Site Effects Assessment Using Ambient Excitations

SESAME

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Report on the
Array data set for different sites
University of Potsdam, Germany

WP05
Instrumental layout for array measurements

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Summary

In the following we report on the acquired array data set for different sites in Europe in the year 2002. The measurements have been taken out under the framework of the SESAME Project (Site Effects Assessment Using Ambient Excitations, EC-RGD, Project No. EVG1-CT-2000-00026 SESAME), Task B (Array measurement technique), Work Package 05 (WP05 – Instrumental layout for array measurements).

The geographic location of the selected test sites for performing ambient noise array measurements are shown in Figure 0-1. The site selection has been carried out by the SESAME consortium during the SESAME kick-off meeting in Grenoble (2001) guided by the idea to collect data sets of ambient vibration array measurements for a variety of distinct geological situations. An additional criterion for the selection was the availability of geotechnical and/or other a priori information about the subsurface structure in order to allow the comparison of the dispersion curve results obtained from the array measurements. The field experiments have been performed from March to August 2002 in three field campaigns in cooperation between the IGUP Potsdam, Germany, ULGG Liege, Belgium, ETHZ Zurich, Switzerland, INGV Rome and Naples, Italy and ITSAK Thessaloniki, Greece. An overview of all experiments is given in Table 1-1. Preliminary results of FK-analysis processing for all data sets are provided in Appendix 3 of report WP05-D07.05. The results obtained for test sites in Greece have been presented by Scherbaum et al. (2002).

Figure 0-1 Location of test sites for ambient vibration array measurements (red circles). Names are given for all sites where field data has been acquired in 2002 within the scope of the SESAME project. Green squares indicate the location of SESAME partner institutions.
Table 1-1 Resume of array experiments performed within the SESAME project in 2002.

<table>
<thead>
<tr>
<th>CODE</th>
<th>Date and Time of Experiment</th>
<th>Location</th>
<th>Digitisers/recorders + Seismometers Sampling, Sensitivity</th>
<th>Institutions involved</th>
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</thead>
<tbody>
<tr>
<td>Baviere</td>
<td>2002-04-09 whole day</td>
<td>Liege, Belgium Urban area</td>
<td>10 Marslite + Le3D-5s 250 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany UL, Liege, Belgium</td>
</tr>
<tr>
<td>Uccle</td>
<td>2002-04-10 whole day</td>
<td>Brussels, Belgium Urban area</td>
<td>10 Marslite + Le3D-5s 250 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany UL, Liege, Belgium</td>
</tr>
<tr>
<td>Botanique</td>
<td>2002-04-11 whole day</td>
<td>Liege, Belgium Urban area</td>
<td>10 Marslite + Le3D-5s 250 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany UL, Liege, Belgium</td>
</tr>
<tr>
<td>Otterbl</td>
<td>2002-04-09 whole day</td>
<td>Otterbach – Weil am Rhein, German-Swiss Border region</td>
<td>13 Marslite + Le3D-5s 13 Mars88 + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ETHZ, Zurich, Switzerland</td>
</tr>
<tr>
<td>OtterblI</td>
<td>2002-04-10</td>
<td>Otterbach</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ETHZ, Zurich, Switzerland</td>
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<td>Loerr</td>
<td>2002-04-11</td>
<td>Lœrrach, German-Swiss Border region</td>
<td>9 Marslite + Le3D-5s 250 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany</td>
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<td>ColfA+B</td>
<td>2002-07-29</td>
<td>Colfiorito, parallel deployment of two 12 station arrays –central + SE part of valley</td>
<td>13 Marslite + Le3D-5s 11 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
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<td>ColfC</td>
<td>2002-07-30</td>
<td>Colfiorito, 4 parallel station lines in E-W direction - NW part of valley</td>
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<td>ColfD+E</td>
<td>2002-07-30</td>
<td>Colfiorito, parallel deployment of two 12 station arrays –central + SE part of valley D-array repitition of B-Array</td>
<td>13 Marslite + Le3D-5s 11 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
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<td>Lefkas</td>
<td>2002-08-03</td>
<td>Lefkada, Island at western coast of Greece</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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<tr>
<td>Kal</td>
<td>2002-08-05</td>
<td>Thessaloniki - Kalamaria</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
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<td>Villa</td>
<td>2002-08-05</td>
<td>Thessaloniki – Villa Blanca</td>
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<tr>
<td>Tyf</td>
<td>2002-08-06</td>
<td>Thessaloniki – Blindschool</td>
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<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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<td>Lep</td>
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<td>Thessaloniki – Lefkos Pyrgos (White Tower)</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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<tr>
<td>Ago(ra)</td>
<td>2002-08-07</td>
<td>Thessaloniki – Agora ancient roman market</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
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<tr>
<td>Ote</td>
<td>2002-08-07</td>
<td>Thessaloniki – OTE Hellenic Organization of telecommunication</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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<tr>
<td>Tst + GA</td>
<td>2002-08-08</td>
<td>Volvi graben – Euroseistest + borehole site GA</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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<tr>
<td>Pro + B7</td>
<td>2002-08-09</td>
<td>Generic rock site, shoulder of Volvi graben and borehole site B7</td>
<td>13 Marslite + Le3D-5s 125 Hz, 2µV/C</td>
<td>IGUP, Potsdam, Germany ITSAK, Thessaloniki, Greece</td>
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</table>
1 Description of array measurement sites

