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Project S4: **ITALIAN STRONG MOTION DATA BASE**

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Scientific Report - II phase

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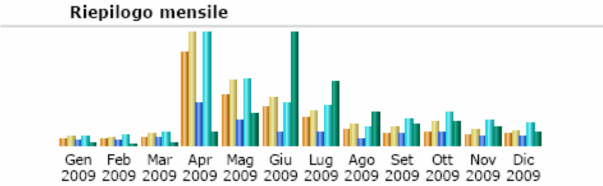
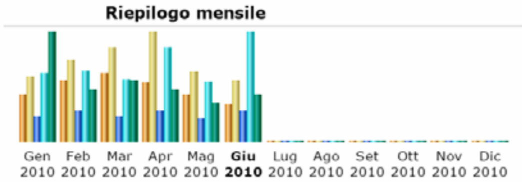
Section 1: Report on Project S4 by Coordinators

1.1 Project S4 results: general

The main objective of Project S4 has been to make available through the Internet an updated and improved release of the Italian strong motion database (ITACA), originally developed within project S6, in the framework of the 2004-2006 DPC-INGV agreement. A first release of the beta version of ITACA (http://itaca.mi.ingv.it) was published in the Internet on July 2008, and migrated to a robust system (INGV server) on November 2008.
After that, Project S4 faced two major emergencies, namely, the M_w5.1 Parma earthquake on Dec 23, 2008, and, most important, the L'Aquila earthquake sequence with the M_w6.3 Apr 6 2009 mainshock. These events represented the opportunity to test procedures for quasi real-time data transmission and for publication of waveforms on the web within a reasonable delay after the earthquake. In both cases, strong motion data from the mainshocks were released in ITACA only about two-three weeks after the earthquake, even though many stations were of recent installation and not present yet in the ITACA database.
A new significant update of ITACA was released in January 2010, where two major achievements were implemented: (i) all records were corrected according to a new processing procedure, suitable to preserve compatibility of acceleration, velocity and displacement waveforms, reponse spectra calculated on a wider range of periods, and improved file headers, as required by many users of ITACA after L'Aquila earthquake; (ii) the REXELite software was implemented for the automatic selection of records from ITACA according to a target response spectrum.
The ITACA release 1.0 is now available, which includes a significant amount of improvements in terms of search criteria, graphic presentation, download options. Probably the most important improvement with respect to the previous beta release of January 2010 is the availability of the new station monographs, including the results of the in-field surveys for seismic site characterization carried out within this Project and the availability of more than 400 strong motion data with magnitude $M \geq 3.0$, recorded in the period between 2005 and 2007.
Especially after the L'Aquila earthquake, the ITACA web site faced a dramatic increase of the number of accesses. The number of visits has now stabilized around 40 visits/day, around twice larger than it was before April 2009 (Figure 1). This means that ITACA has now consolidated its role as the reference database of Italian strong motion records. Digital records of ITACA have been included in the NERIES web portal (Network of Research Infrastructures for European Seismology, http://www.neries-eu.org/) while the link with the COSMOS consortium (Consortium of Organizations for strong motion observation systems, http://www.cosmos-eq.org/) has not yet been finalized, although ITACA records have already been converted in the format required by COSMOS.
Besides providing a real benchmark for ITACA, L'Aquila earthquake caused a major revolution in the project plans, mainly because all the RUs of the Project were deeply involved in the post-earthquake emergency, either for seismic monitoring, or for the microzonation studies. Project S4 had to redirect part of the planned activities to face the challanges posed by the earthquake, and to contribute as well to a better understanding of the ground motion characteristics and site characterization of recording stations. On one side, some the most important recording stations of L'Aquila earthquake were investigated for seismic site characterization, with new results published for the first time in the station monographs. On the other side, the research on new ground motion prediction equations, seismic site classification schemes, and distinctive features of the seismic response of ITACA stations took advantage of the enormous amount of new data available.



Mese	Visitatori diversi	Numero di visite	Pagine	Accessi	Banda usata
Gen 2009	346	483	9155	15282	432.97 MB
Feb 2009	305	439	7246	16847	269.69 MB
Mar 2009	409	607	13176	23869	541.38 MB
Apr 2009	5420	6588	78999	214661	3.21 GB
Mag 2009	2964	3849	46316	128590	7.52 GB
Giu 2009	2233	2834	25764	78773	26.28 GB
Lug 2009	1572	2017	24411	74274	14.66 GB
Ago 2009	881	1182	11231	33819	7.70 GB
Set 2009	641	1092	19926	48727	4.91 GB
Ott 2009	762	1321	24520	62547	5.30 GB
Nov 2009	560	949	15674	46948	4.21 GB
Dic 2009	601	857	14957	40944	3.14 GB
Totale	16694	22218	291375	785281	78.14 GB



Mese	Visitatori diversi	Numero di visite	Pagine	Accessi	Banda usata
Gen 2010	623	855	24694	68896	3.46 GB
Feb 2010	805	1083	31394	70516	1.64 GB
Mar 2010	904	1241	24928	62148	1.95 GB
Apr 2010	785	1445	31264	93388	1.62 GB
Mag 2010	619	916	21784	59604	1.22 GB
Giu 2010	494	808	30959	108792	1.49 GB
Lug 2010	0	0	0	0	0
Ago 2010	0	0	0	0	0
Set 2010	0	0	0	0	0
Ott 2010	0	0	0	0	0
Nov 2010	0	0	0	0	0
Dic 2010	0	0	0	0	0
Totale	4230	6348	165023	463344	11.39 GB

Figure 1 - Summary of the ITACA monthly statistics for the years 2009 and 2010

Following is a synthesis of the operational and research activities carried out within the various Tasks of the Project.

1.2 Project S4 results: description by Tasks

1.2.1 Task 1. ITACA update

The final version of the database, ITACA 1.0, has been released as originally planned (**Deliverable 2**). A great deal of work has been dedicated to update the information contained in ITACA, that has also led to important changes in the structure of the database.
In particular, all the general information relating to the stations (address, housing, coordinates, instrumental history, etc.) and the instrumental characteristics of digital recordings have been reviewed. Information from the Tasks 2 to 5 of the Project were included in ITACA and reported in the station monographs and partially in the web-interface. In particular, station data concerning EC8 site classification, topography category, morphological description and fundamental frequency from microtremor measurements have been updated or added (*from Task2*). When available, V_{S30} values and S-wave velocity at bedrock have been included (*from Task3*). Finally, a short note has been added, when required, at the synthesis page of the station monograph to summarize specific aspects related to the seismic response of the station site or possible effects of soil structure interaction (*from Task4*).
Other modifications in the structure of the database are a consequence of the implementation of the tool to perform the dynamic compilation of the station monographs, to allow the storage of additional information relative to the sites (maps, spectral ratios, references, image files, pdf documents, etc.).
The new web version of ITACA is characterized by a new home page, which contains more information than in the beta version (i.e. a section on new data, the description of the project history and many links and utilities) and by three main user-friendly interfaces (Figure 2), one for waveforms, one for stations and one for events, that, through the setting of the search fields, allow to perform queries to look for and download strong motion data. New search-fields have been added to enable users to explore in detail the contents of the database and the options to download and display data have been expanded to make use of ITACA in a way as flexible as possible. Details on the structure and on the use of the database can be found in the **user-manual** downloadable from the home page of ITACA.

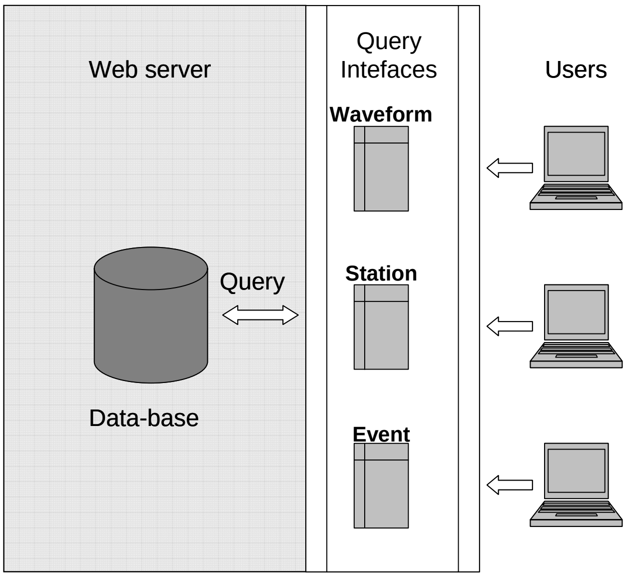


Figure 2 - Structure of the ITACA portal

Further utilities have been added, such as the **glossary** of the most used engineering and seismological terms, a user's guide of the database and the manual explaining the station reports, in order to help the site exploration.
A useful engineering tool has been added, **REXELite** (Iervolino et al., 2009), which is a simplified version of the software formerly released in the framework of the RELUIS projects (http://www.reluis.it). This application allows one to search a suitable combination of natural strong motion records compatible with a target spectrum, either based on the Italian Building Code (NTC 08) or the Eurocode 8, or defined by the user. The search can also be associated to magnitude and epicentral distance of the target event.

To keep track of the ITACA users, a **user's registration** has been introduced in the 1.0 release, that is required only for download operations. This is expected to provide useful information for DPC and for the ITACA operating team to understand which are the professions and the objectives of the ITACA users.

Although the waveforms available at the start of Project S4 in the alpha version of ITACA were treated by following the worldwide accepted techniques, aiming to remove low and high frequency noise, the compatibility among acceleration, velocity and displacement waveforms was not guaranteed. For these reasons, a novel approach for processing the ITACA strong-motion records has been devised.
Referring to **Deliverable D15** and to Paolucci et al. (2009) for details on the procedure, its basic steps are the following:

- baseline correction (constant detrending);
- application of a cosine taper, based on the visual inspection of the record (typically between 2% and 5% of the total record length); records identified as late-triggered are not tapered;
- visual inspection of the Fourier spectrum to select the band-pass frequency range (Figure 3); whenever feasible, the same range is selected for the 3-components;
- application of a 2nd order acausal frequency-domain Butterworth filter to the acceleration time-series;
- double-integration to obtain displacement time series;
- linear detrending of displacement; double-differentiation to get the corrected acceleration

Particular attention was paid to identify the late-triggered records, typically on the S-phase, that form a large portion of analogue records in the ITACA database, from small-to-medium magnitude earthquakes.

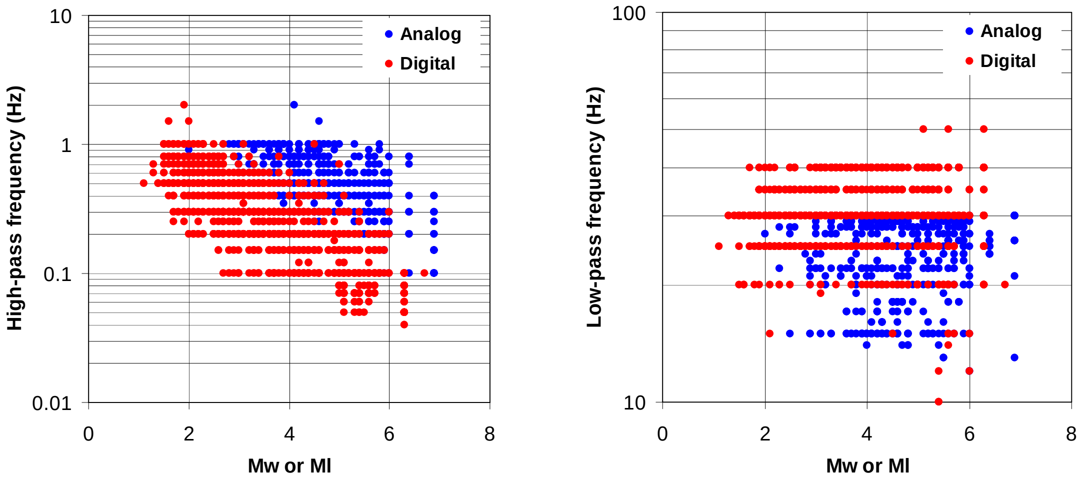


Figure 3 ITACA data set: Frequencies filtering (Ns component) plotted as a function of magnitude

Compared to the alpha version, the ITACA data set has been updated by 1110 accelerograms recorded by the Accelerometric National Network (RAN), in the period 2005-2007, from 740 events and 369 stations.
In addition, about 300 strong motion data recorded by three local networks were included, i.e., the Strong Motion Network of Northern Italy, Rete Accelerometrica dell'Italia Settentrionale, *RAIS* http://rais.mi.ingv.it/, the Seismic Network of the Basilicata region, *BAS*, and the Seismic Network of the Autonomous Province of Trento, *PVTR*). Moreover 30 records relative to temporary stations and networks (analogue and digital), either installed in the framework of Project SISMOVALP (*INTERREG IIIB Alpine Space Programme 2001-06,* network *SVALP*) or during the post-earthquake emergency phase, namely the Gemona (GMN) station, installed by ING during the 1976 Friuli seismic sequence, and the 4 stations installed by INGV-MI during the L'Aquila seismic sequence (MI01-02-03-05). In addition, waveforms recorded during the L'Aquila seismic sequence, including the mainshock, by the accelerometer installed at Aquila Castello station (AQU) (http://mednet.rm.ingv.it) are also present. Table 1 summarizes the information described above.

Table 1. Stations and records added in ITACA from permanent or temporary networks other than DPC. For Rais Network only data with magnitude M=3.0 were included

	BAS	RAIS	PVTR	SVALP	MN/ING
Stations	21	17	4	8	2
Records	120	140	26	9	13/11

The ITACA strong-motion dataset has been included in two international initiatives: the EU project NERIES (Network of Research Infrastructures for European Seismology, http://www.neries-eu.org/) and the COSMOS consortium (Consortium of Organizations for strong motion observation systems, http://www.cosmos-eq.org/).
As regards NERIES, a sub-set of ITACA recordings has been prepared, containing 801strong motion data from 390 events and 103 stations, recorded in the period 1998-2004. The strong motion data have been converted in the required format and preliminary processed following the criteria given by the NEREIS Project to produce the parameters table necessary to query

the database. Figure 4 shows an example of the NERIES portal with a focus on the Italian data (http://www.seismicportal.eu/jetspeed/portal/).

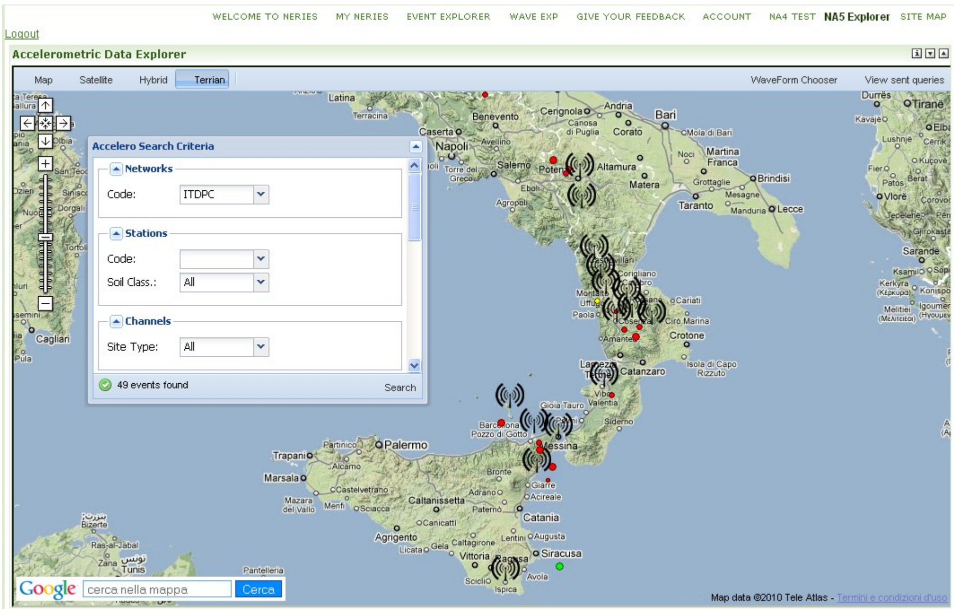


Figure 4: Italian strong motion data in the NERIES portal

A sub-set of ITACA recordings has been constructed for the COSMOS virtual data centre, consisting of 645 strong motion data from 40 events with magnitude M ≥ 5 and 276 stations. Records have been converted in the COSMOS format and the header file, consisting of more than one hundred fields, has been filled in. Details on the progress of the ITACA-COSMOS project, not finished yet, are illustrated in the Appendix A of this report.

ITACA Data-set

The database in its final version includes the strong-motion records in the period 1972 – 2007 and the strong-motion data of the strongest events occurred in the period 2008-09 (Mw 5.4 Parma and Mw 6.3 L'Aquila earthquake sequences) (Figure 5).

To date, a total of about 3900 uncorrected 3-components accelerometric records, 2934 of which available in the corrected form, are actually included in ITACA spanning in the magnitude range from 1 to 6.9 and epicentral distance from 0 to 600 km.

Figures 6 and 7 summarize the main characteristics of the ITACA dataset in terms of focal parameters and distance ranges. As shown in Figure 6, magnitude (either M_w or M_L) ranges from 2 to 6.9 with the best sampled distance interval from 5 to 100 km. The epicentral distance (R_{epi}), for M<5.5 events, and the Joyner-Boore distance (R_{jb}) for stronger earthquakes are considered, based on the fault geometry data available in the DISS database (DISS Working Group, 2009). Distributions of records as a function of magnitude, focal depth and focal mechanism are plotted in Figure 7. Most events with magnitude less than 4 have unknown focal mechanisms.

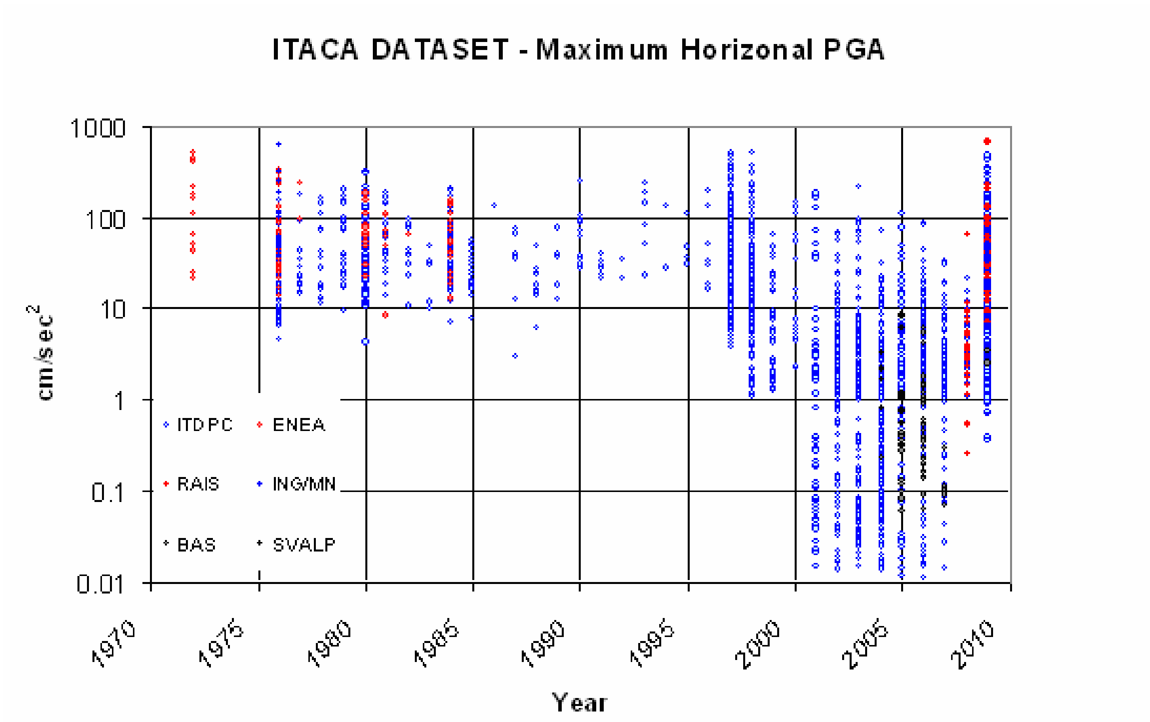


Figure 5 – Annual distributions of maximum horizontal Peak ground Acceleration from corrected accelerograms. Data recorded by different networks are indicated with different colours

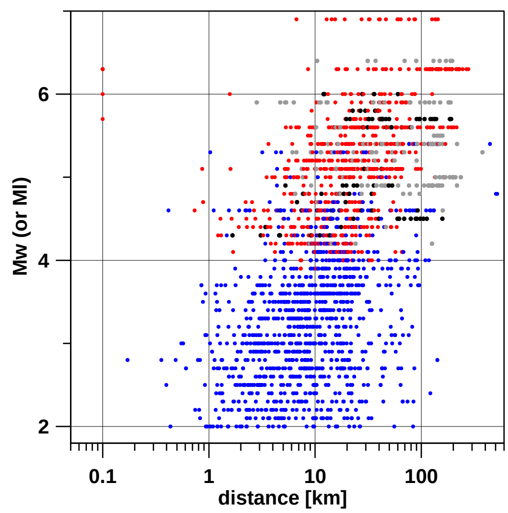


Figure 6. Magnitude vs. distance (either Joyner-Boore for M>5.5 or epicentral distance otherwise) distributions for the ITACA dataset. The records are grouped by focal mechanism (blue: normal; gray: reverse, black: strike, blue: unknown).

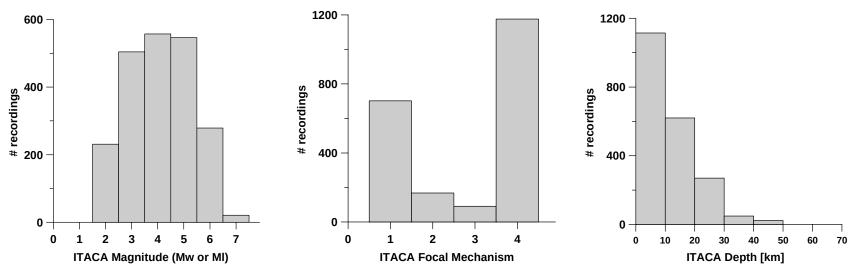


Figure 7. Distribution of ITACA records plotted as a function a) Magnitude; b) focal mechanism, (1: normal; 2: reverse, 3: strike, 4: unknown); c) focal depth.

More than 700 strong-motion stations are include in ITACA, 312 of which are presently not in operation, since they were part of temporary networks or equipped with analogue instruments, which were dismissed. Among these, 635 stations belong to DPC while the others are distributed between the various network owners.
At present, the ITACA waveforms were recorded by 446 stations, since many stations are recently installed or were dismissed without recording any data.
All station in ITACA were classified following the Eurocode 8. Measurements of Vs_{30} are available for 131 stations, 50 of which were characterized in this Project (Task3). Among stations with V_{s30}, according to the EC8, 15% were classified as A, 49% B, 25 % C, 6% D and 5% E. All the other stations are classified only based on the existing geological/geophysical information and denoted by a star (*) in the database. For each site the topography category was also assigned according to the Italian norms (see **Deliverable D10**).

Figure 8 shows the ITACA station distribution according to EC8 site classes and NTC08 topography classification.

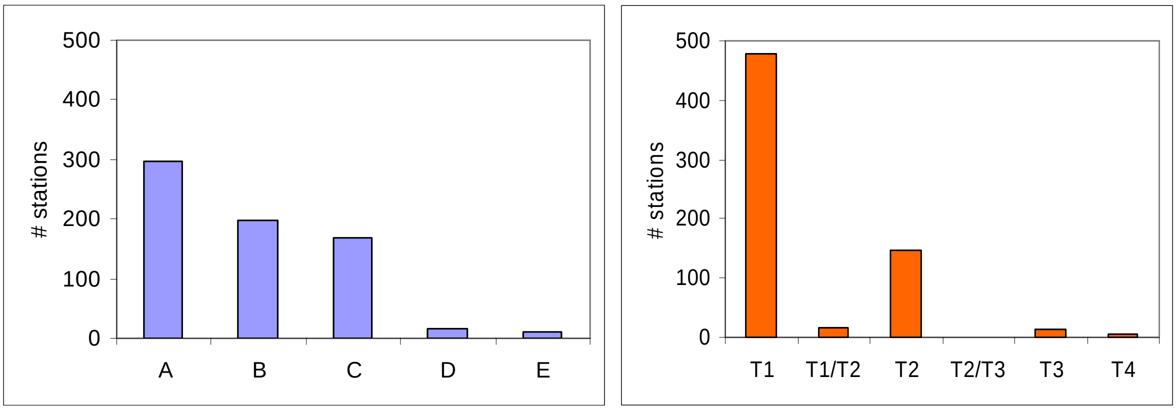


Figure 8 - Distribution of ITACA stations as a function of a) Topography category; b) EC8 seismic site class.

Summary of activities, problems and difficulties

This is the Task where all the other Project activities converged to provide information. Therefore it enjoyed and suffered the same benefits and drawbacks of the other Tasks. Besides the specific activities illustrated in Table 2, it is difficult to summarize all the minor changes, improvements, checks and updates of the different pages and fields of the database. This "backstage" activity was, *in se*, one of the most important involvements of the whole Project.

Table 2. Summary of Task 1 activities

Summary of Task 1 activities	Notes
ITACA update	
Publication in the Web of beta version of ITACA, after test and debug	**Deliverable D1**
Modification of ITACA database structure	New queries and search-keys added. New options to downloaded data, table and maps included
Check of record processing procedures, implementation of an updated one and re-processing of all ITACA waveforms	High-pass frequencies checked with corrected strong motion available from international databases. New file header. Response spectra computed for 121 periods between 0 – 4s. → **Deliverable D14**.

Upload in ITACA of 2005-07 records from the RAN	484 records with M ≥ 3.0 and 780 with M<3. Correction only for M>3.
Collection of records from local networks and previous research projects and upload in ITACA	91 records included
Upload of Parma and L'Aquila earthquakes waveforms	358 records included
Tool for automatic selection of strong motion records based on spectral compatibility	REXELite accessible from the Home page of ITACA, along with its user-manual
Link of ITACA within NEREIS and COSMOS	See http://www.seismicportal.eu/ for NERIES and Appendix A to this report for COSMOS
Implementation of the Web-GIS interface	Task removed after 1st year of Project
Protocol for quasi real-time data transmission	Implemented and successfully tested after l'Aquila earthquake
Compilation of a glossary to help consulting ITACA	Available in both English and Italian version
Publication in the Web of version 1.0 of ITACA, after testing and debugging	**Deliverable D2**

1.2.2 Task 2. Catalogue of ITACA sites

This Task has involved a considerable effort throughout the Project, probably larger than expected in the initial activity plan. Many important activities were added in the course of the Project, such as:

- the critical review of available information from many previous studies on some of the most important recording stations in ITACA, that proved to be affected by several contradictory information;
- the setup of a dynamic procedure for the compilation of the monographs, that caused a delay in the production of monographs in the first part of the Project, but eventually allowed the RUs to speed considerably up the work progress and to end up with a very satisfactory result, also useful for the future compilations and upgrade of the information;
- the processing and upload in the ITACA monographs of about 200 microtremor measurements performed at the ITACA stations either by DPC (150), or by the RUs working at Task3 (30) or by previous surveys and experiments (20);
- the production of about 500 new station localizations on a geological map, some of them associated to a geological cross-section;

and, last but not least, the occurrence of L'Aquila earthquake produced a substantial change of priority in the work to be carried out.

In spite of such major changes with respect to the initial plans, that caused significant delays in the first phase of the Project, this Task has eventually yielded a satisfactory performance, that is summarized in Table 3 .

Table 3. Percentage of compiled pages in the ITACA station monographs

Pages compiled in the station monographs	# of stations	% of total
General information	696	100
Geographical information	696	100
Geomorphology	199	29
Geology	550	79
Geotechnical & Geophysical information (Vs profile)	108	16
Microtremor H/V spectral ratios	220	32
Site classification (with Vs30)	108	16
Site classification (without Vs30)	588	84
Topography classification	688	98

Summary of activities, problems and difficulties

As shown in the Task 2 summary table, many important activities were added with respect to the initial work plan, but the final result of this Task was in line, and likely beyond, the expectations. Details about the compilation of the station monographs are reported in the **Deliverable D5**. There is a slight delay in the delivery of the user's manual for consultation of the monographs, as an Appendix to Deliverable D5, but this is expected to be released within few weeks from the end of the Project.
Furthermore, it was not possible to finalize by the end of the Project the procedure for the automatic generation of GIS maps for the regional localization of the station. As a matter of fact, the initial choice of producing such maps using Google faced a copyright problem difficult to be solved . An automatic procedure to produce a location map as shown in Figure 9 is being devised and implemented in a GIS. This will be accomplished by September 2010.

