Ground vibration at the site of ESRF and comparison with some other places

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Background

Ground vibrations measurement was simultaneously carried out at the sites:

- ESRF
- SuperACO in the south of Paris
- Orme des Merisiers (for SOLEIL project) near SuperACO

during 8-11 October 1996

the initial purpose of this investigation:

- measurement of the ground vibration at the site of Orme des Merisiers
- comparison with the sites of ESRF and SuperACO.
Outline

- Measurement instruments, set-up and procedure
- Analyses and results in the frequency range (1-100 Hz)
  — Temporal signal analyses and results
  — Spectral analyses and results
  — Study of high level events
- Analyses and results in the low frequency range (0.05-1 Hz)
  — Temporal signal analyses and results
  — Spectral analyses and results
  — Correlation between the 3 sites
Instruments & set-up

at each site, installed:

- **data acquisition system** (*RefTek 72A-06 or 72A-07, 6 channels, 16 or 24 bits*)
- **long period seismometer** (*Guralp CMG-3ESP : 3D, 0.03-50Hz*)
- **1 Hz geophone** (*Mark Products L4C : vertical*)

additionally

- **1 spectrum analyser** (*HP35670, 4 channels, 80 db*) + **4 geophones** (*L4C vertical + horizontal*)

for special study (homogeneous, 3D)

all materials were just placed on the floor within about 1 m² surface area.
Instruments & set-up

Data acquisition system
(Reftek 72A-07)

Seismometer
(Guralp CMG-3ESP)

Geophone
(Mark Products L4C)

at L’Orme des Merisiers
Instruments & set-up - seismometer study (1992)

- **LNM**: Low Noise Model from Document of Lennartz
- **LE-5s**: Lennartz Geophone LE-3D/5s
- **ESRF**: Noise level in ESRF
- **3ESP**: Guralp seismometer CMG-3ESP
- **40T**: Guralp seismometer CMG-40T
- **LNM_G**: Low Noise Model from Document of Guralp

![Graph showing RMS displacement vs frequency for different seismometers at ESRF and other places.](image-url)
Measurement procedure

considerations for defining the measurement procedure:

• collect maximum amount of data
• hard disk capacity 500 Mb for data storage
• a reasonable number of files for the convenience of data processing

synchronisation accuracy < 1 second for periodical measurements at the three sites

two types of measurements:

• i) with the vertical 1 Hz geophone, (sampling rate 250 pts/s)
  
  1.5 minutes measure + 3 minutes break + 1.5 minutes measure + 3 minutes break + ...

• ii) with the long period seismometer, (sampling rate 125 pts/s)

  15 minutes measure + 90 minutes break + 15 minutes measure + 90 minutes break + ...

these measurements (data acquisition) covered at least a period of 60 hours
(from 8-Oct-1996, 6pm to 11-Oct-1996, 8am) in the three sites.
General data processing procedure

Time domain (SAC : Seismic Analysis Code, LLNL) for (0.05-1 Hz)
(MatLab, The Math Works Inc) for (1-100 Hz)

Frequency domain (MatLab)

2 frequency ranges:
— intermediate : 1-100 Hz
— low : 0.05-1 Hz
Quantity of data and formats

collected DATA during more than 60 hours of measurements from the 3 sites :

<table>
<thead>
<tr>
<th>format</th>
<th>quantity</th>
<th>for use</th>
</tr>
</thead>
<tbody>
<tr>
<td>compressed</td>
<td>250 Mb</td>
<td>raw data stored in the acquisition system</td>
</tr>
<tr>
<td>.segy</td>
<td>500 Mb</td>
<td>visualisation and simple analysis with PQL</td>
</tr>
<tr>
<td>.sac</td>
<td>500 Mb</td>
<td>Dpp and Drms calculation with SAC</td>
</tr>
<tr>
<td>.mat</td>
<td>1 Gb</td>
<td>advanced analyses with Matlab</td>
</tr>
</tbody>
</table>

order of conversion

total number of files :

from 1 Hz geophones L4C : 2700
from seismometers CMG-3ESP : 312

all these files were visualised
(1-100 Hz) - *temporal signal analyses / data processing*

