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Geophysical surveys and velocimetric measurements in the Cerreto di Spoleto area (Italy), aiming at a seismic microzoning

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Abstract - Geophysical prospecting and velocimetric measurements, aiming at the seismic microzoning of the Cerreto di Spoleto area (Perugia, Italy), are presented. Starting from the data obtained by previous geological-geomechanical surveys, seismic-refraction investigations were carried out in order to obtain a dynamic characterisation and a geometrical description of both soil and rock materials. The velocimetric measurements were performed through temporary free-field arrays, recording both ambient noise and small-magnitude seismic events. The analysis of the obtained records is still in progress in order to evaluate the local seismic wave amplification.

1. Introduction

The small historical hilltop town of Cerreto di Spoleto (Perugia, central Italy) was selected as a case study to assess mitigation methodologies of earthquake effects on the Italian cultural heritage, in the frame of the ENEA-MURST project “Catastrofi naturali e loro conseguenze sul patrimonio culturale ed ambientale italiano. Mitigazione e previsione di alcune tipologie di eventi” (Natural catastrophes and their effects on the Italian cultural and environmental heritage. Mitigation and forecast of some types of events).

Starting from previous detailed geological surveys (Bongiovanni et al., 2000; Martino et al., 2002), different geophysical investigations were carried out in order to characterise the alluvial deposits of the Nera River as well as to directly measure the shear and compressive seismic wave velocities (Vs and Vp respectively) of the jointed limestone outcropping in the Cerreto di Spoleto ridge area.

In addition, temporary velocimetric seismic arrays were deployed at seven sites of the ridge (close to the most ancient part of the town) and five sites of the alluvial plain (within

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Borgo Cerreto, the more recent part of the town, which is actually expanding), investigating geomorphologic and geotechnical features of particular interest. These arrays allowed us to simultaneously record both small-magnitude earthquakes (Md < 2) and ambient noise, sampled for some minutes in different hours of the day.

Cerreto di Spoleto was chosen as a case study since it displays several features typical of the Central Apennine area, such as high seismic hazard and geological and topographical conditions prone to ground motion amplification (Romeo et al., 2000).

In particular, the Cerreto di Spoleto area is characterised by local earthquakes (Table 1), felt with intensity levels up to IX MCS (Sieberg, 1930), and high frequency of intermediate intensity seismic events (VII-VIII MCS). In particular, according to the studies performed by the Gruppo Nazionale per la Difesa dei Terremoti (1997) owing to the 1997 Umbria-Marche seismic sequence, the VII-VIII MCS intensity level has a 60%-70% exceedence probability in 50 years.

Different local seismic wave amplification conditions can be widely observed in the Cerreto di Spoleto area; they are related to some particular geological and geomorphologic features (Bongiovanni et al., 2000) such as the shape of the ridge, the significant variations of the rock mass joint condition, the travertines buried in the alluvial plain, the wide taluses along the bottom of the slopes.

Due to its churches of the XII-XIII century (Chiesa dell'Annunziata, San Giacomo, San Lorenzo) and of the XIV-XVI century (San Paterniano, Santa Maria De Libera), Cerreto di Spoleto can be moreover considered representative of many other small Umbria towns that are part of the Italian cultural heritage.

Finally, a further reason for choosing Cerreto di Spoleto as a study-site was the availability of several strong motion data from the ENEA local array, which has been operating in this area since the end of the Eighties (Rinaldis et al., 1998).

2. Geological features

The small historical town of Cerreto di Spoleto is located on a 550 m-high calcareous ridge, NE-SW oriented, 200 m above the alluvial plain of the Nera River. The width of the ridge ranges from about 500 m at the bottom to about 200 m at the top. The recent part of the town (Borgo Cerreto) is expanding in the alluvial plain, close to the confluence between the Vigi and

Table 1 - Historical earthquakes felt at Cerreto di Spoleto according to Monachesi and Stucchi (1997).

year	epicentral location	epicentral distance (km)	maximum intensity (MCS)	observed intensity (MCS)
1328	Norcia	10	X	IX
1703	Norcia	23	X	IX
1838	Valnerina	7	VIII	VIII
1279	Camerino	31	X	VII-VIII
1979	Norcia	17	VIII-IX*	VII

*Ms = 5.9

Nera Rivers. The formations of the Umbria-Marche Succession outcropping in the Cerreto di Spoleto ridge area are Scaglia Bianca, Scaglia Rossa and Scaglia Variegata (Bartoccini et al., 1995). Westwards, along the right side of the Vigi River, some of the higher formations of the Umbria-Marche Succession outcrop, such as the Scaglia Cinerea and Bisciaro Formations (Fig. 1). All the outcropping limestones and marly-limestones are characterised by intensely jointed conditions. The alluvial plain deposits (Holocene) fill the Nera River valley and are represented by silty and sandy deposits from fine to rough with interlayered gravel, especially close to the confluences (Bongiovanni et al., 2000). Travertines widely outcrop close to the Colle il Tonno site, between Cerreto di Spoleto and Triponzo, in fytoclastic facies interbedded with medium to fine sands. These travertines constitute one sub-horizontal flat, southward and eastward bounded by the Nera River. A smaller travertine flat, starting 6 m below ground level, was found in three 30 m-deep geognostic drillings, close to Borgo Cerreto (Bongiovanni et al., 2000). All over the studied area, wide taluses lay partly above and partly under the alluvial plain deposits. Such melted or poorly cemented debris, are characterised by a thin to coarse sandy matrix, very degraded at parts.

The studied area shows a complex tectonic structure related to a polyphasic tectonic starting in the Upper Miocene (Calamita et al., 1994; Cipollari et al., 1995), due to the Apennine orogenesis. Both the Scaglia Rossa and Scaglia Bianca Formations, at the outcropping scale, show pervasive hysoclinalic fold structures, SE dipping, especially close to the nuclei of the major scale folds. These structures point out the main pervasive feature of the plicative style, while the disjunctive tectonics are related both to the compressive and to the tensive-transtensive stress field (Lavecchia et al., 1984; Boccaletti et al., 1986; Bigi et al., 1995).

In particular, three tensile faults split the Cerreto di Spoleto ridge close to the centre of the town: a western fault is located near the San Nicola church ruins, a central one crosses the City Hall, an eastern fault outcrops near the school buildings. The latter produces significant geomorphologic effects along the southern slope of the ridge, such as a very deep channel and an important change of the direction of the Nera River. Moreover, the same fault is connected to a 3 m wide milonitic zone which can be also found under the school gym, causing it significant damage during the 1997 Umbria-Marche seismic sequence.

3. Rock-mass geomechanical features

A geomechanical characterisation was performed for the Scaglia Rossa and Scaglia Bianca rock masses, outcropping in the Cerreto di Spoleto ridge area, aiming at evaluating the rock-mass joint condition by measuring the volumetric joint number (Jv in joint/m^3) and the block dimension number (Ib in m). According to their definition (International Society for Rock Mechanics, 1978), both the increase of Jv value and the decrease of Ib value are related to a more intensely jointed rock mass.

Several (22) widely spaced (about 250 m) geomechanical scanlines were chosen in the Cerreto di Spoleto ridge area in no-degraded rock mass outcrops, close to important geological elements (Fig. 2).

