Spectral analysis of seismic noise using HVSR technique

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Summary: The aim is to analyze, in the absence of seismic activity, the environmental noise detected by a seismic station (located in Gualdo in the province of Macerata equipped with an accelerometer sensor) and compare the average HVSR noise curves with the average ones related to seismic events detected in the same station during a certain time period. The noise can be divided into various types: sensor noise, natural environmental noise, anthropic noise, microseismic noise. In this study we want to analyze both the noise and the seismic events in the frequency domain to understand if it is possible to extrapolate useful information, from the seismic noise recording acquired by accelerometer rather than by velocimeter, in order to determine sensor's limits.

Keywords: seismic noise, microtremor, microseisms, ambient vibrations, H/V, HVSR

1. Introduction

Seismic noise is any kind of seismic signal not generated by an earthquake and whose presence can alter the recording of a seismic event. The seismic noise is a stochastic stationary process rapidly varying over time: it can change from site to site and depends on many factors; for example, the noise generated by the wind is broadband and usually goes from 0.5 Hz to 15 Hz [1] while high-frequency sources are typically due to anthropic noise. In the presence of localized noise sources, the amplitude of the horizontal components is typically higher with respect to the vertical component.

The statistical variability of the Power Spectral Density (PSD) is studied to identify the main causes of noise at the recording sites (assessing possible variations during the day) to determine the noise characteristic levels. In fact, studying the noise is also useful to obtain information on the detention thresholds of seismic events (in early warning systems the parameters are set, based on the noise, to detect better the seismic activity respect false positive). In microseismic noise evaluation, velocimeters are more sensitive than the accelerometers and therefore they are used to detect the fundamental frequency of a site.

A method for microzonation rather popular and convenient in terms of costs/benefits is based on the Nakamura technique that estimate the fundamental frequency evaluating the peak in the ratio of power spectral density of the horizontal component to the vertical component [2]. This technique is extremely advantageous because it allows the evaluation of the site response without the need to have a reference spectrum and the possibility of eliminating the effects of instrument responses.

Among seismic surveys, those based on the acquisition and analysis of environmental seismic noise or the continuous vibration of the soil due to both anthropic and natural causes are becoming increasingly important, very useful for a rapid identification of the seismic substrate. These types of techniques (defined as passive seismic methods) do not need any external energization because they use vehicle traffic, industrial production, wind, rain and all that can produce a minimal vibration on the source soil surface. Moreover, is totally non-invasive, very fast, applicable everywhere, low cost and not requires drilling. Using SSR (Standard Spectral Ratio) [3], it is possible to determine the amplification of the spectral components of the horizontal motion of a site with respect to a reference one; but this technique require a reference site where the site effects are absent (identify and separate the source from site effects is the main impediment encountered in spectral analysis). For these reasons other techniques should be investigated.

2. Method and Materials

The HVSR method (Horizontal to Vertical Spectral Ratios called also simply H/V), or Nakamura technique, is used to study the site response. When the HVSR technique is applied to seismic noise, often are used terms as HVSRN or NHVSR (Noise Horizontal Vertical Spectral Ratio). This passive HVSR method is known in literature as "Single Station" and it is defined as the ratio between the PSD spectral amplitudes of the horizontal components (mediating the two axes) and the PSD spectral amplitudes of the vertical component of the motion [2] [4].

The HVSR technique, applied for the first time by [5] to seismic recordings (taking only S-waves), is based on the fundamental assumption that the vertical component of the ground motion is not influenced by the amplification effect caused by the trapping of seismic waves in the surface layer. Furthermore, the HVSR method can carry out measurements on an aseismic area using only seismic noise [6].

The most important parameter for a good NHVSR acquisition is the recording time: the more you have a noisy environment (e.g. heavy road traffic in the vicinity, bad weather conditions, presence of industries etc.) and the longer the duration of the registration to be made.

The nature of the seismic noise wave is approximately the same as the propagation of surface waves [13] [14], a close relation exists between H/V spectral ratio and the ellipticity of the Rayleigh waves, which dominate the seismic noise.

3. Signal Processing

For the environmental noise processing, a total time duration of 10 hours was used (equal to 3.600.000 samples) and a window width of 100 s (equal to 10.000 samples), allowing 360 windows to be obtained, with data acquired at a sample frequency fs = 100 Hz.

