Seismic Ground Motion Assessment

DATABANK OF SEISMIC MOTION FOR EUROPE – RESORCE 2013 version :

Improvement of metaparameters
Inclusion of weak motion data
Internet portal
Perspectives and related European initiatives

(Deliverable D2-91)

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Seismic Ground Motion Assessment

DATABASE OF EARTHQUAKE GROUND MOTION DATA FOR EUROPE – RESORCE, 2013 version

Improvement of metadata
Inclusion of weak motion data
Data access Internet portal
Validation and review process
Perspectives and related European initiatives

(Deliverable D2-91)

Attached document : Akkar et al. (2013) RESORCE paper

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ABSTRACT

This document presents the overall procedure followed to assemble, implement, improve and validate the 2013 version of RESORCE (REference databaSe fOR seismiC ground-motion in Europe). RESORCE is the most up-to-date and largest pan-European seismic motion database.

RESORCE - 2013 principally updates and extends the previous version by the inclusion of recently compiled Greek, Italian, French, Swiss and Turkish accelerometric archives. The updates also include information taken from earthquake-specific literature studies published in recent years. The current version of RESORCE includes 5640 multi-component and uniformly-processed accelerograms from 1713 events and 1481 strong motion stations. The moment magnitude range covered by RESORCE - 2013 is $2.8 \leq M_W \leq 7.8$. The source-to-site distances are given in terms of common point- and extended-source distance measures.

Executive Summary

With the aim of improving seismic ground-motion models and reducing associated uncertainties, the compilation of a high-quality database of seismic-motion recordings and associated meta-parameters is of primary importance.

RESORCE is meant to be an up-to-date, homogeneous, integrated European seismic-motion database for developing and testing ground-motion models used in engineering seismology and for earthquake engineering purposes. It only contains validated data.

This deliverable shows the progress made starting from the previous version of RESORCE, presented at the May and December 2011 Scientific Committees (SIGMA deliverables SIGMA-2011-D2-09 and SIGMA-2011-D2-15). The previous version of RESORCE mainly contained strong-motion recordings of Italy and Turkey that were gathered from the ITACA (Luzi et al., 2010) and T-NSMP (Akkar et al., 2010; Sandikkaya et al., 2010) projects as well as ISESD (Ambraseys et al., 2004). Recordings from the other parts of Europe and the Middle East were quite limited. RESORCE-2013 has upgraded the data content by including accelerograms from Greece, Switzerland and France. The additional Greek accelerograms were retrieved from the HEAD (HEllenic Accelerometric Data; http://www.itsak.gr/en/db/data) database. The French accelerograms were incorporated from the RAP (French Accelerometric Network; http://www-rap.obs.ujf-grenoble.fr) whereas the Swiss data were compiled from the Swiss Seismic Network (SED; www.seismo.ethz.ch). The latter two data sets mainly consist of accelerograms from small and moderate earthquakes increasing the coverage of RESORCE towards lower magnitudes. In this way the seismicity of low-seismicity regions in Europe is represented in a more comprehensive way in RESORCE. Improvements in data processing have also been made, as well as corrections of some inconsistent metadata. The collection of both (the data and the metadata) as well as the data processing were carried out by the METU (Middle East Technical University) team.

As for the previous version, the content of RESORCE-2013 was reviewed by the members of the RESORCE Scientific Board, composed of: John Douglas, Gabriele Ameri, Bruno Hernandez, Lucia Luzi, Paola Traversa and Fabrice Cotton. This process led to the validation of the content of RESORCE-2013.

The previous version of RESORCE was used to derive five new European ground-motion models (Akkar et al., 2013b; Bindi et al., 2013; Derras et al., 2013; Bora et al., 2013; Hermkes et al., 2013). The feedback provided by these modelers constituted an additional input for RESORCE-2013. A special issue of the Bulletin of Earthquake Engineering, illustrating these models is in press (the articles are available on the journal's website). An introductory paper describing RESORCE (Akkar et al., 2013a), as well as a article comparing the different models (Douglas et al., 2013) also feature in the special issue.

