Bull Earthquake Eng
DOI 10.1007/s10518-007-9040-7

ORIGINAL RESEARCH PAPER

Evaluation of the influence of experimental conditions on H/V results from ambient noise recordings

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Received: 22 May 2006/Accepted: 17 May 2007

Abstract The H/V-noise technique is now widely used to estimate site effect parameters (fundamental frequency and sometimes the associated soil amplification), and many surveys using this technique have provided convincing results. However, a general agreement on a methodology for data acquisition, data processing and result interpretation has yet to be found. H/V measurements from ambient noise recordings imply both reliability of the results and rapidity of data collection. It is therefore important to understand which experimental conditions (1) influence data quality and reliability, and (2) can help speeding up the recording process. Within the framework of the SESAME European project, a specific task was defined to investigate the reliability of the H/V spectral ratio technique in assessing the site effects. The aim of WP02, one specific Work Package of the SESAME project, is to study the effects of experimental conditions on both stability and reproducibility of H/V results. This study has been conducted in a purely experimental way, by testing the possible influence of various experimental conditions on H/V results both on the frequency peak value and on its ampli-

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tude. WP02 results help setting up the experimental conditions under which ambient noise recordings have to be performed in order to provide reproducible, reliable and meaningful H/V results. In this paper we present the results of the WP02 SESAME project concerning the evaluation of the influence of experimental conditions of ambient noise recording on H/V results.

Keywords Microtremor · Site effects · Field conditions · Measurements

1 Introduction

The H/V-noise technique (Nakamura 1989) is now widely used to estimate site effect parameters (fundamental frequency and sometimes the associated soil amplification), and many surveys using this technique have provided convincing results (see Bard 1999, for a review). However, a general agreement on a methodology for data acquisition, data processing and result interpretation has yet to be found.

H/V measurements from ambient noise recordings imply both reliability of the results and rapidity of data collection. It is therefore important to understand which experimental conditions (1) influence data quality and reliability, and (2) can help speeding up the recording process.

H/V measurements in cities are conducted within the following context:

(a) it is quite rare to be able to get data directly on the ground per se. Most data will be obtained on streets (i.e., asphalt, or pavement), sidewalks (i.e., asphalt, cement or concrete), and to a lesser extent in parks (i.e., on grass or ground);
(b) recordings are performed in an environment dominated by buildings of various dimensions, other devices such electric poles, and where trees can also be encountered;
(c) recordings are performed next to transients such as cars, trucks, tramways, trains, pedestrians and various source points of ambient noise from works, machineries, etc.;
(d) recordings, often, are not performed at the same time and under the same weather conditions.
Therefore, the estimation of the possible influence of asphalt, grass, cement and concrete interfaces, of nearby buildings, of weather conditions and stability of the results over time are crucial issues for data quality and reliability. It is also crucial to make sure that the results are not equipment dependent.

Rapidity of data acquisition, besides the duration of recording, is mainly dependent on the sensor* setting and recorder parameterization. It is also sometimes useful to use an artificial interface, such as a plate, to help installing the sensor (on a slope, in soft soil, ...). It is therefore also important to test the possible influence of the experimental conditions and recording set-ups.

However, only very few studies have dealt with evaluating the influence of experimental conditions on H/V results from ambient noise recordings and are always concerned with only some of the experimental conditions or stability of H/V over time (Mucciarelli 1998; Mucciarelli et al. 2003; Cara et al. 2003; Volant et al. 1998; Mucciarelli and Monachesi 1998; Bour et al. 1998; Whiters et al. 1996).

A European project, Site EffectS assessment using AMbient Excitations (SESAME) (Bard 2002; Bard and the SESAME team 2003; SESAME Project 2002, 2003), was launched in 2001 aiming to study the site effects assessment techniques using ambient vibrations. Twelve work packages (WP) were defined to carry out this project. Within the framework of this project, a specific task was defined to investigate the reliability of the H/V spectral ratio technique in assessing the site effects. The work has been conducted in mainly three different lines with the following objectives: (1) to study the effect of the experimental conditions, (2) to find out the influence of the data processing and (3) to compare the results from different techniques and data sets to empirically assess the reliability of its usage in microzonation studies. The final goal is to provide guidelines explaining the influence of different factors, and give recommendations on how the H/V technique should be applied. As the project is now finished, such documentation is finalized.

The aim of WP02, one specific Work Package of the SESAME project, is to study the effects of experimental conditions on both stability and reproducibility of H/V results. This study has been conducted in a purely experimental way, by testing the possible influence of various experimental conditions on H/V results both on the frequency peak value and on its amplitude. WP02 results help setting up the experimental conditions under which ambient noise recordings have to be performed in order to provide reproducible, reliable, and meaningful H/V results.

In this paper we present the results of the WP02 SESAME project concerning the evaluation of the influence of experimental conditions of ambient noise recording on H/V results.

2 Experimental conditions

2.1 Experimental conditions to be tested

The experimental conditions tested in this study are grouped in nine families, termed P1–P9.

Two types of experimental conditions can be distinguished:

- conditions related to the characteristics of the site itself and/or to the instrumentation:
  P1: Instrument and recording parameters
  P2: In situ soil-sensor coupling
  P3: Modified soil-sensor coupling
  P4: Nearby structures (trees, poles, houses, buildings . . .)
  P5: Underground structures (cave, subway line . . .)
- conditions related to the variation of external conditions at the same place:
  P6: Weather
  P7: Water table
  P8: Time (day, night, repetition over various periods of time from days to years . . .)
  P9: Noise sources (cars, pedestrians, trains . . .).

In order to draw general conclusions for all these tests one should perform the tests on sites with different characteristics. In that aim, for each of them we distinguished four families of sites, according to their fundamental frequency (f_0):

- $f_0 \leq 1$ Hz: low frequency site (LF);
- $1\,\text{Hz} < f_0 \leq 5$ Hz: medium frequency site (MF);
- $f_0 > 5$ Hz: high frequency site (HF);
- flat curve without identifiable peak: “no peak”, or flat site (NP).

2.2 Recording conditions

For the first series of experimental conditions (P1–P5) the experiments consisted in comparing a reference recording to a test recording, with only one change in the recording conditions tested at a time. It was recommended to perform the two recordings at the same time, or at least immediately one after another, the two recordings being separated by a time lag roughly corresponding to the recording duration. We tried our best to perform at the same place on each of the four types of site with the reference recordings completed with the same recording parameters (gain, sampling rate, length of recording).

The recordings of the reference and tested experimental condition of the second series are performed at the same place, but obviously not at the same time.

The recording duration has been fixed to 15 min, and the acquisition sample rate from 100 to 200 Hz.

2.3 Equipment

Various teams of the SESAME project performed the tests with the following recorders:

CityShark (Chatelain et al., 2000), CityShark II, Mars Lite, Hathor3, Mars 88, Reftek, and Geosig GBV316, and the following sensors:

Five-second Lennartz, 4.5-Hz Mark Products L-28, 20-s Lennartz, 1-Hz Lennartz LE-3D Lite, 2-Hz Mark Products L22, 1-Hz Mark Products L4-3D, Guralp CMG40, and a 4.5 Hz built-in sensor with the Geosig recorder.

3 Data processing

For each tested experimental condition, H/V are computed for both the reference and the tested condition. The results are the averages of H/V amplitudes and their corresponding standard deviations. A Student-*t* test is then performed to analyze the degree of similarity between the two curves. Finally, the average frequency and standard deviation from individual windows of the two frequency peaks are computed.

At the time of the analysis, no stable complete JSESAME H/V package (now freely downloadable from the SESAME website http://sesame-fp5.obs.ujf-grenoble.fr/) was available, and comparison between two data sets was not planned to be developed as part of this package. However, the processing routines used in this study are the ones on which the JSESAME package has been built. The only differences between the software used in this study and the JSEAME software are (1) the user's interface, and (2) the output of a technical card (described in a following section) to allow the comparison between the results from the reference and the tested condition. Later comparisons between the two program outputs showed that both programs give identical results.

3.1 Windowing parameters

H/V computation is performed only on the stable windows of the signal, which are detected using an anti-trigger system with the following parameters, as recommended in the SESAME user manual (http://sesame-fp5.obs.ujf-grenoble.fr/):

- STA: 1 s
- LTA: 30 s
- STA/LTA min.: 0.3
- STA/LTA max.: 2
- Window length: a minimum window length of 25 s is entered and the program is looking for stable windows of this length up to the next power of 2 of the number of samples. The window length can therefore vary from 25 s to 32.76 (for data acquisition sample rates

of 62.5, 125, 250 Hz) or 40.96 s (for data acquisition sample rates of 50, 100, 200 Hz). Window overlapping is not used.

When the experimental condition to test is composed of perturbations in the signal (e.g., transients), in order for the program to keep and process the windows where the perturbations occur, the anti-trigger has been artificially deactivated by using the following windowing parameters:

- STA/LTA min. = 0.01
- STA/LTA max. = 10

These changes were applied to the processing of the tests P1-3, P9-1, P9-2, P9-3, P9-4, P9-6, and P9-7 described in the next section.

It should be noticed however that Parolai and Galiana-Merino (2006) question the need of using an anti-trigger algorithm to select stable windows to get rid of transients, which have not always significant effects on H/V results. This point is also discussed further in the paper.

3.2 H/V computation

H/V computation is performed through the following steps:

1. Offset removal: the mean of the entire recorded signal is deducted from each sample value.
2. Stable signal windows are selected, as described in the previous section, and processed one by one:
   - a cosine tapering with a length of 5% is applied on both side of the window signal of the vertical (V), North–South (NS) and East–West (EW) components;
   - a FFT is applied to the signal of the three components to obtain the three spectral amplitudes;
   - a Konno and Ohmachi (1998) smoothing, with a bandwidth parameter of 40 and arithmetical average, is applied to the three spectral amplitudes;
   - H/V is computed by merging the horizontal (NS and EW) components with a quadratic mean $\mathrm{H} = \sqrt{\frac{\mathrm{NS}^2+\mathrm{EW}^2}{2}}$.

   Thus, for each of the n_{windows} windows the distribution of $\log_{10}(\mathrm{H/V})$ is obtained as a function of the frequency.
3. The geometric mean of H/V is calculated:
   - H/V is averaged over all selected windows: $\mathrm{H/V}_{\text{average}} = \frac{\sum \log_{10}(\mathrm{H/V})}{\mathrm{n}_{\text{windows}}}$.
   - H/V standard deviation is calculated: $\sigma_{\mathrm{H/V}} = \sqrt{\frac{\sum \log_{10}^2(\mathrm{H/V}) - n_{\text{windows}} \times \log_{10}^2(\mathrm{H/V}_{\text{average}})}{(n_{\text{windows}}-1)}}$.
4. $\mathrm{H/V}_{\text{average}}$ and $\sigma_{\mathrm{H/V}}$ are set back to a linear scale by calculating $\overline{\mathrm{H/V}} = 10^{\mathrm{H/V}_{\text{average}}}$ and $\sigma_{\overline{\mathrm{H/V}}} = 10^{\sigma_{\mathrm{H/V}}}$

3.3 Similarity between the reference and tested experimental conditions

In order to evaluate the effect of a given change in the recording experimental condition the H/V results of the reference and the tested recording condition have to be compared. This comparison has to be made in an objective way, i.e., with the use of a statistical method. It has been decided to use the Student t-test as (1) it deals with the problem associated with inference based on small sample sizes (<30), which is the case of the number of windows we are working with, and (2) we do not make comparisons between randomly selected samples, as the second sample is the same as the first after some treatment has been applied, i.e., the change of one experimental condition.

The t-test can be performed knowing just the means, standard deviation, and number of data points. The two-sample t-test yields a statistic t for a given probability level p. The higher the value of t, the greater the confidence that there is a statistically meaningful difference. Probability tables have been prepared based on the t-distribution. To use the table, one has to find the critical value (t_0). If $|t|$ exceeds t_0, in the two-sample case the means are significantly different with a $(1 - 2p)$ probability, where p is the probability level listed in the table. In this study, it has been decided beforehand to use the probability level $p = 0.001$ to find the t_0 to be compared to t.

The Student-t test has been applied to compare both the H/V amplitudes and peak frequencies of the reference and tested experimental condition.

In order to have a better graphic visualization of the test, instead of plotting t and t_0, we plotted $\mathrm{Diff}_{\mathrm{H/V}} = \overline{\mathrm{H/V}_1} - \overline{\mathrm{H/V}_2}$ and $t = t_0\sqrt{A \times B}$, where $A = \frac{(n_1+n_2)}{n_1 n_2}$, $B = \frac{(n_1-1)\sigma_1^2+(n_2-1)\sigma_2^2}{n_1+n_2-2}$, s is the sample standard deviation and n_{i} the number of points in the sample.

In this case, if $|\mathrm{Diff}_{\mathrm{H/V}}|$ exceeds t, the H/V amplitudes are significantly different at the probability level (1–2p).

For a homogenous use of the Student-t test, for the value of the frequency peak we plotted $\mathrm{Diff}_{\mathrm{f}} = (\overline{\mathrm{f}_1} - \overline{\mathrm{f}}_2)$ and $t = t_0\sqrt{A \times B}$ as for the H/V curves. In this case, if $|\mathrm{Diff}_{\mathrm{f}}|$ exceeds t, the peak frequencies are significantly different at the probability level (1–2p).

3.4 Automatic conclusion

The value of the peak frequency $\bar{\mathrm{f}}_0$ is automatically computed for both the reference and the test recordings in the 0.2–20 Hz range, as well as their standard deviations $\sigma(\bar{\mathrm{f}}_0)$. From these results a "peak zone" is determined as the frequency interval $[\bar{\mathrm{f}}_0 - \sigma(\bar{\mathrm{f}}_0), \bar{\mathrm{f}}_0 + \sigma(\bar{\mathrm{f}}_0)]$.

As an effort to be as objective as possible in the conclusion reached for each test, a "conclusion" was automatically generated, depending on the behavior, with respect to the Student t-test, (1) of the two frequency peaks (f_0) of the reference and the tested parameter, and (2) of their H/V curves inside and outside the "peak zone." Of course, each result was carefully checked by several eyes in order to avoid any meaningless computed peak frequency value or automatic conclusion.

The automatic conclusion based on the Student-t analysis of the difference $\mathrm{Diff}_{\mathrm{f}}$ between the values of the peak frequencies of the reference and the tested experimental condition, both obtained from the individual windows, were the following:

- if $|\mathrm{Diff}_{\mathrm{f}}| \le t$: the peak frequencies of the reference and the tested parameter are similar. The conclusion is "Similar peak frequencies;"
- if $|\mathrm{Diff}_{\mathrm{f}}| > t$: the peak frequencies of the reference and the tested parameter are different. The conclusion is "NOT similar peak frequencies."

Then a general conclusion was found for the tested experimental condition, with priority given to the behavior of the H/V amplitudes inside the "peak zone," using the following procedure:

- if the conclusion of the Student-t test for the peak frequencies is "NOT similar peak frequencies," the general conclusion is "NOT RECOMMENDED," i.e., the tested parameter greatly influences the H/V results, and no further analysis of the H/V results is undertaken;
- if the conclusion of the Student-t test for the peak frequencies is "Similar peak frequencies," the general conclusion varies according to the percentage of "bad" points on the

H/V curve, fulfilling the condition $\mathrm{Diff}_{H/V} > t$ inside and outside the peak zone. The total number of points, as well as the number of "bad" points, both inside and outside the peak zone are obtained as $\sum\left[\log_{10}(f + \Delta f/2) - \log_{10}(f - \Delta f/2)\right]$, where Δf is the frequency step from the Fourier transform.