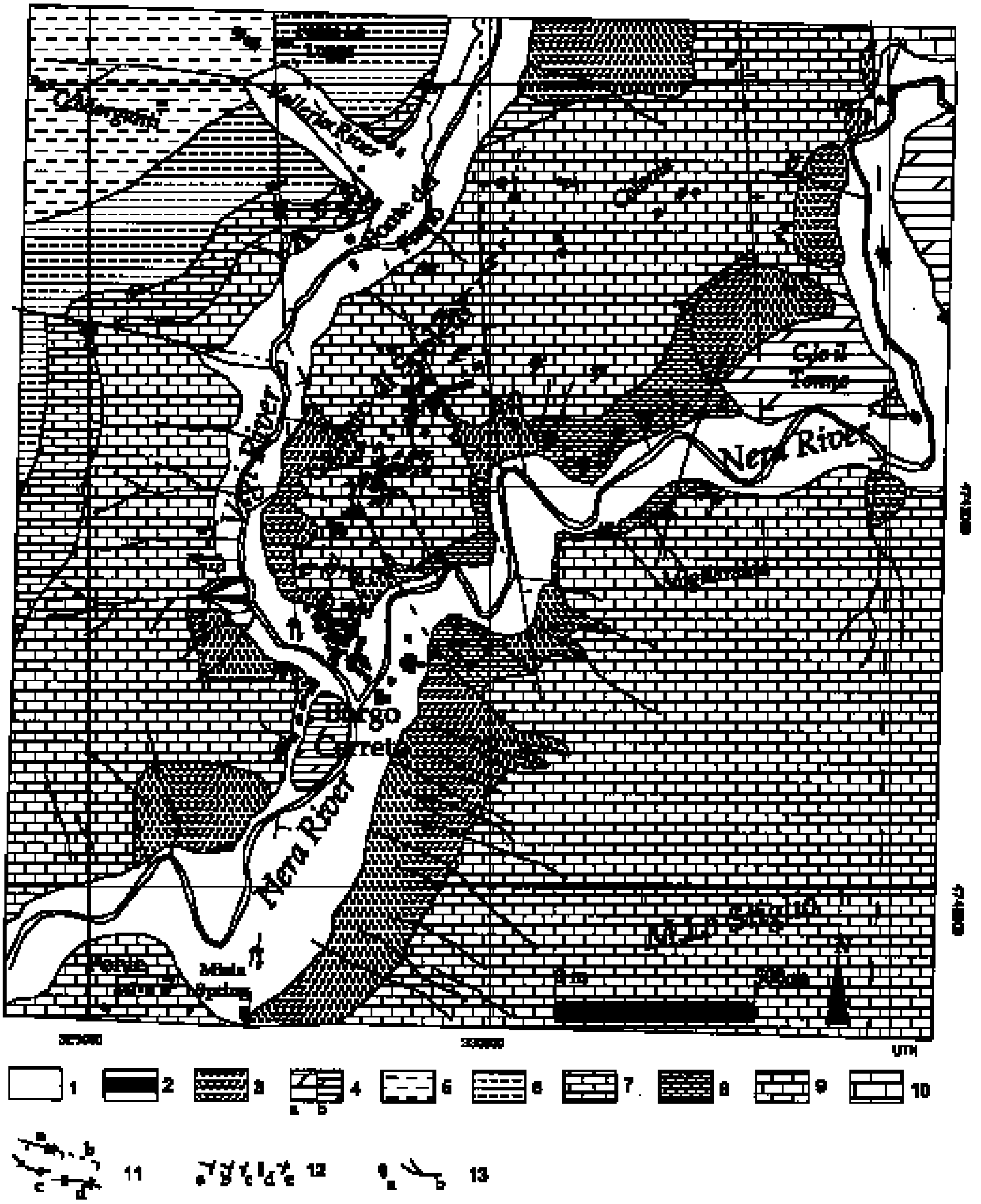


Fig. 1 - Geological map: 1) alluvial deposits (Holocene); 2) fluvial conoid (Holocene); 3) talus (Pleistocene-Eocene); 4) travertine (Pleistocene) outcropping (a) and buried (b); 5) Bisciaro (Lower Aquitanian-Burdigalian p.p) marl and marly-limestone; 6) Scaglia Cinerea (Upper Eocene p.p.-Lower Aquitanian) marl and clayey-marl; 7) Scaglia Variegata (Middle Eocene-Upper Eocene p.p.) marl and clayey-marl; 8) Scaglia Rossa (Turonian p.p. – Middle Eocene) limestone and marly-limestone; 9) Scaglia Bianca (Upper Albian p.p. – Turonian p.p.) limestone; 10) Maiolica (Titonian-Barremian) limestone; 11) certain (a) and uncertain (b) fault, crossbar shows the lowered side, anticlinal axis (c) and synclinal axis (d); 12) attitude of beds: <30° (a), 30°-50° (b), >50° (c), vertical (d), reverse (e); 13) spring (a), impluvium (b).

In every scanline the main joint sets were characterised by measuring average attitude (dip and direction), opening, spacing and kind of filling material of the observed joint sets.

The following different kinds of jointed rock masses related to the rock block shape