The data access web portal, allowing for interactive metadata-driven data searches has been improved and is accessible at the address: www.resorce-portal.eu. The web portal is developed by EMSC (Euro Mediterranean Seismological Centre). Access to this web site is currently possible only by means of a username and a password that can be obtained by request to the management team.

In order to ensure the traceability of the database, a versioning system has been set up. It consists of freezing each RESORCE version and making it immediately accessible from the web portal. The end user can simply chose what RESORCE version he wants to access. In the future this system will allow returning to any published RESORCE version and retrieving the data used to develop a given ground-motion model. At the moment the two existing versions of RESORCE are accessible.

Exchanges and collaborations with related EC-funded projects, particularly EPOS and NERA, are ongoing. These activities seek to guarantee the long-term sustainability of RESORCE.

One should note that improvements of the current version of RESORCE are still needed. In particular, apart from some cases, the metadata associated to records coming from an original database have been kept as they are. Improvements can be made by the inclusion of parameters estimated in specific studies. The catalog published by ISC-GEM should be compared with RESORCE metadata. In some particular cases location and magnitude estimations are of better quality in the former source. In the current version of RESORCE this comparison has been made for a few earthquakes; it should be extended to all $M \geq 5.5$ earthquakes. The completeness of the database can be improved by integrating very recent earthquake data that have not yet been included.

Within SIGMA, RESORCE is the basic ingredient for the ground-motion model developments and ground-motion studies in WP2 that will be used in WP4 for the seismic hazard computations. WP5 benefits from RESORCE ground-motion records that are used for structural dynamic computations. WP1 contributes to RESORCE in terms of event metadata for the French seismic records. WP3 also contributes to RESORCE in terms of station metadata for French and some Italian seismic records.

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1. Introduction

Two years ago, the idea of implementing RESORCE (REference databaSe fOR seismiC ground-motion in Europe), devoted to the development and testing of ground-motion models to be used for seismic hazard studies and other engineering seismology and earthquake engineering purposes, emerged from the need of having a single integrated database for Europe, constructed with high standards and containing only verified data. Indeed the quality, completeness and level of information associated to data are highly heterogeneous among the different seismological networks and agencies in Europe. On top of this, ground motion developers use their own data and meta-data processing procedures, which increases the epistemic uncertainties associated to ground-motion models.

The most successful attempt to gather strong-motion data in and around Europe was led by Prof. Ambraseys and the Engineering Seismology and Earthquake Engineering section of Imperial College London, through FP4 and FP5 (and earlier) projects. The group collected, compiled and processed the accelerometric data through collaborations with seismic agencies since 1971. One of the remarkable products of this endeavor is a CD-ROM released in 2004 (Ambraseys et al., 2004b) and a web site known as ISESD (Internet Site for European Strong-motion Data, Ambraseys et al., 2004a), which disseminates the available pan-European strong-motion recordings assembled up until that date. The metadata information, as well as the data processing of strong-motion recordings disseminated in these sources was roughly uniform. Several ground-motions models (e.g. Ambraseys et al., 2005, Berge-Thierry et al., 2003) benefited from this database. This attempt became silent after 2004 because of lack of financial support, inadequate manpower as well as the limited involvement of seismic agencies providing data to this initiative.

