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Combination of Active and Passive Seismic Methods for Subsoil Characterization of Seismic Stations

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SUMMARY

Within the framework of Alertes-RIM (Regional and on-site earthquake early warning system for the Ibero-Maghrebian region) project twenty five seismic stations located in this region have been characterized. The aim of this work is the application of a methodology based on combination of active and passive seismic techniques in order to study potential soil effects at these stations. During the first step of this study, seismic noise recordings are extracted from seismic stations in order to apply the H/V spectral ratio technique and classify sites as rock or soft soil. Once identified seismic stations installed on soft soil the second stage is done. This phase consists on carrying out the fieldwork in the location of seismic stations. Surface wave analysis (MASW) and linear seismic noise array analysis are performed to get the shear-wave velocity model of soil column. Seismic refraction tomography (SRT) provides a 2D P-wave velocity model to identify bedrock geometry and soil parameters. The H/V spectral ratio is used in different places along the seismic profiles in order to obtain soil fundamental frequencies and compare these values with the fundamental frequency obtained from seismic stations recordings. The proposed methodology ensures a good characterization of seismic station subsoil.

Introduction

The seismic recordings are essential in order to know ground motion, to assess seismic hazard or even to identify the effects of soft soil. For all these applications it is recommended to characterize the subsoil of seismic stations to determine the influence of these materials in modifying the seismic record in amplitude, duration and frequency content.

The Spanish ALERTES-RIM (Regional and on-site earthquake early warning system for the Ibero-Maghrebian region) project was set up to evaluate the feasibility of implementing an Earthquake Early Warning System (EEWS) to warn the potentially damaging earthquakes that can occur in the Ibero-Maghrebian region. One of the goals of this project is to characterize the subsoil structure and the seismic response of the stations involved in the EEWS (Figure 1).

The objective of this work is to perform the geophysical characterization of these seismic stations (25 sites). Firstly, find out if a station is settled on hard rock or soft soil. The second step is to obtain the geometry and geophysical parameters of the subsoil layers of the seismic stations located on soft soil and assign the EC8 soil class.

In this study, the methodology and its application are presented in one seismic station as a case study (ESPR). The obtained results in the six seismic sites studied are summarized in discussion and conclusions sections.

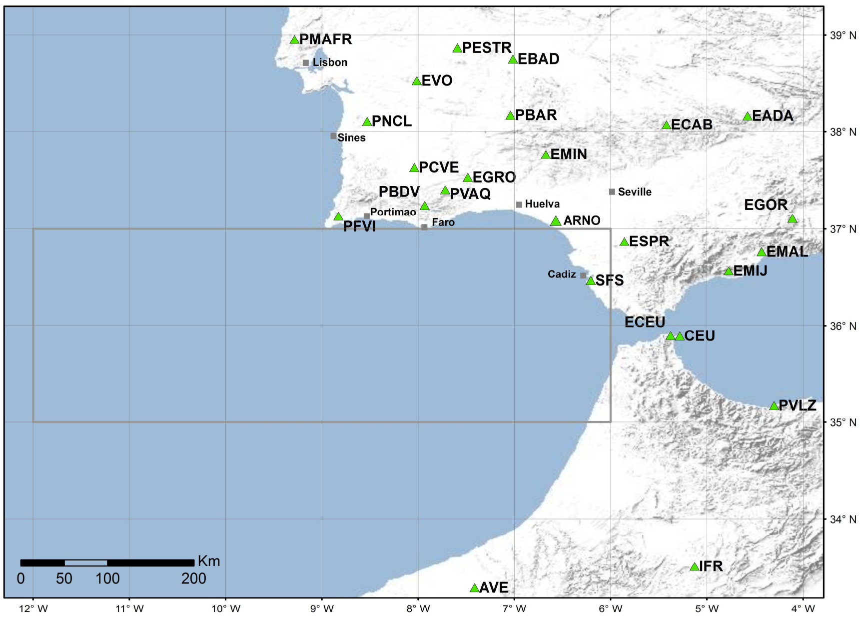

***Figure 1** Study area map and location of the seismic stations (triangles) characterized in this work.*

Methodology

The methodology applied in this work to achieve the objectives includes two phases. First, seismic noise recordings from seismic stations are extracted to apply the H/V spectral ratio technique. This known method (Bonnefoy-Claudet et al., 2006) is used to classify the site: rock outcrop or soft soil. Note that H/V spectral ratio has no significant peaks in rock sites. After this calculation 16 seismic stations sites are classified as rock and 9 seismic locations are categorized as soft soil.

