

## SITE CHARACTERIZATION IN ITACA DATABASE

L. Luzi<sup>1</sup>, C. Felicetta<sup>2</sup>, R. Puglia<sup>1</sup>, E. Russo<sup>3</sup>, F. Pacor<sup>1</sup>, M. D'Amico<sup>1</sup>, G. Lanzano<sup>1</sup> and Working Group 2014<sup>4</sup> INGV-DPC Project S2-Task2

<sup>1</sup> Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano.

<sup>2</sup> Istituto di Geologia Ambientale e Geoingegneria, Area della Ricerca di Roma 1, Montelibretti (RM).

<sup>3</sup> Centro Nazionale Terremoti, Roma.

<sup>4</sup> Working Group 2014 INGV-DPC Project S2-Task2: Research Unit 1: Barnaba C., Laurenzano G., Priolo E., Moratto L., Bertoni M., Tamaro A. (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste), Gallipoli M.R. (Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale, Tito Scalo - PZ), Lizza C., Vignola L. (Mallet s.r.l.). Research Unit 2: Lovati S., Massa M. (INGV, Milano), Ladina C. (INGV-CNT-Roma). Research Unit 4: Barani S., De Ferrari R., Ferretti G., Scafidi D., Spallarossa D. (Università degli Studi di Genova). Research Unit 5: Albarello D., Francescone M., Lunedei E., Paolucci E., Papisidero M. P., Peruzzi G., Pieruccini P. (Università degli Studi di Siena). Research Unit 8: Castellaro S., Panzeri R., Borgia U., Perricone L. (Università di Bologna). External to the project: Moscatelli M. (CNR-IGAG).

**Introduction.** Ground motion characteristics are strongly influenced by local geologic, geomorphological and geotechnical conditions as well as by seismic source and propagation path. The local site conditions can modify the ground motion in terms of amplitude, frequency and duration of the seismic shaking (Rathje *et al.*, 2010).

Theoretical studies and empirical observations have allowed to discriminate three main types of site effects caused by:

- presence of sediments buried geometry;
- particular topographic settings;
- lateral heterogeneities that can determine 2D and/or 3D effects.

Available information at seismic stations are frequently inadequate for a proper characterization and can have a significant impact on the definition of seismic hazard both at large and local scale.

**ITACA station database.** The database ITACA (ITalian ACcelerometric Archive <http://itaca.mi.ingv.it>, Luzi *et al.*, 2008; Pacor *et al.*, 2011) is not only a waveform repository, but also a tool to archive the results of site characterization. The database contains data that were mainly acquired by: the Italian Civil Protection Department (DPC) through the Italian Strong-motion Network (RAN) and the national seismic network operated by Istituto Nazionale di Geofisica e Vulcanologia (INGV). The results of site characterization were obtained from different sources such as: DPC-INGV seismological projects (2006 S6-Project; 2007-2009 S4-Project and 2014 S2-Project) and a joint project (GeoRAN 2014-2015) between CNR-IGAG and DPC.

ITACA ([itaca.mi.ingv.it](http://itaca.mi.ingv.it)) can host stations metadata such as location, housing, geological and geomorphological details, shear-wave velocity profiles ( $V_s$ ) or resonance frequency obtained by analysis of ambient noise. In general the station information is available at different levels of details depending on extent of researches performed on the site.

Fig. 1 shows the web page for the RAN station AQV (L'Aquila – V. Aterno – Centro valle). This page contains details related to the station and they are grouped into four main categories: 1) descriptive metadata of recording site such as station code and localization in terms of geographic coordinates, address and housing of the recording instrument; 2) information regarding soil category, value of  $V_{s,30}$ , type and quality of measurement to estimate the shear-wave velocity; 3) morphologic and topographic description; 4) quantitative information for seismic site characterization such as Standard Penetration Test (SPT) logs,  $V_s$  and/or  $V_p$  profiles, and stratigraphic logs.

Station information and other details are included in the station monography that can be downloaded from the web page. The monograph collects extended information, when available, such as photo, geological maps at different scales, geophysical and geotechnical surveys, position of logs, stratigraphic profile, plot of  $V_s$  and/or  $V_p$  profiles, report of microtremor H/V spectral ratio and a frame with a synthesis of information. At the end of the page links to other documents relating to the stations are present.