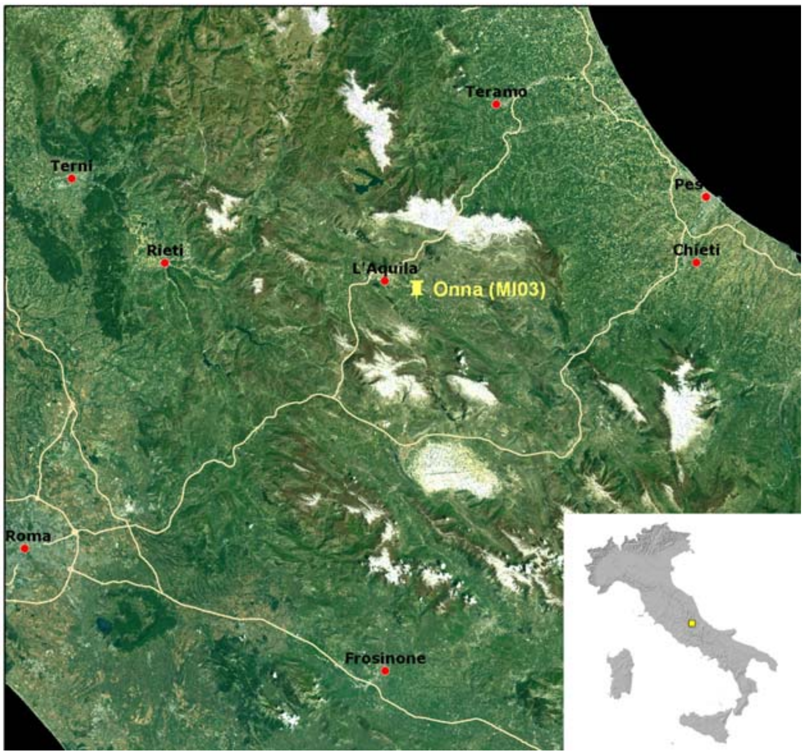


Figure 9 - Example of a regional location map of ITACA station produced in a GIS environment.

Table 4. Summary of Task 2 activities

Summary of Task 2 activities Geological-geotechnical catalogue of ITACA sites	Notes
Definition of a standard format	see **Deliverable D3**
Check and critical review of available information	added wrt to initial plan
Setup for dynamic compilation of station monographs	added wrt to initial plan
Collect and process of microtremor measurements (with DPC)	added wrt to initial plan
Collect new information about L'Aquila stations	added wrt to initial plan
Synthesis of results and upload in ITACA	see **Deliverable D5**

1.2.3 Task 3. Seismic site characterization by surface wave methods.

More than 50 ITACA station sites were selected for seismic site characterization by surface wave methods. The sites were selected with the main purpose to maximize with the available budget the number of ITACA stations with a reliable Vs profile, including sites in moderate/high seismicity areas with limited knowledge about their seismic characterization.
This is the reason why, as shown in Figure 10 which illustrates the location of the selected sites for seismic survey, the areas already covered by a relatively good amount of information, such as Friuli, Irpinia and Umbria were skipped. On the other hand, the geographic distribution of sites with available Vs profile is now much more homogeneous throughout the Italian territory. In Table 5, the stations where the seismic surveys were carried out are listed, together with some relevant parameters for the seismic response characterization. Several stations were added, such as La Salle (Valle d'Aosta), Torre Pellice (Piemonte), Gemona (Friuli Venezia Giulia), coming from other research projects.
The activity of Task 3 was strongly influenced by the occurrence of the L'Aquila earthquake. Fortunately, the RUs were able to redraw their initial plans, and to devote some of the available funding to some of the most important stations that recorded the earthquake. Table 6 illustrates the survey activity close to L'Aquila, mostly carried out with the Project S4 funds, regarding stations close to the epicentral region.
All the Vs profiles estimated in this Task were included in ITACA. For each stations a short report describing the measurements and the results was prepared and enclosed in station monograph.

Figure 10.- ITACA stations where surveys of Task3 were carried out.

Table 5 – Summary list of the investigated sites. For each site the main information is reported

Site	Station	VS_{30} (m/s)	Bedrock (m)	VS_h (m/s)	f_0 (exp.) (Hz)	f_0 (Hz)	Test	RU
RONCO SCRIVIA	RNS	737					MASW	4
SESTRI LEVANTE	SEL	606					MASW	4
GENOVA	GNV	987	3	366		29	MASW	4
VARESE LIGURE	VRL	758	6	456		18	MASW	4
TORTONA	TRT	483	13	306		6	MASW	4
PINEROLO	PNR	383					MASW	4
FIUME ATERNO	AQA	495	26	449		4	MASW	4
GELA	GEL	245					MASW	4
CALTAGIRONE	CLG	373					MASW	4
PATTI (CAB. ENEL)	PTT0	251					MASW	4
TORRE FARO	TRF0	302					MASW	4
TORTORICI	TOR	525	18	368		5	MASW	4
ISPICA	ISI	1482	1	338		106	MASW	4
NOTO	NTE	710	8	384		13	MASW	4
RAGUSA	RGS	1091	2	297		37	MASW	4
SANTA CROCE	SCR	894	4	299		20	MASW	4
CATANIA - PIANA	CAT	160					MASW	4
PALAZZOLO	PLZ	670	7	308		11	MASW	4
PACHINO	PCH	593	15	460		8	MASW	4
GEMONA	GMN	445					MASW	4
LA SALLE 2	LSA2	684					DH	4
LA SALLE 4	LSA4	540					DH	4
TORRE PELLICE 4	PE4	1048	3	366		29	DH	4
TORRE PELLICE 7	PE7	856	6	456		18	DH	4
BEVAGNA	BVG	170			1.22	1.72	ESAC/FK	8
NORCIA ZONA	NRZI	557	146	559	0.72	0.95	ESAC/FK	8
GRUMENTO NOVA	GRM	283			0.59	0.92	ESAC/FK	8
SANT ARCANGELO	SNA	420			0.34	1.03	ESAC/FK	8
LAGONEGRO	LGN	451	88	619		4.75	ESAC/FK	8
BAZZANO	BZZ	679	22	640			ESAC/FK	8
ONNA	ONNA	378			2.50		ESAC/FK	8
CATTOLICA	CTL	208			1.16	1.40	ESAC/FK	8
ARGENTA	ARG	170			0.34	0.34	ESAC/FK	8
FAENZA	FAZ	293				0.38	ESAC/FK	8
MODENA	MDN	213			0.65	0.75	ESAC/FK	8
NOVELLARA	NVL	190			0.65	0.66	ESAC/FK	8
ASSERGI	GSA	488	40	531	4.5	5	MASW	2
AVEZZANO	AVZ	199	160	390	0.8	0.7	MASW	2
BIBBIENA NUOVA	BBN	1000-1200			No peak		MASW	2
BORGO OTTOMILA	BTT2	92	300	250	0.3	0.3	MASW	2
CASSINO	CSS	630	?	?	2.5-3.5	2.5-	MASW	2
DICOMANO	DCM	1000			20-25		MASW	2
RIETI	RTI	170	200	390	0.8	0.7	MASW	2
CAPESTRANO	CPS	730	19	630	2.7		ESAC/HV	7
AQUILA COLLE DEI	AQG	1150	0	0	6.3		ESAC/HV	7
PESCASSEROLI	PSC	1000	0	0	4.3		ESAC/HV	7
AQUILA PETTINO	AQP	830	7	500	1.9		ESAC/HV	7
SCANNO	SCN	840	20	750	3.6		ESAC/HV	7
MORMANNO	MRM	1400	0	0	No		ESAC/HV	7
SPEZZANO SILA	SPS	320	29	310	3.4		ESAC/HV	7
VIBO MARINA	VBM	450	34	460	5.2		ESAC/HV	7
VIBO VALENTIA	VBV	510	24	450	13.5		ESAC/HV	7
MONTECASSINO	MTC	1000	5	400	18.3		ESAC/HV	7
MARSICO VETERE	MRV	680	17	590	7		ESAC/HV	7
PIGNOLA	PGA	430	20	340	5.6		ESAC/HV	7
SATRIANO	STL	390	53	530	No		ESAC/HV	7
TRICARICO	TRO	780	0	0	No		ESAC/HV	7

Site	Station	VS_{30} (m/s)	Bedrock (m)	VS_h (m/s)	f_0 (exp.) (Hz)	f_0 (Hz)	Test	RU
AQUILA F. ATERNO	AQA	552					DH	6
AQUILA C GRILLI	AQG	685					DH	6
AQUILPARK	AQK	717					DH	6

Table 6. Accelerometric stations that recorded L'Aquila earthquake with site characterization within Project S4

Station	Survey	RU	Vs30 (m/s)	Notes
AQA	MASW	RU3	495	
	DH	RU6 + DPC	552	Borehole at 30 m depth
AQG	ESAC+HVSR	RU7	1150	DH survey close to station. ESAC at the foot of the hill.
	DH	RU6	685	Borehole at 40 m depth
AQK	DH	RU6 + DPC	717	Borehole at 50 m depth
AQP	ESAC+HVSR	RU7	830	
AQV	CH	-	474	Available in ITACA from Project S6
BZZ	ESAC	RU8	679	
MI03 (Onna)	ESAC	RU8	378	
GSA	MASW	RU2	488	

Summary of activities, problems and difficulties

All the activities within this Task finished on time and provided reliable results for the determination of the Vs profile at the selected stations, that were uploaded within the ITACA station monographs. The summary of Task 3 activities and reference to the corresponding Deliverables is given in Table 7.

Table 7. Summary of Task 3 activities

Summary of Task 3 activities **Seismic site characterization by surface waves methods**	Notes
Definition of procedures for site characterization	see **Deliverable D6**
Application of active and passive techniques to Bevagna test case and comparison of results obtained by different research groups	see **Deliverable D6**
Selection of sites and preliminary field surveys	see **Deliverable D7**
Determination of shear wave velocity profiles at a selected number of accelerometer stations	see **Deliverable D7**
Synthesis of results and upload in ITACA through Task 2	

1.2.4 Task 4. Identification of stations and records with distinctive features of seismic response

Due to the heterogeneity of ITACA stations and records, that span about 40 years of strong motion recording activity in Italy, the identification of stations presenting distinctive features or anomalies of their seismic response is a major outcome of the Project. To pursue this objective, various research activities were carried out, that are reported in the **Deliverable D9** and the related Appendices, namely:

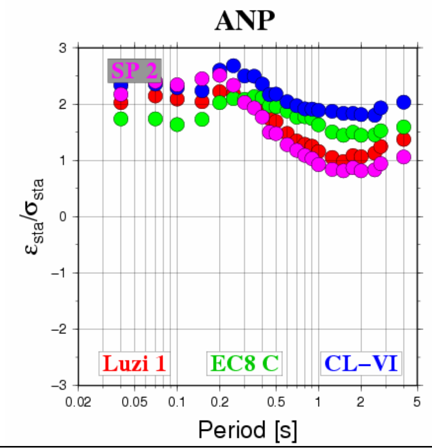
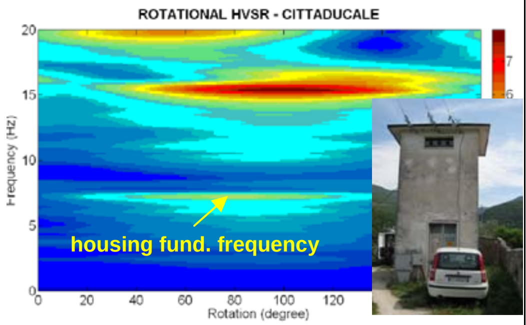
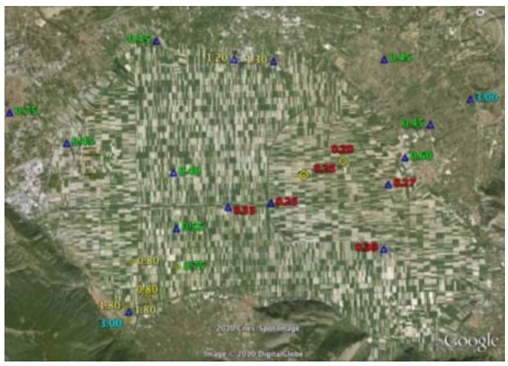
- the statistical analysis of strong motion records of the ITACA stations;
- the study of interaction effects of stations with surrounding structures;
- the seismic monitoring at several selected sites where seismic response is expected to be affected by significant complex geology effects, such as alluvial basins and topographic irregularities;
- the numerical modelling of seismic response in a complex geological configuration and comparison of results of 1D, 2D, 3D simulations.

As a starting point for the statistical analysis of records, but functional as well to the research activities of Task5 related to improved site classification schemes, a novel ground motion prediction equation (GMPE) from the ITACA data set was calibrated, which includes the L'Aquila earthquake records as well. The data set consists of 1213 records relative to 218 earthquakes and 353 recording stations, in the magnitude range 4 - 6.9 and distance range up to 200 km. The recording sites have been classified according to the EC8, as resulting from Task 2, although further classification schemes were also tested, both to study their performance (Task 5) and to study as well the possible anomalous station response (Task 4). Details on the data set, functional form and the coefficients of the regression are described in the **Deliverable 14**.
A very significant amount of research work has been carried out in the framework of this Task. In this short report, we limit ourselves to summarize in the Table 8 some of the most relevant scientific outcomes.

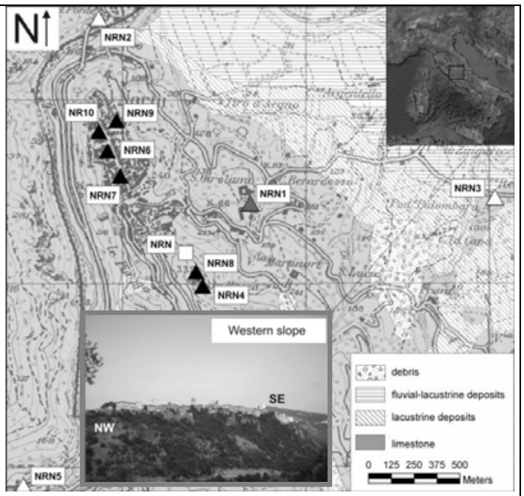
Summary of activities, problems and difficulties

A considerable amount of research work was carried out within this Task, accomplished within the scheduled time. On one side, this work had the merit to have provided a deep insight on the quality of the ITACA records, on the typical site and housing conditions so to provide a useful documentation for future investigations and improvements of the national strong motion network operated by DPC of the ITACA database itself. On the other side, a significant amount of new data were collected from the experimental activity, that "enjoyed" the occurrence of the L'Aquila earthquake, while original numerical studies were carried out to improve the understanding of complex site effects in alluvial basins and topography irregularities. The summary of Task 4 activities and reference to the corresponding Deliverables is given in Table 9.

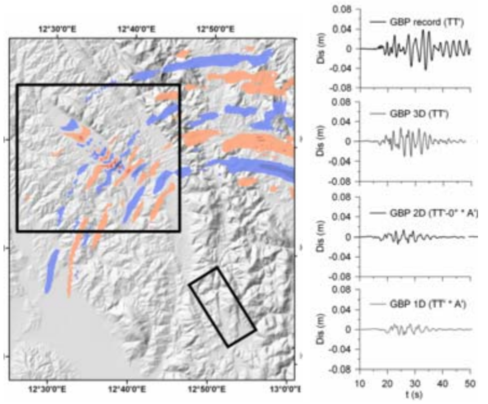
Table 8. Summary of scientific outcomes of Task 4

(a) the identification of 38 ITACA stations presenting peak values of ground motion lying systematically beyond (or below) the average trend lines obtained by the empirical GMPE calibrated on the ITACA data. A catalog of the ITACA stations with at least 6 records used for calibration of the GMPE is presented in Appendix A, each station with an associated graph showing the average residues with respect to the GMPE with different site classifications schemes (see e.g. the plot at right for the ANP station). For such stations, the distinctive feature resulting from this analysis is reported in the station monograph. **→ Deliverable D9 – Appendix A**	
(b) the identification of possible building-soil interaction effects on the recordings of several ITACA stations, by coupling (i) numerical modelling, (ii) identification of anomalous rotational HVSR in 41 stations, (iii) validation of observed anomalies by dynamic identification of 5 housings. An example of the results of such procedure is reported in the plot at right for CTD station. In agreement with DPC results of these analyses were not included yet in the station monographs, for further investigations to be carried out to confirm results. **→ Deliverable D9 – Appendix B**	
(c) the seismic monitoring of Norcia basin, where a temporary seismic network (right panel) was installed from January to May 2009 along two linear transects (EW and NS oriented) close to the ITACA stations NOR, NRC and NRZI. Records from about 90 earthquakes occurred before L'Aquila earthquake on April 2009 have been extracted and spectrally analyzed to determine the site amplification effects at each site, considering both the HVSR and the SSR spectral ratios. Time-frequency analyses have been also performed to investigate differences in the wavefield composition in the basin. **→ Deliverable D9 – Appendix C**	 *Stations of Norcia basin temporary network*
(d) the seismic monitoring of Fucino basin, where a temporary seismic network was installed starting from Oct 2008 and operated until Sept 2009. The network was installed along two cross sections running in SW-NE and E-W directions. Two stations were installed at the ITACA sites of Avezzano (AVZ) and Ortucchio (ORC). Spectral techniques were applied both to microtremor and earthquake data. In particular HVNSR on microtremor and HVSR on earthquakes supplied good information about sediments resonance frequency. SSR results are less reliable due to the very low frequency response of the basin that is not easily recovered by small magnitude and short duration events. **→ Deliverable D9 – Appendix D**	 *Values of resonance frequency (Hz) as derived from HVNSR technique in the Fucino basin*

(e) the seismic monitoring and numerical simulations of seismic response at the Narni hill, where from March to September 2009 a dense velocimetric network was installed at the top of a massive limestone ridge where Narni village is located. A remarkable dataset was obtained, composed by 706 earthquakes (9744 3-components waveforms in the M_L range 1.5-5.3), the largest part of which occurred after the 6th April 2009, Mw 6.3, L'Aquila earthquake. Site amplifications were investigated through spectral techniques with and without reference site, including directional effects. 2D numerical simulations were also performed using a direct boundary element method, showing amplification patterns similar to the experimental ones.
→ **Deliverable D9 – Appendix E**



(f) the numerical simulations of earthquake ground motion in the Gubbio basin during the Sep 26 1997 Umbria-Marche mainshock, with different assumptions: (a) 3D model of the basin + 3D kinematic model of the seismic source; (b) 2D models of longitudinal and transverse cross-sections of the basin under vertical/oblique plane-wave propagation, using, as input, the output of the 3D simulation at outcropping bedrock; (c) 1D model under vertical plane-wave propagation. A comprehensive comparison of results from the various approaches is presented to clarify the role of advanced 3D numerical models for the seismic response studies of complex geological structures.
→ **Deliverable D9 – Appendix F**



Numerical simulations of the seismic response of Gubbio basin by 1D, 2D and 3D models

Table 9. Summary of Task 4 activities

Summary of Task 4 activities **Identification of sites and records with distinctive features**	Notes
Bibliographic search	see **Deliverable D8**
Preliminary analyses for the identification of anomalous sites based on strong-motion records and geo-morphological evidence	see **Deliverable D8**
Ground Motion Prediction Equations (GMPEs) derived form ITACA	see **Deliverable D14**
Analysis of strong motion records for identification of stations with distinctive seismic response	see **Appendix A – Deliverable D9**
Identification of stations with possible significant interaction effects with the hosting or surrounding structures	see **Appendix B – Deliverable D9**
Seismic monitoring of selected sites: Norcia basin	see **Appendix C – Deliverable D9**
Seismic monitoring of selected sites: Fucino basin	see **Appendix D – Deliverable D9**
Seismic monitoring of selected sites: Narni hill	see **Appendix E – Deliverable D9**
1D, 2D, 3D numerical modelling of seismic site response in the Gubbio basin	see **Appendix F – Deliverable D9**

1.2.5 Task 5. Seismic site classification of ITACA stations

This Task included an operational activity, i.e., the **seismic classification of ITACA stations** according to current seismic norms (EC8), and a research activity, aiming at **proposing and testing new criteria for seismic site classification**, including possible improvements of rock site classifications.

The first activity was carried out in parallel with Task 2. The following criteria were followed for classification:

1. assign the site class according to $V_{s,30}$, where available;
2. in all other cases assign the site class according to an expert judgment that jointly takes into account (i) the surface geology, (ii) the information collected from nearby sites, (iii) available geophysical information, including H/V spectral ratios from noise measurements and earthquake data.

In the latter case, it was decided to denote by a * the soil class, so to underline that the classification is not strictly based on the Vs profile. In addition, and in cooperation with Task 4, it was decided to support the topography classification of the station based on GIS analysis.

As a final result, 84% of the total ITACA station have been classified according to criterion (2), while the remaining 16% are classified based on $V_{s,30}$ (criterion (1)). Furthermore, practically all ITACA stations (98%) have been classified according to the topography class of Italian seismic norms, that is in agreement with the Eurocode 8 (Part 5 – Annex A).

A detailed presentation of the activities related to the seismic site classification of ITACA stations are reported in **Deliverable D10**, with related Appendices.

In parallel to the previous work for direct application to ITACA, a research activity to improve seismic site classification criteria was also carried out, based on the analysis of observations from a well documented set of recording stations, for which geophysical and geotechnical investigations were available. Two data sets were merged for this purpose: 63 RAN stations and 25 stations operated by the University of Basilicata. The complete data set of recording stations characterized by geophysical and geotechnical data is reported in the **Annex of Deliverable D13**. Several parameters correlated to the seismic response of a site were selected, such as the average shear wave velocity at different depths, depth to bedrock and resonant frequency obtained with different methods (1D theoretical response, HVSR from earthquakes and microtremors, H/V from acceleration response spectra).

To test the performance of the various classification schemes proposed in this work, compared to other soil classifications proposed in literature, a set of Ground Motion Prediction Equations (GMPEs) was derived. The error associated to each GMPE is evaluated in terms of total and inter-station standard deviation. The classification proposed in this project (UR-MI5 in Figure 11) gave the best results reducing the inter-station standard deviation (σ_{sta}) especially in the high period range. This activity is described in detail in the **Deliverable 13**.

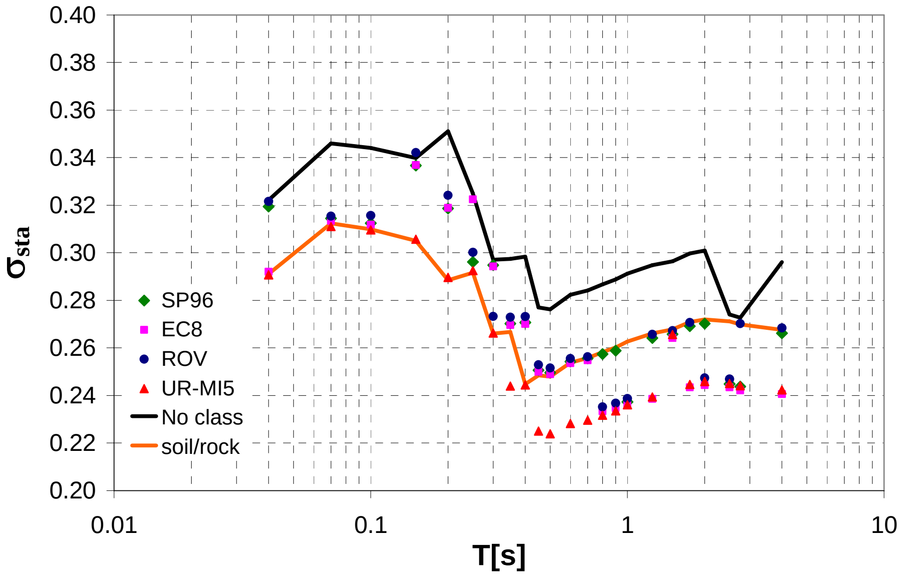


Figure11 - Inter-station sigma as function of period for the five classification schemes considered.

Finally, criteria for improved seismic investigations and site classification at rock sites were also planned within this Task, also based on the geomechanical characterization of the soil mass. However, the local geology at the various outcropping rock sites investigated within Project S4, described in detail in the **Deliverable D11**, revealed to be too much complex for this type of analysis. Therefore, the scope of the work was modified and attention was mainly focused to highlight the best procedures for low-cost seismic investigations at rock sites.

Summary of activities, problems and difficulties

The following table summarizes the progress of the activities planned within Task 5. Except for the modified scope for the improved classification at rock sites, all activities were finalized on time, without major problems. Note the addition of the topography classification of all ITACA stations, not initially planned. The summary of Task 5 activities and reference to the corresponding Deliverables is given in Table 10.

Table 10. Summary of Task 5 activities

Summary of Task 5 activities **Seismic site classification of ITACA stations**	Notes
Preliminary simplified classification criteria based on surface geology maps and check of applicability	see **Deliverable D4**
Revised site classification at recording stations based on the Italian and European seismic norms	see **Deliverable D5**
Seismic classification according to EC8 topography categories based on GIS analyses	Added wrt to initial workplan. see **Deliverable D5**
Improved classification of rock sites	Modified in scope. See **Deliverable D11**
Bibliographic search and selection of descriptive parameters for site conditions in addition to Vs,30	see **Deliverable D12**
Statistical analyses to check improved site classification schemes	see **Deliverable D13**
Synthesis of results and implementation in the database	

1.3 Deliverables

All Deliverables in the form of Technical Reports are available at the Project web site (http://esse4.mi.ingv.it). Only Deliverables due by the end of the Project are listed in this table. The other ones (D1, D3, D4, D6, D8, D12) were completed by the end of the first year of the Project.

With respect to the planned list of Deliverables, two additional Deliverables were added, namely:

– D14: including the new ground motion prediction equations calibrated within ITACA;

– D15: introducing the criteria for updated processing of ITACA records.

Furthermore, Deliverable D11 was limited in scope, taking away the part related to the identification of reference sites and records, that is still a controversial issue. Particularly, the analysis of the ITACA sites and records clearly highlighted that records of engineering relevance at sites not affected by important seismic amplification effects are still very few, if any. This is a major research issue, worth to be addressed in future projects.

Deliverable	Title	Notes
D2 *Responsible* RU1- INGV-MI	Final release of ITACA [ITACA v1.0]	*Completed and available at the web site: http://itaca.mi.ingv.it*
D5 *Responsibles* RU2-INGV-RM1 RU6-Uni-RM1	Catalogue of geological/geotechnical information at accelerometric stations	*Technical Report presenting the activities to prepare the station monographs in the format defined in Deliverable D3. The report contains 2 Appendices: (A) Handbook for describing and compiling the ITACA monographs; (B) Activities following the April 6, 2009, L'Aquila earthquake. All monographs produced in this Task are available in ITACA.*
D7 *Responsibles* RU4 – Poli-TO RU8 - GFZ	Application of surface-waves methods for seismic site characterization of ITACA stations	*Technical Report, summarizing the survey activities at more than ITACA stations. It includes a single Appendix: Description of the execution and interpretation on surface wave tests*
D9 *Responsibles* RU2-INGV-RM1 RU3-POLI-MI	Experimental and numerical results for all stations selected to study distinctive features of seismic response	*Technical Report presenting the research work carried out in Task 4. It includes 6 Appendices: (A) Analysis of strong motion records for identification of stations with distinctive seismic response; (B) Identification of stations with possible significant interaction effects with the hosting or surrounding structures; (C) Seismic monitoring at Norcia basin; (D) Seismic monitoring at Fucino basin; (E) Seismic monitoring and numerical simulations at Narni hill; (F) 1D, 2D, 3D numerical modelling of seismic site response in the Gubbio basin.*
D10 *Responsibles* RU2-INGV-RM1 RU6-Uni-RM1	Revised seismic classification of the ITACA stations, according to the EC8 and the Italian norms site classes	*This deliverable is provided as a Technical Report with 5 Appendices, including: (A) EC8 subsoil classification of ITACA stations based on surface geology; (B) NTC08 topographic site classification of ITACA stations; (C) EC8 subsoil classification of ITACA stations based on Vs profiles (Vs30); (D) Spectral classification of ITACA stations; (E) EC8 subsoil and NTC topographic classification of ITACA stations (version 3.0).*
D11 *Responsible*	Seismic characterization of stiff soil/ rock	*Technical Report with identification of problems and solutions for seismic characterization of outcropping bedrock sites.*

RU7-Uni-Siena	accelerometric sites from ambient vibrations monitoring	
D13 *Responsibles* RU1-INGV-MI RU5-Uni-BAS	Identification of new site parameters for improved seismic classification criteria	*Technical Report reporting research activities to improve seismic site classification criteria*
D14 *Responsibles* RU1-INGV-MI RU2-INGV-RM RU8-GFZ	Ground Motion Prediction Equations (GMPEs) derived from ITACA	*Technical Report, reporting the new GMPEs calibrated on the ITACA data, including records from the L'Aquila earthquake sequence.*
D15 *Responsibles* RU1-INGV-MI RU3-PoliMI	Record processing in ITACA	*Technical Report, reporting the updated procedure for record processing in ITACA*

1.4 Management

Project structure and interaction among RUs

The Project has enjoyed a strong cooperation among RUs, that was essential for the successful accomplishment of the various activities, with information and results from the various partners collected in the data exchange areas created in the Project web site, and then conveyed within the database.