This conclusion has been obtained for all reference-tested experimental condition pairs and then visually checked. When one of the two f_0 was obviously miss-peaked, the program was re-run with an imposed f_0 interval. When the site did not show an obvious frequency peak, the program was re-run with an imposed no-peak-site solution in which of course the t-test was performed only on the H/V amplitudes and not on the frequency peaks.

3.5 Presentation of the results

After data processing, the program produces a technical card (Fig. 1), which includes:

- four graphs: H/V curves of the reference and the tested parameter, the Student-t test graph and the two standard deviations grouped on a graph. All graphs are presented in the 0.2–20 Hz frequency range. The lowest frequency bound has been chosen at 0.2 Hz because it has been observed that the H/V behavior below this value is rather erratic, and the highest bound has been fixed at 20 Hz because fundamental frequencies over that value are of no interest in seismic risk evaluation and therefore not critical in H/V studies;
- two tables describing the peak frequency results, some acquisition parameters and some processing parameters, as well as the automatic conclusion on the influence of the tested parameter on the H/V results.

4 Tests results

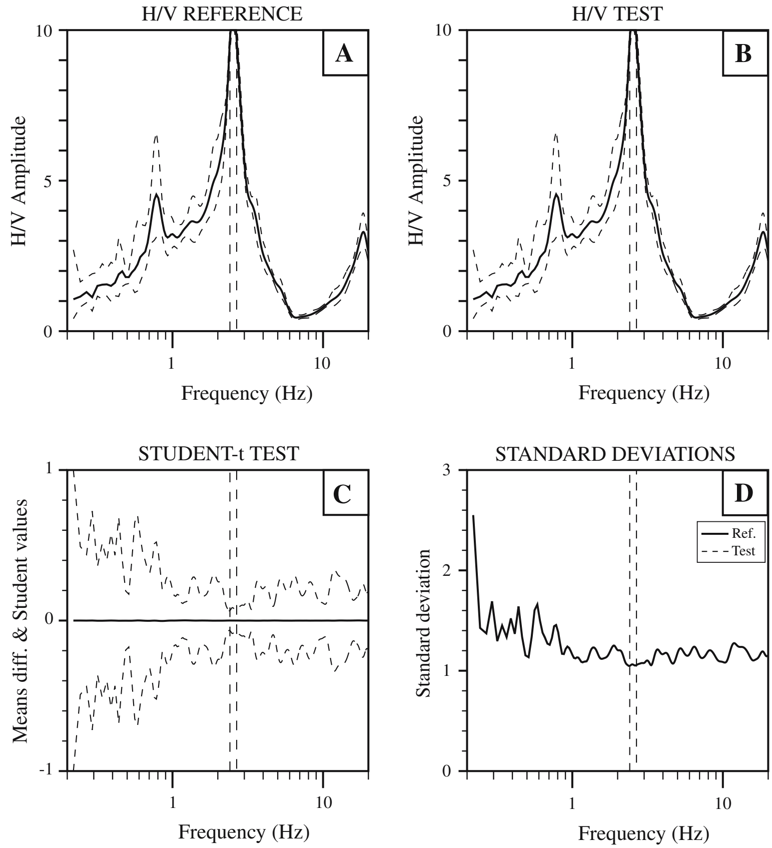
The WP02 results are based on a total of 596 recordings that were used to test 60 experimental conditions (See Table 1 of SESAME project 2003). No-peak and high frequency sites are less documented (20 and 43 recordings, respectively) than low and medium frequency sites (291 and 242 recordings, respectively).

The whole series of results is fully available from http://sesame-fp5.obs.ujf-grenoble.fr/. Here we will limit the presentation to the lessons of each test, sometimes illustrated with an experimental result.

4.1 P1 Recording and instrument parameters

These experimental field tests complement the laboratory instrumental tests performed in Bergen in 2002 (Guillier et al. 2002a,b, 2005), where the manufacturers specifications and equipment reliability were checked. The goal of this series of tests is to check if the various recording settings (gain, sample frequency, . . .), the way the equipment is setup, and the type of equipment used have an influence on H/V curves.

Concerning the P1-1 (recorder influence) and P1-2 (sensor influence) series of tests, only the additional tests performed by various teams of the SESAME project are presented in this paper. The results and conclusions of the Bergen series of tests are presented by Guillier et al. (2005) and SESAME WP02 team (2002) and are not further developed in this paper.



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Station a	2.51	5	200	900	2.53	0.04	5	$\lvert$diff$\rvert$ = 0.00 t = 0.13 Similar peak frequencies
Test	Station b	2.51	5	200	900	2.53	0.04	5	
	Conclusion	NO INFLUENCE							

	Recorder	Sensor	Rec. type : simultaneous	Medium frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P1-1-1-Grenoble-test8** Influence of recorder One sensor with several recorders	
Test	CityShark	5-second Lennartz LE3D		

Fig. 1 Example of technical card (signal from one sensor recorded by two recorders). The results shown in the card include *four graphs* showing: the H/V results of the reference (**A**, *top left*); the H/V results of the tested parameter (**B**, *top right*); a graph showing the Student-*t* values obtained from the results of graphs **A** and **B** (**C**, *bottom left*); a graph showing the standard deviations of graphs **A** and **B** (**D**, *bottom right*). Graphs **A** and **B**: $\overline{H/V}$ is shown by the *black line*. The two *dashed lines* on both sides of the *black line* are $\overline{H/V}/\sigma_{H/V}$ and $\overline{H/V}x\sigma_{H/V}$. Graph **C**: $\text{Diff}_{H/V}$ is shown by the *black line*. The two *dashed lines* on both sides of the *black line* are the Student-*t* values t and $-t$. Graph **D**: $\sigma_{H/V}$ of the reference is shown by the *black line*, and $\sigma_{H/V}$ of the tested parameter by a *dashed line*. All four graphs: the *vertical* dashed lines in all four graphs delimit the interval $[\overline{\text{f}_0} - \sigma(\text{f}_0), \text{f}_0 + \sigma(\text{f}_0)]$ from the results shown in the *bottom box* of the technical card. In graphs **A**, **C**, and **D** the interval is the one obtained for the reference, and in graph B the one obtained for the tested parameter

4.1.1 P1-1 Recorder

Simultaneous recordings performed with different recorders. Two types of experiments were conducted to test the influence of recorders:

P1-1-1 The signal from one single sensor is recorded by several recorders of the same type: ten tests were performed with CityShark stations (Chatelain et al. 2000) coupled to 5-s Lennartz LE-3D seismometers, on both low-and high-frequency sites (Fig. 1). Fortunately, no differences in the H/V results are observed.

P1-1-2 Recorders of different types record the signal from several sensors of the same type. The stations tested were the Hathor-3, Mars-Lite, Mars-88, CityShark (Chatelain et al. 2000), and CityShark II. 12 tests were performed. The type of recorder has no influence on the results, although results obtained with the Mars Lite show negligible differences outside the peak frequency zone, toward the high frequencies.

P1-2 Sensor: Recording the same noise with different sensors and the same recorder. The following comparisons between sensors have been performed, through 17 tests:

- 5-second Lennartz LE-3D vs. 1-Hz Lennartz LE-3D lite (6 tests: 3 on MF sites and 3 on LF sites);
- 5-second Lennartz LE-3D vs. 4.5-Hz Mark Products L28 (3 tests: 1 on MF site and 2 on LF sites);
- 5-second Lennartz LE-3D vs. 20-seconds Lennartz (3 tests on MF sites);
- 5-second Lennartz LE-3D vs. 2-Hz Mark Products L22 (2 tests: 1 on MF site and 1 on LF site);
- 1-Hz Lennartz LE-3D vs. 4.5-Hz Mark Products L28 (1 test on MF site);
- 1-Hz Lennartz LE-3D vs. 2-Hz Mark Products L22 (1 test on MF site);
- 4.5-Hz Mark Products L28 vs. 2-Hz Mark Products L22 (1 test on MF site);

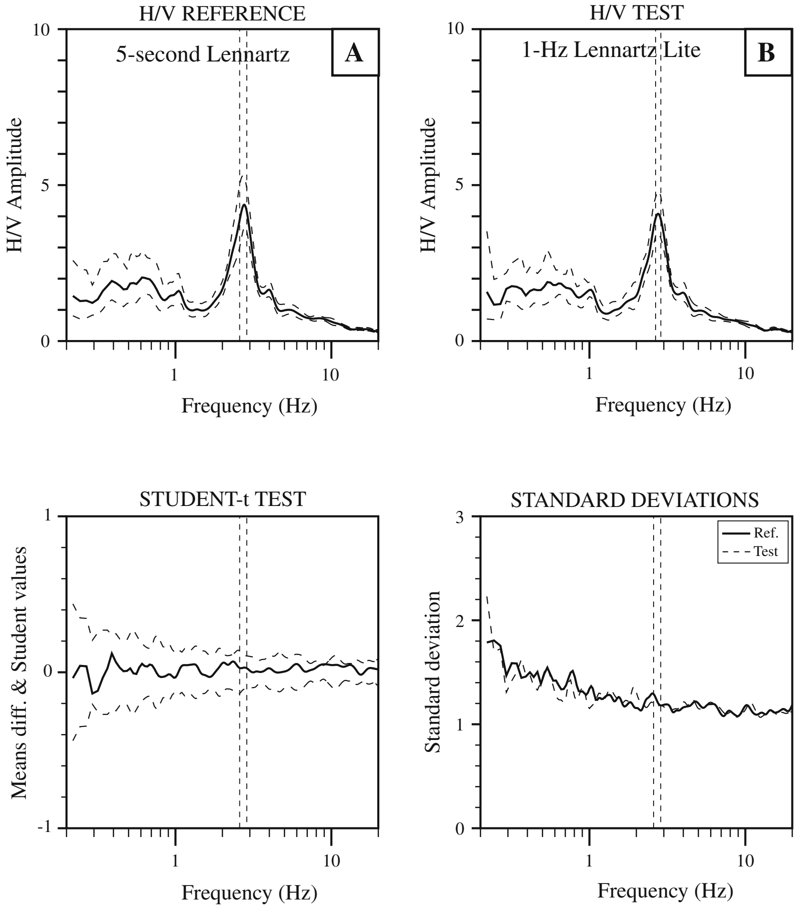
Similar H/V curves are found (Fig. 2). The only problem is encountered with the 2-Hz Mark Products L22, with which (1) even the peak frequency is found to be different, and (2) marked amplitudes differences show up below about 1 Hz. As both the Grenoble and the Nice teams obtain comparable results, using two different sensors, deeper investigations concerning this type of sensor are recommended.

On the contrary, it is very interesting to note that results obtained with a 4.5-Hz Mark Products L28 give the same peak frequency, even on low frequency (<0.5 Hz) sites on which, however, the amplitude of the peak is a little flattened (Fig. 3). However, it should be pointed out that even if the results of these experiments indicate that a 4.5 Hz sensor can be used on a low-frequency site, only a specific 4.5 Hz sensor has been tested. It is not proved that this result is relevant for any other 4.5 Hz sensors available in commerce, for example the ones used in applied geophysics for refraction surveys.

In order to avoid misapplication of the method, it is strongly recommended that the user use a sensor that can reach the frequency of interest.

4.1.2 P1-3 Time for stabilization of the sensor

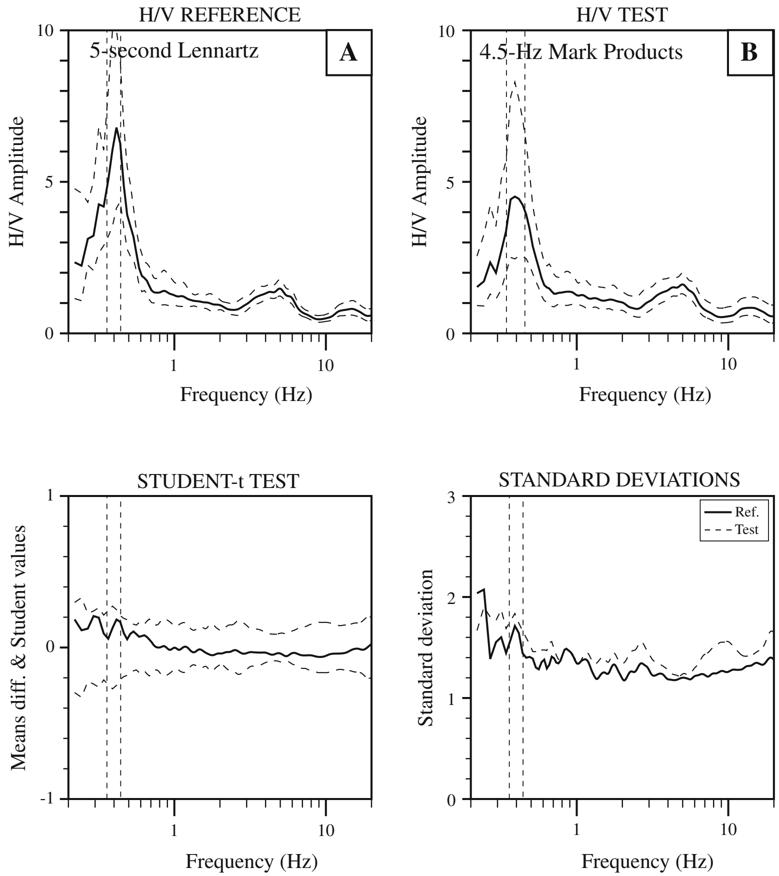
It is not worth testing the influence of time stabilization of the most commonly used sensors (e.g., 5-s Lennartz LE-3D, 1-Hz Lennartz LE-3D, 2-Hz Mark Products L22, 4.5-Hz Mark Products L28 or even 20-s Lennartz) as experience shows that they are stabilizing very rapidly (few tens of seconds) after the shaking from setting up the sensor. Anyway, if the recording is started before the sensor has stabilized, the first signal window must definitively be ignored during data processing with properly set processing parameters.