Station Detail

Station Name	L'AQUILA - V. ATERNO - CENTRO VALLE		Station Code	AQV	
Network	IT - Italian Strong Motion Network [DPC]				
Type	Permanent				
Lat	42.37722	Long	13.34389	Projection	GEOGWS84
Elev [m.a.s.l.]	692	Install. Date	1997-01-01	Removal date	
Macros. records					

Location			
Address	Strada Statale 80, 67100 L'Aquila, Province of L'Aquila, Italy		
Nation	Italy		
Region	Abruzzo		
Province	Province of L'Aquila		
Municipality	L'Aquila		

Housing			
Sensor Id	Housing type	Location	Installation
00	Fiberglass box	Free-field	

Notes			
Site Class			
EC8 Code	B		
V <sub>30</sub> m/sec	474.0	Reference	S6_2004-2006
Estimation	Cross-hole measurement	Quality	High

Morphology			
Morphology	Valley centre		
Topography	T1 - Flat surface, isolated slopes and cliffs with average slope angle $\alpha \leq 15^\circ$		
Map	IGM sheet 139, sector II, orientation SE	Scale	1:25000

GEOTECHNICAL LOGS						
Id	Reference	Latitude	Longitude	Nspt profile	Vs/Vp profile	Cu profile
1	S6_2004-2006					

STRATIGRAPHY				
Id	Reference	Latitude	Longitude	Detail
1	DBDAL.1	42.377049	13.343855	

Fig. 1 – Web page of ITACA database for AVQ (L’Aquila – V. Aterno – Centro Valle) RAN station.

**Measurements of ambient noise.** In ITACA database, about 400 microtremor measurements are available. The major of them was provided by the Department of Civil Protection through 2 campaigns conducted in the period 2011-2014. In order to make these measurements comparable, all noise-records were processed with the same procedure (Puglia *et al.*, 2011).

The main steps of the processing are: i) application of 1st order baseline correction and a 4th order acasual Butterworth band-pass filtering to the entire time series; ii) subdivision of each record in windows and definition of the relevant minimum expected  $f_0$ , following the criteria recommended in the SESAME project (2005); iii) application of 1st order baseline correction and a 5% cosine taper to each window; iv) calculation of the Fourier spectra and smoothing through the Konno and Ohmachi (1998) algorithm, fixing the relevant parameter  $b$  to 40; v) computation of the Horizontal –to–Vertical–Spectral Ratio (HVSr) values for each window as the ratio between the vector summation of the Fourier spectra of horizontal components and the spectrum of the vertical component; vi) HVSr curve computation by averaging the single HVSr curves, considering a log-normal distribution of amplitudes to obtain the mean with the relevant 68% confidence interval.

Windows exhibiting large transients were generally excluded from the analysis; these windows were visually identified from the velocity time series and from the single window Fourier spectra and spectral ratio.

In the analysis of the resonance peaks, the minimum expected  $f_0$  was always set to a value equal to or higher than the lower frequency recordable by the instrument. For example, in the case of Lennartz LE-3D/5s sensor this value is set to 0.2 Hz.

For each microtremor measurement, a report (Fig. 2) is generated and published in ITACA on the station monograph under the section “Microtremor H/V spectral ratio”. In this report,

