NEtwork of Research Infrastructures for European Seismology

Report
on in-situ measurements at the 20 selected sites

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Summary

In the following, we report on the field measurements carried out within task C of JRA4. During autumn 2007 and spring 2008, measurements were conducted at 19 of the selected sites in Greece, Turkey and Italy. Ambient vibration array measurements with an adaptive, wireless eight-station array were performed together with active seismics (refraction and MASW) at each site. The field books provided here contain details on the locations, geometries, timing, duration of the individual measurements, any special occurences and first in-field results.

1. Introduction

JRA4 aims at developing prototype, reliable, low cost tools for the geotechnical characterization of European strong motion sites and broad-band stations. An overview of available methods used in site characterization suggested that array recordings of ambient vibrations, while non-standard until now, could be a cheap tool of satisfactory accuracy to derive the shear wave velocity structure of the uppermost 50 or more meters. When including H/V analysis, spatially distributed noise measurements can also give an indication of the subsurface geometry, and thus potential 2D or 3D effects on site amplification. However, various previous experiments had shown the difficulty in measuring the high-frequency asymptote of dispersion curves even with small arrays. The match of the dispersion curves in the overlapping region between small and larger arrays was often not satisfactory. To investigate these problems further and to extend the measured dispersion curves to higher frequencies for a detailed and faithful image of velocity variations in the uppermost meters, active seismics (refraction and MASW) were performed in conjecture with the ambient vibration array measurements. These measurements along seismic lines can also help to resolve first-order 2D effects.

Within subtask C of JRA4, the suggested prototype tools should be tested and validated under a variety of real field conditions at various European strong motion sites. The sites were selected within JRA4 subtask A3 (Picozzi et al., 2007) to present a wide range of possible soil conditions (soft, stiff, rock sites; variable depth to bedrock) and EC8 classes as well as variable measurement environments (city centre vs. city outskirts and rural sites). While 20 sites (and additional replacements) were selected, measurements have taken place at 19 sites (Figure 1).

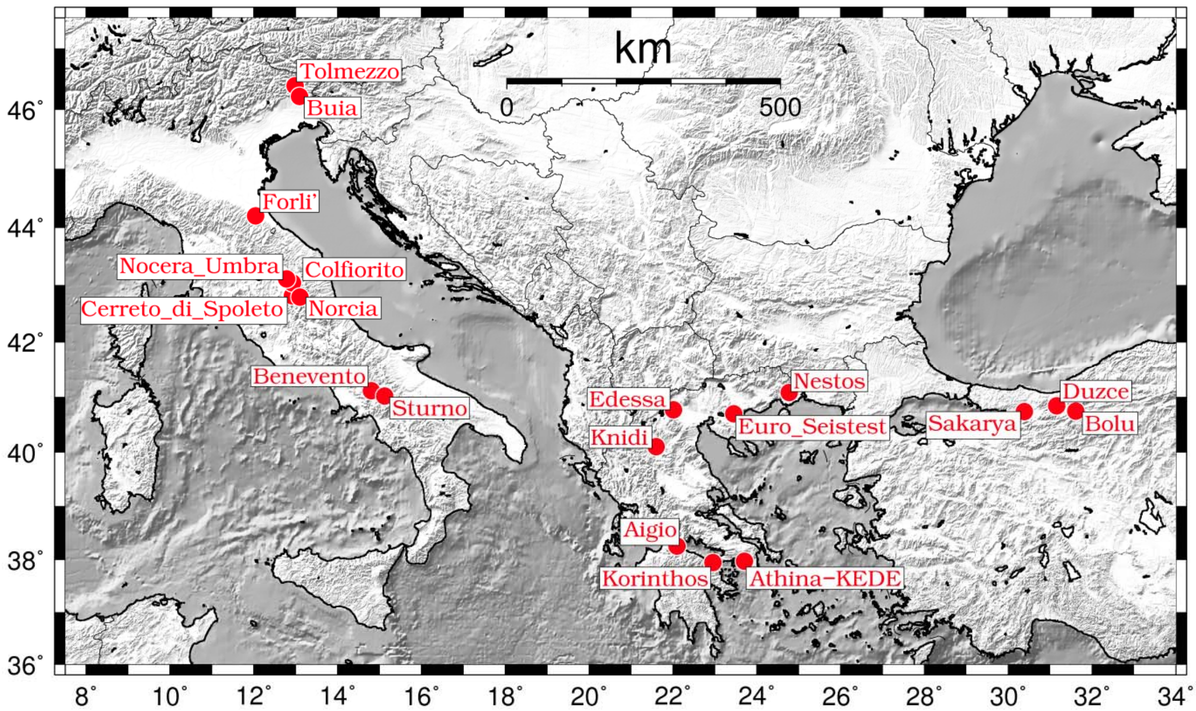

Figure 1: *Map showing the locations of the 19 pre-selected sites at which ambient vibration and active seismic measurements were carried out within the last 9 months under JRA4, subtask C.*

For the site in Grenoble valley (Montbonnot), data from a range of ambient vibration measurements from different years and with different layouts and spatial scales (array size from 30 m to 1275 m) are available at LGIT (Scherbaum et al., 1999; Bettig et al., 2001; Kudo et al., 2001; Cornou et al., 2004; Banton et al., 2004; Cadet et al., 2006). Therefore, additional measurements at this site were considered low-priority. In Italy, logistical and organisational difficulties at one of the selected sites (Bagnoli Irpino) led to its replacement by another site (Sturno) for which new borehole information (dating later than the original site selection study) was available. Besides, new borehole data from Bagnoli Irpino had also cast severe doubt on its initial classification as an EC-8 "A" site. For a first order grouping of the 19 measured sites, see Table 1.

