The need for standardized H / V spectral ratio approach:

Data collection, processing and interpretation

Kuvvet Atakan and the SESAME Team

Department of Earth Science, University of Bergen,

Allegt. 41, N-5007 Bergen, Norway, atakan@geo.uib.no

SESAME-Team: Acerra,C., Alguacil,G., Azzara,R., Bard, P-Y., Blarel,F., Bonnefoy-Claudet,S., Borges,A., Cara,F., Cornou,C., Cultrera,G., Chatelain,J-L., Dimitriu,P., Dunand,F., Duval, A-M., Fäh,D., Grandison,M., Guéguen,P., Guillier,B., Haghshenas, E., Havskov,J., Kind,F., Koller, M., Lacave, C., Marcellini, A., Moreno,B., Ohrnberger,M., Rao,S., Panou, A., Ripperger,J., Roquette,P., Sørensen,M.B., Tento,A., Teves-Costa,P., Theodulidis, N., Vidal,S., Vollmer,D., Zacharapoulos,S.

The present study is based on the results of the European Project **SESAME** (EC-EVG1-CT-2000-00026)

Background and our motivations

In metropolitan areas the method is popular due to its simplicity

There is therefore a need for a standard approach

Challenges in the built environment and engineering applications




The nature of the ambient noise field

	Natural	Human
Name	Microseism	Microtremor
Frequency	0.1 – f_{nh} (0.5 Hz to 1 Hz)	f_{nh} (0.5 Hz to 1 Hz) – > 10 Hz
Origin	Ocean	Traffic / Industry / Human activity
Incident wavefield	Surface waves	Surface + body
Amplitude variability	Related to oceanic storms	Day/ Night, Week / week-end
Rayleigh / Love issue	Incident wavefield predominantly Rayleigh	Comparable amplitude – slight indication that Love waves carry a little more energy
Fundamental / Higher mode issue	Mainly Fundamental	Possibility of higher modes at high frequencies (at least for 2-layer case)
Further Comments	Local wavefield may be diffe-rent from incident wavefield	Some monochromatic waves related to machines and engines. The proximity of sources, as well as the short wavelength, probably limits the quantitative importance of waves generated by diffraction at depth

The reliability of the H/V technique is evaluated systematically through the following aspects:

- Experimental conditions
- Data processing
- Empirical evaluation and comparison to SSR
- Interpretation of the results

Influence of the experimental conditions were studied with respect to two different aspect:

• **Influence of the instruments:** Instrument calibration and testing, and comparison of the instruments that are used in the project were completed, following a dedicated workshop in Bergen, Norway.
(see Atakan et al., 2004; Guillier et al., 2007)

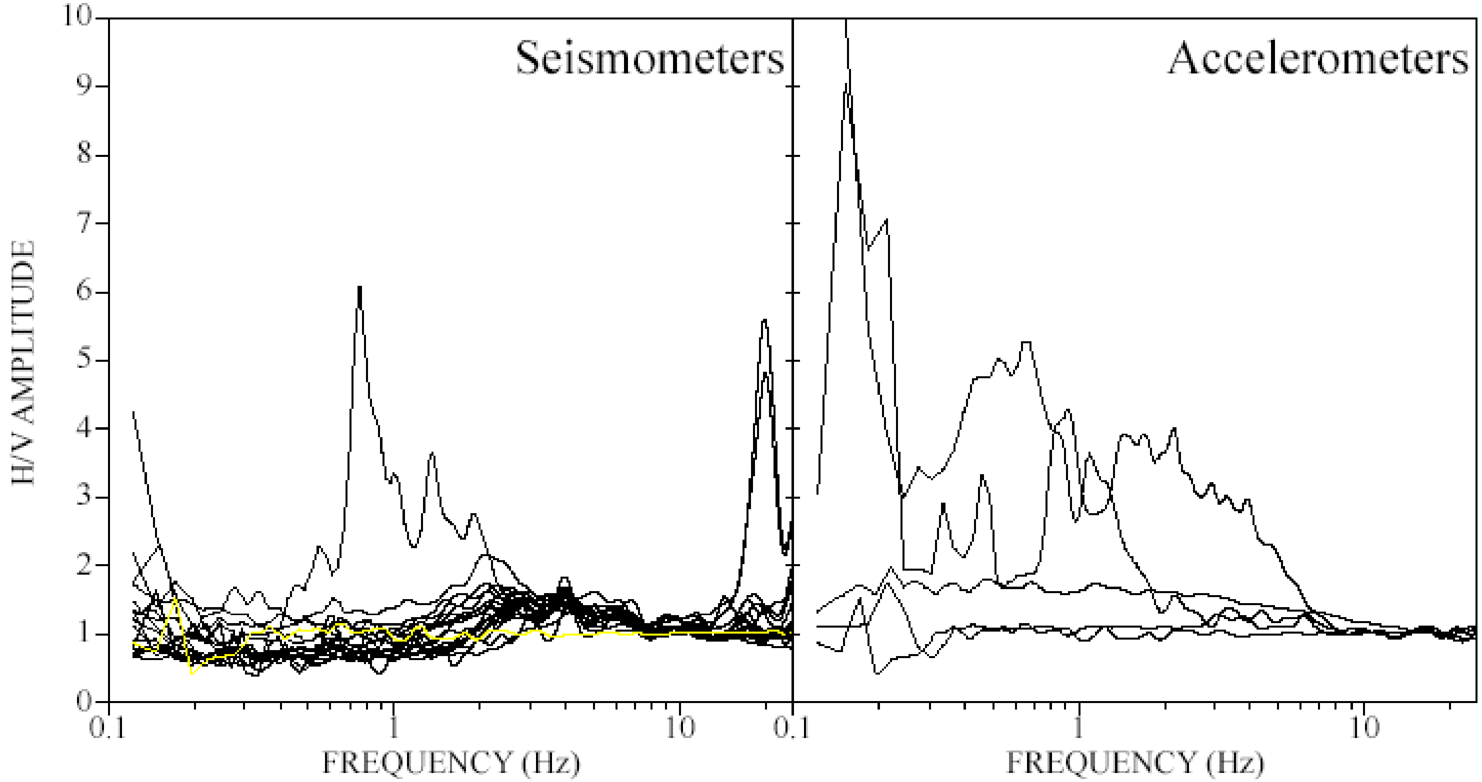
• Assessment of the **effects of the experimental conditions** is performed through a large number of tests.
(see Atakan et al., 2004; Duval et al., 2004; Chatelain et al., 2007)

Examples of instrumentation

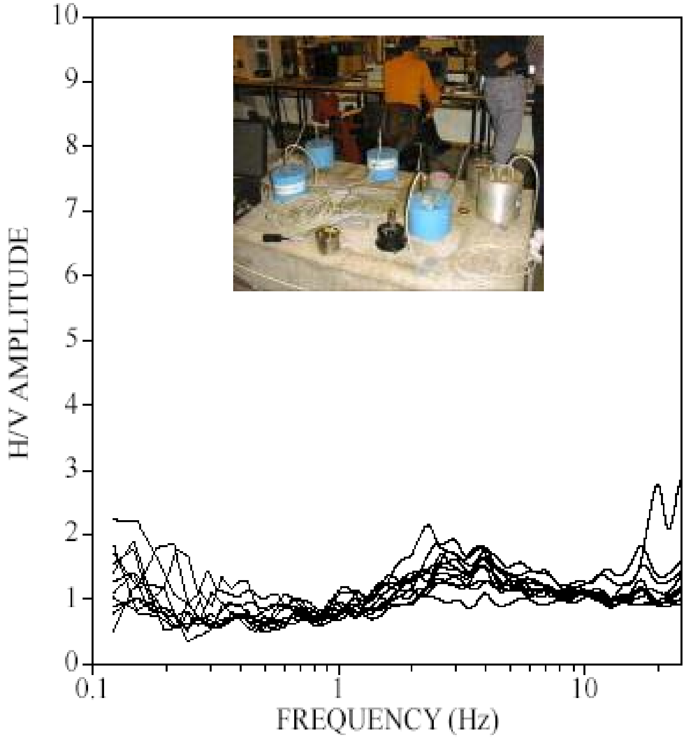
GBV-316´s are used with different casing

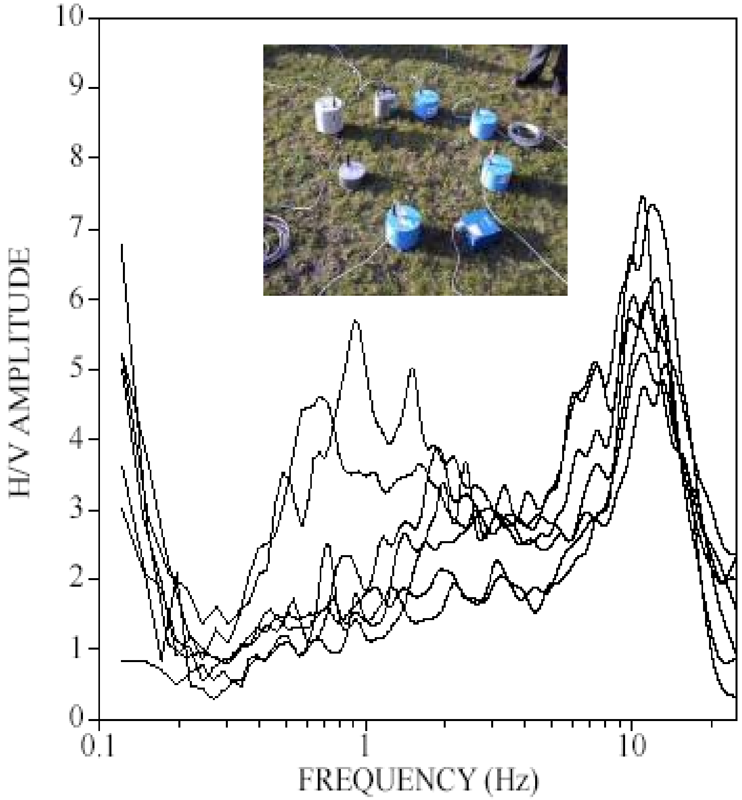
Data acquisition is a Pocket-PC based SEISLOG system