After this initiative, the European Commission funded various projects within the context of the 6th and 7th Framework Programs (FP6 and FP7).None of these projects aimed to deliver an up-dated version of the pan-European strong-motion database. Among these projects, the recently concluded NERIES (Network of Research Infrastructures for European Seismology) project focused on the implementation of a real-time database of accelerometric records. Several tools for accessing (e.g. NERIES portal) and processing accelerometric data (e.g. PARAMAC software) were developed within NERIES. The goal of this kind of approach is to provide data and tools for earthquake monitoring and real-time strong-motion data processing (e.g. real-time hazard and shake maps). The products do not aim to allow detailed seismological and engineering studies, in particular the development of ground-motion models. NERIES was succeeded by NERA (Network of European Research Infrastructure for Earthquake Risk Assessment and Mitigation). NERA ensures the continuity and improvement of previously developed tools and research interactions. During the past decade, seismically-active countries like Turkey and Italy improved their strong-motion databases through national projects. These projects implemented their own procedures while assembling the databases, which may result in a lack of uniformity in metadata compilation and record processing when integrated in a single strong-motion databank. The SHARE project gathered data from recent strong-motion databanks but no attempt was made to homogenize the data processing of the accelerograms. Improvements to the earthquake and station metadata from recent studies in the literature were also out of scope of the SHARE strong-motion databank. The recordings from recent earthquakes of engineering significance in the broader European region (e.g., 2009 L'Aquila Earthquake Mw 6.3; 2011 Van Earthquake Mw 7.1; 2011 Van-Edremit Earthquake Mw 5.6; 2011 Kütahya-Simav Earthquake Mw 5.9; 2010 Elazıg Kovancılar Earthquake Mw 6.1) are either entirely or mostly disregarded in the SHARE strong-motion databank.

The primary motivation behind RESORCE is to be a single integrated accelerometric databank for the broader European area. The basic ingredient of RESORCE is the pan-European sub-set of the SHARE strong-motion databank (Yenier et al. 2010). It updates and expands the ISESD accelerometric archive using information gathered from recently carried out strong-motion database projects as well as from other relevant earthquake-specific studies. The uniform data processing of accelerograms as well as improved magnitude and source-to-site distance distributions constitute other important steps in RESORCE.

2. RESORCE-2013 content and improvements

This chapter gives detailed information about the current status of the Reference Database for Seismic Ground-Motion in Europe (RESORCE), with special emphasis on the improvements made while integrating the additional Greek, French and Swiss accelerometric data. We also describe the approach followed to remove bad quality and distant accelerometric data from RESORCE. The filtering of bad quality and distant accelerometric data was the suggestion of review panel as they are of little significance in engineering-related studies. The previous version (version 1) of RESORCE – that is described in Akkar et al. (2013), attached to this document – mainly contains strong-motion recordings of Italy and Turkey that were gathered from the ITACA (Luzi et al., 2010) and T-NSMP (Akkar et al., 2010; Sandikkaya et al., 2010) projects as well as ISESD (Ambraseys et al., 2004). Recordings from other parts of Europe and the Middle East were quite limited. The recent version of RESORCE has upgraded the data content by including accelerograms from Greece, Switzerland and France. The additional Greek accelerograms were retrieved from the HEAD (HEllenic Accelerometric Data; http://www.itsak.gr/en/db/data) database. The French accelerograms were incorporated from RAP (French Acceleremoteric Network; http://www-rap.obs.ujf-grenoble.fr) whereas the Swiss data were compiled from the Swiss Seismic Network (SED; www.seismo.ethz.ch). The latter two national datasets mainly consist of low-to-moderate magnitude accelerograms increasing the magnitude coverage of RESORCE towards lower magnitude events. Additional data from France and Switzerland enable better representation of low-seismicity regions in Europe by RESORCE.

The first part of this chapter describes the procedure followed to integrate the Greek, French and Swiss accelerometric data. The second part presents the metadata information of each one of these national datasets to better explain their contribution to RESORCE. The third part provides information about the ground-motion data processing. The procedure followed for the removal of bad quality as well as distant accelerometric data is given in the fourth part, which is followed by a conclusive section presenting the overall picture of the current version of RESORCE.