<table>
<tr><td></td><td>File name</td><td>f0 ($\overline{H/V}$) (Hz)</td><td>Nb win</td><td>Sample rate (Hz)</td><td>Recording duration (s)</td><td colspan="4">Frequency stastistics from individual windows</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>$\overline{f0}$ (Hz)</td><td>Sigma (Hz)</td><td>Nb win</td><td>Student-t test</td></tr>
<tr><td>Ref.</td><td>T1S1C8_2002 0514_1122.saf</td><td>2.76</td><td>13</td><td>100</td><td>600</td><td>2.72</td><td>0.14</td><td>13</td><td rowspan="2">|diff| = 0.04
t = 0.18
Similar peak frequencies</td></tr>
<tr><td>Test</td><td>T1S2C8_2002 0514_1145.saf</td><td>2.76</td><td>14</td><td>100</td><td>600</td><td>2.76</td><td>0.11</td><td>14</td></tr>
<tr><td></td><td>Conclusion</td><td colspan="8">NO INFLUENCE</td></tr>
</table>

	Recorder	Sensor	Rec. type : sequential	Medium frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P1-2-Lisbon-test1** Influence of sensor	
Test	CityShark	1-Hz Lennartz LE3D-Lite		

Fig. 2 Example of H/V results obtained at the same point from two types of sensors shown in a technical card. Legend of the technical card as in Fig. 1. **(A)** Five-second Lennartz LE-3D; **(B)** one-second Lennartz LE-3D Lite. No difference on the results is noted



<table>
<tr><th rowspan="2"></th><th rowspan="2">File name</th><th rowspan="2">f0 ($\overline{H/V}$) (Hz)</th><th rowspan="2">Nb win</th><th rowspan="2">Sample rate (Hz)</th><th rowspan="2">Recording duration (s)</th><th colspan="4">Frequency stastistics from individual windows</th></tr>
<tr><th>$\overline{f0}$ (Hz)</th><th>Sigma (Hz)</th><th>Nb win</th><th>Student-t test</th></tr>
<tr><td>Ref.</td><td>09_LEN_5sec</td><td>0.42</td><td>22</td><td>200</td><td>900</td><td>0.40</td><td>0.04</td><td>22</td><td rowspan="2">|diff| = 0.00
t = 0.05
Similar
peak frequencies</td></tr>
<tr><td>Test</td><td>09_MP_4.5Hz</td><td>0.39</td><td>20</td><td>200</td><td>900</td><td>0.40</td><td>0.06</td><td>20</td></tr>
<tr><td></td><td>Conclusion</td><td colspan="8">NO INFLUENCE</td></tr>
</table>

	Recorder	Sensor	Rec. type : Simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P1-2-Grenoble-test6** Influence of sensor	
Test	CityShark	4.5-Hz Mark Product L28		

Fig. 3 Example of H/V results obtained at the same point from two types of sensors shown in a technical card. Legend of the technical card as in Fig. 1. **(A)** Five-second Lennartz LE-3D; **(B)** 4.5-Hz Mark Products L28. Surprisingly, except for a slight squeeze of the peak, no influence on the results is noted, while the frequency peak is around 0.4 Hz. The two sensors were connected onto two CityShark stations (Chatelain et al. 2000), and the gain of the 4.5-Hz sensor recording was set-up at four times of the 5-s gain. However, it is not recommended to use a sensor which natural frequency is far away from the site frequency

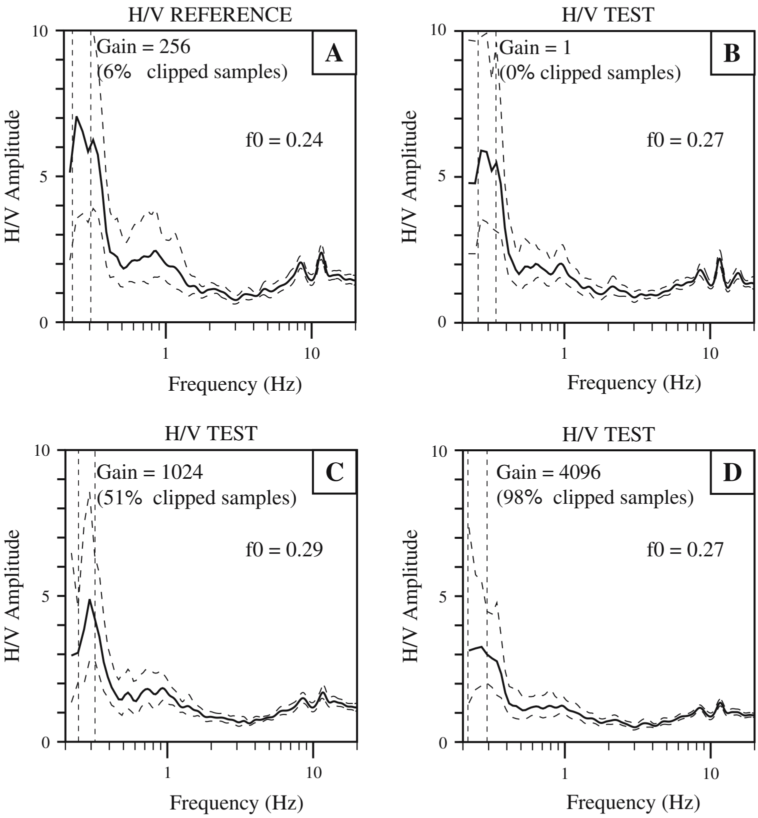


Fig. 4 Example of four H/V results obtained at the same point with different gains. Legend as in Fig. 1A,B, plus the indication of the percentage of clipped signal samples. All recordings were performed with a City-Shark station (Chatelain et al. 2000) connected to a 5-s Lennartz LE-3D. For each test a station was recording at gain 256 simultaneously with a station with one of the other gain. The gain 256 shown as reference was obtained together with gain 4,096. **(A)** reference gain set to 256; **(B)** gain 1; **(C)** gain 1,024; **(D)** gain 4,096. It clearly appears that at higher gains, with high percentage of clipped signal samples, while the value of the frequency peak is conserved, the shape of the H/V curve is considerably squeezed and may therefore lead to misinterpretations in the case of relative H/V amplitude studies. The gain should definitively be chosen as the maximum possible value without clipping. Lower values of gain should be used only if it is sure that the electronic noise/signal ratio of the recording station is very low

The only tests were performed with a Guralp CMG40T (eight tests), showing no differences in the H/V results. However, the standard deviation of H/V amplitudes from the shacked sensor is over ten times bigger than the one from the not shacked sensor when looking at the results after less than 5 min from shaking.

4.1.3 P1-4 Gain

Twenty-four tests, using various gains for recordings at the same place, were performed, showing that the gain does not influence the results as long as the signal saturation level is small. When the gain is so high that the saturation level becomes too important, the frequency peak value is not changed, but the H/V curve is somewhat flattened. On the opposite side, a gain of 1 appears to give very good results. (Fig. 4).

It is therefore highly recommended to be rather conservative to set up the gain, which should be set up to the highest value avoiding signal saturation.

4.1.4 P1-5 Sampling rate

Eight comparisons were performed between 50, 100, 125, 200, and 250 Hz sampling frequencies, showing that the data acquisition sampling rate has no influence on the results.

4.1.5 P1-6 Sensor cable length

Nine tests were performed under quiet conditions (i.e., without wind blowing) with lengths of the cable linking the sensor to the recording station varying from 10 up to 100 m. The length of cable has no influence on the results, at least up to 100 m, no matter how the cable is installed (rolled or stretched). This takes only in consideration the cable length by itself, without considering possible external considerations such as strong wind, for example.

4.1.6 P1-7 Azimuth of the sensor

The sensor used in the test has been rotated successively 30°, 60°, 90°, and 180° with respect to the reference sensor. The orientation of the sensor has no influence on the H/V results. However, all tests were performed over a homogeneous alluvium basin. Tests next to geologic discontinuities or 2D structures still have to be performed.

4.1.7 P1-8 Sensor horizontality

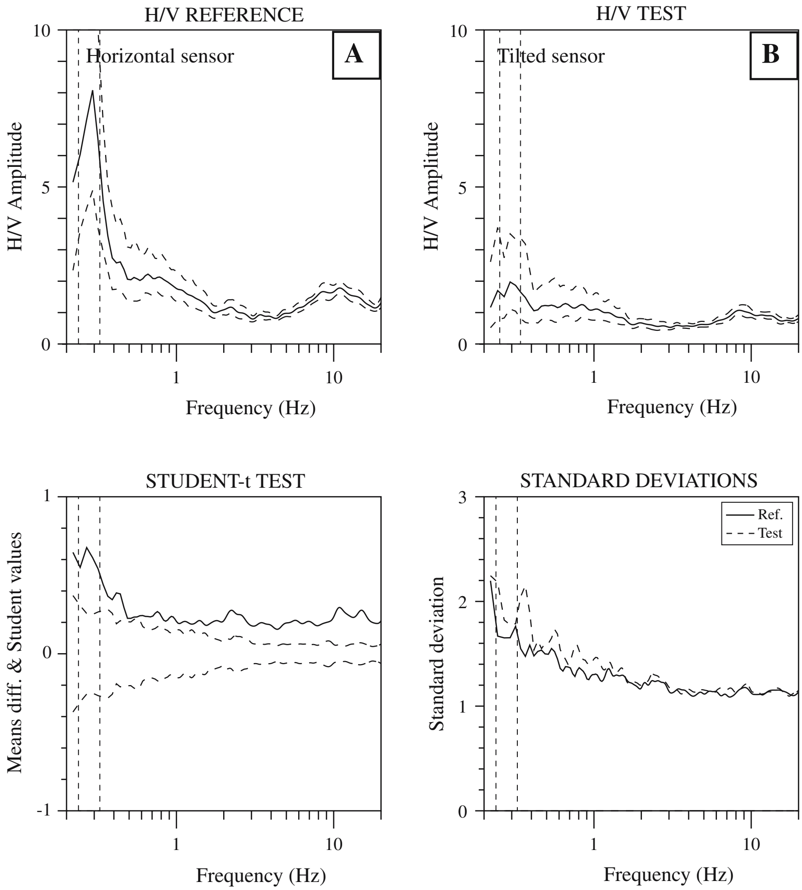
Only the 5-s Lennartz LE-3D has been tested by tilting successively the test sensor 4° and 8° with respect to the reference sensor kept horizontal. The sensor can be tilted up to a point where the peak frequency can still be found, although hardly, but the H/V curve is drastically flattened (Fig. 5). It is recommended to avoid important tilting of the sensor, i.e., >4°, in the 5-s Lennartz LE-3D case, and to follow in any case the recommendations of the manufacturer.

4.1.7.1 P1-Conclusion: In our study, the only problem encountered with the equipment is the difference in H/V results obtained when using the 2-Hz Mark Products L22 sensor. Some differences are observed in the amplitudes when a 4.5-Hz Mark Products L28, but surprisingly the frequency peak is well established even on sites with a fundamental frequency as low as 0.3 Hz. It is however strongly recommended to use a sensor with a natural frequency at least on the order of the site fundamental frequency.

Recording settings do not have any influence on H/V results as long as common sense is used: follow the manufacturer indication as to how much a sensor can be tilted, and do not use too high a gain to minimize as much as possible signal saturation. When there is an influence on the results, in most cases it is observed on the H/V curve shape, while the fundamental frequency compares very well between the test and the reference.

4.2 P2 In situ ground-sensor coupling

In most cases, ambient vibrations recording is not performed directly on the ground, which is commonly topped, especially in cities, by asphalt, cement, grass, . . . or the ground condition can be artificially and temporarily modified (ploughed, muddy . . .). It is therefore of primary



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Reference	0.29	22	200	900	0.28	0.04	22	|diff| = 0.01 t = 0.05 Similar peak frequencies
Test	Tilt 8	0.29	22	200	900	0.30	0.04	22	
	Conclusion	NOT RECOMMENDED (100% inside peak zone)							

	Recorder	Sensor	Rec. type : simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P1-8-Grenoble-test2** Influence of sensor horizontality Ref : 0° tilt ; Test : 8¡ tilt	
Test	CityShark	5-second Lennartz LE3D		

Fig. 5 Example of H/V results obtained at the same point with a sensor set up horizontally **(A)** and tilted **(B)**, shown in a technical card. Both seismometers are 5-s Lennartz 3D sensors. Legend of the technical card as in Fig. 1. When recording with a tilted (8°) sensor, H/V results are totally misleading as they show, in this example, a “no peak” site instead of a low-frequency site, even though the value of the frequency “peak” is similar

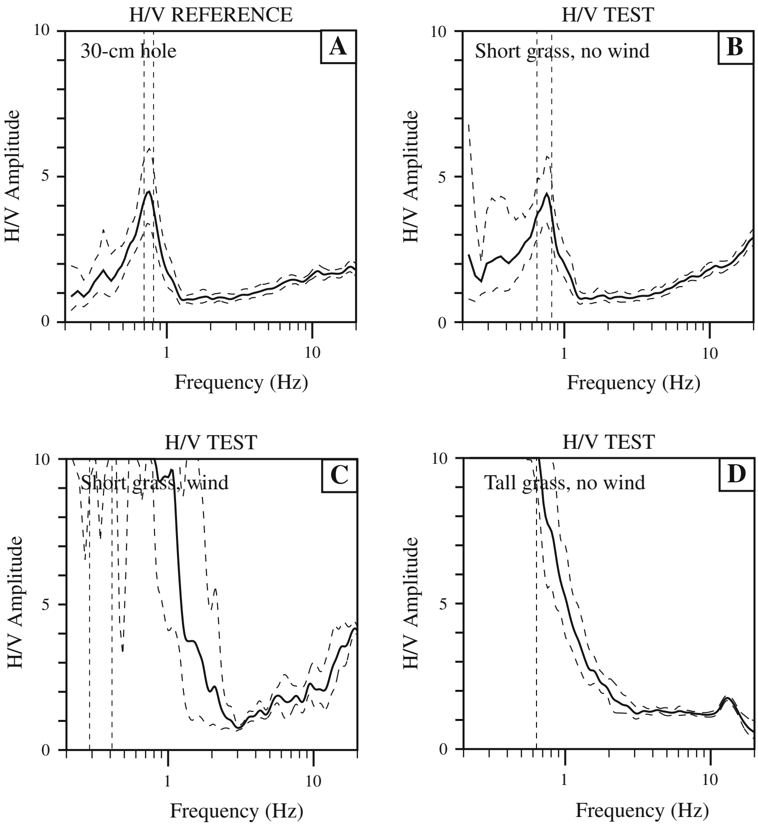
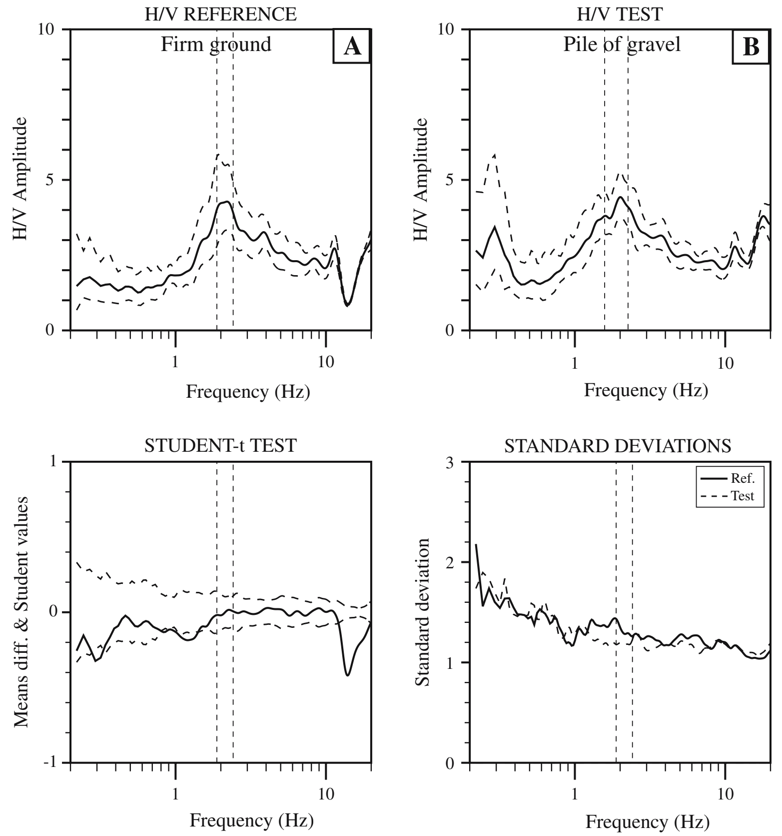


Fig. 6 Example of H/V results obtained at the same point topped with grass on a low-frequency site. **(A)** sensor installed in a 30 cm hole; **(B)** sensor on short grass, without wind blowing; **(C)** sensor on short grass, with wind blowing; **(D)** sensor on top of tall grass that is folded under the sensor's weight, without wind blowing. Recordings A, B, and C are within 40–50 cm of each other, while recording D has been performed about 20 m away from the three others. Note the similarity of the effect of the wind **(C)**, to the one of the sensor not being firmly installed on the ground **(D)**

importance to check whether recordings obtained in these conditions give or not the same H/V curves as recordings performed directly on natural ground.