A close and continuing cooperation with the staff of the Department of Civil Protection which operates the RAN was crucial to obtain updated information on records and stations, as well as for the development itself of ITACA.

The "backstage" work behind the construction and upgrade of the database was huge, and difficult to summarize in few lines, involving many meetings and discussions with the responsible of the software company IMteam, Andrea Spinelli, who was in charge of the development of ITACA

A further fundamental interaction of Project S4 was with the research group coordinated by Iunio Iervolino of the Department of Structural Engineering of the University of Naples Federico II, the cooperation of which produced the software REXELite.

Project meetings

Two plenary meetings were held in the second phase of the Project: the first one in Rome, during the general meeting of Projects S on 19-21 October 2009, and the second in Siena on 28-29 April 2010. An intermediate meeting was also held in Torino, on January 26, 2010, attended by all RUs, to establish the final procedures to convey in ITACA the results of seismic site surveys and of noise measurements.

Meetings were held with colleagues of other European countries to share experience for construction of the national strong motion databases such as with researcher of the Middle East Technical University of Ankara (December 2009) of the ETH Zurich (April 2010).

Dissemination

Since the very start of the Project, a significant effort has been paid to dissemination of Project activities and results, especially by presentations within national and international workshops and conferences. In the second year of the Project, also promoted by the L'Aquila earthquake occurrence, ITACA was introduced at several international conferences and workshop such as the ACES (Corfu) workshop on Performance-Based Seismic Design (July 2009), the 2nd Euro-Mediterranean Accelerometric Data Exchange and Archiving Workshop, Ankara (November 2009), the NERIES workshop on Improving Strong Motion Data for Engineering Applications, Lisbon (March 2010), and the 5th Int. Conf. on Recent Advances in Earthquake Geotechnical Engineering, San Diego (May 2010).

1.5 Problems and difficulties

During the early stage of development of ITACA, it was realized that several activities, not initially planned, were fundamental in order to improve the quality of data, the effectiveness of compilation of the information, and the tools for the queries in the database. Particularly, much care was devoted to:

- check of the record correction procedures and re-processing of all records according to uniform criteria;
- compilation of station monographs according to a dynamic module online;
- search of ITACA records based on spectral ordinates, that lead to the development of RexeLite, in cooperation with the University of Naples.

The accomplishment of such activities implied several changes in the working plan of the Project, as well as the occurrence of the Parma and, more crucially, of the L'Aquila earthquakes. The latter one provided a benchmark not only for the processing and distribution through ITACA of a huge amount of data, but also for all RUs of the Project, that were deeply involved in the post-earthquake phase, especially in the seismic monitoring activity and in the microzonation studies. On one side, this caused several delays in the specific activities of the Project, since an important fraction of the human power was devoted to the post-earthquake studies. Also the recording instruments, initially devoted to Project S4, were forcedly moved to L'Aquila and surroundings. On the other side, Project S4 provided the means to gather within ITACA much of the information obtained in the post-earthquake research, such as the records from the mainshock and aftershocks not only from the RAN stations but from temporary networks as well, and the inclusion within the ITACA monographs of the relevant information obtained at the most important stations that recorded the earthquake.

In spite of such major facts and changes occurred since the start of the Project, the scheduled activities were accomplished. Probably, the only important issue that is still unresolved at the end of the Project, is the inclusion within ITACA of the stations and of the related records of two important local networks in Italy, such as:

- Irpinia Seismic Network (ISNet): isnet.amracenter.com/
- Friuli Venezia Giulia Accelerometric Network: www2.units.it/dst/RAF06/RAF/index.html.

The link to these networks has been added in the ITACA home page. Furthermore, we did not receive several records, and the related information on the recording stations, belonging to ENEA (National Agency for Innovative Technologies).

One of the most relevant requirements at the start of the Project was to link ITACA to other worldwide strong motion databases. Such link has been fully accomplished with the database of the European Project NERIES (www.neries-eu.org/). However, the most important link of ITACA for engineering applications is the one with the COSMOS Virtual Data Center (http://db.cosmos-eq.org), a web portal through which the user may query and access worldwide strong motion databases. For this purpose, the ITACA records were recently converted into the COSMOS format, but the final link that is expected from the COSMOS side has not been activated yet when writing this report (see Appendix 1 of this report).

1.6 Conclusions, perspectives and open issues

Within Project S6 of the previous DPC-INGV 2005-07 agreement, and the present Project S4, the new Italian strong motion database was given birth. Given the ambition of the Project and the relatively short amount of time and resources invested, the delivery of the release 1.0 of the ITalian ACcelerometric Archive (ITACA) at the web site http://itaca.mi.ingv.it is *in se* an important event for all researchers and professionals involved in the broad range of activities related to the seismic risk mitigation.

The occurrence of the L'Aquila earthquake and the public availability, in a very short lapse of time from the earthquake, of the uncorrected records on the DPC web site and, after only a couple of weeks, of the records processed and organized in the ITACA web site, has definitely imposed ITACA as the reference Italian strong motion database not only at a national, but also at an international scale as well. This has also been witnessed by the words of appreciation coming from many authoritative sources in the world after publication of records in ITACA, such as from C. Stephens, of the US Center for Engineering Strong Motion Data (CESMD): " (...) By the way, members of the CESMD staff, both at the USGS and CGS, have commented on the effectiveness and level of station metadata, and the rapidity with which the Italian network collected and preliminarily processed the L'Aquila earthquake data". Furthermore, the implementation of the REXELite tool, to search records according to a specific target spectrum, has expanded the audience to professionals working in the field of earthquake engineering

The success encountered by ITACA, and the continuing accesses and download of records from a broad range of sources, imposes now several important needs that should be pursued starting right after the end of Project S4, in order for such successful efforts, jointly made by the staff of DPC with the installation and maintenance of the National strong motion network (RAN) and by the researchers of Project S6 and S4, *in primis* those of INGV Milano, not to be wasted. Namely:

- continuing maintenance and improvement of the database soon after the end of Project S4;
- development and completion of the evolution of ITACA in parallel with the completion of RAN, planned within 2011;
- closer connection between the management of RAN with that of ITACA.

Although many major achievements have been made throughout the Projects, ITACA needs a continuining development and upgrade of its various constitutive elements, such as: (i) tools for communication with the RAN and semi-automatic procedures for entering data and metadata (ii) completion and better characterization of the stations, (iii) improving the criteria and procedures for data processing, (iv) improving the database query procedures.

To achieve these objectives, it is the opinion of the Project S4 coordinators that a permanent operating structure be created, within the DPC-INGV agreement, managed under a technical and scientific multidisciplinary supervision, including both seismological and earthquake engineering well recognized experts. This development was also advocated by the International Evaluation Committee: "Create a permanent operational and administration environment and most important a stable funding for ITACA (given its international, multidisciplinary user base)", following the Rome meeting in October 2009:

As a second important step to strengthen the role of ITACA as a reference point for Italian strong motion data, multidisciplinary research activities should be promoted to exploit the dataset, aimed at improving knowledge on the seismic hazard and the earthquake ground motion, as a basic seismic input for microzonation and seismic design applications. Namely, such researches should include one or more of these issues:

- Integration of ITACA with other European databases as, for example, the Turkish strong-motion database, recently developed under the coordination of the Middle-East Technical University in Ankara, with a similar path as ITACA. This activity may also include the creation of a consortium in Italy for consultation and distribution of accelerometer data that includes local strong motion networks as well.
- Improvement of the selection tools of strong motion records for engineering applications, through the construction of accelerometer data set containing European and world records, chosen for their quality and which cover ranges of magnitude, distance, spectral ordinates, site conditions, etc. not documented by the Italian data.
- Refinement of predictive equations of motion and seismic criteria for seismic site classification, using the data set made available by ITACA and by other European and global databases.
- Development of reliable techniques for the generation of synthetic broad-band accelerograms, usable for various engineering applications, including: (i) generation of artificial strong motion records at rock sites for different ranges of magnitude, focal mechanisms, directivity conditions, etc.; (ii) determination of seismic input for the analysis of strategic structures, in the case of complex site conditions, such as proximity to the fault, alluvial basin effects, etc.).

1.7 Selected publications

ITACA web site
ITalian ACcelerometric Archive: http://itaca.mi.ingv.it.

Albarello D., Lunedei E., 2009. On the feasibility of surface waves approximation to interpret ambient vibrations wave field. Socco V. and Campman X. (eds.) “Surface wave analysis for exploring at different scales”, WS 7, 71st EAGE Conference and Exhibition, Amsterdam, The Netherlands, 80-84.

Albarello D., Lunedei E., 2010. Alternative interpretations of Horizontal to Vertical Spectral Ratios of ambient vibrations: new insights from theoretical modeling. *Bull. Earthq. Engng*., **8**(3), 519-534.

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Attolico A., M.R. Gallipoli, P. Harabaglia, V. Lapenna, M. Mucciarelli, A.B. Rosa, 2010. A review of the activity of two accelerometric networks in Basilicata (Italy), in press on *Bullettin of Earthquake Engineering*, doi: 10.1007/s10518-009-9129-2

Bindi D., Pacor F. , Luzi L., Massa M., G. Ameri, 2009. The Mw 6.3, 2009 L’Aquila earthquake: source, path and site effects from spectral analysis of strong motion data. Geophys. J. Int. **179**, 1573–1579.

Bindi D., Luzi L., Pacor F., 2009. Interevent and Interstation Variability Computed for the Italian Accelerometric Archive (ITACA). *Bulletin of the Seismological Society of America*, **99**(4), 2471–2488.

Ditommaso R., M. Mucciarelli, M. R. Gallipoli, F. C. Ponzo, 2010. Effect of a single vibrating building on free-field ground motion: numerical and experimental evidences, *Bullettin of Earthquake Engineering*, **8**, 693-703

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1.8 Appendix A - The Italian strong motion data base (ITACA) in the COSMOS project. Data conversion routines and the current state of progress.

1.8.1 Goals of the COSMOS project

One of the major objectives of COSMOS (http://db.cosmos-eq.org) is to promote the advancement of strong-motion measurement in densely urbanized areas and other locations of special significance to a society likely to be struck by future earthquakes. Membership in COSMOS is open to all agencies, organizations, private companies and consultants, professional institutions, professional societies, and universities. As of today, partners from many nations have joined the COSMOS project, providing data about earthquakes occurred in their areas of interest. In the course of Project S4, INGV and DPC have planned to join the COSMOS project, sharing the ITACA strong motion data. For this purpose, several meetings occurred between the coordinators of Project S4 with the scientific coordinators of COSMOS, Prof. Ralph Archuleta and Dr. Jamison Steidl of the University of California, Santa Barbara. This short report summarizes the current state of the activity to link ITACA to COSMOS.

1.8.2 The ITACA and COSMOS data formats

In ITACA, records are stored in ascii files, with a small header containing only essential information about the event, the station, and the instrument. Further details are stored within a relational database. The data base stores all information regarding the seismic events, the recording stations, the installed instruments, the main features of the recordings and the engineering parameters.
In COSMOS project, the format of data is based exclusively on a flat-file storage model. In short, COSMOS formatted data are self-conclusive as they contain detailed information about the event, the station, and the instrument. Each data file consists of a header followed by data. More specifically, a file contains a header and data for a single component of motion and for a single type of data (acceleration, velocity, displacement, etc.) The data header itself has three sections (text, integer and real), each of which contains information of the corresponding type. The Text Header provides intrinsic text information (names, descriptions, etc.) and allows a readable quick introduction to the file.

1.8.3 Conversion routines

Since the data file formats are different, custom conversion software has to be written and executed to "translate" the ITACA information into the target format, that is the newest COSMOS version 1.20. Following the ITACA and COSMOS (http://www.cosmos-eq.org/menu/2_Publications/cosmos_format_1_20.pdf) documentations, the ITACA staff has prepared and tested custom automatic routines for data conversion (*itaca2cosmos*). The software is written in the Perl programming language, following strict syntax directions and using the official Perl Data Base Interface (DBI) for interacting with the ITACA MySQL database.

1.8.4 The current progress of the ITACA-COSMOS activity

At the time of this writing, conversion software is ready and has been tested against the current set of ITACA data. Moreover, the ITACA network administrators have been informed of the project and are ready to set-up a network link allowing the COSMOS servers to crawl the data. However, since ITACA has just undergone its release 1.0 at the end of Project S4, with a substantial amount of new and more accurate metadata about stations and instruments, and, at the same time, the COSMOS staff is involved in a demanding post-earthquake activity after the M7.2 Baja California earthquake occurred on April 4 2010, it was jointly decided to delay the last step of the project (i.e., the actual file transfer), that will be worked out likely by the end of September 2010. At that time, the *itaca2cosmos* conversion routines will be executed again after the database update, and network access to the new data set will be allowed upon request from the COSMOS staff.

Section 2: Report on project S4 by RU Responsibles

1 Report on the project activities by RU1 INGV-MIPV

Responsible: Lucia Luzi, Istituto Nazionale di Geofisica e Vulcanologia, Milano-Pavia

1.1 Activity of RU1 in phase 2

The UR Milano – Pavia participated to all tasks necessary for the completion of the project. The activity, as well as in the report of phase I, will be summarized task by task.

Task1 ITACA update

The final version of the database, ITACA 1.0, has been released as originally planned (Deliverable 2). To date, a total of about 3900 uncorrected 3-components accelerometric records, 2900 of which are also available in the corrected form, are actually included in ITACA spanning in the magnitude range from 1 to 6.9 and epicentral distance from 0 to 600 km.

The waveforms collected in ITACA were recorded by 726 strong-motion stations, 312 of which are presently not in operation, since they were part of temporary networks or equipped with analogue instruments, which were dismissed.

A useful engineering tool has been added, REXELite (Iervolino et al., 2009), which is a simplified version of the software formerly released in the framework of the RELUIS projects (http://www.reluis.it). This application allows the search of combination of natural strong motion records compatible with the spectra of the Italian Building Code (NTC '08) and the EUROCODE 8, or defined by the user.

The Italian strong-motion database has been included in two international initiatives: the EU project NERIES (Network of Research Infrastructures for European Seismology, http://www.neries-eu.org/) and the COSMOS consortium (Consortium of Organizations for strong motion observation systems, http://www.cosmos-eq.org/). Figure 1 shows an example of the NERIES portal with a focus on the Italian data.

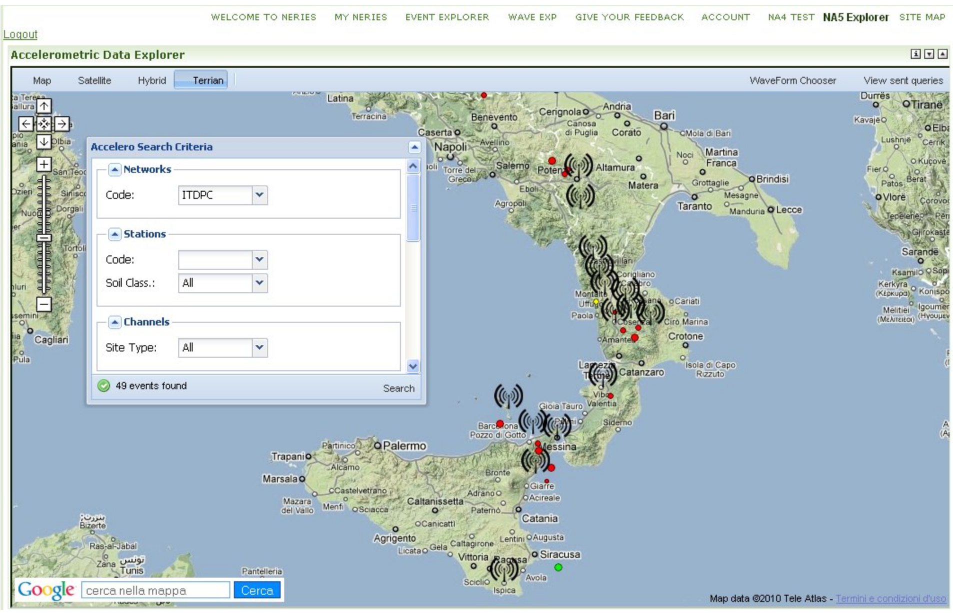

Figure 1: Italian strong motion data in the NERIES portal

Task 2 Geological-geotechnical catalogue of ITACA sites

The research unit was involved in this task for establishing a procedure for the automatic generation of station reports at the user request and calculating the resonance frequency of about 150 recording sites from ambient noise records.
The first activity required a remarkable effort, as the tables of the relational database had to be modified to include several fields for the storage of images (photos, geographic location and geologic maps of each station) and a report including the geotechnical and geophysical investigations. This procedure ensures the perfect alignment between the reports and the information contained in the database.
In order to characterize the seismic response of the recording stations, the fundamental frequency was evaluated from the horizontal to vertical spectral ratio (HVSR) of the microtremor measurements.
The fundamental frequency was evaluated following the criteria proposed in the SESAME project (Bard, 2002) and an automatic procedure was established to evaluate the band width associated to the fundamental frequency. Only the results with good reliability have been entered in the database (collaboration to Deliverable 5). The results of the steps described above are shown in Figure 2.

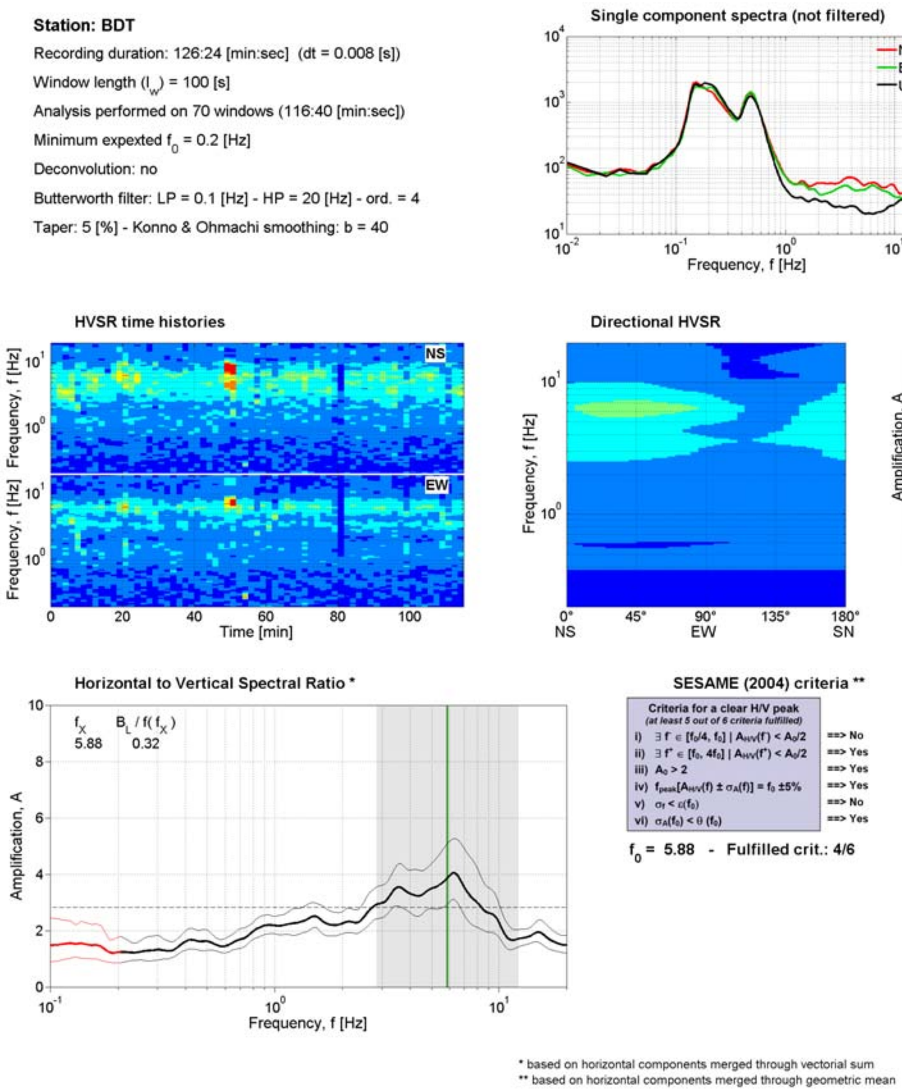

Figure 2. HVSR of the microtremor measurements for the station Badia Tedalda (BDT)

Task3: Site characterization by surface waves methods

The RU collaborated with GFZ in the evaluation of the shear wave velocity profiles of 12 recording sites (collaboration to Deliverable 7), located in Abruzzo, Basilicata, Emilia Romagna and Umbria regions. For each site the Rayleigh wave dispersion curve was estimated considering the vertical component of the recorded microtremors. In particular, the Extended Spatial Auto Correlation (ESAC; Ohori et al., 2002) and the Frequency-Wavenumber (FK; Lacoss et al., 1969) methods were adopted. Both high-quality Rayleigh wave dispersion and *H/V* ratio curves were used for a joint inversion scheme, as proposed by Parolai et al. (2005 and 2006), to estimate the local S-wave velocity profile. Figure 3 shows the result for the CTL station: the selected shear wave velocity model (curve with the best fit, white line in Figure 3), the dispersion curve, the fit to the dispersion curve and the H/V ratio are also shown.

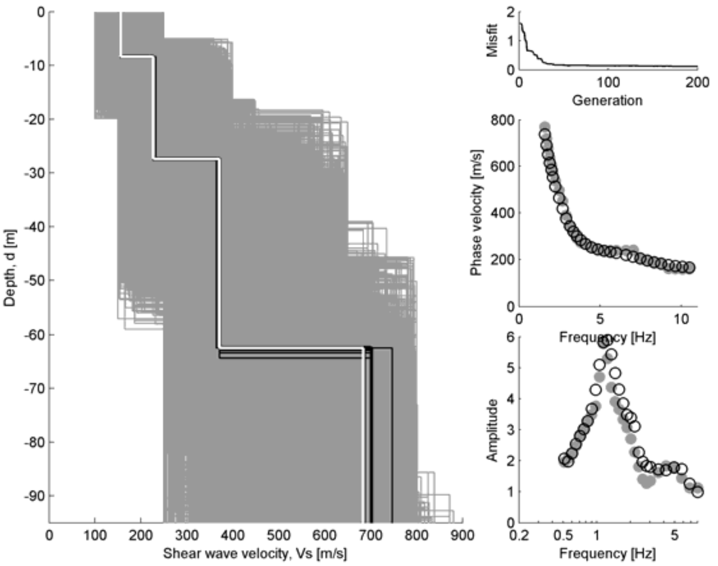

Figure 3: Shear wave velocity model at the CTL station (left) and fit to the dispersion and H/V ratio curves (right). Grey lines are the tested models, white line is the minimum cost model, while black lines are models lying inside the minimum cost + 10% range.

Task 4: Identification of anomalous sites and records

The RU was involved in this task in the monitoring of the Narni hill (Figure 4) and in the collaboration with GFZ to the installation of a temporary network in the Norcia plain (Figure 5), both located in central Italy. Two different temporary networks, consisting in velocimetric sensors coupled with high dynamic digitizers, were set up for about four months. The two networks were operative during the L'Aquila seismic sequence and a relevant amount of aftershocks was recorded. The Narni data set is formed by 9744 waveforms relative to 706 events in the magnitude range 1.5 – 5.8, recorded from March to September 2009. Site amplifications related to the ridge morphological features were investigated through empirical techniques which consider a reference site (Spectral Standard Ratio, SSR) or a single station (Horizontal to Vertical Spectral Ratio, HVSR). Directional spectral analyses were also performed. The results of the SSR technique show an amplification factor up to 4.5 with

respect to the reference station. The highest amplification level (almost two times) was observed along the direction perpendicular to the major axis of the ridge.
In the Norcia plain the array was build using 15 EDL 24bit digitizers, with GPS timing, coupled with short-period Mark-L4-C-3D 1Hz sensors and it was operative from January to May 2009. At the moment a set of 80 earthquakes, occurred before L'Aquila sequence, has been extracted and analyzed. HVSR and SSR have been calculated on windows encompassing the S-wave arrival, which have been visually selected. In general there is a good agreement between HVSR and SSR: the Norcia plain amplifies low frequencies, in the range between 0,4 – 2 Hz, depending on the position of the sites inside the plain. Further analysis is hoped to better understand the mechanism of seismic amplification in this area.

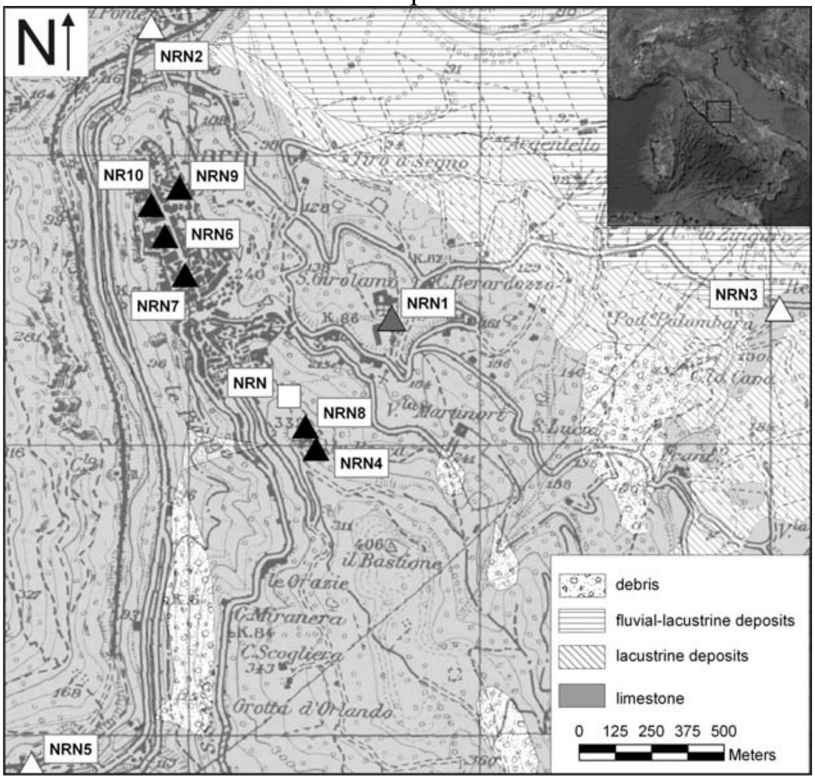

Figure 4: configuration of the temporary network installed in the Narni hill.

