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INFLUENCE OF EXPERIMENTAL CONDITION FOR « H/V » ON AMBIENT NOISE VIBRATION METHOD

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SUMMARY

The H/V-noise technique is now widely used to estimate site effect parameters, and many surveys using this technique have provided convincing results. However, a general consensus on a methodology for data acquisition and result interpretation has yet to be found. One of the aims of SESAME is to evaluate the influence of experimental conditions on the results of this technique. The SESAME WP02 team defined nine general parameters (P) to be tested, including the influence of (P1) recording/instruments parameters, (P2) in situ soil-sensor coupling, (P3) modified soil-sensor coupling, (P4) nearby structures, (P5) underground structures, (P6) weather conditions, (P7) water table level, (P8) time-period on results stability, (P9) noise sources. An experimental protocol for data acquisition and result comparison has been elaborated. For each test, records were performed simultaneously for a reference and for the tested parameter, with only one parameter changing at a time. In order to improve this evaluation, each test has been performed by several teams within various contexts. Hence, several hundreds of records were converted into a common format and processed in the same way to obtain the H/V curves. The similarity of the results obtained for a reference and a tested parameter is checked with the means of statistic tools applied on both the amplitude all along the H/V curve and the frequency peak value. The results of this study are used to propose recommendations for ambient noise data acquisition.

INTRODUCTION

The project named SESAME (Site EffectS assessment using AMbient Excitations) aims to investigate the reliability of two techniques born in Japan using ambient noise recordings: the very simple H/V technique ("Nakamura"), and the more advanced array technique. They offer many advantages, especially in urban areas, and their use (perhaps misuse) is rapidly spreading world-wide; but their physical basis and actual relevancy for site effect estimates has never reached a scientific agreement. The project goal is to tackle

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these methods under different viewpoints, understand their physical basis, assess their actual meaning in view of site effect estimation, and propose user guidelines and processing software to ensure a correct use, and thus improve significantly the mitigation tools. The aim of WP02 is to evaluate the influence of experimental parameters in stability and reproducibility of “H/V on ambient vibrations”. This evaluation was conducted in a purely experimental process by means of various test of parameter. The variations of the “H/V curves” had to be checked both in frequency domain and in amplitude for each experimental parameter. The investigations carried out in this WP02 allow to precise the experimental conditions under which measurements have to be performed to provide reproducible, reliable and meaningful results.

LIST OF PARAMETERS TO TEST

The experimental tested parameters are classified in nine categories, termed P1 to P9 for more convenience. Three types of parameters can be distinguished:

• Parameters relative to the acquisition system and configuration:
P1: recording/instruments parameters.
A special workshop was devoted to the instrument influence: H/V curves obtained from many instrument type have been compared.

• Parameters of the site itself.
P2: in situ soil-sensor coupling
P3: modified soil-sensor coupling
P4: nearby structures
P5: underground structures

• Parameters relative to the variation of external conditions at the same place:
P6:weather conditions (temperature, wind, rain, snow, ice)
P7: water table level, pore pressure
P8: results stability with time according to the type of soil response
P9 : noise sources (car passage, train passage, human step, engine, machinery …)

EXPERIMENTAL PROTOCOL

This empirical evaluation lays on the multiplicity of test performed by several team performed on the bases of the same experimental protocol. Each parameter should be evaluated several times in different environment, with different mean before conclusion could be reach.
For the first and second series of parameters a reference recording is compared to test recording (i.e. with a change in the recording conditions with respect to the reference recording). Only one change in the recording conditions should be tested at a time. It is also recommended to perform the two recordings at the same time, or at least immediately one after another.

The recordings of the reference and tested parameter of the third series are performed at the same place, but obviously not at the same time. In this case either noise sources or environment change between the two measurements.

This survey is not devoted to check the influence of soil category in itself. But seismic response of the soil can be considered as one of the parameters that may control the influence of another experimental condition. That is why sites were classified following their fundamental frequency (f0):

- f0 = 1 Hz : low frequency site
- 1 Hz < f0 = 5 Hz : medium frequency site
- f0 > 5 Hz : high frequency site
- flat curve without identifiable peak: no peak site.

Ideally the parameters should be tested at all of the four types of sites.