2.1. Overall procedure for the integration of Greek, French and Swiss accelerometric data

The applied strategy to integrate the accelerometric data from these three countries is similar to the one followed while establishing the previous versions of RESORCE (see Akkar et al., 2013 for the general procedure used in the compilation of RESORCE). However, there are differences between the current and former data integration strategies in terms of identifying the duplicated recordings.

We studied the new databases in five steps:

1. **Determination of duplicated recordings, stations and earthquakes**. We first studied the existence of duplicated events by considering RESORCE – version 1 as it already contains data from France, Greece and Switzerland. The earthquake metadata information of RESORCE – version 1 was preferred for the duplicated events as we gave a careful consideration to the event information during its compilation. To this end, we only updated the station and site information of duplicated entries for the newly added data.

2. **Event metadata compilation of non-duplicate earthquakes.** The event metadata of new data that were not included in RESORCE – version 1 is gathered from peer-reviewed literature as well as global, regional and local seismological agencies. The contributions from peer-reviewed literature and global sources are limited during this phase as most of the additional events have small-to- moderate magnitudes, for which reliable event-based information could only be gathered from regional and local seismological agencies. For the Italian earthquakes whose Mw information is unavailable, Castello et al. (2007) magnitude conversion equations are applied as in RESORCE – version 1. The regional seismological agencies played an important role in supplying the moment-tensor solutions and moment magnitudes. Among the newly added earthquakes, 26% contain double-couple fault-plane solutions that indicate reliable information about their moment magnitude values and focal mechanisms. The style of faulting (SoF) of these events are classified according to the procedure proposed by Boore and Atkinson (2007). This procedure uses the plunge angles of the T- and P-axis of the double-couple fault-plane solutions. It does not require the actual fault plane solution and determines a unique SoF, which is not the case for SoF classifications based on the rake angle. (The rake angles of actual and auxiliary planes from double-couple fault-plane solutions can sometimes result in two different SoF classifications for the same earthquake). Table 1 lists the plunge angle intervals of the T- and P-axis for SoF classification in RESORCE.

Table 1 Plunge angle ranges for P- and T-axis for SoF classification

Style of Faulting	P-axis plunge angle	T-axis plunge angle
Normal	P-pl>40	T-pl<40
Reverse	P-pl<40	T-pl>40
Strike-slip	P-pl<40	T-pl<40

3. **Compilation of station and site information (station metadata).** The information that is directly gathered from the Greek, Swiss and French databases was used while compiling the station information. Not all the new entries contain the complete site and station information (e.g., instrument shelter and VS30). Thus, additional site-specific studies are necessary to complete the missing station metadata for the newly added databases.

4. **Calculation of source-to-site distance metrics.** As in the case of RESORCE-version 1 R_{epi}, R_{hyp}, R_{JB} and R_{rup} are calculated for the recently added Greek, French and Swiss accelerometric data. The calculations of extended-source distance metrics (R_{JB} and R_{rup}) are limited for the newly added data as most of the events do not have fault-plane solutions due to their small sizes. The extended-source distances were computed when fault-plane solutions exist. If the newly added earthquakes have double-couple fault plane solutions, the nucleation point was assumed to be at the center of the fault surface and the rupture dimensions of the fault (length and width) were estimated from Wells and Coppersmith (1994). The extended source metrics were calculated as pairs for each plane using the procedure described in Kaklamanos et al. (2011). The computed R_{JB} and R_{rup} for each plane as well as their arithmetic average were then incorporated into the RESORCE ground-motion archive.

5. **Ground-motion data processing:** The data processing scheme that was implemented in RESORCE-version 1 was also used for the newly added data. The details of the processing scheme in terms of removing the non-standard errors, band-pass filtering and post-processing can be found in our previous reports as well as in Akkar et al. (2013). They are summarized in the "*Processing of the accelerograms*" section.

