	1.7	X	X						
2000/04/25	13:13:03.92	46.223	12.285	4.8	1.6	X	X						
2000/04/29	10:51:46.71	46.197	12.420	9.0	1.4	X	X						
2000/05/01	05:01:40.37	46.268	12.337	13.0	2.1	X	X						
2000/05/01	11:57:26.98	46.268	12.336	12.9	2.0	X	X						
2000/06/26	13:29:51.64	46.392	12.691	10.6	2.5	X	X						
2000/06/26	16:38:40.26	46.381	12.703	9.5	2.2	X	X						
2000/08/30	15:26:51.90	46.222	12.500	11.3	2.7	X	X	X					
2000/09/10	19:01:12.99	46.170	12.400	10.7	2.5		X	X					
2000/09/12	21:54:02.24	46.108	12.331	11.4	1.9		X	X					
2000/09/18	22:48:33.49	46.247	12.507	12.1	1.9		X	X					
2000/09/19	00:07:36.53	46.334	12.530	11.1	1.9		X	X					
2000/09/24	21:42:35.72	46.359	12.761	11.0	2.6		X	X					
2000/10/22	01:30:53.19	46.132	12.377	11.9	1.4		X	X					
2000/10/22	07:56:28.72	46.225	12.518	9.6	1.4	X	X	X					
2000/10/23	10:06:21.42	46.271	12.918	10.5	2.5	X	X						
2000/11/03	05:35:58.42	46.149	12.397	10.6	1.4		X	X					
2000/11/23	21:40:48.73	46.343	13.198	13.2	2.7			X	X				
2000/11/23	23:51:36.77	46.261	12.657	9.3	1.6	X		X	X				
2000/11/26	12:41:36.94	46.411	12.727	15.1	2.6	X		X	X				
2000/11/30	01:11:59.60	46.479	12.679	11.4	2.4	X		X	X				
2000/12/09	11:52:25.34	46.190	12.423	8.5	1.8	X	X		X				
2000/12/21	01:47:52.56	46.221	12.552	8.6	1.7	X	X		X				
2000/12/28	00:42:17.38	45.581	14.317	3.1	3.0		X		X				
Subset 2													
2001/06/20	21:46:47.10	46.610	12.377	2.2	1.5	X	X	X		X	X	X	X
2001/06/26	01:00:42.31	46.197	12.470	7.1	1.5	X	X	X	X	X	X	X	X
2001/07/17	15:06:15.24	46.696	11.066	6.4	5.2	X	X	X	X	X	X	X	X
2001/08/08	00:26:43.60	46.227	12.457	9.1	1.0	X	X	X	X	X	X		X
2001/08/08	22:02:04.11	46.251	12.337	11.9	2.4	X	X	X	X	X	X		X
2001/08/28	08:40:30.19	46.259	12.511	10.7	2.5	X	X	X	X		X	X	X

each site. In Figs. 4 and 5, we show the Fourier amplitude and response spectra for one of the recorded events. The plot shows that the results do vary significantly from site to site although the distances between them are contained within a few hundred metres (Fig. 2).