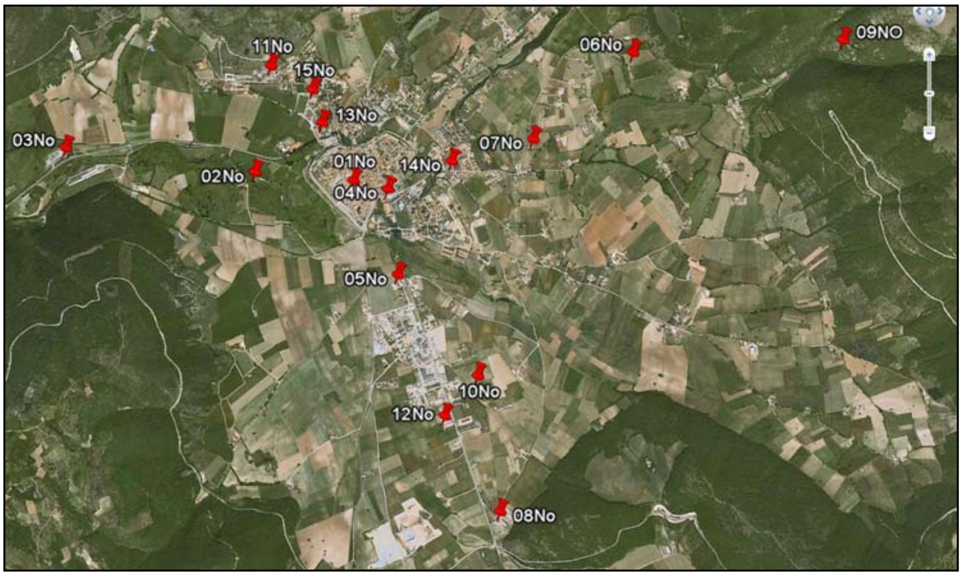

Figure 5: configuration of the temporary network installed in the Norcia plain.

The identification of anomalous sites and records has been performed to calculate the errors between the observed ground motion at the sites and the predictions of GMPE developed using a ITACA sub set. The philosophy behind this work is to classify the ITACA sites according to the soil classes used in the GMPE and verify whether the sites fit or exceed the average response spectra ordinates of the respective class.
The site have been classified according to different schemes (see deliverable 13) and the proposed analysis allows to identify station peculiarities. In Figure 6 the normalized error in function of the period is shown for significant stations of the ITACA database.

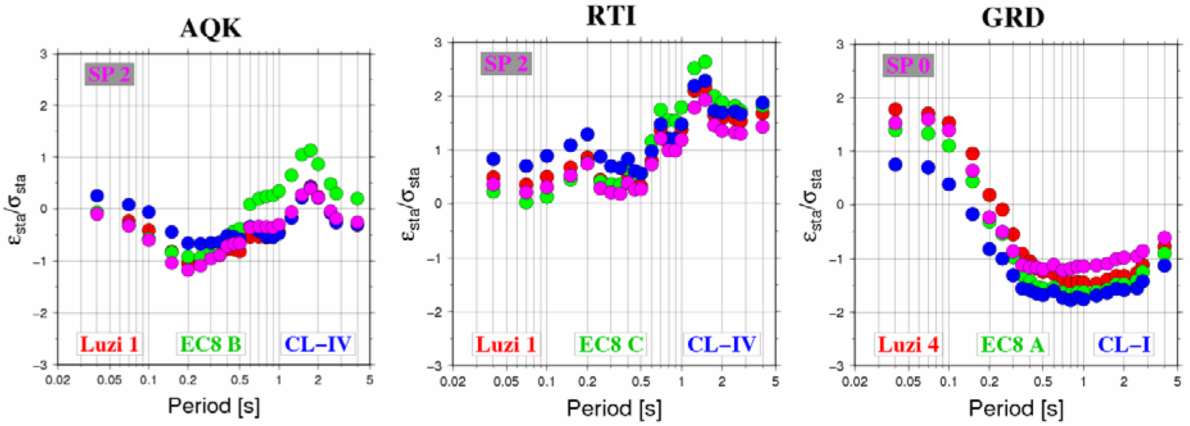

Figure 6: normalized error in function of period for stations Valle Aterno Aquilpark (AQK), Rieti (RTI) and GRD (Guardiagrele)

A further study performed within this task regards the topographic classification of the ITACA recording stations. It was achieved through an automatic procedure implemented into a GIS (ArcGis, ESRI®). The stations have been classified into four categories (from T1 to T4), as indicated in the Italian seismic code and Eurocode 8 (NTC08 and EC8). About 660 stations have been classified and the results have been included in the station reports (Task 2). The activities described above have been included in the Deliverable 9.

Task 5: Site classification

One of the goals of this task is to find a "low-cost" classification method, which allows to subdivide the ITACA recording stations into a limited number of soil classes to be introduced in a ground motion prediction equation. This study approaches the site classification issue by a direct analysis of observations. We collected a set of well documented recording stations, characterized by geophysical and geotechnical investigations, merging two data sets: a set of 63 stations belonging to the RAN and a set of 25 stations managed by the University of Basilicata. A set of parameters correlated to the seismic response of a site were selected, such as the average shear wave velocity for different depths, depth to bedrock and resonant frequency obtained with different methods (1D theoretical response, HVSR from earthquakes and microtremors, H/V from acceleration response spectra). A cluster analysis was performed to individuate the soil classes from the observations and the best combinations were found for the couple $Vs_{,30} - f_0$ and the resonant frequency, f_0,alone. Figure 7 shows the data clusters.

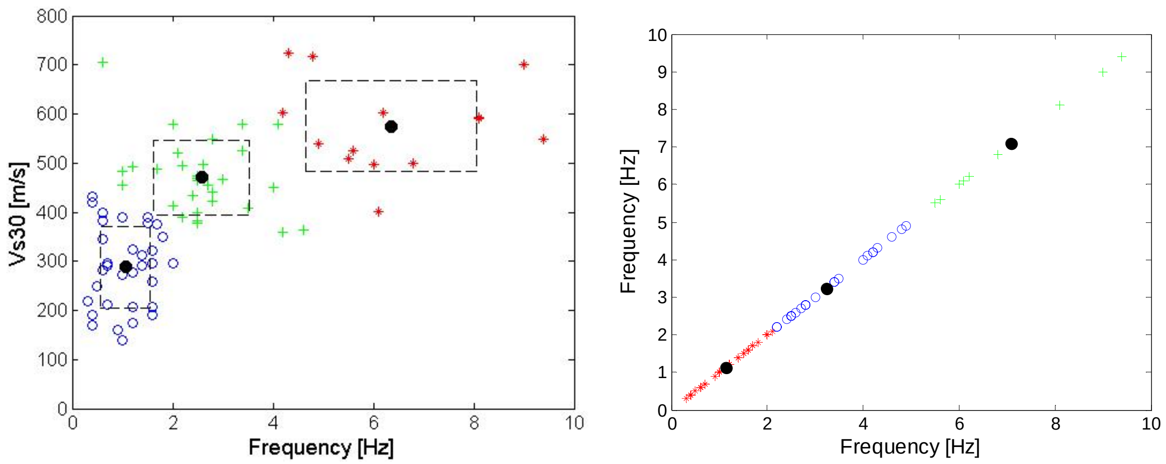

Figure 7: three clusters obtained from the combination of $Vs_{,30}$ – f_0 (left) and f_0 (right)

The recording sites have been then classified by calculating the degree of membership to each of the individuated class, in terms of probability density. Table 1 displays the f_0 ranges used to classify the RAN stations. Two classes are independent on f_0, namely the rock sites, with flat response over the entire frequency band, and class 5, characterized by multiple amplitude peaks on the entire frequency band.

Table 1: soil classification proposed in this work (Pd is the probability density)

Soil class	Description	Parameters
1	Pd1 > Pd2 > Pd3	mean f_0 = 1.1341; std f_0 = 0.5285
2	Pd2 > Pd1 and Pd2 > Pd3	mean f_0 = 3.2269; stdf_0 = 0.8702
3	Pd3 > Pd1 and Pd3 > Pd1	mean f_0 = 7.0800; std f_0 = 1.4459
4	Flat response amplitude < 3 over the entire range	
5	Multiple peaks and amplitude > 3 over a broad period range (0.1 – 1 s)	

In order to test the performance of this classification, and compare it with different soil classifications proposed in literature, we derived a set of GMPEs, from a common data set of the 5% damping acceleration response spectra in the period range 0.04 – 4 s. The adopted soil classifications are: i) soil /bedrock; ii) Sabetta and Pugliese (1996); iii) Ec8 and iv) D'Alessandro et al.(2008). The error associated to the GMPE is evaluated in terms of total and inter-station standard deviation.

The classification proposed in this project (UR-MI5 in Figure 8) gave the best results reducing the inter-station standard deviation (σ_{sta}) especially in the high period range.

This activity is described in detail in the Deliverable 13.

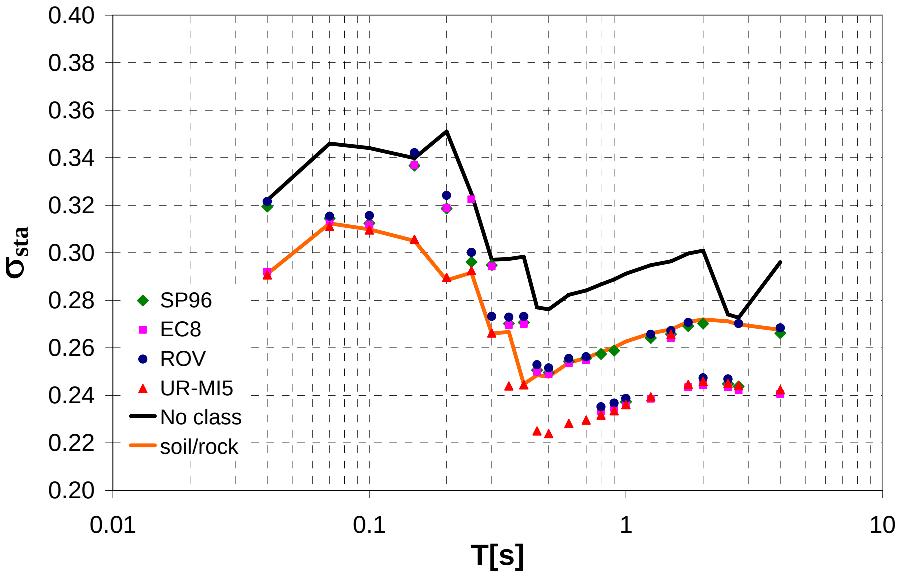

Figure 8: inter-station sigma as function of period for the five classification schemes considered.

An additional activity, transversal to task 4 and task 5, was carried out, that is the calibration of ground motion prediction equation (GMPE) from the updated ITACA data set. The prediction regards peak ground motion parameters, such as peak ground acceleration and velocity and acceleration response spectra calculated at 5% damping. The data set is composed by 1213 records relative to 218 earthquakes and 353 recording stations, in the magnitude range 4 - 6.9 and distance range 200. The recording sites have been classified according to the EC8, as resulting from task 2. Details on the data set, functional form and the coefficients of the regression are described in the Deliverable 14.

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1.2 Deliverables

Deliv.	Original description	Role of the UR
D2	Final release of ITACA (version. 1.0)	The UR was the responsible of this deliverable, for the verification and release of the final version of the database (web site)
D5	Catalogue of the geological / geotechnical information at accelerometric stations	The UR collaborated to this deliverable in the evaluation of the fundamental frequency from microtremor measurements
D7	Application of surface – waves methods for seismic site characterization of ITACA stations	The UR collaborated to this deliverable in the analysis of the array measurements of the stations located in Emilia Romagna region
D8	Identification of ITACA sites and records presenting anomalies in the seismic response	The UR collaborated to this deliverable analyzing the ITACA data set to identify the stations with peculiar behaviour.
D9	Experimental and numerical results for all stations selected to study the effects of anomalous site conditions	The UR collaborated to this deliverable in the spectral analysis of the experimental data of the Narni hill.
D10	Revised seismic classification of the ITACA stations, according to the EC8 and the Italian norms site classes	The UR collaborated to this deliverable in the topographic classification of the recording stations, according to the Italian norms.
D13	Identification of new site parameters for improved seismic classification criteria	The UR was the responsible of this deliverable, for calculating the site parameters and develop and test a new soil classification
D14	Calibration of new ground motion prediction equations from the ITACA database	The UR was responsible of this deliverable for the preparation of the input data and the implementation of the regression analysis

1.3 Problems and difficulties

In the second phase the delays accumulated during the first phase, due to extra-work caused by the occurrence of L'Aquila sequence, had to be faced and solved. On the other hand, the scientific results of the project benefit from L'Aquila data set. First of all in terms of relevant waveforms in the near fault area, which represent a patrimony not only for the Italian, but also for international data sets. Then, several investigations were conducted in the epicentral area and new geological, geophysical and geotechnical data were collected. These data have been used in several analyses: i) derivation of a new soil classification, ii) identification of anomalous sites and iii) derivation of ground motion prediction equations for Italy.
Another important modification to the original plans was the automation of the station reports which required a relevant change in the database and in the software applications resident in the web server.
An issue we had to face was represented by the relations with the population resident in the sites investigated with the temporary arrays (Narni and Norcia). In origin it was planned to leave the arrays for about two-three months, but, after the occurrence of L'Aquila event, we had to ask people to leave the stations for a longer time. We want to underline that the collaboration of the population involved was excellent.

1.4 Publications

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Luzi L., Gallipoli M.R., Pacor F., Mucciarelli M., 2009. Characterization of Italian strong-motion recording sites in the perspective of a new soil classification. Abstract presented at the DPC-INGV 2007-2009 General Meeting S-Projects, Roma 19-21 October

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Massa M., Bindi D., Luzi L., Pacor F., Ameri G., 2009. Confronto tra equazioni predittive del moto del suolo a scala regionale, nazionale e globale e dati accelerometrici italiani. Abstract presented at the Conference of the Gruppo Nazionale Geofisica della Terra Solida, Trieste (Italy), 16 - 19 November 2009.

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Pacor F,. Paolucci R, .S4 RUs, 2009. Contributions from Project S4 to the investigations on the L'Aquila earthquake. Abstract presented at the DPC-INGV 2007-2009 General Meeting S-Projects, Roma 19-21 October

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Paolucci R., Pacor F., Puglia R., Ameri G., Cauzzi C., Luzi L., Massa M., 2009. Problems and solutions for processing strong-motion records in the Italian ITACA database. Abstract presented at the DPC-INGV 2007-2009 General Meeting S-Projects, Roma 19-21 October

Pessina V., Fiorini E., Paolucci R., 2010. GIS-Based Identification of Topographic Sitesin Italy with Significant Ground Motion Amplification Effects. 5th Intern. Abstract presented at Conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics and Symposium in honor of professor I. M. Idriss, San Diego, CA, May 24-29

Pessina V., Paolucci R., Fiorini E., Giorgetti S, 2008. GIS-based topographic classification of ITACA recording stations, Abstract presented at the *DPC-INGV 2007-2009 General Meeting S-Project*s, Roma 19-21 October

Working Group ITACA, 2009. Data Base of the Italian strong motion records: http://itaca.mi.ingv.it

2 Report on the project activities by RU2 – INGV RM

Responsible: Giuliano Milana, Istituto Nazionale di Geofisica e Vulcanologia, Roma.

2.1 Activity of RU in phase 2

In phase 1 the RU2 was involved in three of the five tasks of the project, namely in Task2, Task4 and Task5. In this section follows a synthetic description of the activities sorted by task.

2.1.1 Task 2

The new ITACA Monograph: compiling phase

The activities carried out within Task 2 were aimed to collect, organize and synthesize geological, geomorphologic, geotechnical and geophysical data for the RAN stations sites, and to improve the knowledge about the subsoil permitting a site classification based on EC8.
This activity continued in the second phase of the project. The monographs compiled by SOGIN for 136 stations in 15 of the 20 Italian regions were recovered. The RU2 was responsible for uploading all these monographs into the S4 project online warehouse (http://esse4.mi.ingv.it), so that they could be available to all RUs.
Subsequently, the RU2 contributed to the development of one online form for the dynamic compilation of the new ITACA monograph and its testing. The online form allows transferring all the information collected in the ITACA database into a remote system that provides the automated preparation of the station monographs. This system was specifically requested by the international evaluation committee. It turned out to be an important and widely used tool in the project also essential in the future for updating the already available monographs and / or to compile the new ones. Moreover, the RU2 contributed to the compilation of new monographs made both using the information already available or collected in previous S6 project, and preparing new topographical and geological maps, respectively at 1:25,000 and 1:100,000 scale. Overall, RU2 compiled 77 monographs, using the new standard format. Among these, 57 monographs refer to the accelerometric stations that recorded the April 6th L'Aquila Earthquake.
All data were uploaded into the online ITACA database using the web form, with the exception of those related to the stations that recorded the Irpinia-Basilicata 1980 Earthquake. In this case monographs were compiled in the first phase, before the introduction of the form; anyway also these monographs are available on the ITACA web site.
In addition, the topographic characteristics of the sites have been analyzed using Google Earth and defining 8 morphological situations (Plain, Valley centre, Valley edge, Alluvial fan, Saddle, Slope, Edge of scarp, Ridge). This feature has been provided in the monographs related to 174 stations (figure 1). For the 174 above mentioned stations the possible presence of landslides was also provided by consulting the maps produced by the IFFI Project (Inventory of Italian Landslides: http://193.206.192.244/cartanetiffi/).

Subsoil and topographic classification of the ITACA sites

These activities were requested by the project coordinators in order to provide an early version of the site classification of the accelerometric stations and to enable to interface the ITACA database with the software REXEL, that allows selecting, in terms of magnitude and epicentral distance, natural accelerograms compatible with the "Norme Tecniche per le Costruzioni" (NTC2008) and the EUROCODE 8 (EC8) spectra.

At the end of the project 689 stations have been classified using a hybrid approach, based on surface geology, spectral classification and Vs profiles derived from many possible approaches (DH, CH, MASW, ESAC). The RU2 has created a Microsoft Excel Database which also keeps track of all changes that have been made since the beginning in terms of site classification.
The database contains the following fields:
- Station code.
- Latitude (N).
- Longitude (E).
- Altitude (m a.s.l.).
- EC8 site classification based on surface geology (vers. 1.1).
- EC8 site classification based on surface geology (vers. 2.0).
- Vs30 (m/s).
- Notes Vs30.
- Depth to bedrock (m).
- Vs to bedrock (m/s).
- Fo, calc (Hz).
- F0, exp (Hz).
- Spectral classification (single or multiple recordings).
- EC8 site classification (vers. 1.1).
- EC8 site classification (vers. 2.0).
- EC8 site classification (vers. 3.0).
- Morphological situation.
- EC8 topographic classification (vers. 1.0).
- Presence of landslides from IFFI project.
- General notes.

Since it was necessary to provide the classification for all ITACA stations, a first attempt based on geological data available at a homogeneous level for all the sites was made. This goal was achieved through the use of a lithological map at a national scale, produced by INGV. This map derives from the Geological Map of Italy at 1:100,000 scale by grouping the geological formations in terms of EC8 subsoil classes, based on lithological and geological age criteria. The resolution of this instrument does not give a detailed result, but it certainly allows a first level of knowledge. In the second phase of the project an upgraded version (ver. 2.0) of a previous map has been produced.

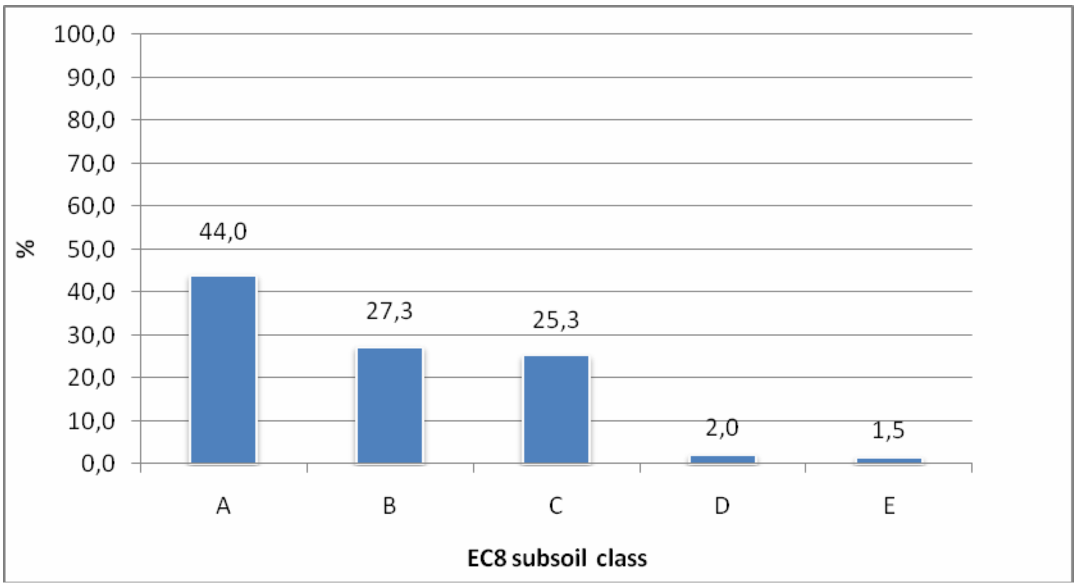


Figure 1) Distribution of the EC8 subsoil classes evaluated for 689 ITACA station sites.

The site classification based on the geological map was subsequently "corrected", for the stations where detailed geological data, a geological "expert" evaluation, a flat H/V spectra from earthquake recordings (classified as CL-V by Di Alessandro et al., 2008, see also §2.1.4 of this report) were available. At the end of the second year activity the site classification, version 3.0, according to the EC8 subsoil categories, has been produced for all ITACA stations. It will be used in the ITACA-REXEL interfacing. In the figure 1, the distribution of the EC8 subsoil classes for the 689 ITACA sites is shown.
Finally, an evaluation of the topographical classification using the 4 classes (T1, T2, T3, T4), provided by NTC2008, has been also produced for 174 stations. This classification has been obtained using a "manual" approach, based on topographic maps and Google Earth (Figure 2).

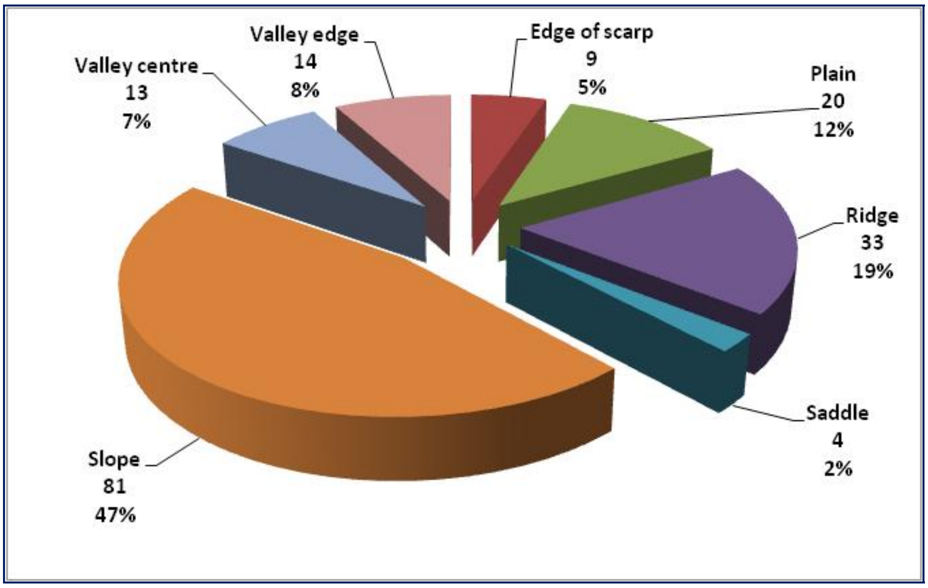


Figure 2) Distribution of the morphological situations evaluated for 174 ITACA station sites.

Activities after the L'Aquila Earthquake

After the April 6, 2009 earthquake many activities were conducted in the area of L'Aquila to check for the local geology and morphological characteristics of the stations that recorded the mainshock. A report of these activities is available in Di Capua et al., (2009) (http://esse4.mi.ingv.it/images/stories/Classificazione_Sito_Stazioni_RAN_AQ.pdf).
In order to better understand the seismic response of the epicentral accelerometric stations AQG, AQA and AQV, a geological SW-NE cross of the Aterno River Valley was drawn. It has been realized using surface and borehole geological data already available or collected during the phase 2 by RU6. The section shows the presence of Quaternary alluvial deposits, with a thickness not exceeding 50 m, filling a river valley excavated in Mesozoic limestones. In the case of AQG station (Colle dei Grilli) these limestones are highly fractured and sometimes tectonized.

2.1.2 Task 3
The activities of the RU2 in Task 3 will contribute to the Deliverable 7 that presents some application of surface-waves methods to the seismic characterization of selected ITACA sites.

The RU analysed seven ITACA sites with a big variability of surface geology conditions, including deep and shallow soft sediments and stiff soils. For all the selected sites 1D (active and passive) MASW investigations were performed, for deeper sites also a 2D passive approach, with array geometries chosen according to the required depth of investigation, was followed. For 1D array a 72 channels instrument was deployed using 4.5 Hz. vertical geophones. Passive 2D data were recorded using 12 or 13 stand alone high resolution seismic data loggers linked to high sensitivity seismometers with a frequency response band extended to 0.2 Hz. in order to investigate properly the low frequency range. Advanced kinematic GPS techniques were applied for an accurate positioning of 2D array sensors. The data were analysed using several software and numerical algorithms (conventional f-k, high resolution f-k, MSPAC) in order to verify the influence of the analysis techniques on the obtained results. Additional HVNSR measurements allowed to infer extra information on the site behaviour (1D or 2/3D) and on the site resonance frequency fo. As a result of the performed investigations a table with shear wave velocity, thickness of surface sedimentary layers and VS30 were produced. All the collected information can be inserted in the ITACA sites monographs.

2.1.3 Task 4

The seismic monitoring of the Fucino Basin (Central Italy) was accomplished by the operation of the network based on 18 stand alone seismic stations installed during the phase I of the project (Figure 3).

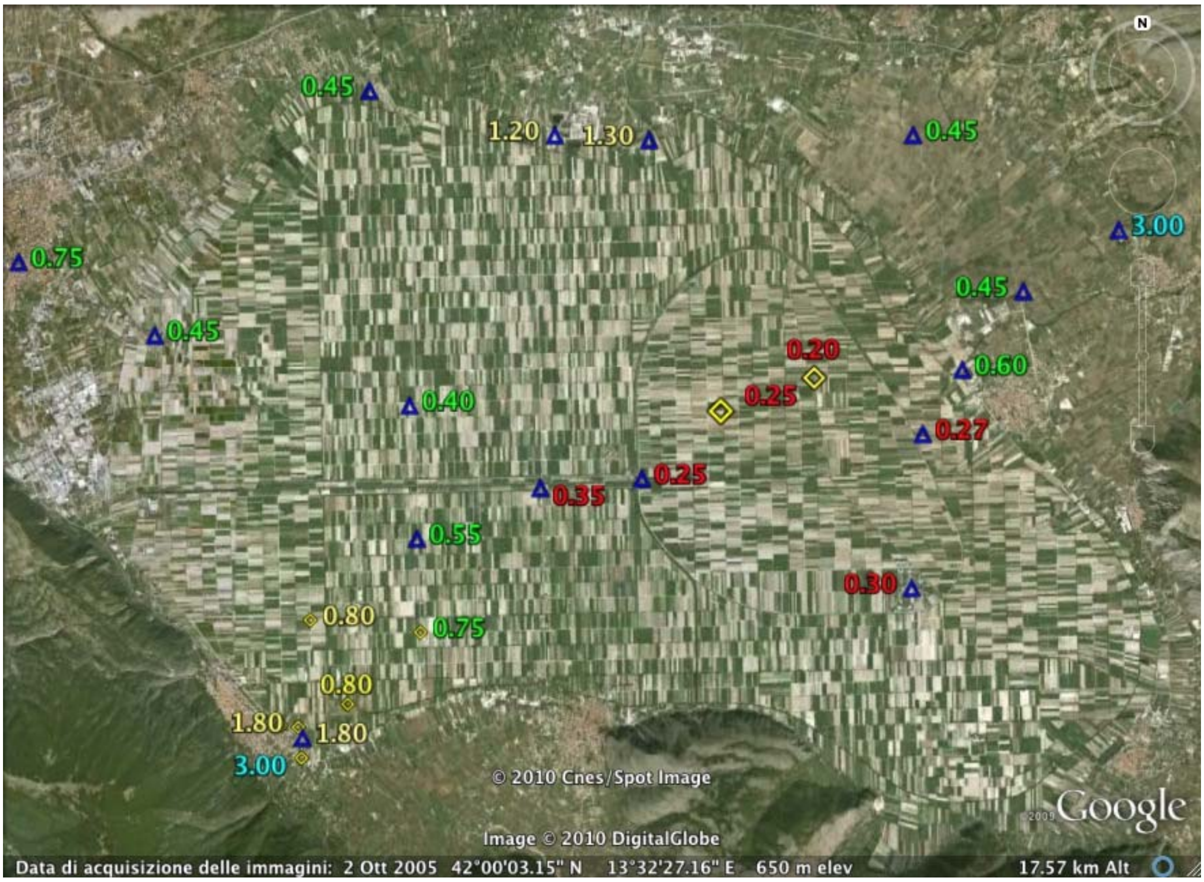


Figure 3) Resonance frequency in the Fucino Basin as derived using the monitoring network data. Blue triangles indicate the network stations. Yellow diamonds short microtremor measurements. Labels refer to the fo values.