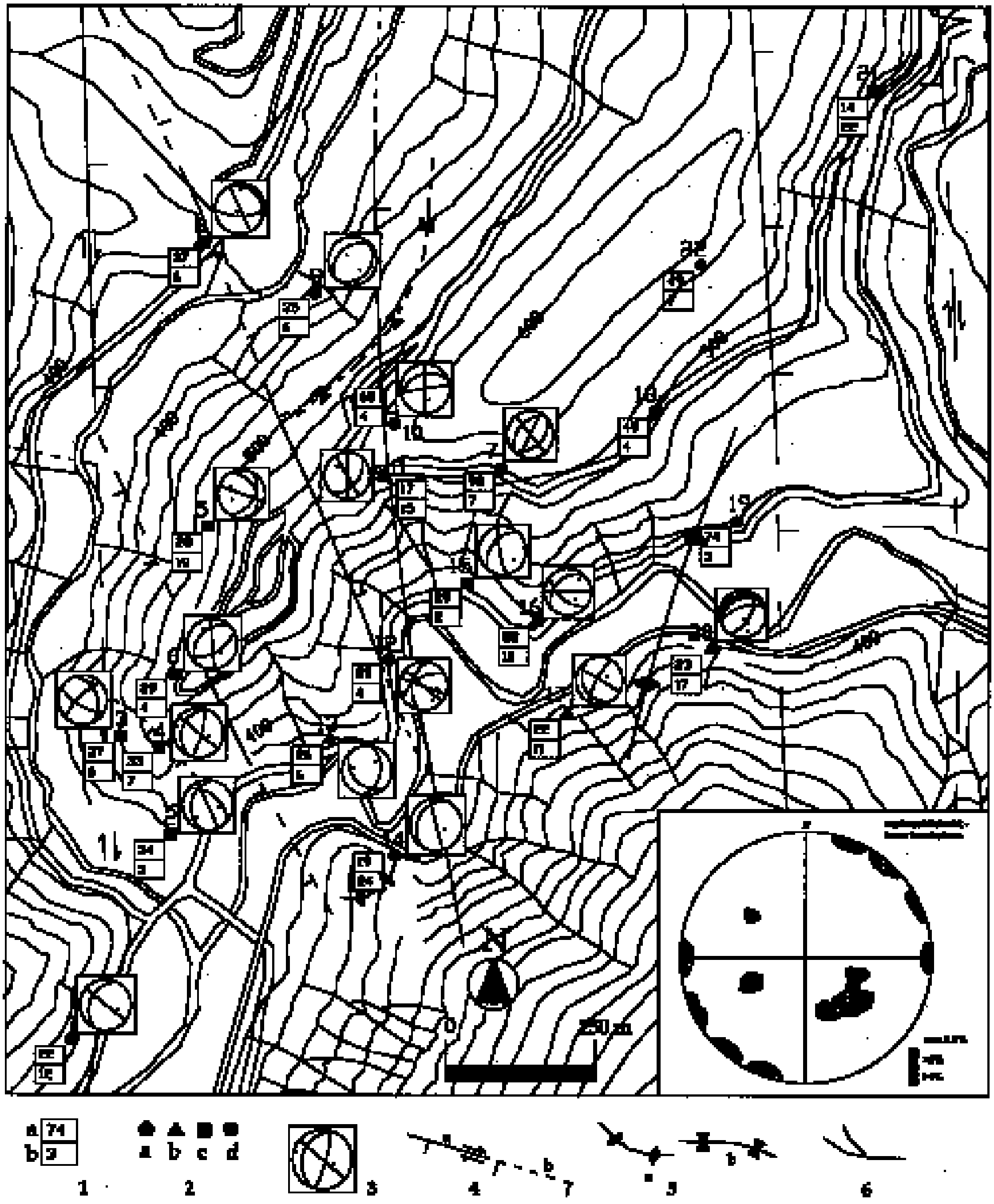


Fig. 2 - Geomechanical scanlines: 1) geomechanical indices Jv (a) and Ib (b); 2) rock mass: tabular (a), block split (b), irregular (c), intensely jointed (d); 3) Schmidt equiareal (lower hemisphere) projection of the observed joint sets; 4) certain (a) and uncertain (b) fault (crossbar shows the lowered side and arrows the strike versus); 5) anticlinal (a) and synclinal (b) axes; 6) impluvium.

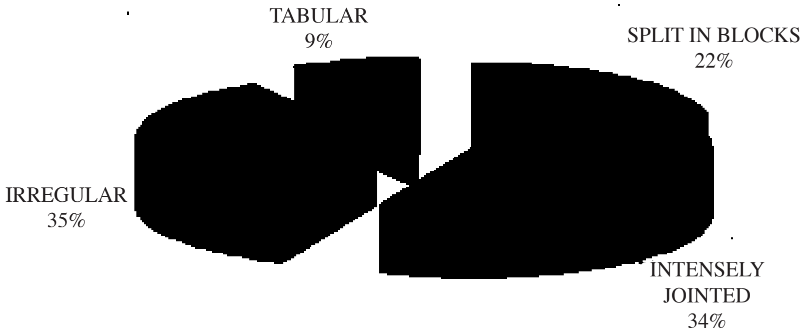


Fig. 3 - Percent distribution of different kinds of jointed rock masses.

(International Society for Rock Mechanics, 1993) were identified in the Cerreto di Spoleto ridge area:

- tabular: one dimension of the rock block much smaller than others;
- split in blocks: almost equal rock block dimensions;
- irregular: very different rock block dimensions;
- intensely jointed: rock mass with at least three joint sets (including milonitic zones).

The average joint attitudes were projected on the equiareal Schmidt plain (lower hemisphere) relating them to main structural elements, such as geological beds, faults and axes of folds (Fig. 2). Everywhere, in the Cerreto di Spoleto ridge area, it is possible to distinguish a joint set related to the attitude of the beds and mainly conditioned by the folding tectonics. In addition, the attitudes of the joint sets are well correlated to the tectonic elements of the Cerreto di Spoleto ridge area. For instance, the high dipping joint sets, respectively directed about N-S and about N25°W, are well related to the N-S ± 10° and to the N25°W ± 10° fault systems.

The percentage distribution of the different kinds of jointed rock masses (Fig. 3) shows that the irregular and intensely jointed rock masses are the ones most frequently outcropping in the Cerreto di Spoleto ridge area (68%).

In the Cerreto di Spoleto ridge area the average rock block dimension (Ib index) varies from 0.05 m to 0.25 m, for the tabular and block split rock masses, and from 0.03 m to 0.07 m, for the intensely jointed rock masses; the average volumetric joint number (Jv index), varies from 20 to 30 for the tabular and block split rock masses, while Jv values are higher than 65 for the intensely jointed rock masses (Fig. 4). Moreover, all the analyzed rock masses are characterised by close joints (from 0.001 to 0.025 m opened) with a marly filling material.

The areal distribution of the highest Jv and the lower Ib values (Martino et al., 2002) outline an intensely jointed area, which fits the most intensely faulted and folded zone in the Cerreto di Spoleto ridge area.

4. Seismic refraction prospecting

Seismic refraction prospecting along the calcareous ridge of Cerreto di Spoleto was carried out by six 50-m arrays (Fig. 5) using a single shot point and one geophon, in order to directly

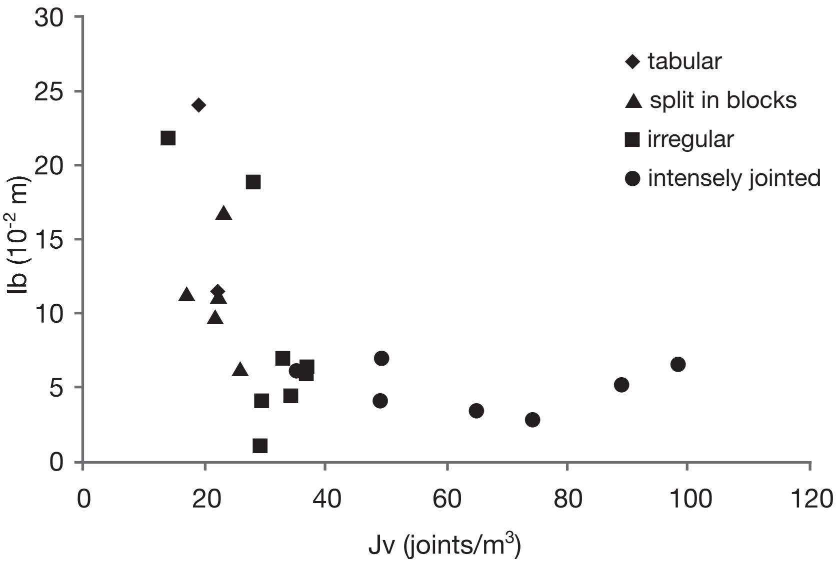
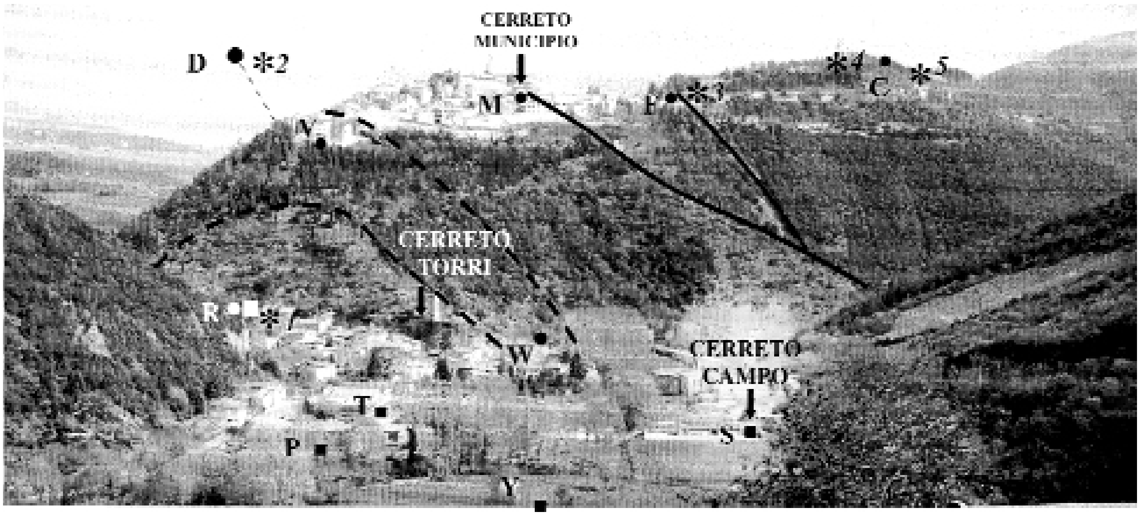


Fig. 4 - Ib versus Jv from the 22 geomechanical scanlines.

measure Vp values related to the different joint mass condition. In addition, direct Vs values were measured close to an intensely jointed rock mass, in order to obtain the Vp/Vs ratio.