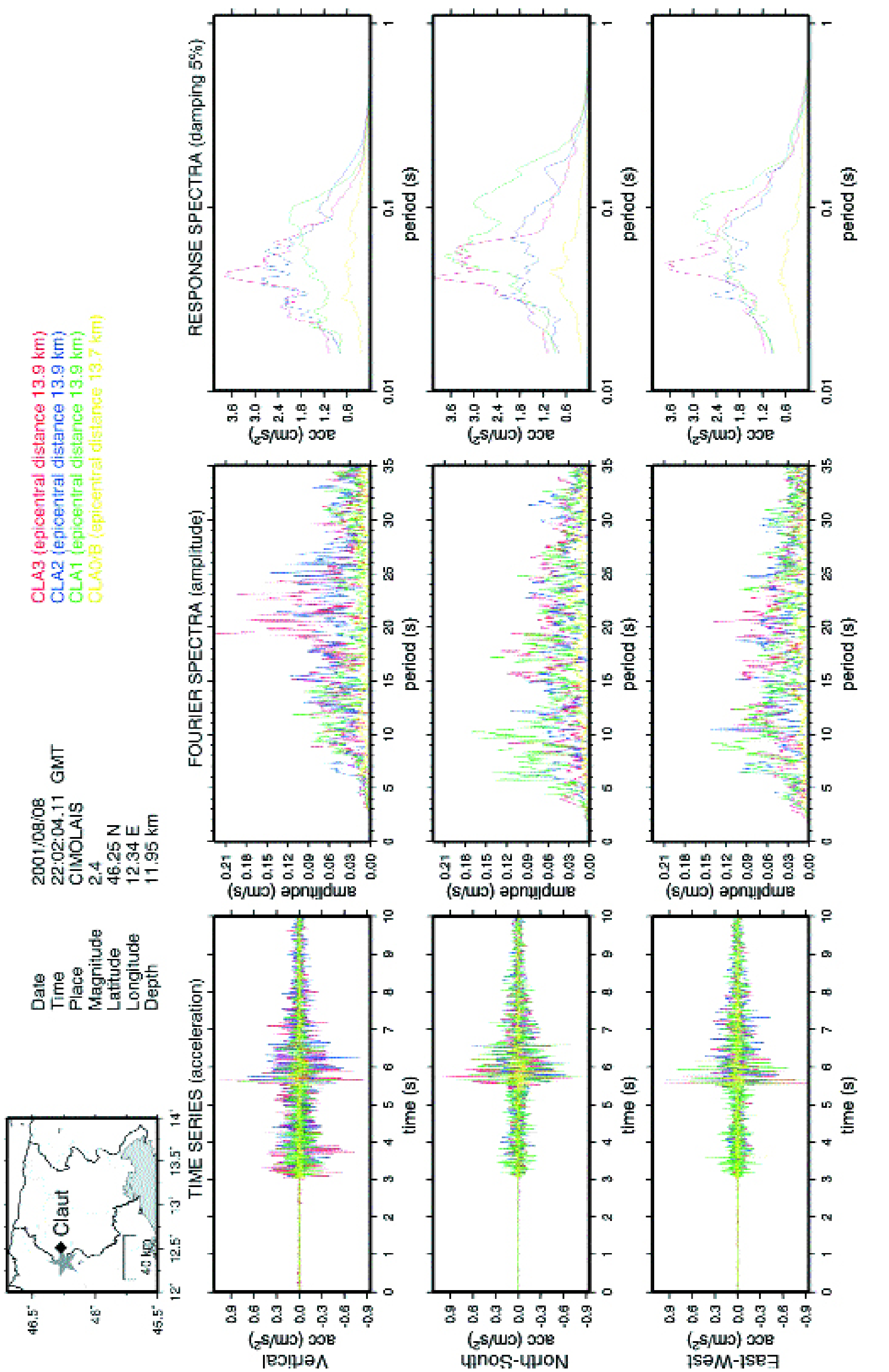

Fig. 4 - Fourier and response spectra representation relative to the August 8, 2001 event located in Cimolais and recorded by MarsLite stations (Cla0/B, Cla1, Cla2, Cla3).