- instrument correction
- time integration
- high pass filtering
- peak-to-peak (or RMS) displacement calculation
  - peak-to-peak displacement
    \[ D_{pp} = \max(D_{max\_i} - D_{min\_i})_{i=1,2,...,10} \]
  - RMS displacement
    \[ D_{rms} = \max(D_{rms\_i})_{i=1,2,...,10} \]

*each file of 90 seconds was divided into 10 windows of 8.192 seconds (2048 pts):*

- \[ D_{pp}\_1 \quad D_{pp}\_2 \quad \ldots \quad D_{pp}\_10 \]
- \[ D_{rms}\_1 \quad D_{rms}\_2 \quad \ldots \quad D_{rms}\_10 \]

\[ t : \text{beginning time of the file} \]
(1-100 Hz) - *temporal results*

Peak-to-peak displacement (Dpp) versus time

*in the bandwidth of 1-100 Hz*

![Graph showing peak-to-peak displacement (Dpp) versus time for Orme des Merisiers, ESRF, and SuperACO.](image)

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(1-100 Hz) - *temporal results*

![Graph showing peak-to-peak displacement at the ESRF site](image)

**Ground vibration at the site of ESRF and comparison with some other places**

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Summary of results - in the frequency range (1-100 Hz)

- The vibrations level varies clearly with time.

- Typical values are summarised as below:

<table>
<thead>
<tr>
<th></th>
<th>ESRF</th>
<th>Orme des Merisiers</th>
<th>SuperACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpp during day</td>
<td>0.9 µm</td>
<td>0.4 µm</td>
<td>0.4 µm</td>
</tr>
<tr>
<td>Dpp during night</td>
<td>0.4 µm</td>
<td>0.08 µm</td>
<td>0.16 µm</td>
</tr>
<tr>
<td>Drms during day</td>
<td>0.15 µm</td>
<td>0.04 µm</td>
<td>0.04 µm</td>
</tr>
<tr>
<td>Drms during night</td>
<td>0.08 µm</td>
<td>0.01 µm</td>
<td>0.02 µm</td>
</tr>
<tr>
<td>high level events</td>
<td>yes, up to 3 µm</td>
<td>no</td>
<td>yes, up to 2 µm</td>
</tr>
</tbody>
</table>
(1-100 Hz) - *Spectral analyses*

- **Instrument correction**
- **Spectral displacement calculation**
  - integration of measured velocity in time domain
  - FFT, displacement spectrum
  - averaged velocity spectrum
- **some parameters used for spectra averaging**
  - window length of FFT : 16.384 s
  - windows overlap : 14 s
  - number of spectra used for average : 31
Different form of spectral results and units

\( v_{FT} \)  
Fourier Transform of velocity over a window length of \( T \) (unit: \( \mu m/s/Hz \))

\( v_{sp} \)  
real spectrum of velocity (output of spectrum analyzer) (unit: \( \mu m/s \))
\[ v_{sp} = \frac{2}{T} v_{FT} \]

\( PSD_v \)  
velocity Power Spectrum Density (unit: \( (\mu m/s)^2/Hz \))
\[ PSD_v = \frac{T}{2} v_{sp}^2 = \frac{2}{T} v_{FT}^2 \]

\( d_{sp} \)  
real spectrum of displacement (unit: \( \mu m \))
\[ d_{sp} = \frac{v_{sp}}{\sqrt{2} \pi f} \]

\( PSD_d \)  
displacement Power Spectrum Density (unit: \( \mu m^2/Hz \))
\[ PSD_d = \frac{T}{2} d_{sp}^2 \]

\( PSD_d^{0.5} \)  
root squared displacement Power Spectrum Density (unit: \( \mu m/\sqrt{Hz} \))
\[ PSD_d^{0.5} = \sqrt{PSD_d} = \sqrt{\frac{T}{2} d_{sp}} \]