Instrument tests in the lab



Comparison between the lab-records and the free-field measurements





Effect of weather conditions

Reference

Rain and strong wind

Snow

Effect of ground coupling

Pavement

Asphalt

Grass

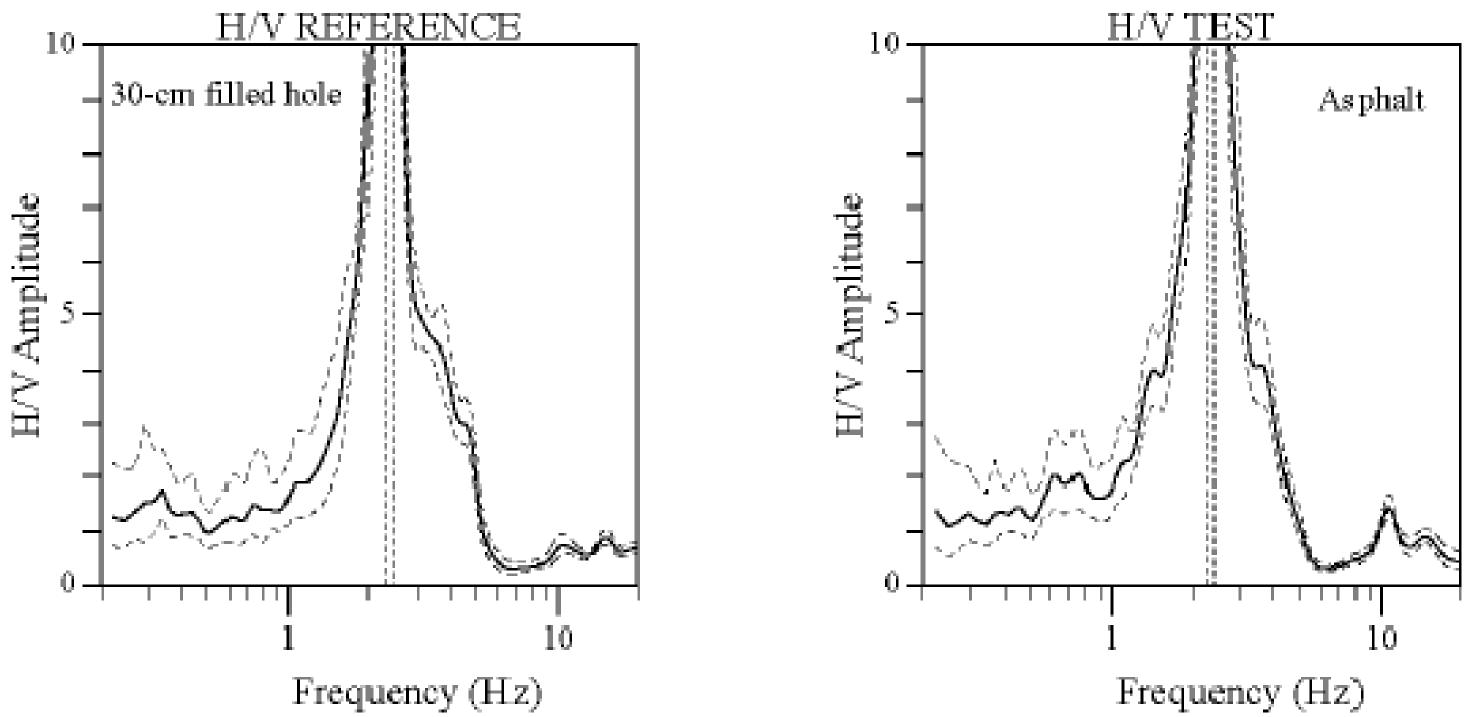
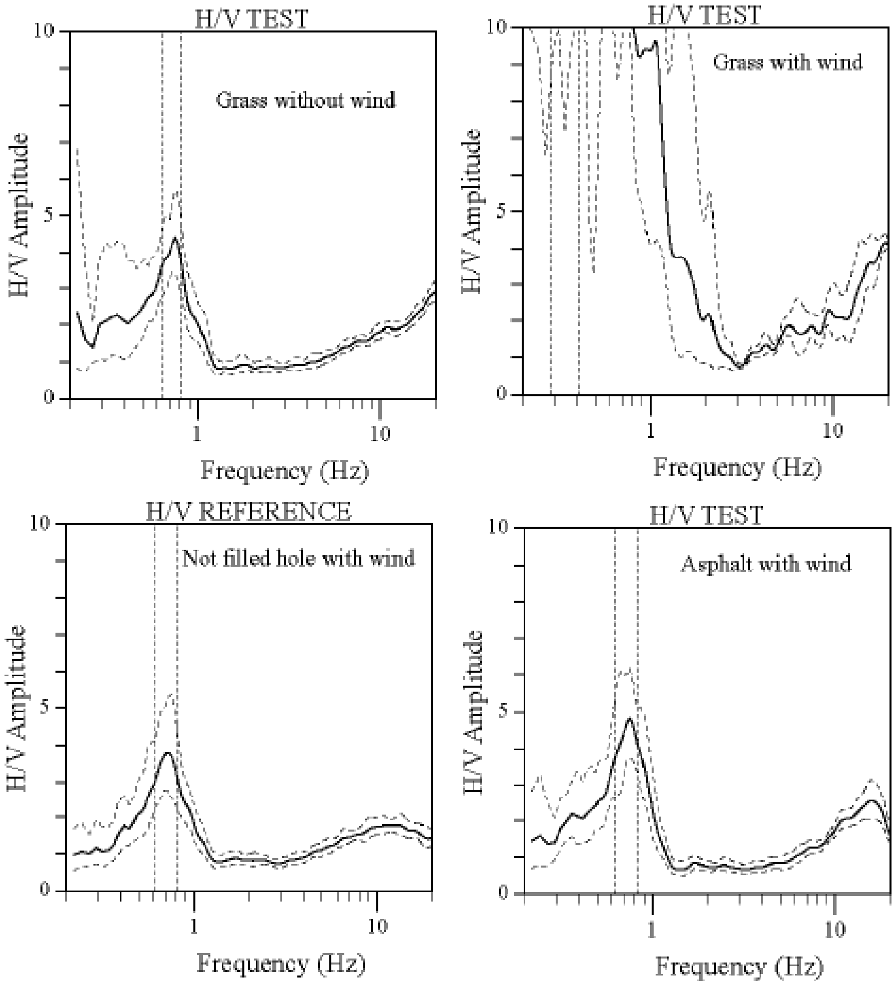


Figure 1. Comparison of the H/V curves obtained with and without asphalt, at the same site, showing no significant effect of the asphalt layer.

Chatelain et al., 2007



Chatelain et al., 2007

Figure 2. Comparison of the H/V curves obtained at the same site on grass with and without wind (top), and in a hole, on asphalt (bottom) and again on grass with wind. This comparison shows the strong effect of the wind combined with grass, whereas on asphalt or in a hole, the wind has no significant effect (if far away from any structure).

Out of 58 different tests that were performed:

- 22 tests in general do not influence (OK) the H/V results
- 17 tests may influence (May Infl.) the results
- 13 tests show that the results influence the H/V ratios and are not recommended (N.R.)
- 6 tests have not enough data (N.E.D) to reach a conclusion

Following test results influence the H/V ratios and are not recommended (N.R.):

- Some ground-sensor coupling conditions (gravel, karstic limestone, etc.)
- Modified sensor coupling (i.e. artificial interface between the sensor and the ground)
- Weather conditions (rain and especially wind)
- Buried underground structures

SESAME Recommendations regarding the experimental conditions

Type of parameter	Main recommendations	
Recording duration	Minimum expected f_0 [Hz]	Recommended minimum recording duration [min]
	0.2	30'
	0.5	20'
	1	10'
	2	5'
	5	3'
	10	2'
Measurement spacing	→ <u>Microzonation</u>: start with a large spacing (for example a 500 m grid) and, in case of lateral variation of the results, densify the grid point spacing, down to 250 m, for example. → <u>Single site response</u>: never use a single measurement point to derive an f_0 value, make at least three measurement points.	
Recording parameters	→ level the sensor as recommended by the manufacturer. → fix the gain level at the maximum possible without signal saturation.	
In situ soil-sensor coupling	→ set the sensor down directly on the ground, whenever possible. → avoid setting the sensor on "soft grounds" (mud, ploughed soil, tall grass, etc.), or soil saturated after rain.	
Artificial soil-sensor coupling	→ avoid plates from "soft" materials such as foam rubber, cardboard, etc. → on steep slopes that do not allow correct sensor levelling, install the sensor in a sand pile or in a container filled with sand. → on snow or ice, install a metallic or wooden plate or a container filled with sand to avoid sensor tilting due to local melting.	

Nearby structures	→ Avoid recording near structures such as buildings, trees, etc. in case of wind blowing (faster than approx. 5 m/s). It may strongly influence H/V results by introducing some low frequencies in the curves → Avoid measuring above underground structures such as car parks, pipes, sewer lids, etc.
Weather conditions	→ Wind: Protect the sensor from the wind (faster than approx. 5 m/s). This only helps if there are no nearby structures. → Rain: avoid measurements under heavy rain. Slight rain has no noticeable influence. → Temperature: check sensor and recorder manufacturer's instructions. → Meteorological perturbations: indicate on the field sheet whether the measurements are performed during a low-pressure meteorological event.
Disturbances	→ Monochromatic sources: avoid measurements near construction machines, industrial machines, pumps, generators, etc. → Transients: In case of transients (steps, cars,...), increase the recording duration to allow for enough windows for the analysis, after transient removal.

Table 1. Recommended recording duration.

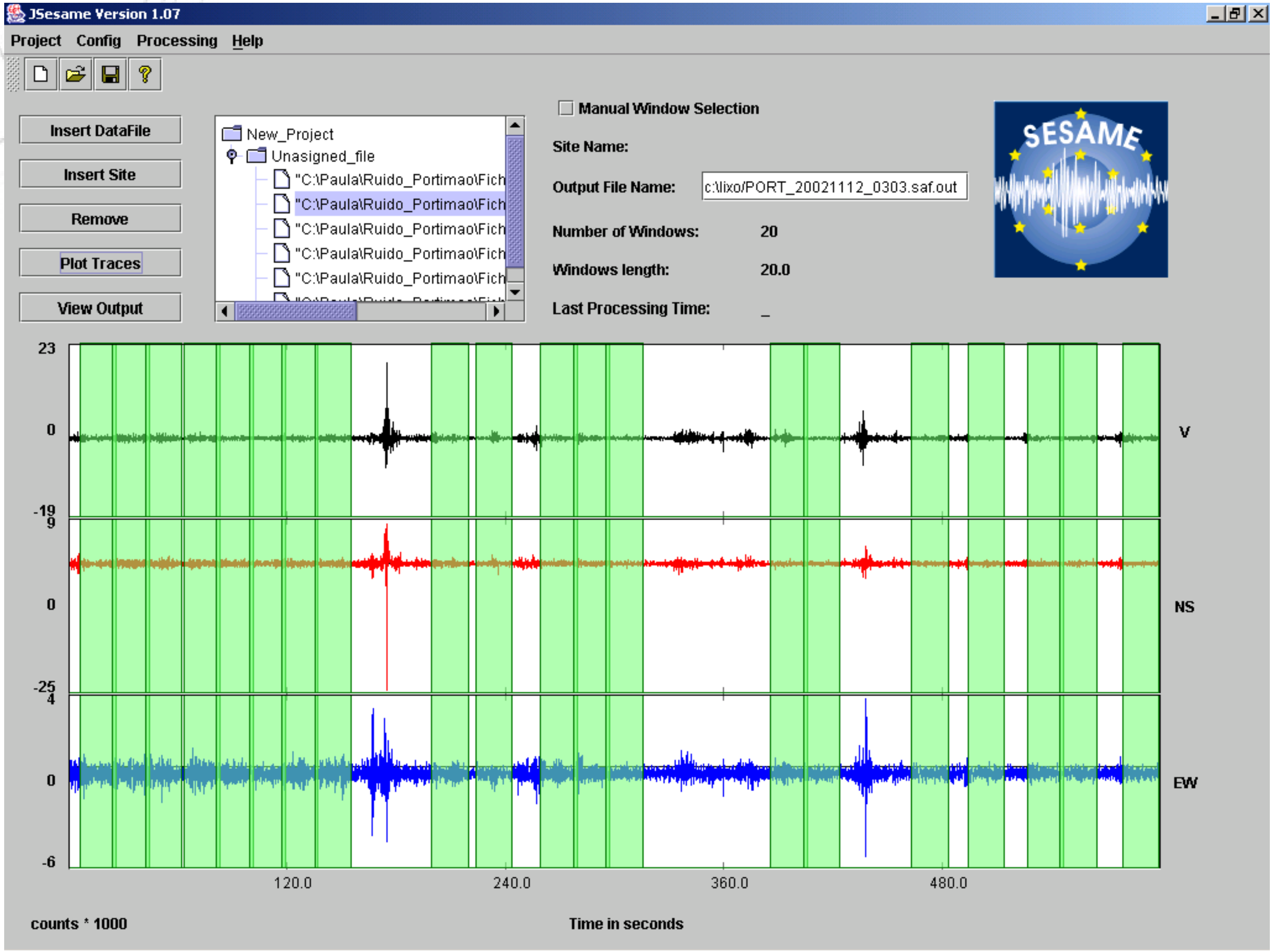
f_0 [Hz]	Minimum value for l_w [s]	Minimum number of significant cycles (n_c)	Minimum number of windows	Minimum useful signal duration [s]	Recommended minimum record duration [min]
0.2	50	200	10	1000	30'
0.5	20	200	10	400	20'
1	10	200	10	200	10'
2	5	200	10	100	5'
5	5	200	10	40	3'
10	5	200	10	20	2'

