AZIMUTHAL DEPENDENCE OF THE ROTATED H/V RELATIONSHIP IN FOUR CITIES OF THE MERIDA ANDES

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Abstract

The rotated H / V spectral relationships obtained from seismic noise records from four cities of the Mérida Andes, Venezuela: Boconó, Valera, Trujillo and Mérida, are studied. A total of 305 stations were included, with a recording time between approximately 20 and 30 minutes for each station. The spectral ratios were computed after rotating the horizontal components in 10^0 steps from 0^0 (north) to 180^0. In almost all cases, the orientations for the maximum amplification values of the H / V ratios are orthogonal or almost orthogonal with respect to those of the minimum values. For each of these cities, the results clearly show directional effects, with the azimuths of the maximum and minimum amplifications related to surface geology and/or topography. In some cases, mainly in particular geoforms such as ejection cones, or on terraces with quite heterogeneous sediments, the azimuths obtained for nearby stations can vary significantly.

Keywords: H/V rotated, Geopsy, directional effects, topography, Andes de Mérida.

DEPENDENCIA ACIMUTAL DE LA RELACIÓN H/V ROTADA EN CUATRO CIUDADES DE LOS ANDES DE MERIDA

RESUMEN

Se estudian las relaciones espectrales H/V rotadas, obtenidas a partir de registros de ruido sísmico provenientes de cuatro ciudades de Los Andes de Mérida, Venezuela: Boconó, Valera, Trujillo y Mérida. Se incluyeron un total de 305 estaciones, con un tiempo de registro entre 20 y 30 minutos, aproximadamente, para cada estación. Las razones espectrales fueron calculadas para intervalos de 10^0 desde 0^0 (norte) hasta 180^0. En casi todos los casos, las orientaciones para los valores maximos de amplificación de las razones H/V son ortogonales o casi ortogonales con respecto a las de los valores mínimos. Para cada una de estas ciudades los resultados muestran claramente efectos direccionales, con los acimutes de las amplificaciones máximas y mínimas relacionados con la geología superficial y/o la topografía. En algunos casos, principalmente en geoformas particulares como conos de deyección, o en terrazas con sedimentos bastantes heterogéneos, los acimutes obtenidos para estaciones cercanas pueden variar de manera significativa.

Palabras Clave: H/V rotado, Geopsy, efectos direccionales, topografía, Andes de Mérida.

INTRODUCTION

The H/V spectral ratios from seismic ambient noise have become a very valuable tool for the studies of site conditions, especially for the determination of the fundamental period of the sites where a soft layer overlies stiffer bedrock (Nakamura, 1989; SESAME, 2004). In its traditional form this technique has been applied averaging the horizontal components without considering anisotropic effects in the spectral ratios. However, more recently, some workers (Pischiutta *et. al*, 2010 y Pischiutta *et. al*, 2011; Panzera et al., 2013) have shown that the rotated H/V spectral noise ratios exhibit maximum and minimum values for orthogonal azimuths depending on the orientation of faults, fractures and valleys.

This work is the first application of this technique to the study of geological structures in Venezuela, as a part of a project for seismic hazard determination, which is being carried out under the larger, umbrella project GIAME (Integrated Geociences of the Mérida Andes). Recordings of ambient seismic noise were carried out in the west of the country detailing in the Merida and Trujillo States (Cerrada et al, 2016). In most results, a strong dependence of the rotated H/V with the topography and geological structures was observed.