2.2. Particular Features of New Databases Added to RESORCE

The Greek, French and Swiss accelerometric archives are integrated into RESORCE by following the procedure summarized in the previous section. The procedure is almost the same that was implemented in RESORCE – version 1 (see the previous reports or Akkar et al., 2013) except for the strategy applied for the duplicated events The following subsections individually details each database in terms of metadata as well as their overall impact on RESORCE. The results of data processing will also be discussed separately for each database.

Greek Accelerometric Archive

The HEllenic Accelerometric Data (HEAD) project provides Greek strong-motion recordings from stations operated by either ITSAK or NOA. The accelerometric data in HEAD spans from 1973 to 1999. Besides this database includes two recent Greek earthquakes that occurred in 2003 (Lefkada, Mw 6.2) and 2006 (Kythera, Mw 6.7).

The strategy described in the previous section was applied to HEAD and a total of 262 accelerograms (from 142 earthquakes) were added to RESORCE. The HEAD database provides information on earthquake location, depth, magnitude – most of them have reported Mw values (we employed Papazachos et al. (2002) magnitude conversion equation for Greek events that lack reported Mw) –, station coordinates, measured shear-wave velocity profiles (or estimated site classes according to Eurocode 8), shelter information, location of instrument deployment, type of recording (analog vs. digital), instrument model and processing information.

The event information of 142 earthquakes was compiled from the literature as well as global, regional and local seismological agencies. Table 2 lists the order of preferred sources for the Greek event metadata. The Greek accelerograms are recorded at 83 strong-motion stations. Of the Greek strong-motion stations, 48 of them have site class information. Of the Greek sites with site class information, 30 of them are inferred from local geology and only 18 strong-motion stations have measured VS30 values. The remaining stations have no site class information. The site class information is gathered from HEAD, Pitilakis and Riga (pers. comm., 2012), ISESD and ESMD (Ambraseys et al., 2004b). Only one third of the Greek accelerograms have extended-source distance measures after implementing the procedure used for source-to-site distance calculation. (See Akkar et al, 2013 for the details of computing source-to-site distances in RESORCE).

The plots of Mw versus source-to-site distance measures of Greek accelerograms are shown in Figure 1. Figures 2 and 3 give the histograms of events and recordings with respect to depth and style-of-faulting, respectively. Figure 4 presents site class distribution of strong-motion stations and recordings.

Table 2. Preferred references for the metadata information of Greek events

References	Event
Benetatos et al. (2007)[¥]	2003 Lefkada Earthquake
Boore et al. (2009)[¥]	2003 Kythira Earthquake
Louvari et al. (1998)[*]	1983 Kefallinia Island Earthquake
Lyon-Caen et al. (1988)[*]	1986 Kalamata Earthquake
Makaris et al. (2000)[*]	1997 Strofades Earthquake
Tselentis and Zahradnik (2000)[*]	1995 Kazani Earthquake
Tselentis et al. (1996)[*]	1995 Aigion Earthquake
ISESD[§] ESMD[§] HEAD[§] GCMT[§] RCMT[§]	Rest of events

[*] Literature survey from ISESD (Ambraseys et al., 2004a).
[¥] Additional literature survey made for the new RESORCE version
[§] See Appendix A for abbreviations

Swiss Accelerometric Archive

SED (arclink.sed.ethz.ch) is the primary source for Swiss accelerograms and this source has been used in the compilation of Swiss data for RESORCE. Except for the ruptured fault dimensions and information on actual fault planes from the double-couple solutions, the earthquake metadata required for RESORCE is obtained from SED. The sources that are used for the compilation of Swiss earthquake metadata are given in Table 3. One of the most seismically active regions in Switzerland is the border with Italy. Almost half the earthquakes that are recorded by Swiss strong-motion stations are in the Italian territory, for those events the earthquake information provided by ITACA or RCMT is preferred. This approach is consistent with the procedure followed in the compilation of RESORCE – version 1.