1.1 Liege and Uccle, Belgium

The field measurements at three selected sites in the cities of Liege and Uccle have been performed in cooperation with ULGG, Liege and LGIT, Grenoble from 19.-21.03.2002.

The measurements have been performed with 10 Marslite data loggers and 10 Lennartz 3D-5s sensors. The timing for all data loggers is achieved by external GPS-receivers. Sensor locations have been measured as relative cartesian coordinates by theodolite measurements with respect to the central station location and additionally absolute geographical coordinates have been taken with a handheld GPS and differential correction signal.

The following persons have been participating in the field measurements:

- Hans Havenith  
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- Matthias Ohrnberger  
  IGUP, Potsdam, Germany
- Daniel Vollmer  
  IGUP, Potsdam, Germany
- Marc Wathelet  
  ULGG, Liege, Belgium + LGIT, Grenoble, France

1.1.1 Baviere (Liege)

The site Baviere is a small open space of ca. 150 m diameter surrounded by streets and edifices on a river island within the city of Liege (compare Figure 1-1). The ambient noise conditions are mainly dominated by the river Meuse and sporadic traffic on the surrounding streets. The supposed thickness of sedimentary soft layer over the first strong impedance contrast is estimated to be around 10 m for site Baviere.

In total 3 array geometries have been deployed on the 19.03.2002. The first two array configurations consisted in three azimuthally tilted triangles surrounding a central station. The radii for the first setup have been selected as 25m, 40m and 75m, respectively. For the second deployment the three outer stations (75m radius) have been moved inside, then conforming the innermost triangle with ca. 10m radius. The third deployment has been realized as a ring of 9 stations surrounding the central station. The radius of the 9 station circle has been set to 40m. For all configurations, the sampling rate has been set to 250 Hz. Total recording time has been several hours. The geographic coordinates and station distribution for site Baviere is shown in Figure 1-2. The sensors have been installed directly onto the surface, where fine gravel has been found. In a few cases we have used ground plates to improve the sensors coupling.
Figure 1-1 Location of the test site Baviere within the urban area of Liege. The maximal extension of the triangle shaped open space is ca. 120 m, surrounded by streets and buildings. Street map is copyright http://www.viamichelin.com.

Figure 1-2 Array geometries realized at site Baviere (city of Liege). First deployment consisted in a central station, second smallest triangle, 40 degree tilted medium triangle and 40 degree tilted large triangle. For the second deployment, the outer triangle has been shifted in between the inner triangle and the middle triangle. For the last deployment we realized a ring of 9 stations surrounding the central station. The maximum aperture for the first deployment is ca. 120 m.
1.1.2 Uccle (Brussels)

The park of the Royal Observatory of Belgium is located in Uccle, a district of Brussels in the southern part of the city. The park is surrounded by a ring road with a diameter of ca. 270m (compare Figure 1-3). The thickness of the sediments is estimated to be around 100m for this location. The environmental noise conditions during measurement time are dominated by a construction site at one of the edifices of the Royal Observatory within the park limits. As the Uccle district can be characterized mainly as a residential area, the traffic on the ring road can be described as very quiet for an urban environment.

Two array configurations could be realized on the 20.03.2002. In the first setup we deployed three tilted triangles surrounding a central station with radii of 25m, 70m and 130m, respectively. For the second array geometry we chose a ring of 9 stations surrounding the central station with a radius of 130m. The geographic coordinates of all sensor positions are shown in Figure 1-4. The major part of the sensors has been installed directly onto gravel roads or pavement. Wherever a sensor location was on the turf, a deeper soil excavation (ca. 40 cm) and additional use of a ground plate has been necessary, as the soil was extremely wet due to the heavy raining the night before.

Figure 1-3 Location of the test site Uccle within the urban area of Brussels. The maximal extension of the park of the Royal Observatory of Belgium is ca. 270 m. The site is located within a residential area and is surrounded by a ring road. Street map is copyright http://www.viamichelin.com.
1.1.3 Botanique (Jardin Botanique, Liege)

The site Botanique lies within the park of the botanic garden of the city Liege. The park is surrounded by small streets and has an extension of approximately 150m in NS and 120m in EW direction. The park area is inclined towards the river Meuse (in the east, compare Figure 1-5). The thickness of the sediments is estimated to be around 10m for this location. The environmental noise conditions during the measurement time are dominated by sporadic traffic in the surrounding streets and heavier traffic on the nearby city-highway (south and west of park area, compare Figure 1-5).

