Seismic microzonation in two Pyrenean Valleys: Val d'Aran and Luchonnais

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SUMMARY:
Within the frame of the European Interreg SISPYR project (Seismic Information System for the Pyrenees) Val d'Aran and Luchonnais, two neighbourhood valleys located respectively in Spanish and French Pyrenees, have been selected as pilot sites for seismic risk assessment. In this framework, lithological soil effects have been taken into account for local hazard evaluation. Soil response characterization is performed based on field surveys, for both H/V and array measurements, in order to obtain soil fundamental frequency and shear-wave velocity profiles. In Val d'Aran soil fundamental frequency ranges between 1.7 and 9.0 Hz, typical values of thin soils. However, in Luchonnais unexpected low frequency resonances in the alluvial formations have been obtained, with values reaching 0.5 Hz. EC8 classification of shear-wave velocity profiles shows heterogeneous results: on the Spanish part it the class B predominates and on the French side B and C classes are observed.

Keywords: Site effects, seismic noise, fundamental frequency, shear-wave velocity, Pyrenees

1. INTRODUCTION

The Pyrenees are one of the most active seismic zones for both Spain and France. Seismic risk mitigation is then a priority in this area. In this context, European project SIPYR (Seismic Information System of Pyrenees) aimed at developing of rapid response systems to help planning emergency interventions in case of major seismic crisis. One of the objectives of the SISPYR project is the estimation of the seismic risk and to obtain damages scenarios in two Pyrenean valleys: Val d'Aran (Spain) and Luchonnais (France). These two study areas were chosen by their specific seismicity and their high vulnerability since they are main touristic area. Both areas are characterized by quaternary glaciers valleys covered with thin soils.

Local geology can be responsible for important modifications of seismic ground motion both in amplitude and frequency content. It is then essential to take it into account in seismic scenario generation. The different studies carried out to perform a seismic microzonation in the zones of study are presented in this work in which site effects are taken into account through maps of soil fundamental frequency (H/V method) and shear-wave velocity profiles (obtained using array and MASW techniques).

2. SEISMIC HAZARD AFFECTING THE AREA

The historical seismicity and the recent tectonic data indicate a level of considerable seismic hazard in the Pyrenees. The higher seismic activity is located in the western part of the mountain range. In 1373 a broad zone of the Ribagorça was affected by a destructive earthquake with an epicentral intensity of VIII-IX (Olivera et al., 2006). In 1427 and 1428 Eastern Pyrenees was affected by a seismic crisis with maximum intensity of IX (Olivera et al., 2006). In 1660 the Central part of the mountain range (Bagnères-de-Bigorre region) suffered a destructive shock (I=VIII-IX). During the XXth century, important damages have been produced in the 1923 Aran Valley (I=VIII) and 1967 Arette (I=VIII) earthquakes. Recently, with the increase of population and the economic activities, some moderate magnitude earthquakes have inflict considerable economic losses, for example the earthquakes of Saint Paul de Fenouillet (M=5.2) in February 1996, Hautes Pyrénées (M=4.7) in May 2002 and Ripollès (M=4.0) in September 2004 (Susagna and Goula, 1999).

Within the framework of a previous project (ISARD, Information of Seismic Automatic Regional Damage) a probabilistic seismic hazard study has been performed in the Pyrenees using an unified seismic catalogue, considering a sismotectonic zonation and an attenuation adapted to the zone (Secanell et al., 2008). This study was carried out considering a return period of 475 years. In Fig 2.1 the Peak Ground Acceleration (PGA) values proposed by Secanell et al. (2008) for each municipality are shown. PGA values increase from 0.14 to 0.16g from east to west.