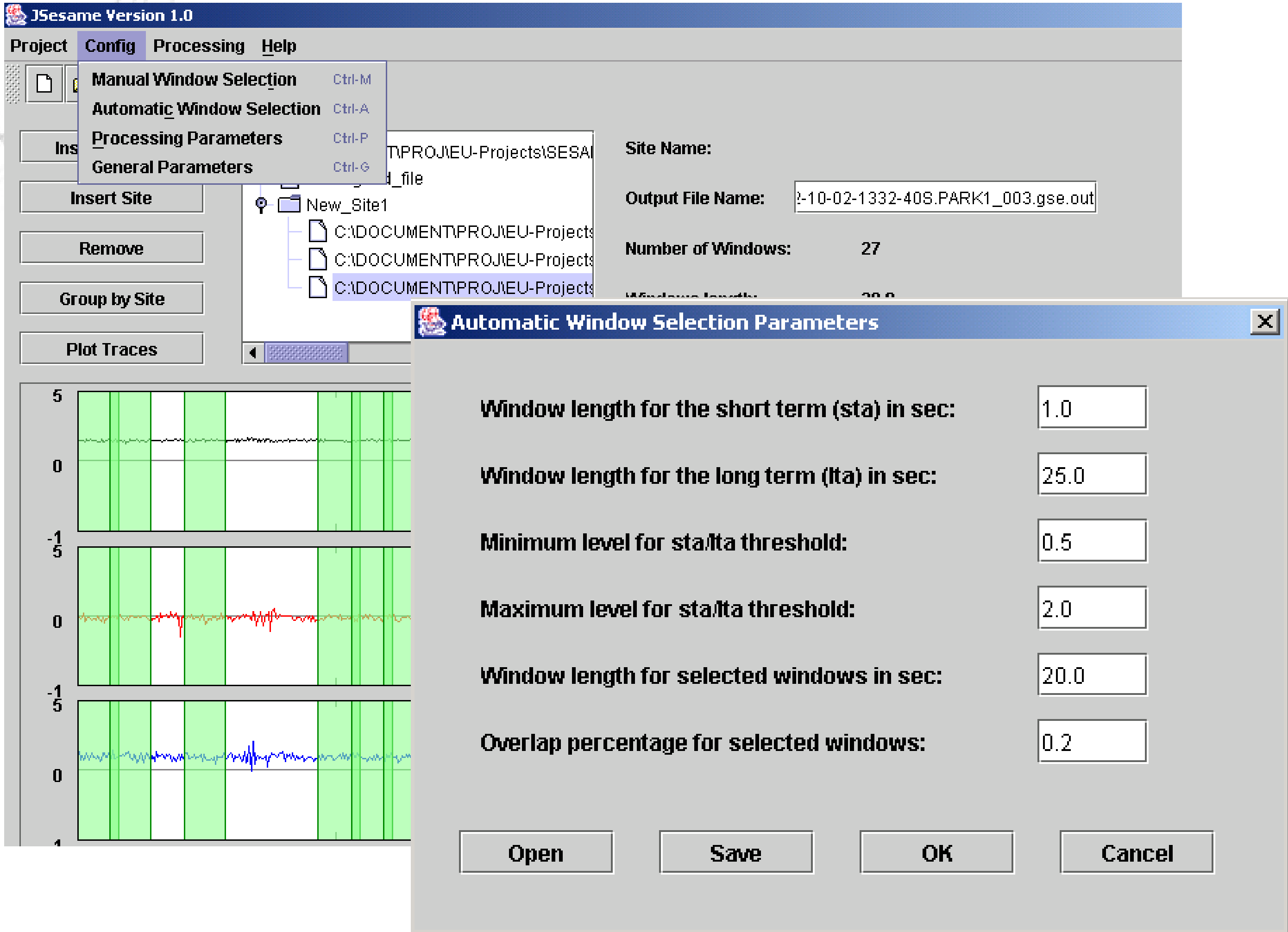
H/V Spectral ratio technique:

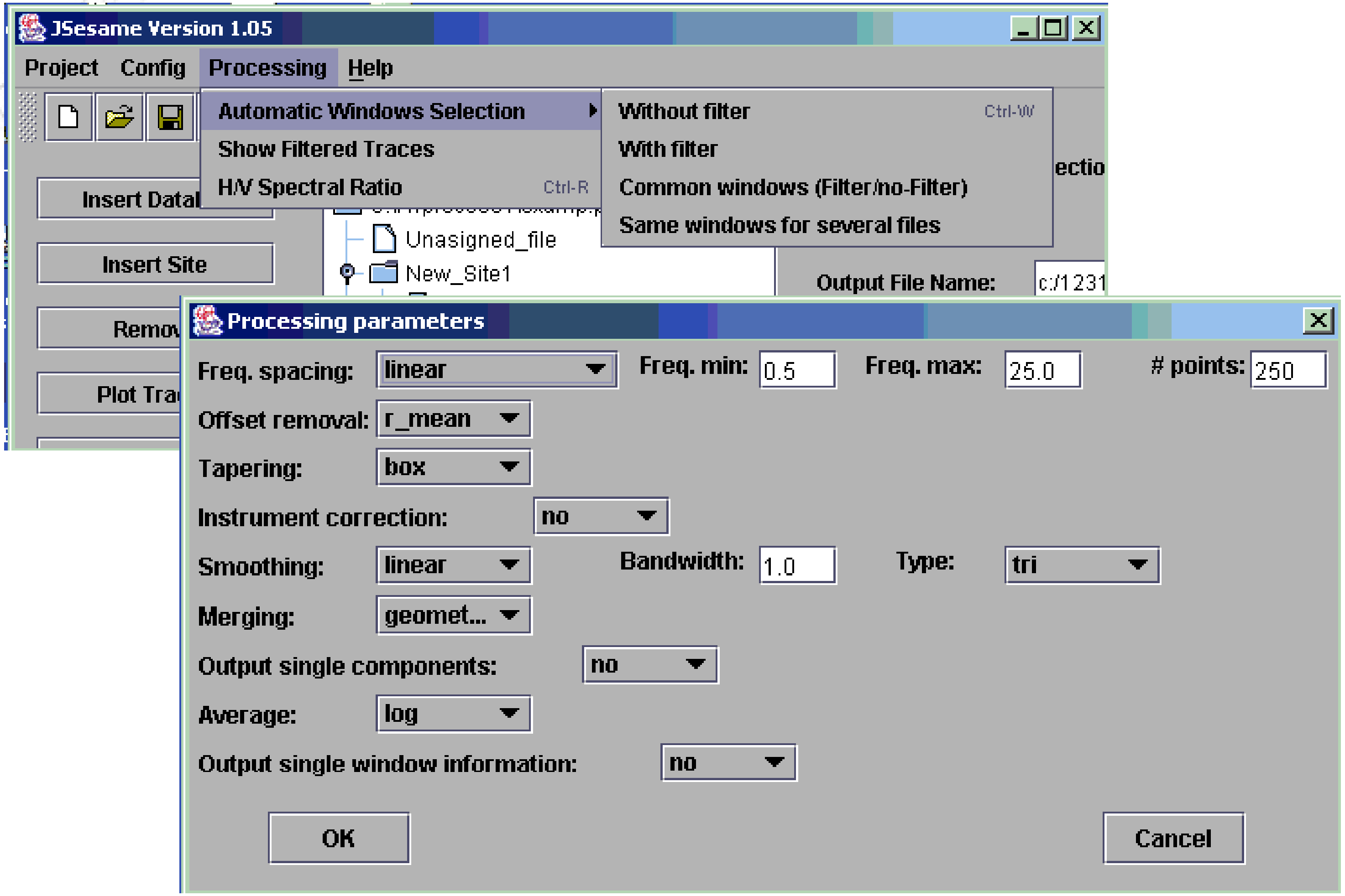
Standard data processing software

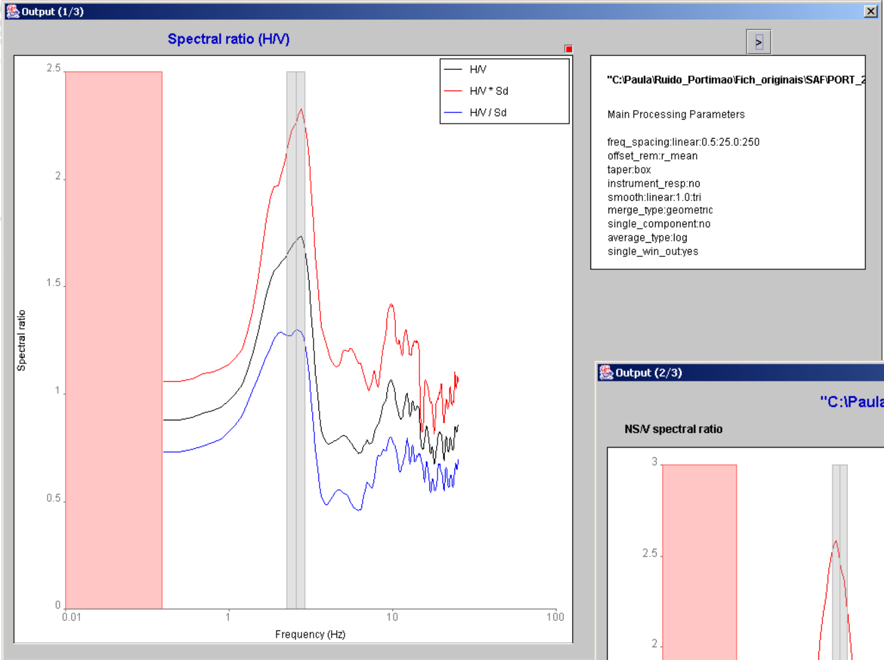
J-SESAME

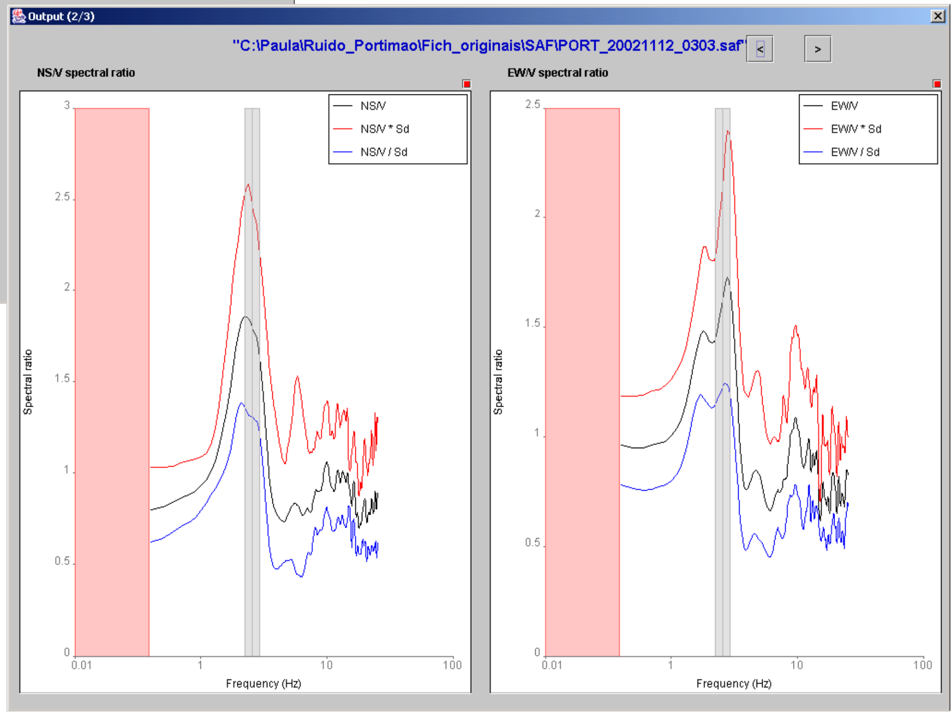
Data processing software J-SESAME




JSesame Version 1.0
Project
Config
Processing
Help
Manual Window Selection Ctrl-M
Automatic Window Selection Ctrl-A
Processing Parameters Ctrl-P
General Parameters Ctrl-G
Insert Site
Remove
Group by Site
Plot Traces
New_Site1
C:\DOCUMENT\PROJ\EU-Projects
Site Name:
Output File Name:
2-10-02-1332-40S.PARK1_003.gse.out
Number of Windows:
27
Automatic Window Selection Parameters
Window length for the short term (sta) in sec:
1.0
Window length for the long term (lta) in sec:
25.0
Minimum level for sta/lta threshold:
0.5
Maximum level for sta/lta threshold:
2.0
Window length for selected windows in sec:
20.0
Overlap percentage for selected windows:
0.2
Open
Save
OK
Cancel


JSesame Version 1.05
Project
Config
Processing
Help
Automatic Windows Selection
Show Filtered Traces
H/V Spectral Ratio
Ctrl-R
Without filter
Ctrl-W
With filter
Common windows (Filter/no-Filter)
Same windows for several files
Insert Site
Unasigned_file
New_Site1
Output File Name:
c:/1231
Processing parameters
Freq. spacing:
linear
Freq. min:
0.5
Freq. max:
25.0
points:
250
Offset removal:
r_mean
Tapering:
box
Instrument correction:
no
Smoothing:
linear
Bandwidth:
1.0
Type:
tri
Merging:
geomet...
Output single components:
no
Average:
log
Output single window information:
no
OK
Cancel


Output (1/3)
Spectral ratio (H/V)
H/V
H/V * Sd
H/V / Sd
Spectral ratio
Frequency (Hz)
"C:\Paula\Ruido_Portimao\Fich_originais\SAF\PORT_2
Main Processing Parameters
freq_spacing:linear:0.5:25.0:250
offset_rem:r_mean
taper:box
instrument_resp:no
smooth:linear:1.0:tri
merge_type:geometric
single_component:no
average_type:log
single_win_out:yes


Output (2/3)
"C:\Paula\Ruido_Portimao\Fich_originais\SAF\PORT_20021112_0303.saf"
NS/V spectral ratio
EW/V spectral ratio
NS/V
NS/V * Sd
NS/V / Sd
EW/V
EW/V * Sd
EW/V / Sd
Spectral ratio
Frequency (Hz)