The integral of PSD\(_d\) over frequency leads to rms displacement:
\[ Drms = \sqrt{\int_0^\infty (PSD\_d) df} = \sqrt{\sum (PSD\_d)/T} = \sqrt{\sum d_{sp}^2 / 2} \]
(1-100 Hz) - *Spectral results*

examples of spectral displacements at the 3 sites

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Ground vibration at the site of ESRF and comparison with some other places

\(1-100\ \text{Hz}) - Spectral results

<table>
<thead>
<tr>
<th>Location</th>
<th>Principal Peak Frequencies (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESRF</td>
<td>2,92, 16.4</td>
</tr>
<tr>
<td>Orme des Merisiers</td>
<td>12.2, 24.3, 49.3, 100</td>
</tr>
<tr>
<td>SuperACO</td>
<td>6.9, 12.7, 24.8, 33.1, 34.2, 46.0, 48.5, 92.8, 100</td>
</tr>
</tbody>
</table>
(1-100 Hz) - *some high level events*

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(0.05-1 Hz) - *Analyses Procedure*

**Temporal signal analyses (SAC)**
- band pass filtering: \( f_{\text{high}} = 0.05 \text{ Hz}, f_{\text{low}} = 1 \text{ Hz} \)
- FFT: *velocity spectrum*, window length = 128 seconds, over 7 windows (900s)
- Integration in the spectral domain: *displacement spectrum* (dividing by \( \omega = 2\pi f \))
- IFFT: *temporal displacement*
- Dpp and Drms calculation: similar as in the frequency range (1-100 Hz)
  \[
  \text{Dpp} = \max(\text{D}_{\text{max}_i} - \text{D}_{\text{min}_i})_{i=1,2,...,7} \\
  \text{Drms} = \max(\text{Drms}_i)_{i=1,2,...,7}
  \]

**Spectral analyses**

FFT → *velocity spectrum* → averaged velocity spectrum → *displacement spectrum*

- window length of FFT : 131.072 s
- windows overlap : 120 s
- number of spectra used for average : 69
(0.05-1 Hz) - temporal results / Dpp

<table>
<thead>
<tr>
<th></th>
<th>Peak-to-Peak Displacement (µm)</th>
<th>RMS Displacement (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>North-South</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>East-West</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>

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(0.05-1 Hz) - *temporal results / Dpp*

![Graph showing peak-to-peak displacement vs time for different locations: ESRF, Orme des Merisiers, and SuperACO. The graph displays data points for different dates and times, illustrating the vibration levels at each location.](image-url)
(0.05-50 Hz) - displacement spectra at the 3 sites

vertical spectral displacements at the 3 sites

Vertical displacement spectra at 3 sites on 9-Oct-1996

During day
\[ t_{\text{begin}} = 16:14:59.910 \]

During night
\[ t_{\text{begin}} = 23:14:59.706 \]
(0.05-50 Hz) - 3D displacement spectra at the site of ESRF
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(0.05-1 Hz) - *differential vertical displacements*

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Concluding remarks

- **time dependence** of ground vibration
- in the frequency range of 1-100 Hz, \( \text{dpp}(t) \) varies as quasi \( \sin(2\pi t/T) \) with a period of \( T=24 \) hours
- there is a quite **good space correlation** of the vibration in the frequency range of 0.05-1 Hz
Influences of **helicopters** flying over the site

**Spectrogram of**

**vertical acceleration**

\[(dB.\mu m/s^2)\]

**Doppler Effects:**

\[
\frac{\Delta f}{f} = \frac{V_{helico} \cos \theta}{(V_s - V_{helico} \cos \theta)}
\]

\[V_s : \text{sound speed}\]

\[\Delta f/f \sim 1/8\]

\[\rightarrow V_{helico} \sim 40 \text{ m/s}\]

\[\sim 144 \text{ km/h}\]