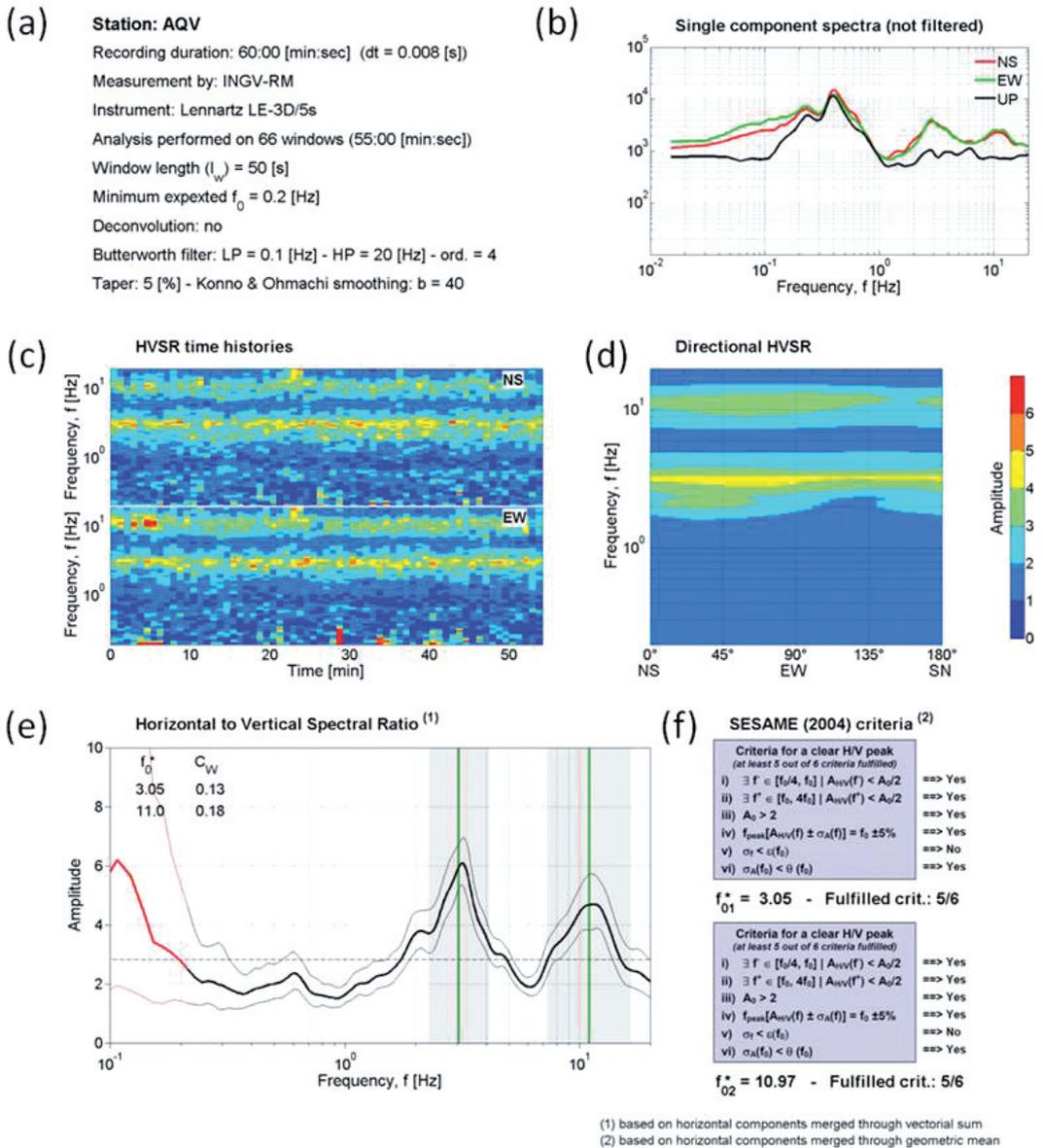


Fig. 2 – Example of microtremor report published on station monograph of ITACA: a) information about the measurements and processing parameters; b) smoothed/unfiltered Fourier spectra; c) HVSR time histories; d) HVSR azimuthal variations; e) mean HVSR; f) SESAME reliability criteria for the peaks identified in the HVSR.

details about the measurement and the parameters adopted for the analysis are reported (Fig. 2a), such as the duration of the recording, the sensor model, the minimum expected fundamental frequency ( $f_0$ ), etc. The results are displayed in terms of: unfiltered smoothed Fourier spectra for each component (Fig. 2b), time histories relevant to the components (Fig. 2c), rotated HVSRs (Fig. 2d), mean HVSR (Fig. 2e) and SESAME criteria indicating the degree of reliability of the HVSR peaks (Fig. 2f).

The main goal of the technical reports published on ITACA is to provide the end-user with the information about the quality of the microtremor measurement and the reliability of the HVSR peak, if any. In order to provide an immediate indication about the quality of the single

measurement and preventing misinterpretation of low-quality measurements, a reliability classification scheme was developed in the frame of the seismic microzoning activities following the 2009 L'Aquila earthquake by Albarello *et al.* (2011). This classification, is more conservative than the one proposed by the SESAME group (SESAME 2005), since it includes more criteria. Albarello *et al.* (2011) defines three classes:

- class A: trustworthy and interpretable HVSR curve, it represents a reference measurement that can be considered by itself for the site of concern;
- class B: ambiguous HVSR curve, should be used with caution and in case of coherency with other measurements performed nearby;
- class C: poor quality HVSR curve (hardly interpretable), to be discarded.

The majority of measurements of ambient noise can be grouped in classes A and B while about less than 10% are poor quality HVSR curves.

**Resonance peaks detection.** In order to physically interpret the curve in terms of “absence/presence” of resonance phenomena, two situations should be distinguished:

1. possible resonance: the HVSR curve presents at least one clear peak in the frequency range where the measurement could be considered reliable;
2. the HVSR curve does not present any clear peak in the frequency range where the measurement could be considered reliable: flat (F) or broad-band (BB) curves.