The second phase of this study is to perform several geophysical field surveys to characterize the seismic stations placed on soft soil. Due to logistical constraints the fieldwork has not been done in three locations (AVE, IFR and PVLZ). Figure 2 shows the H/V spectral ratio at the seismic stations where the fieldwork has been conducted (ARNO, EBAD, EGRO, EMAL, ESPR and SFS) and table 1 presents characteristics of the geology and preliminary site classification at each location. Most of the locations show a clear peak in the H/V spectral ratio. Although EGRO site shows a weak peak, this seismic station is included because its H/V shape is not the predicted behavior for a rock site.

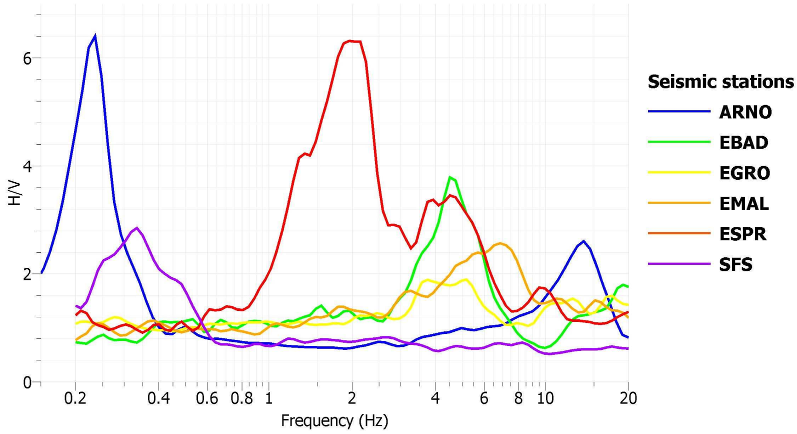

Figure 2 *H/V spectral ratio curves obtained at each seismic station characterized in this work.*

Table 1 *Geology of each station analysed. The geology and preliminary site classification have been assigned from 1:50.000 scale geological maps.*

Code	Station	Lithology	Age (Epoch)	Class
ARNO	Arenosillo	Mantle wind	Holocene	Soft soil
EBAD	Badajoz	Sandstones	Early Tortonian (Late Miocene)	Soft soil
EGRO	El Granado	Shales and mudstones	Visean (Mississippian)	Rock
EMAL	Málaga	Shales	Paleozoic	Rock
ESPR	Espera	Olistostromic unit	Langhian (Medium Miocene)	Soft soil
SFS	San Fernando	Calcareous sandstones	Late Pliocene-Early Pleistocene	Soft soil

Different geophysical techniques have been implemented in order to perform the soil geophysical characterization at the seismic stations sites:

- Surface waves analysis (MASW) has been applied in order to provide the shear-wave velocity model (Vs) of soil column for each site (Xia et al., 1999).
- Linear seismic noise array analysis has been performed in order to complement surface wave analysis and increase investigation depth.
- Seismic refraction tomography (SRT) has been carried out in order to obtain 2D P-wave velocity models. These P-wave models are used to characterise near-surface layers, to identify subsoil geometry and to assist the interpretation of Vs profile.
- H/V (horizontal to vertical) spectral ratio from seismic noise recordings. This method has been used to obtain the soil fundamental frequency in different places along the seismic profiles. The objective of this exercise is to compare these values with the fundamental frequency obtained from seismic stations data.

