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Seismic Noise and Site Response Analysis Using Accelerometer Sensors

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Abstract: We present an analyse of the environmental noise in absence of seismic activity detected by a seismic station (located in Gualdo in the province of Macerata equipped with two type of accelerometer sensors) and compare the average H/V noise curves with the results obtained using a velocimeter. The noise can be divided into various types: sensor noise, natural environmental noise, anthropic noise, microseismic noise. In this study we want to analyse the noise in frequency domain acquired by different sensors 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 the sensor's limits.

Keywords: Seismic noise, Microtremor, Accelerometer, 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 (Fig. 1) 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 seismic noise manifest as micro-vibrations that are acquired along the three axes by the sensor and that are visible if the acquisition system produce a noise lower than the seismic noise amplitude in the range of interest.

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. For this reason, in this analysis a velocimeter is used as reference.

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 for a rapid identification of the seismic substrate.

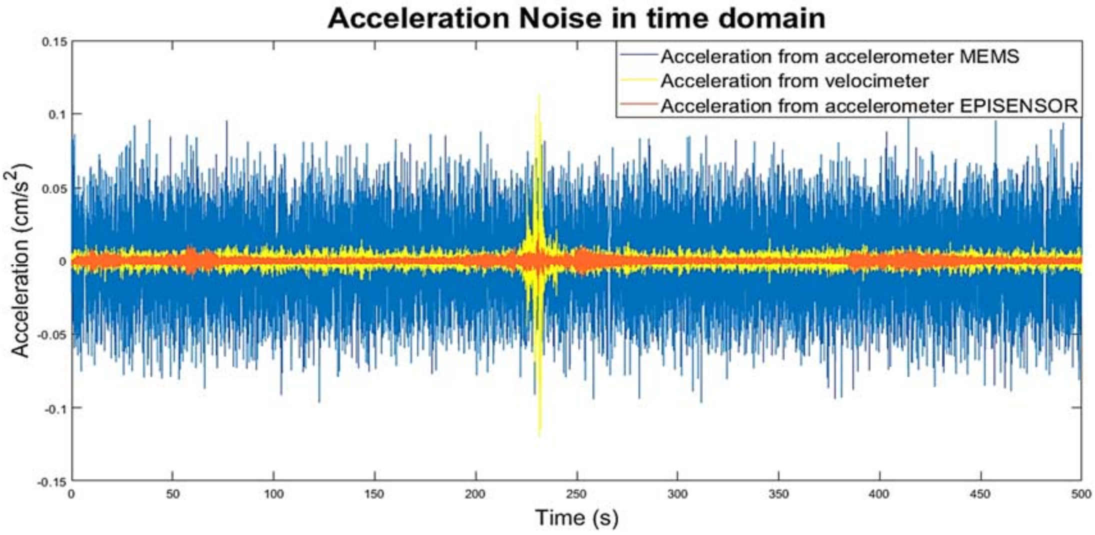

Fig. 1. Comparison between seismic noise accelerations (this is only one horizontal axis).

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 [4].

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), otherwise if it is applied to the seismic events EHVSR (Earthquake Horizontal Vertical Spectral Ratio) term is used. 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 (1)) and the PSD spectral amplitudes of the vertical component of the motion [2, 5]. The HVSR technique is also useful to study the soil response during earthquake events and was applied for the first time to seismic recordings by [6] (taking only S-waves). This technique 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 [4, 7].

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 [8-9] and a close relation exists between H/V spectral ratio and the ellipticity of the Rayleigh waves, which dominate the seismic noise.

The accelerometers used and compared in this analysis are:

- EpiSensor model FBA ES-T (external triaxial sensor) consists of three orthogonally mounted force balance low-noise accelerometers (FBAs) inside a sensor casing. EpiSensor is a triaxial accelerometer (X-axis, Y-axis and Z-axis) optimized for earthquake recording applications with high-performance, high-dynamic instrument (155 dB dynamic range), full g-scale range from ±0.25 to ±4 g (user selectable). The implemented technology allows to have very low self-noise, low non-linearity (<1000 µg/g^2), low hysteresis (<0.1 % of full scale), low cross-axis sensitivity (<1 %), and low thermal drift (<500 µg/°C) [12].