The stations performed properly until the end of the acquisition time in September 2009 recording a big amount of local and regional seismic events including the sequence of

L'Aquila (April 6th, 2009) earthquake. The application of HVNSR, HVSR and SSR techniques allowed obtaining important information both on the resonance frequencies and on the amplification factors and on their variability inside the basin. The collection of many available information about the deep structure of the basin (deep seismic surveys, deep water well) allowed to calibrate the results obtained using seismic data and to put some constraint on the share waves velocity (Vs) in the area. Through the combined use of all the available data it was possible to reconstruct a velocity model based on an exponential grows of Vs with depth along a SW – NE section covered by the stations of the monitoring network. In this approach the depth of bedrock was derived from borehole data, the resonance frequency of the sedimentary layer from spectral ratio technique, surface shear waves velocity from available geotechnical data. Once known the above mentioned parameters it is possible to evaluate the exponential law and to apply it in areas where no information is given about the depth of bedrock. To better define the chosen section some extra microtremor measurements were performed along the section itself and in other sectors of the basin. HVNSR and surface wave analysis were also done at the ITACA stations operating in the area (Avezzano, Ortucchio and Borgo Ottomila). As an example of the performed analysis we show in figure 3 the resonance frequency fo distribution in the basin.

2.1.4 Task 5

The ground motion predictive equations (GMPE) formulated in the first year of activity using different criteria of site classification are applied in a new Deliverable (D14), not planned at the beginning of the project. The aim of D14 was to discuss the different method used for site classification, and the novelty character of new proposals based on the spectral properties of stations. In particular, this UR proposed the use of the predominat period in H/V spectral ratios of 5% damped response spectra as a discriminating parameter for the attribution of site classes. Figure 4 summarizes the seven classes proposed by this UR. In Deliverable D14 the performance of conventional (soil/rock and EC8) criteria are compared with classifications using spectral characterization of sites. We demonstrate that the best performance is achieved when a limited number of classes is adopted based on the predominant frequency.

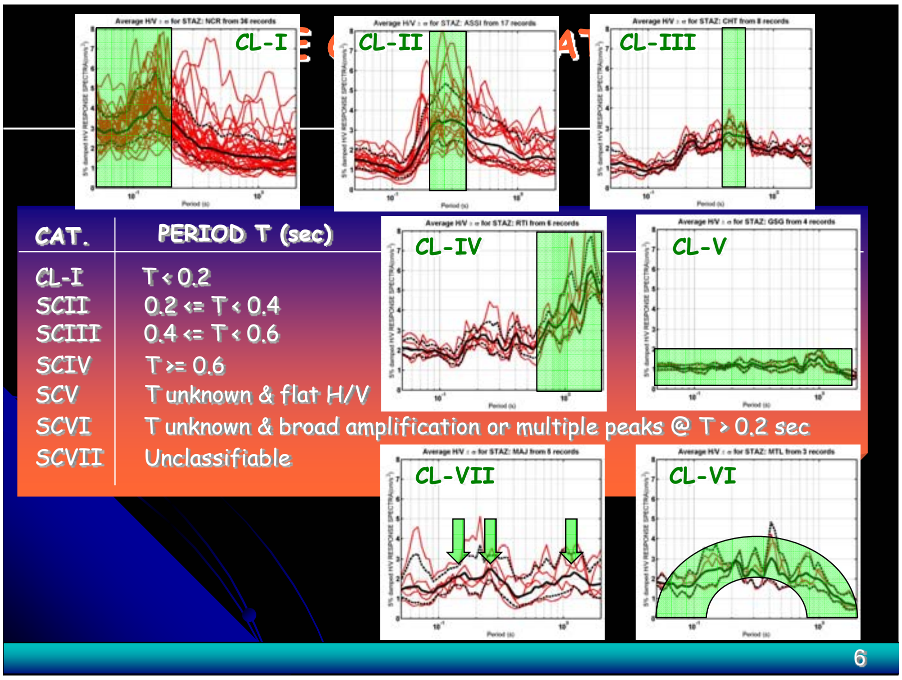


Figure 4) Site classification based on predominat period in H/V spectral ratios of 5% damped response spectra. The figure shows one example for each of the seven site classes that have been defined in the project.

2.2 Deliverables

During the phase 2 the UR2 participated to the following deliverables:

Deliverable D5 – Site monographs project and compilation;

Deliverable D7 – Surface waves technique application on 7 selected sites;

Deliverable D9 – Fucino Basin seismic monitoring network operation and data analysis;

Deliverable D10 – Sites classification according to EC8;

Deliverable D14 – Ground motion predictive equations with conventional and innovative site classification schemes.

2.3 Problems and difficulties

The April 6th L'Aquila earthquake diverted a big amount of people, instruments and working time form the field activities requested by the project. As a result of this some experimental activities were performed at the end of the project and not time was left to refine some of the collected data.

2.4 Selected publications

Di Alessandro, C., Bonilla, L.F., Rovelli, A., Scotti, O., 2008. Influence of site classification on computing empirical ground-motion prediction equations in Italy, Abstract presented at AGU Fall Meeting, San Francisco, California, December 9-12 2008.

Di Alessandro, C., Rovelli, A., Milana, G., Marcucci, S., Bonilla, L.F., Boore, D.M., 2009. A new site classification scheme for Italian accelerometric stations, Abstract presented at the SSA 2009 Annual Meeting, Monterey, California, April 8-10 2009.

Di Alessandro, C., Rovelli, A., F. Bonilla, Scotti, O., 2010. Predominant-period site classification for predictive equations of response spectra in Italy, to be submitted to BSSA.

Di Capua, G., Lanzo, G., Luzi, L., Pacor, F., Paolucci, R., Peppoloni, S., Scasserra, G., Puglia, R., 2009. Caratteristiche geologiche e classificazione di sito delle stazioni accelerometriche della RAN ubicate a L'Aquila (http://esse4.mi.ingv.it/images/stories/Classificazione_Sito_Stazioni_RAN_ _AQ.pdf).

3 Report on the project activities by RU3 POLI-MI

Responsible: Roberto Paolucci, Politecnico di Milano

3.1 Activity of RU3 in phase 2

Besides contributing to Project coordination, UR3 has given its scientific contributions to Tasks 1 and 4, especially for what concerns:

Task 1
- implementation of a new processing procedure for ITACA records and contribution with UR 1 to re-processing of all ITACA records;
- preparation of an extended glossary of main items in ITACA;
- check of the updated releases of ITACA;
- contribution to REXELite, the software for automatic selection of ITACA accelerograms based on target response spectra.

Task 4
- synthesis of research activity to identify stations with distinctive features of seismic response;
- 3D numerical analysis of the seismic response of Gubbio basin and synthesis of results.

In addition, UR3 has substantially contributed to the various stages of processing and analysis of records from the L'Aquila earthquake, with special care paid to the near-fault records (Ameri et al., 2009; Paolucci and Smerzini, 2010).

More specifically, the research activities where the UR has been mostly involved are summarized below.

A. Implementation of a new processing procedure for ITACA records

Although the waveforms available at the start of Project S4 in the alpha version of ITACA were treated by following the worldwide accepted techniques that aim to remove low and high frequency noise, the compatibility among acceleration, velocity and displacement was not guaranteed. Therefore, before publication of the ITACA beta version, several points have been addressed, dealing with the quality and reliability of corrected records, namely:
- to check the accuracy and reliability of the frequency range of the corrected re-cords and compare them with the corresponding records available in other inter-national databases, such as PEER and European Strong Motion Database (ESMDB);
- to ensure the compatibility of corrected accelerograms, so that no further correc-tion is required to obtain the velocity and displacement traces by single and double integration, respectively ;
- to identify the late-triggered records, typically on the S-phase, that form a large portion of analogue records from small-to-medium magnitude earthquakes.

To provide a rational solution to the previous problems and to set up a sufficiently robust and reliable procedure to be effectively used for reprocessing of all the ITACA records, a novel approach for processing the ITACA strong-motion records has been devised.
Referring to Paolucci et al. (2009) for details on the procedure, its basic steps are the following:
- baseline correction (constant detrending);

- application of a cosine taper, based on the visual inspection of the record (typically between 2% and 5% of the total record length); records identified as late-triggered are not tapered;
- visual inspection of the Fourier spectrum to select the band-pass frequency range; whenever feasible, the same range is selected for the 3-components;
- application of a 2nd order acausal frequency-domain Butterworth filter to the acceleration time-series;
- double-integration to obtain displacement time series;
- linear detrending of displacement;
- double-differentiation to get the corrected acceleration.

An example of corrected ITACA record, compared with the corresponding record provided by the European strong motion (ESMDB) and by the PEER databases is illustrated in Fig. 1.

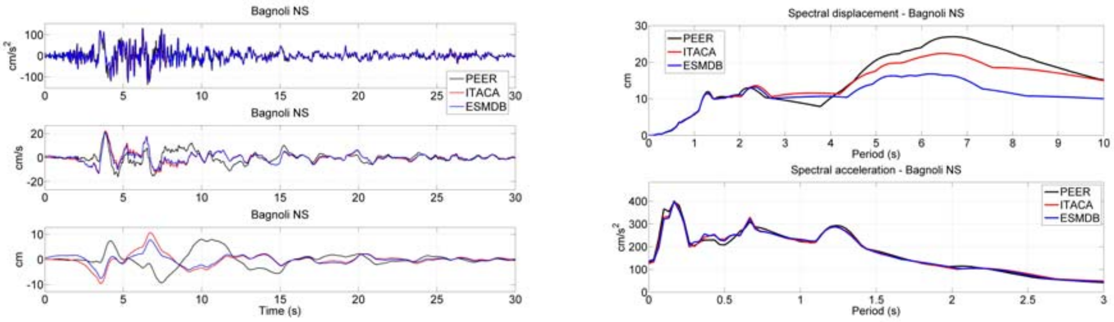


Figure 1. Comparison of Bagnoli corrected record, NS component, from the M_w6.9 Irpinia earthquake, 1980, as available from ITACA, ESMDB and PEER databases. Left: corrected acceleration, velocity, displacement. Right: spectral displacement and spectral acceleration.

B. Identification of stations with distinctive features of seismic response

The scope of the research activity within Task 4 was to identify which stations within ITACA exhibit a seismic response significantly different with respect to the expected one, based on the empirical ground motion prediction equations (GMPEs) calibrated on the ITACA dataset. The dataset used for the study and the resulting GMPEs is described in detail in Deliverable D14 of Project S4. The method consists of computing the residuals of the recorded 5%-damped response spectral acceleration with respect to the estimate provided by the various GMPEs for the corresponding site class, as follows:

$$r_{p,q}(T) = \frac{Log\left[SA_{p,q}^{obs}(T)\right] - Log\left[SA_{p,q}^{GMPE}(T)\right]}{\sigma^{GMPE}} \qquad \text{for } p = 1 \ldots N_S,\ q = 1 \ldots N_E \qquad (1)$$

where $SA_{p,q}^{obs}(T)$ and $SA_{p,q}^{GMPE}(T)$ are, respectively, the observed and predicted spectral acceleration for the station p and earthquake q and σ^{GMPE} is the logarithmic standard deviation of the selected GMPE. Subsequently, residuals have been corrected for the inter-event variability, as follows:

$$R_{p,q}^{N}(T) = r_{p,q}^{N}(T) - \varepsilon_q(T) \quad \text{with} \quad \varepsilon_q(T) = \frac{\sum_{k=1}^{N_q} r_{k,q}^{N}(T)}{N_q} \qquad \text{for } q = 1 \ldots N_E \qquad (2)$$

where $\varepsilon_q(T)$ quantifies the error associated with the q^{th} earthquake, computed as the average normalized residual over the N_q records coming from the same earthquake. Only stations that recorded more than 7 earthquakes were considered, so to make more robust the analysis.

Among the processed stations, those showing a clear trend below or above the median ± 1σ, independent of the GMPE, were identified. As an example, Figure 2 shows those stations exhibiting spectral ordinates larger than the standard dispersion band for long periods (upwards-right arrow), in most cases related to long period amplification of ground motion in the presence of alluvial basins.

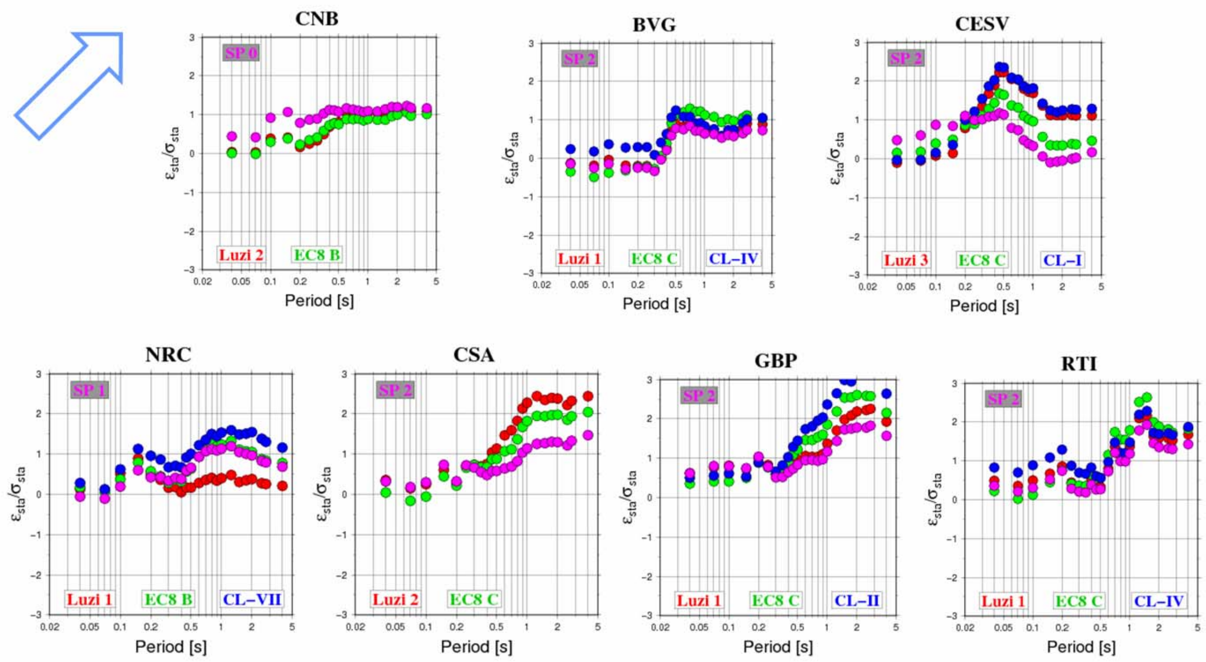


Figure 2. Examples of synthesis of results: stations showing a trend with respect to the ground motion prediction equations calibrated on the ITACA data, involving higher spectral ordinates at long periods with respect to the median values for the whole ITACA records and the corresponding site class.

C. 3D numerical analysis of the seismic response of Gubbio basin and synthesis of results

The scope of this research activity was to study some of the most relevant features of the seismic response of the Gubbio sedimentary basin (Central Italy) at long periods, based on different numerical assumptions. Specifically, the following models were used to verify the accuracy of different numerical approximations in predicting earthquake ground motion in the Gubbio plain during the M_W 6.0 26 Sept, 1997, Umbria-Marche mainshock:

(a) 3D model of the basin along with a proper 3D kinematic characterization of the seismic source;

(b) 2D models of longitudinal and transverse cross-sections of the basin under both vertical and oblique plane wave propagation, using, as input, the output of the 3D simulation at outcropping bedrock ;

(c) 1D model under vertical plane-wave propagation, using the same input as for point (b).

Since the main goal of this work is the comparison of results obtained through different numerical approaches, the same stratigraphy and bedrock topography was used for all models. 3D and 2D numerical simulations were performed by means of a high performance spectral element code GeoELSE (http://geoelse.stru.polimi.it), enriched by the possibility of dealing with different seismic excitation modes, including: i) heterogeneous kinematic models for an extended fault and ii) plane wave incidence with an arbitrary propagation direction.

The most significant results (see Appendix F of Deliverable 9 for details) can be summarized as follows:

- the 3D simulated ground motion time histories at GBB and GBP stations (see location of the accelerometric stations in Figure 3) compare well with the recordings up to about 3 Hz;
- after performing a parametric numerical analysis as a function of the earthquake magnitude, it turned out that the amplification effects at long periods are not magnitude independent, but they show an increasing trend with increasing magnitude;
- the distinctive features of long period ground response in presence of a deep basin, such as the Gubbio plain, cannot be accurately predicted but with advanced tools based on 3D wave propagation theory. To clarify this point, Figure 3 shows the comparison between recorded, 3D, 2D (for both transverse and longitudinal cross-section under vertical plane wave incidence) and 1D Response Spectral Ratios (RSR) of GBP station with respect to the corresponding reference rock station. It is apparent that both 1D and 2D numerical approaches tend to significantly underestimate the spectral response at long period, T>~ 1 s, by a factor of about 4 on average.

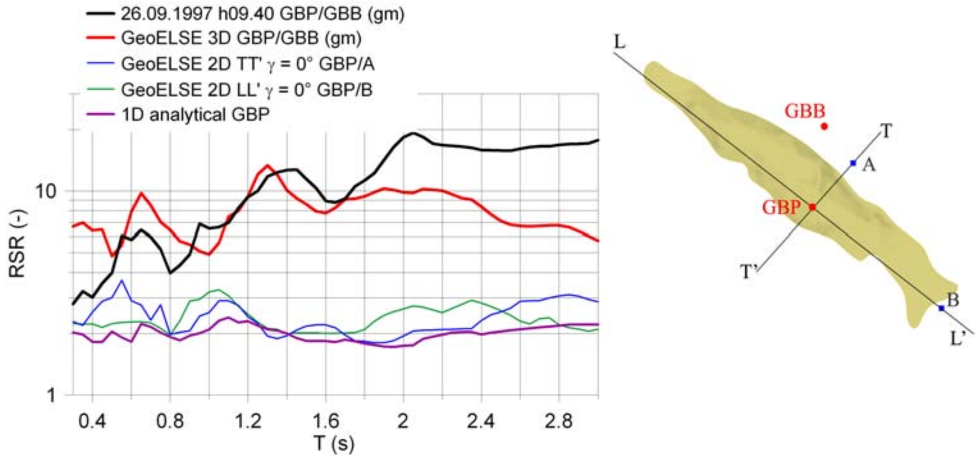


Figure 3. Comparison between recorded, 3D, 2D (for both transverse TT' and longitudinal LL' cross-section under vertical plane wave incidence γ=0°) and 1D Response Spectral Ratios (RSR) of GBP station with respect to the corresponding reference rock station (GBB for records and 3D simulations, A and B for TT' and LL' cross-sections, respectively).

3.2 Deliverables

UR3 has substantially contributed to Deliverable D2 (Final release of ITACA), within the different steps involved by the Project coordination, the formulation of the ITACA glossary, and the re-processing of all ITACA records.

Furthermore it has edited Deliverable D9, contributing specifically to preparation of Appendix A (Analysis of strong motion records for identification of stations with distinctive seismic response) and Appendix F (1D, 2D, 3D numerical modelling of seismic site response in the Gubbio basin)

3.3 Problems and difficulties

No major problems have been encountered.

3.4 Selected Publications

Ameri G, M. Massa, D . Bindi, E D'Alema, A. Gorini, L. Luzi, S. Marzorati, F. Pacor, R. Paolucci, R. Puglia, C. Smerzini. The 6 April 2009, Mw 6.3, L'Aquila (Central Italy) earthquake: strong-motion observations. Seismological Research Letters, **80**(6), 951-966, 2009.

Celebi M., P. Bazzurro, L. Chiaraluce, P. Clemente, L. Decanini, A. De Sortis, W. Ellsworth, A. Gorini, E. Kalkan, S. Marcucci, G. Milana, F. Mollaioli, M. Olivieri, R. Paolucci, D. Rinaldis, A. Rovelli, F. Sabetta and C. Stephens. Recorded Motions of the Mw6.3 April 6, 2009 L'Aquila (Italy) Earthquake and Implications for Building Structural Damage: A Review. Accepted for publication in *Earthquake Spectra*.

Iervolino I., Galasso C., Paolucci R., Pacor F. REXELite, online record selection for the ITalian ACcelerometric Archive, Proc. 14 Europ. Conf. Earthq. Eng, Skopje, 2010.

Pacor F., R. Paolucci, I. Iervolino, M. Nicoletti, G. Ameri, D. Bindi, C. Cauzzi, E. Chioccarelli, E. D'Alema, L. Luzi, S. Marzorati, M. Massa, R. Puglia. Caratteristiche dei dati accelerometrici registrati durante la sequenza sismica aquilana. *Progettazione sismica*, **3**, 57-68, 2009.

Paolucci R. Long-period earthquake ground motion: recent advances and observations from the April 6 2009, Mw6.3 L'Aquila earthquake, Italy. *Proc. ACES Workshop on Performance-Based Earthquake Engineering*, Corfù, Greece, 5-6 July 2009.

Paolucci R., F. Pacor, R. Puglia, G. Ameri, C. Cauzzi and M. Massa. Record processing in ITACA, the new Italian strong-motion database. Proc. 2nd Euro-Mediterranean meeting on Accelerometric Data Exchange and Archiving, Ankara, Turkey, 10-12 Nov, 2009.

Paolucci R. and C. Smerzini. Strong ground motion in the epicentral region of the MW 6.3, Apr 6 2009, L'Aquila earthquake, Italy. Proc. 5th Int. Conf. on Recent Advances in Geotech. Earthq. Engineering and Soil Dynamics, Paper EQ4, San Diego, CA, 2010.

Pessina V., E. Fiorini e R. Paolucci. GIS-based identification of topographic sites with significant ground motion amplification effects. Proc. 5th Int. Conf. on Recent Advances in Geotech. Earthq. Engineering and Soil Dynamics, Paper 6.20b, San Diego, CA, 2010

Stupazzini M., Paolucci R. and H. Igel. Near-fault earthquake ground motion simulation in the Grenoble Valley by a high-performance spectral element code". *Bulletin Seismological Society of America*, **99**(1), 286-301, 2009.

4 Report on the project activities by RU4 POLI-TO

Responsible: Sebastiano Foti, Politecnico di Torino

4.1 Activity of RU4 in phase 2

The work of UR4 – Politecnico di Torino has been focused mainly on Task 3. For the characterization of RAN sites active and passive surface wave data have been collected and interpretated in Sicilia, Liguria, Piemonte. Moreover data from other projects in which the RU has been involved in the past have been compiled for Itaca Database. In particular down-hole test results were available for the temporary stations at Torre Pellice and La Salle, whereas surface wave data were available for Gemona site.

In the following table, a list of the investigated station, with the retrieved results in terms a Vs30 are summarized:

Site	**Station Code**	**VS_{30}** (m/s)	**Bedrock depth** (m)	**VS_h** (m/s)	**f_0 (exp.)** (Hz)	**f_0 (calc.)** (Hz)	**Test**
RONCO SCRIVIA	**RNS**	684					**MASW**
SESTRI LEVANTE	**SEL**	540					**MASW**
GENOVA	**GNV**	1048	3	366		29	**MASW**
VARESE LIGURE	**VRL**	856	6	456		18	**MASW**
TORTONA	**TRT**	483	13	306		6	**MASW**
PINEROLO	**PNR**	383					**MASW**
FIUME ATERNO	**AQA**	495	26	449		4	**MASW**
GELA	**GEL**	245					**MASW**
CALTAGIRONE	**CLG**	373					**MASW**
PATTI (CAB. ENEL)	**PTT0**	251					**MASW**
TORRE FARO (MESSINA) (CAB. ENEL)	**TRF0**	242					**MASW**
TORTORICI	**TOR**	525	18	368		5	**MASW**
ISPICA	**ISI**	1322	1	338		106	**MASW**
NOTO	**NTE**	658	8	384		13	**MASW**
RAGUSA	**RGS**	999	2	297		37	**MASW**
SANTA CROCE CAMERINA	**SCR**	865	4	299		20	**MASW**
CATANIA - PIANA	**CAT**	160					**MASW**

Site	Station Code	VS_{30} (m/s)	Bedrock depth (m)	VS_h (m/s)	f_0 (exp.) (Hz)	f_0 (calc.) (Hz)	Test
PALAZZOLO ACREIDE	**PLZ**	638	7	308		11	**MASW**
PACHINO	**PCH**	593	15	460		8	**MASW**
GEMONA	**GMN**	445					**MASW**
LA SALLE 2	**LSA2**	684					**DH**
LA SALLE 4	**LSA4**	540					**DH**
TORRE PELLICE 4	**PE4**	1048	3	366		29	**DH**
TORRE PELLICE 7	**PE7**	856	6	456		18	**DH**

The Flow chart of surface wave tests is summarized in Figure 1a. Active surface wave data were acquired using a linear array with 24 or 48 vertical geophones with natural frequency of 4.5 Hz; the source was 5kg sledge hammer.
Multimodal apparent dispersion curves were retrieved form data using the f-k spectrum.
Passive surface wave data were acquired using 12 vertical geophones arranged along a circle, and 4 three component geophones in the interior of the circle. An example of the acquisition geometry is shown in Figure 1b. Multimodal dispersion curves were retrieved from passive data using a beamforming procedure (f-k_x-k_y transform) which does not require any assumption on the source position.

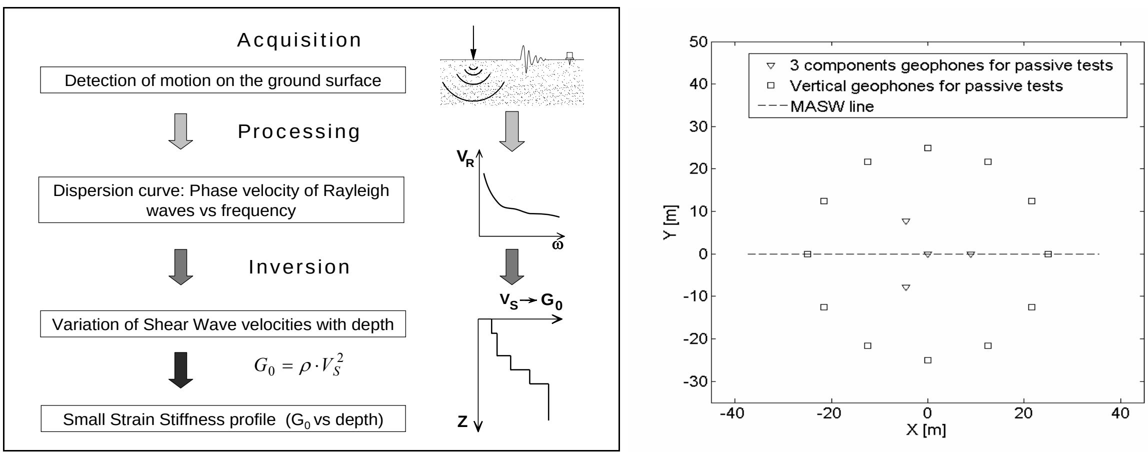


Figure 1 – a) Flow chart of surface wave tests; b) acquisition geometry.