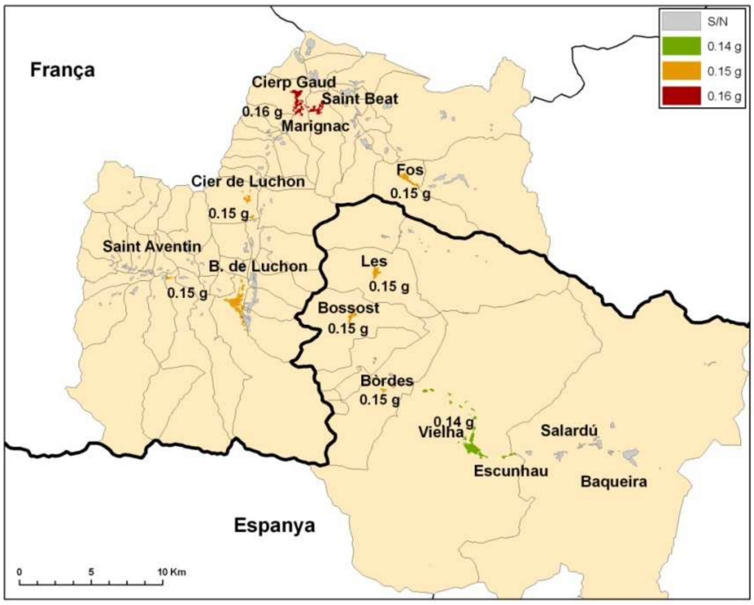

Figure 2.1. PGA values (return period of 475 years) for Val d’Aran and Luchonnais.

3. MICROZONATION IN TERMS OF FUNDAMENTAL FREQUENCY

In this work seismic noise measurements have been carried out in Val d’Aran and Luchonnais in order to obtain the soil fundamental frequencies. The station locations have been chosen considering topography, geology, geotechnics and easy access.

3.1. Val d’Aran (Spanish side)

The seismic noise was recorded using a six-channel Cityshark datalogger connected to two Lennartz LE-3D 0.2Hz sensors. Record length was 10 minutes with a sampling frequency of 100 Hz. On the Spanish side, 98 H/V measurements were distributed along four municipalities: Les, Bossòst, Vielha and Arties (Fig 3.1). The H/V ratios were calculated using Geopsy software (http://www.geopsy.org) The Fourier spectrum for each component was smoothed in 50% overlapped windows. Portions of the time sections with non-stationary signals have been removed by applying a STA/LTA anti-trigger algorithm (Lee and Stewart, 1981). The time series window length was 30T where T is the period in seconds. Criteria for interpretation of the H/V peaks have followed SESAME guidelines (Bard & SESAME-Team, 2004). For example, only sufficiently sharp peaks with amplitudes higher than 2 have been considered to obtain soil fundamental frequency.

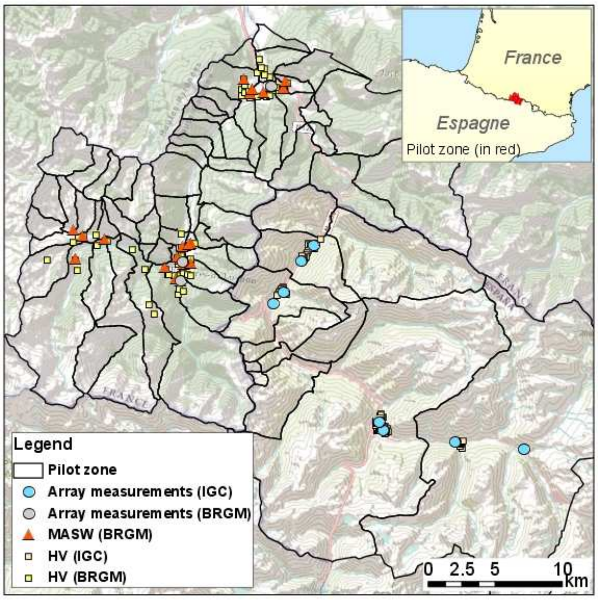

Figure 3.1. Geophysical measurements location.

Soil fundamental frequencies ranges between 1.7 and 9.0 Hz, typical values of thin soils. Locations with fundamental frequencies higher than 10 Hz have been considered as rock sites. The interpolation of the soil fundamental frequency values (Kriging method) provides a complete map for each municipality. Fig 3.2 shows the soil fundamental frequency map of Vielha. Lower frequencies are concentrated at the center of the basin and high values are distributed on the slopes of the basin. This behavior is observed in the other studied municipalities: Les, Bossòst and Arties.