GEOLOGICAL SETTING

The cities of Boconó, Valera, Trujillo y Merida, in the Trujillo and Merida states respectively (Figure 1), are located in Western Venezuela, within the Mérida Andes, a tectonically active chain that extends about 400 km from the Colombian border in a SW – NE direction to the city of Barquisimeto. It is related with the interactions between the Caribbean, South American and Nazca Plates (Audemard and Audemard, 2002; Monod et al., 2010) and exhibits strain partitioning with thrusting along thrust faults on both foothill fronts, associated with the transverse shortening of the range in a NW-SE direction. In SW-NE direction, the right lateral strike slip shearing is absorbed mostly by the Boconó fault. Between this fault and the N-S striking Valera fault, which diverges to south along the Momboy and Motatan faults (Figure 1), partitioning is accompanied by the tectonic escape of the Trujillo block towards the NE. Uplifting combined with mass wasting and depositional processes have produced structures formed by sedimentary layers in many places that present significant impedance contrast with the underlying bedrock, such as the locations of the four cities under study. As this region has experienced many destructive earthquakes, some of them of magnitude Mw 7 or higher (Grases et al., 1999; STSHV, 2005), site effects must be assessed in order to correctly quantify the seismic hazard (Kawase, 2003; Faccioli & Pessina. 2003; Duval et al, 1998; Yamazaki et al, 2005).

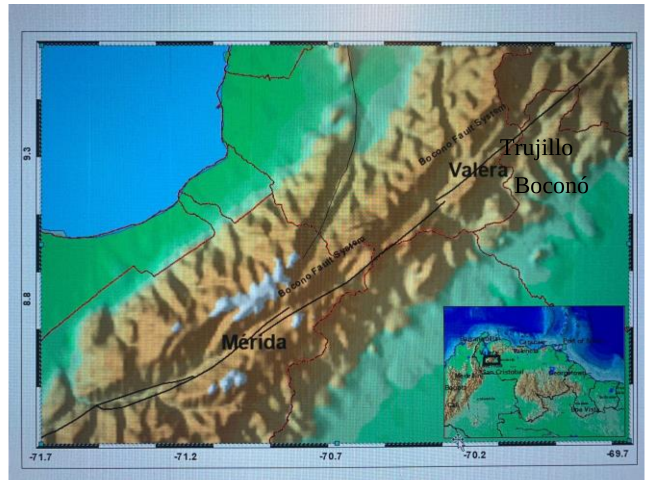

Figure 1. General location of the study area

ROTATED H/V SPECTRAL RATIO

In this work, presence of anisotropic effects in the amplification of ground motion was addressed following the methodology proposed by Panzera et al. (2013), computing the H/V spectral ratio after rotating the horizontal components by steps of 10˚ starting from 0˚ (north) to 180˚ and plotting the contours of the spectral ratios as a function of frequency and direction of motion. (Figure 2).

The data was collected using two sets of instruments. A Guralp CMG-3T sensor (borrowed from FUNVISIS) with three components, flat in velocity response from 0.03 Hz to 50 Hz. A high-resolution Taurus digital seismograph, with ADC (Analog to Digital Converter) of 24 bits, with a high precision GPS, internal storage capacity of 64 Gbytes, from Nanometrics (https://www.nanometrics.ca).

At every site, the seismic ambient noise was recorded for about 20 minutes. All the records were processed and analyzed using the software package GEOPSY, 2.9.0 version (*geopsypack* 2.5.0, http://www.geopsy.org). A total of 305 sites were studied: 94 in Boconó (figure 3), 112 in Valera (figure 4), 64 in Trujillo (figure 5), and 35 in Merida (figure 6). The seismic sensors were situated following the recommendations given by the SESAME Group (Bard and The SESAME Team, 2004), that is, avoiding sites close to underground openings, pumps, machinery and so on. A 0.10 Hz to 20 Hz band pass filter and time windows of 30 seconds with a 5% taper was applied to the signals. For each record, it was possible to work with more than 15 windows, and the periods, where peak amplitudes were identified, were in general smaller than 3 seconds, which satisfies the processing requirements for reliable results (Bard and The SESAME Team, 2004).

In figure 2, an example of the processing (selected windows and rotated H/V) is shown. The maximum value of H/V occurs at a frequency of 1.3 Hz and for an azimuth of 20˚ measured clockwise from north. The minimum value, for this frequency, occurs for an azimuth of about 110˚ measured clockwise from north. For almost all sites, the angular difference between the maximum and the minimum amplification azimuths was very close to orthogonality, a result consistent with the ones obtained by other workers ((Pischiutta *et. al*, 2010 y Pischiutta *et. al*, 2011; Panzera et al., 2013; Pischiutta et al., 2013). At a frequency of 4 Hz, there is a secondary maximum with a value of 2, but in this case, it is independent of azimuth. This situation where for a given wavelength, the H/V maximum depends of azimuth, and for another wavelength does not, is not uncommon. This result may occur if a recording instrument is installed within an area that is laterally homogeneous up to a radius R around the instrument. In a sedimentary deposit, a set of boulders randomly distributed in a fine-grained matrix would fit the homogeneity condition for wavelengths much larger than the size of the boulders and the separation between them. On the other hand, if these wavelengths are smaller than R, the H/V ratio will be independent of azimuth, but for wavelengths larger tha R, the ratio may be dependent of azimuth.