As far as possible, the reference recordings used for different tests should be performed with the same recording parameters.

DATA ACQUISITION

Equipment:
The tests were performed with the use of different stations (Geosig GBV316, Mars Lite, Mars88, Cityshark I and II, Hathor3).
Many sensor were also used: Geosig (4.5 Hz built-in), Lennartz (5 seconds-LE3D, 1Hz LE3D, LE3Dlite) and MarkProduct (4.5 Hz, 2Hz L22, 1Hz L4-3D) and Guralp (CMG40).

Volume of data:
The measurements were mainly performed between 2001 October and 2003 March. 593 recordings are used to test 60 parameters. “No-peak” and “high frequency” sites are less documented (20 and 41 recordings respectively) than “low” and “medium” frequency sites (291 and 241 recordings respectively).

Data base:
Most of the data collected were transformed into a common format design by SESAME team (SAF format).
For each test, a table was filled explaining as precisely as possible all experimental conditions. These data together with pictures were gathered in a common data base. After processing, resulting curves and graphs were also arranged in the data base.

DATA PROCESSING

For each tested parameter, average H/V and standard deviation are computed for both the reference and the tested parameter recordings. Then, a statistical tool is used to determine the degree of similarity between the two curves. The analyze attempts to qualify the variation of amplitude of the main peak between the test and the reference but also the variation of frequency of this main peak.

Data were first processed by each team with the common SESAME software for H/V computing. Then they were gathered and processed using a program written by B. Guillier and JL. Chatelain. Except for the Student-t test computation this latter program is based on the same routines to those used by the SESAME software. This free software designed in SESAME WP04 is deeply commented in another paper of the same conference.

H/V computation:
H/V computation is performed from the three file of a recording (North-South, East-West, vertical) through the following steps :

1. Offset removal : the mean of the entire signal recorded is deducted from each sample value. No sensor nor station correction is applied to the rough signal.

2 Single window processing:
The second step of the process consists in selecting portions of the signal that do not contain transients. It must be noticed here that the assessment of local source effect was part of WP02 goal. But the automatic window selection parameters were only designed to eliminate transient that appeared on signal in a given frequency range without taking into account neither the nature of this transient nor their effect in the resulting curves.

Automatic window selection parameters:
· - Window length for the short term (STA): 2 seconds
· - Window length for the long term (LTA): 30 seconds
· - Minimum level for STA/LTA threshold: 0.3
· - Maximum level for STA/LTA threshold: 2
· - Selected Window length: from 25 to 40.96 seconds.
· - For parameter P9, to check the effect of local sources (considered as transient), the following parameters were applied: STA/LTA min. = 0.01 and STA/LTA max . = 10.

Processing of individual windows:
· - 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 smoothing, with a bandwidth 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, in each of the windows the distribution of $\log_{10}(\mathrm{H/V})$ is obtained as a function of the frequency.

3. Average result by recording:

The geometric mean of H/V is calculated :

- H/V is averaged over all window results : $\mathrm{H/V}_{average} = \dfrac{\sum \log_{10}(\mathrm{H/V})}{\mathrm{n_{windows}}}$
- H/V standard deviation is calculated: $\sigma_{\mathrm{H/V}} = \sqrt{\dfrac{\sum \log_{10}^2(\mathrm{H/V}) - \mathrm{n}_{windows} \times \log_{10}^2(\mathrm{H/V}_{average})}{(\mathrm{n}_{windows} - 1)}}$

4. $\mathrm{H/V}_{average}$ and $\sigma_{\mathrm{H/V}}$ are set back to a linear scale by calculating $\overline{\mathrm{H/V}} = 10^{\mathrm{H/V}_{average}}$ and $\sigma_{\overline{H/V}} = 10^{\sigma_{\mathrm{H/V}}}$

Similarity between Reference and Tested Parameter

In order to evaluate the effect of a given change in the recording parameters we have to compare the H/V results of the reference and the tested parameter. This comparison has to be made in an objective way, i.e. with the use of a statistical method.