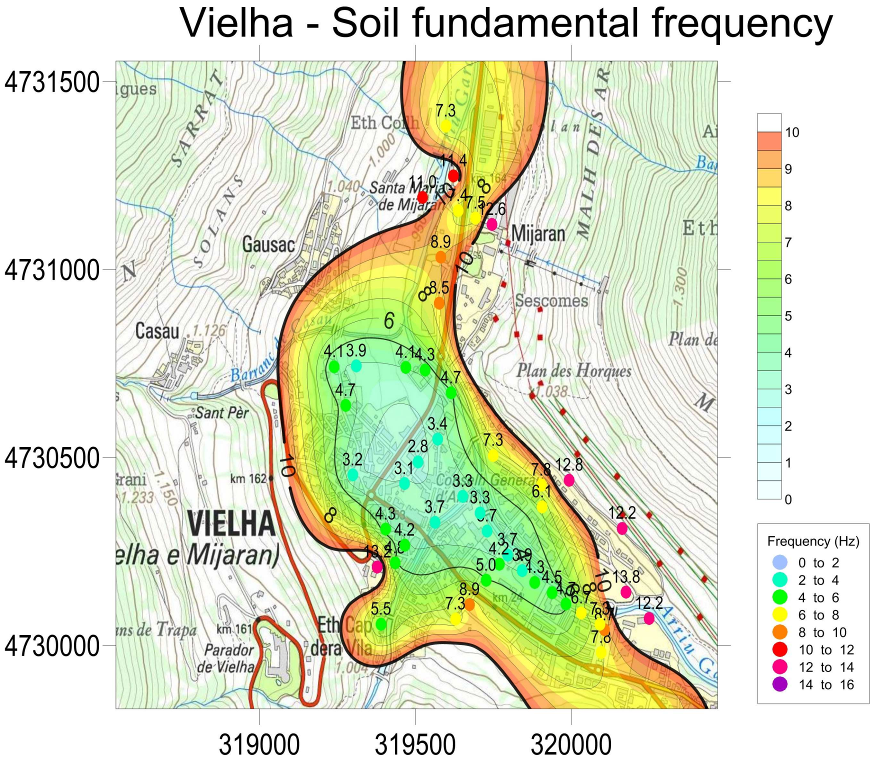

Figure 3.2. Interpolation of all the soil fundamental frequencies values obtained in Vielha from H/V method. Locations with fundamental frequencies higher than 10 Hz have been considered as rock sites.

3.2. Luchonnais (French side)

On the French side (Luchon valley), H/V measurements and processing were performed with the same equipment and tools that on the Spanish side. Measurements duration and processing windows were lengthened (respectively to 20 minutes long and 100 T long) due to lower fundamental frequencies than in Val d’Aran. 66 H/V measurements were performed on three sites (see Fig. 3.1): the western site of Garin-St Aventin characterized by moraine deposits; the central site of Bagnères-de-Luchon with alluvial deposits on the central part of the valley and alluvial fans on the edges; and the northern site of Cierp-Gaud with alluvial deposits in the plain, alluvial fans on the plain border and moraine deposits on the highest part of the site.