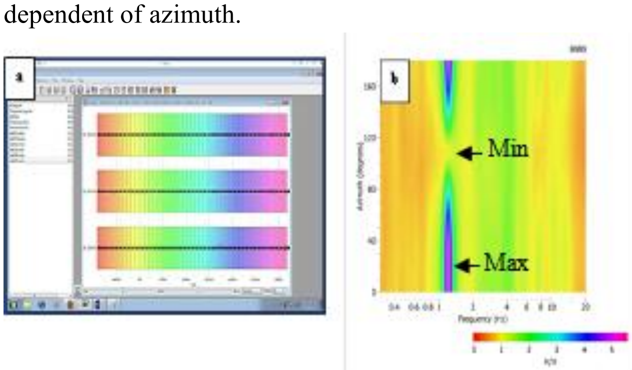

Figure 2. (a) Windows accepted by GEOPSY, using the parameters mentioned above. (b) Rotated H/V.

RESULTS

The maximum and minimum amplification azimuths of the rotated H/V obtained from the processing of the records of the 320 sites are shown in figures 3, 4, 5 and 6, which correspond to the cities of Boconó, Valera, Trujillo and Merida, respectively.

BOCONO CITY

The city of Boconó occupies two valleys. One of them runs almost S-N, and the other SW – NE. They are close to, or are cut by the Boconó and local faults (figure 3). Most of the maximum amplification azimuths are approximately orthogonal to the axis of each of the valleys and/or the strike of the faults. A total of 94 stations are obtained. The values of the minimum amplification azimuths range from 20° to 80°, and for the maximum, from 80° to 180°. The influence of both, the geometry of the valley and the faults that run through the city, are clearly observed. In the rectangular box of figure 3, that encloses part of the Boconó fault, it is seen that most maximum amplification azimuths are almost perpendicular to this fault.

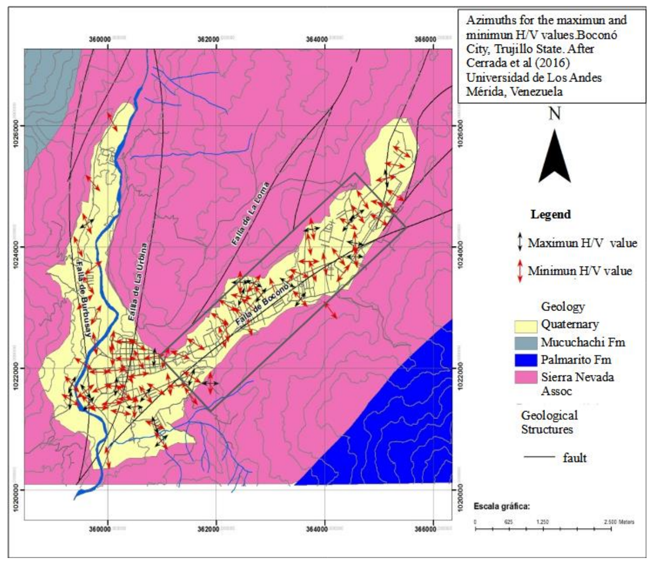

Figure 3. Maximum and minimum amplification azimuths in the city of Boconó.

VALERA CITY

The fluvial Terraces (Q3 – Q0) of Valera city overlie rocks of Miocene – Pliocene age known as Isnotu and Betijoque formations, the Rio Momboy Association and the Granite of Valera. The city is bordered by several tectonic faults such as Valera, Momboy and minor faults. Records from 112 stations were obtained. The values of the minimum amplification azimuths are presented in the range from 20 ° to 160°, and for the maximum values in the range from 60° to 180°.