4.2.1 P2-1 Grass

Thirty-seven tests were performed on grass. When recording without wind, no differences are noticed. However, results can be very different when the wind is blowing, even lightly. A peak or a bump can be observed at places below about 1 Hz and artificial peaks can appear in the high frequencies (Fig. 6). These observations can be reproduced artificially by setting the sensor on top of two layers of grass or on tall grass with the sensor sitting on the folded grass (Fig. 6), i.e., when the sensor is not firmly set up on the ground. It is recommended, in general, to remove grass to set the sensor up, especially when grass is tall, or at least to make sure that the sensor feet are set on the ground and not on the grass itself. In any case, recording on grass should be avoided when wind is blowing or the sensor should be installed in a hole. The grass case is more thoroughly discussed in a later section.



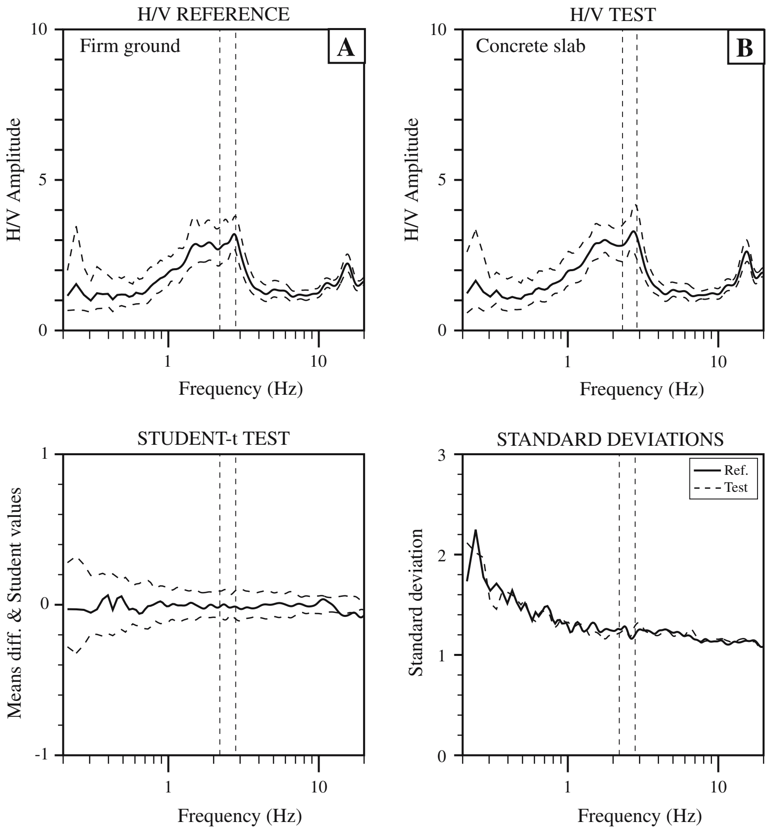
	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	02032711.saf	2.20	20	100	903	2.15	0.27	20	|diff| = 0.23 t = 0.35 Similar peak frequencies
Test	02032710.saf	2.00	20	100	903	1.92	0.34	20	
	Conclusion	No influence inside the peak zone, caution outside (27%)							

	Recorder	Sensor	Rec. type : simultaneous	Medium frequency site
Ref.	Mars Lite	5-second Lennartz LE3D	**P2-2-Nice-test1** Influence of gravel Ref : on natural soil ; Test : on gravel	
Test	Mars Lite	5-second Lennartz LE3D		

Fig. 7 Example of H/V results obtained at the same point with a sensor set up on firm ground **(A)** next to a sensor set up on a pile of gravel **(B)**, shown in a technical card. Legend of the technical card as in Fig. 1. While the value of the soil frequency does not vary much, the rest of the H/V curve may be strongly influenced

4.2.2 P2-2 Gravel

From the three tests performed on a pile of gravel, while the value of the peak frequency is not strongly influenced, the rest of the curve may show noticeable variations, including the creation of secondary peaks (Fig. 7). The same kind of results is obtained when gravel is used as artificial layer to set the sensor (P3-7). It is not recommended to record on gravel, as the feet stability of the sensor is not always properly insured.



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Ref1	2.75	26	250	900	2.50	0.30	26	|diff| = 0.09 t = 0.29
Test	1-Plaque beton	2.75	26	250	900	2.60	0.28	26	Similar peak frequencies
	Conclusion	No influence inside the peak zone, negligible influence outside (8%)							

	Recorder	Sensor	Rec. type : synchronous	Medium frequency site
Ref.	CitySharkII	5-second Lennartz LE3D	**P2-3-Grenoble Nice-test1** Influence of concrete Ref : natural soil ; Test : on concrete slab	
Test	CitySharkII	5-second Lennartz LE3D		

Fig. 8 Example of H/V results obtained at the same point with a sensor set up on firm ground **(A)** next to a sensor set up on a concrete slab **(B)**, shown in a technical card. Legend of the technical card as in Fig. 1. Only marginal differences are noted between the two H/V curves

4.2.3 P2-3 Concrete

Recording on concrete is not a problem: the peaks are the same and H/V curves are quite similar from the 11 tests that were performed. Only marginal influences may appear in the higher frequencies (above about 10 Hz) (Fig. 8). A similar result is obtained by Mucciarelli (1998) who found that concrete was a filter only for amplitude and not for the frequency.

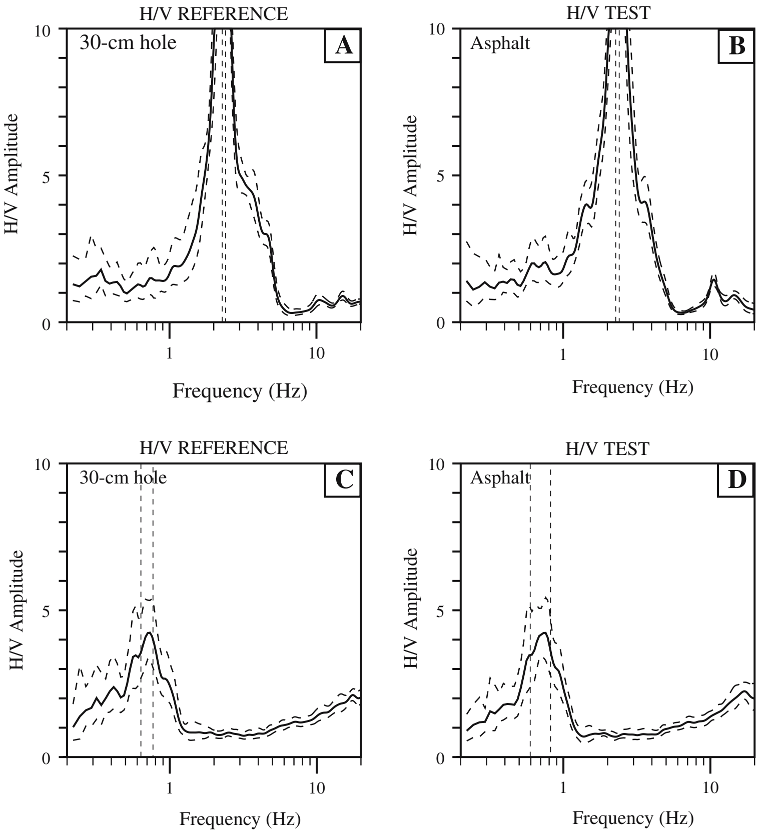


Fig. 9 Example of H/V results at the same point topped with asphalt, on a medium frequency site (*top*) and low-frequency site (*bottom*). **(A)** Sensor installed in a 30 cm hole; **(B)** sensor on asphalt; **(C)** sensor installed in a 30 cm hole; **(D)** sensor on asphalt. Note that no artificial effect is evidenced when recording on asphalt, besides, sometimes, marginal effects above about 7–8 Hz. In particular, the strong effect around 5 Hz evidenced by Mucciarelli (1998) does not show up at all

4.2.4 P2-4 Asphalt

When recording on asphalt, peaks may be a little flattened, while amplitudes over 7–8 Hz may be marginally different. Out of the 36 tests, none were performed on high frequency sites. Recording on asphalt does not seem to be a real problem, even for the slightly different H/V amplitude values over 7–8 Hz (Fig. 9). Tests should be performed on high-frequency sites in order to check how higher amplitude values observed on other types of sites reflect in the higher frequencies range. In any case the drastic effect claimed by Mucciarelli (1998) around 5 Hz appears on none of our tests (Fig. 9). The asphalt case is discussed in more details in a further section.

4.2.5 P2-5 Ice

From our three tests it looks like recording on ice is not recommended. The feet of the sensor produce local ice melting that destabilizes the sensor and causes important perturbations in the signal. We observe much higher amplitude levels in the lower frequencies. It is only once the sensor has stabilized, i.e., when the body of the sensor lies on the ice, that results are no longer disturbed. Recording using an artificial interface in-between the sensor and the ice should be tested.

4.2.6 P2-6 Snow

P2-6-1 Compacted snow: Two tests were performed on days without sun shining. Recording on compacted snow is not a problem, at least up to a thickness of 30 cm, and when the sun is not shining.

P2-6-2 Not compacted snow: The 14 tests show that there is a noticeable difference depending on whether records are performed under the shade or exposed to the sun. For records under the shade no differences appear between the test and the reference H/V curves. Recording under the sun faces the same problem as recording on ice, i.e., the sensor feet are progressively melting the snow thus provoking a step-by-step sink of the sensor that highly perturb the signal. More tests should be performed under sunny conditions with the sensor not set up directly on the snow but on an artificial interface, which should prevent snow melting under the feet of the sensor.

4.2.7 P2-7 Ploughed soil

The four tests show that recording on ploughed soil is not a problem on thin ploughed layer, but for a thick ploughed layer peaks with very high amplitudes can show up, the H/V curve can be pushed towards higher amplitudes, or the fundamental peak frequency can be shifted. These effect are due to the recording over a small thickness layer (10 s of cm) with very low S-wave velocity (20–70 m/s). It is better to avoid recording on ploughed soil, as the limit between “thin” and “thick” ploughed layer is not quite established.

4.2.8 P2-8 Mud

From our two tests different results are obtained depending on both mud thickness and the proportion of water left in the mud. For recording performed in the thicker layer in presence of water, the peak frequency does not change, however amplitudes are much higher and an artificial peak appears in the higher frequencies. For the thin layer no change is observed over the entire H/V curve. However as only two tests were performed, further investigations are needed to better control the effect of mud on the results. It is recommended to avoid setting up the sensor in mud or up to the surface water saturated soil.

4.2.9 P2-9 Synthetic cover

One test has been performed in a stadium on a tartan track cover, showing that recording on synthetic cover, such as tartan, influence H/V results and should be avoided. In this case, the sensor should definitively be setup on nearby more convenient surface.

4.2.10 P2-10 Karstic filling

Completely different results were obtained from two tests on the calcareous rock and the filling thus showing that recording on karstic filling greatly influence H/V results.

4.2.10.1 P2-Conclusion As far as ground topping is concerned, and letting aside weather conditions, grass, cement and asphalt do not dramatically change H/V results: the frequency peak is the same, and when changes are observed, mainly on asphalt, only marginal changes in amplitudes are observed.

We put particular attention on asphalt measurements, as Mucciarelli (1998) found dramatic effects on H/V results when recording ambient noise on asphalt, and as some of our results deserved more detailed investigations. These results are discussed in a more detailed way in a further section of this paper.

In the case of snow and ice topping, the main effect is not linked to the topping itself but to the behavior of the sensor, which can induce partial melting at the sensor feet, which in return induces differential motion of the sensor resulting in a rather erratic signal. Although not tested, the use of an artificial interface may help solving this problem. Also, in these cases, recordings are performed in rather low temperature environment, raising the problem of the equipment behavior.

Recording in mud or on ploughed soil does not influence H/V results below 20 Hz as long as the modified part of the ground is not too thick. More tests are needed to determine more precisely what “not too thick” really means, but from our tests 10–15 cm should represent the upper limit, corresponding to a S-wave velocity as low as 10 m/s in revolved or water saturated soils.

Recording on gravel and karstic filling should definitively be avoided. The behavior of karstic filling is of primary importance in some zones such as the Nice (France) region. In this study it is evidenced that it poses a real problem, as H/V results depend on how deep the filling is, or, when performed on the calcareous rock, on the dimension of the rock. A more detailed survey should be carried out on this type of environment.

Although the aim of these experiments was not to test the influence of weather conditions, they enhance the influence on H/V results of the wind or of the water saturation of the surficial layer from rain, and to a lesser extent of the temperature. The influence of wind was particularly clear when recording on grass, which lead us to discuss the grass case in more details in a further section of the paper.

4.3 P3 Modified ground-sensor coupling

As already been discussed for P1 experimental conditions, it is important to save time when setting up the recording equipment. Aside from the P1 experimental conditions, another important point is to evaluate the possible influence on H/V results of the ground-sensor coupling depending on the way the sensor is installed on the recording site. On the one hand, it is sometimes useful to use an artificial interface to help installing the sensor (on a slope, in soft soil, . . .). On the other hand, it is time consuming to setup the sensor in the same manner as when it is used for earthquake seismology experiments, i.e., burying it in 30–50 cm deep holes. It is therefore worth determining to what extend artificial interfaces and “quick way” of installing the sensor can influence H/V results.

4.3.1 P3-1 Artificial interface between in situ ground and sensor

Recording with the sensor set on an aggregated wood plate (three tests), a PVC plate (two tests) does not influence H/V results nor when the sensor is set on a stratified wooden plate or a ceramic plate, but only one test has been preformed in these two later cases.

Very variable results were obtained when using plain wood plates (five tests), from no influence to high influence depending on the kind of wood used and the thickness of the plate.

A series of ten tests were performed with the sensor set on a metal plate with legs on soil, concrete, grass, and asphalt. It does not influence significantly the results. Only slight influences on the frequency value of the fundamental peak are sometimes observed resulting in a double peak or higher amplitudes in the lower frequencies.

The same type of observations are made with a metal plate (ten tests), with or without legs, a cement plate (four tests), a cardboard plate (two tests), Styrofoam (14 tests), foam (two tests), and an empty plastic container (three tests): while in all cases there is no influence on the frequency value of the fundamental peak, variable results were obtained on the rest of the curve with, in some cases, high-abnormal amplitudes, and even sometimes creating artificial peaks (Fig. 10), depending on the thickness of the plate and, for the metal plate, on the kind of metal.

4.3.2 P3-2 Sensor anchoring

From our 18 tests, H/V results are thoroughly not influenced by setting up the sensor in a hole whether filled (Fig. 11) or not (Fig. 12). Some tests, however, show marginal differences of the H/V amplitude over 10 Hz (Fig. 12).

4.3.3 P3-3 Ballast on sensor

Four tests were performed. For a light ballast, while the frequency value of the peak is not changed, its H/V amplitude is quite higher and some light secondary peaks can show up. A heavy ballast completely changes the curve. It is not recommended to set up ballast on the sensor, even if there are reasons to do it.

4.3.4 P3-4 Feet of sensor not blocked

Three tests were performed with 5-s Lennartz seismometers. No difference in H/V results has been evidenced when recording with or without blocking the feet of the sensor, at least in the tested 0.2–20 Hz frequency range.

4.3.5 P3-5 Feet of sensor removed

Six tests were performed directly on the ground, or in sand or gravel with 5-s Lennartz seismometers. The results are influenced on the ground and in gravel, for which a squeeze of the H/V amplitude is observed all along the curve. No perturbations are observed when the sensor is set in sand.

4.3.6 P3-6 Sand

Five tests were made both on a pile of sand and on sand in a plastic container, showing no influence in H/V results in both cases (Figs. 13 and 14, respectively).