One single array configuration has been realized on the 21.03.2002. We have deployed two semicircles with 3 and 6 stations, respectively surrounding a central station. The radii of the semicircles have been set approximately to 20m and 60m. The geographic coordinates of all sensor positions are shown in Figure 1-6. some of the sensors have been installed on ground plates after removing the uppermost soil layers and grass roots, other have been placed without additional support directly onto the gravel roads of the park.
Figure 1-5 Location of the test site Botanique within the urban area of Liege. The maximal extension of the park is ca. 120 m, surrounded by streets and buildings. Arrow points to location of site Baviere. Street map is copyright http://www.viamichelin.com.

Figure 1-6 Array geometry realized at site Botanique (city of Liege). Two semi-circles surrounding the central station with radii 20m and 60m, respectively. The maximum aperture of the deployment extends in N-S direction and is approximately 120 m.
1.2 Weil am Rhein, Swiss-German Border Region

The field measurements at three selected sites in the cities of Weil am Rhein and Lörrach have been performed in cooperation with ETHZ, Zurich from 09.-11.04.2002. On the first two days we have realized two larger array configurations (aperture D ~ 0.8-1km) in a free-field recreation area in Otterbach (part of Weil am Rhein, compare Figure 1-7). The topography of the site Otterbach is flat. According to Kind (2002) the thickness of quaternary and tertiary sediments varies between 100m to 150m slightly dipping from west to east. On the third day we moved to site Lörrach, a neighboring town of Weil am Rhein, installing a smaller array configuration in a park area in the north of the city. The sediment cover is estimated to be of around 100m thickness (Brüstle, pers. comm.).

The measurements have been performed with instrumentation supplied by the ETHZ, Zurich and IGUP, Potsdam. In total 25 mobile stations were available for the experiment consisting of 12 Mars88-OD stations (ETHZ) with 12 Lennartz 3D-5s sensors and 13 Marslite-HD stations with additional 13 Lennartz 3D-5s sensors. The timing system used differs for the two data logger types in use. Whereas the Mars88 data acquisition system uses a DCF77 time synchronization the Marslite loggers are equipped with GPS-time receivers. Time delays of the DCF77 antennas used with the ETHZ stations have been measured in a laboratory environment at ETHZ and resumed by Fortunat Kind (compare Appendix 3 of report WP05-D07.05).

The sensor positions have been measured both as relative cartesian coordinates with respect to the central station location by using a theodolite and additionally absolute geographical coordinates (WGS84 reference ellipsoid) have been taken with a handheld GPS with additional differential correction signal. After removing the uppermost soil layer and grass roots, the sensors have been installed using either ground plates (IGUP stations) or an aluminum trihedron (ETHZ) directly pinched to the ground.

The following persons have been participating in the field measurements:

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cecile Cornou</td>
<td>ETHZ, Zurich, Switzerland</td>
<td></td>
</tr>
<tr>
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<td>ETHZ, Zurich, Switzerland</td>
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<td>Jörg Kirsch</td>
<td>ETHZ, Zurich, Switzerland</td>
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<td>Matthias Ohrnberger</td>
<td>IGUP, Potsdam, Germany</td>
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<td>IGUP, Potsdam, Germany</td>
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<tr>
<td>Jochen Wössner</td>
<td>ETHZ, Zurich, Switzerland</td>
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</tbody>
</table>
Otterbach

1.2.1 Otterbach I

The first array deployment at site Otterbach has been planned as a larger array with identical sub-array geometries. The availability of 25 stations allowed to install 3 sub-arrays with 7 stations each surrounding a central sensor site. The central station has been occupied in parallel with each one instrument of the ETHZ and one of IGUP. This procedure has been necessary in order to determine the time delay of DCF77 antenna reception for the Mars88 with respect to the GPS-receiver clock synchronization for the Marslite data loggers. Together with the relative time delays between the DCF77 antennas which have been measured at the ETHZ, we were able to apply time corrections to all instruments for the analysis. Three additional sensors have been installed on the swiss part of the surrounding area at a distance of approx. 1 km from the larger array setting. One of those (not shown in the station geometry in Figure 1-9) was malfunctioning.

Due to problems with GPS-time reception at some of the selected sites and problems with the visibility of station positions for the theodolite measurements, we have not been able to achieve the desired configuration very well. The geometry is shown in Figure 1-8. Nevertheless, the analysis of sub-arrays can be performed as has been planned.
1.2.2 Otterbach II

For the second array setup at site Otterbach on 10.04.2002 we tried to deploy a more arbitrary geometry with variable inter-station distances covering the whole accessible area. Two of the three sensors which had been installed on the swiss part of the surrounding area the day before were still recording and the malfunctioning station has been put in operation. As on the first day we recorded the central station position in parallel with two Lennartz 3D-5s sensors with a few decimeter spacing and each one Mars88 (DCF77) and one Marslite (GPS) recorder. The geometry is shown in Figure 1-9. The installation of the seismometers has been handled as the day before.