Conjugate (two shot points) and crossed arrays were laid (Fig. 6) in the alluvial plain of the Nera River to directly measure the Vp and Vs values, obtaining Vp/Vs ratios, and to better define the buried alluvial plain deposits. An eight-channel HP recorder and seven 1 Hz



● **velocimetric recording station, ridge-array (I)**
■ **velocimetric recording station, alluvial plain-array (II)**
↓ **accelerometric recording station of the ENEA local array**
* **seismic refraction 50 m laying**
— — **certain fault**
– – **uncertain fault**

Fig. 5 - Panoramic view of the Cerreto di Spoleto area with the location of the recording stations and of the seismic refraction layings.

Fig. 6 - Detail of the geological map showing the seismic refraction layings in the alluvial plain of the Nera River and the trackline (BB') of the geological section in Fig. 10 (grey: Scaglia Rossa, triangles: talus; lines: travertine; S: bore hole).

velocimeters (SS1 Kinemetrics) were used, while a trigger system, connected to the eighth channel, allowed us to synchronize the starting time of the records.

Vertically oriented velocimeters were used in the alluvial plain to measure Vp values; the source was a hammer hitting a steel slab.

During the geophysical survey a new seismic refraction methodology was tested in order to measure the first S-wave arrivals directly. The S-wave source was a linear one (a wooden sleeper of 2 x 0.2 x 0.2 m) alternately hit by a hammer at opposite ends and mainly able to produce shear waves.

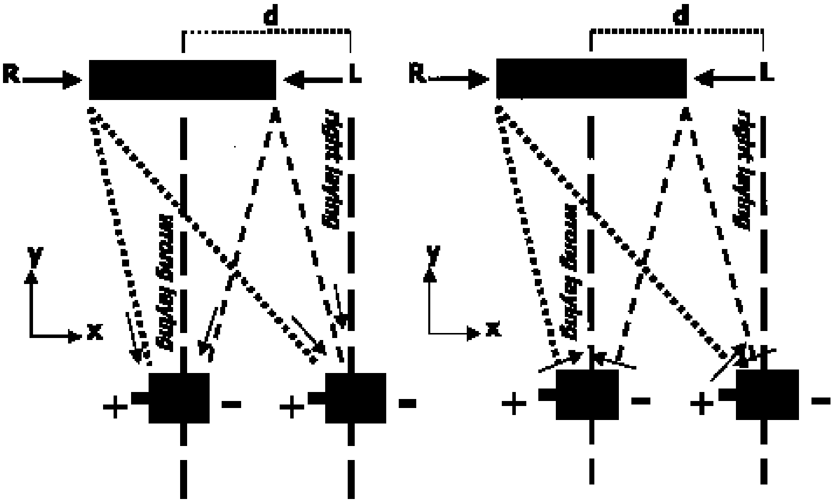


Fig. 7 - Right and wrong laying of the horizontal sensing devices to directly measure P-wave and S-wave first arrival times.

Horizontal sensing devices were coupled to vertical ones to read the first S-wave arrivals with higher resolution. These arrivals are estimated by overlaying the records related to the two hits at the opposite ends of the linear source (L - left hit; R - right hit) and taking into account the time of the first phase change. In particular, hitting the linear source on opposite end (L and R in Fig. 7), P-waves are generated in phase and S-waves are generated out of phase.

However, in order to correctly identify the arrival times, particular attention is necessary in laying the sensing devices. In fact, if the axis of the laying is aligned to the source (wrong laying in Fig. 7), the sensing devices record the P-wave first arrivals out of phase (Fig. 8b) and, therefore, the S-wave first arrivals can not be detected. If, instead, the laying axis is set outside the end of the linear source (right laying in Fig. 7), the P-wave arrivals are recorded in phase and the S-wave first arrivals can be identified (Fig. 8a).

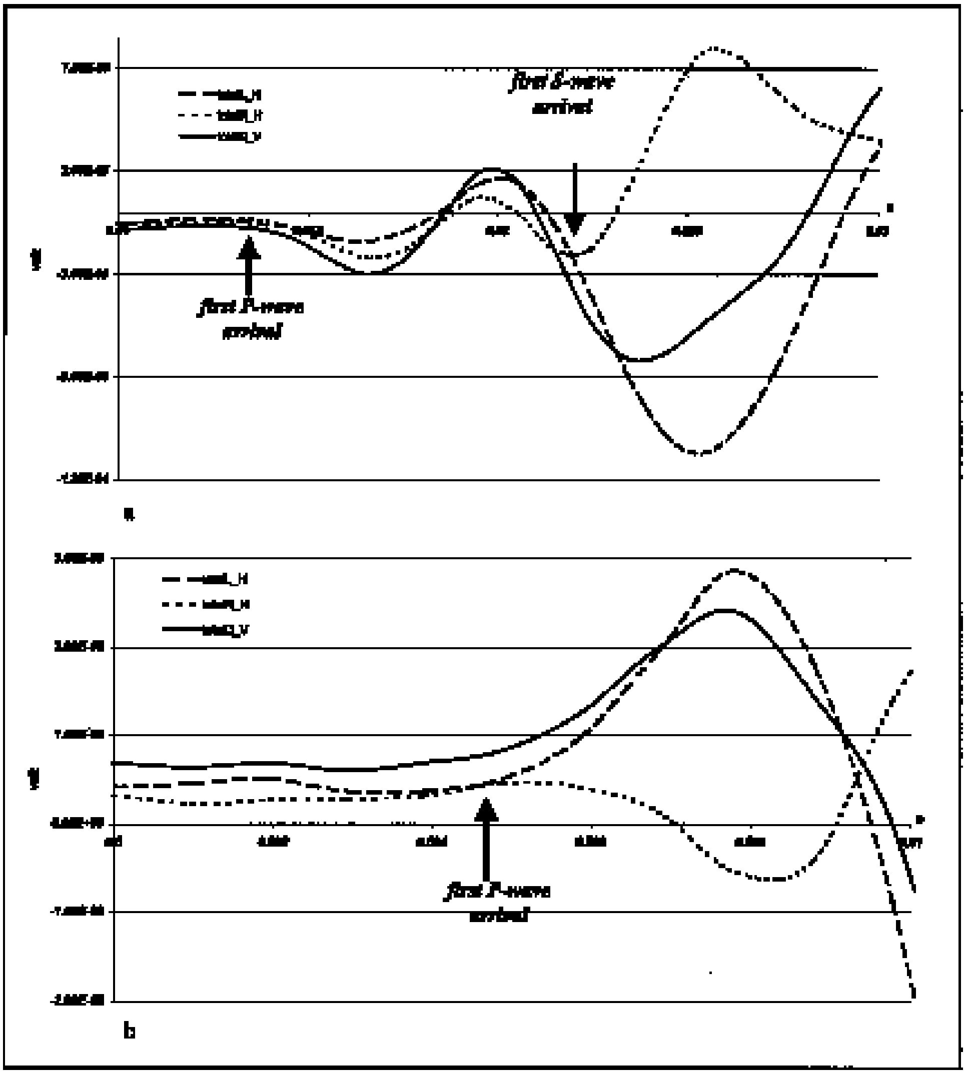


Fig. 8 - Example of P-wave and S-wave first arrival records by use of a right (a) and a wrong (b) laying of the horizontal sensing devices.

