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Presentation of a state of art of the project SESAME and redaction of a paper.

Extracting information from ambient seismic noise: The SESAME project

(Site EffectS assessment using AMbient Excitations)

Pierre-Yves BARD
LGIT / LCPC, Grenoble Observatory, Joseph Fourier University, Grenoble

Content

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1 Introduction : motivation and objectives

After recent earthquakes, a priori estimations of site effects became a major challenge for an efficient mitigation of seismic risk. In the case of moderate earthquakes, or moderate motion at some distance from large events, severe damage is often limited to zones of unfavourable geotechnical conditions that give rise to significant site effects. In the case of large events, although damage distribution in the near-source area is also significantly affected by fault geometry and rupture history, and despite the generally beneficial influence of non-linear behavior in soft soils, there exist famous examples of tremendous site effects even in the near-field of large events (Northridge 1994, Kobe 1995, Quindio 1999, Kocaeli 1999, Athens 1999, Bhuj 2001). This underlines how important it is to account for site effects in the design of new constructions, in the retrofitting of existing structures - including the assessment of retrofitting priorities - , and in land use planning as well. This is particularly valid in areas of low and moderate seismicity, as is the case for most European countries.

As illustrated by the blind tests performed in the nineties (Turkey Flat and Odawara), the numerical prediction of site effects with a reasonable confidence level is usually possible only if some key geophysical or geotechnical parameters are known. The ideal case would be to perform a geophysical measurement campaign, with for instance cross hole tests in order to get a reliable S wave velocity profile of the site. On the other hand, the known experimental techniques to obtain reliable estimates of site effects (site to reference spectral ratio, generalized or parameterised inversion) require to obtain several tens of good quality earthquake recordings at the sites under study, which ends up with high costs in urban areas because of the high noise level, especially in areas of moderate seismicity where events are unfrequent.

However, although the need to consider site effects in the design of structures is more and more recognized, today's economical reality is unfortunately that the budgets allocated to site investigations diminish more and more. The few methods known as reliable then systematically appear as far too expensive for local and national authorities, especially in moderate seismicity countries or in developing countries. This is in particular the case of most of Europe, where the budget allocated for seismic prevention often remains at very low levels compared to Asia or California.

There is therefore a drastic need for reliable, low cost techniques, from an economical as well as from a safety point of view. Very promising developments were launched over the last decade, based on the use of ambient vibration measurements, which are very easy easy to obtain whatever in any conditions:

- On the one hand, the H/V technique, widely known as the "Nakamura's" technique although it was initially proposed by Nogoshi and Igarashi in 1971 [1] spread all over the world after Nakamura's paper published in 1989 [2]: the spectral ratio of the horizontal components to the vertical component of ambient vibration is claimed not only to indicate the fundamental eigenfrequency of the site under investigation, but also, according to some authors, to provide some quantitative information on the actual site amplification.

- On the other hand, several Japanese scientists and engineers claim to be able to retrieve the velocity profile from array measurements of ambient vibrations: these are very promising results that need to be checked, both experimentally and theoretically.

Ambient vibration techniques are much cheaper than classical geophysical site investigations. In addition, the latter investigations are often almost impossible in urban environments (where, for instance, use of explosives is either forbidden or very strictly regulated, or the level of noise and artefacts prevents the use of refined techniques). That is why they have the potential to significantly contribute to effective seismic risk mitigation, in particular in urban areas (where the risk is the largest and keeps growing). That is why also their use is rapidly spreading world-wide, especially again in urban areas.

However, it remains also mandatory that these low cost tools be reliable. Concerning these two techniques based on ambient vibration measurements, one must admit that their physical basis and actual relevancy for site effect estimates has never reached a scientific overall agreement. It is therefore most likely that these techniques, especially the H/V one, are often misused and may lead to wrong results.

The objectives of the SESAME project are precisely to investigate thoroughly the reliability of these two techniques. It thus gathers teams having expertise in many different fields (seismology, engineering geology, surface geophysics, data processing, numerical modelling, ***Table 1***), in order to tackle these methods under different viewpoints. The anticipated, main outcome of the project are to clearly and solidly assess the physical basis of these techniques and of their actual relevancy for site effect estimation, and to issue practical recommendations for their routine implementation. This will more specifically materialize through user guidelines and processing software that will be open for international discussion, and freely and widely disseminated. The consequences will be two-fold: on one side, their wide dissemination will hopefully prevent misuses, wrong microzonation maps and misleading earthquake safety feelings. On the other side, for countries which till now have been reluctant to use them, it will offer a validated, simple, low-cost tool to contribute in systematic, first-level evaluations of seismic risk in urban areas.