Figure 1-9 Array geometry at the site Otterbach on 10.04.2002. All three sensors on the swiss territory have been in operation this day. Array aperture is ca. 0.8 km.
1.2.3 Lörrach

At the site Lörrach we have deployed an array setup within the park of the city on 11.04.2002. The geometry resulted from logistical constraints along a ring-road surrounding an open field. Only 9 stations could be deployed due to time limitations for this measurement. Within only one hour we were able to install the instruments, record around 35 minutes of continuous data with all stations and finished the measurement. The array geometry which had an aperture of ca. 400 m is shown in Figure 1-10.

![Array geometry realized at site Lörrach on 11.04.2002. The stations have been located following a ring-road around an open field within the park of the city of Lörrach. Only 9 stations have been deployed in this setting due to time limitations. The array aperture is approximately 400 m.](image)

1.3 Colfiorito, Italy

Colfiorito is a small village located at the SW-edge of a small intramountain valley of the Apennine in Umbria, Central Italy (see Figure 1-11). The region has been affected seriously by the two mainshocks (M_L 5.6 and 5.8) of the Umbria-Marche seismic sequence starting from September, 26, 1997 to mid of 1998. Since this time detailed geophysical surveys and several array measurements have been performed in the alluvial plain of the intramountain basin in order to understand the strong ground motions which have been observed during the seismic sequence. Especially interesting is the observation of high-amplitude S-wave coda with periods around 1 s which seems to be generated from one of the basin edges (Rovelli et al., 2001).

The ambient vibration array measurements within the scope of the SESAME project have been carried out during the days 29.-31.07.2002 in cooperation between the INGV-Rome, INGV-OV (Osservatorio-Vesuviano) Naples and the IGUP. Four different site locations (one of those has been reoccupied for reference) within the basin have been selected for the
measurements. In total 24 Lennartz Marslite recorders and 24 Lennartz 3D-5s sensors (11 of which provided by OV-INGV and 13 by IGUP) have been available for this purpose. All stations used GPS-receivers for time synchronization. Sensors positions have been determined by a differential GPS receiver provided by the GeoForschungsZentrum Potsdam. This GPS-receiver reaches absolute horizontal positioning accuracies of ca. 0.5 m in real-time by making use of a high-quality correction signal supplied by commercial satellites. This allowed us to install previously determined array geometries with high accuracy using the navigation function of this equipment.

The following persons have been participating in the field measurements:

<table>
<thead>
<tr>
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<td>Fabrizio Cara</td>
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<td>Rosalba Maresca</td>
<td>Univ. Sannio, Italy, OV-INGV, Naples, Italy</td>
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<tr>
<td>Daniel Vollmer</td>
<td>IGUP, Potsdam, Germany</td>
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</table>

Figure 1-11 Colfiorito in Umbria, central Italy, is located ca. 30 km in the east of Assisi. The black circle indicates the intramountain valley, where strong ground motions have been observed during the 1997/1998 Umbria-Marche seismic sequence. Array measurements of ambient vibrations have been performed at four distinct sites within the alluvial plain of the basin.
1.3.1 Colfiorito A+B

Two array configurations have been realized on 29.07.2002, which have been named colfA and colfB. Due to the availability of 24 stations it has been possible to deploy the arrays for parallel recording and similar geometries. The arrays consisted of 12 stations each, a central station surrounded by 3 squares with radii 30m, 60m, and 120m, respectively. At each of the array sites, one station has been left out for the innermost square geometry. The central stations of the array sites colfA and colfB are separated by around 750 m. The array site colfA is located close to the south-eastern edge of the basin, whereas colfB nearly lies in the centre of the valley. The array geometries of colfA and colfB are shown in Figure 1-12. The sensors installation has been very different from one seismometer location to the next. Some of the seismometers have been buried deeper into the ground (where the soil was very soft); others have been directly installed on gravel roads or onto the surface after removing the uppermost soil layers. All seismometers have been protected with a basket.

![Array geometries for sites colfA and colfB. The arrays have been operated in parallel with nearly identical geometries. The central stations of both configurations are separated approximately 750 m. The apertures of arrays A and B are ca. 240 m.](image)

1.3.2 Colfiorito C

One large array configuration has been deployed at site colfC from the morning to afternoon of the 30.07.2002. The 24 instruments have been arranged in a rectangular configuration in four lines extending in the EW-direction. The two southernmost lines have been occupied with stations of IGUP, whereas the two lines in the north have been equipped with station from OV-INGV. The total area covered by the array is of size 200m x 200m. The maximum aperture is ca. 300m. The array geometry of colfC is shown in Figure 1-13. The sensors of IGUP stations have been mainly installed onto ground plates, after removing the uppermost part of the soil layers for leveling reasons. The equipment of OV-INGV has been buried.
deeply (> 40 cm) and completely refilled with soil in order to achieve a good coupling of the whole casing. The weather conditions at that day have been quite windy – the unburied stations showed much higher noise levels for the higher frequency range (> 5Hz).