4.1. Results obtained for the Cerreto di Spoleto ridge

The results obtained for the Cerreto di Spoleto ridge show a correlation between the joint rock mass condition (described by Ib and Jv indices) and the measured Vp values (Fig. 9).

This correlation is particularly significant since both the geomechanical indices and the measured wave velocity values are related to the same geological formation (Scaglia Rossa – Umbria-Marche Succession), although in different jointing conditions. In addition, since the geomechanical scanlines were scattered far from weathered rock-mass and at different

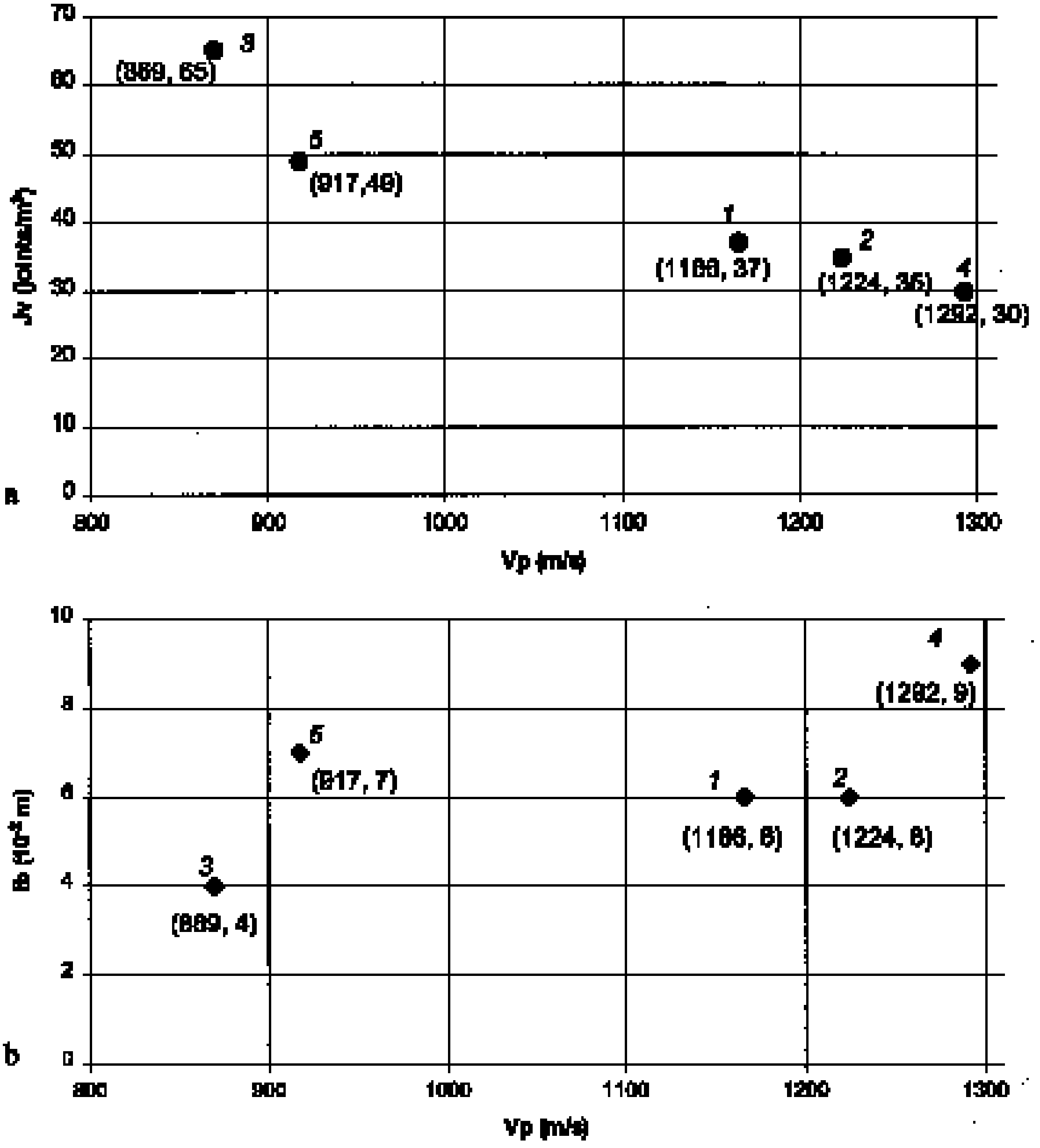


Fig. 9 - Jv versus Vp (a) and Ib versus Vp (b); numbers 1-5 are related to the seismic refraction layings in Fig. 5.

elevations, it is possible to assume that the measured jointing conditions are representative of rock-mass volumes comparable with those investigated through the seismic surveys.

The seismic P-wave velocity values measured in the Cerreto di Spoleto ridge area vary from about 350 to about 1300 m/s and can be related to both the intensely jointed rock mass condition and the dry state of the outcropping limestones. In particular, the minimum Vp value (348 m/s), obtained close to the milonitic fault zone (Fig. 5 - laying n°3), can be referred to a mainly clayey debris. A Vp/Vs ratio of 1.96 was obtained for a N50°E oriented array close to an intensely jointed rock mass (Colonia - Fig. 1): this ratio is higher than 1.73, conventionally considered for a non-jointed rock mass (Norinelli et al.,1992).

4.2. Results obtained for the alluvial plain of the Nera River

Three arrays were laid in the alluvial plain of the Nera River for refraction seismic prospectings (Fig. 6; Haeni, 1990; McGee, 2000; Steeples, 2000):

1. AB-BA array, N45°E oriented, close to the eastern side of the plain, near the Borgo Cerreto sport field (Campo Sportivo);
2. CD-DC array, N-S oriented, crossing the AB array with an angle $\beta = 45°$;
3. EF-FE array, N20°W oriented, close to the western side of the plain, above the buried travertine.

The results obtained on the western side (array EF-FE) of the plain confirm the presence of both the travertine under-filling soil about 5 m thick and the freatic water table, 4 m below ground level (Table 2). On the eastern side, calcareous debris belonging to the talus is found under the gravelly alluvial deposits and a carbonatic bedrock is expected at more than 13 m below ground level (Table 2).