Active + passive dispersion curves have been inverted using a stochastic inversion code developed by the RU during for the project, which allows all the modes to be taken into account without the need of numbering them. This feature of the code is particularly important for shallow bedrock sites (like Liguria and Sicilia sites) because, in this case, the passage of the apparent dispersion curve on the higher modes in the low frequency band is a quite common feature.
In the algorithm a multimodal misfit function was used. This function is based on the Haskell-Thomson method for dispersion curve calculation (Thomson 1950, Haskell 1953, Herrmann e Wang 1980, Herrmann 2002). For a given subsoil model, and an experimental data, the misfit of the model is the L^1 norm of the vector containing the absolute value of the determinant of

the Haskell-Thomson matrix (which is zeros in correspondence of all the modes of the dispersion curves of the numerical model) evaluated in correspondence of the experimental data (Maraschini et al. 2010). The misfit function adopted has the advantage of being able to include any dispersive event present in the data without the need of specifying to which mode the data points belong to, avoiding errors arising from mode misidentification, in particular in the low frequency range. This misfit function is applied in a Global Search Methods (GSM), in order to reduce the possibility of falling in local minima. A uniform random search is applied; ranges for the inversion have been chosen, for the different sites, based on the experimental dispersion curves; in particular the range of the S-wave half space velocity is close to the maximum surface wave velocity retrieved on experimental data. The results of the inversion are selected as the ensemble of the best shear wave velocity profiles obtained by the Monte Carlo inversion.
The obtained results are, for each site, the set of the equivalent profiles. Results in terms of Vs_{30}, Vs_h, natural frequency are retrieved from the soil model associated to the lowest misfit value.
For the considered sites, the final models of the shear wave velocity are in good agreement with previous information, and data fitting is good. In several cases, as expected, the apparent dispersion curve passes to higher modes both in the low and in the high frequency band, and consequently, in these cases, a fundamental mode inversion would have provide incorrect results (Figure 2).

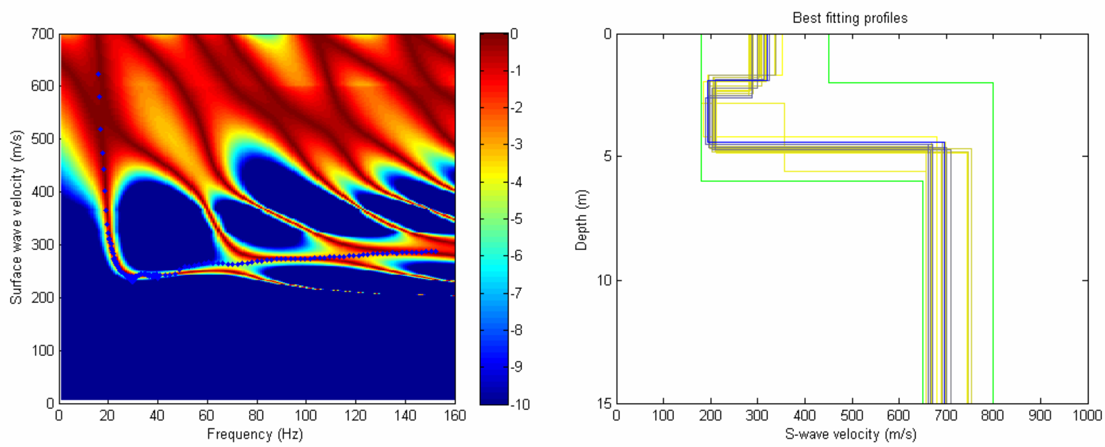


Figure 2 Sestri Levante – a) Experimental dispersion curve compared with the misfit surface of the best fitting model; b) Monte Carlo results (from yellow to blue) of the inversion with the boundaries (green).

The degree of innovation concerns the possibility of the interpretation of surface wave results also for problematic sites (shallow bedrock sites, class E sites, sites with velocity inversion), which can't be handled by other approaches (unless they are very cost expensive). The scientific relevance of the new inversion approach of the developed algorithm is testified by its publication on the most important geophysical journals.

4.2 Deliverables

The research unit has edited and has contributed to the deliverale D7.

4.3 Problems and difficulties

No major problems have been encountered. With respect to the initial choice of sites to be investigated some small variation have been introduced because of logistic problems for the execution of the tests.

4.4 Publications

Bergamo, P., Comina, C., Foti S.,, and Maraschini, M.. 2010 Characterization of sites with shallow bedrock: Soil dynamics and earthquake engineering, in preparation.

Comina, C., Foti, and S., Maraschini, M.. 2010 Integration of seismic refraction data in stochastic inversion of surface wave data: Near Surface Geophysics (Special Issue on Surface Wave Analysis Workshop, EAGE conference, Amsterdam, The Netherlands) in preparation.

Comina C., Foti S., Boiero D. and Socco L.V. 2010 Reliability of Vs,30 evaluation from surface waves tests. Journal of Geotechn. and Geoenv. Eng., ASCE, submitted

Maraschini, M., Ernst, F., Foti, S., and Socco, L.V., 2010. A new misfit function for multimodal inversion of surface waves. Geophysics, in press.

Maraschini, M. and Foti, S., 2010. A Monte Carlo multimodal inversion of surface waves: Geophysical Journal International, submitted.

Maraschini, M., Foti, S., and Comina, C., 2009. Inversione multimodale delle onde di superficie per la caratterizzazione di siti della rete accelerometrica nazionale. Incontro Annuale dei Ricercatori di Geotecnica 2009.

Maraschini, M., Bergamo, P., Comina, C., Foti, Socco, L.V., and Tokeshi K., 2009. Caratterizzazione di siti della rete accelerometrica nazionale con il metodo delle onde di superficie. GNGTS 2009.

Tokeshi K., Foti S., Parolai S., Picozzi M., Puglia R., Massa M., D'Alema E., 2010 Love and Rayleigh waves dispersion analysis from microtremor measurements at Bevagna (Italy): Near Surface Geophysics (Special Issue on Surface Wave Analysis Workshop, EAGE conference, Amsterdam, The Netherlands) in preparation

5 Report on the project activities by RU5 UNI-BAS

Responsible: Marco Mucciarelli, Università della Basilicata

5.1 Activity of RU5 in phase 2

RU5 was involved in the following tasks:

1. Update of ITACA data base(Task1)
2. Surface waves procedures for site investigations (Task 3)
3. Identification of anomalous recordings (interaction with buildings- Task 4)
4. Site classification (Task 5)

As for the update of the data base, it was agreed to transfer the data of 21 stations of the DiSGG-IMAA network, selected on the base of two criteria: availability of a number of good quality digital recordings and accessory data for site characterization, including detailed geological survey, HVSR microtremor data, Down-hole measurements and in some cases geotechnical laboratory tests. For each station the R.U. prepared also the identification sheet with all the available data in the format agreed within the ITACA project, and an example is given as annex at the end of this report.
Figure 1 shows the Magnitude/Distance space covered by the recordings.

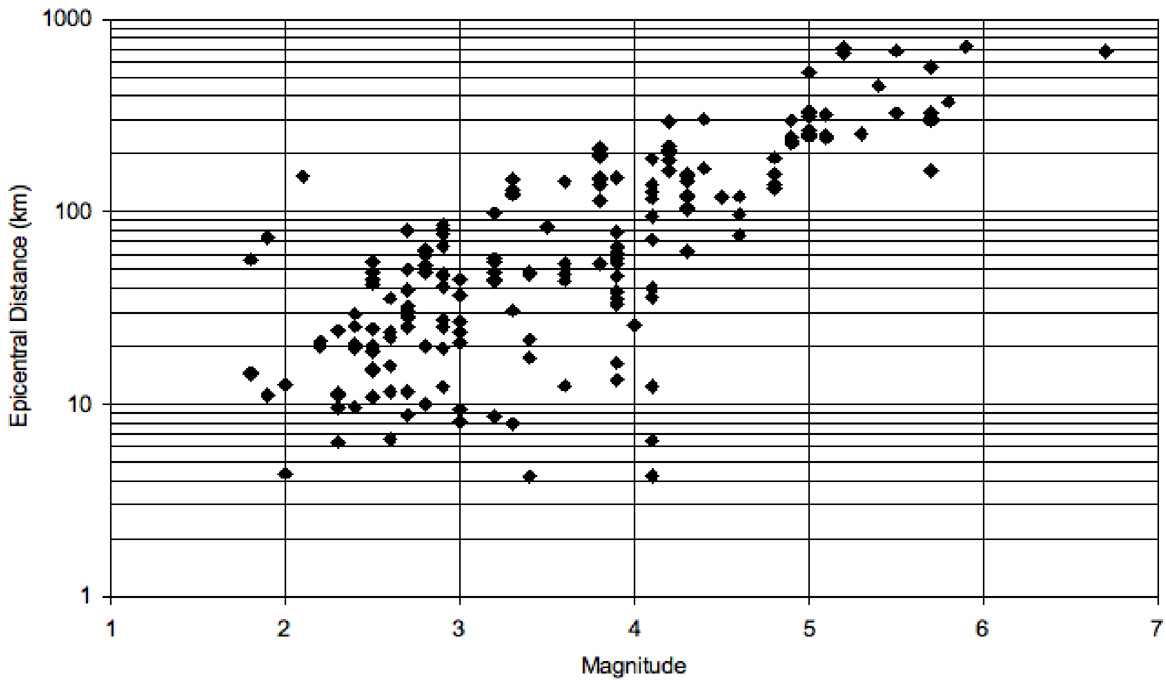


Figure 1: Magnitude and Distance covered by the data provided to ITACA

Table 1 reports the name of stations, the identification code in ITACA database and the number of strong motion records provided for each station, summing up to at total of 220 accelerograms.

Stazione	Cod.	N° eventi
Anzi	ANZ	11
Balvano	BLV	1
Costa della Gaveta	GVT	7
Ferrandina	FRR	10
Grassano	GSS	16
Latronico Bagni	LTB	17
Latronico scuola	LTS	15
Marconia	MRC	10
Marsico Nuovo	MRN	21
Melfi	MLF	6
Pescopagano	PSP	11
Policoro cinema	POLC	7
Policoro municipio	POLM	4
Ruvo del Monte	RVM	9
Sant'Angelo le Fratte	SNF	5
Santarcangelo	SANL	2
Scanzano municipio	SCZM	9
Scanzano Porto Greco	SCZP	7
Tito Scalo	TTS	13
Tricarico Case Monaco	TRCM	31
Tricarico frana	TRCF	8

Table 1 : name of stations, the identification code in ITACA database and the number of strong motion records provided

As for the surface wave procedures, the task of the R.U. was to perform surface wave measurements to be transferred to the R.U. at UniSI. The measurements were carried out at Marsico Vetere, Tricarico, Maratea, Pignola and Melfi, using an L-shaped array, non-equispaced sensors and acquiring at least 10 minutes of ambient noise sampled at 125 Hz with 4.5 Hz vertical geophones. At the same sites also HVSR measurements were carried out and all the data were then transferred to UniSI for the joint inversion.

As for the identification of anomalous recordings, the scope of the R.U. at UniBas was to identify the presence of possible building-soil interaction analysing the recordings at the ITACA stations. The activities performed can be subdivided in:

- Numerical modelling to validate prior results obtained by ISMES in the '90.
- Identification of anomalous rotational HVSR in 41 stations.
- Validation of observed anomalies by dynamic identification of 5 housings.

The numerical results confirms the suspect that even small structures can adversely affect the "free field" recordings, both for masonry and RC housings.
Most of the stations analysed showed an anomalous pattern of rotational HVSRs, in a frequency range from 6 to 20 Hz. The dynamic identification on selected stations confirmed that these directional effects occur exactly at the same frequency of the fundamental modes of investigated structures.
We analysed the station listed in table 2:

Region	Housing				Number of Records			
	Building (B)	ENEL Box (E_B)	Box	Dam	(B)	(E_B)	Box	Dam
ABRUZZO				VLB				8
BASILICATA	MRV	BRN	STL		7	5	2	
	PTZ	LRG			5	30		
		LRS				14		
CAMPANIA	LVN	ARN	ARI		4	5	5	
		CLT				6		
		MRT				3		
		STR				9		
		TDG				3		
FRIULI	SRCO	BRC	CLA	TLM1	8	4	2	12
		MAI				4		
MARCHE	MNF	CLF	ARQ		6	25	3	
		FHC				4		
		MTL				3		
		PGL				4		
UMBRIA	ASS	BVG	ANNI		76	9	21	
	CLC	CSA			123	9		
	GLT	CSC			8	10		
	NOR	GBP			46	14		
		NCR				46		
		NCR2				136		
		NRC				15		
Number of Stations	9	21	5	2	Total Stations 37			

Table 2: Stations analysed for the building-soil interference

The analysis technique was rather simple. We took the average of the rotational HVSR looking for a specific pattern: the signature of the translational modes of a building should be made of two directional peaks (the first higher) separated by 90° (rotational modes make this pattern more complex).
Figure 2 reports the behaviour of a pure 1-d amplification effect due to plane-parallel, undisturbed soils (right) and the HVSR atop a 3-storey building (left).

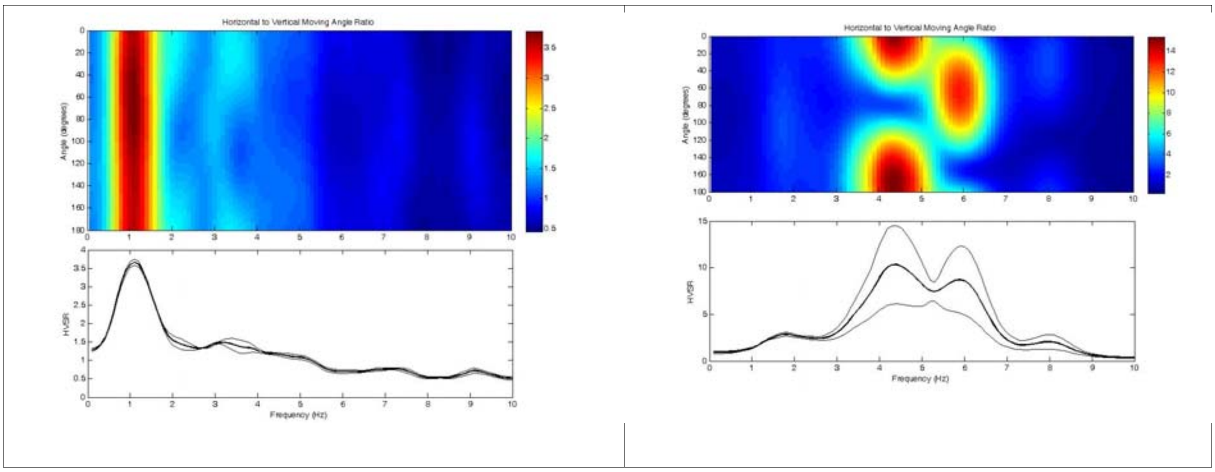


Figure 2: Rotational HVSR for 1-d soil (right) and atop a 3-story building (left)

We first analysed the effect for station hosted inside a building. The presence of this effect for the station hosted within ENEL sub-station was known since the beginning of the '90s, due to numerical simulation performed at ISMES. Those grey-papers were never published and no field measurement or data analysis were performed to substantiate their findings.

We found that the two-peaks signature is always present within ENEL substations, ranging from 6-8 Hz to 12-18 Hz depending on the building's typology (masonry or pre-cast r.c.).
The following figures reports an example for a station that recorded the Umbria-Marche earthquake.

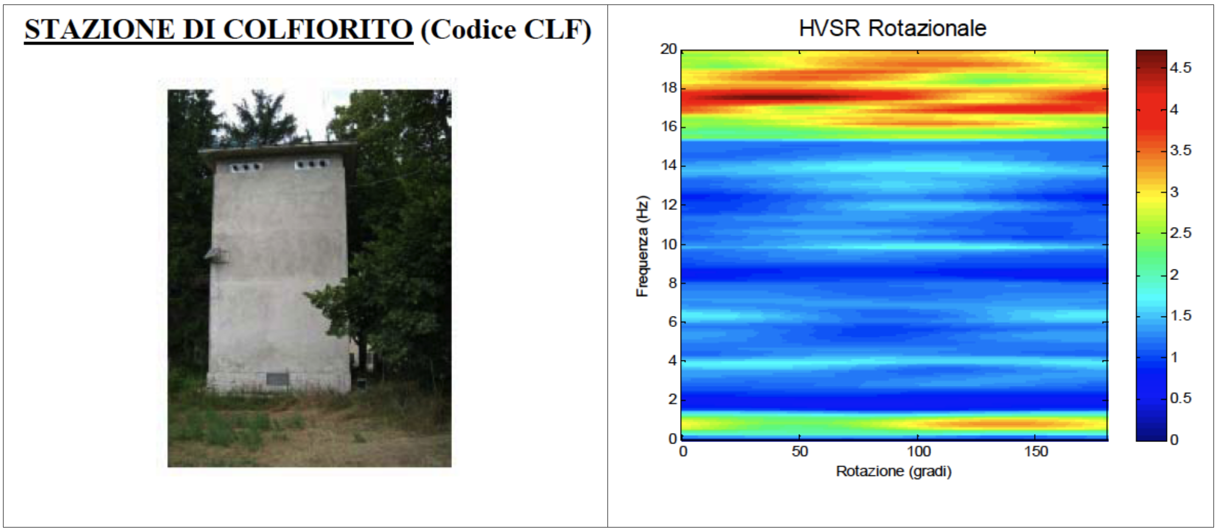


Figure 3 :Rotational HVSR for the station Colfiorito in Umbria

Also station hosted in other buildings may show the presence of peaks due to the structure, as its is evident for the Colfiorito Casermette (CLC) in figure 4.

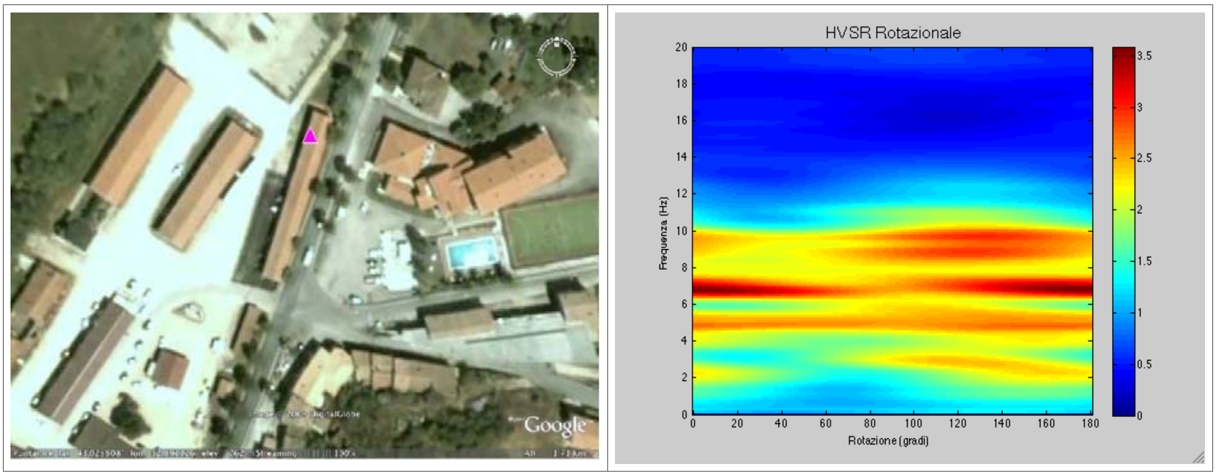


Figure 4 :Rotational HVSR for the station Casermette in Umbria

We then considered the interaction with structures located at some distance, starting from dams that are known to affect the recordings as shown for the Italian case of Tolmezzo (Ambiesta Dam) by Barnaba et al. (2007). We observed the structure "footprint" in both the examined cases, the dams at Villetta Barrea and Fiastra (Monte Fiegni station).
Figure 5 reports the results for the Villetta Barrea station. Note two peaks at 4 and 6 Hz possibly due to the upstream-downstream motion of the arch dam, and a peak in the E-W direction possibly due to the sloshing of the reservoir.

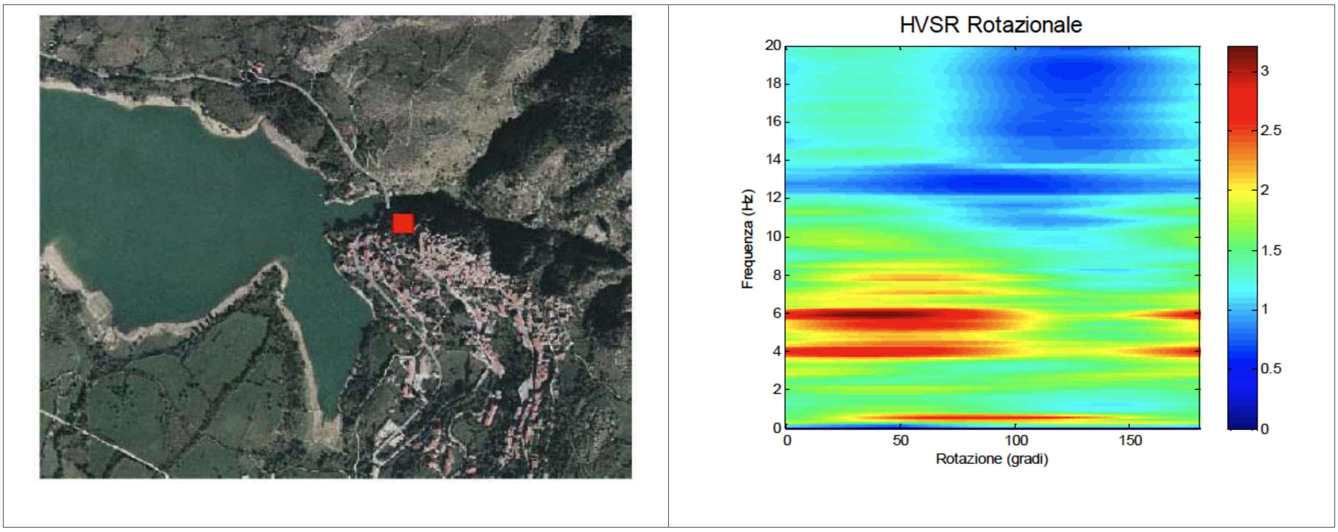


Figure 5 Rotational HVSR for the station Villetta Barrea near the same arch dam

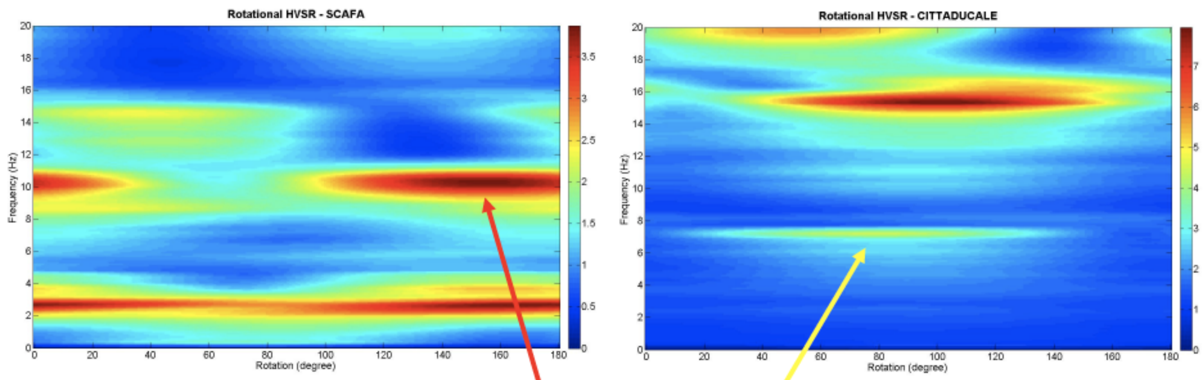
Table 3 summarises the data analysis, showing that in most cases we observed building interaction with the free field recordings.

REGION	STATION	HOUSING	RECORDS	DIRECTIONAL EFFECTS
FRIULI	Tolmezzo	Dam	12	f = 2Hz, Azimut = N75°
ABRUZZO	Villetta Barrea	Dam	8	f = 4-6Hz, Azimut = N40°
BASILICATA	Marsico Vetere	Building	7	f = 6Hz, Azimut = N75°
	Potenza	Building	5	f = 12Hz, Azimut = N50°
	Brienza	ENEL Box	5	f = 6Hz, Azimut = N75°
	Lauria Galdo	ENEL Box	30	f = 6Hz, Azimut = N75°
	Lauria	ENEL Box	14	f = 10Hz, Azimut = N165°
	Satriano di Lucania	Box	2	f = 4Hz, Azimut = N125°
				f = 6Hz, Azimut = N160°
CAMPANIA	Laviano	Building	4	f = 2Hz, Azimut = N100°
	Arienzo	ENEL Box	5	f = 5Hz, Azimut = N75°
	Calitri	ENEL Box	6	f = 2Hz, Azimut = N60°
	Mercato S. Severino	ENEL Box	3	no peaks
	Sturno	ENEL Box	9	f = 7Hz, Azimut = N60°
	Torre del Greco	ENEL Box	3	f = 16Hz, Azimut = N20°
	Ariano Irpino	Box	5	f = 1Hz, Azimut = N160°
FRIULI	Forgaria nel Friuli	Building	8	f = 8Hz, Azimut = N90°
	Barcis	ENEL Box	4	f = 5Hz, Azimut = N90°
	Maiano	ENEL Box	4	f = 0.5Hz, Azimut = N140°
	Claut	Box	2	several small peaks
MARCHE	Monte Fiegni	Building	6	several small peaks
	Colfiorito	ENEL Box	25	f = 1Hz, Azimut = N140°
	Forca Canapine	ENEL Box	4	f = 5Hz, Azimut = N75°
	Forca Matelica	ENEL Box	3	f = 20Hz, Azimut = N25°
	Forca Peglio	ENEL Box	4	f = 4Hz, Azimut = N160
	Arquata del Tronto	Box	3	f = 11Hz, Azimut = N125°
UMBRIA	Assisi	Building	76	f = 3Hz, Azimut = N90°
	Colfiorito Casermette	Building	123	f = 3Hz, Azimut = N90°
	Gualdo Tadino	Building	8	f = 18Hz, Azimut = N20°
	Norcia	Building	46	f = 1Hz, Azimut = N125°
	Bevagna	ENEL Box	9	f = 0.5Hz, Azimut = N75°
	Castelnuovo Assisi	ENEL Box	9	f = 3Hz, Azimut = N20°
	Cascia	ENEL Box	10	several peaks
	Gubbio Piana	ENEL Box	14	f = 4Hz, Azimut = N10°
	Nocera Umbra	ENEL Box	46	f = 7Hz, Azimut = N170°
	Nocera Umbra 2	ENEL Box	136	several peaks
	Norcia	ENEL Box	15	f = 6Hz, Azimut = N75°
	Annifo	Box	21	f = 3Hz, Azimut = N160°

Table 3: Summary of the building-soil interaction analysis

Following the advice of the International Consultant Panel after the first year of the project we tried to validate the results performing dynamic identification of some ENEL substation, taking advantage of the accessibility during a maintenance trip performed by DPC after the 2009 L'Aquila earthquake.
We studied 4 stations (Scafa, San Demetrio nè Vestini, Bussi and Cittaducale) deriving the fundamental modes of the buildings from ambient noise measurements on top, base and outside the building.

The following figure reports an example for two stations (more details are given in Appendix B of Deliverable 9). It can be seen that the fundamental frequency of the building (lower table) is always visible in the rotational HVSR for the aftershocks sequence of L'Aquila earthquake (upper figures), and some case (Scafa) its is the strongest site-dependent signal recorded



Example 1: **Scafa**

Pre-cast RC

electrical substation

Municipality	Typology	Housing Fundamental Frequency (Hz)	Pillar Fundamental frequency (Hz)
Scafa	Pre-cast	10.5	70
San Demetrio	Masonry	6.7	60
Bussi	Masonry	9.5	-
Cittaducale	Masonry	7.3	105

Example 2: **Cittaducale**

Masonry electrical substation

Figure 5 : Comparison between earthquake HVSR and housing frequency

As for the site classification activity, the R.U. interacted with the R.U. at INGV-MI to create a data base of stations (even outside ITACA) having both good quality recordings and down-hole profile reaching at least 30 m.
The R.U. re-analysed the data in its possess, providing the data listed in the following table.
The result of the analysis of the joint database is reported in Deliverable 13.