Figure 1-13 Array geometry realized for site colfC. 24 stations have been deployed in four lines with 7, 6, 5 and 6 stations respectively. The station spacing has been kept relatively constant between 40m to 60m. The total area of this rectangular array deployment covers approx. 200m x 200m. Maximal aperture of this configuration is around 300m.

1.3.3 Colfiorito D+E

In the afternoon of 30.07.2002 two array configurations have been installed again in the SE and central part of the basin. The sensor positions of colfD are identical to the array colfB. The site has been reoccupied for reference. The geometry of array colfE is equivalent to the configuration of colfA, however, the array has been shifted closer to the site of colfD (=colfB) in north-western direction. The central stations of arrays colfD and colfE are separated ca. 300m. Array apertures are ca. 240m equivalent to arrays colfA and colfB. Parallel recordings have been performed starting in the afternoon of 30.07.2001 until morning hours of 31.07.2002. The array geometries of colfD and colfE are shown in Figure 1-14. The sensors have been installed as the days before, some deeply buried (ColfD), others only put to the ground (colfE).
Figure 1-14 Array geometries realized for sites colfD and colfE. The sensor positions of array colfD are identical to the positions of colfB. The site has been reoccupied for reference. The configuration of colfE resembles the configuration of colfA, but has been shifted from site colfA closer to site colfD (=colfB) towards NW. The central stations of arrays colfD and colfE are separated approximately 300m. Array apertures are 240m.

### 1.4 Lefkas, Greece

The town of Lefkadas is located on a small island of the same name at the north-western coast of Greece (compare Figure 1-15). The ambient vibration array measurement within the scope of the SESAME project has been carried out on the 03.08.2002 in cooperation between the SESAME partners ITSAK, Thessaloniki and IGUP, Potsdam.

Due to the particular urban environment at site Lefkas (no open spaces or parks) we have not been able to set up a specific array configuration. The objective of the finally realized array configuration has been to cover the area in between two permanent accelerograph station sites showing significant differences in their respective site response characteristics (Savvidis, pers. comm.). Dimitriou et al. (2001) further found evidence for non-linear site effects from strong motion records recorded at these stations. The depth of soft sediments is estimated to ca. 75m for the array site. All 13 stations of IGUP have been deployed and recorded for ca. 2 hours during noon time. The sensor positions have been determined by a differential GPS receiver with high accuracy. The geometry of the array configuration is shown in Figure 1-16. Nearly all sensors have been installed directly on the pavement. Only two stations could be installed on soil. The measurements have been performed during noon time. In order to protect the equipment from the direct sun radiation, we wrapped them into aluminum rescue blankets.
The following persons have been participating in the field measurements:

Matthias Ohrnberger  IGUP, Potsdam, Germany
Alexandros Savvaidis  ITSAK, Thessaloniki, Greece
Frank Scherbaum   IGUP, Potsdam, Germany
Daniel Vollmer   IGUP, Potsdam, Germany

Figure 1-15 Geographic location of the town of Lefkadas at the NW-coast of Greece. The array measurement has been performed within the urban environment of Lefkadas on 03.08.2002.

Figure 1-16 Array geometry realized for site Lefkas in the city of Lefkadas (NW-Greece). The station spacing varies between 20m to 80m and the overall aperture is approximately 200m.
1.5 Thessaloniki, Greece

In cooperation between SESAME partners ITSAK, Thessaloniki and IGUP, Potsdam, we have recorded ambient vibration array data sets within the city of Thessaloniki (compare Figure 1-17) at six distinct locations, named KAL, TYF, VIL, LEP, AGO and OTE. The measurements have been carried out within a period 3 days from 05.08.2002 to 07.08.2002. Due to the weather conditions (40 degrees C at noon hours), we performed all array measurements either in the morning (before 10 a.m.) or in the later afternoon hours (after 5 p.m.)

At each array site we have deployed all available 13 Marslite data loggers and 13 Le3D-5s sensors. For determining the station coordinates we have used a differential GPS receiver with commercial satellite correction signal. Only at site OTE, we were not able to use this equipment due to strong interferences with high-power communication antennas. Due to the urban environment, the seismometers have been installed in almost all cases on pavement or concrete. We have abstained from trying to deploy any specific array geometry because of logistical constraints within the city. Although the aperture of array deployment is also restricted within certain bounds for feasibility reasons, it is the parameter that can most easily varied in different array setups. We have fixed the array apertures in relation to the estimated bedrock depths for the individual sites (Anastasiadis et al., 2001).