To provide such distinction, an automatic procedure was adopted (Puglia *et al.*, 2011) to identify the resonances peaks, their reliability and the sharpness of the HVSR curve nearby each of these values. Though the procedure it also to identify the broad-band or flat HVSR curves.

In case of resonance, we identify three different frequency – amplification bands:

- $f_0 \leq 1$  Hz      Low frequency (LF)
- $1 \text{ Hz} < f_0 \leq 4$  Hz   Intermediate frequency (MF)
- $f_0 > 4$  Hz      High frequency (HF)

and three amplitude – amplification range:

- $2.7 < A f_0 \leq 4.2$       Small amplitude (LA)
- $4.2 < A f_0 \leq 5.7$       Medium amplitude (MA)
- $A f_0 > 5.7$       Large amplitude (HA)

We apply these criteria to the noise measurement set collected in the Itaca database. Tab. 2 summarizes the results. The flat HVSR curves are the majority, however no clear correlation are found with the EC8 soil categories since most of the recording stations are classified on the base of geological information.

Tab. 2 - Results of frequency – amplification bands and amplitude – amplification range of HVSR curves collected in ITACA.

			amplitude – amplification range		
			LA	HA	MA
frequency – amplification range	F	129			
	BB	30	27	0	3
	LF	65	37	14	14
	MF	56	29	11	16
	HF	48	26	11	11

**Site classification in ITACA 2.0.** The geographic distribution of the 922 recording stations, that will be available in the next release of ITACA (ITACA 2.0), is shown in Fig. 3 (left panel). The majority of the stations (601) belongs to RAN (network IT) operated by DPC, while the remaining 321 are part of other networks.

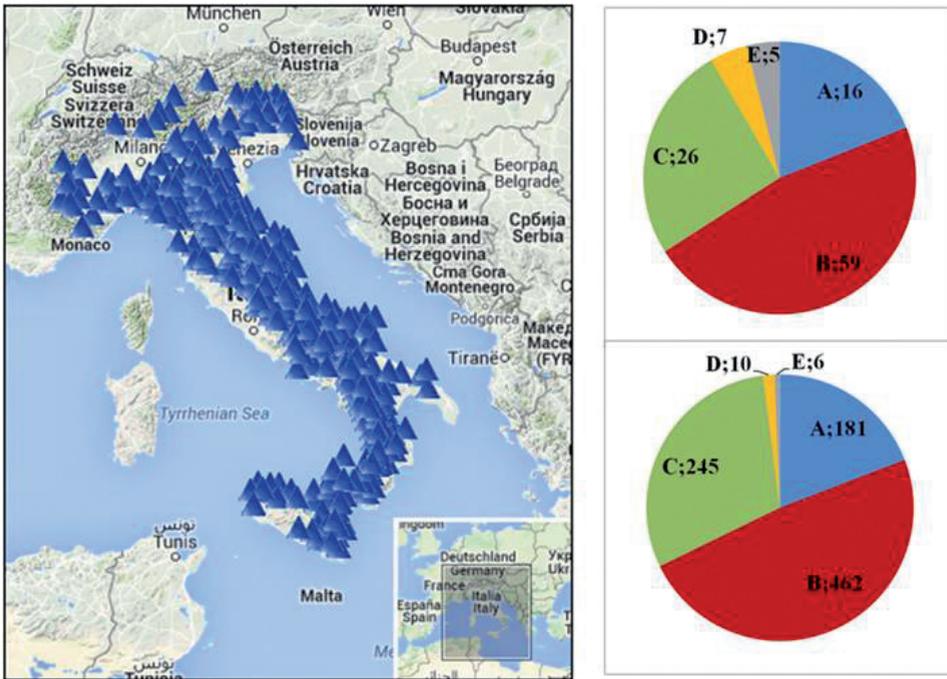


Fig. 3 – Left panel: map showing the geographic distribution of recording stations presented in the next release of ITACA (ITACA 2.0). Right panel: distribution of site classification according to EC8 code for the stations with available shear-wave velocity profile (top) and distribution that include station categorized according surface geology (bottom).

The recording stations are classified based on the Italian seismic provisions NTC08, which adopts a similar scheme as the EC8 Code. The seismic site response of the station is categorized according to the average shear – wave velocity between 0 and 30 m depth ( $V_{s,30}$ ), when available, or according to an expert judgment based either on surface geology or available geophysical information such as fundamental frequency.