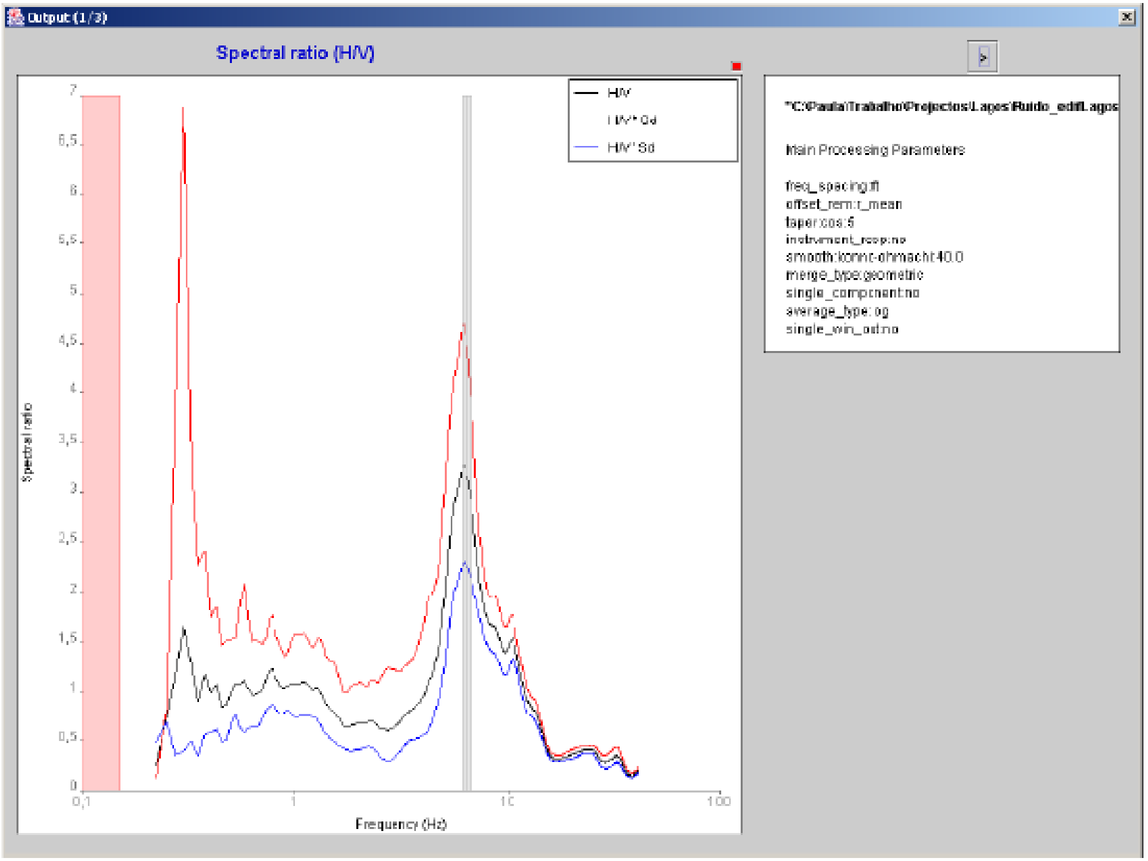
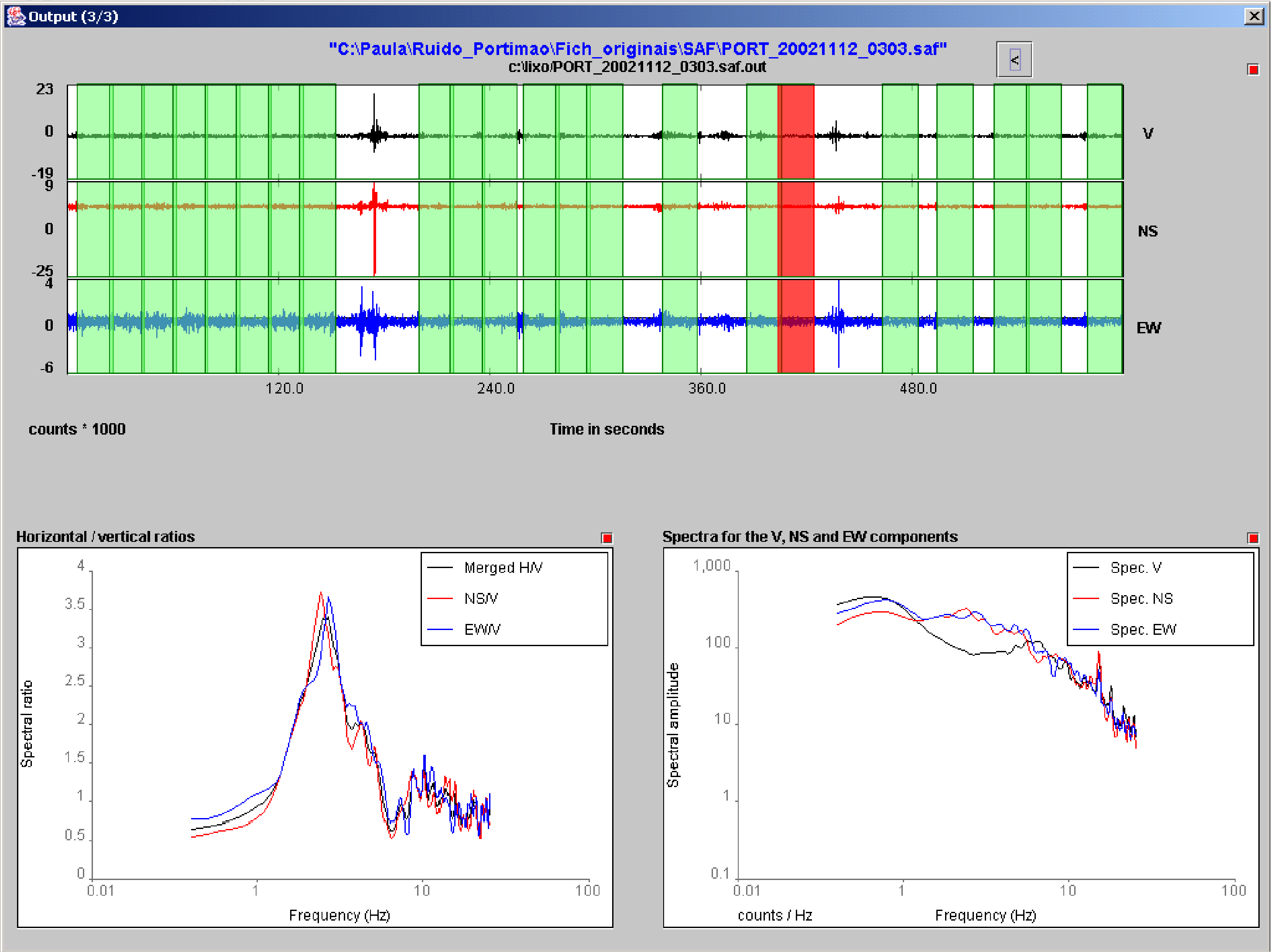


Figure 6. H/V ratio for the merged horizontal components (mean in black, mean multiplied and divided by $10^{\sigma(\log H/V)}$, in red and blue). The pink strip shows the frequency range where the data has no significance, due to the sampling rate and the window length. The grey strip represents the mean f_0, plus and minus the standard deviation. It is calculated from the f_0 of each individual window.



Output (3/3)
"C:\Paula\Ruido_Portimao\Fich_originais\SAF\PORT_20021112_0303.saf"
c:\lixo/PORT_20021112_0303.saf.out
23
0
-19
9
0
-25
4
0
-6
V
NS
EW
120.0
240.0
360.0
480.0
counts * 1000
Time in seconds
Horizontal / vertical ratios
Merged H/V
NS/V
EW/V
Spectral ratio
4
3.5
3
2.5
2
1.5
1
0.5
0
0.01
1
10
100
Frequency (Hz)
Spectra for the V, NS and EW components
Spec. V
Spec. NS
Spec. EW
Spectral amplitude
1,000
100
10
1
0.1
0.01
1
10
100
counts / Hz
Frequency (Hz)

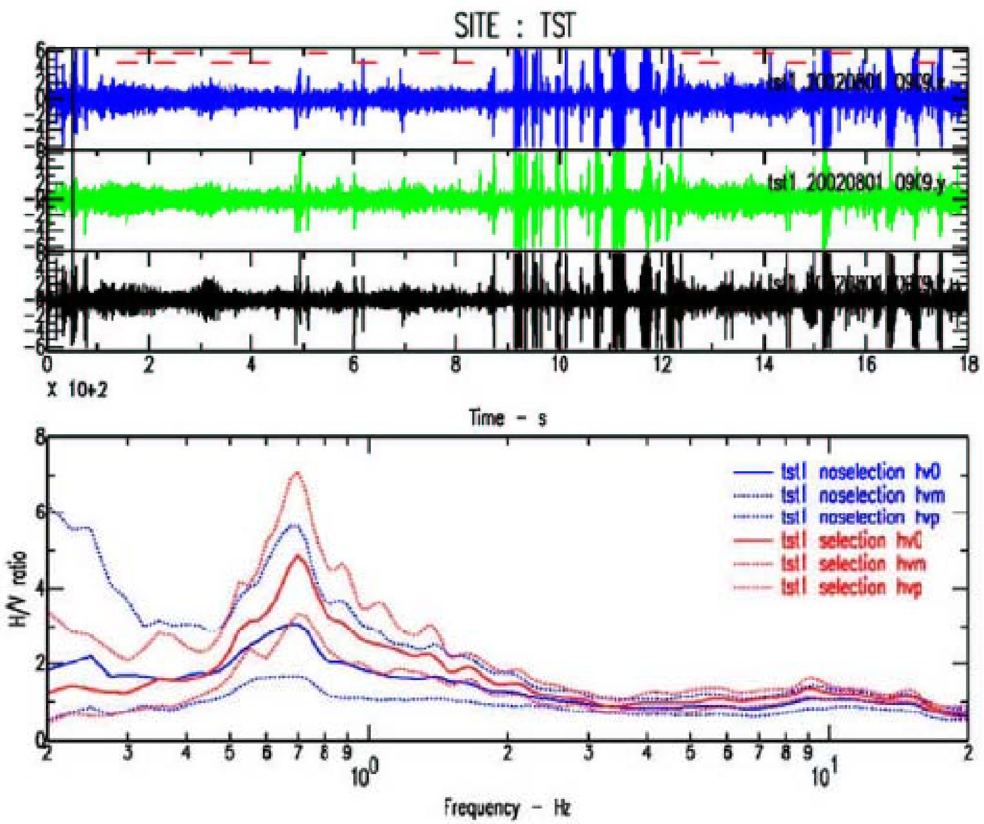


Figure 5. Signal (top) processed with (red curves bottom) or without (blue curves bottom) the automatic window selection (selected windows are indicated by the red segments on the top of the signal). The peak on the H/V curve is much clearer when the transient removal is applied, and also the standard deviation is lower, especially at low frequencies.

Interpretation of the H/V spectral ratio curves based on the User Guidelines of the H/V spectral ratio technique on ambient noise recordings

Criteria for a reliable H/V curve

i) $f_0 > 10 / l_w$

and

ii) $n_c (f_0) > 200$

and

iii) $\sigma_A(f)<2$ for $0.5f_0<f<2f_0$ if $f0>0.5Hz$

or $\sigma_A(f)<3$ for $0.5f_0<f<2f_0$ if $f0<0.5Hz$

Criteria for a clear H/V peak

(at least 5 out of 6 criteria fulfilled)

i) $\exists\, f^- \in [f_0/4, f_0] \mid A_{H/V}(f^-) < A_0/2$

ii) $\exists\, f^+ \in [f_0, 4f_0] \mid A_{H/V}(f^+) < A_0/2$

iii) $A_0 > 2$

iv) $f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$

v) $\sigma_f < \varepsilon(f_0)$

vi) $\sigma_A(f_0) < \theta\,(f_0)$

- l_w = window length
- n_w = number of windows selected for the average H/V curve
- $n_c = l_w \,.\, n_w .\, f_0$ = number of significant cycles
- f = current frequency
- f_{sensor} = sensor cut-off frequency
- f_0 = H/V peak frequency
- σ_f = standard deviation of H/V peak frequency ($f_0 \pm \sigma_f$)
- $\varepsilon\,(f_0)$ = threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$
- A_0 = H/V peak amplitude at frequency f_0
- $A_{H/V}(f)$ = H/V curve amplitude at frequency f
- f^- = frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$
- f^+ = frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$
- $\sigma_A(f)$ = "standard deviation" of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided
- $\sigma_{logH/V}(f)$ = standard deviation of the $\log A_{H/V}(f)$ curve, $\sigma_{logH/V}(f)$ is an absolute value which should be added to or subtracted from the mean $\log A_{H/V}(f)$ curve
- $\theta\,(f_0)$ = threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$
- $V_{s,av}$ = average S-wave velocity of the total deposits
- $V_{s,surf}$ = S-wave velocity of the surface layer
- h = depth to bedrock
- h_{min} = lower-bound estimate of h