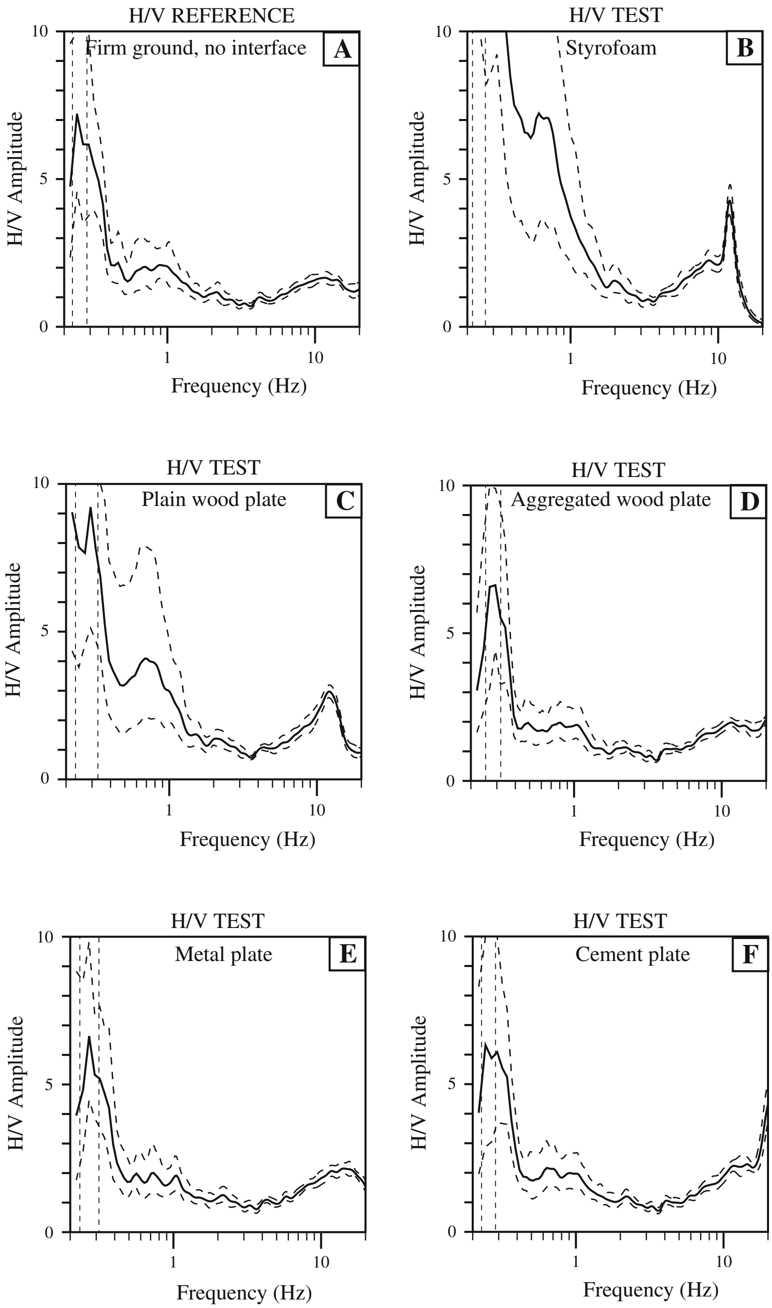
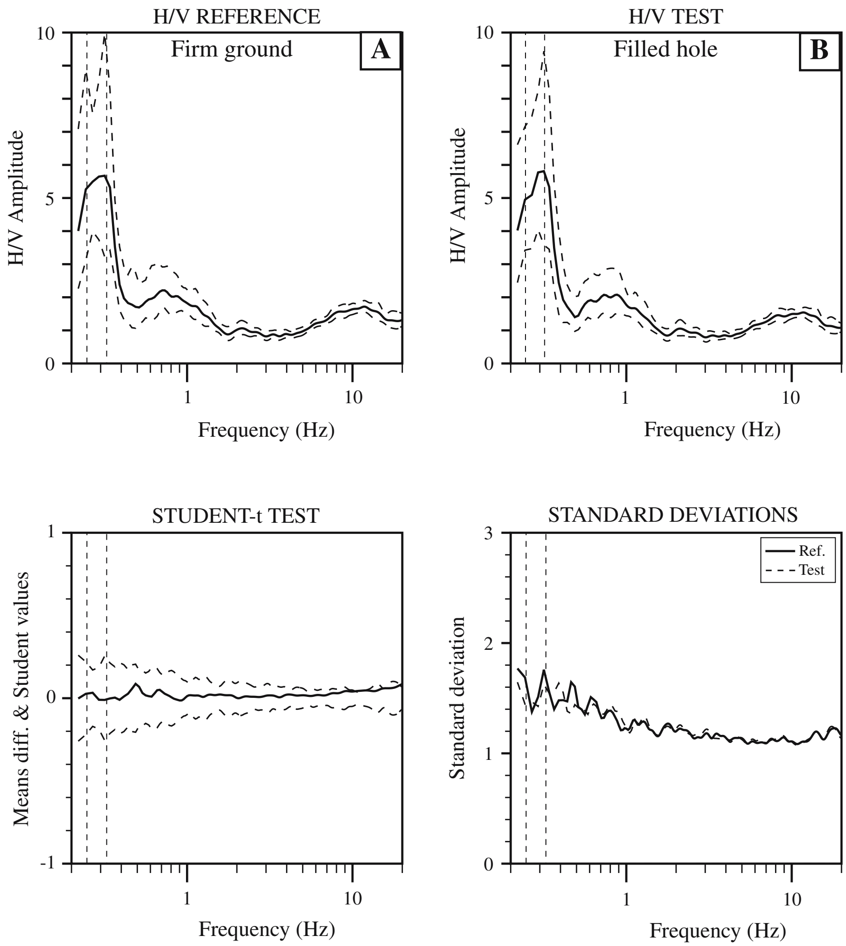


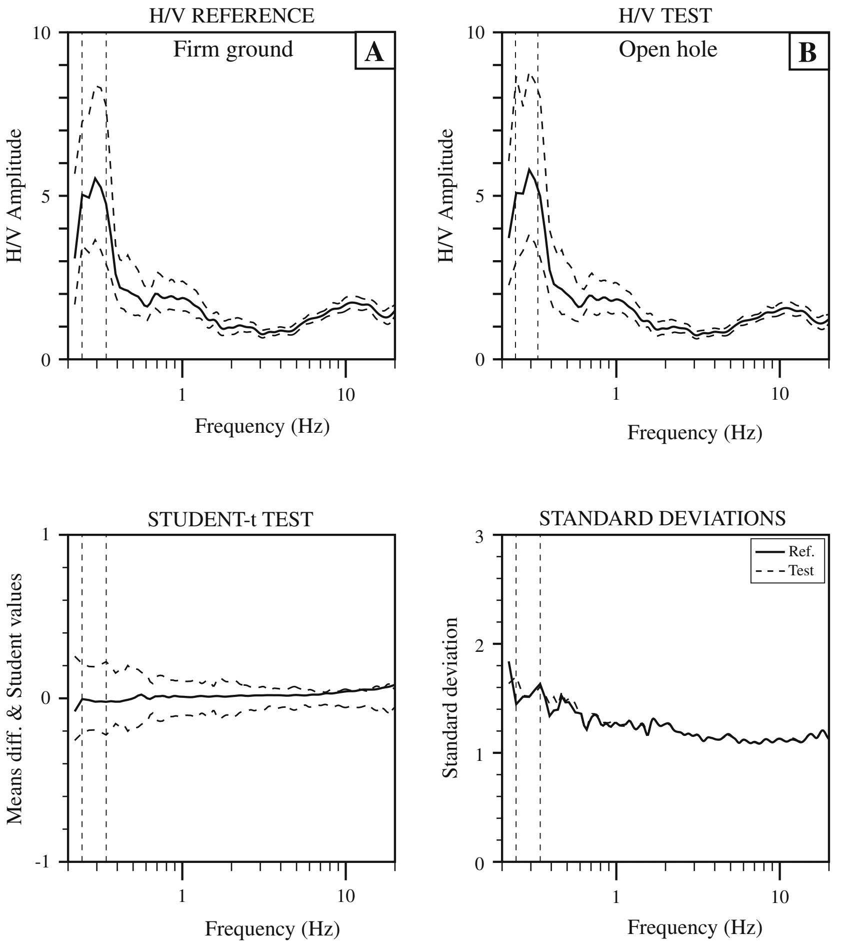
Fig. 10 Examples of H/V results at the same point, on a low-frequency site, to illustrate the influence on H/V curves of some artificial interfaces that may be used to set up the sensor. Sensor installed on **(A)** firm ground, without interface, used as the reference; **(B)** a Styrofoam plate; **(C)** a plain wood plate; **(D)** an aggregated wood plate; **(E)** a metal plate; **(F)** a cement plate. While some interfaces, such as Styrofoam (a), should definitively be discarded, the variable results obtained with the various tested interfaces favor the idea of testing beforehand any interface that, in some particular conditions, has to be used in order to help setting up the sensor



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Ref 2	0.32	21	200	900	0.29	0.04	21	|diff| = 0.00 t = 0.04
Test	2-20 cm filled	0.32	20	200	900	0.28	0.04	20	Similar peak frequencies
	Conclusion	NO INFLUENCE							

	Recorder	Sensor	Rec. type : simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P3-2-Grenoble-test2** Influence of sensor anchoring Ref : natural soil ; Test : 20-cm filled hole	
Test	CityShark	5-second Lennartz LE3D		

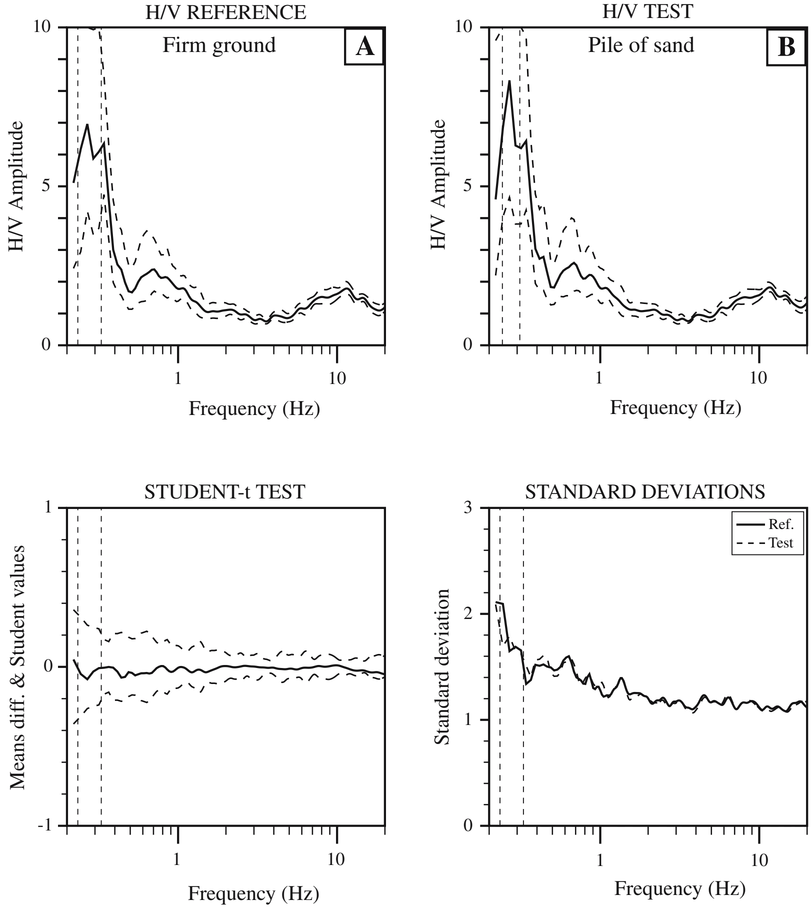
Fig. 11 Example of H/V results obtained at the same point with a sensor set up on firm ground **(A)** next to a sensor buried in a 20-cm filled hole **(B)**, shown in a technical card. Legend of the technical card as in Fig. 1. Clearly no differences are noticed when the sensor is buried, suggesting that is not necessary to bury the sensor at least under normal conditions



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Ref 1	0.29	22	200	900	0.29	0.05	22	|diff| = 0.01 t = 0.05 Similar peak frequencies
Test	1-20 cm not filled	0.29	22	200	900	0.29	0.04	22	
	Conclusion	No influence inside the peak zone, negligible influence outside (5%)							

	Recorder	Sensor	Rec. type : simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P3-2-Grenoble-test1** Influence of sensor anchoring Ref : natural soil ; Test : 20-cm unfilled hole	
Test	CityShark	5-second Lennartz LE3D		

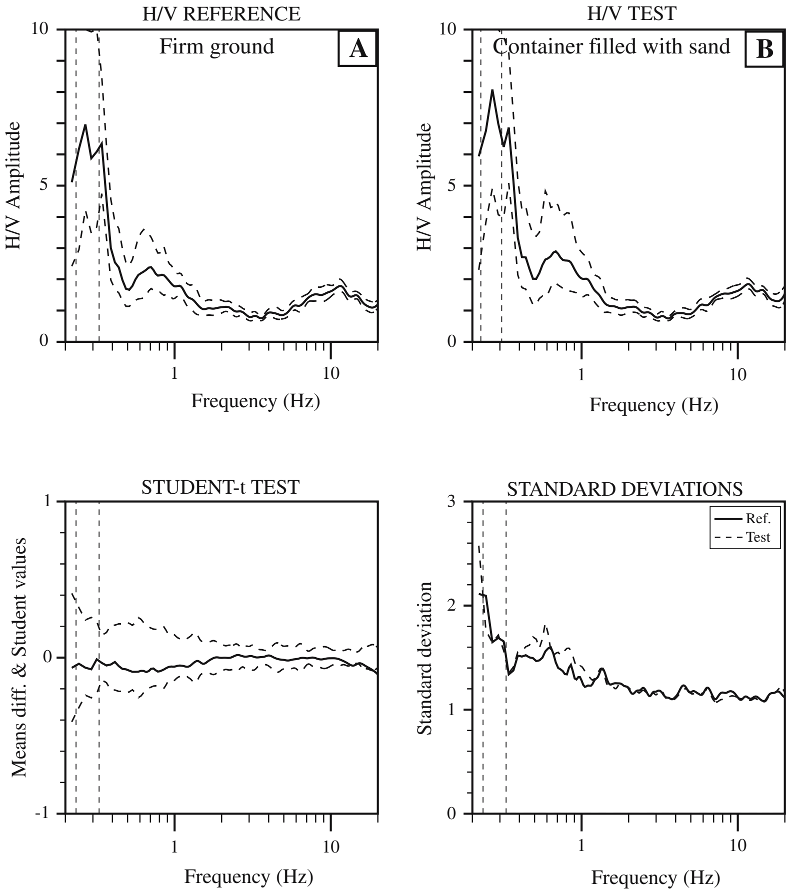
Fig. 12 Example of H/V results obtained at the same point with a sensor set up on firm ground **(A)** next to a sensor buried in a 20-cm filled hole **(B)**, shown in a technical card. Legend of the technical card as in Fig. 1. Only very marginal differences appear above about 10 Hz



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows: $\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Ref 1	0.27	21	200	900	0.28	0.05	21	|diff| = 0.00 t = 0.05 Similar peak frequencies
Test	1-Sand	0.27	20	200	900	0.28	0.03	20	
	Conclusion	NO INFLUENCE							

	Recorder	Sensor	Rec. type : simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P3-6-Grenoble-test4** Influence of a pile of sand Ref : natural soil ; Test : pile of sand	
Test	CityShark	5-second Lennartz LE3D		

Fig. 13 Example of H/V results at the same point with the sensor installed directly on the ground **(A)** and the sensor installed on top of a sand pile, the feet of the sensor being removed **(B)**. Note that there is no influence of this type of artificial interface on the H/V curve, which makes it a good candidate when artificial interface is needed to help level the sensor



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Ref 1	0.27	21	200	900	0.28	0.05	21	|diff| = 0.01 t = 0.05 Similar peak frequencies
Test	1-Sand & container	0.27	20	200	900	0.27	0.04	20	
	Conclusion	NO INFLUENCE							

	Recorder	Sensor	Rec. type : simultaneous	Low frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P3-6-Grenoble-test5** Influence of a pile of sand Ref : natural soil ; Test : plastic container filled with sand	
Test	CityShark	5-second Lennartz LE3D		

Fig. 14 Example of H/V results at the same point with the sensor installed directly on the ground **(A)** and the sensor installed in a plastic container filled with sand, the feet of the sensor being removed **(B)**. Note that there is no influence of this type of artificial interface on the H/V curve, which, when artificial interface is needed to help level the sensor, makes it an even better candidate than a pile of sand (Fig. 13) as it is easier to use and carry around sand in a container rather than just sand

4.3.7 P3-7 Gravel

Four tests were made both on a pile of gravel and on gravel in a plastic container. While the peak frequencies are not influenced, the H/V amplitudes are somewhat higher, and therefore recording on gravel either on a pile or in a plastic container is not recommended.