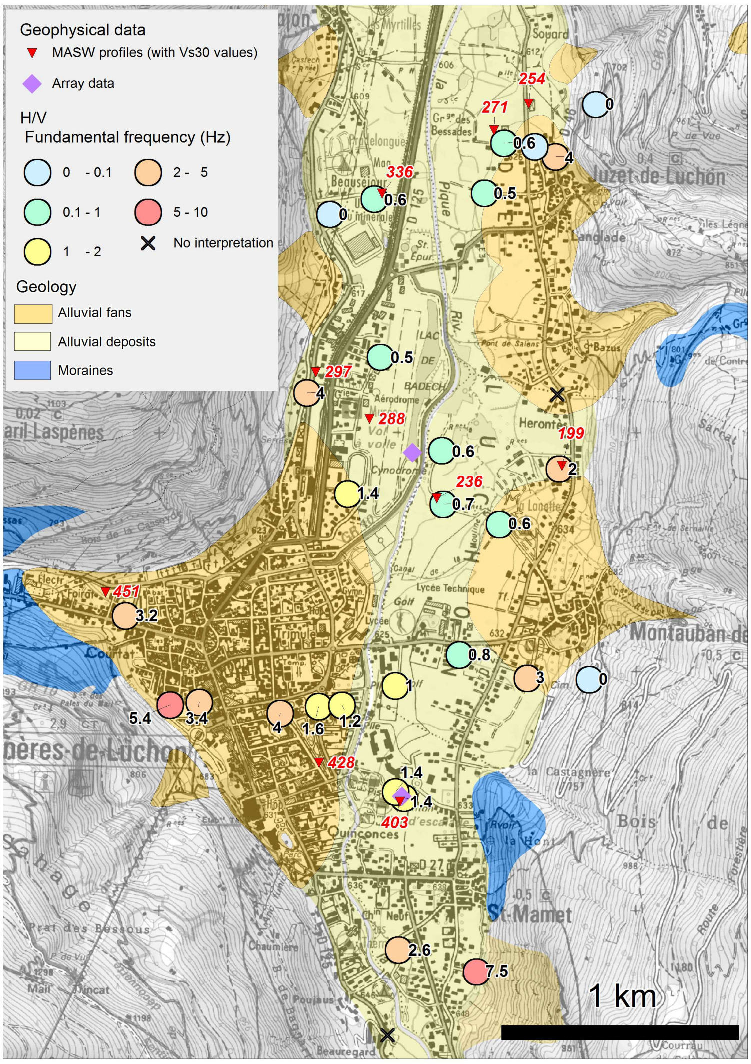

Figure 3.3. Fundamental frequencies and Vs30 values obtained in Luchon valley from H/V measurements and seismic profiles. Simplified geology and topography (© IGN) are also represented to help for interpretation.

Strong site effects were detected both on alluvial deposits and alluvial fans of the Luchon and Cierp-Gaud sites with homogeneous seismic responses in terms of frequency range and amplification. On the Luchon site, alluvial fans (orange filling) show fundamental frequencies ranging from 1.2 in the central part of the deposit to 5.6 Hz on the edge, corresponding to a thinning of the layer from centre to edge. Alluvial deposits (yellow filling) show low fundamental frequencies from 0.6 to 0.8 Hz along the valley. It corresponds to a homogeneous thick deposit without strong thickness or velocity spatial variations. On the Cierp-Gaud site, analysis is quite similar with fundamental frequencies ranging from 1.1 to 3 Hz on the alluvial fans and low fundamental frequencies around 0.8 Hz on the alluvial deposits. On the contrary, moraines and other glacial deposits (blue filling) showed heterogeneous behaviours with strong site effects in the northern part (Cierp-Gaud) and no clear site effect on the western part (Garin).

4. EC8 SOIL CLASIFICATION

In order to obtain shear-wave velocity profiles seismic noise array and active surface wave measurements were carried out. The surveys were conducted in sport camps, parks and farmlands, where open areas are suitable for seismic noise array deployment (100 m x 100m) inside the municipalities limits.

4.1. Val d'Aran (Spanish side)

Seismic noise array measurements were carried out in 8 sites over Val d'Aran (Fig 3.1). Array equipment consisted of 11 Mark sensors (cut-off frequency of 1 Hz), a DMT seismic recorder (Summit) and a field computer. Sensors were arranged into two concentric circles as we can see in Fig 4.1. Record length was fixed to 32 minutes with a sample interval of 8 ms.

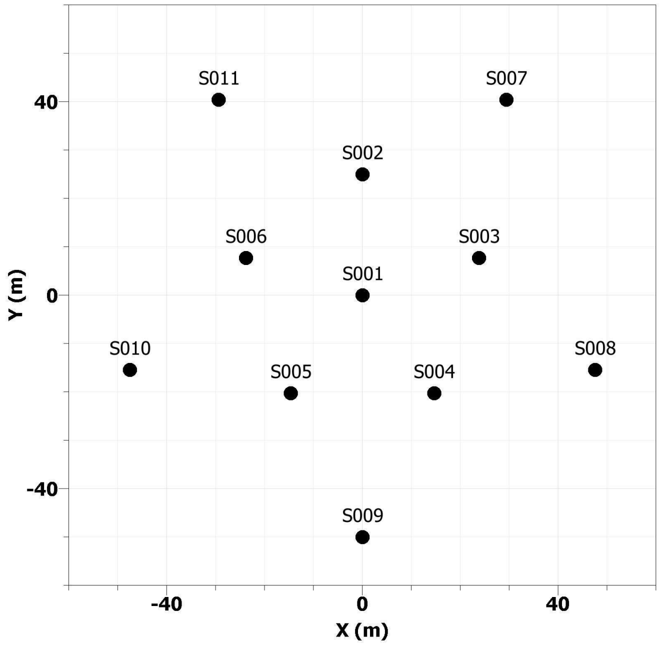

Figure 4.1. Typical geometry used for the seismic noise array measurements carried out in this work.