Table 2 - Seismic refraction results obtained in the Nera River alluvial plain.

western side					eastern side				
layers	**depth (m)**	**Vp (m/s)**	**Vs (m/s)**	**Vp/Vs**	**layers**	**depth (m)**	**Vp (m/s)**	**Vs (m/s)**	**Vp/Vs**
filling	5	520	132	3.94	filling	0 - 1	833	-	-
travertine*		1284	404	3.18	gravels*	11 – 13	1928	473.5	4.07
					limestone or talus*		> 2618		

* wet condition

The geological section across the alluvial valley features a typical asymmetrical “V shape” having a carbonatic bedrock and filled by alluvial deposits with interlayered gravels and travertines (Fig. 10).

It is worth remarking that the Vp/Vs ratios obtained in the plain, ranging from 3 to 4 and significantly higher than the typical values of dry soils, are affected by the saturated soil conditions related to the observed water table.

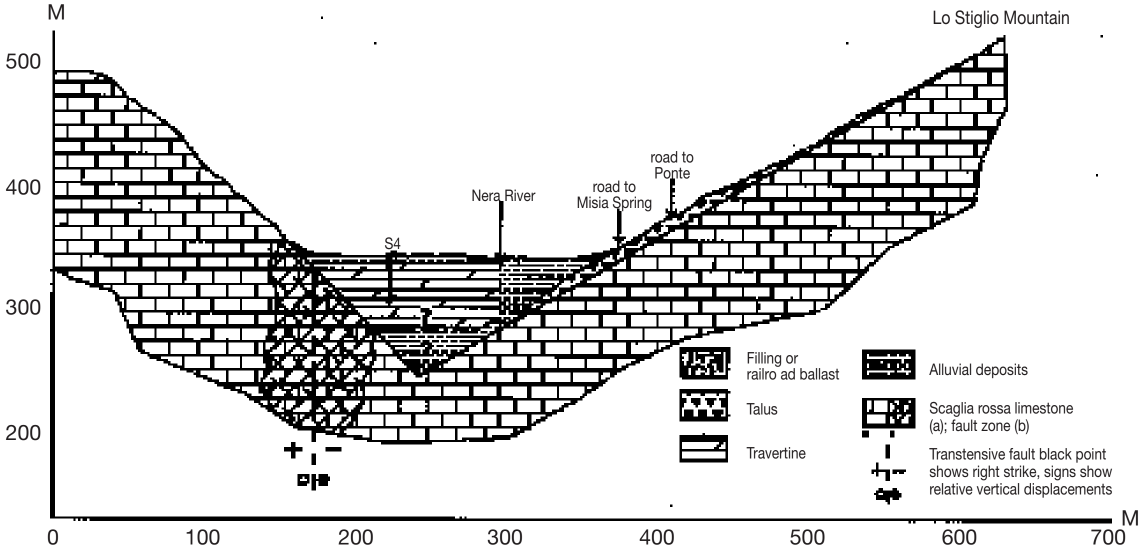


Fig. 10 - BB' geological section (Fig. 6) showing the asymmetrical "V shape" of the Nera River valley, close to Borgo Cerreto, and the geometrical relations between the calcareous bedrock and the alluvial plain deposits.

5. Velocimetric measurements

Two local seismic free-field arrays were deployed, at different times, on both the carbonatic ridge (7 stations) and the alluvial plain (5 stations) with the aim of recognizing and characterising the effects of the local geological and geomorphological conditions (Table 3 and Fig. 5).

Each station was instrumented with triaxially arranged (N-S, W-E, UP) short-period seismometers SS-1 Kinemetrics, connected to a K2 Kinemetrics recorder, and absolute GPS timing.

The "ridge-array" (n° 1 in Table 3) was aimed at monitoring the effects related to the morphology, as well as the presence of tectonic elements and variation of the joint rock mass conditions (Li et al., 1990, 2000; Azzara et al., 2001; Di Bucci et al., 2001; Spudich and Olsen, 2001). The stations were distributed longitudinally (R, V, M, F, C) and transversally (D, M, W) in relation to the ridge shape, close to some of the observed faults (M, F, W, D) or to intensely jointed mass zones (F). The relative "reference station" (R; Borcherdt, 1994) was selected at the bottom of the ridge where better joint rock mass condition can be found (Fig. 9). One of the stations (M) was close to a station of the ENEA accelerometric local array (Cerreto Municipio; Fig. 5).

The "alluvial plain-array" (n° 2 in Table 3) was aimed at monitoring the effects related to the geological-geomorphological features (limits between calcareous bedrock and alluvial deposits; shape of the valley) and the lithological heterogeneities inside the alluvial deposits (travertines) (Bard, 1997; Azzara et al., 2001; De Luca et al., 2001). The stations were deployed along a transversal section: the relative "reference station" (R - the same one as in the ridge-array), two stations over the buried travertine (T, P), one station at the sport field (S) close to a device of

Table 3 - Geological, geomorphological and geomechanical features of the temporary velocimetric recording stations which operated in the Cerreto di Spoleto area.

codex	array	elevation (m a.s.l.)	geomorphologic features	geological features	geomechanical features
R	1 - 2	415	bottom of the slope	Scaglia Rossa, 210/50 (strRH, dip)	irregular rock mass: Jv = 37, Ib = 6 m; Vp = 1166 m/s
D	1	370	bottom of the slope	Scaglia Rossa, 40/48 (strRH, dip)	intensely jointed rock mass: Jv = 35, Ib = 6 m; Vp = 1224 m/s
M	1	550	flat-top of the hill	Scaglia Rossa	irregular rock mass: Jv = 28, Ib = 19 m
F	1	565	flat-top of the hill	milonitic fault zone	Vp = 348 m/s
C	1	618	flat-top of the hill	Scaglia Rossa	intensely jointed rock mass: Jv = 49, Ib = 7 m; Vp = 917 m/s, Vs = 469 m/s
V	1	475	flat-top of the hill	Scaglia Rossa, 225/50 (strRH, dip)	irregular rock mass: Jv = 33, Ib = 7 m
W	1	375	bottom of the slope	Scaglia Bianca, 225/50 (strRH, dip)	irregular rock mass: Jv = 26, Ib = 6 m
T	2	357	plain	5 m filling, 25 m travertine, water table 4 m below g.l.	filling: Vp = 520 m/s, Vs = 132 m/s; travertine: Vp = 1284 m/s, Vs = 404 m/s
P	2	357	plain	5 m filling, 25 m travertine, water table 4 m below g.l.	filling: Vp = 520 m/s, Vs = 132 m/s; travertine: Vp = 1284 m/s, Vs = 404m/s
S	2	358	plain	gravely alluvial deposits, calcareous bedrock about 20 m below g.l.	alluvial deposits: Vp = 833 m/s, Vs = 474 m/s; alluvional deposits: Vp = 1928 m/s, Vs = 474 m/s
Y	2	353	plain	sandy-silty alluvial deposits with interlayered gravel, calcareous bedrock about 35 m below g.l.	alluvional deposits: Vp = 428 m/s; gravel: Vp = 1176 m/s

the ENEA accelerometric local array (Cerreto Campo) and a last station (Y) in the middle of the alluvial plain (Fig. 5).

Due to the high seismic activity of the area, each array operated for about three days in an STA/LTA acquisition mode, to record small, local earthquakes. At the same time, ambient noise was recorded for 5 minutes at different hours of the day.

Data are being processed with spectral analysis using both the Nakamura (1989) methodology and the conventional spectral ratio method, comparing spectra of different stations. A 10 s moving window was used for the ambient noise analysis.