With respect to the totality of recording stations included into ITACA database, only 1/6 is characterized with a measurement of the  $V_s$  profile. In particular, the database contains: 151 shear-wave velocity profiles for RAN station; 4 for the strong-motion network operated by ENEA (Agenzia nazionale per la nuove tecnologie, l’energia e lo sviluppo economic sostenibile), 6 for the University of Basilicata network, 5 for the Rete Sismica Nazionale operated by INGV, while the remaining 2 are for temporary network.

Fig. 3 (right panel) shows the distributions of site classification according to EC8 code for the stations with available shear-wave velocity profile (top). Stations categorized according to surface geology (Di Capua *et al.*, 2011) are marked with an asterisk and are shown in the bottom of the right panel. These temporary categories can change, once the relative shear-wave velocity profiles are acquired.

During the past INGV-DPC S2 Project, an extensive campaign of site characterization has been carried out, allowing to provide detailed site-specific characterization for about 50 recording sites. Notably, about 1/2 of the studied stations had changed their previously soil categories, assigned only on the basis of surface geology.

As an example, the station MLD (Meldola) classified as A\* in according to the surface geology, changed its soil category as C ( $V_{s,30} = 214$  m/s) after the  $V_s$  measurement.

In general, the class affected by the largest error is class B\*, as about half of the stations have been assigned to other classes after the experiments. This large uncertainty is probably due to

the large  $V_{s,30}$  interval characterizing this soil class (360-800 m/s) and to the difficulty to detect rock sites from the geological map. On the contrary, class C\* is more stable, as deep sediments are easily identifiable on the basis of the surface geology.

Tab. 1 quantify the upgrade in terms of EC8 class classification before and after the S2 DPC-INGV project (2014-2015).

Tab. 1 - Number of EC8 site class classification before and after the S2 DPC-INGV project (2014-2015).

# EC8 site class	Before S2	After S2
A	1	9
A*	8	2
B	1	14
B*	25	3
C	0	18
C*	14	2
E	0	1

In general, the  $V_{s,30}$  measurements provides a reliable estimation of the site amplification when the geological settings are close to one-dimension approximation.

When the sites are located in complex geological settings, the  $V_{s,30}$  is not a good proxy of site response. As an example, we present the case of the Malcesine station (code MLC). This station is located on one of the flanks of the Garda Lake and was formerly classified as A\* on the base of the geological information (Di Capua *et al.*, 2011). After the geophysical surveys carried-out in the frame of ING-V-DPC S2 Project (Barnaba *et al.*, 2015), the station moved to soil category B since the measured average shear wave velocity is  $V_{s,30} = 580$  m/s.

The variability of the ground-motion observed at this station were investigated by Lanzano *et al.* (2015) through the residual analysis according to Rodriguez-Marek *et al.* (2011) and Luzi *et al.* (2014). This analysis was carried out on a 2015 updated data set of records (retrieved by ITACA 2.0 and the European Strong Motion database (ESM <http://esm.mi.ingv.it>)), using the Bindi *et al.* (2011) as a reference Ground Motion Prediction Equations.

The residuals have been decomposed to retrieve the event, site and record-to-record errors. In particular, the site-term could be used to evaluate if the site response is coherent with the median predictions for the soil category assigned to the considered site.

The MLC station recorded 18 earthquakes, most of them belonging to the 2012 Emilia seismic sequence. Independently on the soil classification adopted to MLC, the site term estimated through the residual analysis always shows a remarkable amplification around  $T=0.1$  s; this behavior is also confirmed by the noise measurements. This high frequency amplification is not predicted for EC8-classes A and B and could be ascribed to the specific geological setting that are not represented by a simple 1D scheme.

**Conclusion.** The results of geophysical and geomorphological surveys performed in the framework of different scientific projects, collected in the ITACA 2.0 release, allow us to: i) update site-information at strong-motion Italian recording stations; ii) better individuate peculiar features that can be ascribed to site effects or soil-structure interaction; iii) improve the performance of empirical model for ground motion prediction.

Site classification inferred only from geological information can be misleading and surveys of site characterization of the recording stations should be promoted, in the future, in order to improve the current knowledge on strong motion seismology (site effects, Ground Motion Prediction Equations, hazard map validation).