Records of each seismic noise array were analyzed with the Frequency-Wave number (FK) and Spatial Autocorrelation (SPAC) methods (Aki, 1957) and the inversion process (Wathelet, 2003; Wathelet et al., 2004). The processing of seismic noise array data has been carried out following the guidelines proposed by the SESAME research group and using the GEOPSY package. The outputs of both FK and SPAC computations for Vielha football array are shown in Fig 4.2, as an example. The minimum and maximum wavenumber limits determined from the theoretical response of the array are used to define the resolution and aliasing limits (exponential curves in Fig 4.2 (left)). In this case a good agreement can be observed in the higher frequencies between the dispersion curve obtained from FK and the maxima in the SPAC histogram revealing a coherence of the result. The inversion processing of dispersion curve from FK and SPAC curves has been done with Dinver software included in the Geopsy package based on neighborhood algorithm (Wathelet, 2003; Wathelet et al., 2004); the Vs models obtained at the Vielha football site are shown in Fig 4.3. The models with minimum misfit obtained by FK and SPAC analysis are coherent for the first layer, the mean shear-wave velocity ranges between 330 m/s (FK) and 350 m/s (SPAC) and the thickness is 20 meters. The mean shear-wave velocity of the second layer shows important differences; varies from 1000 m/s (SPAC) to 1400 m/s (FK).

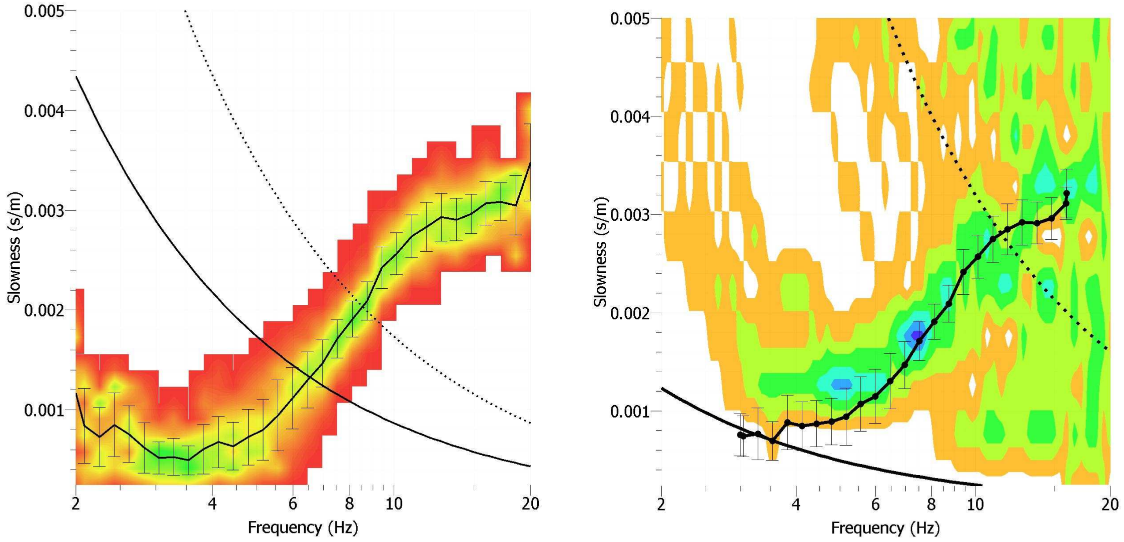

Figure 4.2. Comparison of FK and SPAC methods applied to the seismic noise array measurements in the Vielha football site, from left to right: FK histograms with a selected dispersion curve (black) and histogram from SPAC (colour scale) with dispersion curve from FK (black).