- *Generality on Student-t test:*

The Student-t test elaborated by WS Gosset in 1908 is one of the most commonly used techniques for testing an hypothesis on the basis of a difference between sample means. It determines a probability that two populations are the same with respect to the variable tested.
The t-test can be performed knowing just the means $\bar{x}$, standard deviation σ, and number of data points n of each series. The two sample t-test yields a statistic t, in which:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{A \times B}} \qquad (1)$$

where

$$A = \frac{(n_1 + n_2)}{n_1 n_2} \qquad (2)$$

$$B = \frac{(n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2}{n_1 + n_2 - 2} \qquad (3)$$

The higher the value of t, the greater the confidence that there is a difference between the two series.

Probability tables have been prepared based on the t-distribution originally worked out by W.S. Gossett. To use the table, one has to find the critical value (t_0) that corresponds to the number of degrees of freedom $(n_1 + n_2 - 2)$. If $|t|$ exceeds t_0, the means are significantly different with a (1-2p) probability, where p is the probability level listed in the Student table.

As the Student-t test is very sensitive, it has been decided 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 parameter.

- H/V amplitudes t-test :

The H/V amplitude t-test has been computed using the output of H/V amplitude averages of the reference and tested parameter and their corresponding standard deviations. The parameters of formulas (1) to (3) were determined for each frequency as follows :

$\overline{x_1}$: H/V amplitude of the reference
$\overline{x_2}$: H/V amplitude of the tested parameter
σ_1 :standard deviation of $\overline{x_1}$
σ_2 :standard deviation of $\overline{x_2}$
n_1 :number of signal windows used to compute $\overline{x_1}$
n_2 :number of signal windows used to compute $\overline{x_2}$

As the outputs of the H/V computation are $\overline{\mathrm{H/V}} = 10^{\mathrm{H/V}_{\mathrm{average}}}$ and $\sigma_{\overline{H/V}} = 10^{\sigma_{\mathrm{H/V}}}$, we have to use $\overline{x} = \log_{10}(\overline{\mathrm{H/V}})$ and $\sigma = \log_{10}(\sigma_{\overline{H/V}})$.

In order to have a better graphic visualization of the test, instead of plotting t and t_0, we plotted $\mathrm{Diff}_{\mathrm{H/V}} = \overline{\mathrm{x}_1} - \overline{\mathrm{x}_2}$ and t = $t_0\sqrt{\mathrm{A}\times\mathrm{B}}$. In this case, if $|\mathrm{Diff}_{\mathrm{H/V}}|$ exceeds t, the H/V amplitudes are significantly different at the probability level (1-2p).

- *Frequency peak t-test:*

The parameters of formulas (1) to (3) were determined as follows :
$\overline{x_1}$: average frequency peak of the reference
$\overline{x_2}$: average frequency peak of the tested parameter
σ_1 : standard deviation of $\overline{x_1}$
σ_2 : standard deviation of $\overline{x_2}$
n_1 : number of $\overline{H/V}$ windows used to compute $\overline{x_1}$
n_2 : number of $\overline{H/V}$ windows used to compute $\overline{x_2}$
The peak frequencies (f_0) of the reference and the tested parameter are obtained from the H/V results of each window used to compute $\overline{\mathrm{H/V}}$. In each individual H/V window the frequency peak is searched in the interval $[\mathrm{f}_0/\mathrm{R}_\mathrm{f}, \mathrm{f}_0\times\mathrm{R}_\mathrm{f}]$, from which the average frequency peak $(\overline{\mathrm{f}}_0)$ is obtained. We have decided to set :
$$\mathrm{R}_\mathrm{f} = 1.5 - 0.25\frac{(\mathrm{f}_0 - \mathrm{f}_{\min})}{(\mathrm{f}_{\max} - \mathrm{f}_{\min})}$$
For WP02 it has been decided to use $\mathrm{f}_{\min} = 0.2\mathrm{Hz}$ and $\mathrm{f}_{\max} = 20\mathrm{Hz}$.

Windows without peak (i.e. where no point was both preceded and followed by at least one point with a lower amplitude) were rejected.
The standard deviation was calculated as $\sigma(\overline{\mathrm{f}}_0) = \sqrt{\frac{\sum(\mathrm{f}_\mathrm{i} - \overline{\mathrm{f}}_0)^2}{(\mathrm{n}-1)}}$, where n is the number of windows kept to calculate $\overline{\mathrm{f}}_0$.
For a homogenous use of the Student-t test, instead of plotting t and t_0, we plotted $\mathrm{Diff}_\mathrm{f} = (\overline{x_1} - \overline{x_2})$ and t = $t_0\sqrt{\mathrm{A}\times\mathrm{B}}$ 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).