In the city of Valera, there are areas without preferred orientation (figure 4, enclosed in boxes), although these orientations are not completely random. This may reflect the fact that the sedimentary deposits (Quaternary) that form the terrace came from different sources and that these areas do not have a long and narrow shape, like in the area enclosed by the box in the center of the figure. The sedimentary deposits in the area enclosed by the southernmost box seems to be geometrically complex, probably due to different processes of mass wasting, but the maximum and minimum amplification azimuths, in most cases, follows the local geometry.

Similarly, in the area enclosed by the northernmost box, the azimuths follow the local geometry in most cases. On the other hand, toward the southwest, the plateau is narrow and elongated and the rotated H/Vs show in most cases a preferred orientation, with the maximum perpendicular to the axis of the valley.

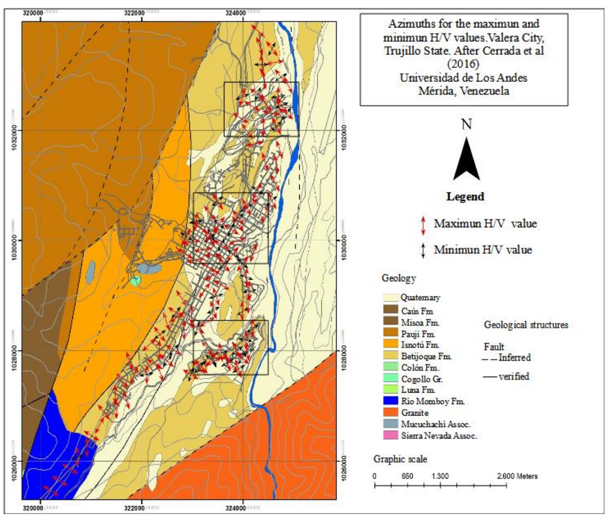

Figure 4. Maximum and minimum amplification azimuths in Valera City.

TRUJILLO CITY

The city of Trujillo is located in a narrow valley and shows an irregular topography. The lithology is dominated by the Mucuchachi Association and sedimentary formations such as La Luna, Colón, La Quinta, Peñas Altas and sedimentary deposits. The El Zamuro and Trujillo faults exert an important tectonic control in the area. A total of 64 stations were measured. The values of the minimum amplification azimuths range from10° to 170°, and for the maximum values from 80° to 180°. The azimuths of the maximum amplification are in most cases close to the perpendicular to the local axis of the asymmetric valley (figure 5).

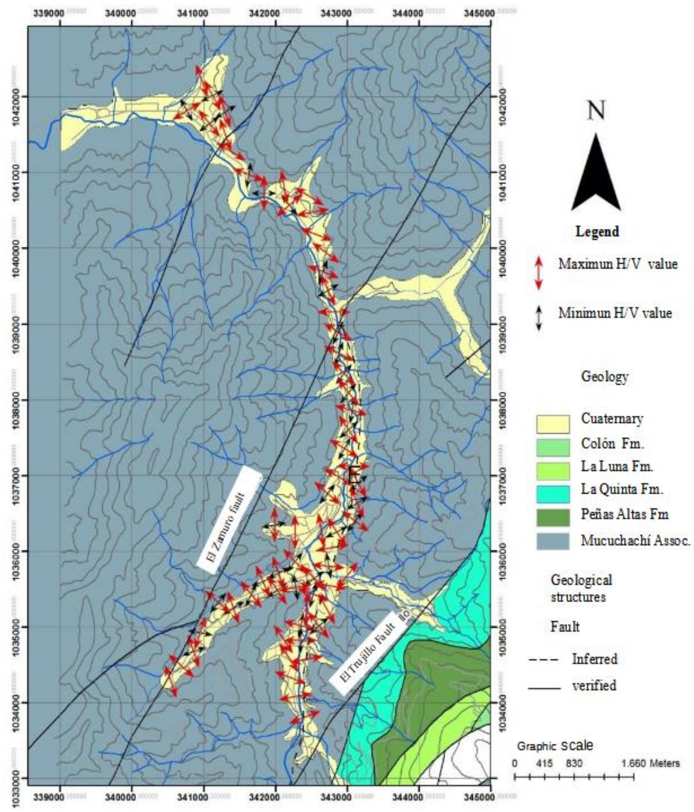

Figure 5. Maximum and minimum amplification azimuths for 64 sites in the city of Trujillo.