Seismic profiles were acquired using a DMT seismic recorder with 24 channels and 4.5 Hz vertical geophones located every 3, 4 or 5 m, depending on the available space at each seismic station. Seismic data were recorded at a 0.125 ms sample rate and the record length was enlarged up to 1.024 s or 2.048 s (depending on the velocity of each site) to assure the acquisition of the complete surface wave train. Source positions were varied along the geophone spread in order to have data suitable for refraction analysis; in total seven shot locations were occupied (G1-G2, G5-G6, G9-G10, G12-G13, G16-G17, G20-G21 and G23-G24). In order to apply the MASW method, two shots were located on each side of the profile. The source was a 5 kg hammer striking a metal base plate. Seismic P-wave velocity model was obtained by first break inversion using Rayfract software (by Intelligent

Resources Inc.). SurfSeis© software using Phase-shift algorithm (Park et al., 1999) was utilized to get the seismic image of the shot gather in the frequency–velocity domain, and invert the dispersion curve to compute shear-wave velocity profile. The linear seismic noise array data were analysed with the Geopsy package (http://www.geopsy.org) using the FK method to retrieve the dispersion curve and subsequently inverted using neighborhood algorithm (Wathelet, 2008) to calculate shear-wave velocity profile.

The seismic noise vibrations were recorded using a three-channel SARA SL06 datalogger connected to one Lennartz LE-3D 0.2 Hz triaxial sensor. The record length ranged between 20 and 30 minutes with a sampling frequency of 200 Hz. Three H/V measurements were distributed along each seismic profile (G5, G12 and G20). The H/V ratio was calculated using the Geopsy software.

Case study: the seismic station of Espera (ESP)

Figure 3 shows the P-wave velocity model from SRT obtained at the ESPR seismic station located in southwest of Spain (Figure 1). The model is characterized by low velocity values (V_P < 2700 m/s) up to 30 meters depth. This first layer is interpreted as soft soils. At the southern part of the profile we can observe higher velocity values (V_P > 3000 m/s) at 35 meters depth. This layer could be interpreted as bedrock.

Figure 4a shows the seismic image of one shot gather in the frequency-velocity phase domain and the dispersion curve obtained from surface wave analysis. The dispersion curve exhibits a sharp phase velocity change around 10 Hz. The phase velocity is lower than 500 m/s for frequencies above 10 Hz. On the other hand, the phase velocity reaches about 800 m/s at 5 Hz. Shear-wave velocity model has been obtained from dispersion curve inversion (figure 4b). A velocity change is observed around 36 m increasing from 700 m/s to 1300 m/s. As in the P-wave model, this velocity variation could be related to the presence of bedrock. This subsoil structure is consistent with the soil fundamental frequency obtained along the seismic profile.

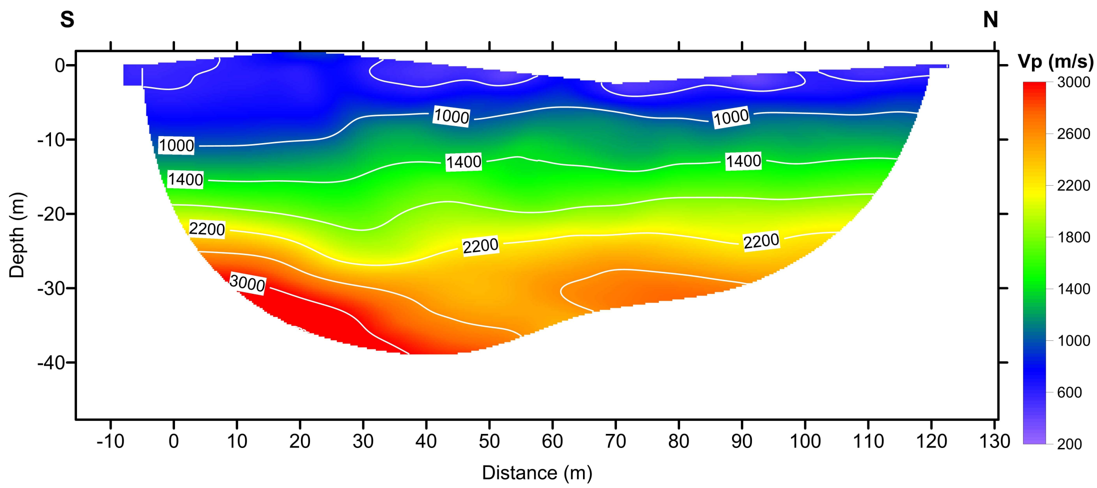

Figure 3 *P-wave velocity model from SRT obtained at the seismic station of Espera.*