The location of array sites within the city of Thessaloniki is shown in Figure 1-18. The map of estimated bedrock depth (Anastasiadis et al., 2001) shows a strong dipping of the interface towards SW. The thickness of sediment cover for the selected sites increases from ca. 10m for site AGO to values of ca. 400m for KAL.

The following persons have been participating in the field measurements:

- Matthias Ohrnberger  IGUP, Potsdam, Germany
- Areti Panou    ITSAK, Thessaloniki, Greece
- Alexandros Savvaidis  ITSAK, Thessaloniki, Greece
- Frank Scherbaum   IGUP, Potsdam, Germany
- Nikos Theodulidis   ITSAK, Thessaloniki, Greece
- Daniel Vollmer   IGUP, Potsdam, Germany
Figure 1-17 The city of Thessaloniki is the most important city in northern Greece with a population of nearly 2 million inhabitants. Its continuous history as a cultural, commercial and economical centre is recorded for over 2300 years. Today Thessaloniki houses the most important harbor in the region and has evolved to the main gate of goods for a large part of the Balkan.

Figure 1-18 Site location map of array sites within the city of Thessaloniki (map of bedrock depth after Anastasiadis et al., 2001). The sediment/bedrock interface shows strong topography, with increasing bedrock depth from NE to SW (towards the sea).
1.5.1 Kalamaria (KAL)

The district of Kalamaria is located in the southern part of Thessaloniki. It is a residential area with typically 5 to 6 story buildings. The thickness of soft sediment layers is unknown, as the bedrock has not been reached by borehole drillings. According to Anastasiadis et al. (2001), the estimated bedrock depth is around 400m. We have therefore tried to deploy an array setup with an aperture as large as possible. The final geometry of the array setup is shown in Figure 1-19. The aperture in EW direction is approximately 500m, whereas in NS direction the array geometry extends ca. 350m. The array recordings have been carried out on 05.08.2002 in the morning hours. The closest distance between the shoreline and the array setup is ca. 700m in southern direction.

Figure 1-19 Array geometry for the site KAL. Aperture is approximately 500m in EW and 350m in NS direction. Inter station distances range from 100m to 150m.

1.5.2 Villa (VIL)

The array site Villa is located in the southern part of Thessaloniki. The thickness of soft sediment has been estimated to ca. 260m (Anastasiadis et al., 2001). The final geometry of the array setup is shown in Figure 1-19. The aperture in EW direction is approximately 400m, whereas in NS direction the array geometry extends ca. 300m. The closest distance to the seaside is ca. 1 km in western direction. Measurements have been performed on 05.08.2002 in the afternoon hours.
Figure 1-20 Array setup at site VIL. Array measurements have been performed on 05.08.2002, later afternoon hours.

1.5.3 Blind school (TYF)

The array site TYF is located directly at the sea side. Two main roads are aligned parallel to the coastline. The westernmost stations of the array configuration shown in Figure 1-21 are located in small parks along the coastline. Stations located in the north-eastern part are surrounded by tall edifices, whereas the remaining sensor positions are mostly deployed in open spaces (parking lot, parks along coastline and pedestrian area). The measurements have taken place on 06.08.2002 in the morning hours.

Figure 1-21 Array geometry realized for site TYF. The coastline extends in NS direction in the west of the array setting. Easternmost seismometers are located on the pedestrian sidewalk directly at the seaside (ca. 10m of shoreline). Additionally two main roads are aligned in NS direction crossing the array in the centre and limiting the array to the east, respectively. Array dimension is approximately 200m (EW) by 400m (NS). Estimated bedrock depth is given by Anastasiadis et al. (2001) as 220 m.
1.5.4 White Tower (Lefkos Pyrgos – LEP)

The array site LEP is located directly at the sea side. Being an important historic building within Thessaloniki, the White Tower is located at the crossing point of several main roads both parallel and perpendicular to the coastline. The array configuration, which has been deployed on 06.08.2002 in the later afternoon hours, is shown in Figure 1-21. The ambient noise conditions of this area are characterized by strong traffic and strong microseisms from the sea. Sediment thickness according to geotechnical information (Anastasiadis et al., 2001) is approximately 180m.