Table 3. Preferred sources for the compilation of Swiss events

References	Event
ISESD[§] Bommer et al. (2007) SED[§] SED1[§] SED2[§] ITACA[§] RCMT[§]	Rest of events

[§] See Appendix A for abbreviations

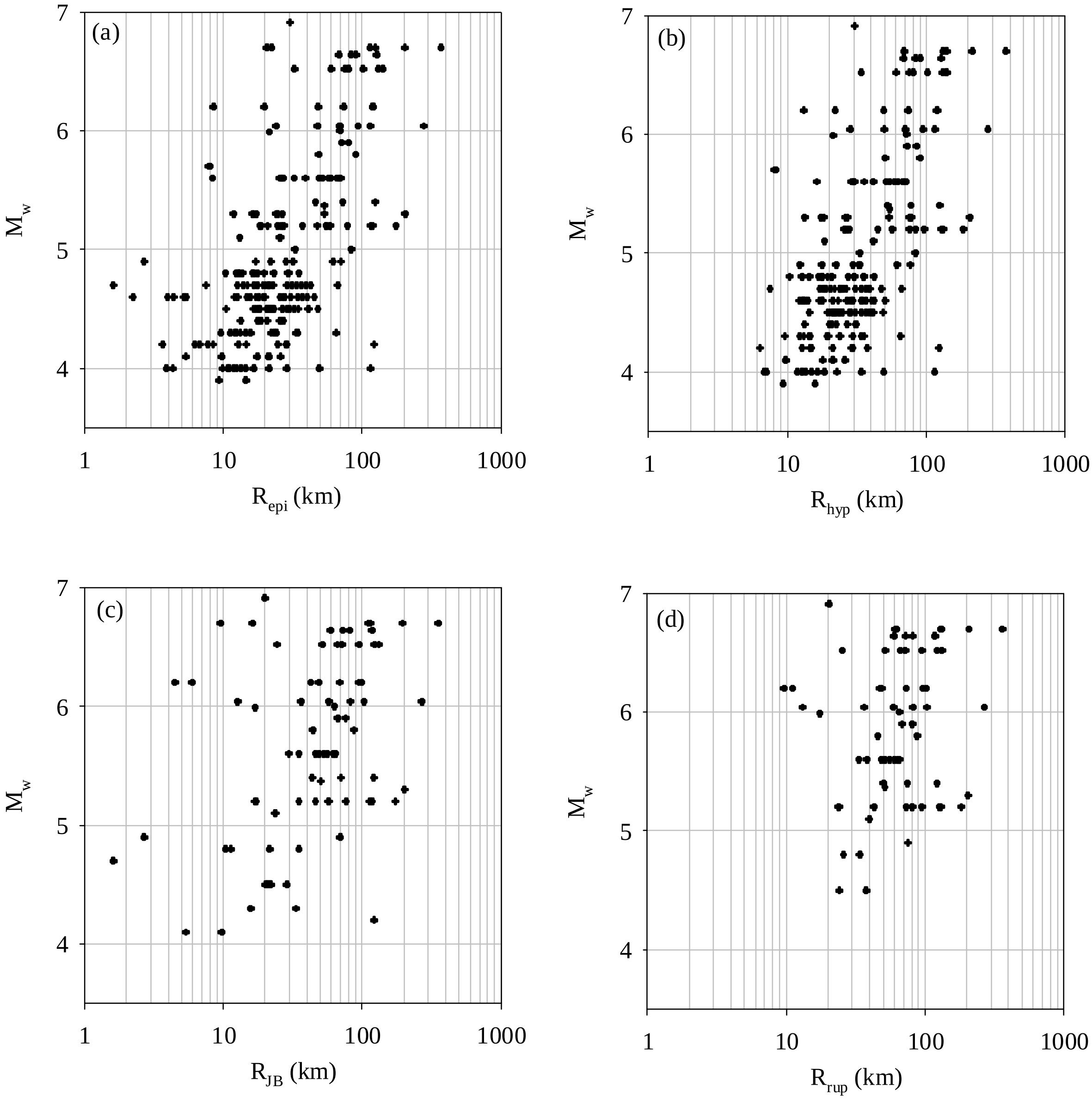


Figure 1. Scatter plots of Greek data for Mw vs. (a) R_{epi}, (b) R_{hyp}, (c) R_{JB} and (d) R_{rup}.