Site Name	Vs30	Classe	Vs5	Vs10	Vs15	Vs20	Vs25	Fmax	Amax	F0	A0	Geology
Aliano	390	B	256	296	321	345	375	-	-	-	-	Conglomerate
Balvano	413	B	207	267	317	360	392	6.93	3.08	2.00	3.00	Flisch
Bernalda Scuola Elem.	383	B	410	429	408	394	390	0.60	1.90	0.60	1.90	Conglomerate
Cagli Municipio	591	B	238	323	403	480	541	3.38	2.80	3.38	2.80	Alluvium
Cagli S.Geronzio	726	A	275	399	520	606	673	-	-	-	-	Limestone
Cagli Vigili del Fuoco	334	C	165	183	219	257	298	4.16	3.60	4.16	3.60	Clay
Costa Gaveta	235	C	178	216	221	217	225	3.50	2.70	5.00	3.60	Clay-Landslide
Latronico scuola	376	B	217	269	304	329	350	4.08	2.38	1.69	2.19	Clay-Landslide
Marsico Nuovo	399	B	325	335	336	359	382	2.50	3.00	2.50	3.00	Alluvium
Melfi	434	B	232	301	348	376	408	2.40	2.02	2.40	2.02	Volcanic ash
Metaponto Borgo	323	C	362	339	312	334	328	1.20	3.00	1.20	3.00	Alluvium
Montescaglioso	415	B	194	273	329	366	399	-	-	-	-	Cemented Sand
Offida Cappuccini	455	B	297	321	338	380	422	2.24	3.50	1.00	2.52	Clay
Offida Municipio	332	C	195	226	250	272	303	1.82	2.10	1.82	2.10	Clay
Offida Rocca	378	B	239	248	280	320	353	1.48	2.10	1.48	2.10	Flisch
Offida Stadio	482	B	370	375	390	427	458	1.20	2.40	1.20	2.40	Clay
Passo di Treia	525	B	263	357	419	463	498	3.38	3.50	3.38	3.50	Alluvium
Pisticci Cantisano	399	B	270	311	355	376	410	0.60	2.00	0.60	2.00	Conglomerate
Policoro Agrifela	278	C	242	249	260	262	273	1.20	4.00	1.20	4.00	Alluvium
Policoro Municipio	390	B	312	376	425	399	401	1.00	2.80	1.00	2.80	Conglomerate
Potenza Campus	553	B	312	483	705	722	722	4.31	2.40	4.31	2.40	Clay
Potenza Viale UNICEF	580	B	212	336	418	468	529	4.50	3.50	2.00	2.50	Alluvium
Rionero	398	B	209	272	313	341	372	1.19	2.95	1.19	2.95	Volcanic ash
S.Basilio-Scanzano Porto Greco	292	C	262	266	270	278	285	1.40	3.50	1.40	3.50	Alluvium
Scanzano Ionico Municipio	420	B	366	431	456	417	428	1.00	2.80	0.41	2.48	Conglomerate
Senigallia Marchetti	262	C	166	202	230	238	246	-	-	-	-	Alluvium
Senigallia Saline	220	C	103	134	155	173	197	2.40	4.20	2.40	4.20	Clay
Senigallia Stadio		C	90	135	175	203		5.81	2.70	5.81	2.70	Alluvium
Sera de' Conti Scuola	416	B	170	240	296	348	387	1.48	2.30	1.48	2.30	Clay
Serra de' Conti Deposito	420	B	186	220	283	338	383	1.48	2.30	1.48	2.30	Clay
Serra de' Conti Municipio	586	B	386	414	497	535	562	-	-	-	-	Clay
Tito Scalo	175	D	95	123	141	155	166	1.17	4.50	1.17	4.50	Clay
Treia Carabinieri	396	B	288	330	478	466	466	2.75	2.30	2.75	2.30	Clay
Treia Casa Riposo	460	B	284	314	372	414	444	0.98	2.10	0.98	2.10	Sandstone
Venosa	413	B	224	301	342	375	395	0.43	2.80	0.43	2.80	Conglomerate
Villa d'Agri Barricelle	408	B	222	287	328	359	384	3.50	3.00	3.50	3.00	Alluvium

5.2 Deliverables

The unit was involved with two 12-months deliverables:
- D8 Identification of ITACA sites and records presenting anomalies in the seismic response
- D12 Critical review of methods proposed in the literature for site classification

The unit was involved with two 24-months deliverables:
-D9 Experimental and numerical results for all stations selected to study the effects of anomalous site conditions
-D13 Identification of new site parameters for improved seismic classification criteria

All were completed 100%.

5.3 Problems and difficulties

No problem were encountered during the two years, and no delay affected the scheduled activities.

5.4 Selected publications

M.R. Gallipoli and M. Mucciarelli (2009) Comparison of Site Classification from VS30, VS10, and HVSR in Italy, Bulletin of the Seismological Society of America, Vol. 99, No. 1, pp. 340–351

R. Ditommaso, M. Mucciarelli, M. R. Gallipoli, F. C. Ponzo (2010) Effect of a single vibrating building on free-field ground motion: numerical and experimental evidences, Bullettin of Earthquake Engineering, vol. 8; p. 693-703

A. Attolico, M.R. Gallipoli, P. Harabaglia, V. Lapenna, M. Mucciarelli, A.B. Rosa (2010) A review of the activity of two accelerometric networks in Basilicata (Italy), in press on Bullettin of Earthquake Engineering, doi: 10.1007/s10518-009-9129-2

6 Report on the project activities by RU6 - UNI-RM1

Responsible: Giuseppe Lanzo, Università di Roma "La Sapienza"

6.1 Activity of RU6 in phase 2

During Phase 2, the activity of RU6 has been essentially devoted to Task 2 (Geological-geotechnical catalogue of ITACA sites) in collaboration with the RU2 INGV-RM. The work done in this task represents the basis for the seismic classification of the ITACA recording stations, which is the main objective of Task 5 (Site classification), in which RU6 has also collaborated. The overall activity is hereafter summarized.

Task 2: Geological-geotechnical characterization of ITACA sites

The primary aim of this task was to complete the catalogue of available geological and geotechnical information of recording stations in order to provide researchers and professionals information about the subsoil conditions at the stations as well as to allow the seismic classification of the ITACA recording sites. The definition of a standard format for collecting all information and data gathered, in a systematic and organized way, was also a main objective of the task.
This latter assignment was accomplished in the first phase of the project by developing a new monograph template, that is composed of 12 modules and various sub-modules summarizing the state of knowledge of the accelerometric station (see Deliverable D3: "*Definition of the standard format to prepare descriptive monographs of ITACA stations*", http://esse4.mi.ingv.it/images/stories/Deliv_D3templeate_monografia.pdf). The structure of the monograph and the first phase of the compilation work is described in the Deliverable D4: "*Progress report on the ongoing activity for constructing a catalogue of geological/geotechnical information at accelerometer stations*" (http://esse4.mi.ingv.it/images/stories/deliverable_d4.pdf). In particular, it was decided to begin the compilation of monographs considering the subset of stations which recorded the 1980 Irpinia earthquake (19 stations) because they contain a wealth of geological, geophysical and geotechnical data.
The activities carried out in the second phase has been concerned with the continuation of the data collection on the geological, geotechnical and geophysical information of the accelerometric stations as well as the acquisition of new V_S data by means of in-situ measurements carried out within the project.

Compilation of station monographs

The activities carried out by RU6 concerned the completion of the catalogue of recording stations having shear wave velocity profile. For these stations geotechnical data, if available, were also collected, organized and synthesized in the station monograph. In particular the following modules of the monograph were compiled:

- Geotechnical, Geomechanical & Geophysical Information containing information on the location of the boreholes, stratigraphic profile, Vs and Vp profiles, the results of standard in situ tests (CPT, SPT, piezometric measurements) and geophysical tests (down-hole, cross-hole, SASW, MASW, etc.) as well as those from laboratory tests for the determination of physical and mechanical soil properties;
- Site classification (EC8) (Lithostratigraphic classification based on in-situ measurements).

- Synthesis of information (for the part concerning the information relevant to site classification, Geological and geotechnical information, other information relevant to seismic site response).

The compilation was made using the data already available or collected in the previous S6 project (DPC-INGV 2004-2006 agreement) and that obtained in the framework of the new S4 Project, collected as well as measured front *ad hoc* in situ tests carried out by different research units. Particular attention was paid to the stations with shear wave velocity profile. Overall, 102 monographs with V_S profile were compiled using the new standard format. For each monograph the value of V_{S30} was also computed. If the velocity profile was available only to depth d< 30m, a correlation between shallow velocity and V_{S30} was used. Specifically, V_{S30} was determined by means of the relationship calibrated based on the borehole data of the KikNet network (Figini, 2006), which is reported below:

$$\log V_{s,30} = a + b \log V_{s,d}$$

In this equation V_{Sd} is the equivalent shear wave velocity to a depth d< 30m, calculated according to the following equation:

$$V_{s,d} = \frac{d}{\sum \frac{h_i}{V_{s,i}}}$$

while a and b are regression coefficients tabulated for each depth d.
All data were uploaded into the online ITACA database using the web form, except for information related to station monographs that recorded the 1980 Irpinia Earthquake, compiled in the first phase, when the web form had not yet been prepared. In any case, also these monographs are available on the ITACA web site. A list of these stations is reported in Tables 1 (43 stations with V_S profiles from collected data) and 2 (61 stations with V_S profiles in situ tests within the S4 project) together with the V_{S30} value and the EC8 site classification. The two stations Aquila Colle Grilli (AQG) and Aquila Valle Aterno (AQA) have been investigated by different research units by means of down-hole as well as MASW tests but the V_S profile reported in the monograph as well as the V_{S30} value are based on the DH test.

Table 1 – List of accelerometer stations with shear wave velocity profile obtained from collected data and EC8 site classification according to V_{S30}

#	Name	Code	V_{S30} (m/s)	EC8
1	AULETTA	ALT	1149	A
2	BISACCIA	BSC	997	A
3	SANNICANDRO GARGANICO	SNN	965	A
4	TARCENTO	TRC	901	A
5	ANCONA ROCCA	ANR	549	B
6	BAGNOLI IRPINO	BGI	498	B
7	BAGNONE	BGN	640	B
8	BENEVENTO	BNV	716	B
9	BORGO CERRETO CS	BCC	486	B
10	BOVINO	BVN	364	B
11	BRIENZA	BRN	402	B
12	CALITRI	CLT	495	B

13	CESENA	CSN	540	B
14	CITTÀ DI CASTELLO	CTC	390	B
15	FORGARIA CORNINO	FRC	454	B
16	LAURIA GALDO	LRG	603	B
17	MERCATO S. SEVERINO	MRT	483	B
18	NORCIA	NRC	687	B
18	PIEVE S. STEFANO	PVS	613	B
20	RIONERO IN VULTURE	RNR	538	B
21	S. SEVERO	SSV	390	B
22	SELLANO EST	SELE	520	B
23	SELLANO OVEST	SELW	518	B
24	STURNO	STR	382	B
25	TOLMEZZO DIGA AMBIESTA	TLM1	522	B
26	TRICARICO	TRR	467	B
27	VALLE ATERNO CENTRO VALLE	AQV	474	B
28	VIESTE	VSS	440	B
29	ANCONA PALOMBINA	ANP	256	C
30	BOJANO	BOJ	306	C
31	BUIA	BUI	258	C
32	FIRENZUOLA	FRE1	312	C
33	FORLÌ	FOR	295	C
34	GARIGLIANO	GRG2	191	C
35	GUBBIO PIANA	GBP	224	C
36	MAJANO PRATO	MAP	344	C
37	S. GIULIANO SCUOLA	SGIUB	391	C
38	SAN SEPOLCRO	SNS	322	C
30	COLFIORITO	CLF	140	D
40	ARIENZO	ARN	578	E
41	FIVIZZANO	FVZ	495	E
42	NOCERA UMBRA	NCR	534	E
43	S. CASCIANO DEI BAGNI	SSC	485	E

Table 2 – List of accelerometer stations with shear wave velocity profile obtained from in situ tests carried out within the S4 project (Task 3) and EC8 site classification according to V_{S30}

#	RU	Nome	Code	V_{S30} (m/s)	EC8
1	RU2-INGV RM1	BIBBIENA NUOVA	BBN	1000	A
2	"	DICOMANO	DCM	1000	A
3	"	ASSERGI	GSA	488	B
4	"	CASSINO	CSS	630	B
5	"	AVEZZANO	AVZ	199	C
6	"	BORGO8000	BTT	92	D
7	"	RIETI	RTI	170	D
8	RU4-PoliTO	ISPICA	ISI	1482	A
9	"	GENOVA	GNV	987	A
10	"	SANTA CROCE CAMERINA	SCR	894	A
11	"	RAGUSA	RGS	1091	A
12	"	AQUILA FIUME ATERNO	AQA	495	B
13	"	CALTAGIRONE	CLG	373	B
14	"	ECOURS	LS4	473	B

15	“	GEMONA	GMN	445	B
16	“	LASALLE	LS2	496	B
17	“	NOTO	NTE	710	B
18	“	PACHINO	PCH	593	B
19	“	PINEROLO	PNR	383	B
20		RONCO SCRIVIA	RNS	737	B
21	“	SESTRI LEVANTE	SEL	606	B
22	“	TORRE FARO (MESSINA) (CAB. ENEL)	TRF0	302	B
23	“	TORRE PELLICE 4	TP4	547	B
24	“	TORTONA	TRT	483	B
25	“	TORTORICI	TOR	525	B
26	“	VARESE LIGURE	VRL	758	B
27	“	GELA	GEA	245	C
28	“	PATTI (CAB. ENEL)	PTT0	251	C
29	“	TORRE PELLICE 7	TP7	290	C
30	“	CATANIA - PIANA	CAT	160	D
31	“	PALAZZOLO ACREIDE	PLZ	670	E
32	RU6-UNI RM1	AQUIL A FIUME ATERNO	AQA	552	B
33	“	AQUILA COLLE GRILLI	AQG	685	B
34	“	AQUILPARK	AQK	717	B
35	RU7-UniSI	AQUILA COLLE GRILLI	AQG	1150	A
36	“	AQUILA PETTINO	AQP	830	A
37	“	MARATEA	MRA	1020	A
38	“	MONTECASSINO	MTC	1000	A
39	“	MORMANNO	MRM	1400	A
40	“	PESCASSEROLI	PSC	1000	A
41	“	SCANNO	SCN	840	A
42	“	CAPESTRANO	CPS	730	B
43	“	MARSICO VETERE	MRV	680	B
44	“	PIGNOLA	PGA	430	B
45	“	SATRIANO DI LUCANIA	STL	390	B
46	“	TRICARICO	TRO	780	B
47	“	VIBO MARINA	VBM	450	B
48	“	VIBO VALENTIA	VBV	510	B
49	“	SPEZZANO SILA	SPS	320	C
50	RU8-GFZ	BAZZANO	BZZ	679	B
51	“	LAGONEGRO	LGN	431	B
52	“	NORCIA ZONA INDUSTRIALE	NRZI	557	B
53	“	ONNA	MI03	378	B
54	“	SANT ARCANGELO	SNA	420	B
55	“	CATTOLICA	CTL	208	C
56	“	FAENZA	FAZ	293	C
57	“	GRUMENTO NOVA	GRM	283	C
58	“	MODENA	MDN	213	C
59	“	NOVELLARA	NVL	190	C
60	“	ARGENTA	ARG	170	D
61	“	BEVAGNA	BVG	162	D

Seismic characterization of the RAN stations located in the near-fault area of the L'Aquila earthquake

The mainshock on 6 april 2009 was recorded by 56 digital strong motion RAN stations at distances within 280 km from the epicenter. Of particular interest are the stations located in the epicentral area. The high-quality strong motion data produced makes the L'Aquila earthquake the best-recorded normal fault event world-wide and the best-recorded earthquake in Italy in a near-fault area. Ground motion recordings from these stations represent therefore a valuable set of data because they provide new information regarding ground shaking and site effects in a near-fault region.

The majority of near-fault stations belong to an array which was installed across the upper Aterno valley in 2001 by the DPC. This array is formed by six stations, namely *Colle Grilli* (AQG), *Fiume Aterno* (AQA), *CentroValle* (AQV), *Il Moro* (*AQM*), *Ferriera* (AQF) and *Monte Pettino* (AQP). However, three of these stations (AQM, AQF and AQP) did not trigger or malfunctioned during the mainshock. Another station which recorded the mainshock and many afterschocks is located in downtown L'Aquila (AquilPark, AQK). The location of these strong-motion stations is shown in Figure 1.

Figure 1. General view of the Aterno valley and bordering mountains showing the location of the RAN strong-motion stations (AQG, AQA, AQV, AQM, AQF, AQP); in the rear the station AQK in downtown L'Aquila (vertical scale exaggerated 2x)

A subsoil classification of the above mentioned stations was first carried out mainly based on the geological information available and is described in Di Capua et al. (2009). A geological map (scale 1:100.000) of L'Aquila and the eastern Aterno valley is shown in Figure 2, together with the locations of the strong-motions stations.

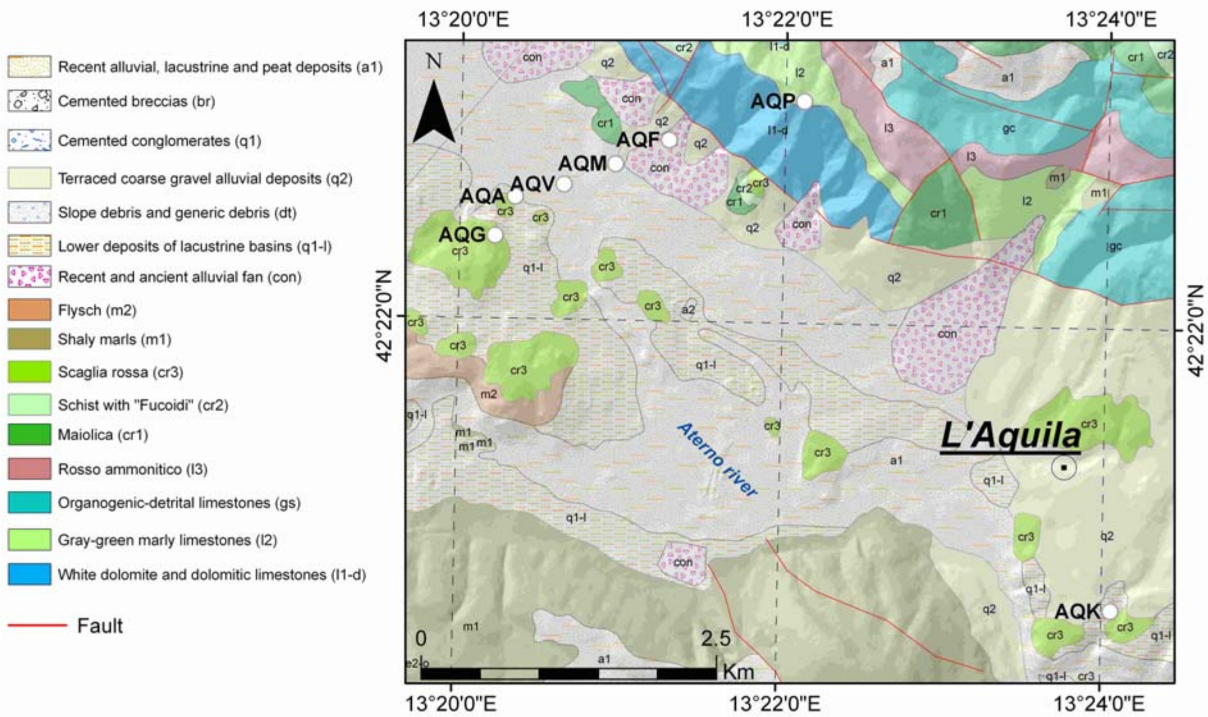


Figure 2. Geologic map of the Aterno valley in correspondence of L'Aquila (Geologic Map of Italy, scale 1:100.000, Sheet 139 "L'Aquila")

However, it was soon recognized that the major shortcoming of the accelerometric dataset was a lack of good information on site conditions. To properly use this significant set of strong motion records it is desirable to identify the site conditions at the stations. A major effort was therefore undertaken by this research unit to improve the characterization of subsoil conditions at these sites. Boring logs and down-hole tests were carried out at AQG, AQA and AQK (for AQV a cross-hole test was already available). Further, an additional borehole was drilled approximately between AQA and AQV. The results of these tests are presented hereafter in terms of stratigraphic and V_S-V_P profiles.

AQG

The AQG station is located at the hilltop of Colle Grilli, which is a calcareous highly fractured ridge having height of 50 m and width at the base of 300 m. A borehole was drilled adjacent to the recording station to a depth of 40 m. Boring log and V_S and V_P profiles are presented in Figure 3. Along the whole profile pervasively tectonized calcirudite, locally in sandy/silty matrix, has been found. The V_{S30} for this site is 685 m/s, making it a stiff site (B) in the Italian code and EC8 classification system.

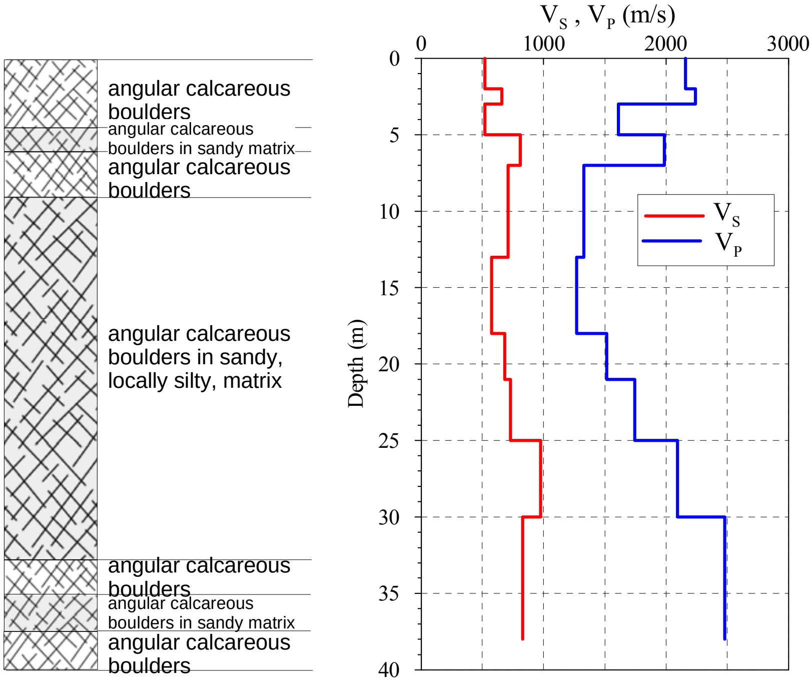


Figure 3. Stratigraphic, V_S and V_P profiles at AQG station.

AQA

The AQA station is located in proximity of the right bank of the Aterno river. The geology of the area indicates that the station is located on the Holocene deposits, at the southern edge of the alluvium valley (Figure 4). A 30m-depth borehole was drilled by the Department f Civil Protection on the left bank of the river (the right bank was not accessible), approximately in front of the station. Soil profile consists of 6 m of calcareous gravels in sandy/silty matrix with layers of silty/clayey soils overlying talus debris constituted by angular gravels to 30 m depth. The down-hole was carried out by this RU (Figure 4). The V_{S30} for this site is 552 m/s, making it also a stiff site (B) in the Italian code and EC8 classification system.

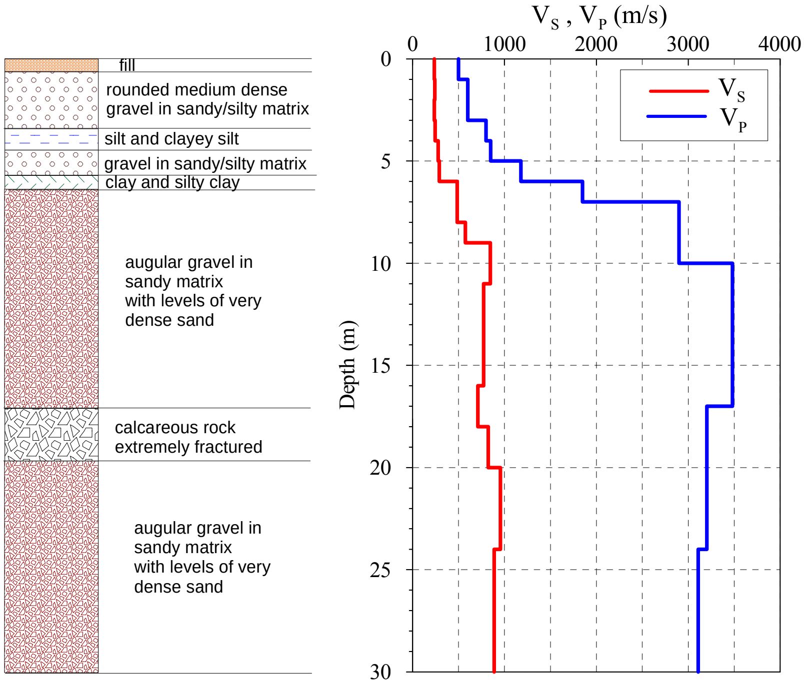


Figure 4. Stratigraphic, V_S and V_P profiles at AQA station.

AQK

The AQK station is located in downtown L'Aquila, in proximity of the entrance of the tunnel connecting the Bus Station with downtown L'Aquila. The geology of the area indicated that the station is located on cemented breccias (locally known as "megabreccia") overlying lacustrine sediments resting on limestones. A 50 m-depth borehole was drilled 200 meter apart from the station AQK by the Department of Civil Protection. The soil profile consists essentially of dense gravel in sandy/silty matrix with calcareous boulders ("megabreccia") to a depth of 36 m underlain by stiff silt layer with frequent levels of sand (Fig. 5). The down-hole was carried out by this RU (Figure 5). The V_{S30} for this site is 717 m/s, making it a stiff site (B) in the Italian code and EC8 classification system.

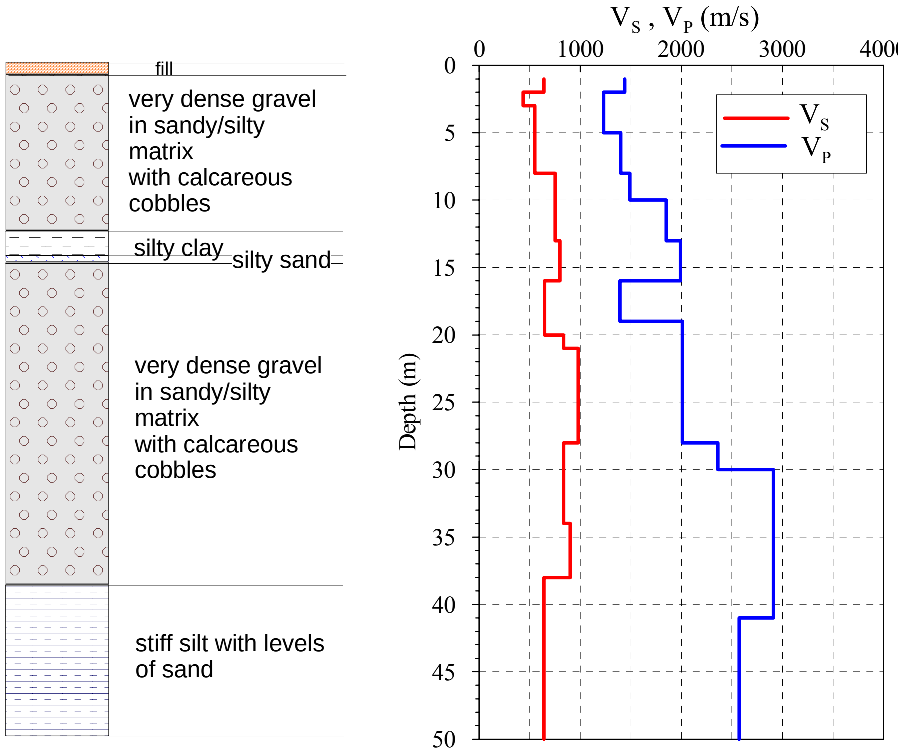


Figure 5. Stratigraphic, V_S and V_P profiles at AQK station.

Borehole in the Aterno valley

An additional borehole was drilled in the Aterno valley at approximately 250 m from AQA station. The borehole, named AQA2, was carried out in proximity of the left bank of Aterno river. The main motivation for this drilling was to obtain information on the position of the calcareous bedrock in order to construct a reliable 2D cross-section of the Aterno valley along the transect. This information will help in modelling the 2D seismic response analysis of the cross-section of the valley with the aim of reproducing the recorded ground motion at the stations and quantify the importance of site effects in the epicentral area. The stratigraphic profile in AQA2 is illustrated in Fig. 7. A seismic dilatometer test (SDMT) is also planned at the site.

Figure 6. Location of the AQA2 borehole.