![Figure 1-22 Array geometry realized for the site LEP. Apertures are ca. 250m EW and 350m NS. The measurement has been carried out on 06.08.2003 in the afternoon hours.](image)

1.5.5 Agora – ancient roman market (AGO)

The array site AGO is located within the central part of Thessaloniki. There is a small pedestrian area to the south of the archaeological site of the old ancient roman market (Agora), where the stations could be deployed. The bedrock depth is very shallow and estimated to ca. 10m (Anastasiadis et al., 2001). Therefore the array aperture and station spacing have been selected relatively small. The dimension of the realized array setup is approximately 150 by 180 m, with station spacing as small as 20 m. The geometry of this array setup is shown in Figure 1-23. The array recordings have been performed on 07.08.2002 during the morning hours.
1.5.6 OTE – Hellenic organization of telecommunications

The array site OTE is located at the parking lot of the Hellenic organization of telecommunications (OTE). We could not make use of the differential GPS receiver for measuring the station position. We suppose that the bad reception of the satellite signal is connected with interferences of the signal with the high-power communication antennas installed on the roof of the OTE building. Only a very small aperture array setting could be achieved, as we had to use theodolite measurements to determine the relative station geometry. Due to time limitation, we could not extend the array geometry to larger apertures. The realized geometry is shown in Figure 1-24. The measurements have been carried out on 07.08.2003 in the later afternoon hours.

Figure 1-24 Array geometry realized for site OTE. The aperture of this configuration is approximately 100m. The station aperture has been limited due to difficulties of station coordinate measurements.
1.6 Volvi graben, Greece

The Euro-Seistest site located in the Volvi graben close to Thessaloniki in NE Greece has been subject of a number of site amplification studies (e.g. Riepl et al., 1998, Dimitriu et al., 1998, Raptakis et al., 2000, Chavez-Garcia et al., 2000, Marrara and Suhadolc, 2001). The Volvi graben structure is well known from both geophysical as well as geotechnical investigations (Jongmans et al., 1998, Pitilakis, et al., 1999). During the field campaign in August 2002 several small aperture arrays have been deployed both within the valley as well as on the valley shoulder (Profitis generic rock site) in cooperation between the SESAME partners ITSAK (Thessaloniki) and IGUP (Potsdam).

1.6.1 Euro-Seistest (TST) + Greenhouse A (GA)

On 08.08.2002 we have performed array measurements at the sites TST and GA in the Volvi basin. At the location of the Euro-Seistest there are very few buildings and the whole area is in agricultural use. Therefore we have been relatively free in the choice of station geometry and to achieve a good seismometer coupling, we buried all seismometers to a depth of approx. 40 cm. We started with a configuration at site TST. Similar to the geometries realized in Colfiorito, we chose a configuration with three squares surrounding a central station. The aperture of the first deployment (TST1) has been approximately 500m (compare Figure 1-25, TST1). In a second step, we re-deployed the outermost stations of TST1 to locations within the remaining array geometry. The inter-station distances in the new array configuration TST2 (Figure 1-25) have been reduced significantly, and the array aperture has been ca. 260m then. For the last configuration TST3, we just removed 6 out of the 13 stations from configuration TST2. The removed stations have been setup at an additionally site (GA) for parallel registration (compare Figure 1-26).

![Array configurations realized for site TST. TST1 is the first deployment with an aperture of ca. 500m. In a second step, we re-deployed the outermost stations to locations within the remaining array geometry (TST2). The inter-station distances have been reduced significantly, and the array aperture has been ca. 260m then. For the last configuration, we have just removed 6 out of the 13 stations from configuration TST2.](image-url)
1.6.2 Profitis (PRO) + Borehole 7 (B7)

On 09.08.2002 we have performed array measurements at the sites PRO and B7. The site PRO (Profitis) is located on the valley shoulder on top of a hill within the village of Profitis. PRO is equipped with a strong motion station and is classified as reference rock site. The site shows a very strong topography and height differences between seismometers are in the order of 30m within the array setting. The aperture of the realized geometry has been approx. 200m and the smallest inter-station distance is ca. 20m. In a first setup all 13 stations have been deployed. Seismometers have been installed on pavement or gravel. After a recording approximately 1 hour with all stations, we re-deployed 6 of the stations at site B7. B7 is located at the edge of the Volvi basin and has been the location of a borehole site. The distance to site PRO is around 1 km. Parallel recordings at both sites have been performed for around one hour. The geometries of the installed array configurations are shown in Figure 1-27).
Figure 1-27 Array configurations realized for sites PRO and B7 on 09.08.2003. 13 stations have been deployed in a first experiment at the reference rock site PRO. On top of a small hill within the village of Profitis, a permanent strong motion station (PRO) is hosted in the installations of a church. The location shows a strong topography and the centre of the array surrounds the permanent station PRO.

After one hour recording time, 6 seismometers have been removed from site PRO and have been installed at the site B7 on a free field location. B7 is located approximately 1 km apart from the site PRO at the edge of the Volvi basin and has been the location of a borehole site. The aperture of B7 is approx. 150m. The parallel recording at both sites has been performed for 1 hour.