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Table 1: SESAME Partnership

1	UJFG.LGIT	University Joseph Fourier (Lab. Géophysique Interne et Tectonophysique)	Grenoble
13	CNRS.LGIT	National Center for Scientific Research	Grenoble
14	LCPC	Central Laboratory for Bridges and Roads	Paris
2	RICSA	Résonance Ingénieurs-Conseils SA	Geneva
3	UPOTS.GEO	University of Potsdam (Geophysical Department)	Potsdam
4	ULGG.DG0.GIH	University of Liège (Lab. Engineering Geology and Hydrogeology)	Liège
5	UIB.ISI	University of Bergen (Institute of Solid Earth Physics)	Bergen
6	ETH.GEOP.SSS	Polytechnic School of Zürich (Swiss Seismological Service)	Zürich
7	IESEE	Institute of Engineering Seismology and Earthquake Engineering (ITSAK)	Thessaloniki
8	ICTE.IGI	Institute of Earth and Space Sciences	Lisbon
9	INGV	National Institute of Geophysics and Volcanology	Roma
11	IGSAS.SD	Geophysical Institute – Slovak Academy of Sciences	Bratislava
10	CNR.IDPA	National Research Council (Istituto per la Dinamica dei Processi Ambientali)	Milano
12	CETEMED.LRE	CETE Méditerranée (Center of Technical Studies, Ministry of Equipment)	Nice

2 Specific issues and project structure

2.1 Scientific Issues

2.1.1 H/V ambient vibration technique

The seismological community agrees that the H/V technique gives valuable results if applied "with care" or "appropriately". However, the problem is that nobody seems to really know what this means. As detailed in [3], too many questions are still waiting for an answer, or at least for a common answer, since different teams usually proceed and interpret differently.

The key problem is that the method has been developed empirically. Only few theoretical investigations have been performed to clarify its underlying physics. The interpretation most commonly (but not unanimously) accepted in the seismological community may be summarized as follows:

- seismic noise is basically consisting of surface waves (and thus of Rayleigh waves for the vertical component)
- the Rayleigh wave ellipticity is varying with frequency in layered soils
- In presence of large impedance contrast (beyond 2.5 – 3), the vertical component of Rayleigh waves vanishes around the fundamental frequency of S-waves (Vs / 4h).

According to this interpretation, the peak in the H/V ratio should therefore coincide with the fundamental soil frequency, but there should not exist any link between H/V peak amplitude and actual amplification.

However, nobody really knows in detail what kind of waves, to what proportion, are usually measured as ambient vibrations. Nobody really understands why there apparently exist, at least in some areas, some quantitative correlation between H/V peak amplitude and S-wave amplification ratio.

Developing some guidelines in order to assure a reasonable quality standard for ambient noise measurements - data acquisition and treatment as well as interpretation - , can be done only on the basis of

- a better understanding of the physical/theoretical background,
- a comprehensive experimental/statistical comparisons with other techniques a priori thought to be "more correct" (weak and strong motion classical spectral ratios, damage distributions from earthquakes, etc.).
- a "standardization" of the field measurement conditions and of the data processing as well, in order to insure a minimum quality, as this type of measurement is expected to become a routine geotechnical in situ testVelocity profile from array measurements of ambient vibration

As mentioned earlier, one of the great need for numerical prediction of site effects is to feed the models with reliable parameter values concerning the geometry and mechanical characteristics of the subsurface structure. Many geophysical tools do exist, but they are not used so often for common projects. In addition their use is often very limited in urban areas, because of the difficulties to install some heavy equipment and/or they most often provide information only for the very surficial layers (upper 30-50 m). [There are tools to go deeper (such as seismic reflection or borehole drilling), but up to now to our knowledge they have never been used - in Europe - for routine seismic design purpose because of their prohibitive cost].

There is therefore a need for "urban" geophysical exploration tools, which can allow to investigate deep soil properties (down to several hundred meters), and would complement very surficial geophysical tools such as seismic prospecting. Array measurements of ambient vibrations do apparently meet these requirements. Several Japanese teams have indeed recently claimed the possibility to retrieve the dispersion curves of surface waves from array measurements (with either a classical frequency - wavenumber analysis, or the spatial autocorrelation technique put forward by Aki in [4]), and thus to invert the velocity profile for both S and P waves down to large depths (several kilometres with a 2-4 km aperture array). This of course requires the assumption of a horizontally stratified structure, a condition that is not always met in reality.

There were, however, only a few groups in Japan that use these techniques applied on noise measurements, and none in Europe or USA (where there have been however, some attempts to use array techniques for very particular signals, the volcanic tremors). Our objective here is therefore to investigate the ability of this technique to provide useful information on site conditions, for simple (1D) as well as for less simple (2D, 3D) geological structures. Besides theoretical and signal processing developments, an important component of this work is dedicated to the use of existing data for exploiting array noise measurements, e.g. introduce the a priori information in the inversion of the dispersion curves. This information could come from shallow geophysical experiments and/or geotechnical investigations which are usually numerous in towns and must be taken into account when possible.

Research about retrieving velocity profiles from array measurements is obviously interesting in itself. However, it furthermore has the merit to significantly contribute to a better understanding of the H/V technique, since it will give some valuable insight into what kinds of waves are usually measured. As a consequence, the H/V technique will be much better understood and many open questions (see above) are expected to find their answer.