Discussion and conclusions

Figure 4b presents the shear-wave velocity model obtained in all characterized seismic stations and table 2 shows a summary of the results. The major outcomes are:

- One seismic station initially classified as rock site (EMAL) show a significant peak in the H/V spectral ratio related to soil fundamental frequency. Therefore, this site must be considered as soft soil site (EC8 soil class B).
- The seismic station of EGRO shows a weak peak in the H/V spectral ratio (figure 2), however it cannot consider as soil effect since the station is in rock (EC8 soil class A).

This geophysical characterization will be used to compute soil transfer function at each seismic station. These results will be applied in the seismic hazard studies for the accurate characterization of the ground motion.

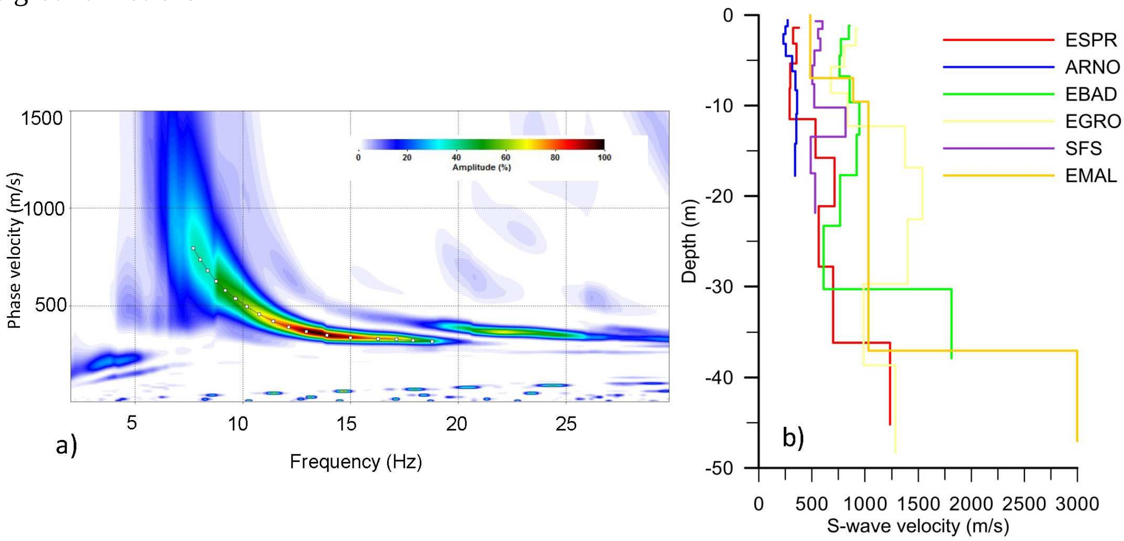

Figure 4 *a) Seismic image of one shot gather in the phase velocity–frequency domain and dispersion curve (white dots) obtained from surface wave analysis at the seismic station of ESPR. b) S-wave velocity profiles from surface wave analysis at each seismic station characterized in this work.*

Table 2 *Soil fundamental frequency, mean shear-wave velocity at 30 meters depth and EC8 soil class (CEN, 2003) for each seismic station.*

Code	F_0 (Hz)	Vs_{30} (m/s)	EC8 soil class
ARNO	0.23	325	C
EBAD	4.6	773	B
EGRO	-	1097	A
EMAL	7.0	773	B
ESPR	2.0	441	B
SFS	0.33	546	B

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