According to the preliminary results, at the M station of the “ridge-array” (Fig. 5) the observation of a 6-7 Hz amplified wave-train, after the S-wave arrival, is reccurrent in all the components of the ground motion (Figs. 11 and 12). This behaviour could be related to a seismic trapped mode, caused by a 100-200 m intensely jointed fault zone (Li et al., 1990, 2000) close to the most ancient part of Cerreto di Spoleto town (Figs. 1 and 2). Further velocimetric measurements exclude any structural effect related to the nearby buildings.

In the "alluvial plain-array", the records of the western side stations (T, P) and eastern side stations (Y, S), located above the travertine and on the Nera River alluvial deposits respectively, show relevant differences in both amplitude and duration, as well as in the frequency

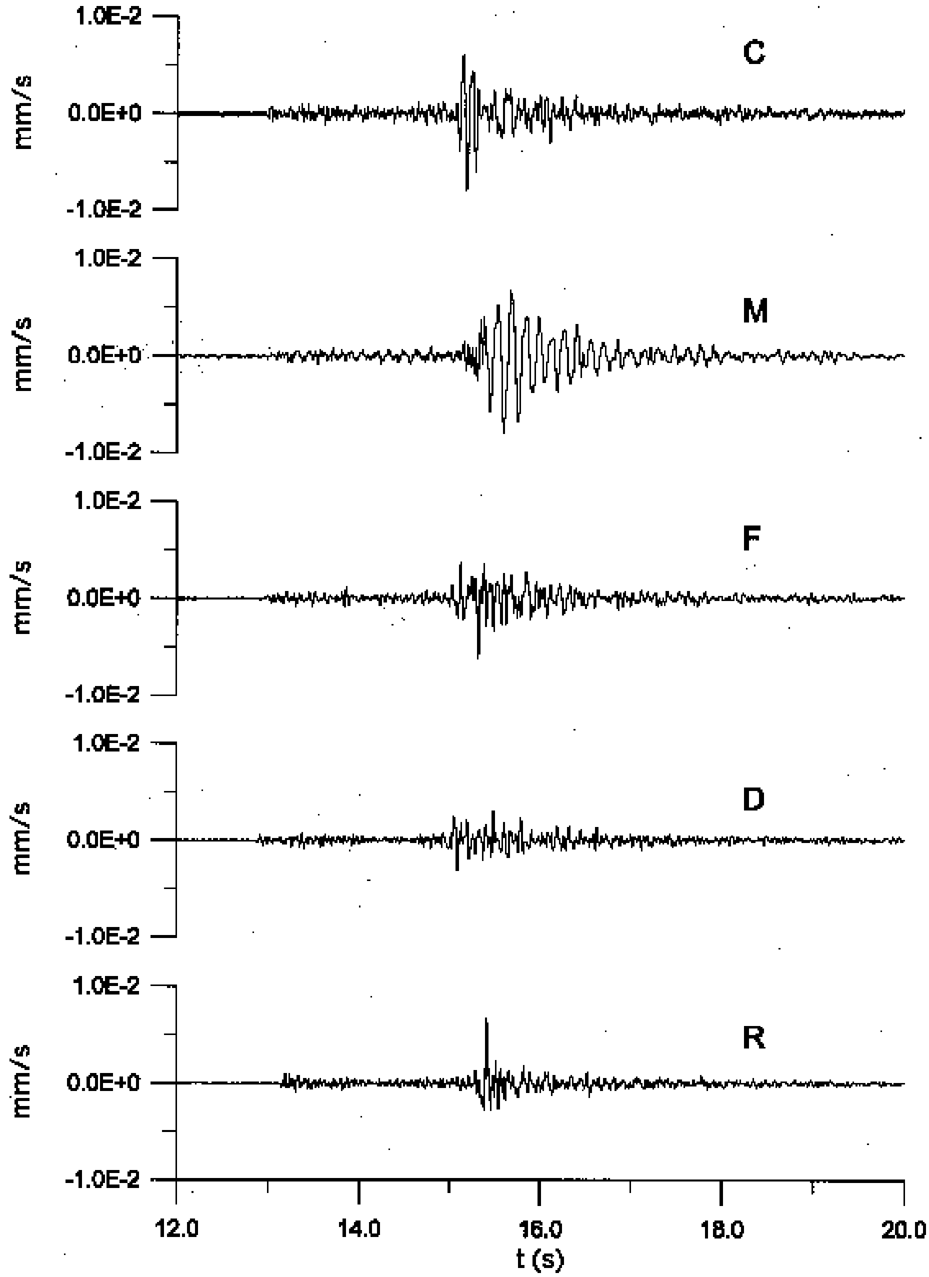


Fig. 11 - 24/09/2001 18:05:48 earthquake: velocimetric records (N-S component) obtained by the "ridge-array". A strongly amplified 6-7 Hz wave-train can be observed after direct S-waves in the record of the M station.

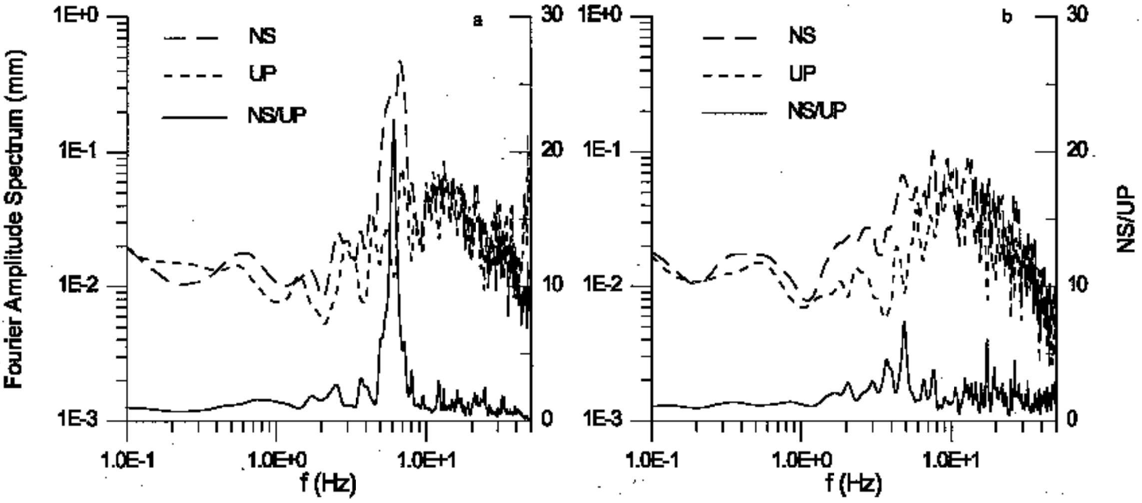


Fig. 12 - 24/09/2001 18:05:48 earthquake: smoothed Fourier Amplitude Spectra of the N-S and UP components (left Y-axis) and N-S/UP Nakamura ratios (right Y-axis) at the M station (a) and at the R-reference station (b).

content (Fig. 13). In addition, all the stations located in the plain, point out a strong amplification at about 2 Hz compared to the relative “reference station” (Fig. 14). This amplification is clearly related to the presence of alluvial deposits and is particularly evident at the Y station, which is located in the middle of the alluvial plain, where the alluvial deposits are deeper (about 40 m).

On the whole, the velocimetric measures and the data analyses confirm the good choice of the “reference station”, that is anyway related to the local conditions. (Figs. 12 and 14).

A sensitivity analysis for the significant amplifications is being carried out by implementing a numerical model of the Nera River valley, to discriminate site effects from those of the source and/or the path ones.