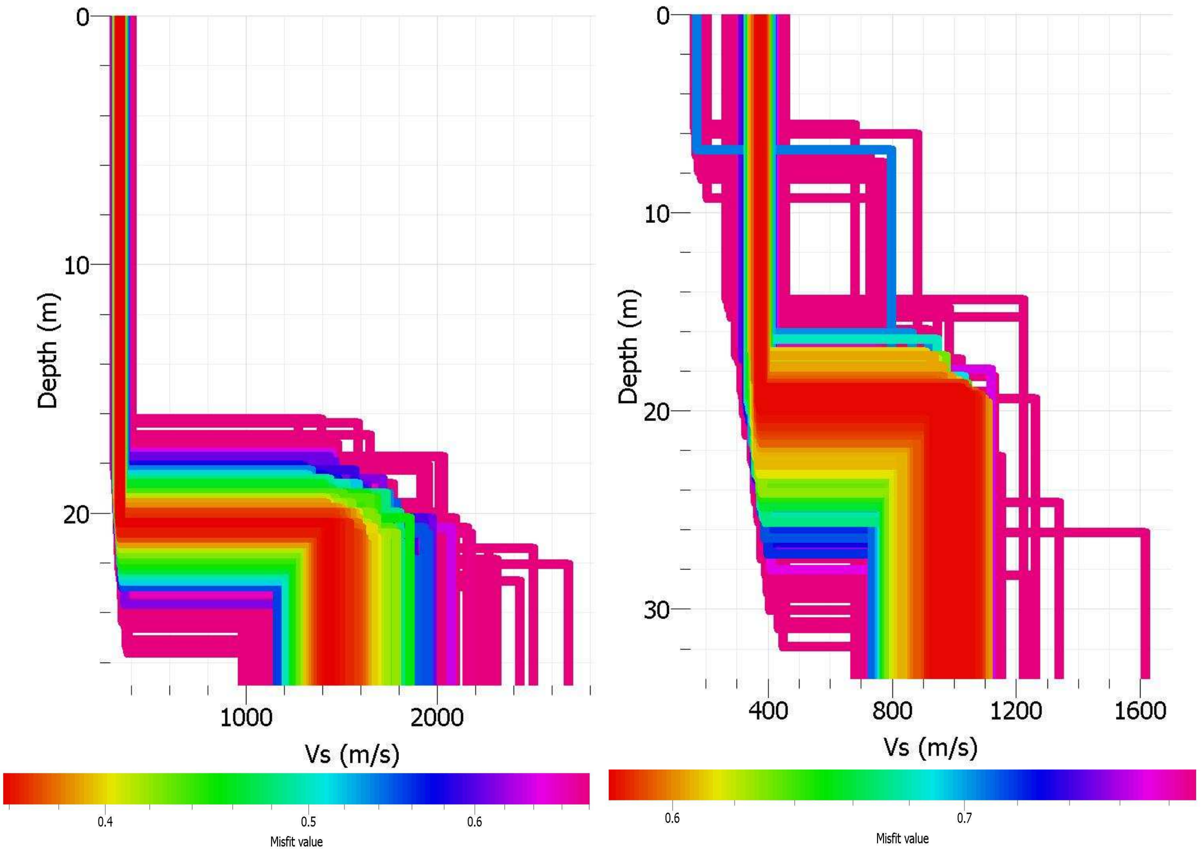

Figure 4.3. Vs profiles obtained at the Vielha football site. Left: Models with a misfit lower than 0.7 obtained from the inversion of FK dispersion curve. Right: Models with a misfit lower than 0.8 obtained from the inversion of SPAC curves.

Time-average shear-wave velocity from surface to 30 meters depth (Vs_{30}) have been obtained from seismic noise array analysis (table 4.1) for all sites. Array measurements sites have been classified considering the Eurocode EC8 soil classification (CEN, 2003) (table 4.1).

Table 4.1. Mean shear-wave velocity (Vs_{30}) and EC8 soil class for each array site (Spanish site).