TECHNICAL CARD:

After the processing, the above algorithms produce a technical card (Figure 1), which includes graphs and tables. The following section describes these elements.

Graphs of the technical card

The technical card of each test include four graphs :

Graphs A(reference) and B (test): the H/V results $\overline{\mathrm{H/V}}$ is shown by the black line. The two dashed lines on both sides of the black line are $\overline{\mathrm{H/V}}/\sigma_{\mathrm{H/V}}$ and $\overline{\mathrm{H/V}}\times\sigma_{\mathrm{H/V}}$.

Graph C : the Student-t values obtained from the results of graphs A and B . $\mathrm{Diff}_{\mathrm{H/V}}$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 : the standard deviations of graphs A and B $\sigma_{\mathrm{H/V}}$ of the reference is shown by the black line, and $\sigma_{\mathrm{H/V}}$ of the tested parameter by a dashed line.

The vertical dashed lines in all four graphs are the interval $[\bar{f}_0-\sigma(\bar{f}_0),\bar{f}_0+\sigma(\bar{f}_0)]$ from the results of table 1 commented hereafter. In graphs A, B, and C the interval is the one obtained for the reference, and in graph C it is the one obtained for the tested parameter.

Tables of the technical card

Table 1 (upper table) summarizes the frequency peak results of the reference and of the tested parameter, together with some information about ambient noise signal acquisition for both data sets :

• H/V results and processing parameters:

Column 2 : H/V average maximum peak frequencies ($f_0(\mathrm{H/V})$, in Hertz) from graphs A and B.

Column 3 : Nb win: number of stable signal windows used in the H/V processing.

• Results obtained from individual windows :

Column 6 : average peak frequencies ($\bar{f}_0$, in Hertz).

Column 7 : standard deviation of the average frequency peak (σ ($\bar{f}_0$), in Hertz)

Column 8 : numbers of individual windows used to calculate the average frequency $\bar{f}_0$. This number can be different from the one in column 3.

• Student-t test for individual windows(Column 9) :

|diff| : absolute value of the difference of the average peak frequencies ($\bar{f}_0$) of the reference and of the tested parameter.

t : value of $t_0\sqrt{A\times B}$ obtained with the standard deviations of column7, and the number of windows of column 8.

Conclusion of the Student-t analysis on the frequencies obtained from individual windows :

if |diff| = t : the peak frequencies of the reference and the tested parameter are said “similar”.

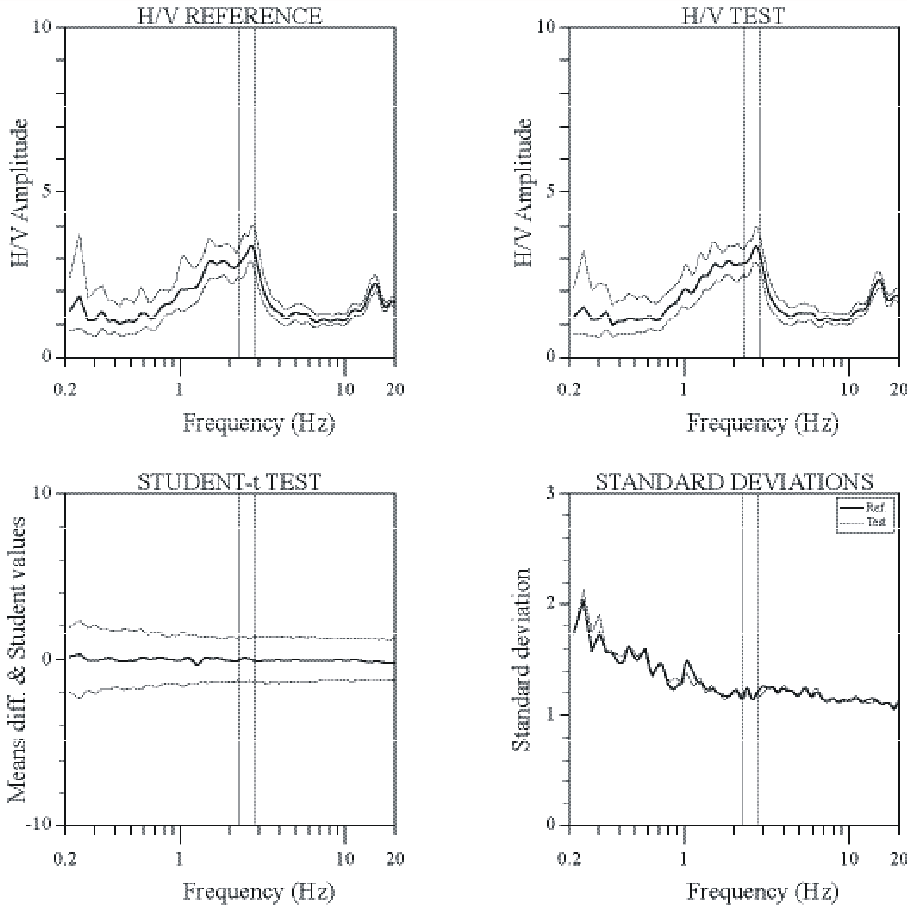
if |diff| > t : the peak frequencies of the reference and the tested parameter are said “not similar”.