Threshold Values for σ_f and $\sigma_A(f_0)$

Frequency range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon\,(f_0)$ [Hz]	$0.25\,f_0$	$0.20\,f_0$	$0.15\,f_0$	$0.10\,f_0$	$0.05\,f_0$
$\theta\,(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
$\log\theta\,(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

Sharp peaks and industrial origin

see §3.3.2.d and appendix A

If industrial origin is proved, i.e., if

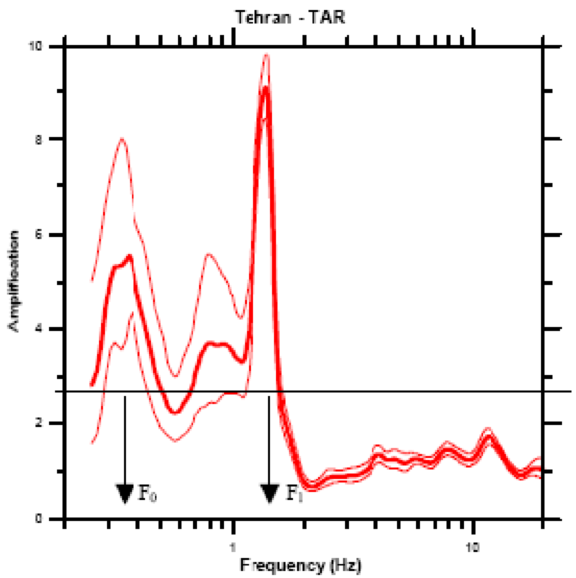
- raw spectra exhibit sharp peaks on all components
- random decrement technique indicates very low damping (< 5%)
- peaks get sharper with decreasing smoothing

no reliable f_0

If industrial origin is **not obvious**

- Perform continuous recordings during day and night
- Check the existence of 24 h / 7 day plant within the area

5. Sharp Peaks and Industrial Origin



Basin geometry: Unknown

Frequency (Hz)

Site Information
TAR site is overlain with stiff soil (coarse grained alluvium).

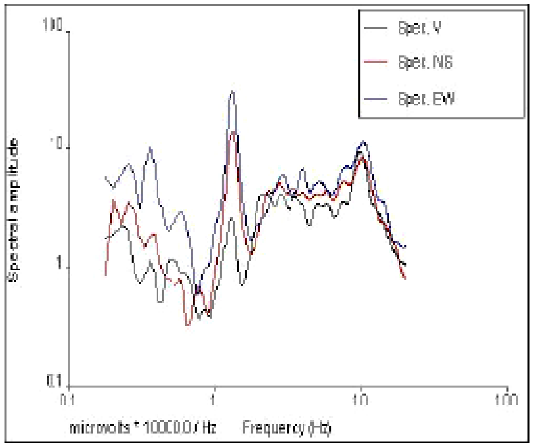
Comments
Criteria for a reliable H/V curve are fulfilled, that is:

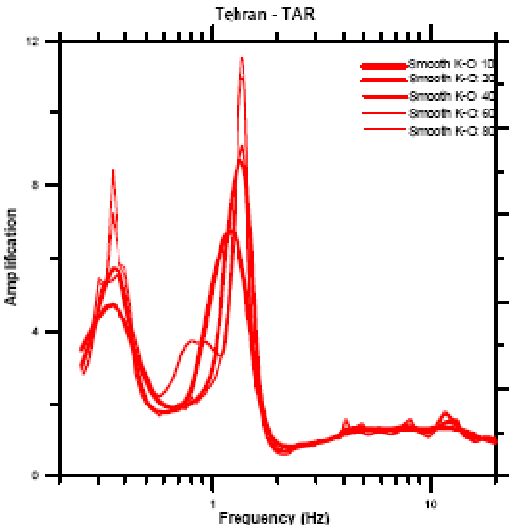
$f_0 > 10 / l_w$

$n_c (f_0) > 200$

$\sigma_A(f) < \log_{10}(2)$

The F_1 local narrow peak has an industrial origin. This (H/V) spectral ratio peak is due to manmade noise/machinery; the reprocessing with different smoothing parameters (bottom right) shows it becomes narrower and narrower, with a larger and larger amplitude when the b-value (Konno-Ohmachi smoothing approach) is increasing: this behaviour is typical of industrial origin. Another confirmation is obtained form the fact this narrow peak occurs at the same frequency in the Fourier spectra of all three components (Figure on bottom left).





Clear peak

see $3.3.1 and appendix A

If industrial origin (*$3.3.2.d*) , i.e.

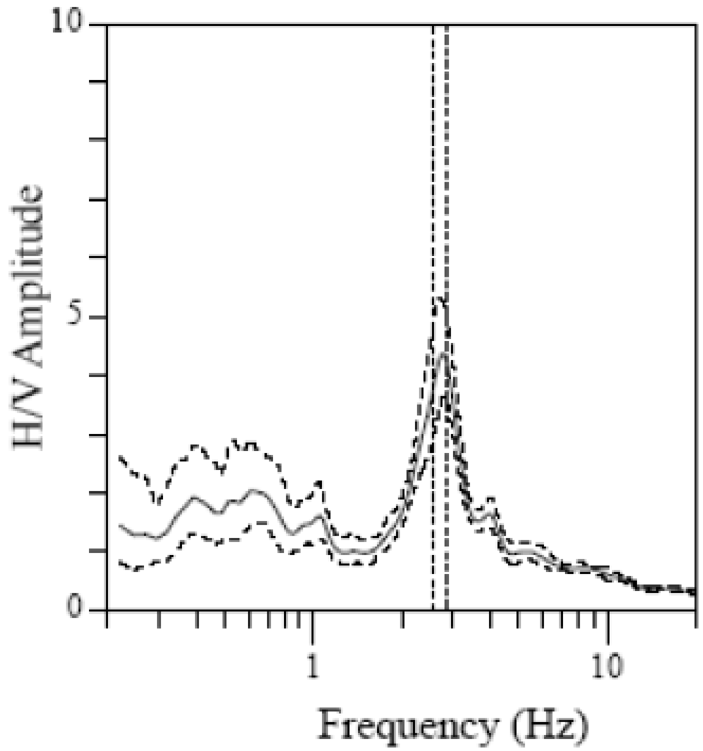
- the raw spectra exhibit sharp peaks on all three components
- the random decrement technique indicates very low damping (< 5%)
- peaks get sharper with decreasing smoothing

no reliable f_0

If $f_0 > f_{sensor}$ and no industrial origin

f_0 reliable

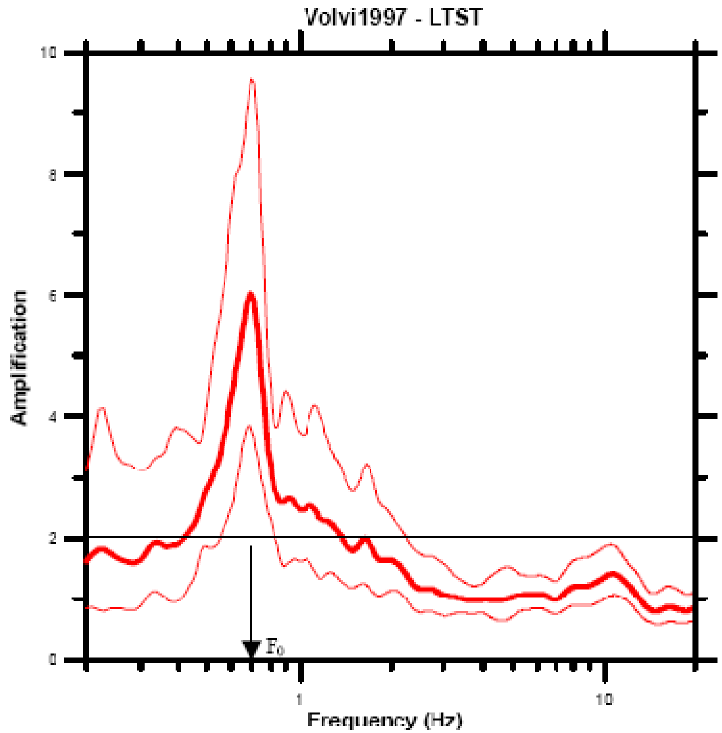
- Likely sharp contrast at depth (A_0 > 4-5)
- f_0 = fundamental frequency
- If h is known then $V_{S,av} \sim 4h.f_0$
- If $V_{S,surf}$ is known then $h_{min} \sim V_{S,surf}/4f_0$



Window length l_w [s]	Number of windows n_w	Number of significant cycles n_c	Frequency statistics from individual windows			
			f_0 [Hz]	σ_f [Hz]	A_0	$\sigma_A(f_0)$
41	14	1561	2.72	0.11	4.4	1.2

Figure 9. Example of a clear H/V curve, that fulfils all the criteria for "reliability" and "clarity" given in sections 3.2 and 3.3.1.

Basin geometry: Elongated alluvial valley, width~5km, length~40km, Depth~200m



Site Information
LTST site depth to bedrock: 196m
Type of bedrock: Gneiss
Average shear wave velocity of deposits: 570m/s

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

$f_0 > 10 / l_w$
$n_c\,(f_0) > 200$
$\sigma_A(f) < \log_{10}(2)$

Criteria for an ideal H/V peak are also fulfilled:

$A_0\,(=6) > 2$
$\exists\, f^- \in [f_0/4,\, f_0] \mid A_{H/V}(f^-) < A_0/2$
$\exists\, f^+ \in [f_0,\, 4f_0] \mid A_{H/V}(f^+) < A_0/2$
$\sigma_f\,(=14\%) < \varepsilon\,(f_0)\,(=15\%)$
$\sigma_A(f_0)\,(=1.6) < \theta\,(f_0)\,(=2)$

Interpretation : All criteria are fulfilled, the fundamental frequency of the site may be reliably estimated at 0.7 Hz.

Unclear low frequency peak	*see $3.3.2.b and appendix A*

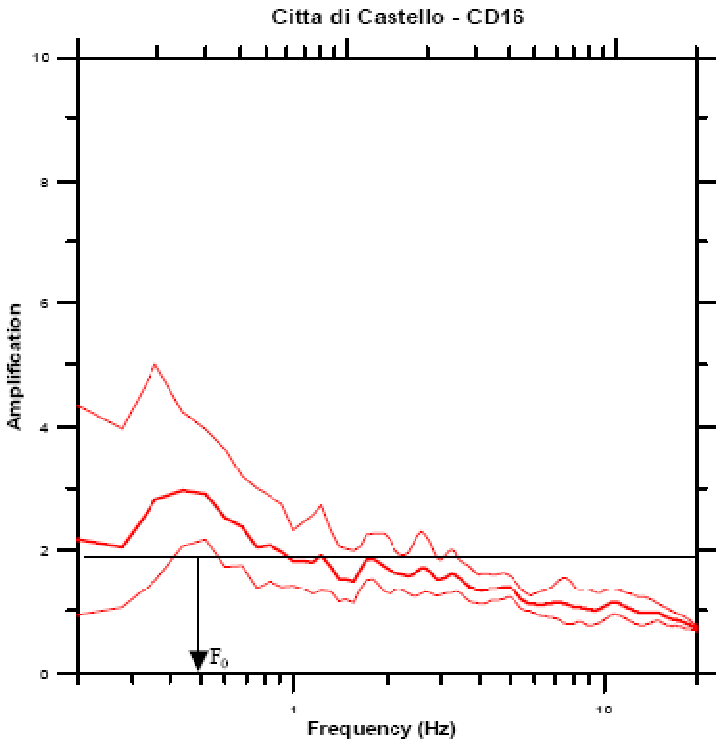
If rock site	**no reliable f_0**

If steady increase of H/V ratio with decreasing frequency

- Check H/V curves from individual windows and eliminate windows giving spurious H/V curves
- Use longer time windows and/or more stringent window selection criteria
- Use proportional bandwidth and less smoothing

If reprocessed H/V curve **fulfils** the clarity **criteria**	**f_0 reliable**
If reprocessed H/V curve does **not fulfil** the clarity **criteria**	Perform **additional measurements** over a longer time and/or during night and/or quiet weather conditions and/or use earthquake recordings using also a nearby rock site

2. Unclear Low Frequency Peak



Basin geometry: Elliptical alluvium valley, width~10km, length~25km, depth~0.1km

Site Information
CD16 site is situated on soft alluvium sediments and silty clay.
Type of bedrock: Sandstone (Middle Miocene).