4.3.7.1 P3-Conclusion If it is necessary to use an artificial interface to install the sensor, the best is to use either sand in a container, which have no influence on H/V results. If another type of interface is used, it is recommended to perform a series of tests beforehand in order to determine if it influences the results, but soft interfaces such as Styrofoam, foam or cardboard should definitively be avoided, as well as gravel.

Aside from using an artificial interface, common sense dictates the way to install the sensor, the basic idea being that the sensor has to have a good contact with the ground, although it is not necessary to firmly block its feet, but neither put a weight on it to better anchor it to the ground.

The results are not influenced when the sensor is installed in a hole, either filled or not, compared to recording directly on firm ground.

4.4 P4 Nearby structures

Throughout a city, ambient vibrations are recorded over an artificially changing environment composed of large structures such as buildings and small structures such as poles or trees. It is therefore worth estimating if these structures are, by themselves, influencing H/V results.

4.4.1 P4-1 Large nearby structures

Thirteen measurements were made at various distances from a building before and after its construction. Close to the building strong changes are observed, especially in the 5–10 Hz range. The recording conditions have to be investigated more deeply. The number of tests is not sufficient to reach a real concluding statement.

4.4.2 P4-2 Small nearby structures

Twelve measurements were made at various distances from small structures. Close to the structures, up to about 10 m, the influence is highly noticeable especially under windy condition. This influence decreases very rapidly with the distance (Fig. 15). More investigations should be conducted.

4.4.2.1 P4-Conclusion Large structures may influence H/V results. In fact, several studies have evidenced structure-soil interaction, which may perturb H/V studies (e.g. Guéguen 2000; Chavez-Garcia and Cardenas-Soto 2002; Gallipoli et al. 2004; Dunand 2005; Cornou et al. 2005; Di Giulio et al. 2005). However, unlike influence from other experimental conditions it is a real interaction and other peak frequencies may appear on the H/V curves due to structure-soil interaction. But as they are related to the nearby structures they should be easily identified and discarded using, for example, a damping procedure evaluation to evidence them, or to perform measurements on nearby buildings to estimate their fundamental frequency.

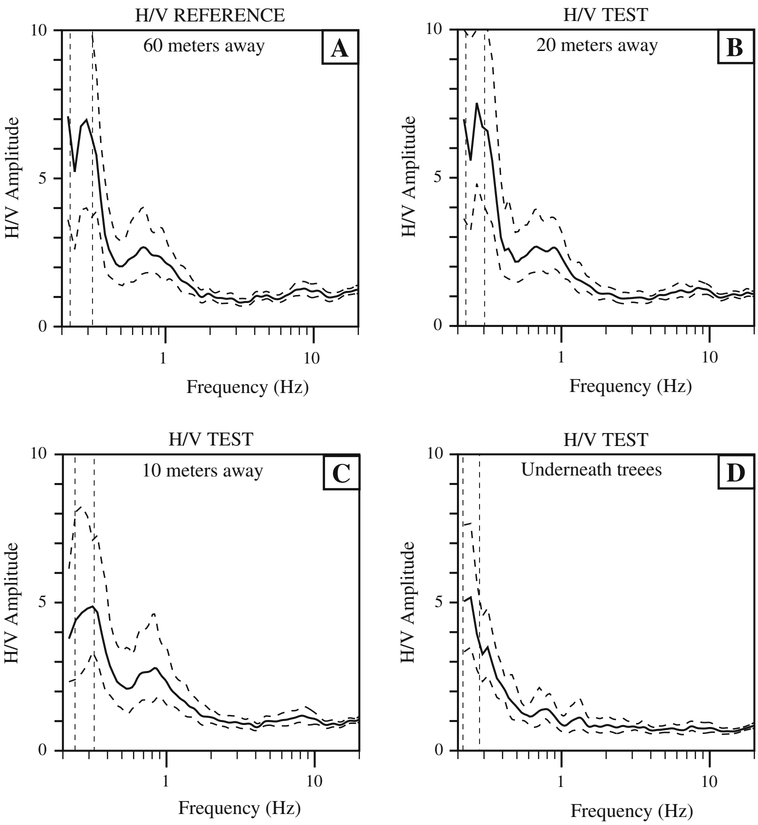


Fig. 15 Example of H/V results, under windy conditions, at points **(A)** 60-m away from a group of tall trees, **(B)** 20-m away from the trees, **(C)** 10-m away, and **(D)** underneath the trees. All the sensors were installed on the firm ground, without any protection against wind, and recorded synchronously with a CityShark II station. The point 60-m away is used as the reference point, and coincides with the reference point used in the other low-frequency sites figures, when no wind was blowing

Small structures, such as trees, by themselves do not influence H/V results, unless excited by an external solicitation, such as wind. The presence of such features should be indicated on the "field sheet."

4.5 P5 Underground structures

When performing ambient noise recording it may happen that the sensor is set-up, voluntarily or not, close to or on top of underground structures such as, for example, a parking lot a water or a gas pipe or a subway tube. It is important to evaluate to what extent such a drastic modification of the topmost layer of the ground may impact H/V results when recording either on top or at distance of such structures.

4.5.1 P5-1 Large underground structures

Twelve tests were conducted above a large cave and next to a subway tube. H/V results are considerably changed when recording over the large cave. Results obtained next to the subway tube show contradictory results, which might be explained by the influence of another experimental condition as no change is observed at the largest distance from subway compared to the reference next to it. More tests are necessary.

4.5.2 P5-2 Small underground structures

Four tests show mitigated results. It is recommended anyway to avoid recording, for example, on top of a sewer lid.

4.5.2.1 P5-Conclusion While more tests are necessary for establishing more thoroughly how H/V may be influenced by small underground structures it is definitely not recommended to record ambient noise over voids, either large or small.

4.6 P6 Meteorological conditions

As H/V experiments may spread over time, weather conditions may vary along a given experiment. It is therefore of prime importance to check if H/V results can be dependant on climatic changes.

4.6.1 P6-1 Wind

The Five specific tests show that H/V results are heavily influenced by strong wind when recording next to a feature connected to the ground. Tests for some experimental conditions (grass, trees or H/V stability over time) also clearly show that wind can modify the results in great proportions, while tests from others (asphalt, cement, . . .) show no direct influence of the wind. Tests on grass also show that even slight wind can influence the results. The wind and grass cases are discussed in more details in a further section.

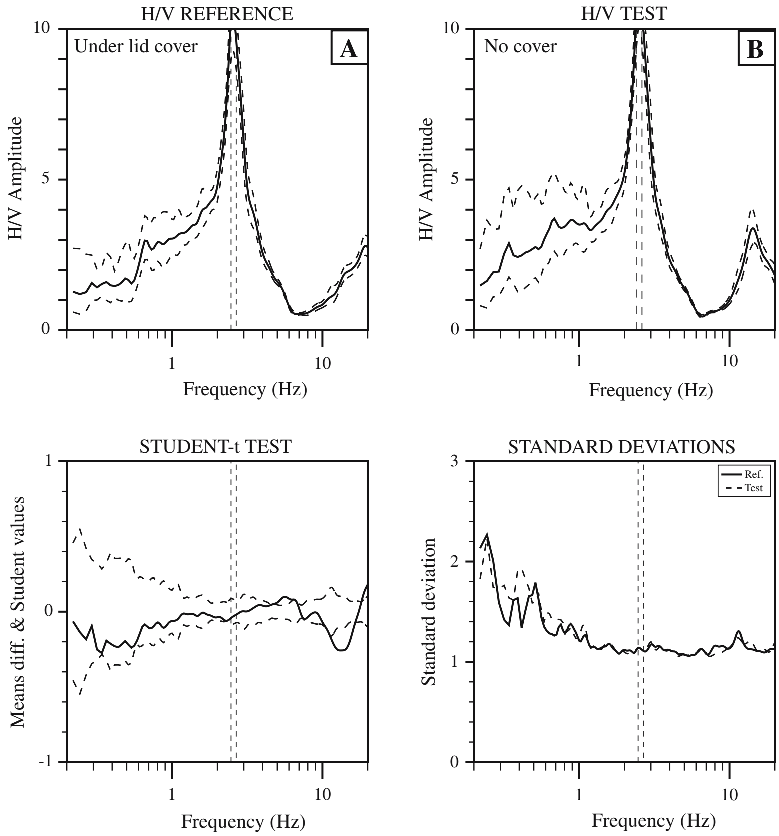
4.6.2 P6-2 Rain

Five tests were conducted. The value of the frequency peak is not changed in any case. However, the H/V amplitude is flattened under heavy rain and/or secondary peak appear in the higher frequencies (Fig. 16), but it is not really expected that people go on recording under such weather conditions anyway. Light rain does not have a noticeable influence. It has not been estimated at what level rain passes from light to heavy, though.

4.6.3 P6-4 Temperature

Nine tests were conducted only to compare morning and afternoon temperatures. No influence on H/V results is observed in the 17.2–22.8°C range. However, some squeeze of the amplitude of the fundamental peak can be observed for higher temperatures. Tests from other experimental conditions (snow, ice) show that recording under low temperature conditions (around 0°C) may affect the results, mainly due to equipment problems.

4.6.3.1 P6- Conclusion As long as they are not “too strong,” wind and rain by themselves do not influence H/V results. The combination of wind with grass or nearby structures (trees, buildings. . .) can however severely change H/V curves, especially in the low frequencies (below 1 Hz).



	File name	f0 ($\overline{H/V}$) (Hz)	Nb win	Sample rate (Hz)	Recording duration (s)	Frequency stastistics from individual windows			
						$\overline{f0}$ (Hz)	Sigma (Hz)	Nb win	Student-t test
Ref.	Sous abri	2.54	11	200	900	2.57	0.10	11	|diff| = 0.05 t = 0.12 Similar peak frequencies
Test	Sous pluie	2.51	13	200	900	2.52	0.04	13	
	Conclusion	No influence inside the peak zone, slight influence outside (19%)							

	Recorder	Sensor	Rec. type : simultaneous	Medium frequency site
Ref.	CityShark	5-second Lennartz LE3D	**P6-2-Grenoble-test1** Influence of rain Ref : under protection ; Test : under rain	
Test	CityShark	5-second Lennartz LE3D		

Fig. 16 Example of H/V results at the same point from records obtained under the rain, with the sensor under lid cover **(A)** and without cover **(B)**, shown in a technical card. Legend of the technical card as in Fig. 1. Light rain as in this example does not strongly influence H/V results

A side conclusion of a test for H/V variation with time (P8-2) with a sensor installed on the ground, without interface of any kind, without protection against wind nor rain show that these weather conditions do not influence H/V results.

The only concern about temperatures appears to be on extreme values either low or high. More tests on this subject are needed though. In any case, it is recommended to follow the manufacturer specifications.

4.7 P7 Water table

This test is not easy to conduct, it is why only one test could be conducted, with a 1 m change in the water table level from about 4.5 to 5.5 m, showing no influence of this experimental condition on H/V results. More tests are needed to better investigate this case.

4.8 P8 H/V stability over time

H/V experiments may be conducted over a long period of time (several months), or the recordings may be performed during both day and night. One has therefore to make sure that H/V results at a given site are not dependent upon when they have been performed and are reproducible over time.

4.8.1 P8-1 H/V variation with time on no-peak sites

Only two tests were performed with time intervals varying from 3 to 5 years. There is no variation with time. However, given the fact that there are only two tests, it is hazardous to give a definitive conclusion. Some perturbations were observed however in case of strong meteorological storms (Cara et al. 2003).

4.8.2 P8-2 H/V variation with time on low frequency sites

Sixty tests were performed, testing time lags varying from hours to 1 year. There is usually no variation with time. The differences that appear in some tests are not related to time, as later tests do not show differences any more but a return to previous results; they might be due to variations of weather or human activity. More tests should be performed with a follow-up of the other possible variable experimental conditions. Another test was running in the Grenoble (France) region for about 3 months on a low-frequency site, with 15 min recording every hour, confirming the H/V stability with time both along the 3 months recording as well as between day and night.

4.8.3 P8-3 H/V variation with time on medium frequency sites

Fifty tests were performed with time lags varying from hours to 1 year. No variation with time is observed inside the peak zone. The marginal differences that appear for some tests on the rest of the H/V curve are not related to time, as later tests do not show differences; they might be due to variations of weather or human activity. However, with the eight tests performed with a very long period seismometer (Guralp CMG-40 T), while some of the curves are very similar to each other, very high variations from the reference curve. In this case, either the reference is not right or the seismometer is not suitable for this type of experiment. Anyway, more tests should be performed with the follow-up of other possible variable experimental conditions.

4.8.3.1 P8-Conclusion. With the exception of the tests performed with a long period seismometer, no noticeable H/V variation with time has been evidenced, for periods varying from hours to weeks and years, as also evidenced by several authors (Volant et al. 1998; Mucciarelli and Monachesi 1998; Bour et al., 1998). However, there might be some low frequency perturbations for low frequency and "no peak" sites associated with meteorological storms.

4.9 P9 Noise sources

Ambient vibrations recorded for H/V experiments are supposed to be much closer to white noise than to monochromatic signals. However, recordings may be perturbed by close noise sources either with a monochromatic content or producing a specific pulse-like signal. It is therefore of prime importance to check how H/V results can be influenced or not by close sources of noise. There is no agreement on this topic as, on one hand most authors consider that non stationary noise should be excluded from H/V processing (e.g., Horike et al. 2001), while, on the other hand Mucciarelli (1998) showed that this type of noise can be used in the processing and indeed is beneficial.

4.9.1 P9-1 Steps

Seven tests were performed on asphalt with people walking around the sensor at distances varying from 0.5 to 25 m from it on a low-frequency site. It is not sure that it is representative of people passing by during a real life recording. No influence is noted, except when people are walking at 1 m or less from the sensor. Three tests were also performed on natural soil at 1, 5, and 10 m from the sensor on a medium frequency site. The results show very large variations from the reference, with the peak being completely squeezed and the curve of the tests looking much like a “no peak” site case. It is not recommended to have recordings with too long periods of people stepping too close to the sensor. It is in any case recommended to remove this type of signal when processing data. However, when recording on asphalt, step influence much less the results than when recording on natural soil.