Name of the array site	Vs_{30} (m/s)	EC8 soil class
Les football	553	B
Les	530	B
Bossòst football	429	B
Bossòst	560	B
Vielha car park	464	B
Vielha football	443	E
Arties	441	E
Vaqueira	916	A

Most of Val d'Aran array sites have been classified as soil class B. However, it must be noted that some sites have values very close to the boundary between classes B and C (360 m/s), for example Bossòst football and Arties. In the municipality of Vielha array sites have class E because most soils show a maximum thickness of 20 meters overlying the bedrock.

4.2. Luchonnais (French side)

One of the aims of this study was to perform 1D numerical simulations of soil seismic responses. Due to poor existing data in terms of lithology, geotechnical and geophysical parameters, additional measurements were carried out for velocity profiles estimation. In this context, 21 active MASW profiles and 3 passive seismic array measurements were carried out.

MASW profiles consisted of 100 m linear profiles of 48 geophones. At least three shots per profile were performed (direct, central, and inverse). MASW data were processed using SURF (Herrmann, 1987). Array equipment consisted of 8 Güralp CMG6-TD sensors (cut-off frequency of 0.1 Hz). Sensors were arranged into two concentric circles of 25 m and 50 m radius. Records length was fixed to 1 hour with a sampling frequency of 100 Hz. As for the Val d'Aran data, processing was performed with GEOPSY. For the 3 sites where both MASW and array measurements were carried out and a combined inversion of dispersion curves was carried out. Array data helped us to improve velocity estimations for depths up to 100 m (maximum resolution depth of the array data) which is higher than the maximum investigation depth of MASW profiles (around 30 m).

EC8 classification of velocity profiles show homogeneous results with C soil class for alluvial deposits in Luchon (see figure 3.3), B soil class for alluvial fans in Luchon and Garin Moraines (Garin moraines are characterized by stiff soils with Vs30 values higher than 500 m/s). In the northern site of Cierp-Gaud, moraines are characterized by a C-soil class whereas alluvial fans and alluvial deposits present Vs30 values ranging between B and C (mostly between 340 and 410 m/s).

Table 4.2. Mean shear-wave velocity (Vs_{30}) and EC8 soil class for each array site (French side).

Site	Vs_{30} (m/s)	EC8 soil class	Geology / Location
1	530	B	Moraines – Garin
2	508	B	Moraines – Garin
3	451	B	Alluvial fan edge – Luchon
4	428	B	Alluvial fan – Luchon
5	288	C	Alluvial deposits – Luchon
6	236	C	Alluvial deposits – Luchon
7	336	C	Alluvial deposits – Luchon
8	408	B	Alluvial deposits – Cierp-Gaud
9	382	B-C	Alluvial deposits – Cierp-Gaud
10	343	B-C	Alluvial deposits – Cierp-Gaud
11	295	C	Moraines – Cierp-Gaud

12	270	C	Alluvial deposits – Cierp-Gaud
13	372	B-C	Alluvial deposits – Cierp-Gaud
14	273	C	Alluvial fans – Cierp-Gaud
15	254	C	Alluvial deposits – Luchon
16	403	B	Alluvial deposits edge– Luchon
17	709	A-B	Moraines – Garin
18	297	C	Alluvial deposits – Luchon
19	271	C	Alluvial deposits – Luchon
20	199	C	Alluvial deposits – Luchon
21	315	C	Alluvial deposits – Oô (Garin area)

5. CONCLUSIONS

In this work, a seismic noise measurement field survey was conducted in Val d'Aran and Luchonnais. H/V, MASW and array techniques were applied in order to characterize site effects. Soil fundamental frequencies obtained in Val d'Aran ranges between 1.7 and 9.0 Hz typical values of thin soils. While in Luchonnais, unexpected low frequency resonances have been obtained, with values reaching 0.5 Hz in the central part of the Luchon valley. Mean shear-wave velocity obtained on the Spanish side from array techniques ranges from 300 to 500 m/s, corresponding to B and E classes in EC8 soils classification. However on the French part shear-wave velocity varies from 200 to 500 m/s that corresponds to B and C classes.

The fundamental period and Vs profiles obtained will be useful for the soil structure characterization in order to perform numerical simulation to assess soil amplification. The amplification due to local effects obtained in both study zones will be considered in terms of spectral values and intensity, jointly with the buildings vulnerability evaluations, for the seismic risk estimation and the assessing of damage scenarios.

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