• General conclusion for the tested parameter (Line 3) :

If the conclusion of the Student-t test for individual windows (in column 9) is "NOT similar peak frequencies", the general conclusion is "NOT RECOMMENDED", i.e. the tested parameter greatly influences the H/V results.

If the conclusion of the Student-t test for individual windows (in column 9) is "Similar peak frequencies", the general conclusion varies according to the percentage of "bad" points, which verify $Diff_{H/V}$ > t (from graph C) inside and outside the interval $\left[\bar{f}_0 - \sigma(\bar{f}_0), \bar{f}_0 + \sigma(\bar{f}_0)\right]$, termed "the peak zone". The total number of points as well as the number of "bad" points 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 ?f is the frequency step from the Fourier transform.

Table 2 (lower table) summarizes data acquisition conditions and gives information about the tested parameter.



<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>01221442.saf</td><td>2.72</td><td>21</td><td>250</td><td>720</td><td>2.53</td><td>0.28</td><td>21</td><td rowspan="2">|diff| = 0.04
t = 0.31
Similar
peak frequencies</td></tr>
<tr><td>Test</td><td>001c7dd60
096dc0.saf</td><td>2.75</td><td>20</td><td>250</td><td>720</td><td>2.57</td><td>0.28</td><td>20</td></tr>
<tr><td></td><td>Conclusion</td><td colspan="8">NO INFLUENCE</td></tr>
</table>

<table>
<tr><th></th><th>Recorder</th><th>Sensor</th><th>Rec. type : simultaneous</th><th>Medium frequency site</th></tr>
<tr><td>Ref.</td><td>Mars Lite</td><td>5-second Lennartz LE3D</td><td colspan="2" rowspan="2">P1-1-2-Grenoble Nice-test5
Influence of recorder
Same type sensors with recorders of different type</td></tr>
<tr><td>Test</td><td>Mars 88</td><td>5-second Lennartz LE3D</td></tr>
</table>

Figure 1 : Example of technical card

RESULTS

The results can be classified into three main categories: (1) the parameters that do not influence the result, (2) those which influence the results only beyond some limits that can easily controlled and (3) those on which there is no possible control. These categories are listed below with some comments for each parameter. Some tested parameters produce rather mitigated results and it would be necessary to conduct further testing. These parameters are nevertheless included in the category corresponding to the conclusion of the available results.

Parameters that do not influence H/V results

• P1 Recording/instrument parameters

Influence of recorder: From the 22 used test, the type of recorder has generally no influence on results.

Time for stabilization of the sensor: From the 8 tests used except for some accelerometers, time for stabilization (of signal and of H/V curves) is around 2 minutes. After this delay, results are generally stable.

Sampling rate: From the 8 tests used (from 50 to 250 Hz), no clear influence could be pointed.

Sensor cable length: From the 9 tests used no influence on results, at least up to 100 meters, no matter how the cable is installed (rolled or stretched).