The selected sites had been studied intensively before with various geological and geophysical tools to present a broad data base for comparison, specifically S-velocity logs from boreholes. Additionally, for all accelerometer sites, recordings of strong ground motion with a maximum acceleration between 0.053 g and 0.821 g from strong earthquakes in the vicinity of the stations are available. They offer a chance to compare predicted site amplification from measured velocity profiles with actual strong ground motion data.

Table 1: *Details on the 19 sites where measurements were performed in JRA4, subtask C. Sites marked yellow are located in Greece, sites marked green are located in Turkey and sites marked blue are in Italy, respectively (compare Figure 1). "Shallow" refers to bedrock depth of less than 30 m, "intermediate" to 30 to 100 m bedrock depth and "deep" to more than 100 m bedrock depth. "Unknown" bedrock depth means that previous geophysical investigations did not reach the bedrock, indicating that it lies deeper than at least 30 m.*

Site Name	EC 8 class	Bedrock depth	Location
Aigio	B/C	shallow	urban
Athens	B	shallow	urban
Benevento	A	deep	urban
Bolu	C	unknown	urban
Buia	C	intermediate	rural
Cerreto di Spoleto	B	shallow	rural
Colfiorito	D	intermediate	rural
Düzce	C	unknown	urban
Edessa	E	shallow	urban
Euro Seistest	D	deep	rural
Forli	B	deep	urban
Knidi	E	shallow	rural
Korinthos	C	unknown	urban
Nestos	C/D	intermediate	rural
Nocera Umbra	E	shallow	urban
Norcia	B	deep	urban
Sakarya	B	shallow	urban
Sturno	B/C	deep	rural
Tolmezzo	A	shallow	rural

2. Field Measurements

Measurements were carried out in two separate field campaigns, from 14th of September to 2nd of October 2007 in Greece and Turkey and from 25th of March to 7th of April 2008 in Italy, respectively. Participants in the first campaign were, from University Potsdam, Matthias Ohrnberger and Brigitte Endrun, from LGIT Grenoble, Cecile Cornou and Florence Renalier, from ITSAK Thessaloniki, Nikos Theodulidis (Euro Seistest, Nestos and the three Turkish sites), Alexandros Savvaidis (Athens, Aigio, Korinthos, Knidi, Edessa and Euro Seistest), Marios Anthimidis (Knidi and Edessa), Markus Gurk (Euro Seistest) and Stephane Drouet (Euro Seistest), from NOA Athens, Ioannis Kalogeras (Athens, Aigio and Korinthos), from GDDA, Ankara, Özgür Tuna Özmen, Ali Zeynel and Mehmet Akif Alkan (all three Turkish sites), Yildiz Iravul and Bekir Tuzel (Bolu) and from METU, Ankara, M. Abdullah Sandikkaya (all three Turkish sites). Participants in the second field campaign in Italy were, from University Potsdam, Brigitte Endrun, Daniel Vollmer, Carsten Riggelsen and Andreas Köhler, from LGIT Grenoble, Florence Renalier, Armand Mariscal and Jean-Marc Nicole, from DPC-SSN, Roma, Salomon Hailemikael and from Universidade de Lisboa, Paula Teves Costa (Benevento and Sturno).

2.1. Ambient vibration measurements – equipment and processing

The equipment used for the ambient vibration array measurements was developed in previous projects (SESAME, HADU) at University Potsdam. It consists of 8 Lennartz 5s three-component sensors, which are connected to EarthData digitizers. At each station, a MeshCube Linux system manages recording and communication between stations. Each station is powered by a 12 Ah battery, which provides sufficient power for a day of recording. Data are transmitted in quasi-realtime via WiFi, employing the Seedlink protocol (Hanka et al., 2000). The WiFi connections need line-of-sight between any single station and at least one other station. However, no central unit which can directly contact all stations is necessary as each station can act as a transmitter as well as a recorder. Data packages can consecutively be transferred between stations until they reach the WiFi receiver (omnidirectional 18 dB antenna) which is connected to the field PC. Data transmission by WiFi allows for a quick and comparatively easy (without laying cables) deployment of quite large arrays, even in an urban environment. On the field PC, all arriving data are archived via Seedlink and can be processed in near-realtime, allowing for first valuable results already in the field. Backup-storage is available on USB keys at each individual station.