MERIDA CITY

The city of Mérida is located on a terrace, not only influenced by the rivers Chama and Albarregas, but also by recent deposits and the Boconó fault and other minor faults (figure 6). A total of 35 stations were measured. The values of the minimum amplification azimuths range from 10° to 60°, and for the maximum values from 60° to 160°. For many stations, the direction of the maximum amplification is about NW-SE, which suggests a possible effect of the scarps associated to the Chama and Albarregas rivers. However, between Paseo Las Ferias and the Faculty of Medicine of the Universidad de Los Andes (Rectangle in figure 6) the direction of the maximum amplification follows approximately the tangent of the upper border of the semicircular gully.

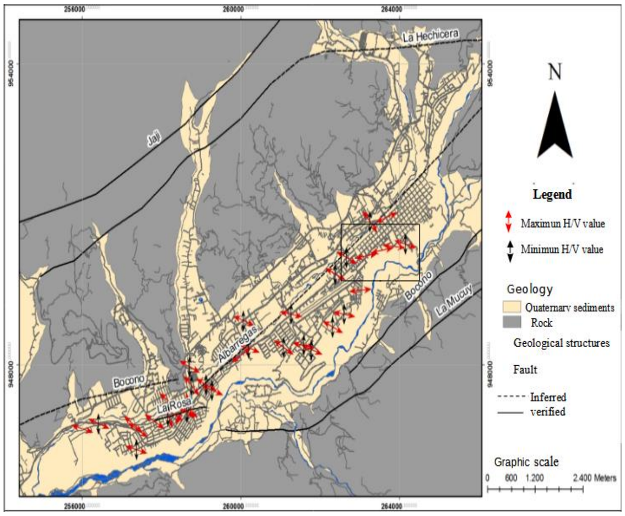

Figure 6. Maximum and minimum amplification azimuths for 35 sites in the city of Mérida. The rectangle encloses the semicircular gully near paseo Las Ferias.

DISCUSSION

The results show in most cases a consistency between the maximum and minimum amplification azimuths and the geological structures such as the valley axis, fault strikes, and scarps, which shows the strong influence that these features have on the maximum and minimum amplification azimuths. In a number of cases, secondary maximums at higher frequencies were observed, that in general do not show azimuthal dependencies in the H/V ratios. As discussed in the section on rotated H/V ratios, these phenomena may occur in limited areas where the sediments do not have significant lateral heterogeneity. The shorter wavelengths corresponding to the higher frequencies do not “see” the lateral boundaries of these limited areas and hence produce horizontally isotropic H/V ratios.

In order to understand better the relationship between these results and the geological structures of the study areas, it will be necessary to produce numerical simulation of rotated H/V ratios, using detailed 3D structural models that includes velocity, density and Q values, to compare with the observed rotated H/V.

CONCLUSIONS

In the cities of Boconó and Trujillo, located within narrow valleys, the directions of the maximum amplifications are in most cases perpendicular or almost perpendicular to the axes of the valleys. In the city of Boconó, that is crossed by the fault of the same name, the azimuths of the maximum amplification are perpendicular or almost perpendicular to the fault, and the azimuth of the minimum amplification is almost parallel to this geological structure.

In the cities of Valera and Mérida, for most of the stations, the azimuths of the maximum and minimum amplification values are related to the geometry of the sedimentary deposits. In the city of Valera, some areas do not show a uniform orientation for the maximum and minimum amplification values; this is probably due to the complex geometry of the deposits and/or that they came from different sources. In the city of Mérida, the presence of scarps associated with the Chama and Albarregas rivers are probably the most important factors in the orientation of the maximum and minimum amplification values; some local characteristics of the scarps, such as gullies, may control of the maximum and minimum amplification.

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