2.2 Project structure

In order to try and answer the issues listed above, the work has been divided into 4 main, complementary tasks, as illustrated in ***Figure 1***. On the upstream side, emphasis is put on understanding the real nature of noise, especially in urban areas. On the technical side, series of investigations are planned in order to clearly identify the key points in each of these techniques and their reliability, and to clearly assess the conditions under which they have to be performed: experimental conditions for the measurements, and processing techniques as well. Finally, on the downstream side, after - hopefully - having shown that these techniques do provide useful information when applied with care, we plan to offer a well-established framework for reliable measurements by proposing user guidelines that could form the basis for a quality label.

The scientific work is thus separated into a total of 12 work-packages, three for each main four task:

1. H/V technique: experimental aspects for warranting the stability and reproducibility of measurements, investigations on the various data processing alternatives and choice of the most robust ones, and finally experimental assessment of the meaning of this ratio by a thorough comparison with instrumentally measured site effects, or damage distribution in several recent earthquakes.
2. Array measurement technique: experimental aspects for an optimal adaptation of the instrumental characteristics and layout to the site under study, analysis of several multitrace signal processing techniques (f-k, spatial autocorrelation) and implementation of a robust software, and improvements in the inversion of velocity profiles with an optimum use of a priori information.
3. Physical background and numerical modelling for cross-checks with observed data: data analysis at several sites to identify the composition of noise wavefield (nature, proportion and origin of surface and body waves) in urban areas, development and validation of numerical models (FD) with random surface sources, and numerical analysis of the H/V and array techniques on noise synthetics, and finally cross checking of observations, numerical simulations, and known structure and site effects for a few well-known test-sites.

4. Finally, organisation of the dissemination of the scientific knowledge and technical know-how through special workshops and special issue in an international journal, redaction of user guidelines and realisation of a CD-ROM with validated processing software for the H/V technique to be advertised in international committees.

3 Main achievements after one year

3.1 Test sites

In order to check thoroughly the two techniques that are concerned in this project (H/V and array), it was decided to apply them to a number of well-known sites, where detailed geotechnical and geophysical information is already available. These test-sites were selected from the experience and background of some consortium teams. They are five:

- **Volvi (Greece)**: the European test site is one of the best known in Europe, thanks to two previous projects (EUROSEISTEST, EUROSEISMOD). It is relatively deep and soft (h = 200 m, f_0 = 0.7 Hz, mainly 2D site)
- **Grenoble (France)**: this very thick, relatively stiff site (h > 500 m, f_0 = 0.3 Hz, 3D site) has been thoroughly studied in recent years because of observed very large, broad band amplifications. It is typical of large alpine valleys.
- **Colfiorito (Italy)**: this site has been extensively studied after the Umbria-Marche sequence of 1997-1998, because of spectacular 2D/3D amplifications and ringing. It is a good example of many small alluvial basins in the Appenine and in "intermediate mountain" areas. It is however, rather deep, and low frequency (h > 100 m, f_0 = 1 Hz).
- **Basel (Switzerland)**: this important urban and industrial area is, alike the Grenoble area, the object of extensive investigations with other funding sources. It is also a rather thick site (h > 200 m, f_0 from 0.5 to 2 Hz).
- **Liège (Belgium)**: this is the only shallow site (h < 20 m, f_0 = 5 Hz), and it is typical of many urban sites with thin alluvial / fluvial deposits.

In addition, some attention is paid also to two other sites:

- **Uccle** (near Brussels, site of the Royal observatory),
- **Nice** (another urban area, typical of many coastal cities along the Mediterranean Sea, with thin to intermediate sediment thickness).

3.2 Task A (H/V technique)

3.2.1 Investigations on experimental conditions

A first goal was to evaluate the influence of experimental parameters in stability and reproducibility of the “H/V ratio”. This requires to test a) the instruments and b) the field experimental conditions.

3.2.1.a Instrumental tests

A series of thorough instrumental tests have thus been performed in Bergen for all the instruments (sensors and digitizers) used within the consortium. The test for the digitizers (16 to 24 bits) consisted in checks about the sensitivity, the internal digitizer noise, the stability (in particular the differences between "cold" and "warm" instruments, i.e., just after or long after the start), and the artifacts due to delays in channel synchronization (see ***Table 2a***). The sensors belonged to three main categories (accelerometers, short period velocimeters, and intermediate to broad band velocimeters, see ***Table 2b***). The tests consisted mainly in analysing the bandwidth where H/V curves are representative of the actual H/V ground motion curve.

These tests and their results are described in much detail in a specific report (report D01.02, [5]). The main conclusion concerns the sensors: accelerometers and very short period seismometers (4.5 Hz), are NOT recommended for ambient noise measurements (unless one is interested only in high frequencies, i.e., above 5 Hz). One should prefer at least 1 s seismometer and preferably at least 5 s seismometers. Some other interesting results were obtained concerning the digitizers.