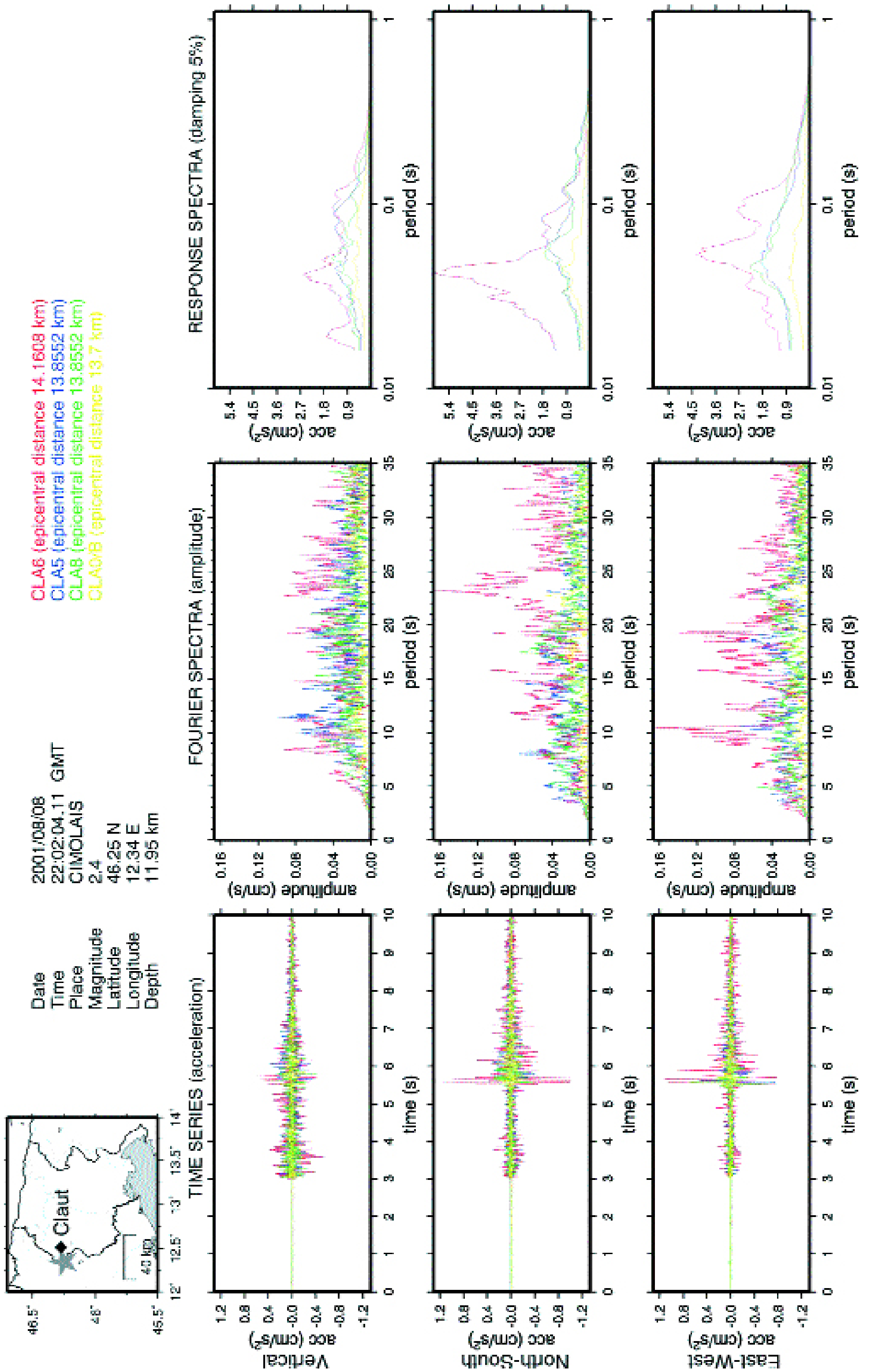

Fig. 5 - Fourier and response spectra representation relative to the August 8, 2001 event located in Cimolais and recorded by Orion stations (Cla5, Cla6, Cla8) plus the reference station Cla0/B.

5.2. Spectral ratios

This method (Borcherdt, 1970) allows us to estimate the average seismic amplification at one site with respect to a chosen reference site (bedrock). In this study, we used the Generalized Inversion Technique (GIT) proposed originally by Andrews (1986). GIT retrieves, simultaneously, from the smoothed Fourier spectra obtained from a set of events, i) the seismic amplification induced at each station with respect to the reference site, generally chosen on a hard-rock outcrop, ii) the source spectrum and iii) the attenuation factor, Q. In Fig. 6, we show the spectral ratios calculated for both the vertical and horizontal components of the first 4 sites (subset 1 data, see Table 2). Fig. 7 depicts instead the spectral ratios, relative to the horizontal component only, retrieved for all the 8 sites monitored (subset 2 data, see Table 2). Overall, we observe a good match between the results obtained using the two data subsets for stations Cla0/B to Cla3; the discrepancies evident for such stations in Fig. 7 as compared to Fig. 6 lie, in fact, always within the error estimates of the spectral ratios calculated for the 2000 data subset.