2 Waveform data description

2.1 Waveform data (format and unit)

The field data has been acquired in all cases with Lennartz data loggers (Marslite and Mars88). The storage media used in the mobile array stations are either 4.5 GB removable SCSI harddisks (Marslite data loggers at IGUP) or optical disks with 540 MB capacity (Mars88 ETHZ, Marslite OV-INGV). The data playback and archiving has been performed throughout during the field campaigns (except Mars88 stations for measurements in Weil am Rhein) in order to perform a quality control of the recorded data.

The data playback has been performed with the Lennartz Marslite (Mars88) software tools (http://www.lennartz-electronic.de/Pages/Homepage_english.html). We have used the software utility disk2gse, which writes 1 hour waveform files in GSE2.0 format. The most detailed information about GSE format can be found online following the index link to GSE/CRP/243 at the Prototype International Data Center PIDC (http://www.cmrr.gov) and is the online version of the Group of Scientific Experts (GSE) Third Technical Test (GSETT-3) Conference Room Paper 243 of 1995. Header format and entries of the GSE2.0 format
descriptions can also be found in the manual of the PITSA software (Appendix 1 to report WP06-D05.06). The format is platform independent (ASCII) and compact in size (compressed format). No conversion had to be performed which minimizes the risk of untrackable amplitude distortions due to subsequent runs of different conversion tools. We are therefore lucky to present a homogeneous data set which does not require any additional amplitude corrections. The unit of the GSE2.0 waveform files is μV, the specific preamplification settings of the data loggers (μV per digital Count) are included in the playback software and should be corrected for. This allows to compute directly true ground velocity by deconvolving the waveform data with the instrument response of the connected sensors. Only a single sensor type has been used throughout all field measurements (Lennartz 3D-5s). Without any better sensors calibration at hand (compare report WP05-D07.05, section 4.2) than the one provided by the manufacturer, there is currently no need to correct individual instrument responses for the purpose of array processing.

2.2 Data archiving and supplied software

The array data sets have been organized in the GIANT database system (Rietbrock and Scherbaum, 1998). This allows an easy access of the waveform data via a GUI interface and the interactive analysis software PITSA (Scherbaum and Johnson, 1992). For details of the GIANT/PITSA analysis system please compare the deliverable WP06-D05.06 and the corresponding Appendix 1. The complete waveform data sets are provided on 12 CDROMs together with the GIANT database files for both SPARC Solaris (2.5.x and higher) and Linux INTEL platforms (Kernel 2.x). The contents of the 12 CDROMs are summarized in Table 2-1.

<table>
<thead>
<tr>
<th>CDROM name</th>
<th>Array data set of site(s)</th>
<th>Included Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>SESAME01</td>
<td>Baviere</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME02</td>
<td>Uccle + Botanique</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME03</td>
<td>Otterbach I</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME04</td>
<td>Otterbach II</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME05</td>
<td>Lörrach</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME06</td>
<td>ColfA+B</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME07</td>
<td>ColfC</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>---------</td>
<td>------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SESAME08</td>
<td>ColfD+E 30.07.2002</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME09</td>
<td>ColfD+E 31.07.2002</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME10</td>
<td>Lefkas</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME011</td>
<td>Thessaloniki</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
<tr>
<td>SESAME012</td>
<td>VOLVI</td>
<td>GIANT + utilities, PITSA, cap, HVDB, fk2disp, both SUN Solaris and Linux Intel versions.</td>
</tr>
</tbody>
</table>

Table 2-1 Contents of CDROM set provided with this deliverable. Directory structures and organization of data are given in the text.
The directory structure of the data CDROMs are visualized in Figure 2-1. On each CDROM we supply the raw waveform data from the respective field experiment in a subdirectory which is named according to the day of recording. Logging information from the field recorders is stored in subdirectory logs. The platform dependent binary executables of the software tools are packed into directories bin_linux and bin_sun, respectively. A digital version of the important fieldbook information is contained in the ASCII file with extension “.info.dat” within the config subdirectory. The information given in this file has been used to populate the GIANT data base records, which are stored in subdirectories base_linux and...
base_sun, respectively. The ASCII files “\texttt{sitename\_linux.env}” and “\texttt{sitename\_sun.env}” are provided to show the correct use of the environment variables for accessing the GIANT database structure on either platform (Linux Intel or SPARC SUN Solaris). Finally, in the subdirectory work, two sample scripts, named “dol\texttt{sitename}” and “doss\texttt{itename}” are provided for ready to use of GIANT on either platform.

\section*{Acknowledgements}

This project (Project No. EVG1-CT-2000-00026 SESAME) is supported by the European Commission – Research General Directorate. We thank all the technical personnel from the participating institutions, who have helped in the preparations of field experiments, the measurement campaigns and data archiving. We owe special thanks to the GeoForschungsZentrum Potsdam (GFZ) for letting us make use of their commercial differential GPS system for accurate station positioning and T. Ryberg for giving us an introduction to the correct use of the equipment.
References:


List of Appendices

Appendix 1: Photos of measurement sites