Table 2a: List of tested digitizers

CODE	Digitisers/recorders	Condition	Sensitivity counts/V	Constructor
HA	Hathor-3	Gain=128	6,711E+06	Leas
TI	Titan 3	Gain=1, 4, 256	1,670E+06	Agecodagis
RE	Reftek 72A07		5,250E+05	Reftek
MA	Mars88		1,000E+06	Lennartz
IN	INGV self-made		1,165E+06	INGV Italy
ET	Altus-Etna int. Digitis.		5,240E+04	Kinemetrics
GB	GBV 316		1,310E+07	GEOSIG Switzerland
NH	Nanometrics CH1-3		7,350E+06	Nanometrics
NL	Nanometrics CH4-6		1,310E+06	Nanometrics
LE	CityShark	Gain=512	2,684E+07	Leas
ML	MarsLite		0,800E+06	Lennartz
SS	Kinem. SSR	Gain=1	13107	Kinemetrics
E3	Earth Data 3CH	Gain=1	1,00E+06	Earth Data
E6	Earth Data 6CH	Gain=1	1,00E+06	Earth Data

Table 2b: List of tested sensors

Velocimeters			
Type	**T0 s**	**Damping**	**GE [V/(m/s)]**
LE-3Dlite 1Hz	1	0,707	400
LE-3D/5s	5	0,707	400
LE-3D Classic	1	0,707	400
Mark L-22	0,5	0,46 (Re=open)	139
Mark L-28B	0,22	0,727 (Re=39k)	97.4
"Chinese" 2Hz	0,5	0,70 (Re=39k)	38
Mark L4-C	1	0,7	175
Kinem. Ranger	1	0,7	145
Sensor GBV	0,22	0,7	27.6
Guralp CMG-40T	30	0.71	800
Geotech KS-2000	100	0.707	2000

Accelerometers	
Type	**Sensitivity**
Kinematics Episensor	80 V/g
Guralp CMG-5T	10 V/g
Altus-Etna int. Episensor	1.25 V/g

3.2.1.b Field experimental protocol

A series of tests have been launched concerning the effects of soil/sensor coupling (burying the sensors or not, putting some plates under the sensor, dry/wet soil, grass, etc.), of weather conditions (wind, rain, …), and the possible artifacts due to urban environment (pipes, asphalt, …). These tests are still under way and no report has been issued yet. They have, however, already yielded somewhat surprising results on soil/sensor coupling conditions and their consequences in the low-frequency domain , which bear an outmost importance for the practical implementation of the method: they will be therefore crosschecked carefully before being reported in the next deliverable from Task A.

3.2.2 Data processing and development of a standard H/V software

Considering the variety of H/V processing used throughout the world, the objective is to propose a "consensus", standard software that can be routinely used by non-specialists (after a short training) all over the world on any computer platform. Its design has therefore been achieved in view of optimizing its portability and simplicity for field or lab uses in developed AND developing countries.

The software will consist of two separate modules: a) a main processing module, and b) a browsing and display module. The first one is written in fortran, while the second one is written in Java, so that it can be implemented on any computer with any operating system (PC, Mac, Linux, Mainframe, …). It will be able to process directly noise data with 2 built-in formats (GSE and a simple ASCII format, named as "saf" format), but conversion programs from any other data format will be very easy to write (and some are already available). The main processing module, which includes different options for window selection, spectral smoothing, and averaging, will also include default parameters for routine use.

The software should be ready by mid 2003, at least for an internal version. At the end of the project, the software will be freely available from the web site, together with a user manual.

3.2.3 Empirical evaluation of the H/V technique

This work package is intended to perform an objective, purely experimental assessment of the reliability of the H/V technique, by comparing its results with those of other, well established experimental techniques, based on a homogeneous data set of ambient noise and earthquake recordings. It will also compare H/V results with observed damage on recent earthquakes.

In this aim, the first step has been to gather all data already existing within the various teams of the consortium (Greece, Italy, France, Switzerland, Portugal).. According to the inventory listed in ***Table 3***, earthquake and ambient noise recordings are simultaneously available at more than 230 sites located in very different geological settings, including soft and stiff, shallow and deep soils, with or without large lateral variations. For each of them, standard site and event information sheets will be filled and archived, and the whole data will be gathered in a common CD-ROM with a standard format.

Table 3: Data inventory for the experimental assessment of H/V technique

Team	Data set	Number of sites	Weak motion (< 0.1 g)	Strong motion (> 0.1 g)	Site Information	Reference site
ITSAK	Strong motion network	> 22	x		Very good	No
		> 10		x	Very good	No
ETHZ	Strong motion network	10	x	-	Poor	No
CNR / IDPA	Fabriano	19	x	-	Fair to good	Yes
	Nocera	25	x	x(1 site)	Fair to good	Yes
	Predappio	20	x	-	Fair to good	Yes
	Valtellina	Refraction profiles		-	Cross section	No
INGV	Benevento	9	x	-	Fair to good	yes
	Catania	7	x	-	Fair to good	yes
	Colfiorito	10	x	-	Fair to good	yes
	Verchiano	10	x	-	Fair to good	yes
	Citta di Castello	> 35	x	-	Fair to good	yes
	Ferrara	2	x	-	Very good	Borehole
LGIT / LCPC / CETE	Annecy	3	x	-	Poor	Yes
	Grenoble	9	x	-	Good toVG	2 (Borehole)
	Ebron	3	x	-	Good	Yes (2)
	Nice	4	x	-	Good	yes
	Pointe-à-Pitre	4	x	-	Fair	Yes (3)
	Volvi	15	x	-	Good to VG	Yes (3, Borehole)
	Thessaloniki	8	x	-	Good to VG	Yes (2)
	Tehran	11	x	-	Fair	Yes (2)