More specifically, Cla1 ratios show a constant trend of amplitude increase with frequency up to a value of 7 times the reference site at about 3.5 Hz, then a roughly constant value of amplification at higher frequencies eventually culminating in a maximum amplitude of 9 times compared to the reference site in correspondence with a frequency value of about 9 Hz (Fig. 7). Cla2 results display consistent seismic amplifications, up to a maximum of 4 times that of the reference site, for frequencies over 3 Hz; in Cla3 amplifications of a factor of 2, and up to a maximum value of about 5 times, start being visible from frequencies above 2 Hz. Cla5 shows peak values of amplification, up to about 4 times relatively to the bedrock site, in the frequency

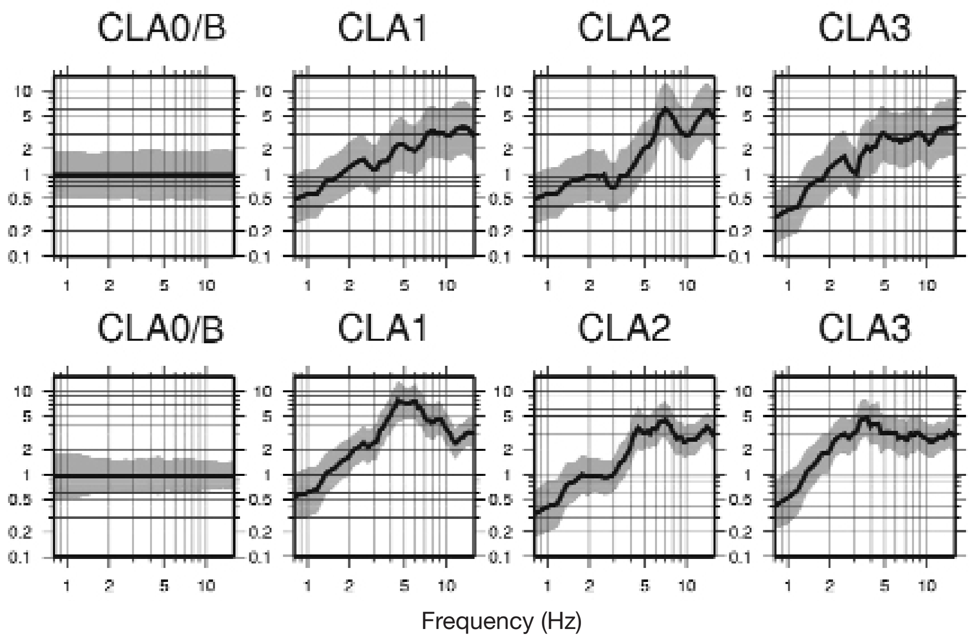

Fig. 6 - Spectral ratios determined for stations Cla0/B, Cla1, Cla2 and Cla3 from year 2000 data subset. Diagrams (with respect to the reference site Cla0/B) displaying vertical component ratios above, horizontal ones illustrated below. The grey area shows standard deviation.

range between 3 and 6 Hz; Cla6 shows instead an amplification level of 2 already at 2 Hz, which remains quite constant with a value of about 3 at higher frequencies with the exception of a peak amplitude of 5 occurring at about 3.5 Hz. Cla7 also shows amplitudes over the 2 times threshold for frequencies above 2 Hz, but with a much more rugged trend with peak values of about 5 times between 4 and 6 Hz and for frequencies over 10 Hz; Cla8 finally shows, in general, the lowermost levels of amplifications of all the sites, with a ratio's peak amplitude of about 3 in the frequency range between 4 and 5 Hz, and values over 2 generally between 3 and 7 Hz. To summarize these findings, we can say that only the Cla1 site features seismic signal amplitudes about 9 times larger than the reference site Cla0, while for all the remaining sites local seismic amplifications values are comprised between 2 and 5 times relatively to the bedrock site.

A survey of the village of Claut just after the 1996 earthquakes showed structural damage to buildings in proximity our monitored sites Cla3 and Cla5, which showed consistent amplification levels in our analysis. This correlation testifies the validity of our site effect estimates.