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

$f_0 > 10 / l_w$
$n_c (f_0) > 200$
$\sigma_A(f) < \log_{10}(2)$

In addition:

Although $A_0(=2.9) > 2$, the peak cannot be qualified "clear" since the amplitude is not decreasing rapidly on each side.
None $f_1 \in [f_0/4, f_0] \mid A_{H/V}(f_1) < A_0/2$
None $f_2 \in [f_0, 4f_0] \mid A_{H/V}(f_2) < A_0/2$

Interpretation : further tests should be performed as listed in section II-3.3.2-b

Broad peak *see $3.3.2.c and appendix A*

Decrease the smoothing bandwidth

If bump **peak** is **not stable** and/or $A_{H/V}(f)$ is very large

no reliable f_0

If bump **peak is stable** and $A_{H/V}(f)$ is rather low

- If clearer peaks are observed in the vicinity and
  - if their related frequencies lie within the frequency range of the broad peak
  - if their related frequencies exhibit significant variation from site to site

Then, examine the **possibility of underground lateral variation**, especially slopes.

- **Otherwise not recommended to extract any information**

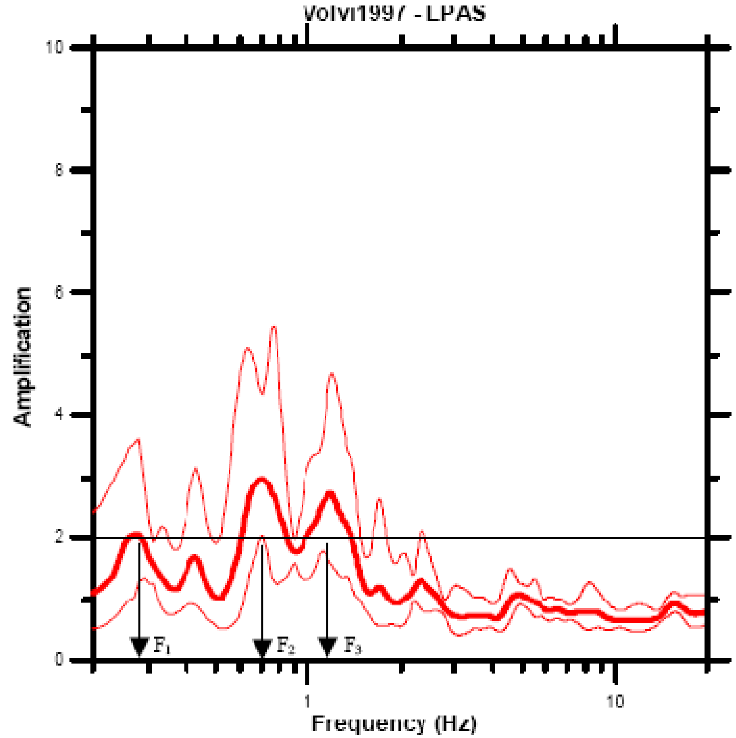
Multiple peaks (multiplicity of maxima) *see $3.3.2.c and Appendix A*

Check no industrial origin of one of the peaks
Increase the smoothing bandwidth

If reprocessed H/V curve **fulfils the** clarity **criteria** — **f_0 reliable**

If reprocessed H/V curve does **not fulfil** the clarity **criteria** — **Redo measurements** over a longer time and/or during night

4. Broad Peak or Multiple Peaks



Basin geometry: Elongated alluvial valley, width~5km, length~40km, Depth~200m

Site Information
LTST site depth to bedrock: ~180m
Type of bedrock: Gneiss
Average shear wave velocity of deposits: 570m/s

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

$f_0 > 10 / l_w$

$n_c (f_0) > 200$

$\sigma_A(f) < \log_{10}(2)$

Interpretation : All three peaks fulfil the criterion for amplitude, A_i>2. However, only the peaks F_2 and F_3 fulfil all "clarity" criteria (3.3.1). The availability of other information (geology, deposit thickness, geophysics) in that area allows us to identify f_2 as the fundamental frequency of the site. The location of this site close to a valley edge may explain the presence of these two peaks with rather low amplitude, while another nearby site (LTST, see above the "clear peak" example") exhibits a clear peak with larger amplitude: the latter is located in the central, part of the graben.

2 peaks cases ($f_1 > f_0$)

see $3.3.2.d and appendix A

If industrial origin of f_0
AND
No industrial origin for f_1

f_0 not reliable and f_1 reliable

- Likely sharp contrast at shallow depth
- f_1 = fundamental frequency
- If h is known then $V_{S,av} \sim 4h.f_1$
- If $V_{S,surf}$ is known then $h_{min} \sim V_{S,surf}/4f_1$

If industrial origin of f_1
AND
No industrial origin for f_0

f_0 reliable and f_1 not reliable

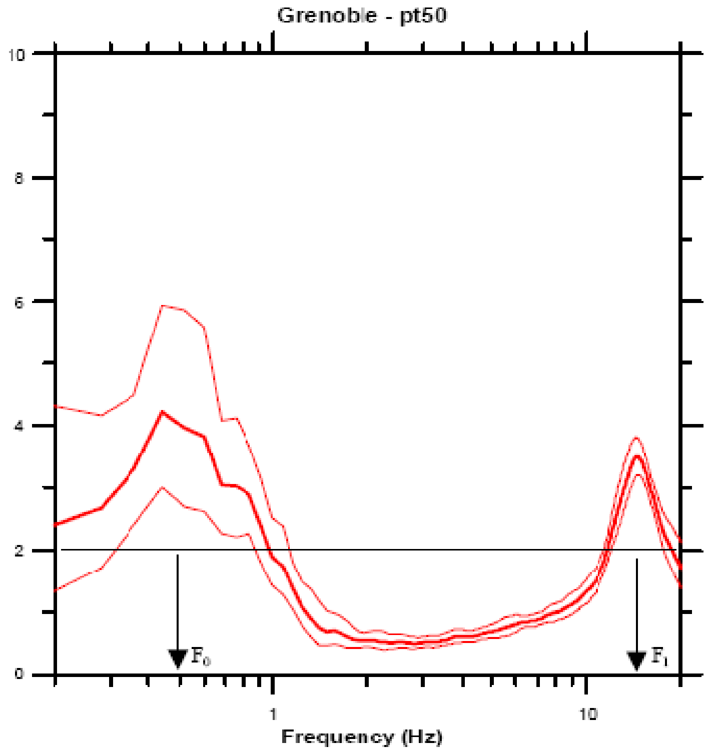
- Likely sharp contrast at rather large depth
- f_0 = fundamental frequency
- If h is known then $V_{S,av} \sim 4h.f_o$
- If $V_{S,surf}$ is known then $h_{min} \sim V_{S,surf}/4f_o$

If the **geology** of the site shows possibility of having **two large velocity contrasts at two different scales**
AND
The **clarity criteria** are fulfilled for **both f0 and f1**

f_0 and f_1 reliable

- Likely two large contrasts at shallow and large depth at two different scales
- f_0 = fundamental frequency
- f1 = other natural frequency
- If $V_{S,surf}$ is known then $h_{1,min} \sim V_{s,surf}/4f_1$

3. Two Peaks Cases (f_1>f_0)



Basin geometry: Y-shaped sedimentary valley, Depth~800m

Site Information
PT50 site is situated on late quaternary post-glacial deposits.
Type of bedrock: Jurassic marls and marly limestone.

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

$f_0 > 10 / l_w$
$n_c (f_0) > 200$
$\sigma_A(f) < \log_{10}(2)$

Interpretation :
For the low frequency peak, $A_0(=4.0) > 2$ and $\exists f_2 \in [f_0, 4f_0] \mid A_{H/V}(f_2) < A_0/2$
Although, strictly speaking, one cannot find $f_1 \in [f_0/4, f_0] \mid A_{H/V}(f_1) < A_0/2$, the general trend of the curve, together with the known geology of the site, allow the meaning of the low frequency peak to be assigned with confidence; another processing with more narrow band smoothing would satisfy the criteria

For the second peak, all the criteria are fulfilled:

$A_1(=3.5)>2$
$\exists f_1 \in [f_1/4, f_1] \mid A_{H/V}(f_1) < A_1/2$
$\exists f_2 \in [f_1, 4f_1] \mid A_{H/V}(f_2) < A_1/2$

This second peak around 13 Hz is certainly associated with a very shallow structure.

Flat H/V curve (meeting the reliability conditions) *see $3.4 and appendix A*

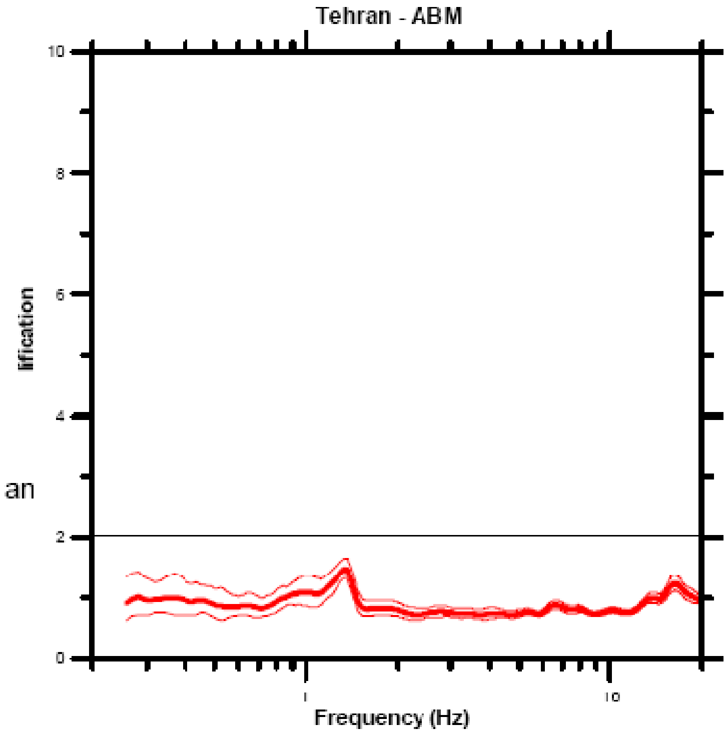
if soil deposits

- Likely absence of **any sharp contrast at depth**
- **Does not necessarily mean no amplification**
- Perform earthquake recordings on site and nearby rock site
- Use of other geophysical techniques

if rock

- likely unweathered or only lightly weathered rock
- **may be considered as a good reference site**

6a. Flat H/V Ratio Curves [on sediments]



Basin geometry: Unknown

Site Information
ABM site is characterised by stiff soil (coarse grained alluvium) overlying bedrock at an unknown depth.

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

$f_0 > 10 / l_w$

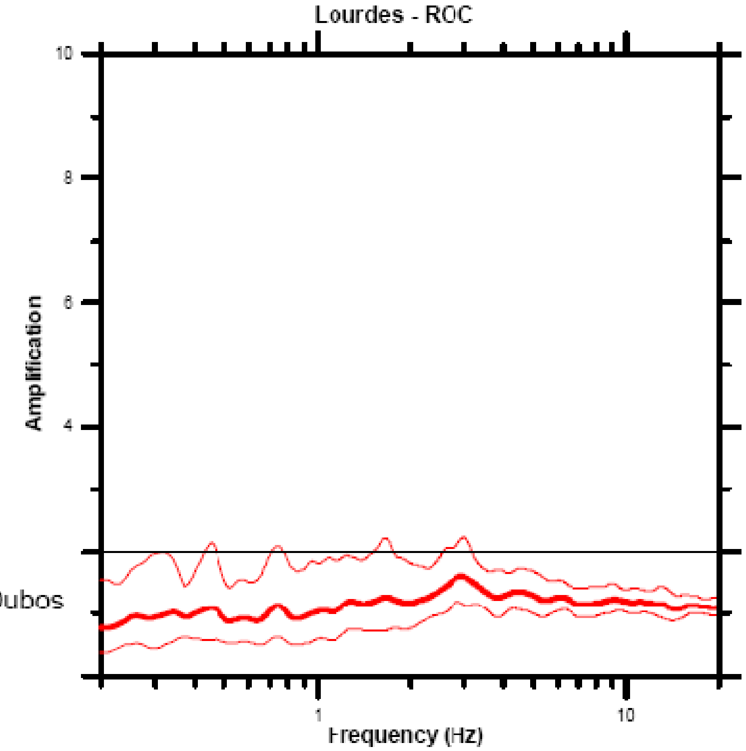
$n_c\ (f_0) > 200$

$\sigma_A(f) < \log_{10}(2)$

Significant low frequency amplification (F<1.0 Hz) was found for the ABM sedimentary site using earthquake data, which does not appear in the H/V ratio. This site is one of the few examples of non-rock sites exhibiting a flat H/V curve though also exhibiting a significant low frequency amplification (less that 5% of the total number of sites studied, as can be seen on Figure 8, section 3.1)

Note: the peak around 1.3 Hz was shown to have an industrial origin.