For more than 180 sites, there exist a nearby rock reference site: it will thus be possible to compare directly the experimental transfer functions (i.e., site-to reference spectral ratios) derived from earthquake recordings, and the H/V ratios derived from noise measurements. This very large data set will be processed in a homogeneous way (window selection, smoothing, averaging) for deriving both the average site-to-reference spectral ratio and the H/V noise ratio. As a consequence, even if we fail in reaching a consensus theoretical interpretation as to the meaning of the H/V ratio, the comprehen-sive comparison of these experimental results will yield a purely empirical, but statistically meaningful and therefore reliable, assessment of the abilities and limitations of the H/V technique.

In addition, a few damaged cities - mainly in Greece and Italy - will serve as experimental sites where ambient noise measurements have been performed or will be performed in order to compare them directly with damage distribution. These cities are Kalamata, Athens, Thessaloniki, Roma, Palermo and Caracas.

3.3 Task B : array measurement technique

The basic aim of this task is to investigate the feasibility and capability of noise array measurements to derive quantitative information on site velocity profile. Apart from the practical problems linked to the instrumental layout in the field, the main issues here are a) the derivation of the surface wave dispersion curves from the array recordings, and b) the inversion of the velocity profile from the dispersion curves, including the possible use of a priori information.

3.3.1 Intrumental layout

The objective is to assess the dependence of the array performance (for phase velocity determination) on the experimental conditions (array geometry, aperture, number of sensors, sensor types, timing accuracy), in order to optimize the instrumental layout. This will be reached through a series of theoretical tests (some of them being already performed), and from the lessons from the ongoing measurements on the various test sites decided within the consortium. By Summer 2002, field measurements have already been performed in the five test-sites [Liège, Grenoble, Basel, Colfiorito, and Volvi], while complementary measurements have also been carried on in Nice and Uccle.

We have selected four standard array methods for the analysis of ambient vibrations. The four selected methods differ both in the assumptions made for the analyzed wavefield as well as in the feasibility of the method-specific experimental setup. Three of those four methods, the “slantstack analysis” (SL, e.g. [6]), the “f-k analysis” (FK, e.g. [7]) and the “high-resolution f-k” (HRFK, [8]) assume the arrival of coherent plane waves crossing the seismic array. Whereas for the SL method only a one-dimensional array setup is required - thus one of the preferred methods in terms of logistical considerations - both FK and CAPON need a two-dimensional array setup. The last method to be investigated is the spatial autocorrelation method (SPAC, [4]). This method assumes a stationary random wavefield and provides a theoretical relationship between the correlation of sensor pairs for differing azimuths and spatial distances and the dispersion characteristics of surface waves. The logistical demand for the experimental setup of the array configuration is high for the SPAC method. A dense semicircular array configuration with a large number of sensors and very exact positioning is required, resulting in a severe drawback for the feasibility of this method within the context of field campaigns in densely populated areas (cities). A modification of Aki’s SPAC has been presented in [9] which relaxes the necessity for an exact deployment of a semicircular array.

In a pilot study performed at the Institute of Geosciences, University of Potsdam [10], the dependence of array geometry, array aperture, distribution of noise sources and the influence of uncertainties of sensor phase responses on the phase velocity determination by standard f-k analysis have been investigated. For the evaluation of the array performance a set of synthetic seismograms have been calculated by passing a broadband input signal through an allpass filter with frequency dependent phase delays derived from the dispersion relation for a realistic site. Several conclusions could be made from this work: within an intermediate frequency band all investigated array geometries give a satisfactory result in terms of the derived dispersion curve. Phase response distortions of seismometers resulting from up to 1% deviation in the calibration information have little influence for the apertures and station distances considered.

However, besides natural limitations at higher frequencies due to spatial aliasing effects, the performance for lower frequencies was not satisfactory. For a dominating noise source region (source-receiver azimuths not equal distributed), the dispersion curve could be recovered, whereas for an azimuth random distribution, the derived apparent velocity values are highly overestimated. The superposition of array transfer functions for signals arriving from different azimuths probably leads to a bias in the slowness estimate.

3.3.2 Derivation of dispersion curves

Within the context of this work package a semi-automatic processing system for the array analysis of ambient vibrations is to be developed. The array processing has the final objective to derive the dispersion curve characteristics for the investigated site. The requirements for this "array software" are very different from those on the H/V software: the simplicity of use is not so important, since the techniques are rather sophisticated and cannot be operated by non-specialists. The software will be tested both on real data from the test sites, and on synthetics from well-controlled models.