- Safran Colibrys model VS1002 capacitive MEMS accelerometer is used in order to measure seismic events in a three-dimensional space (3 Colibrys are positioned orthogonally to each other). The implemented technology allows to have a noise of 7 $g/\sqrt{Hz}$ in band, non-linearity < 0.1 % at full scale, full scale acceleration range of ±2 g, large and flat frequency response (±5 %) from DC to 700 Hz [12].

3. Signal Processing

The noise processing is made on data recorded from 1 March 2017 at 00:00:

- For the accelerometer a time span of nw=30 minutes (equal to 360.000 samples) and a window width of 100 s (equal to 20.000 samples) was used to calculate each H/V, obtaining n=18 windows with data acquired at a sample frequency fs = 200 Hz. Then the total average H/V is calculated using m=24 windows and a total time span equal to mw=12 hours (Fig. 2, Fig. 3, Fig. 4).
- For the velocimeter a time span of nw=60 minutes (equal to 360.000 samples) and a window width of 100 s (equal to 10.000 samples) was used to calculate each H/V, obtaining n=36 windows with data acquired at a sample frequency fs = 100 Hz. Then the total average H/V is calculated using m=24 windows and a total time span equal to mw=24 hours (Fig. 2, Fig. 5).

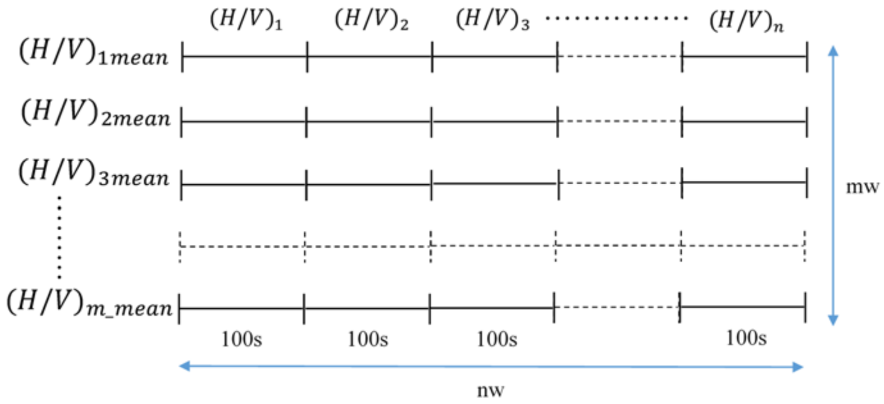

Fig. 2. Representation of H/V time intervals. H/V is calculated for each 100 s window. The mean is calculated for each row and then the total H/V average is calculated.