In general, since the frequencies of engineering interest of the seismic and microseismic action do not exceed 25 Hz, the sampling frequency must not be less than 50 Hz (for the Nyquist-Shannon theorem). For the H/V technique it is also disadvantageous to use sample frequencies higher than 500 Hz, as they involve a considerable increase in the size of the files and consequently of processing times, without substantial improvements in the capacity or accuracy of the analysis. The duration of the acquisition window must be such as to characterize the natural frequency of interest. Therefore, if we have an idea of the first fundamental frequency value, then we can choose a window more appropriate; if instead this value is completely unknown, we will have to put ourselves in the most general conditions (that means to choose a greater window width to include the dynamics of the lower frequencies) [7].

The programming language, used to implement the different elaborations, is Matlab. It allows to display the trace, the PSD, the PSD mean, the Peterson reference noise curves [8] and the spectral ratio between the horizontal and vertical component. Noise acquisitions are analyzed in absence of seismic activity to study the noise level of the environment and the site response. These are the steps that characterize the noise analysis:

1. The 3 components of the seismic noise (acquired by accelerometer sensor [9], EpiSensor ES-T) are loaded and the mean is removed
2. A band pass filtering is carried out corresponding to the frequency range of interest (0.2-20 Hz)
3. The seismic noise is acquired using 100 s windows
4. A 10% cosine tapering is applied for each window to reduce the leakage phenomenon in frequency domain
5. In each window the PSD is calculated for both the horizontal acceleration components and for the vertical component
6. The 3 components are smoothed using Konno-Ohmachi smoothing function [10] (with parameter b = 40). It represents a "smoothing" of the amplitude spectrum to reduce stochastic variability in the estimation of spectral amplitude
7. The quadratic mean is applied to the horizontal components [11] [12] in order to obtain a single mean value
8. The H/V value is calculated for each window dividing the smoothed quadratic mean horizontal component PSD for smoothed mean PSD vertical component
9. The H/V mean is determined by averaging the total number of windows (H/V mean or HVSR mean)
10. The Konno-Ohmachi smoothing function is applied again to smooth out the obtained ratio. In Fig.1. is represented a Konno-Ohmachi smoothing with b=40 while in Fig.2. with b=20 (to better reduce the variations).

A similar procedure is applied to 30 earthquakes signals recorded in the same station, taking a time window of 100 s that include the event. So, in the first H/V mean signal the on-site response is only due by the mean noise acquired, while in the second H/V mean signal the on-site response is due by the mean noise signal plus mean earthquake signal.

4. Results

In Fig.1. and Fig.2. there is a comparison obtained analyzing the H/V mean smoothed earthquake signal and the H/V mean smoothed noise signal, acquired in the same station. The useful range represented is between 0.2 Hz and 20 Hz (frequency range of interest for seismic microzonation and earthquake engineering).

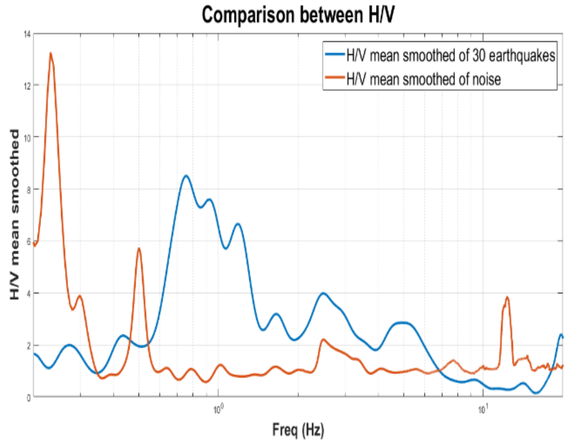

Fig. 1. H/V mean smoothed: comparison between seismic noise and earthquakes signal. With Konno & Ohmachi parameter b=40.

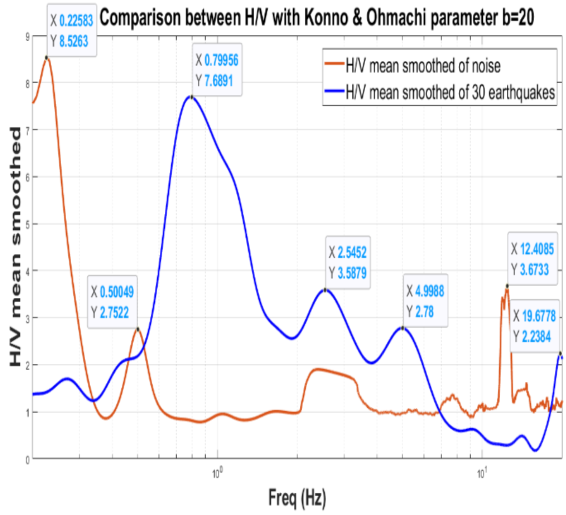

Fig. 2. H/V mean smoothed: comparison between seismic noise and earthquakes signal. With Konno & Ohmachi parameter b=20.