The various array analysis techniques already developed in different teams of the consortium have been listed (slant-stack, f-k, high resolution f-k, SPAC, see ***Table 4***); they all focus on the derivation of the dispersion curve for the fundamental Rayleigh mode. The corresponding computer codes are now organized in a single standalone C-program named „cap“, for a thorough comparison. The field data is organized in a database (GIANT, [11]) and checked interactively within the GIANT/ PITSA analysis environment for suitable time windows. Once the time windows are extracted, cap is started to process this time window with a few command line options and method specific parameters given via a configuration file. As output cap provides the derived dispersion wave curve for the time window under consideration with additional error estimates.

Currently under development is an *automatic* extraction of suitable time windows for processing. Furthermore the database interface is to be ported to a free available SQL-database. Furthermore we intend to use not only vertical component data (as done so far), but also the information of the horizontal components to check the data automatically for the assumption of arriving surface waves (e.g. as suggested in [12]). Both Rayleigh and Love type waves shall be considered.

Table 4: Contribution of array analysis software within the SESAME consortium

SESAME Partner	Array analysis algorithm	coding/platform
3 - University of Potsdam - UPOTS.GEO	Slantstack f-k high-resolution f-k modified SPAC (vertical component)	C / Linux, Solaris
1 - Université Joseph Fourier – UJFG.LGIT	modified SPAC (vertical component) modified SPAC (3 components)	Fortran / Solaris
6 - Polytechnic School of Zürich – ETH.GEOP	Beamforming f-k high-resolution f-k	Matlab signal processing toolbox / MS Windows, Linux, Unix.

In the current phase of the project, the algorithms are tested with both real data sets obtained from test sites and synthetic noise data. For the real data sets used it has been a requirement that for the test sites under consideration a number of geotechnical information is available in order to confirm the results of the dispersion curve inversion.

3.3.3 Inversion of velocity profile

The aim of this WP is to extract the S (Vs) and P (Vp) wave velocity profiles from the dispersion curve derived from the array measurements. Usually, Herrmann's codes [13] are used to perform this inversion but some strong limitations led us to look for another way of converging towards the solution(s). Possible options about the inversion scheme are: linear methods, Monte-Carlo, Simulated Annealing, Genetic and Neighbourhood. The last three methods appear to be a good compromise between the time consumption and the solving of the problem.

In order to implement these methods, it is important to have a quick and robust algorithm to solve the direct problem, i.e. the calculation of the dispersion curve of a theoretical geological model. A C++ program, mainly inspired by the Herrmann's code, has been developed during this year. It presents some slight differences in the way the curves are calculated to overcome the lacks of the former code, in particular to avoid "mode jumping" when phase velocities of different modes are very close to one another. Very good performances compared to the Herrmann's code were observed during the first tests. Intensive runs were performed to correct all bugs; the actual version is stable and ready for the next stage of the development.

Until now, only the Neighbourhood algorithm has been used on very simple synthetics models (a soft sediments layer over a hard bed rock) with promising results for the inversion of Vs and Vp. Further tests have to be done to extend it to more sophisticated geological configurations where the non-uniqueness of the solution will appear.

The a-priori information is very important and can help discriminating among all models that equally comply with the measured dispersion curve. We are looking for a rational way of including it in the inversion process. Real data sets are necessary to test the performances of all possible approaches: This will be possible with the series of array measurements performed in Liège and Uccle (Belgium, March 2002). Many interesting a-priori information are available for both sites: PSV and SH refraction profiles, surface wave's measurements with artificial sources, boreholes with geological description are well distributed over the area and various Cone Penetration Tests are available. The analysis process has just started.

The discussions during the first general meeting outlined a new opportunity which had not been considered in the initial workplan: after an idea from the Zurich partner [14], it seems possible also to get additional and strong constraints on the velocity profile directly from the H/V curve (provided this latter one is derived in a special way to be representative of the elliptic curve of Rayleigh waves). This promising new direction will be investigated and tested very carefully on both synthetics and real data, for use with or without the array measurements.

3.4 <u>Task C</u>

The basic aim of this task is to better understand the physical nature and composition of ambient seismic noise wavefield, especially in urban arfeas, and to develop and validate numerical tools to generate realistic noise synthetics, in view of thoroughly testing the H/V and array techniques for well-controlled conditions (canonical numerical models and test sites).

3.4.1 Nature of noise wave field

The literature review accomplished during this first year confirmed the fact that little has been learnt in recent years about the actual composition of noise wave field. Most of the today's knowledge was obtained during the 60-70's.

Most authors seem to agree about the origin of microtremor. At long periods (T>2s) microtremor are due to large scale oceanic meteorological conditions, at intermediate periods (1<T<2s) they are mainly generated by effect of wind and local meteorological conditions, and at short periods (T<1s) they are linked to human activities. The distinction between long period (T>2s) and short period (T<1s) noise corresponds to the traditional distinction between « microseisms » with natural origin, and « microtremor » with an artificial origin. It may, however, vary from site to site depending on the fundamental site period.