4.9.2 P9-2-1 Moving cars

Thirty-six recordings were made at various distances from two highways, one with quite “heavy” traffic, the second with “lighter” traffic, and three recordings were made with a car running around the sensor at distances from 1 to 20 m. No influence of heavy traffic is noticed at distances larger than about 20–40 m from heavy traffic highway (Fig. 17), and about 15–20 m from light traffic highway. Note that when processing data with the default processing parameters (i.e., with the anti-trigger on, thus eliminating transients from the processing) the results do not show much changes, only some squeeze of the H/V amplitudes compared to the reference results. A car running around the sensor has a strong influence up to 20 m, the meaning of which is not really clear. Our results agree with those of Mucciarelli (1998) who, using fake car traffic, also conclude that traffic is not a problem for H/V results, as long as recording is performed at few tens of meters away from the traffic location.

4.9.3 P9-2-2 Cars turned on, not moving

This situation may be encountered when recording close to a traffic light. From the four tests it is noticeable that amplitudes in the lower frequencies can have a higher value.

4.9.4 P9-3 Trains

Only two tests were performed recording one train, and therefore there are not enough data for interpretation as only one short window of time is perturbed by the train. More tests are needed. However, usually a train does perturbate the recording over a more than a minute of time and is therefore easily removed from the clean signal used for the processing.

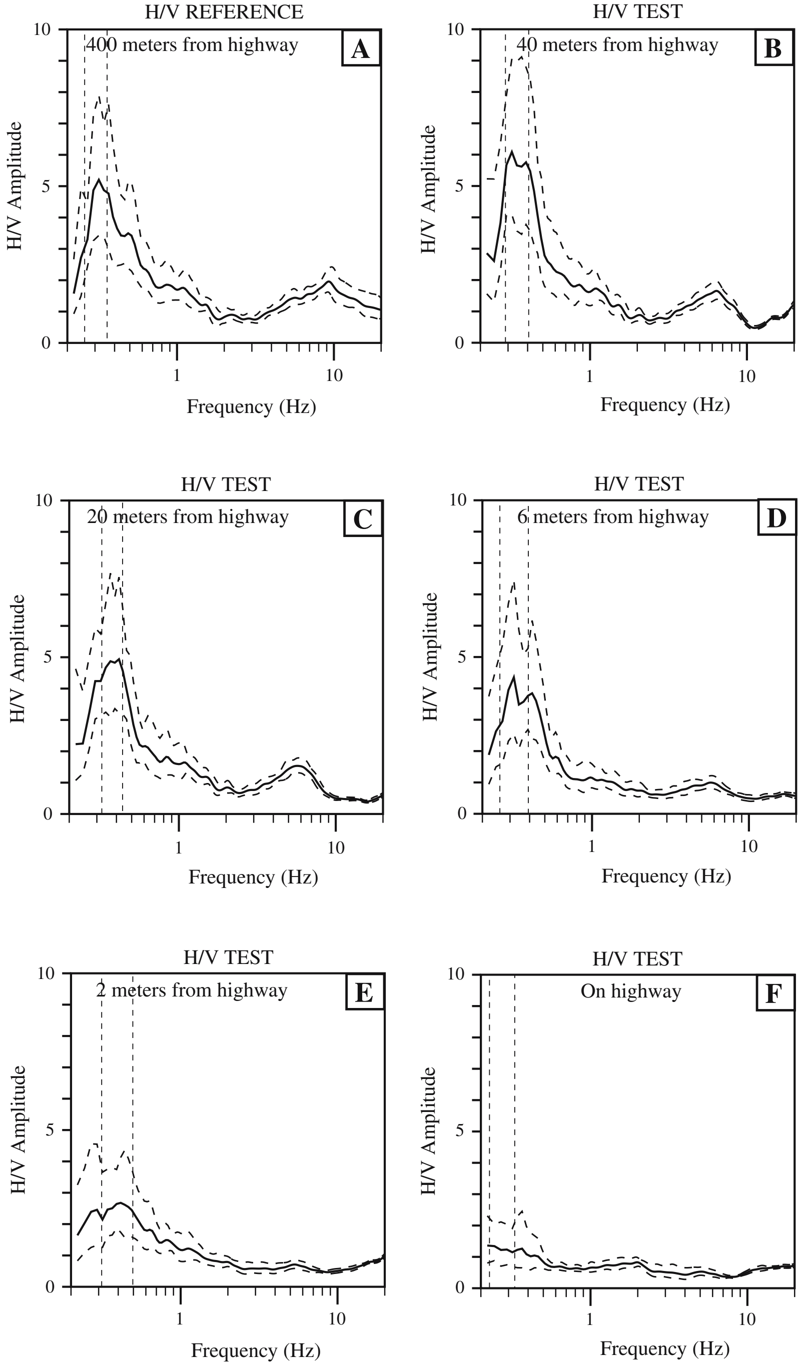


Fig. 17 Example of H/V results obtained at various distance from a high-density traffic highway. The reference, which is supposed to be representative of the studied zone, is located at 400 meters from the highway **(A)**. Then, recordings were made at 40 m **(B)**, 20 m **(C)**, 6 m **(D)**, 2 m **(E)** from the highway, and on the highway itself **(F)**

4.9.5 P9-4 Machinery

Recording too close to a machinery working continuously highly influences H/V results (four tests). In most cases the value of the peak frequency is quite different. However, if the time window perturbed by the machinery is small compared to the total recording (one test) it does not influence the results. If the machine works for long, the H/V curve exhibits a sharp peak at the machine frequency, which is possible to identify. In any case, if it is possible it is always a good idea to wait for the machinery to stop working.

4.9.6 P9-5 High voltage cable

Twenty-two tests were conducted, on a low-frequency site, from 5 to 150 m to a high voltage line perpendicularly to the line in two directions, i.e., going away from the line both to the north and the south. Five tests were also conducted underneath the line. H/V results are not influenced. The marginal differences in amplitude may be rather due to variations in the surficial layer or of the type of soil (some recordings were performed in fields, other on a pathway), not to the power line.

4.9.7 P9-7 Sea

Six tests were performed at distances between 30 and 3,500 m from the sea when it was agitated and not on three low and three medium frequency sites. No influence is noticed inside the "peak zone" and the value of the soil fundamental frequency does not change significantly, except for the closest point to the sea, which exhibits a 15% variation of the frequency peak. It is recommended in case of agitated sea either to postpone the experiment or to stay several hundred meters away from the sea.

4.9.8 P9-8 Music coming from the car participating to the experiment

Two tests were conducted. A slight influence is noticed in the lower frequencies. People in charge of the recordings may listen to the music, not too loud though, but definitively avoid dancing next to the sensor as shown by test P9-1, even though people get bored after several hours of recordings. Just a humoristic way to tell that the team conducting the recording experiment should minimize the production of extra sources of noise.

4.9.8.1 P9-Conclusion Not surprisingly, recording next to strong sources of noise influences H/V results. The main problem is posed by continuous sources, while heavy transient, although having a real influence on results, can easily be eliminated from the data processing. In the case of high occurrence of transients a longer period of recording is recommended. Generally speaking it is recommended to avoid recording close to sources of noise such as heavy traffic, agitated sea or machinery as well as to avoid producing perturbations close to the sensor (steps, engine on . . .).

5 Some specific issues

Four cases of primary importance (grass, asphalt, water, and wind) raised questions because they showed contradictory results either with published cases or among the results obtained by the different teams of the SESAME project. They were therefore more deeply investigated. The recordings used to study these specific issues are not displayed on the SESAME website.

5.1 The grass case

During the tests, it has been claimed that recording with the sensor set up on grass had definitively an influence on H/V results, expressed by artificial peaks in the low-frequency range. This statement could be of great importance, as if grass is nowadays quite scarce in urban environments it is still quite common in the countryside were microzonation experiments can be conducted in view of, for example, city expansions.

We therefore conducted a series of tests dedicated to this problem. First, a CityShark II station was used with six Lennartz 5-s seismometers installed, respectively (1) on meadow grass, (2) on the firm ground about 5–10 m from the grass, (3) in a open hole, (4) buried in a filled hole, and (5, 6) two on lawn grass. Records were performed during 15 m every hour during two periods of 3 days one week apart. The recordings from the 2 seismometers set up in the holes and on the firm ground give consistently the same H/V curves, while the 4 seismometers installed on grass and on the firm ground show irregular departures from a comparable curve to curves highly perturbed in the low frequencies. The only change in recording conditions was the wind blowing or not, although we do not have a measurement of the speed of the wind, showing higher perturbations below 1 Hz with the strength of the wind (Fig. 18). When the wind was not blowing, all six H/V results are consistently comparable.

Second, a CityShark II was used with six Lennartz 5-s seismometers installed, respectively (1) on a paved road, (2) in a 30-cm open hole, (3, 4) two on grass, (5) on a place were a piece of grass has been removed, and (6) on top of the removed piece of grass that is itself laying on the nearby not removed grass. The last of these listed tests was performed to mimic a rather unstable position of the sensor, as its feet were not directly in contact with the ground. Four 15-m records were made. The wind was not blowing and no differences are observed between recordings on grass and ground or asphalt. The only different H/V results are those obtained with the seismometer set up on a layer of grass itself laying on top of the grass field, for which a higher amplitude is observed in the low frequencies.

Finally, four 15-min records were performed with a CityShark II and six Lennartz 5-s seismometers installed, respectively on a paved road, in tall grass (about 1 m), on the ground (grass removed), two on lawn grass and on a car-way. The only problem came from the recording with the sensor setup on tall grass showing both perturbations in the low frequencies and artificial peaks in the high frequencies.

Our experiments very clearly show that grass by itself has no influence on H/V results, except on tall grass. However, recording on grass is very sensitive to the wind, which creates very high perturbations below about 1 Hz, similar to what is observed when using too soft an interface in-between ground and sensor (cf. P3-1), without real influence on higher frequencies. Another problem arises when grass is tall or thick enough that the seismometer is not correctly coupled to the ground, in which case not only low frequencies are perturbed but artificial peaks can also show up on H/V curves. As it is difficult to have an objective guess of the wind strength or of how reliably the sensor is connected to the ground, it looks better to either remove grass or to setup the sensor into a hole when recording over a grassy surface.

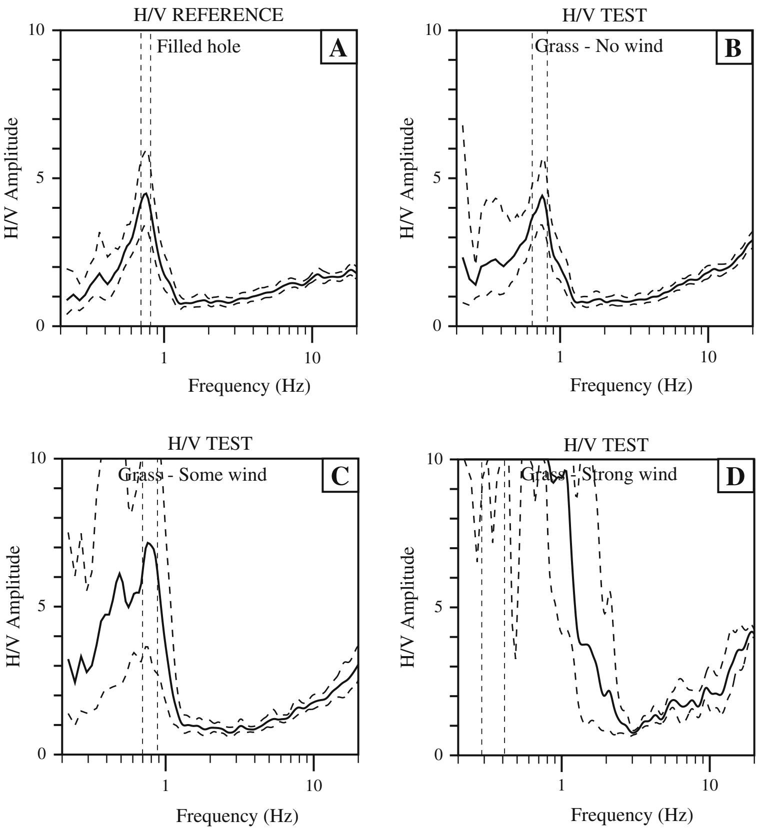


Fig. 18 Example of H/V results obtained at the same point in a buried hole, used as the reference **(A)**, on grass without wind **(B)**, on grass with some wind **(C)**, on grass with strong wind **(D)**. The strength of the wind has not been measured, only estimated as anyone can do commonly when walking around. The degree of perturbations in the H/V curve clearly increases with the strength of the wind. Note also that the grass by itself does not influence the H/V curve by comparing **(A)** and **(B)**, which results are obtained when no wind is blowing

5.2 The asphalt case

Asphalt also deserves more attention as it is, together with cement or concrete, one of the main ground topping encountered in cities and as Mucciarelli (1998) found sharp 5-Hz peak from recordings on a paved road that do not show up on H/V from free-field recordings, making him raise severe doubts about recordings in urban environments. We therefore conducted a series of 47 specific tests. Recordings were performed on roads with various thicknesses of asphalt, next to simultaneous recording on ground. The effect mentioned by Mucciarelli (1998) around 5 Hz is never observed. These recordings confirm the observation mentioned previously in the P2-4 discussion (Fig. 9) that only marginal perturbations are observed in the 7–8 Hz range that do not affect the general shape of the H/V results. In any case it is not observed such things as strong enough artificial peaks that can be misleading in the choice of the frequency value of the peak at a site.

From our study, we conclude, to the contrary of Mucciarelli (1998), that it is not a problem to record ambient noise on asphalt. It should be noticed however that the soil resonance peak of Fig. 9 is clipped at ten while the “asphalt” peak just reaches 2, while in Mucciarelli (1998) the asphalt peak was almost three against a soil resonance peak reaching 3.5. Generally speaking, what is termed “asphalt” is a wide range of mixtures of gravel, bitumen and sometimes cement, with a corresponding large variation of its shear stiffness. It may be that the characteristics of the mix are designed to comply with the climate of different zones, so that “asphalt” in Norway, France or Italy, for example, is not the same thing, so a factor 2 in frequency and 1.5 in amplitude is not so strange.

It should be mentioned that recording seismic waves on asphalt has also been taken into account by other geophysical techniques such as NASW/ReMi or SASW, by Louie (2001) and Miller et al. (1999), respectively, who found that “recording acoustic data on asphalt or cement surfaces generally comes with coupling problems, limited amounts of vertically propagating body waves, and complex high-frequency trapped and guided waves.” It is not proved, however, that this applies when recording ground ambient vibrations at frequencies below 10 Hz.

5.3 The water case

The results obtained with a change of about 1 m of the water table level do not perturbate H/V results. From our results, it appears, however, that water in the most surficial layer of the ground can have some influence on H/V curves. When recordings were on a site performed before and after several days of rain, we evidenced a light shift of the frequency peak towards smaller values (0.32 down to 0.28 Hz on the Grenoble campus site), an effect also shown by Mucciarelli et al. (2003). This effect disappears rapidly after few days without rainfall. For recordings performed on water-saturated ground, other unwilled effects such as artificial peaks in the higher frequencies can appear.

Our conclusion is that variation of water concentration in deeper layer does not influence H/V results, while it is not recommended to perform records on water-saturated ground top layers. Also, a more thorough experiment based on quantitative estimation of the water content would be welcome.

5.4 The wind case

In our study, H/V disturbance from the wind is not linked to the wind by itself, as shown by the results obtained on asphalt or in a small hole, but always comes when somehow the wind can excite the ground around the sensor through devices connected to the ground, such as tree, building, grass ... Cara et al. (2003) observed an effect associated with meteorological storms in the low-frequency range, even though the sensors used for their study are well buried. In the SESAME experiment it has always been possible to get rid of the wind effect from small exciters (e.g., grass or tree) by simply setting the sensor in a hole, not even filled, and just about the size of the sensor, or by setting the sensor few centimeters away from grass, on asphalt for example.