In Fig.3. and Fig.4. there is a comparison obtained analyzing elaborated PSD noise signal about horizontal and vertical components with the noise reference curves defined by Peterson [8]: New Low Noise Model (NLNM) and New High Noise Model (NHNM). These curves have unstable and sudden variations under 2 Hz, so it is no easy to obtain a very accurate information when H/V is calculated. As shown in Fig.3. and Fig.4., the noise acquired by the sensor reflects the Peterson noise curves in the range of interest. There is more noise concentrated about 2.5 Hz in horizontal and vertical axes and between 10 Hz and 15 Hz.

In Fig.5. is shown the PSDxy mean smoothed calculated on 30 earthquakes; the main frequency content for the horizontal component, is between about 0.74 Hz and 1.78 Hz and decrease towards the high frequencies.

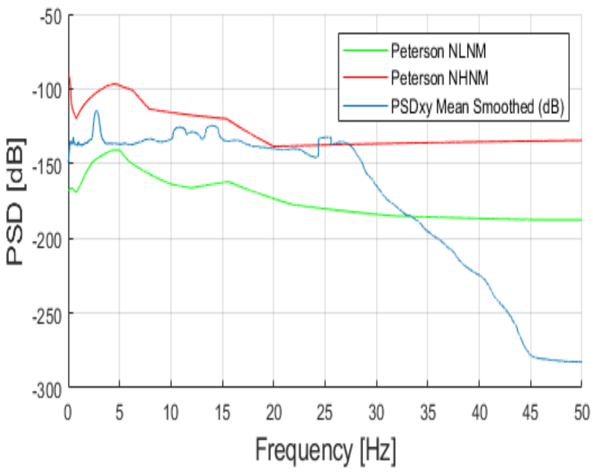

Fig. 3. Comparison between mean smoothed PSD of seismic noise (quadratic mean of horizontal components) and Peterson curves

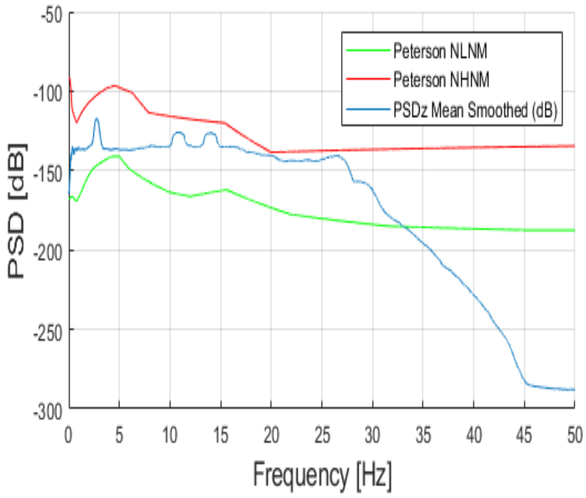

Fig. 4. Comparison between mean smoothed PSD of seismic noise (vertical component) and Peterson curves

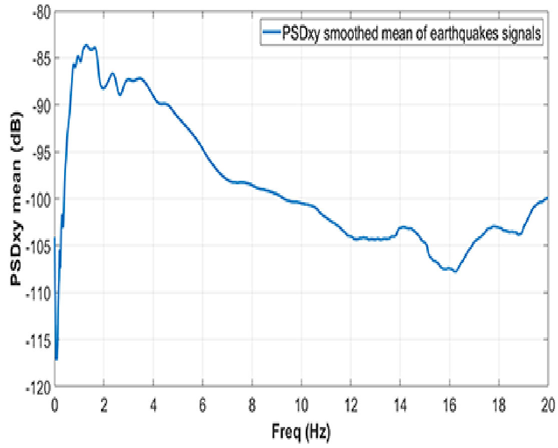

Fig. 5. PSD mean smoothed of seismic earthquakes of horizontal components

5. Conclusions

HVSR technique is used to compare the environmental noise in absence of seismic activity with the recordings related to seismic events detected in the same station. The results show that H/V curves, which hypothetically contain the current site response (Fig.1. and Fig.2.), are different. It is not clear what the peaks at 0.22 Hz, 0.50 Hz and 12.4 Hz in the HVSRN curve are due to; it requires more investigation.