The situation is much different concerning the composition of noise wavefield: this literature survey does not lead to a unique, unambiguous conclusion. While it is usually admitted and demonstrated that microseisms (natural origin) consist mainly in fundamental Rayleigh waves (which may, however, include a few higher modes), it is more difficult to define the nature of microtremor (T<1s): some authors conclude that urban noise consists of P waves, while other conclude in predominant surface waves, and sometimes a mixture of surface and body waves. Moreover, when noise wavefield is assumed or shown to consist of surface waves, there is no definite conclusion as to whether Rayleigh (fundamental and/or higher modes) or Love waves, are predominant (Love wave proportions vary from 30% to 60%, see [15]).

Very little is thus known as to the proportions between surface and body waves, between Rayleigh and Love waves, between fundamental and higher modes; and actually no robust, well accepted method presently exists that can directly lead to these ratios. The only systematic fact is that all the (few) existing quantitative results have been obtained through array measurements. Therefore, our work in the next years will be essentially relying on a detailed analysis of the array data obtained in the various test sites (Grenoble, Volvi, Colfiorito, Basel, Liège, Uccle and Nice) within the SESAME consortium, and on the comparative analysis of synthetic noise simulations performed on those sites and on a number of canonical models as well.

3.4.2 Numerical simulation of noise

The main outcome for the first year is a program package to generate noise synthetics for arbitrary 3D media, detailed in [16]. It is intended to simulate ambient seismic noise originated by human activity, for sites with heterogeneous subsurface structures. This program is based on the assumption that noise sources may be approximated by surface or subsurface forces, distributed randomly in space, direction (vertical or horizontal), amplitude, as well as in time.

This computer code is composed of two separate fortran programs. In the first one, named "**RANSOURCE**", point sources are generated randomly in space, time, and amplitude according to some user-defined criteria. For instance, the time function for each point source is either a delta-like signal or a pseudo-monochromatic signal (a harmonic carrier with the Gaussian envelope) with a random duration and a radom predominant frequency. Its output is stored in a file which serves as input for the second program, named "**FDSIM**", which propagates the seismic waves emitted by this set of noise sources in a hetereogeneous, viscoelastic structure with a planar free surface, and to compute the resulting ground motion at a number of predefined receivers. The computational algorithm is based on the explicit heterogeneous finite-difference scheme solving equations of motion in the heterogeneous viscoelastic medium with material discontinuities. A displacement-velocity-stress scheme is considered, working on staggered grids with 4th order accuracy in space and 2nd order accuracy in time. The rheology of the medium corresponds to the generalised Maxwell body. This makes possible to account both for spatially varying quality factors of the P and S waves and for arbitrary Q-omega law. It also takes advantage of advanced core-memory optimisation to reduce requirements in computer core's memory.

This code is now installed on three sites (Bratislava, Zurich and Grenoble) in order to share the scheduled, very heavy computational work. The same code will be applied to a number of canonical models and to the 5 selected test-sites.

The set of canonical models was chosen for a representative parametric study, especially to assess the reliability and relevancy of H/V and array techniques when there exist significant lateral variations. The set is fully described in [16]; in short, it comprises reference 1D models (a homogeneous halfspace, 1D horizontally layered structures with 1 or 2 surface layers, without and with velocity inversion, also including one case with a velocity gradient), 2D and 3D, shallow and deep valleys, and models with sharp lateral discontinuities, which again may be shallow or deep.

For deep sites with low fundamental frequency, the simulation will also include the response to low-frequency crustal surface waves generated at large distances from the site.

The receivers are selected so as to obtain "individual" 3-component synthetics for H/V processing in relation with the local 1D soil column, and array synthetics as well in order to compare the inverted velocity profile with the input data.

4 Concluding comments

Till now, only partial results have been reached after one year: much work remains to be done before achieving the assigned 3-year goals, which are somewhat ambitious and challenging since they involve several uneasy scientific issues on one hand, and on the other consider the development and finalization of routine application tools. However, the preliminary results allow us to be optimistic about the final outcomes.

Another major milestone of the project will be a workshop held in Slovakia in September 22-24, 2003: it will be dedicated to the use of microtremors for site effect assessment, and will be the opportunity to present the major results (scientific and practical) of the SESAME project. Although the number of participants will be limited by the capacity of the hosting institution, we hope to have some contributions from outside the project consortium, from specialized scientists to end-users.

Only a short summary of the SESAME project and of its first results has been presented here: readers interested in more details could find them in the first year report [17], including many explanatory figures, and also on the project web site (http://SESAME-FP5.obs.ujf-grenoble.fr). As one key objective is the world-wide, free dissemination of a H/V package include a platform-free software and user guidelines, we do hope this short presentation project will excite the interest of many scientists, engineers and managers involved in seismic risk mitigation. All those who are interested are thus kindly invited to visit the web site and to make us know their opinion, experience, data, etc.: all will be welcome, so that we can build upon an as wide as possible basis.

