Basin Thickness Characterization Applying the H/V Method in Seismic Station Data

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Abstract

The H / V method, also called the Nakamura method, is a relatively simple procedure to obtain a surface layer thickness (through seismic wave propagation). The method consists in analyzing the Fourier transform's horizontal and vertical ratio of natural passive seismic noise sources. This spectral ratio identifies a surface wave resonance frequency that depends on the thickness and impedance contrast between strata.

By this method, and using adequate inversion models, it is possible to infer the physical properties of the subsurface with good precision and low cost. This research uses data from several stations of the IAG-USP seismographic network, with special interest in stations located above the Chaco Basin.

The Geopsy free software pack was used to process the data, using filtering to eliminate instrumental tendencies as well as those of urban origin.

The curves of the ratio are specific to investigate the consistency and robustness of the resonance (fo) peaks.

The thickness of strata found were 1.6 and 3.2 km in the Chaco Basin, Argentina, and 4.5 to 3 km in the Chaco basin, Paraguay. In Taquaritinga, SP, it was not possible to obtain the resonance peak of the Paraná Basin, but only the soil layer, estimated between 3 and 9 meters.

Introduction

The H/V method is a relatively new seismic method that consists in analyzing the horizontal to vertical ratio of the seismic noise's frequency spectra in order to find resonance peaks (fo).

The information about resonance peaks were firstly used to access a site's seismic characteristics and their susceptibility to earthquake amplification due to the regional geology of the site.

After the work from Dr. Nakamura (1989) it was discovered that this information can be used to infer the sub surface's physical characteristics, such as the layer's thickness and velocities. The theory behind that, proposed by Nakamura, is that body waves are mostly compromised by Rayleight waves, that resonate inside the layer, and amplifies the wave energy in a certain frequency, creating a peak in the frequency spectrum of a noise signal.

Being a relatively new method with few examples of use in Brazilian territory, this project aims to evaluate the use of this method with seismic signal provided by the IAG-USP seismographic network.

By using this method, it will be possible to infer valuable physical characteristics of the Paraná-Chaco Basin and improve other areas related to seismology, such as epicenter localization, with low cost and considerable accuracy.

Method

The H/V method consists in calculating the seismic noise's Fourier spectra and identifying resonance peaks, those are characterized by sharp, high amplitude peaks in the spectra. Those peaks are result from the resonance of body waves, in that case mostly Rayleight waves, within sediments layers, which frequencies vary according to numerous strata characteristics. Xia et al (2016) has found that the most significant characteristics are layer thickness, S wave velocity, P wave velocity, density and the Poisson constant.

In order for the peaks to be considered as such, it's expected that those fulfill certain criteria stablished the SESAME project (2003). Those criteria help classify peaks through its shape and certain statistical characteristics, assuring its reliability and robustness.

This project uses data from several stations of the IAG-USP seismographic network. The data was collected avoiding days with seismic events or man-made seismic noise, using at least three days for each station in order to rule out any seasonal spectra variation. Each day has 24 hours of data that was processed and edited to maximize the reliability and robustness of the data.

In order to accurately estimate the basin's sediment layer thickness, it's necessary to calibrate an equation using known geological characteristics from the site. Knowing the sediment thickness in some points and calculating the resonance peaks at those points, it's possible to calibrate an empirical equation to estimate the layer thickness in the remaining site area, generally, when adjusting the plotted point to an equation, it's adjusted as h = a + fo^b, where "a" and "b" are the coeficients and "fo" is the resonance frequency

To estimate the layers thicknesses in this research, an empirical equation extracted from Dr. Ullah's doctorate thesis (2017) was used, due to the scarcity of welling data on the stations and the site's similarities shared by both this and Ullah's research site, it is as follows: h = 121,1 + fo^0,9928. Where "a" and "b" are constants found trough the calibration of the equation and "fo" is the resonance frequency.

The Geopsy software, part of the Geopsy Pack made by the Geopsy team led by Dr. Wathelet (2006) was used to calculate the spectra and estimate the resonance peaks, while the Denver software, part of the same software pack, was used to estimate the layer characteristics.

Results

The final results are presented in the table below, with the Station studied, the resonance peak (fo) the standard deviation between the three days selected, the calculated depth from the empirical formula presented in the Method section and the reference basin thickness values obtained from the CPRM (2016).

Table 1. Results obtained from the peaks found in several stations localized at the Paraná Basin.

Station	fo (Hz)	Daily Standard Deviation	Calculated Depth (m)	Thickness Paraná Basin (CPRM)
AZCA	6,86	0,208	5 +- 1	2,5 km
ESFA	0,2141	0,0026	1691+-32	2 km
TICA	0,2107	0,0012	1740 +- 500	5 km
TICA	0,6687	0,0442	248 +- 136	5 km
VACA	0,1468	0,0037	3209 +- 1128	3,5 km
VACA	0,55	0,283	345 +- 65	3,5 km
TQJ2B	8,85	0,125	3 +- 1	4,5 km
TQJ3B	5,0700	0,0960	8 +- 2	4,5 km
PAPY	0,1573	0,0035	2852 +- 264	2 km
PAPY	0,6424	0,0046	263 +- 32	2 km
FDPY	0,1255	0,0020	4179 +- 800	3 km
FDPY	0,4303	0,0124	520 +- 159	3 km

Conclusions

At the stations AZCA, TQJ2B and TQJ3B it was only possible to detect peaks corresponding to very shallow and thin layers of the subsurface, probably corresponding to the uppermost soil layer.

The ESFA station presented one single layer of 1691 meters with an uncertainty of 32 meters for more or less, close to the basin depth reference value of 2000 meters.

The TICA station presented two sediment layers, with 1740 meter with an uncertainty of 500 meters and another layer with 248 meters and an uncertainty of 136 meters, with a sediment thickness of 1988 meters with combined uncertainty of 636 meters.

The VACA station presented two layers, one with 3209 meters and an uncertainty of 1128 meters and another layer with 345 meters and uncertainty of 65 meters, totalizing a basin depth of 3554 meters with a combined uncertainty of 1264 meters.

At the PAPY station there are two layers, one layer with 2852 meters and uncertainty of 264 meters and another one with 263 meters with an uncertainty of 32 meters, those thicknesses summed are equivalent to a single sediment layer of 3115 meters and a combined uncertainty of 296 meters, above the reference basin thickness value of 2 km.

At the FDPY station there were two layers found, one with 4179 meters and another with ~520 meters, totalizing a basin depth of 4699 meters, with a total uncertainty of 959 for more or less. In this station the thickness estimation was over the reference value, in this case 3 kilometers.

Overall, it was possible to estimate relatively thick layers of sediment, for example; the thickest layer detected was over 4000 meters, and some stations presented depth values compatible to that basin.

High uncertainty values found for relatively thick layers of sediments are expected because as the peak frequencies goes lower, the more sensible the equation gets to fo variations.

It is important to remember that the equation used in this project is calibrated using another research site, and might suffer uncertainty due to the regional geological characteristics of the area used for calibration. This project researches stations far away from each other, and due to the scale of the project it is susceptible to high uncertainties.

The reference values are susceptible to uncertainties as well due to the scarcity of reference points to grid the bedrock depth map. The reference values were obtained from the CPRM map visually, which adds another layer of uncertainty.

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