6b. Flat H/V Ratio Curves [on rock]



Basin geometry: Confluence of two valleys

Site Information
ROC site is situated on rock outcrop at the confluence of two valleys (reference site). (Dubos et al., 2003; Dubos, 2003)

Comments
Criteria for a reliable H/V curve are fulfilled, that is:

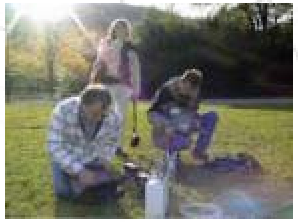
$f_0 > 10 / l_w$

$n_c\ (f_0) > 200$

$\sigma_A(f) < \log_{10}(2)$

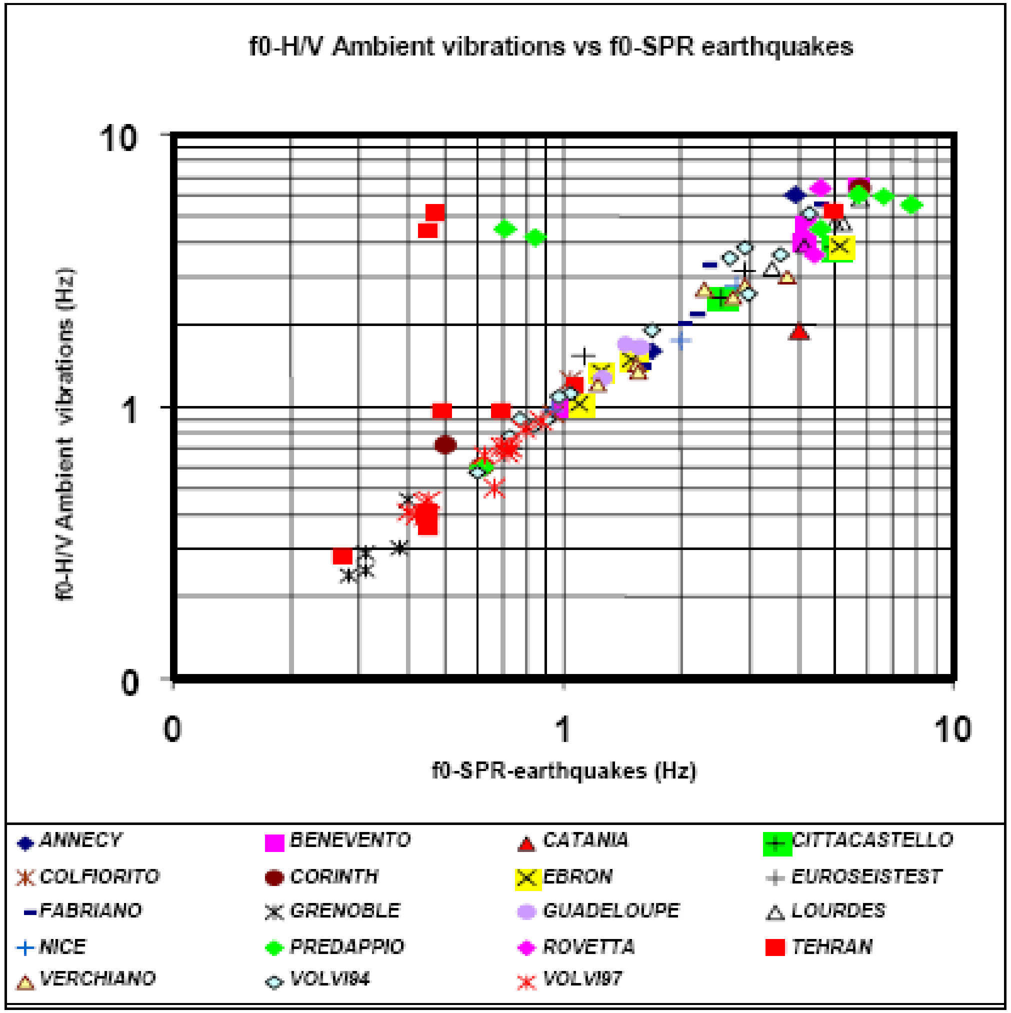
The H/V ratio is flat over the whole frequency range examined. As the available geological information unambiguously indicates that it is a hard rock site, this flat H/V curve may be interpreted as indicative of a good, non weathered reference site free of any amplification even at high frequencies.

Comparison between the H/V on microtremors and earthquake records



Description of the work:

- Collecting existing data sets (earthquake and noise)
- Perform experimental measurements and processing of ambient vibrations at selected sites
- Systematic comparisons with weak- and strong-motion data as well as damage disribution in urban areas
- Comparing experimentally and theoretically estimated transfer functions with H/V ratios



Bard et al., 2004

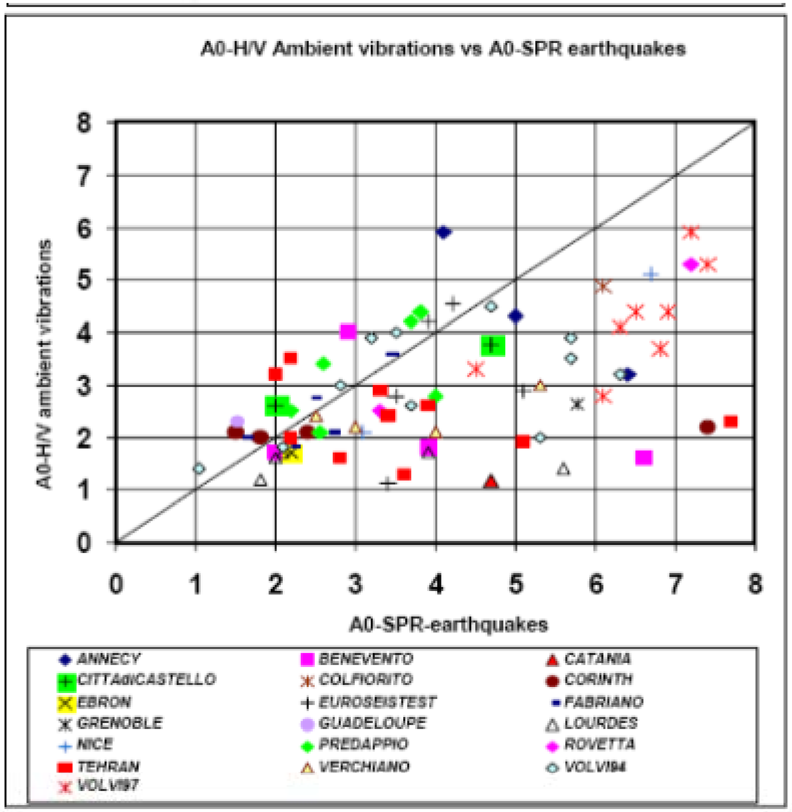
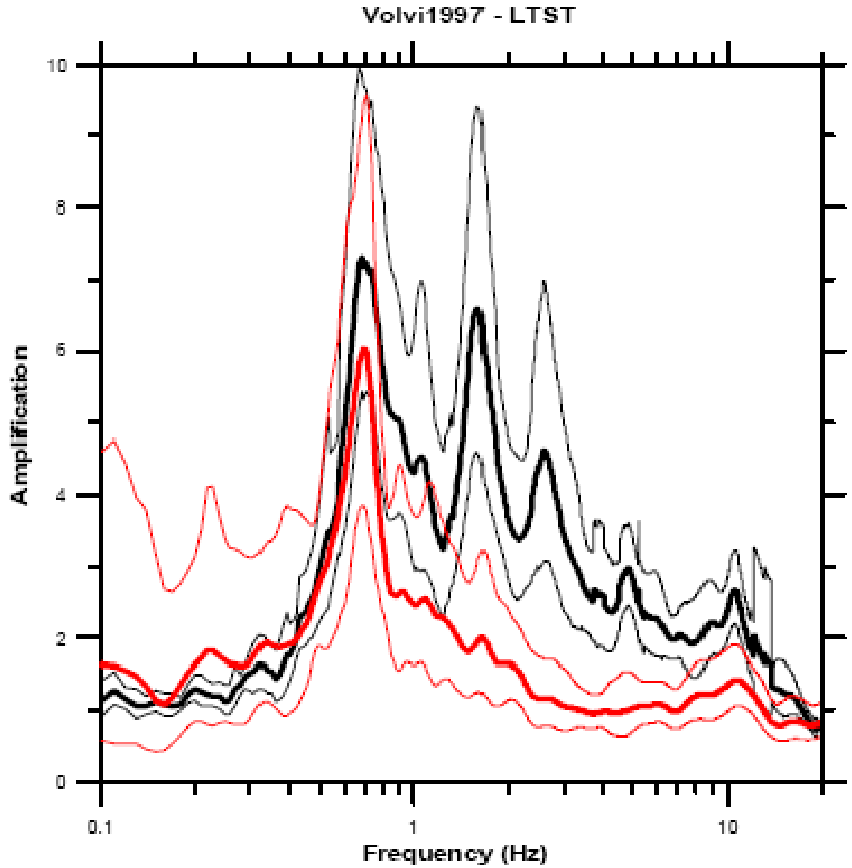


Figure 8. Comparison between H/V ratio of ambient vibrations and standard spectral ratio of earthquakes. Top: comparison of the frequencies f_0, bottom: comparison of the amplitudes A_0.

Bard et al., 2004

Successful correlation

Red lines are for the H/V
Black lines are for SSR

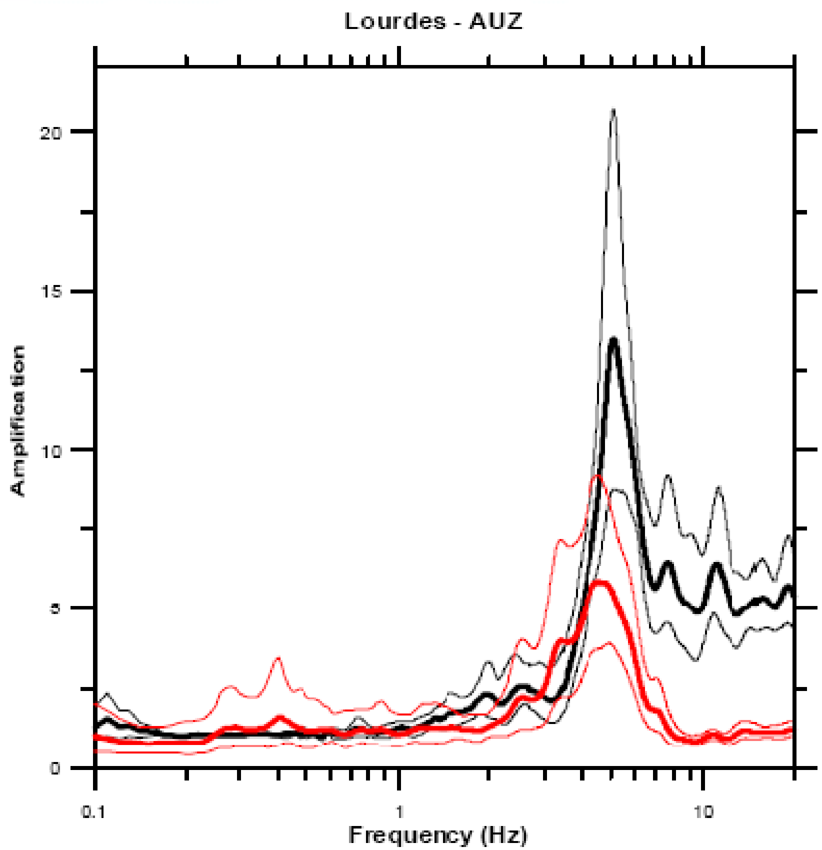


Site: LTST (Mygdonian Basin, Northern Greece)
Surface Geology: Soft
Basin Geometry: Semi-elliptical 3D basin
Surface Topography: Flat
Site Description: Agricultural area

Comments: A clear and unique (H/V) spectral ratio peak is shown. Both approaches (SSR, H/V) exhibit the same fundamental frequency (f_o=0.7Hz). The LTST site is very well documented with geotechnical/geophysical data and the 2D theoretical transfer function is in good agreement with the experimental one.