In Fig.1. both curves have a centered bell around 2.5 Hz. It can be expected that this is the first fundamental frequency of the site (visible in Fig.1. and Fig.2., in both curves) because the station data acquired by INGV (National Institute of Geophysics and Volcanology) shown a site effect between 1.5 Hz and 3.5 Hz (typically 2 Hz).
Other significant peaks but with a reduced amplitude are about 5 Hz and 19.7 Hz. The mean earthquake waves effect is clearly visible in Fig.2. at 0.8 Hz.
So, analyzing only HVSRN seems that is possible to extrapolate information about the site fundamental

frequency, but it is necessary to understand what the other peaks represent.

With the technology advancement and costs reduction more efficient accelerometer sensors will be produced to provide accurate data from a registration site. In future developments it would be interesting to investigate about these results and compare the obtained information with a velocimeter data analysis on the same site.

Spectrogram analysis is useful to identify the noise sources. Once the causes have been identified, the objective will be to reduce the noises.

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References

[1]. M. M. Withers, R. C. Aster, C. J. Young, E. P. Chael, High-frequency analysis of seismic background noise as a function of wind speed and shallow depth, *Bulletin of the Seismological Society of America*, Vol. 86, Issue 5, 1996, pp. 1507-1515.

[2]. Y. Nakamura, A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Railway Technical Research Institute, Quarterly Reports*, Vol. 30, Issue 1.

[3]. R. D. Borcherdt, Effects of local geology on ground motion near San Francisco Bay, *Bulletin of the Seismological Society of America*, Vol. 60, Issue 1, 1970, pp. 29-61.

[4]. J. Lermo, F. J. Chavez-Garcia, Site effect evaluation using spectral ratios with only one station, *Bulletin of the seismological society of America*, Vol. 83, Issue 5, 1993, pp. 1574-1594.

[5]. H. Cruz-Jiménez, F. J. Chávez-García, T. Furumura, Differences in attenuation of ground motion perpendicular to the mexican subduction zone between Colima and Guerrero: An explanation based on numerical modeling, *Bulletin of the Seismological Society of America*, Vol. 99, Issue 1, 2009, pp. 400-406.

[6]. M. Fazlavi, E. Haghshenas, Importance of mode detection in ambient noise array application for shear wave velocity profile determination, *International Journal of Civil Engineering*, Vol 13, Issue 1, 2015, pp. 62-72.

[7]. E. Haghshenas, P. Y. Bard, N. Theodulidis, Sesame WP04 Team, Empirical evaluation of microtremor H/V spectral ratio, *Bulletin of Earthquake Engineering*, Vol. 6, Issue 1, 2008, pp. 75-108.

[8]. J. R. Peterson, Observations and modeling of seismic background noise. *US Geological Survey,*, 1993.

[9]. P. Pierleoni, S. Marzorati, C. Ladina, S. Raggiunto, A. Belli, L. Palma, M. Cattaneo, S. Valenti, Performance Evaluation of a Low-Cost Sensing Unit for Seismic Applications: Field Testing During Seismic Events of 2016-2017 in Central Italy, *IEEE Sensors Journal*, Vol 18, Issue 16, 2018, pp. 6644-6659.

[10]. K. Konno, T. Ohmachi, Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor, *Bulletin of the Seismological Society of America*, Vol. 88, Issue 1, 1998, pp. 228-241.

[11]. D. Albarello, E. Lunedei, Combining horizontal ambient vibration components for H/V spectral ratio estimates, *Geophysical Journal International*, Vol. 194, Issue 2, 2013, pp. 936-951.

[12]. B. C. Sylvette, C. Cécile, B. Pierre-Yves, C. Fabrice, M. Peter, K. Jozef, D. Fäh, H/V ratio: a tool for site effects evaluation. Results from 1-D noise simulations, *Geophysical Journal International*, Vol. 167, Issue 2, 2006, pp. 827-837.

[13]. K. Irikura, T. Kawanaka, Characteristics of microtremors on ground with discontinuous underground structure, *Bulletin of the Disaster Prevention Research Institute*, Vol. 30, Issue 3, 1980, pp. 81-96.

[14]. P. Guéguen, C. Cornou, S. Garambois, J. Banton, On the limitation of the H/V spectral ratio using seismic noise as an exploration tool: application to the Grenoble valley (France), a small apex ratio basin, *Pure and applied geophysics*, Vol. 164, Isuue 1, 2007, pp. 115-134.