5.3. Application of the Nakamura analysis method

This technique assumes that microtremors consist mainly of Rayleigh waves propagating and confined within a single soft layer resting upon a half-space, and that the existence of such cover layer is indeed the cause of the seismic site amplification (Nakamura, 1989). The method assumes that it is possible to separate the source-path and the site response terms of the

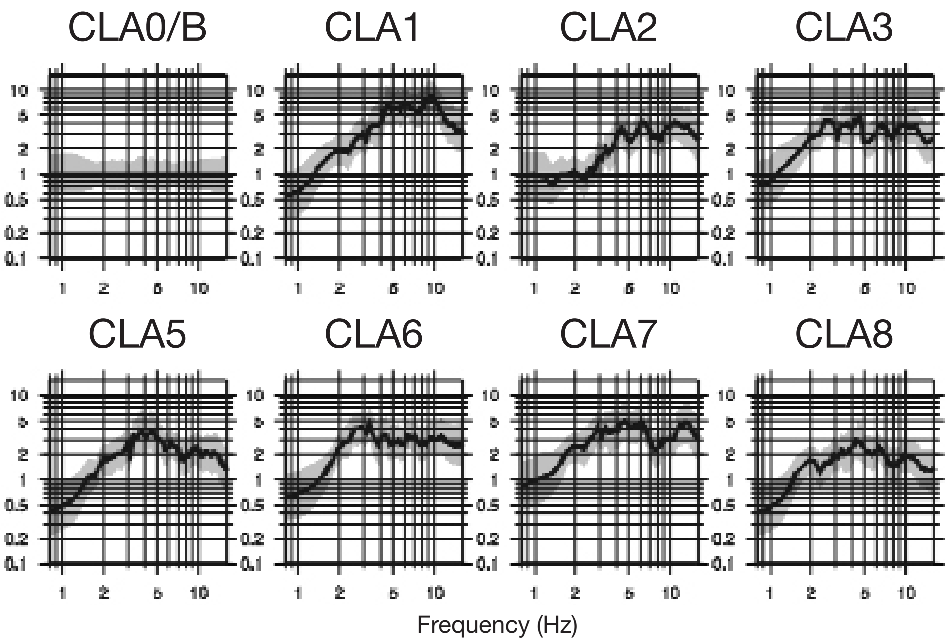

Fig. 7 - Spectral ratios (with respect to the reference site Cla0/B; horizontal components illustrated only) computed for stations Cla0/B, Cla1, Cla2, Cla3, Cla5, Cla6, Cla7 and Cla8 for 2001 data subset. The grey area shows standard deviation.

convolution by taking the ratio between the horizontal and vertical components of the seismic motion. Thus, there is no need to use a reference site.

The amplitude peak in H/V spectral ratios calculated from the ground noise depends strongly upon the stratigraphic sequence at the selected site, and more specifically such peak is correlated with the fundamental resonance frequency of that terrain.

For each of the eight sites monitored, we have acquired one hour of seismic noise sampled at 125 sps. Spectral ratios in Fig. 8 show that horizontal components of the recorded signals are always stronger than the corresponding vertical ones, reaching values of 5 times and higher, except for the only station deployed on bedrock where the ratio does not differ significantly from unity throughout the frequency range. In particular, Cla1 ratios show an amplification of 7 times compared to the reference site at 6 Hz frequency. Cla5 shows values of amplification of about 5 times for frequencies of 4 Hz. While, the other sites show values of amplification of 2-3 times for frequencies comprised between 3.5 Hz and 5 Hz.