Successful correlation

Red lines are for the H/V
Black lines are for SSR

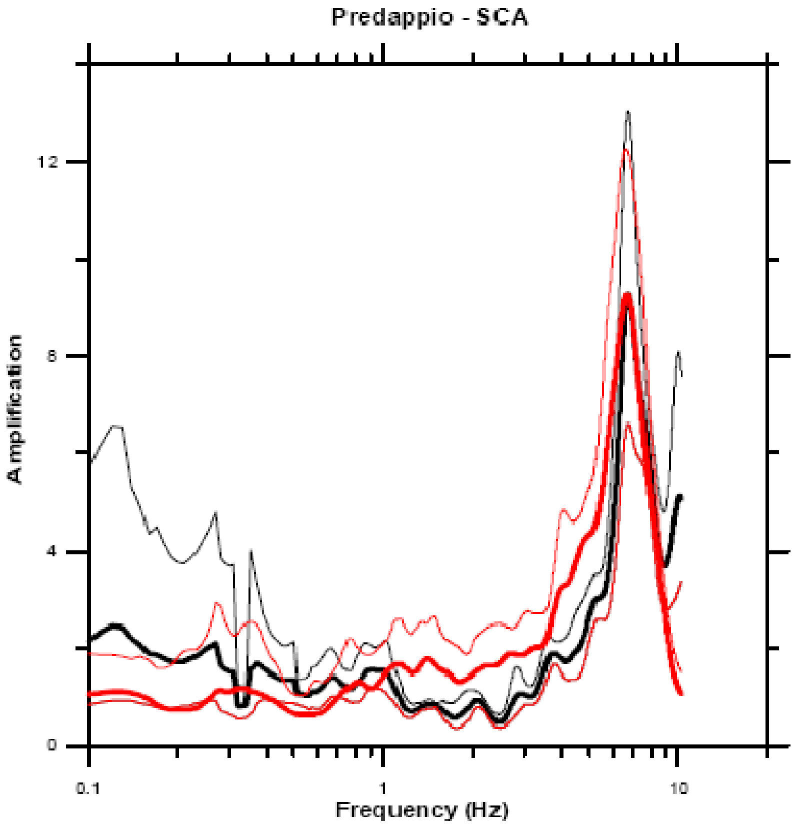


Site: Auzon-Lourdes (France)
Surface Geology: Stiff and shallow sediments (Dubos et al, 2003; Dubos, 2003)
Basin Geometry: 3D Basin
Surface Topography: Flat
Site Description: Urban

Comments: A clear and unique (H/V) spectral ratio peak is shown. Both approaches (SSR, H/V) exhibit almost the same fundamental frequency (f_o=5.0 Hz).

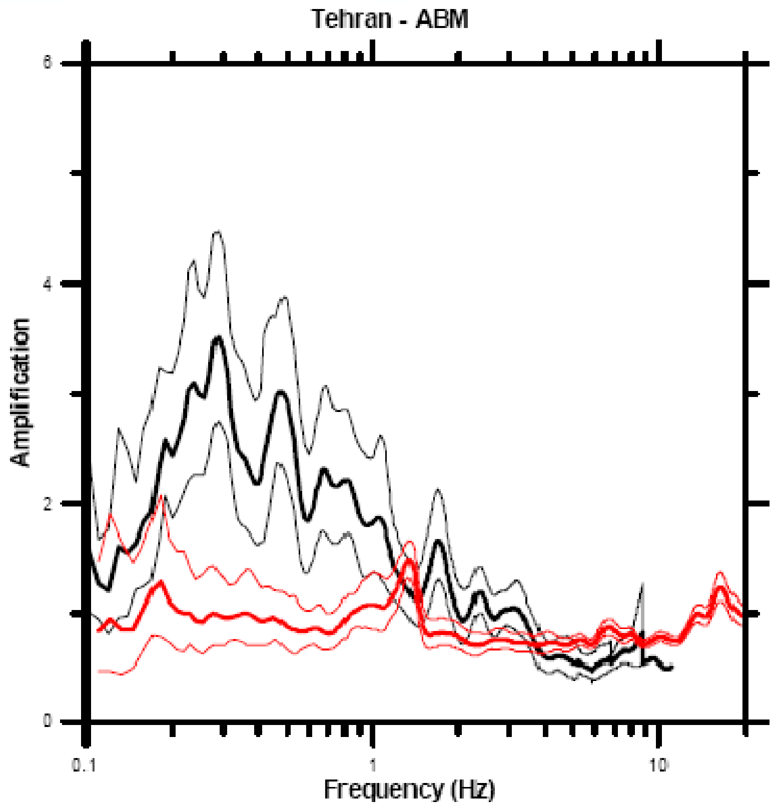
Successful correlation

Red lines are for the H/V
Black lines are for SSR



Site: Predappio (Italy)
Surface Geology: Soft (8m overlying rock)
Basin Geometry: Cylindrical
Surface Topography: Flat
Site Description: Urban

Comments: A clear and unique (H/V) spectral ratio peak is shown in high frequencies. Both approaches (SSR, H/V) exhibit the same fundamental frequency (f_o=7.0 Hz).



No successful correlation

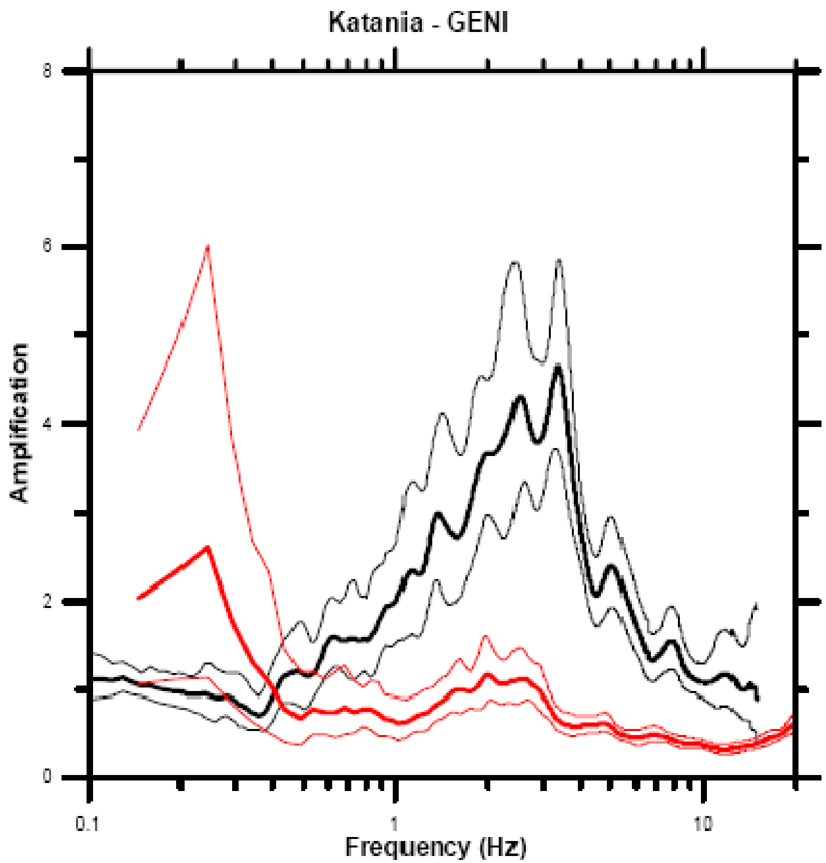
Red lines are for the H/V
Black lines are for SSR

Site: Tehran (Iran)
Surface Geology: Stiff ABM site is characterised by stiff soil (coarse grain alluvium) overlying bedrock at an unknown depth.
Basin Geometry: Unknown
Surface Topography: Flat
Site Description: Urban

Comments: No clear (H/V) spectral ratio peak appears in the low frequency band (f<1.0Hz), although it is clear in the SSR technique. To the contrary, a sharp peak with an amplitude of about 1.5 appears at about 1.3Hz. This (H/V) spectral ratio peak is due to manmade noise/machinery since it appears in the Fourier spectra of all three components.

No successful correlation

Red lines are for the H/V
Black lines are for SSR



Site: Catania (Italy)
Surface Geology: Soft
Basin Geometry: Unknown
Surface Topography: Flat
Site Description: Urban

Comments: No clear (H/V) spectral ratio peak appears in the frequency band [1.0 Hz, 4.0 Hz], although it is clear in the standard spectral ratio technique. The low frequency peak (0.25 Hz) in the H/V curve is not reliable since the associated standard deviation is large, and the amplitude does not decrease enough at lower frequencies.

Results of the SESAME Project
can be obtained at:

http://sesame-fp5.obs.ujf-grenoble.fr

The J-SESAME software and the H/V User Guidelines
can be obtained at:

http://www.geo.uib.no/Seismologi/Software/J-SESAME/

Following are the references for the relevant papers on the reliability of the H/V technique that are based on the SESAME Project results:

Atakan, K., Duval, A-M., Theodulidis, N., Bard, P-Y., and the SESAME Team. 2004. The H/V Spectral Ratio Technique: Experimental Conditions, Data Processing and Empirical Reliability Assessment. *Proceedings of the 13th World Conference on Earthquake Engineering.* Paper No.2268, 1-6 August 2004, Vancouver, Canada.

Atakan, K., Bard, P-Y., Kind, F., Moreno, B., Roquette, P., Tento A., and the SESAME Team. 2004. J-SESAME: A standardized software solution for the H/V Spectral Ratio Technique. *Proceedings of the 13th World Conference on Earthquake Engineering*. Paper No.2270, 1-6 August 2004, Vancouver, Canada.

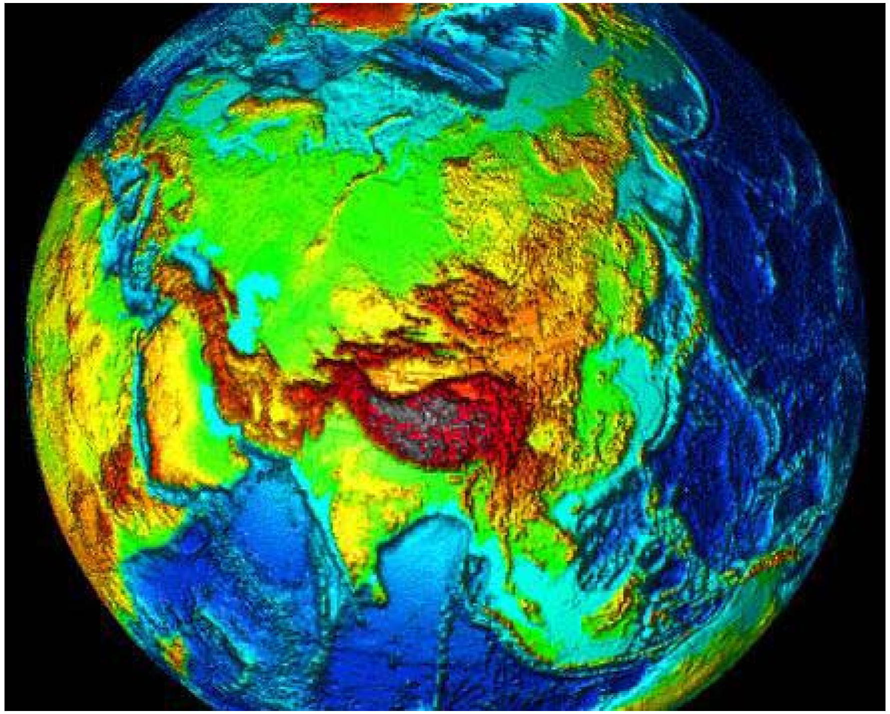
Duval, A-M., Chatelain, J-L., Guillier, B., and the SESAME Team (Ricardo Azzara, Kuvvet Atakan, Pierre-Yves Bard, Sylvette Bonnefoy-Claudet, Fabrizio Cara, Cécile Cornou, Giovanna Cultrera, Donat Faeh, François Dunand, Philippe Guéguen, Mathilde Bøttger Sorensen, Johannes Ripperger, Paula Teves-Costa). 2004. Influence of experimental conditions on the H/V determinations using ambient vibrations (noise). *Proceedings of the 13th World Conference on Earthquake Engineering.* Paper No.306, 1-6 August 2004, Vancouver, Canada.

Theodulidis, N., Cultrera, G., Tento, A., Faeh, D., Atakan, K., Bard, P-Y., Panou, A., and the SESAME Team. 2004. Empirical evaluation of the Horizontal to vertical spectral ratio technique: Results from the SESAME Project. *Proceedings of the 13th World Conference on Earthquake Engineering.* Paper No.2323, 1-6 August 2004, Vancouver, Canada.

Koller, M., Chatelain, J-L-., Guillier, B., Duval, A-M., Atakan, K., Lacave C., Bard, P-Y., and the SESAME Participants 2004. Empirical evaluation of the Horizontal to vertical spectral ratio technique: Results from the SESAME Project. *Proceedings of the 13th World Conference on Earthquake Engineering.* Paper No.3132, 1-6 August 2004, Vancouver, Canada.

Chatelain, J-L., Guillier, B., Cara, F., Duval, A-M., Atakan, K., Bard, P-Y., and the WP02 SESAME Team. 2007. Evaluation of the influence of experimental conditions on H/V results from ambient noise recordings. *Bulletin of Earthquake Engineering.* DOI 10.1007/s10518-007-9040-7. 42p.

Guillier, B., Atakan, K., Chatelain, J-L., Havskov, J., Ohrnberger, M., Cara, F., Duval, A-M., Zacharapoulos, S., Teves-Costa, P., and the SESAME Team. 2007. Influence of instruments on H/V spectral ratios of ambient vibrations. *Bulletin of Earthquake Engineering*. DOI 10.1007/s10518-007-9039-0. 29p.



Thank you for your attention!

www.geo.uib.no