6. Conclusions

The geophysical surveys carried out in the Cerreto di Spoleto area aim at investigating the occurrence of local features which can induce seismic wave amplification. They are represented by geological interfaces, such as limits between heterogeneous lithologies in the alluvial plain and discontinuities related to disjunctive tectonic elements or different joint rock mass condition in the carbonatic ridge. It is worth remarking that these local features are typical of several Central Apennine areas.

In particular, seismic refraction prospecting was performed to directly measure the Vp and Vs values in both the alluvial deposits of the Nera River and the limestones outcropping in the Cerreto di Spoleto ridge. The local seismic amplification is being estimated using the velocimetric measurements of ambient noise and small-magnitude earthquakes ($Md < 2$).

The velocimetric data processing is still in progress; the preliminary results point out significant amplification effects in both the alluvial plain of the Nera River and the Cerreto di Spoleto ridge, which are related to both geological and geomorphological features.

All the collected data will be used in the future to build up a numerical model and simulate the local seismic response for the alluvial valley of the Nera River.

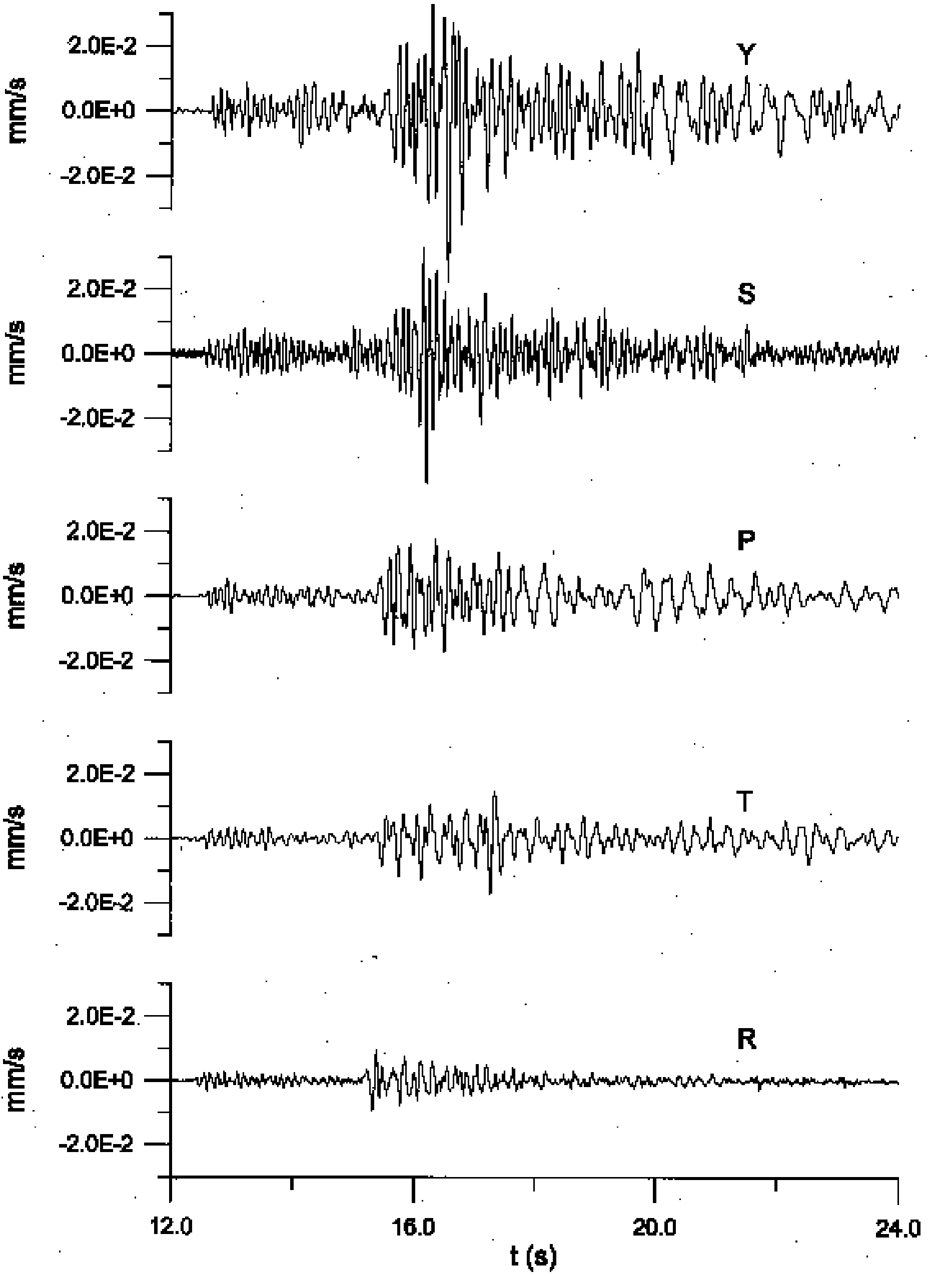


Fig. 13 - 30/11/2001 11:19:00 earthquake: velocimetric records (N-S component) obtained by the "alluvial plain-array". Relevant differences in amplitude and duration, as well as frequency content, can be observed between the measures above the travertine (T, P) and those on the alluvial deposits (Y, S).

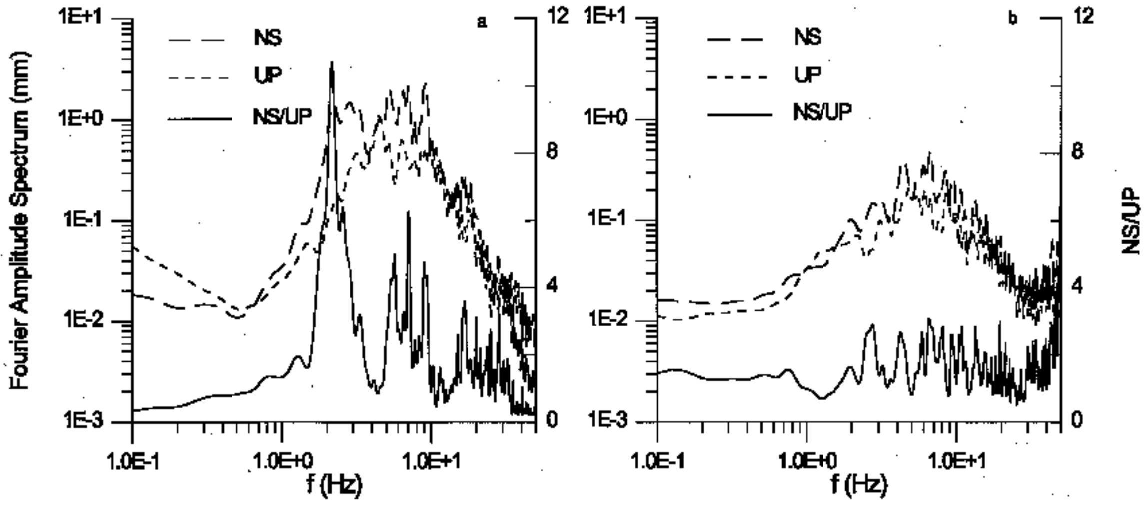


Fig. 14 - 30/11/2001 11:19:00 earthquake: smoothed Fourier Amplitude Spectra of the N-S and UP components (left Y-axis) and N-S/UP Nakamura ratios (right Y-axis) at the Y station (a) and at the R-reference station (b). A significant 2 Hz amplification can be observed in the Nakamura ratio of the Y station.

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