5.4. Receiver function analysis

For each event we determined the spectral ratio between the horizontal and vertical components of motion for the S-wave window. This method provides an independent estimate of the level of spectral amplification of the horizontal components of motion with respect to the vertical ones. Fig. 9 shows that such ratio is larger than unity on a wide range of frequencies

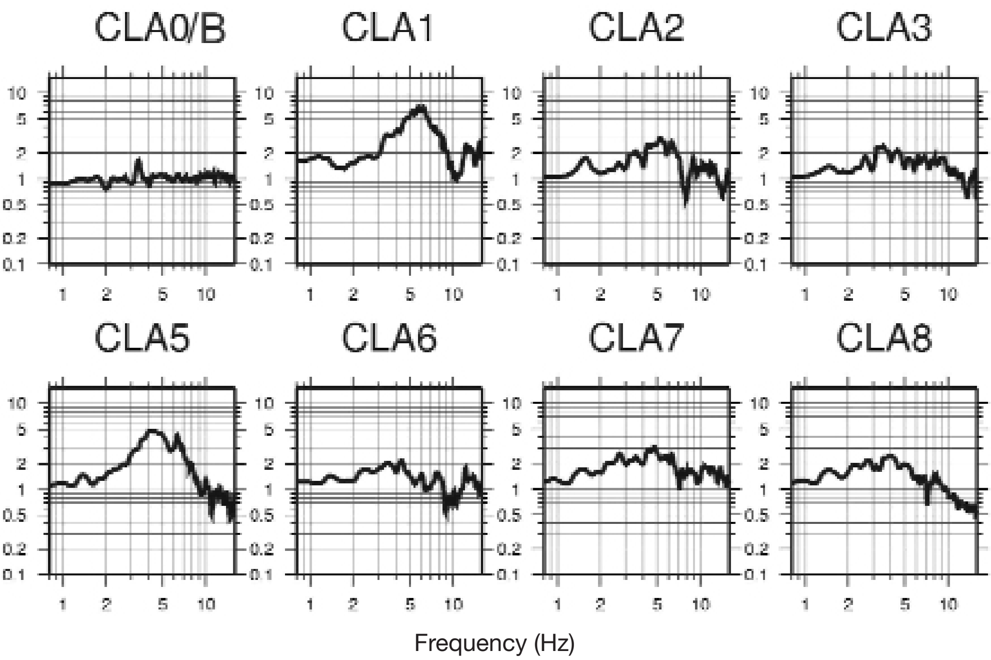

Fig. 8 - Spectral ratios obtained by application of the Nakamura method on data from stations Cla0/B, Cla1, Cla2, Cla3, Cla5, Cla6, Cla7 and Cla8.

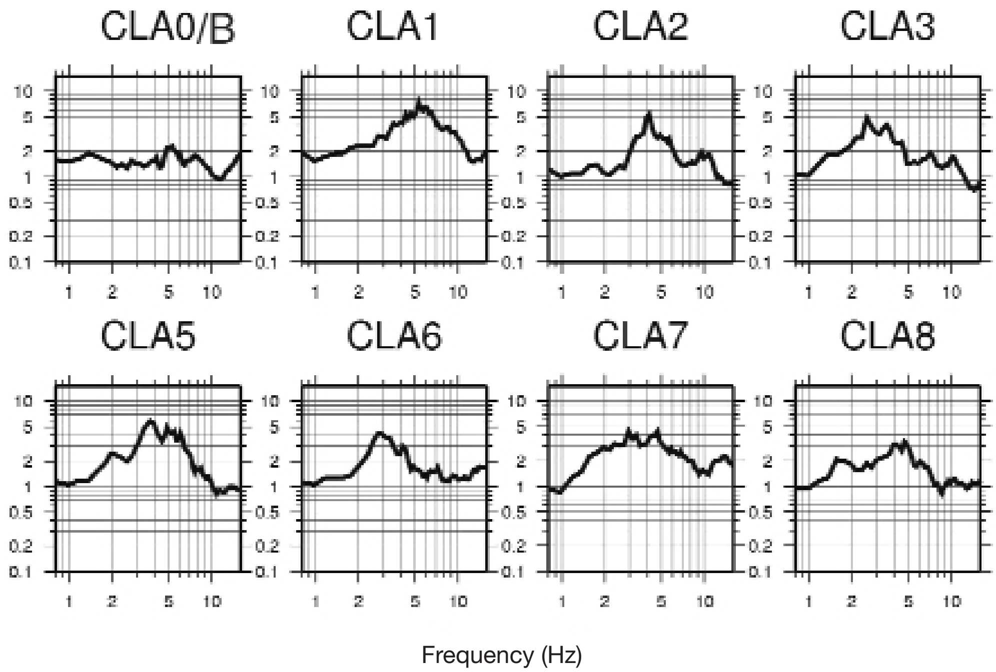

Fig. 9 - Receiver function diagrams retrieved for stations Cla0/B, Cla1, Cla2, Cla3, Cla5, Cla6, Cla7 and Cla8.