## References

- Albarelo D., Cesi C., Eulilli V., Guerrini F., Lunedei E., Paolucci E., Pileggi D., Puzzilli L.M.; 2011:*The contribution of the ambient vibration prospecting in seismic microzonation: an example from the area damaged by the 26th April 2009 L'Aquila (Italy) earthquake*. Boll GeofisTeorApplVol. 52, n. 3, pp. 513-538; September 2011.
- Barnaba C., Bertoni M., Tamaro A.; 2015:*Site characterization of RAN stations performed by the OGS in the frame of S2-2014 Project: IT.MLC*. Technical Report DPC-INGV-S2 Project (<http://esm.mi.ingv.it>).
- Bindi, D., Pacor F., Luzi L., Puglia R., Massa M., Ameri G., and Paolucci R.; 2011: *Ground motion prediction equations derived from the Italian strong motion database*. Bull. Seism. Soc. Am. 9 1899-1920.
- Di Capua G., Lanzo G., Pessina V., Peppoloni S., and Scasserra G.; 2011: *The recording stations of the Italian strong motion network: geological information and site classification*. Bulletin of Earthquake Engineering, 9: 1779–1796.
- Eurocodice 8; 2005:*Progettazione delle strutture per la resistenza sismica*. UNI-EN 1998-1.
- Konno K., Ohmachi T.; 1998: *Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor*. Bull Seismol Soc Am 88:228–241.
- Lanzano G., D'Amico M., Felicetta C., Luzi L., Puglia R., Pacor F.; 2015: *Ground motion variability of the stations selected for PSHA model validation*. Deliverable D2.3, DPC-INGV-S2 Project: Constraining observations into Seismic Hazard.
- Luzi L., Felicetta C., Puglia R., Russo E., Pacor F., D'Amico M., Lanzano G., and Task2 Working Group; 2015:*Site-specific characterization of selected ITACA stations, DPC-INGV-S2 Project-2015-D2.1*.
- Luzi L., Bindi D., Puglia R., Pacor F., and Oth A.; 2014: *Single-Station Sigma for Italian Strong- Motion Stations*. Bull. Seism. Soc. Am. 104 467–483.
- Luzi L., Hailemichael S., Bindi D., Pacor F., Mele F., Sabetta F.; 2008: *Itaca (Italian Accelerometric Archive): A Web Portal for the Dissemination of Italian Strong-motion Data*. Seismological Research Letters, 79(5), 716–722. Doi: 10.1785/gssrl.79.5.716
- NTC08; 2008:*Norme Tecniche per le Costruzioni*. DM 140108, Ministero delle Infrastrutture, Roma, Gazzetta Ufficiale, 29, 4-2-2008.
- Pacor F., Paolucci R., Luzi L., Sabetta F., Spinelli A., Gorini A., Nicoletti M., Marcucci S., Filippi L., Dolce M.; 2011: *Overview of the Italian strong motion database ITACA 1.0*. Bulletin of Earthquake Engineering, Volume 9, Issue 6, pp 1723-1739.
- Paolucci R., Pacor F., Puglia R., Ameri G., Cauzzi C., Massa M.; 2011:*Record processing in ITACA, the new Italian strong-motion database*. In: Akkar S, Gulkan P, Van Eck T (eds) Earthquake data in engineering seismology. Predictive models, data management and networks, Geotechnical, Geological and Earthquake Engineering series, Vol. 14, Chapter 8. Springer, 99–113.
- Puglia R., Albarello D., Gorini A., Luzi L., Marcucci S., Pacor F.; 2011a:*Extensive characterization of Italian accelerometric stations from single-station ambient-vibration measurements*. Bulletin of Earthquake Engineering, 9: 1821-1838. Doi: 10.1007/s10518-011-9305-z.
- Puglia R., Russo E., Pacor F., Luzi L., D'Amico M.; 2014:*A software for the processing of the waveforms of the Italian strong motion database*. Second European Conference on Earthquake Engineering and Seismology, Istanbul. Aug. 25-29, 2014.
- Rathje E.M. Ph.D, Asce M., Kottke A.R., and Trent W.L.; 2010:*Influence of Input Motion and Site Property Variabilities of Seismic Site Response Analysis*. Journal of Geotechnical and Geoenvironmental Engineering, 136(4), 607-619.
- Rodriguez-Marek A., Montalva G. A., Cotton F., and Bonilla F.; 2011:*Analysis of Single-Station Standard Deviation Using the KiK-Net Data*. Bull. Seism. Soc. Am. 101 1242–1258.
- Site Effects Assessment using Ambient Excitations (SESAME) European project (2005) Deliverable D23.12—*Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing and interpretation*. <http://www.sesame-fp5.obs.ujf-grenoble.fr>. Accessed March 2010.