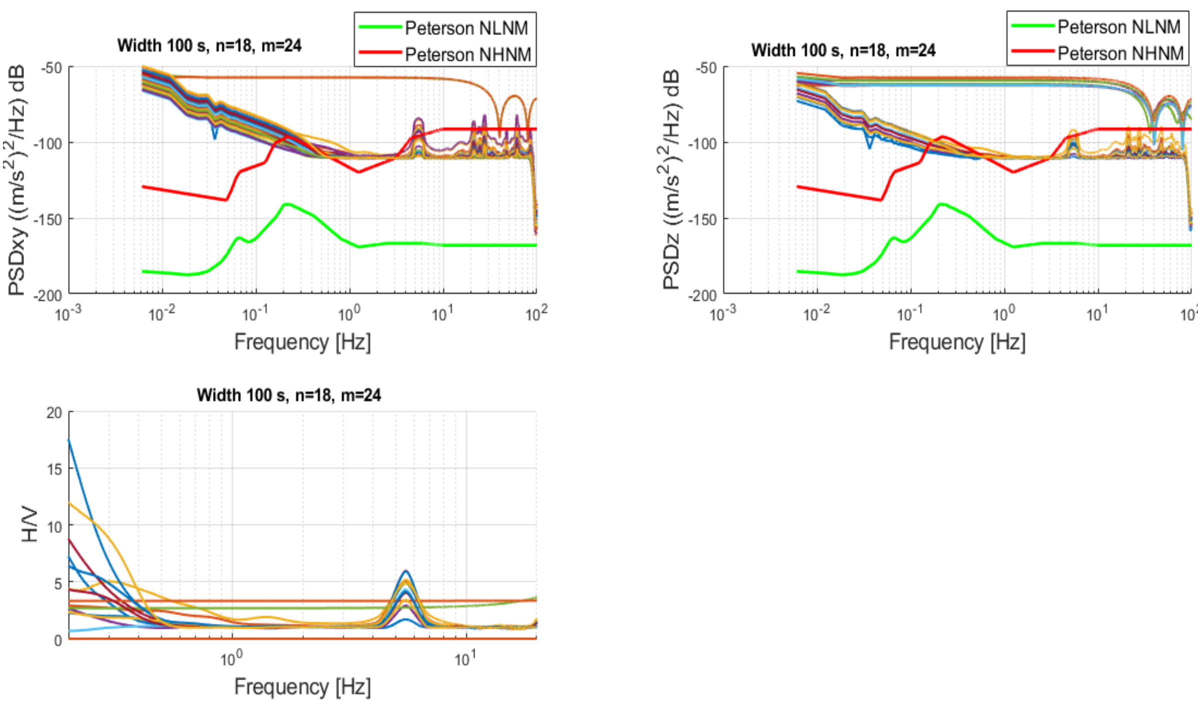

Fig. 3. Results using Safran Colibrys. PSDxy is the power density spectrum of horizontal components Hxy while PSDz of the vertical component.