for all sites sitting on soft alluvium, whereas for the bedrock site H- and V-spectra are almost equivalent. More precisely, Cla1 shows a value of amplifications of 9 times in correspondence with a frequency of about 5 Hz. While for all the remaining sites, local seismic amplification values are comprised between 4 and 6 times relative to the bedrock site in the frequency range between 2.5 and 5 Hz.

5.5. Comparison of the results obtained with spectral ratios, Nakamura and receiver function methods

In Fig. 10 we compare the results obtained with the different methods for each site. We note that, in general, there is a remarkable agreement between the different estimates of the site-amplification. The main differences between single station (receiver function and Nakamura techniques) and reference site estimates occur at frequencies higher than 4 to 7 Hz. In fact, we see that the single station estimates retrieve the first low frequency peak well while they generally miss those at higher frequencies. Also, the Nakamura estimates, when compared to the receiver function ones, appear somewhat subdued. This behavior is not new and has been observed in other studies where the same comparison was carried out.

Specifically, Cla1 presents, the largest seismic amplifications overall. Single-station methods are very consistent with each other, and from about 2 to 7 Hz, also well in accordance with results of the spectral ratios. The latter ones then show an amplitude peak at 9 Hz, whereas Nakamura results in particular, show a sharp low at 10 Hz. The large amplifications measured

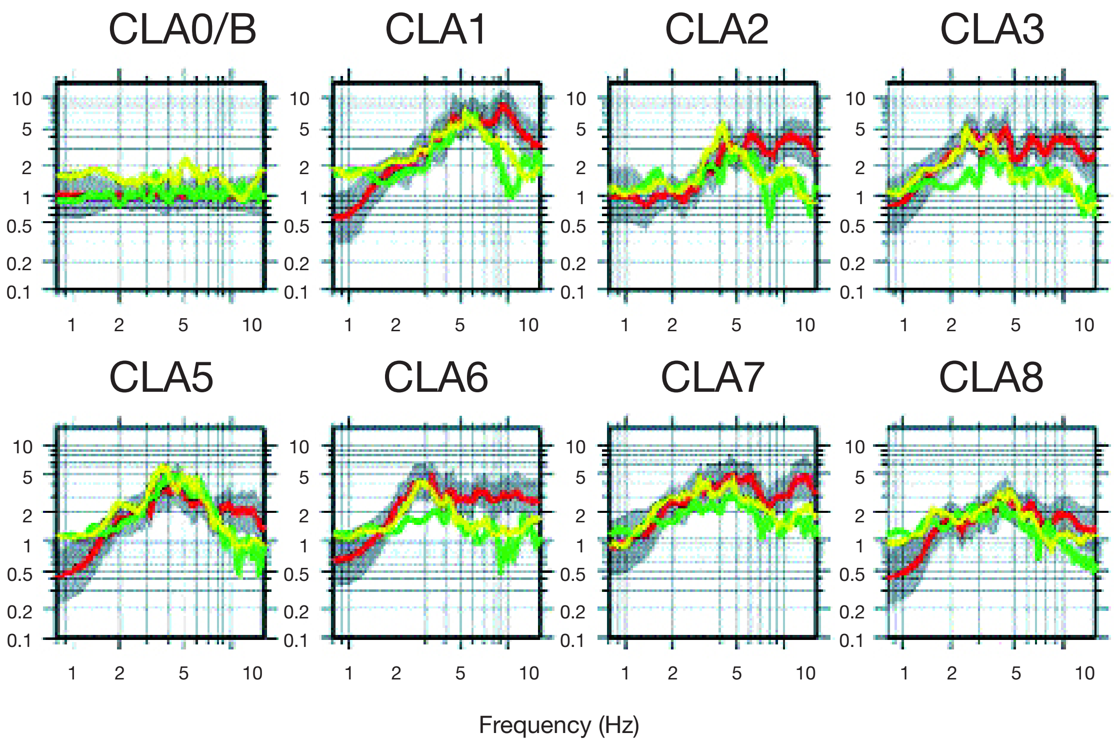

Fig. 10 - Graphic comparison of results from the different spectral analyses performed in our study: spectral ratio (red), receiver function (yellow), Nakamura (green). In grey is represented the confidence limit egual to ± δ.