Azimuth of the sensor: The 4 tests used show no influence on results. However, all tests were performed over a homogeneous alluvium basin. Tests next to geologic discontinuities or 2D structures have still to be performed.

• P2 In situ soil-sensor coupling:

Concrete (as compared to natural soil): the 11 tests used show no influence on results

Compacted snow: The 2 tests used show no influence on results. At least up to a thickness of 30 cm, and when the sun is not shinning.

• P3 Modified soil-sensor coupling:

Artificial interface between in-situ ground and sensor:
- stratified wooden plate: The only test used shows no influence on results.
- agglomerated wooden plate: The 3 tests used show no influence on results.
- PVC plate: The 2 tests used show no influence on results.
- metal plate with legs:The 10 tests used show no influence on results
- trihedron (ETZH metal plate):The 12 tests used show no influence on results.
- ceramic plate: The only test used show no influence on results.

Sensor anchoring: From the 18 tests used, results are thoroughly not influenced by setting up the sensor in a hole whether filled or not. Some tests show some slight differences of the H/V amplitude over 10 Hz.

Feet of sensor not blocked: The 3 tests used show no influence on results

Small pile of sand: The 5 tests used show no influence on results

• P6 Weather

Temperature: Tests were conducted only to compare morning and afternoon temperatures. The 9 tests used show no influence in the 17.2° - 22.7° range. However, a slight squeeze of the peak amplitude can be observed for higher temperatures.

• P8 Stability with time according to site response

H/V variation with time on no-peak sites.
For the 2 used tests (From 3 to 5 years) there is no variation with time.

H/V variation with time on low frequency sites:
The 60 used tests on the same site (From hours to 1 year) show no variation with time.

H/V variation with time on medium frequency sites:
The 50 used tests on the same site (From hours to 1 year) show no variation with time.

• P9 Noise sources
High voltage cable: The 27 used tests show no influence on result.

Parameters that may influence H/V results with possible control

• P1 Recording/instrument parameters

Different type of sensor with one station:
The 17 tests performed with available sensors show equal result except for the 2-Hz one (the tested sensor may have some trouble)

Acquisition gain: As long as the signal is not saturated, the 24 tests show no influence on result.

Sensor horizontality: The 2 tests performed showed that results are stable until 4° tilt for sensor (5-second Lennartz LE-3D)

• P2 Influence of “in situ” soil-sensor coupling:
Grass: The 37 tests show that recording on grass can give quite different results (than directly on soil) when wind is blowing, even lightly.

Ice: The 3 tests used show that the feet of the sensor produce local ice melting that destabilizes the sensor and bring result disturbance.

Not compacted snow: The 14 tests show influence on result at least under sun.

• P3 Modified soil-sensor coupling:

Artificial interface between in-situ ground and sensor :
- Wooden plate: The 5 used tests give variable results.
- Metal plate with no feet: The 10 used tests give variable results.
- Styrofoam: The 14 used tests show strong influence below 1Hz.
- Cardboard plate: The 2 used tests show strong influence below 1Hz.
- Foam: The 2 used tests show strong influence on result.
- Empty plastic container: The 14 used tests show strong influence below 1Hz.
- Cement plate: The 4 used tests show mitigated results

Ballast on sensor: The heavier the ballast the stronger the influence on the results from 4 tests used.

Feet of sensor removed: The 6 used tests give variable results on both gravel and sand.

Pile of gravel and gravel in a plastic container: The 4 tests show that results may be influenced.

• P6 Influence of weather

Wind: From the 5 tests, it appears that strong wind can influence the results.

Rain: From the 5 tests, it appears that strong rain can influence the results.

• P9 Influence of noise sources:

Human steps: The 11 tests used show that steps closer than 5 meters strongly influence results. However, it is sure that this test is representative of reality as people were walking around the seismometer and not passing by as it would be in a street.

Passage of cars: The 36 tests used show that cars moving closer than 5 meters can strongly influence results.

Cars turned on, not moving: The 4 tests used show that engine cars turned on at 1 meter from the sensor can influence results.

Passage of train: The 2 tests used show that train at few meters from sensor strongly influence results.

Machinery: The 5 tests used show that machinery at few meters from sensor can influence the results.

Boat (ferry) departure (sensor on a dock): The 7 used tests show some disturbances in the results.