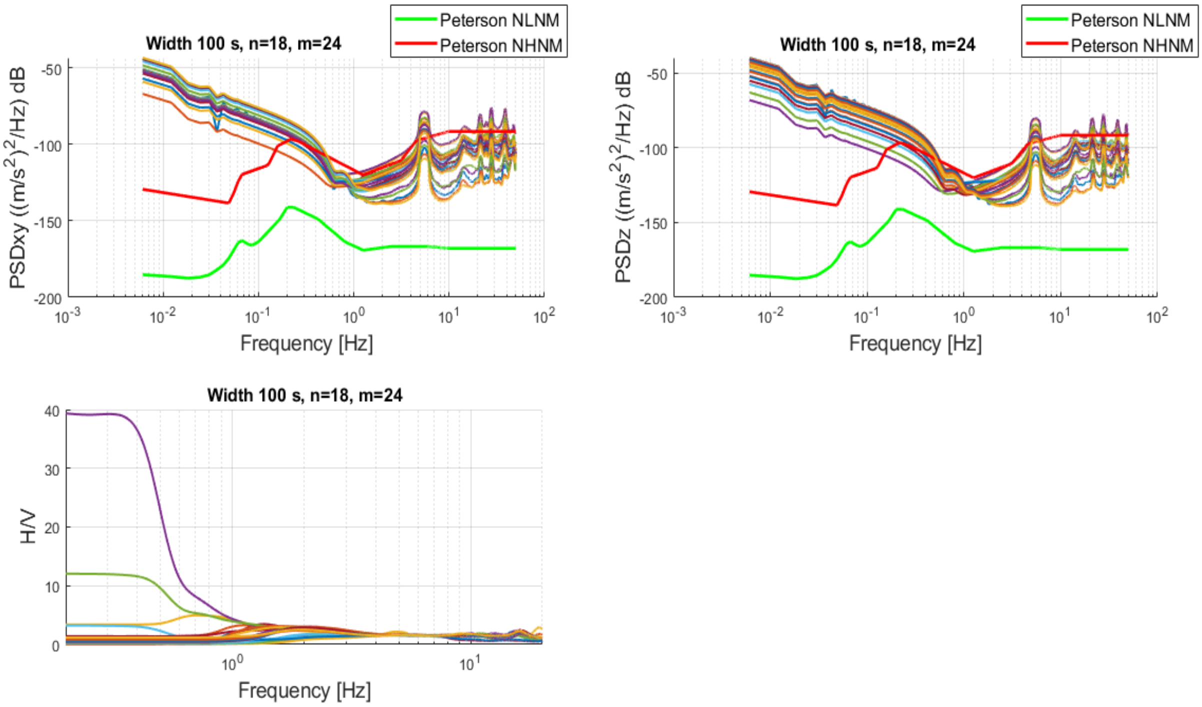

Fig. 4. Results using Episensor.

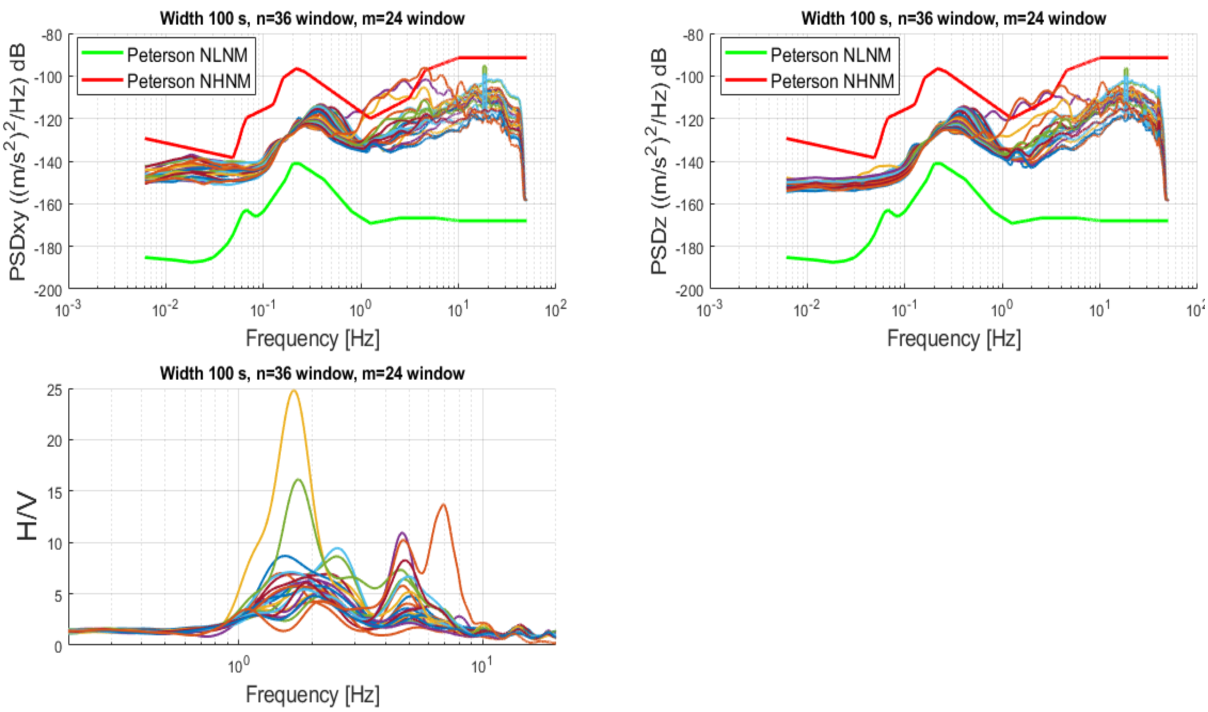

Fig. 5. Results using velocimeter.