at Cla1 are consistent with a combination of geological and topographic factors: the site stratigraphy includes a 20 m thick layer of Quaternary deposits overlaying the bedrock and the site is located at the edge of quite a steep scarp carved by the Cellina River.

A 30 m thick layer of soft sediments covering the bedrock is probably at the origin of the similar seismic amplifications which characterize sites Cla3 and Cla7. For these stations, Nakamura results have generally lower amplitudes than the spectral ratios, while the receiver function curves overlap well with the spectral ratio results up to frequencies of about 4 Hz. Then, they also show slightly lower values of amplification.

Almost equal amplification levels exist also for sites Cla5 e Cla6, where the Quaternary cover thickness exceeds 35 m. Here, Nakamura and receiver function results overlap well along the whole frequency spectrum. Spectral ratios agree well with these findings for frequencies between 1.5 Hz and 7 Hz (Cla5) and between 1.5 and 4 Hz (Cla6), else showing smaller amplifications at low frequencies and larger values at high frequencies.

Finally Cla2 and Cla8 sites, located in areas where the soft sedimentary cover measures no more than about 20 m thickness, put in evidence the lowest levels of amplification only for frequencies above 3 Hz, while Cla8 displays the weakest amplifications overall, indeed relating to the thinnest Quaternary cover which is present in this site, and not the other ones. In fact, Cla8 lies upon a topographical height of the sub-surface bedrock. The results of the three methods are very coherent up to about 6 Hz for Cla2, then showing the usual uplift of the spectral ratio curves, whereas for Cla8 we observe the best overall agreement among all three methods.

6. Conclusions

In this work we performed a quantification of site-effects in the Claut area from weak motion data, aimed at contributing to the preparation of a seismic micro-zonation map of the region. The data we used, included seismometric recordings of earthquake and noise ground motion.

We have found that the results of our seismometric analyses are compatible with the available surface geology information and confirm that within the village of Claut, amplifications of seismic motion do occur. We estimated that these amplifications can be as high as 5 to 7 times when compared to a nearby site, lying on bedrock.

All four methods employed, based on spectral analyses, show, in general, a good agreement in the amplification ratios found for each site.

The retrieved values of seismic amplification are also qualitatively consistent with the damage suffered by the buildings in the different parts of the village of Claut during the 1996 seismic sequences.

References

Andrews D.J.; 1986: *Objective determination of source parameters and similarity of earthquakes of different sizes*. In: Das S., Boatwright J. and Scholz C.H., (eds) Earthquake Source Mechanics, Geophysical Monograph **37**, Washington, DC, American Geophysical Union, pp. 259-267.

Barbano M.S., Bressan G. and Zonno G.; 1986: *Un approccio alla valutazione della pericolosità sismica introducendo significativi elementi riguardanti la sismogenesi: applicazione all'area del Consiglio – Bellunese*. In: Atti del 5° convegno GNGTS, Esagrafica, Roma, pp. 329-344.

Bernardis G., Cecotti C., Poli M.E., Renner G., Snidarcig A. and Zanferrari A.; 1997: *Considerazioni sulla sismicità dell'area di Claut (Prealpi Carniche) e sui danni causati dal terremoto del 13 aprile 1996*. In: Atti del Convegno, La scienza e i Terremoti - Analisi e prospettive dell'esperienza del Friuli 1976-1996, Ed. Forum, Udine, pp. 61-68.

Borcherdt R.D.; 1970: *Effects of local geology on ground motion near San Francisco Bay*. Bull. Seism. Soc. Am., **60**, 29-61.

Nakamura Y.; 1989: *A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface*. Quarterly Report of RTRI, Railway Technical Research Institute, **30**, 25-33.