As Mucciarelli (1998), we observe very high perturbations caused by the wind below and up to 1 Hz, while Cara et al. (2003) observed strong wind disturbances below about 0.2 Hz and, with a minor extent, up to 1 Hz. While we make the same observations as Mucciarelli (1998) on the effect of wind on H/V curves, we show that it is produced when it acts on features coupled to the ground and not when acting directly without coupling on the recording equipment. However, as pointed out by Mucciarelli (1998) himself the quite drastic conditions (wind was simulated using a compressed air stream) he used were certainly responsible of this fact.

Finally, a one-and-a-half month experiment with a sensor set-up directly on the ground, i.e., not in a hole, shows no evidence of H/V variation due to the wind, even though spectral amplitudes on each component were found to have wide variations. Mucciarelli et al. (2005) analyzed the effect of wind from (1) a permanent, three-component seismological station under various wind patterns, and (2) an experiment under controlled condition in a wind room equipped with a laser particle image velocimeter on various sensor-digitizer configurations. They also found that, while the wind increases spectral amplitude of all components, it does not affect H/V.

We strongly recommend to avoid ambient vibration recordings when the wind is blowing, especially for low ($< 1-2$ Hz) frequency sites. The wind excitation is a function of the roughness of the surface, including natural (trees, hills, mountains, etc.) and anthropic structures (houses, antennas, etc.), so the threshold is not unique and can be different in different situations. However, there should be no problem to get the peak frequency value for higher frequency sites (above 1 Hz) that we found not to be contaminated, provided that in this case the wind-induced lower frequency peak is not taken as being the natural frequency of the site, which should not be the case as the usual observed effect is a continuously growing curve rather than a real peak, i.e., with both a growing and a descending part.

6 Conclusion

It should be kept in mind that this study is dealing with frequencies from 0.2 up to 20 Hz. Our conclusions apply only in this frequency range, and it is possible that outbound some of the tested experimental conditions behave in a different way.

The first main concern raised by this study is that it is mandatory to check the recorded signal before performing H/V computation, as blind calculation can lead to severe misinterpretations due to ill recorded signal, as observed, for example, from recordings on ice.

The second point is that the recording equipment, especially the sensor, has to be regularly tested, for example by performing frequent recordings on a well-known site. Some of our tests were first declared as showing that the tested experimental condition had influence on H/V results, while after closer look it appeared to be due to a problem in the reference data due to a failure in the recording system that clearly showed up when checking on the recorded signal.

One of the main result is that no matter how strongly a tested experimental condition influences H/V amplitudes curves, the value of the frequency peak is usually not affected, with the noticeable exception of the wind when the peak is in the low-frequency range ($<1-2$ Hz). Recording under strong wind conditions should definitively be avoided, especially in place where nearby tall buildings, trees, poles, ... are present, although the wind influence is concentrated in the low-frequency range and is easily recognizable.

Another important outcome is that asphalt, concrete and short grass by themselves have no influence on H/V results and that, as long as external conditions do not change (e.g., a naked piece of land that becomes built), H/V results are stable over time. However, this observation only concerns the soil topping, while unknown underground structures, for example, may bias the H/V results. Recording directly on grass during windy periods, especially on low-frequency sites, is definitively not recommended unless the sensor is set-up into a hole.

Transients, such as cars, trains or pedestrians passing-by, may influence the results. This influence, however, is noticed only very close to the transient source (e.g., on the side of an highway) and decreases very rapidly with distance. They can anyway easily be removed during signal processing so that they do not perturb the results. When recording next to a high-transient activity it is recommended to increase the recording length in order to get enough stationary windows to process.

The results from this study show that (1) basically any equipment that has been tested can be used except accelerometers as sensors (for a more detailed discussion see Guillier et al. 2005), (2) recorder parameterization does not matter significantly as long as signal saturation is avoided, and (3) the sensor can be installed without too much precision as long as logical conditions are kept in mind (e.g., no over-tilting nor weight on the sensor) and the sensor is fully in contact with the medium on which it is set up. It is not recommended to use interface to set up the sensor, unless really necessary (e.g., to make it easier to level the sensor), in which case it is recommended to use a container filled with sand. In any case, before using an interface it is strongly recommended to test it to insure that it has no influence on the results. More generally speaking it is strongly recommended to make sure that the sensor is set up on a firm material, as even only a thin layer of soft material laying in-between the sensor and the ground has been shown to provoke very undesirable effects on H/V results, including fake peaks.

It is highly recommended to check the peak that is chosen to be the fundamental peak of the studied site is not a forced peak from industrial origin by applying the random decrement technique (see Dunand et al. 2002) to the noise recordings. If the damping factor around the frequency of interest is low, the peak has an anthropic origin, and the frequency should not be taken as a soil peak.

H/V amplitude is highly dependant on the amplitude level of the recorded ambient noise. Therefore, in order, for example, to make a study using relative H/V amplitudes from various sites it is highly recommended that the processed recordings be without any signal saturation, which may highly minimize H/V amplitudes.

Most of the experimental conditions tested are shown not to affect the H/V results, as long as the wind is not involved and, to a lesser extent, water in the most surficial layer of the ground. However, some experimental conditions would need to be tested more thoroughly in order to get a more precise evaluation of their possible influence.

Concerning the recording team, it has been clearly shown that it is not good to forget to turn the car engine off, and that while it is not a problem to listen to music while waiting for the data to be recorded, as long as it is not too loud, it is recommended not to dance around the sensor, even though the music is great. In other words the recording team should try to avoid as much as possible to produce additional artificial sources of noise. It should, to the contrary, try to make pedestrians passing not too close to the sensor, ask—kindly—cars stopping by and keeping their engine on to move away, etc..

Finally, it is strongly recommended to regularly fill “field sheets” when performing ambient noise recordings, in which all experimental conditions (ground topping, meteorological conditions, transients, nearby structures, . . .) are as extensively reported as possible in order to make sure that any differences in results are not due to differences in experimental conditions and consequently to avoid wrong interpretations and/or misuse of the H/V method.

These SESAME results were extensively used to put together user guidelines proposed by the SESAME project, which preliminary version were presented by Kohler et al. (2004), in order to help people concerned by the use of H/V-ambient noise for such tasks as, for example, microzonation. It will be useful for two main reasons: (1) avoid experiments with wrong recording settings and/or under wrong experimental conditions, and (2) somewhat standardizing data acquisition for this type of experiment, thus making it easier to compare results from different experiments, and guide the user in the result interpretation process. Also an example of a "field sheet," mentioned in the precedent paragraph, is proposed in the SESAME guidelines.

The H/V-ambient vibrations method is interesting in that it is non-expensive, non-destructive, easy and rapid to perform. The good news from this study is that it can be kept these ways, and that it is unnecessary to deploy heavy means such as, for example, blocking streets to car and pedestrian traffic or that it is mandatory to perform recordings during quietest periods (night, week-ends,. . .) or over the shortest possible time lag. However, another important lesson is that easy does not mean anyhow and without a minimum of care, the main concerns being signal saturation, wind, transient density, close sources of noise, wrong type of equipment (avoid accelerometers) or defective equipment, blind data processing and making the method tell more than it can. More extensive propositions and rules of thumb for data acquisition and processing can be found in the SESAME guidelines and user manual, available on http://sesame-fp5.obs.ujf-grenoble.fr/

Acknowledgments This study was a collaborative work between the Laboratoire de Géophysique Interne et Tectonophysique (LGIT, Grenoble, France), the Insitutt for Geovitenskap, Universitetet I Bergen (UIB.ISI, Bergen, Norway), the Swiss Federal Institute of Technology (ETH, Zürich, Switzerland), the Insituto de Ciências da Terra e do Espaço (ICTE-UL, Lisbon, Portugal), the Intituto Nazionale di Geofisica e Vulcanologia (INGV, Roma, Italy), and the Centre d'Études Techniques de l'Équipement Méditerranée (CETEMED, Nice, France). Jean-Luc Chatelain and Bertrand Guillier participated to the project courtesy of the Institut de Recherche pour le Développement (IRD). We thank G. Collombat and J.-P. Glot for their help with the Student-*t* test. We thank the technical staffs from the participating institutions, which have helped in the experiment preparation and data collection. We are very grateful to M. Mucciarelli for is very useful comments and suggestions. Last, but definitively not least, Laurence Bourjot has been appreciated by everyone in the SESAME project as a great and very friendly coordinator, sometimes flying in the sky, however. This project (Project EVG1-CT-2000-00026 SESAME) has been supported by the European Commission—Research General Directorate, as well as by governmental research offices of the various countries participating in the project. This project would never have been possible without a strong, faithful and no short-profit oriented public research, which is nowadays facing the greatest destruction threat ever. Save public research.

References

Bard P-Y (1999) Microtremor measurements: a tool for site effect estimation? In: Irikurak K, Kudok K, Okadah H, and Sasatanit T (eds) The effects of surface geology on seismic motion. Balkema, Rotterdam 1251–1279

Bard P-Y (2002) Extracting information from ambient seismic noise: the SESAME project (Site EffectS assessment using AMbient Excitations). European Project EVG1-CT-2000-00026 SESAME, http://sesame-fp5.obs.ujf-grenoble.fr Review meeting, Brussels, Belgium

Bard P-Y, the SESAME team (2003) The EU SESAME project: presentation, latest results and perspectives. Workshop on effects of surface geology on seismic motion, IUGG/IASPEI 2003, July 11 2003, Sapporo, Japan

Bour M, Fouissac D, Dominique P, Martin C (1998) On the use of microtremor recordings in seismic microzonation. Soil Dyn Earth Eng 17(7–8):465–474

Cara F, Di Gulio G, Rovelli A (2003) A study on seismic noise variations at Colfiorito, Central Italy: implications for the use of H/V spectral ratios. Geophys Res Lett 30(18): 1972

Chatelain J-L, Guéguen P, Guillier B, Fréchet J, Bondoux F, Sarrault J, Sulpice P, Neuville J-M (2000) Cityshark: a user-friendly instrument dedicaced to ambient noise (microtremor) recording for site and building response studies. Seism Res Lett 71(6):698–703

Chávez-García FJ, Cárdenas-Soto M (2002) The contribution of the built environment to the 'free-field' ground motion in Mexico City. Soil Dyn Earth Eng 22:773–780

Cornou C, Guéguen P, Bard P-Y, Haghshenas E (2005) Ambient noise energy bursts observation and modeling: trapping of harmonic structure-soil induced waves in a topmost sedimentary layer. J Seismol 8:507–524

Di Giulio G, Azzara RM, Cultrera G, Giammarinaro MS, Vallone P, Rovelli A (2005) Effect of local geology on ground motion in the city of Palermo, Italy, as inferred from aftershocks of the 6 September 2002 Mw 5.9 earthquake. Bull Seism Soc Am 95(6):2328–2341. doi: 10.1785/0120040219

Dunand F (2005) Pertinence du bruit de fond sismique pour la caractérisation dynamique et l'aide au diagnostic sismique des structures de génie civil. Ph.D. thesis, Grenoble University, France, 378 pp

Dunand F, Bard P-Y, Chatelain J-L, Guéguen P. Vassail T, Farsi M (2002) Damping and frequency from randomdec method applied to in situ measurements of ambient vibrations: evidence for effective soil structure interaction. Proceedings of the 12th European Conference on Earthquake Engineering, London, September 9–13, 2002

Gallipoli MR, Mucciarelli M, Castro RR, Monachesi G, Contri P (2004) Structure, soil-structure response and effects of damage based on observations of horizontal-to-vertical spectral ratios of microtremors. Soil Dyn Earth Eng 24:487–495

Guéguen Ph (2000) Interaction sismique entre le sol et le bâti: de l'interaction sol-structure à l'interaction site-ville. Ph.D. thesis, Grenoble University, France, 184 pp

Guillier B, Atakan K, Duval A-M, Ohrnberger M, Azzara R, Cara F, Havskov J, Alguacil G, Teves-Costa P, Theodulidis N, the SESAME Project WP02-Team (2002a) Influence of instrumentation on H/V spectra of ambient noise. EGS, 22–26 April 2002, Nice, France

Guillier B, Atakan K, Duval A-M, Ohrnberger M, Azzara R, Cara F, Havskov J, Alguacil G, Teves-Costa P, Theodulidis N, the SESAME Project WP02-Team (2002b) Influence of instrumentation on H/V spectra of ambient noise. European Seismological Commission, September 2002, Genova, Italy

Guillier B, Atakan K, Chatelain J-L, Havskov J, Ohrnberger M, Cara F, Duval A-M, Zacharopoulos S, Teves-Costa P, the SESAME Team (2005) Influence of instruments on the H/V spectral ratios of ambient vibrations. this volume

Horike M, Zhao B, Kawaze H (2001) Comparison of site response characteristics inferred from microtremors and earthquake shear waves. Bull Seism Soc Am 91(6):1526–1536

Koller MG, Chatelain J-L, Guillier B, Duval AM, Atakan K, Lacave C, Bard P-Y, the SESAME participants (2004) Practical user guideline and software for the implementation of the H/V ratio technique on ambient vibrations: measuring conditions, processing method and results interpretation. In: Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada August 1–6, 2004, Paper n°3132

Konno K, Ohmachi T (1998) Ground-motion characteristics estimated from sSpectral ratio between horizontal and vertical components of microtremor. Bull Seism Soc Am 88(1):228–241

Louie JN (2001) Faster, better: shear-wave velocity to 100 meters depth from refraction microtremor arrays. Bull Seism Soc Am 91(2):347–364

Miller RD, Xia J, Park CB, Ivanov JM (1999) Multichannel analysis of surface waves to map bedrock. Leading Edge 18:1392–1396

Mucciarelli M (1998) Reliability and applicability of Nakamura's technique using microtremors: an experimental approach. J Earthq Eng 2(4):625–638

Mucciarelli M, Monachesi G (1998) A quick survey of local amplifications and their correlation with damage observed during the Umbro-Marchesan earthquake of September 26, 1997. J Earthquake Eng 2:325–337

Mucciarelli M, Gallipoli M, Arcieri M (2003) The stability of the horizontal-to-vertical ratio of triggered noise and earthquake recordings. Bull Seism Soc Am 93(3):1407–1412

Mucciarelli M, Gallipoli M, Di Giacomo D, Di Nota F, Nino E (2005) The influence of wind on measurements of seismic noise. Geophys J Int 161(2) 303–308. doi:10.1111/j.1365-246X.2004.02561.x

Nakamura Y (1989) A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quaterly Rep Railway Tech Res Inst 30(1):25–30

Parolai S, Galiana-Merino JJ (2006) Effect of transient seismic noise on estimates of H/V Spectral ratios. Bull Seis Sco Am 96(1):228–236 doi: 10.1785/0120050084

SESAME WP02 team (2002) WP02, Controlled Instrumental Specifications, University of Bergen. European Commission—Research General Directorate Project No. EVG1-CT-2000-00026 SESAME, report D01.02, 80 fig., 250 pp

SESAME WP02 team (2003) WP02, Final report on Measurement Guidelines, H/V Technique: experimental conditions, LGIT Grenoble, CETE Nice. European Commission—Research General Directorate Project No. EVG1-CT-2000-00026 SESAME, report D08.02, 57 fig., 96 pp

Volant Ph, Orbovic N, Cotton F (1998) Estimation of site response using the H/V method: application and limits of this technique on Garner Valley downhole array dataset (California). In: Proceedings of the 11th European conference on earthquake engineering, Paris

Whiters M, Aster R, Young C, Chael E (1996) High-frequency analysis of seismic background noise as a function of wind speed and shallow depth. Bull Seism Soc Am 86(5):1507–1515