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) [10].

As explained before in this analysis are used two type of accelerometers (with different features) and a velocimeter as reference to compare the results. In Fig. 1 shows, in time domain, the superimposed accelerations of one horizontal axis to see the amplitude difference (the acceleration of the velocimeter was obtained by deriving the velocity data). As expected, the noise is greater in MEMS accelerometer while for the Episensor and velocimeter the levels are similar (when no particular peaks of noise are present).

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 [11] 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 [4]:

1) The 3 components of the seismic noise 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). In the next graphs the filter is not applied to see the noise levels difference in a greater range.

3) The seismic noise is acquired using 100 s windows (Fig. 2.)

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 [13] (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 [14-15] in order to obtain a single mean value (1):

$$H_{xy} = \sqrt{\frac{H_x^2+H_y^2}{2}}, \qquad (1)$$

where H_x means the East-West component and H_y the North-South component.

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) spanning a total time of nw (Fig. 2).

10) The Konno-Ohmachi smoothing function is applied again to smooth out the obtained ratio with b=20 (to better reduce the variations).

11) The total average H/V is calculated spanning a total time of mw (Fig. 2).

A typical threshold value used in literature to consider a peak on the H/V curves is H/V=2.

4. Results

In Fig. 3, Fig. 4 and Fig. 5 are represented the analysis in frequency domain (the H/V curves are used then to obtain Fig. 6, Fig. 7, Fig. 8). In Fig. 3 is possible to see that until 3 Hz the noise in quite high compared to the NHNM Peterson curve. So, we expect that until 3 Hz is difficult to have any information about the site response because it is masked by the sensor noise. Between 3 Hz and 20 Hz the noise is quite normal, respect the Peterson curve, but with a bell around 5.5 Hz. Then, above 20 Hz the variations are outside the range of interest for site the response so we may not consider it. Are present also some very noisy curves that deviate sharply from the others and this could depend on some peaks of noise whose causes should be investigated.

In Fig. 4 the results are better, we expect that until 0.5 Hz is difficult to have information about the site response because they are masked by sensor noise (against the 3 Hz of the previous sensor). Also here at 5.5 Hz a bell is present in the PSD curves. In Fig. 5 the velocimeter results are better compared to the two previous cases.

In fact, there the noise is under the NHNM Peterson curve in the entire range and the differences between H/V curves are less.

5. Conclusions

From H/V of Fig. 3, Fig. 4 and Fig. 5 is possible calculate the average H/V where we can do the final consideration (Fig. 6, Fig. 7, Fig. 8). In Fig. 6 there is a small bell with a small peak at 5.5 Hz (the initial peak is not considered because the sensor is too unstable and not sensitive enough at very low frequencies, so the electronic noise produces large artificial amplitude in the H/V graphs).

In Fig. 7 there is a small peak at 2 Hz and another peak a 14.7 Hz (which is much smaller in the other curves) where is present a greater dispersion.

In Fig. 8 the curve is more reliable and average H/V have a peak about 1.8 Hz (the first resonance frequency) and 4.8 Hz (the second resonance frequency). The dispersion is greater between about 0.9 Hz and 9 Hz. The result obtained is very similar to the one provided by the INGV for the same station

(Fig. 9). In conclusion the accelerometers do not show sufficiently reliable and consistent results respect the velocimeter [16]. It would be interesting to repeat the same procedure on other days and other sites to obtain further confirmation. The other result from frequency analysis is that the Episensor accelerometer is better than Colibrys.

With the technology advancement and costs reduction more efficient accelerometer sensors will be produced and used to provide accurate data from a registration site together with the development of other different techniques to try to determine the site response. The use of the velocimeter remains of fundamental importance in the analysis of the seismic noise and site response.