Recordings were done with a sampling rate of 100 Hz and a sensitivity of 2.5 μV/bit. GPS receivers are included in each station to synchronise the clock of the recorders. Precise position determination, however, as needed for array analysis methods, necessitates the use of differential GPS measurements, carried out with a Leica GPS1200 system as a reference station and another Leica GPS1200 as rover. This combination leads to a relative accuracy in the centimetre-range for station locations. In-field data processing was carried out with the GEOPSY software (Wathelet, 2005, *www.geopsy.org*) for near-realtime calculation of spectra and H/V ratios (Konno & Ohmachi, 1998) and with a command-line based subroutine of CAP (Ohrnberger et al., 2004) for near-realtime frequency-wavenumber (f-k) array analysis of the vertical component signals and calculation of Rayleigh wave dispersion curves. These curves were displayed and checked in the field with the max2curve feature of GEOPSY.

Previous results from SESAME have proven that it is difficult to cover the whole frequency range of interest of the dispersion curve with any single array installation. Accordingly, several arrays were deployed in an adaptive technique. Starting out with a small (diameter approximately 10 m) array, larger arrays were deployed successively (generally three or four arrays in total per site). The size of the next array can be derived by rule-of-thumb from the frequency range of the dispersion curve covered by the present array (via calculating the true array response with the build_array feature of GEOPSY, Wathelet et al., 2008). Monitoring of the incoming data streams provides direct feat-back on station malfunctions or connection problems. The near-realtime H/V processing allows for first inferences about 2D or 3D structure at the site as well as on the lowest frequency to which the dispersion curve can probably be extended (H/V peak frequency, where the vertical amplitude of Rayleigh waves becomes very small). Online f-k processing helps to judge the recording time needed for each array layout to reliably determine part of the Rayleigh wave dispersion curve.

Arrays were in general constructed as circles with a central station. However, for the larger arrays the shape can significantly deviate from this ideal design due to obstacles imposed by local conditions (line-of-sight between stations for wireless transmission blocked by buildings or vegetation, inaccessibility of areas, e.g. private property or fields with crops, position of roads within the area).

2.2. Active seismic - equipment and processing

The equipment used for active seismics consisted in 24 ABEM 4.5Hz vertical geophones and 24 ABEM 4.5Hz horizontal geophones, connected with two 12 connection cables to a Geode (Geometrics). Acquisition was monitored with the Seismodule Controller software (Geometrics), from the field PC connected to the Geode. Both Geode and PC were powered by a 12V battery. Seismic signals recorded with vertical geophones were generated on an aluminium plate hit vertically with a 5kg sledge hammer. Those recorded with horizontal geophones were generated with the same hammer hitting horizontally both sides of a wooden beam settled perpendicularly to the profile. Recordings were triggered by a piezoelectric sensor fixed on the hammer and connected to the Geode, acquiring data for usually 2s (adapted to record the whole wave train) with 4000Hz sampling rate.

The constant spacing between geophones was chosen from 1m to 5m, depending on the *a priori* information available at each site in order to resolve at best the bedrock depth with both refraction and surface wave methods. For most profiles, at least 5 positions were used to shoot : one in the middle, two at both ends (with distance source - 1st receiver equal to the geophone spacing), and two with offsets. On the sites likely to present 2D / 3D effects, two perpendicular profiles were deployed, in order to provide data for the study of 2D/3D effects within Task B3.

3. Data Processing : State of the Work

Lab processing of the array data from Greece and Turkey yielded Rayleigh-wave dispersion curves covering a broad frequency range (up to 45 Hz and down to 0.5 Hz), H/V curves for all individual locations and high-quality three component spatial autocorrelation curves which also contain some information on Love wave dispersion (Köhler et al., 2007). Preliminary velocity models for two thirds of the sites have been derived from joint inversion of the different data sets using the Neighbourhood Algorithm (Sambridge, 1999; Wathelet et al., 2004, Wathelet 2008). Preliminary results for the active seismic measurements in Greece and Turkey are shown in greater detail in Appendix 3 (see below). These first results were discussed at the JRA4 meeting in Grenoble (March 17th-19th, 2008), while part of the preliminary ambient vibration results was also presented at the Annual Assembly of the German Geophysical Society (DGG, Endrun et al., 2008a) and at the Annual Assembly of the European Geoscience Union (EGU, Endrun et al., 2008b). In general, a very good agreement between the results of the ambient vibration array measurements and the simultaneous active seismic measurements is found in the frequency range covered by both methods. Investigation of the fit to previous available geophysical and geotechnical parameters, especially S-velocity profiles from boreholes, is ongoing. Processing of the data from Italy is continuing both for array measurement and active seismics, but so far showing good results.

4. Introduction to the Appendices

The following Appendix 1 contains the field book from the ambient vibration array measurements at all 19 sites. It gives details on the measurements at each site (recording time and duration, local weather and noise conditions, array location and layout) and shows the in-field results of H/V and f-k processing.

In Appendix 3, the characteristics of the different active seismic acquisitions are given (geophone spacing, shot positions, orientation, sampling frequency and record length), together with their position which is visualised on a map.

Preliminary results of active seismic data are gathered in Appendix 4, showing for each profile the velocity models inverted from first arrival times with a dipping layer algorithm, the surface waves dispersion curves and the spatial spectrograms.

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