We are very much aware that many other teams from E.U. and associated countries would have perfectly fit into this project: it was not possible to include them for financial and logistical reasons. We are aware also that a huge amount of work involving he H/V technique is carried by many teams throughout the world (Latin-America, Asia, Africa, Near-East, India / Indonesia, CEI, South Pacific, North America): we hope this project will be an opportunity to fruitful exchanges allowing to reach a worldwide consensus, and that SESAME will thus help opening the door to sustainable development by offering a carefully assessed, low cost tool for safer urban planning and seismic design.

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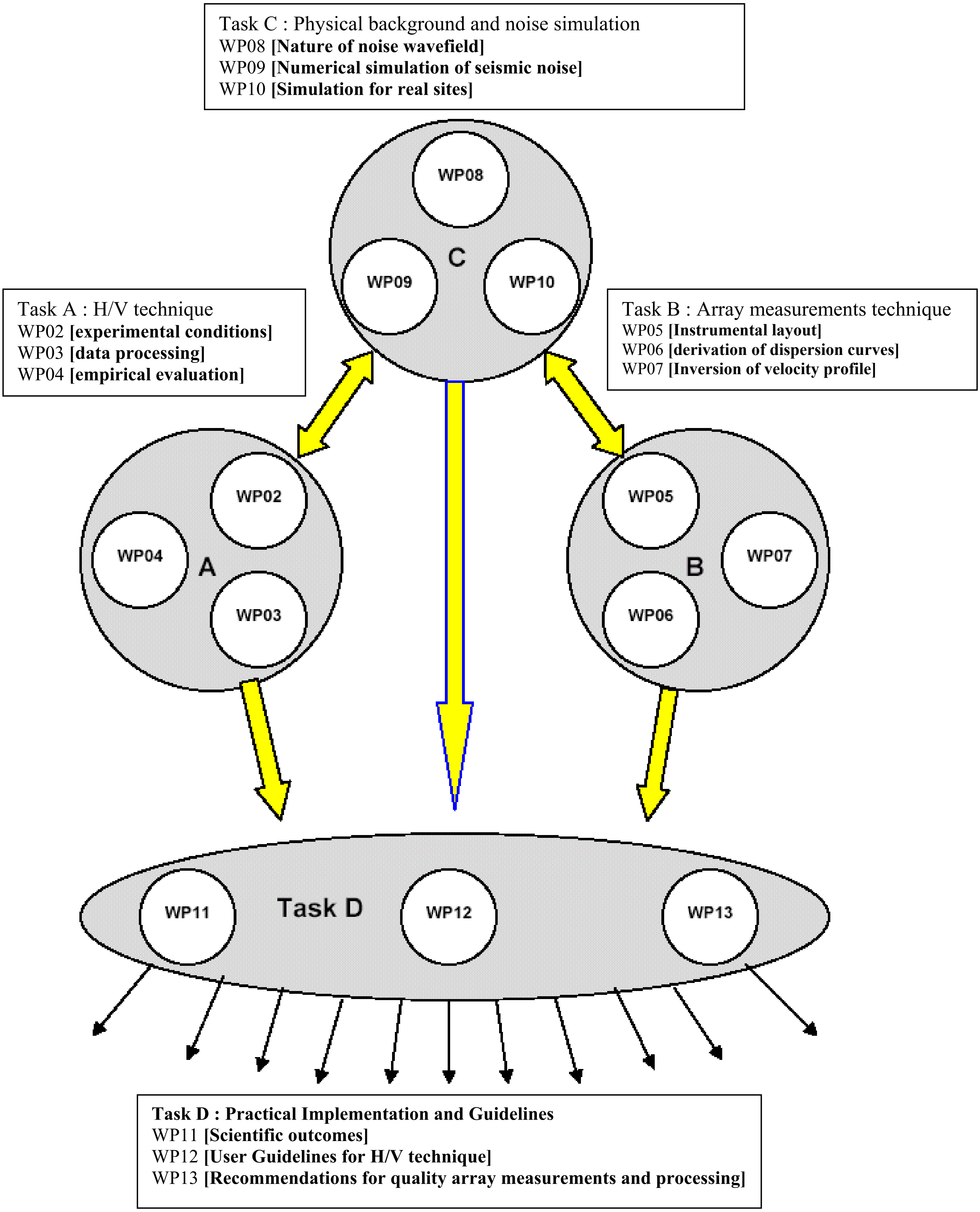

Task C : Physical background and noise simulation
WP08 **[Nature of noise wavefield]**
WP09 **[Numerical simulation of seismic noise]**
WP10 **[Simulation for real sites]**

Task A : H/V technique
WP02 **[experimental conditions]**
WP03 **[data processing]**
WP04 **[empirical evaluation]**

Task B : Array measurements technique
WP05 **[Instrumental layout]**
WP06 **[derivation of dispersion curves]**
WP07 **[Inversion of velocity profile]**

Task D : Practical Implementation and Guidelines
WP11 **[Scientific outcomes]**
WP12 **[User Guidelines for H/V technique]**
WP13 **[Recommendations for quality array measurements and processing]**

Figure 1: Schematic outline of the SESAME project