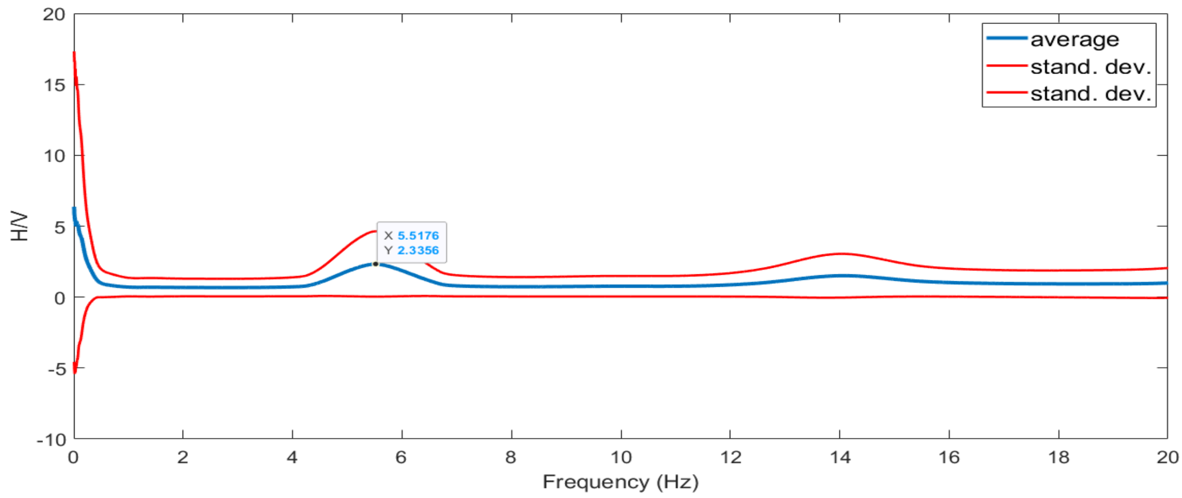

Fig. 6. Final results: H/V average and standard deviation of Colibrys accelerometer, total time span 12 hours.

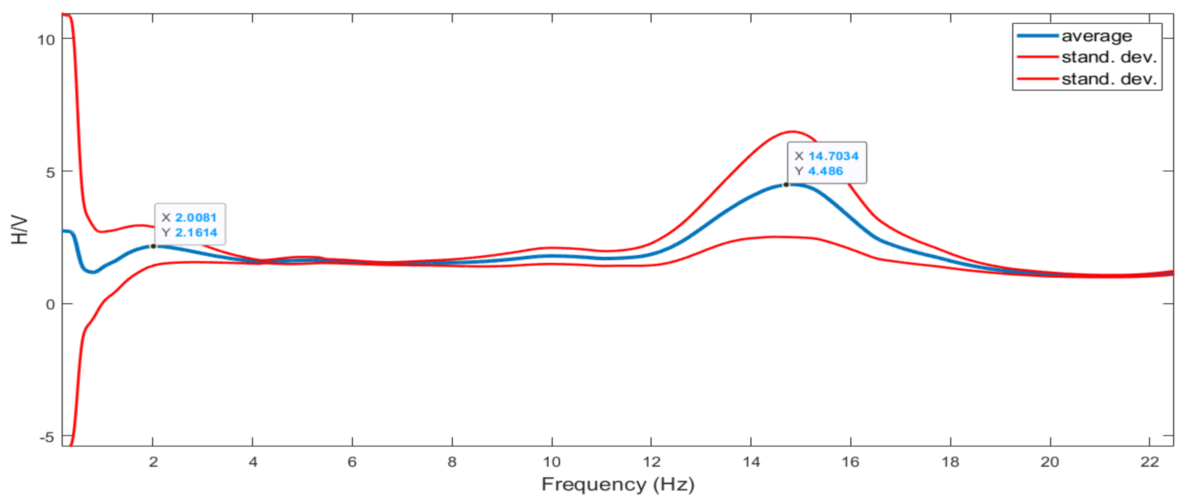

Fig. 7. Final results: H/V average and standard deviation of Episensor accelerometer, total time span 12 hours.