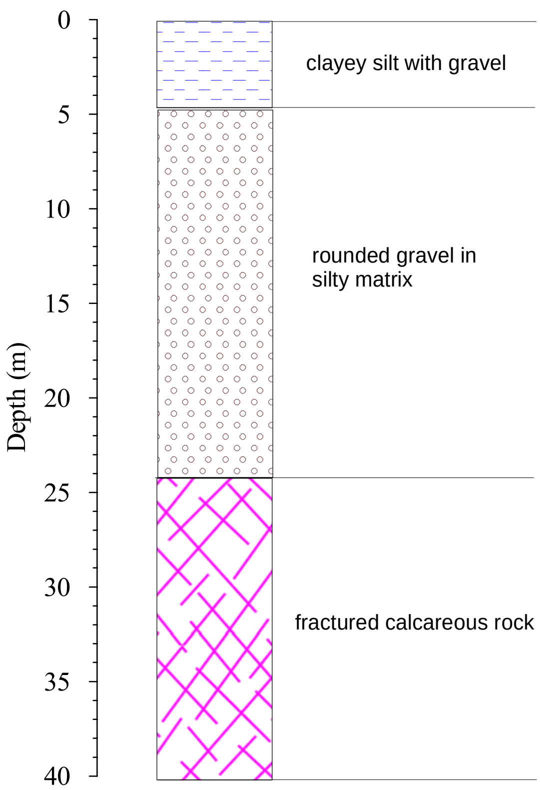


Figure 7. Stratigraphic profile at AQA2 site

Evaluation of the reliability of in situ tests for V_S measurements

This RU was involved in the validation activity of the V_s measured data in collaboration with RU4 Poli-TO. In particular two cases were analyzed. The first case concerns AQK station where, in the same borehole, two down-hole tests commissioned respectively by RU6 and by DPC were performed by two different operators,. The results of the comparison is illustrated in Fig. 8. Significant differences in the shear wave velocity profile are evident in the first 8 meters where V_S varies between about 500 m/s (continuous line) and 750 m/s (dotted line) and between 15 and 40 m depth, where an even larger difference, on average, can be noted. The reasons for these discrepancies are currently under investigation. Large differences between the two velocity profiles can also be noted for V_P between 15 and 50 m.
The second comparison is related to AQA station where down-hole and MASW tests were carried out. The shear wave velocity profiles from both tests are illustrated in Fig. 8 and the overall agreement is quite satisfactorily up to 25 m depth.

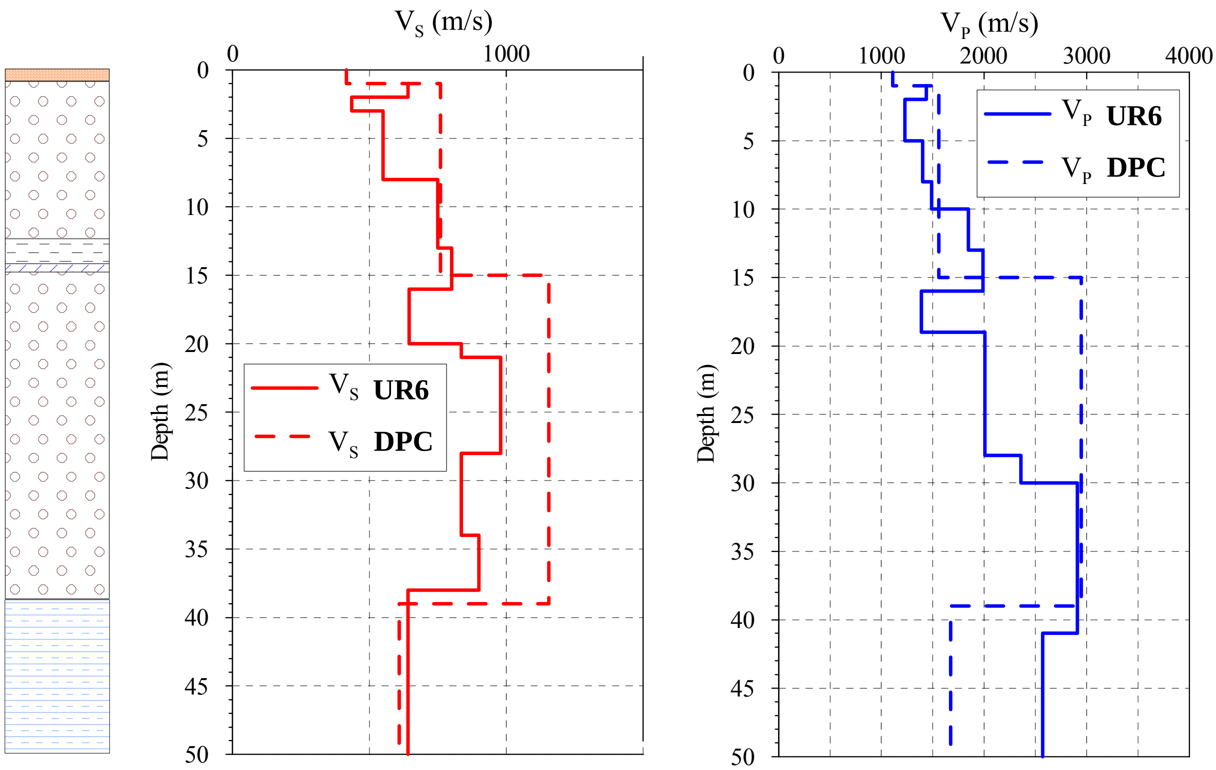


Figure 8. Comparison between Vs profiles obtained at AQK from the same in situ technique (down-hole) and by different operators.

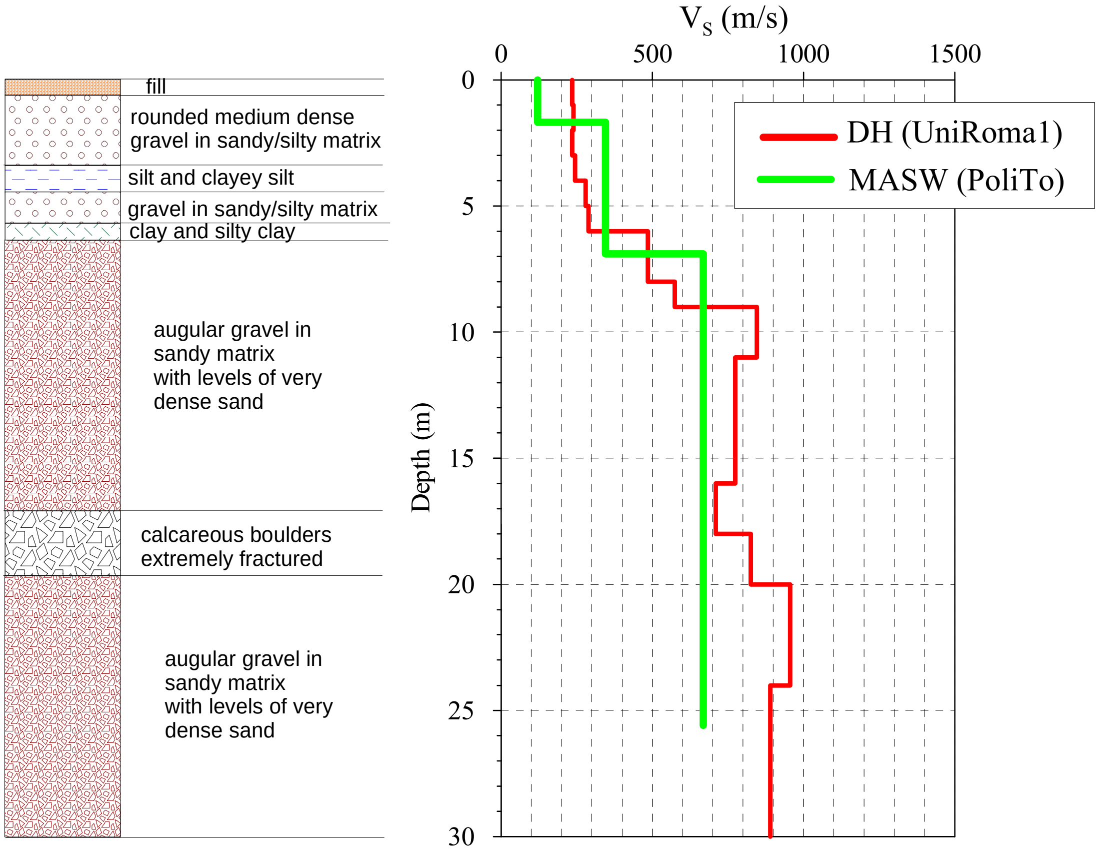


Figure 9. Comparison between Vs profiles obtained at AQA from different in situ techniques.

References

Di Capua G., Lanzo G., Luzi L., Pacor F., Paolucci R., Peppoloni S., Scasserra G., Puglia R. (2009). Caratteristiche geologiche e classificazione di sito delle stazioni accelerometriche della RAN ubicate a L'Aquila". Progetto DPC – INGV S4: Banca dati accelerometrica (http://esse4.mi.ingv.it/images/stories/Classificazione_Sito_Stazioni_RAN_AQ.pdf).

Figini R (2006). Analisi degli effetti di sito sui lunghi periodi degli spettri di risposta di spostamento. Master's Thesis, Politecnico di Milano (in Italian).

6.2 Deliverables

Deliverable D3 (new release of ITACA station monograph) has been completed in the first phase of the project.
Deliverable D4 (Progress report on the ongoing activity for constructing a catalogue of geological/geotechnical information at accelerometer stations, - 12 months) has been completed. This report summarizes all the activities that have been carried out in the first phase for the compilation of the station monographs and for the site classification as well as the solutions that have been identified to overcome the difficulties encountered.
Deliverable D5 (Technical Report - Catalogue of geological/geotechnical information at accelerometer stations - 24 months) has been completed and it includes all the information collected for the recording stations systematically organized in the new ITACA monographs.
Deliverable D10 (Technical Report - Revised seismic classification of the ITACA stations, according to the EC8 and the Italian code site classes) has been completed and the site

classification, version 3.0, according to the EC8 subsoil categories, has been released for 689 accelerometric stations.

6.3 Problems and difficulties

No major problems were found during the second year of the project.

6.4 Selected publications

Lanzo G., Di Capua G., Kayen R.E., Scott Kieffer D., Button E., Biscontin G., Scasserra G., Tommasi P., Pagliaroli A., Silvestri F., d'Onofrio A., Violante C., Simonelli A.L., Puglia R., Mylonakis G., Athanasopoulos G., Vlahakis V., Stewart J.P. (2010). Seismological and geotechnical aspects of the April 6 2009 L'Aquila earthquake in central Italy. Int. Journal of Geo-Engineering Case Histories, Issue 4, Volume 1, ISSN 1790-2045.

7 Report on the project activities by RU7 UNI-SI

Responsible: Dario Albarello, Università degli Studi di Siena

7.1 Activity of RU7 in phase 2

RU7 participated to field and data processing activities devoted to the seismic characterization of a set of RAN accelerometric sites located in Abruzzo, Lazio, Calabria and Basilicata. In particular, these activities focused on the application of geological surveys and passive seismic prospecting for the study of sites located on rocks or stiff soil.

The analysis of this kind of sites is of great importance in the seismological and engineering practice. In fact, it is generally assumed that this kind of sites may act as reference sites for the study of amplification effects induced by resonance phenomena in the presence of sedimentary covers. In these kind of analyses, accelerometric registrations on rock/stiff soil sites are assumed to be representative of the ground motion at the bottom of the sedimentary cover and thus can be used as input motion for the analysis of local amplification phenomena.

However, the identification of actual rock/stiff soil sites is not an easy task. In fact, geological surveys, by alone, are not able to recognize the presence of mechanical layering inside the geological body (due, e.g., to alteration phenomena) that can be responsible for seismic resonance effects. To this purpose, direct measurements are necessary, that are based on in-hole seismic prospecting techniques (down-hole, cross-hole). However, this kind of measurements result relatively expensive and this prevent their widespread application. Furthermore, they require and intensive soil occupation with machinery that can hardly be placed in rock sites typically characterised by a rugged morphology. To overcome these problems surface geophysical prospecting techniques may represent an appealing alternative. In particular, passive seismic techniques (both in the single station and array configuration) have been proposed since these are generally able to reach larger exploration depths in comparison with required field occupation.

However, the application of these techniques in sites characterized by relatively high seismic velocities and rugged morphology, presents specific problems. The major goal of the RU7 activities is a field evaluation of these aspects and setting up of on purpose procedures.

As whole, UR7 explored 10 accelerometric sites (Tab.1). This data set was determined in the first year of the project after a preliminary field survey aiming at the selection of actual rock/stiff soil sites.

Table1 – List of accelerometric RAN sites considered by UR7. Along with the official denomination of each site, major experimental results obtained during the study are reported (F0 is the fundamental resonance frequency at each site)

RAN code	Prospecting techniques	Vs 30	DEPTH TO BED-ROCK	Vs TO BED-ROCK	F0	REGION
CPS	2D array ESAC + HVSR	730 m/s	19 m	630 m/s	2.7	
AQG	2D array ESAC + HVSR	1150 m/s	0	0	6.3	
PSC	2D array ESAC + HVSR	1000 m/s	0	0	4.3	ABRUZZO
AQP	2D array ESAC + HVSR	830 m/s	7 m	500 m/s	1.9	
SCN	2D array ESAC + HVSR	840 m/s	20 m	750 m/s	3.6	
MRM	2D array ESAC + HVSR	1400 m/s	0	0	Flat	
SPS	2D array ESAC + HVSR	320 m/s	29 m	310 m/s	3.4	CALABRIA
VBM	2D array ESAC + HVSR	450 m/s	34 m	460 m/s	5.2	
VBV	2D array ESAC + HVSR	510 m/s	24 m	450 m/s	13.5	
MTC	2D array ESAC + HVSR	1000 m/s	5 m	400 m/s	18.3	LAZIO

After a preliminary survey, the local geological setting was analysed on the basis of field surveys. This allowed the reconstruction of local geological maps (1:5000) for the area surrounding the site, by also defining a representative section indicating major geologic/lithologic units. These maps were implemented in the ITACA database. Aims of this analysis was twofold. First of all, it allowed the correct identification of the geologic body where the station is located and the eventual presence of lithological heterogeneities or tectonic structures (faults, folds, etc.) potentially responsible for lateral and vertical variations in the mechanical properties of the subsoil, that can be responsible for energy trapping and resonance phenomena. To this purpose a suitable geologic legend was set up to enlighten features of major seismological interest. The second aim of this study was supporting interpretation of geophysical measurements and to evaluate the degree of representativeness of measurements carried on at sites located nearby the RAN station but not at the station. In fact, a major problem of the application of seismic techniques for characterization of rock sites, is represented by rugged terrain, that are typical of sites where erosion phenomena are less effective. This implies that in many cases (in particular when seismic array configurations are of concern) it is difficult to find suitable sites at the station and it results necessary to perform prospecting elsewhere. In these cases, it is mandatory to establish a correlation between the seismic profile at the RAN station and the one actually obtained form measurements. This must be performed on the basis of a detailed geological analysis.

As decide in the first year, two passive seismic prospecting techniques were considered. The first one is the single station HVSR (Horizontal to Vertical Spectral Ratios) technique was adopted to determine the fundamental resonance frequency (F0) at each station and to constrain the eventual seismic impedance contrast potentially responsible for observed resonance phenomena. Since this kind of measurements are not time consuming and require negligible soil occupation, several measurements of this kind were carried on at the station and in the surroundings, to evaluate the possible presence of significant lateral variations in the subsoil seismic properties.

Along these measurements, array ambient vibration monitoring was also performed to constrain the local VS profile. To this purpose, the ESAC (Extended Spectral Correlation Analysis) was adopted to retrieve the effective Rayleigh waves dispersion curve. This was jointly inverted along with local HVSR curves by adopting suitable numerical procedures (Genetic Algorithms), to determine depth of the local bedrock (here considered as the depth where Vs values above 800 m/sec are reached or where a major seismic impedance contrast exists) and the average Vs value up to this bedrock.

A major problem encountered in these studies was the evaluation of these pieces of information at the RAN station where surveys were performed at sites located apart from the the RAN site (anyway within few hundreds of meters). In these cases, again, geological interpretations revealed of major importance. Results of these studies were described in detailed station reports included in the ITACA database.

Along this activity, RU7 also supported field activities carried by another research unit (RU5). This support consisted in the data inversion of Array and single station passive measurements carried on at a set of RAN stations located in Basilicata. The set of considered RAN sites and major inversion results are reported in Table 2.

A major result of these analyses was field testing of passive seismic techniques for seismic prospecting of rock/stiff soil sites. Their application presented a number of specific problems (common with other prospecting techniques) that were overcame by adopting new specific protocols that will reveal useful for future applications. Anyway these techniques were able to provide useful results with very low costs and this support their extensive use for the systematic seismic characterization of RAN sites not considered so far.

Table 2 – List of accelerometric RAN sites surveyed by UR5 and analysed by UR7. Along with the official denomination of each site, major experimental results obtained during the study are reported (F0 is the fundamental resonance frequency at each site)

RAN code	Prospecting techniques	Vs 30	DEPTH TO BED-ROCK	Vs TO BED-ROCK	F0	REGION
MRV	2D array ESAC + HVSR	680 m/s	17 m	590 m/s	7	
PGA	2D array ESAC + HVSR	430 m/s	20 m	340 m/s	5.6	
STL	2D array ESAC + HVSR	390 m/s	53 m	530 m/s	Flat	BASILICATA
TRO	2D array ESAC + HVSR	780 m/s	0 m	0 m/s	No measure	
MRA	2D array ESAC + HVSR	1030 m/s	0 m	0 m/s	unreliable	

Another major result, is that seismic resonance phenomena apparently also affect RAN sites located on outcropping bedrock (see tables). This implies that this last condition last cannot be considered, by alone, to representative of an actual reference site for engineering purposes.
A last result, that is in line with findings provided by other RU, is that large scale geology deduced from 1:100000 standard geological map does not allow a correct identification of the local geology at the considered RAN sites. In fact about 50% of sites that where considered on rock/stiff soil subsoil from a preliminary analysis of standard geologic maps revealed to be actually located on outcropping bedrock (Vs>800 m/s).

7.2 Deliverables

RU7 cooperated in the definition of Deliverables 6, . RU7 was responsible for the compilation of deliverable 11: "Criteria for identification of rock/stiff soil sites: examples from ITACA stations"

7.3 Problems and difficulties

A major difficulty was encountered for the geomechanical characterization of the sites under study. This kind of analysis was initially planned but encountered a basic difficulty in the field practice in that it resulted quite difficult to find at the sites here considered representative outcropping bodies, suitable and representative of the actual geomechanical condition. Thus, this kind of analysis was abandoned in favor of standard geological surveys.

7.4 Selected publications

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8 Report on the project activities by RU8 GFZ

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8.1 Activity of RU8 in phase 2

The RU8 co-coordinated Task 3 and participated to the activities developed within Task 4. In the following, the activities will be summarized task by task.

8.1.1 Task3: Site characterization by surface waves methods

The RU co-coordinated this task together with RU4 PoliTo.
The coordination required the re-arrangements of the planned activities of several groups that have been involved in the field campaigns carried out soon after the April 2009 L'Aquila earthquake. Although the emergency situation slowed down some activities in the emergency period, it was possible, with the close cooperation of the RUs and the efforts of the project coordinators, not only to carry out the expected measurements at the selected sites but also to add new sites in the Abruzzo region adding value to the project.
The RU8 performed array measurements at 12 different sites located in Abruzzo, Basilicata, Emilia Romagna and Umbria regions (Figure 1), in collaboration with RU1 and RU5. In particular, in agreement with the choices described in the 1st year report, the investigated stations in Emilia Romagna were: Novellara, Modena, Faenza, Argenta, Cattolica; those in Basilicata were: Sant'Arcangelo, Lagonegro, Grumento Nuova; the sites investigated in Umbria were: Norcia Zona Industriale, Bevagna. Besides the stations decided during the phase I of the project, two additional sites were selected after the 2009 L'Aquila earthquake and investigated by array measurements, namely Bazzano and Onna.
The instruments used are EDL 24bit digitizers coupled with short-period Mark-L4-C-3D 1Hz sensors and GPS timing. Microtremor measurements in 2D array configuration were carried out for more than 1 hour to record ambient noise at 200 sps. For each site the Rayleigh wave dispersion curve was estimated considering the vertical component of the recorded microtremors. In particular, the Extended Spatial Auto Correlation (ESAC; Ohori et al., 2002) and the Frequency-Wavenumber (FK; Lacoss et al., 1969) methods were adopted. Both high-quality Rayleigh wave dispersion and *H/V* ratio curves were used for a joint inversion scheme, as proposed by Parolai et al. (2005 and 2006), to estimate the local S-wave velocity profile. Figure 2 shows the velocity model for station Grumento Nuova (Basilicata) whereas the results obtained for Onna (Abruzzo) are summarized in Figure 3.

Figure 1: Sites investigated by RU8 with surface wave methods

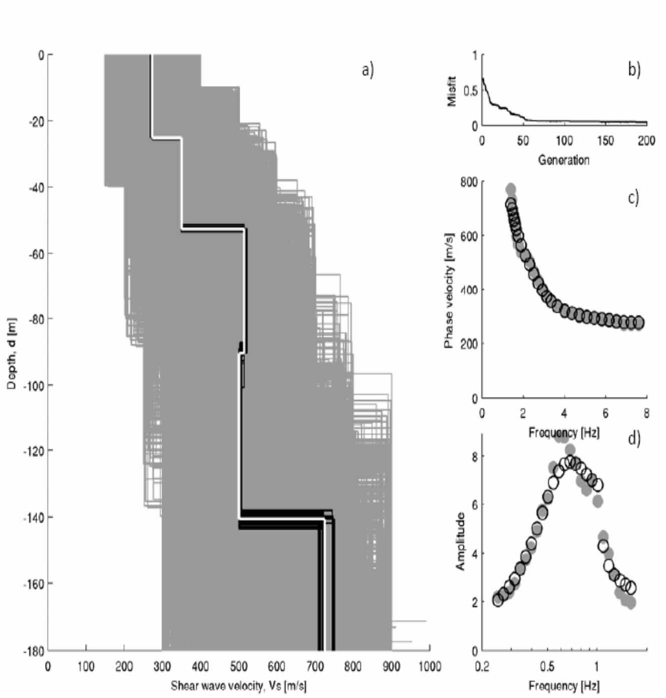

Figure 2: Shear wave velocity model at the Grumento Nuova station (a). Grey lines are the tested models, white line is the minimum cost model, while black lines are models lying inside the minimum cost + 10% range. The misfit function as function of the number of generation is shown in panel b. The comparison between observed (grey circles) and reconstructed by the final model (empty circles) dispersion curve (c) and H/V ratio (d) are shown as well.

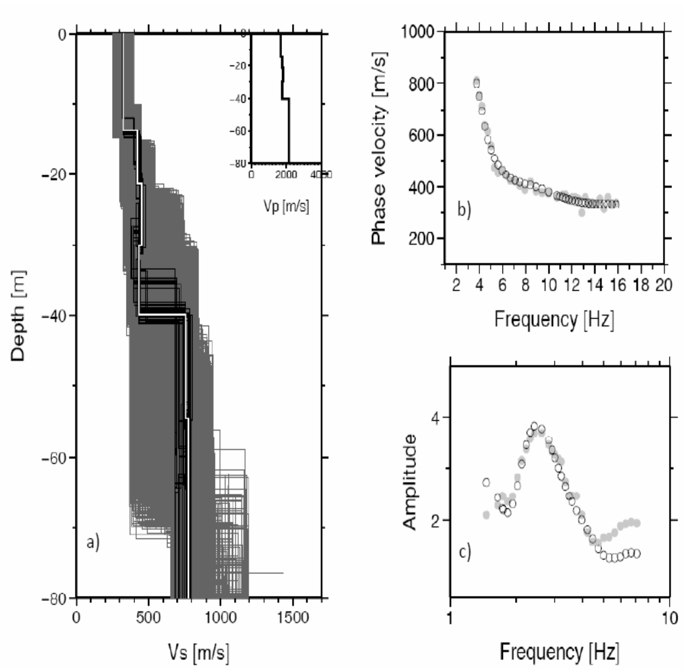

Figure 3: The same as Figure 2 but for Onna. The array was deployed close to the temporary station MI03, installed by INGV to monitor the 2009 L'Aquila sequence.

8.1.2 Task 4: Identification of anomalous sites and records

The RU8 installed, together with RU1, a temporary network in the Norcia plain (Figure 4), in proximity of the the stations NOR, NRC and NRZI of the Italian Strong Motion Network
The seismological network consisted of 15 EDL 24bit digitizers, with GPS timing, coupled with short-period Mark-L4-C-3D 1Hz sensors. It was operative in continuous mode from January to May 2009. At the moment when we are writing a set of 80 earthquakes, occurred before L'Aquila sequence, has been extracted and analyzed. HVSR and SSR have been calculated using signal windows encompassing the S-wave arrival. The signal windows have been visually selected. The obtained results shows that there is a general good agreement between the position of the fundamental peak of amplification identified by HVSR and SSR, In particular, both techniques show that in the Norcia plain, the fundamental frequency is in the range between 0.4 – 2 Hz, depending on the position of the sites inside the basin. On the contrary, significant differences between the results achieved by applying the two techniques are observed at frequencies larger than the fundamental one, due to the presence of amplification peaks over the vertical component (Deliverable D9, Appendix C).

RU8 cooperated with RU3 for the definition of a 3D model for the basin of Gubbio and for the numerical simulations of ground motion for sites located within the valley.

In cooperation with RU1 and RU3, the identification stations with distinctive features has been performed by computing the residual distribution between observations and prediction from Ground Motion Prediction Equations (GMPEs) and evaluating the inter-station distribution of error. Details about the procedure can be found in Deliverable D8, and the results for station NRC are also shown in Deliverable D9.
Finally, RU8 was involved in the development of new Ground Motion Prediction Eaquations (GMPEs) for Italy, derived from the data in ITACA. This activity was transversal to Task 4 and Task 5, and it benefited from the results provided by all the other Tasks. Details on the

data set, functional form and the coefficients of the regression are described in the Deliverable 14.

Figure 4: Configuration of the temporary network installed in the Norcia plain.

8.1.3 Task5: Site classification

RU8 participated to the discussions during the project meetings, in particular to those dedicated to the selection of suitable methods for the identification of anamalous sites and to their result analysis with advices and suggestions.

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Results obtained in the project framework

Task 3: The analysis of seismic noise collected by array of stations at 12 sites has allowed the classification of the the nearby strong-motion stations in term of Vs30. Furthermore it has been possible to provide for these stations the relevant fundamental resonance frequency values and the detailed S-wave velocity profiles well below 30 m, that can be in future used for testing and applying different and more refined site classification schemes.

Task4: The data set collected by the temporary seismic network in Norcia allowed to estimate the modification of ground motion within the basin, that represent a typical structure for central Italy. In particular the large data set collected of events occurred before and during the L'Aquila sequence will be ideal for continuing studies dealing with 2D-3D site effects, for calibrating numerical simulation codes and for better understanding then potential of different seismic phase in determining damages.

Task 4/Task 5. New Ground Motion Prediction Equations for Italy have been derived in the magnitude range 4 - 6.9 and for distances up to 200km. The regressions have been performed for both the geometrical mean of the horizontal components, and for the vertical one. The results of all the field surveys have been exploited to define the site classes accordingly to EC8.

8.2 Deliverables

Deliverable	Original description	Role of the RU
D7	Application of surface – waves methods for seismic site characterization of ITACA stations	The RU collaborated to this deliverable in the analysis of the array measurements of the stations located in Emilia Romagna region. The RU participates to the drawing of the document merging the contributions of the different RUs.
D9	Experimental and numerical results for all stations selected to study the effects of anomalous site conditions	The RU collaborated to this deliverable in the spectral analysis of the experimental data of the Narni hill.
D14	Calibration of new ground motion prediction equations from the ITACA database	The RU was responsible of this deliverable for the preparation of the input data and the implementation of the regression analysis

8.3 Problems and difficulties

The occurrence of the L'Aquila earthquakes required to re-discuss the priorities assigned to the selected sites. A characterization of sites nearby l'Aquila where large ground motion was recorded was considered of primary scientific and social interest. Nevertheless, the possibility of carrying out measurements in the area affected by the earthquake required to re-schedule the activities. RU8, in cooperation with RU1 and RU5-UniBas was able, overstepping logistic

problems, to investigate the sites planned in the original proposal and to perform measurements also at two new sites, Onna and Bazzano, respectively.
Furthermore, the monitoring of Norcia was also extended with respect to the original time table, in order to record the earthquakes of the 2009 L'Aquila sequence.

8.4 Publications

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