Influence of sea (agitated or quiet): The 6 tests at various distances from the sea both, when agitated or not, are difficult to interpret. For recordings at long distances from the sea, the observed differences may (or not) be related to differences in other parameters.

The influence of most of these sources can however easily be removed when processing the signal.

Parameter that may influence H/V results without possible control

- P2 In situ soil-sensor coupling:

Asphalt: From the 36 tests used, peaks can be a little squeezed, while amplitudes over 7-8 Hz can be a little higher. No test has been performed on high frequency sites.

Mud: The only test over thin layer of mud does not show any influence. The other one in thicker layer in presence of water show result disturbance at least for amplitude of H/V curve.

Ploughed soil: The 4 tests show a possible influence on result.

Large pile of gravel: The 3 used tests show mitigated results

Synthetic cover: The only test performed show clear influence of tartan on H/V curves.

Karstic filling: The 2 tests performed show that H/V curves obtained above karstic filling are strongly different to those obtained on hard rock.

- P4 Influence of nearby structures:

Large nearby structures:
Several of the 13 tests performed at various distances from a building before and after its construction indicate strong changes especially in the 5-10 Hz range. However, recording conditions of these tests have to be investigated more deeply.

Small nearby structures. (recordings at various distances):
Close to the structure up to about 10 m the influence is highly noticeable from our 12 tests, especially under windy condition. More investigations on the recording conditions of these tests should be conducted.

- P5 Influence of underground structures

Large underground structures: The 12 tests were conducted above a large cave and next to a subway tube and show influence of the structure on results unless due to another parameter (uncontrolled)

Small underground structure: The 4 used tests tend to indicate that small underground structure may influence results.

CONCLUSION

H/V measurements in cities imply both reliability of the results and rapidity of data collection. It is therefore important to understand which recording parameters influence result quality and reproducibility. To determine the influence of each of these parameters, an important experimental survey was conducted in the framework of the European project SESAME. Numerous experimental parameters were first listed. Then the evaluation survey was designed to obtain for each parameter a reliable estimation on its ability to influence H/V curve. Each parameter had to be tested by several team following a common protocol. Then results were studied statistically to rule on the possibility for each parameter to influence the H/V curve and to precise the context.

It is first crucial to make sure that the results are not equipment dependent. This has been proved for numerous instruments.
In urban area, this kind of measurement is rarely performed directly on soil but on streets and sidewalks or park lawns. Therefore the estimation of the possible influence on H/V curves of asphalt, grass, cement and concrete interfaces as compared to natural soil have been checked. Some conditions tend to modify the results and should be further investigated.

It can be sometimes convenient to use artificial interface to help stabilize the sensor. It is generally not recommended to use such interface.

For microzoning purpose, ambient noise measurements are performed in the vicinity of structures of various size and level as compared to the soil: building, subway, sewage, trees etc. The influence of such structures on the results has begun to be checked even if more investigations are required to conclude.

The ambient vibration source can be very different from one point to another as well as over time. It is obviously of crucial interest to clearly statute on which signal is useful in the H/V method and which has to be eliminated by relevant windowing. That is why we tried to test different kind of sources commonly encountered in urban area: step, cars, machinery etc. Our tests clearly show that result could be strongly influenced by local source and confirm the need to select windows free of such transients. Some of our test attempt to define instability factor in time of the H/V curve. It seams that wind, combined with structures fixed into the soil should be one of the most usual factor that control this stability.

One of the main result of WP02 is that no matter how strongly a tested parameter influences H/V amplitude curves the value of the frequency peak is usually not affected, with the noticeable exception of the wind and with no doubt for other kind of local noise source. As mentioned, new data are required to give evidence of the influence of several parameters. Some of them are of crucial issue for the development of the method, others look less important. But the interest of this work is to provide a standardized protocol to test a recording parameter. Thus, it will be welcome for other teams either to continue the parametric survey with their own data for a given parameter or to test a parameter that is not listed here using the SESAME code, this experimental protocol, the statistical method and the interpretation proposed here. Finally this survey provides elements to avoid experiments with wrong recording parameters and somewhat open the way to a standardized data acquisition process for this type of experiment, thus making it easier to compare results from different experiments.

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