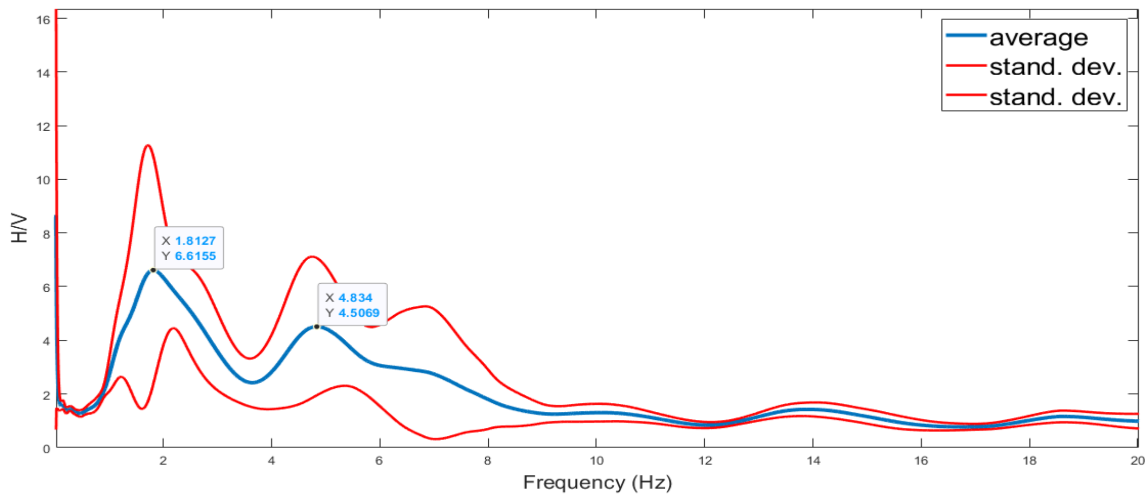

Fig. 8. Final results: H/V average and standard deviation of velocimeter, total span 24 hours.

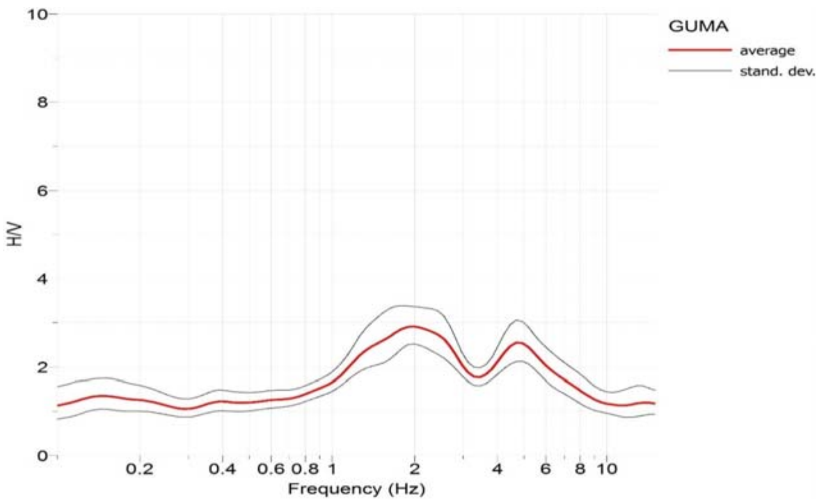

Fig. 9. Results obtained by INGV for the same station using a velocimeter but with different data and different software. This data is available in INGV website for GUMA station.

The knowledge of the resonance frequency of a soil, coupled to the information about the predominant period of a structure can give a reliable idea of potential damages that we can expect for a site in case of an earthquake. And this is of fundamental importance to reduce the effects that the earthquakes have on public and civil structures.

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