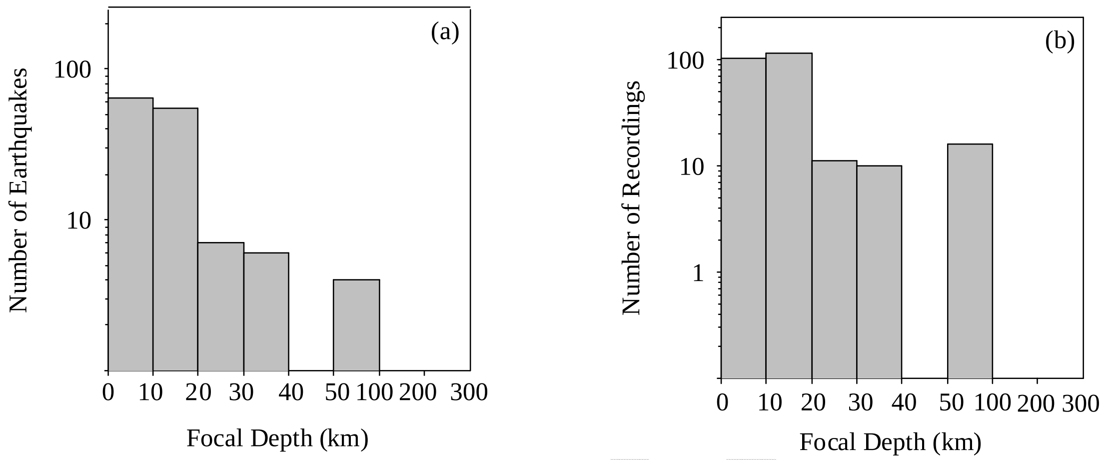


Figure 2. (a) Greek earthquake and (b) accelerogram distributions in terms of focal depth

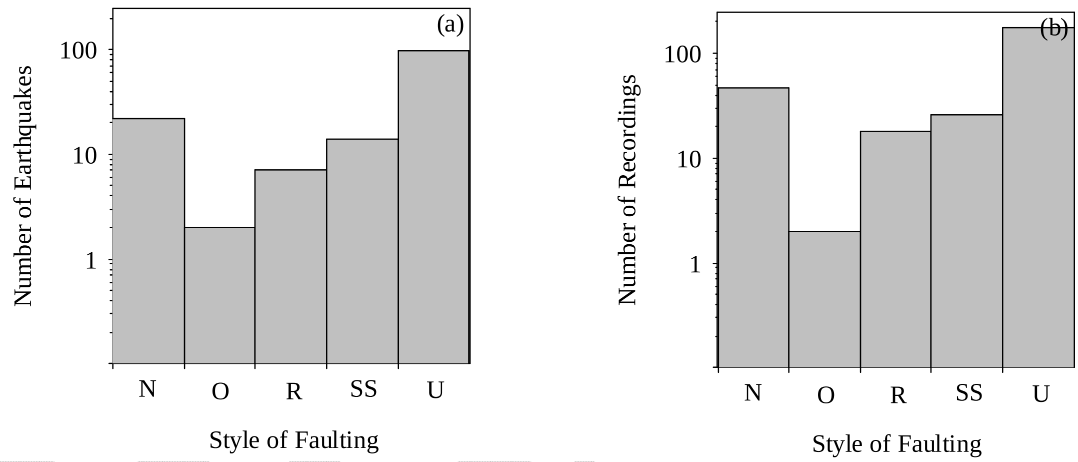


Figure 3. (a) Greek earthquake and (b) accelerogram distributions in terms of style-of-faulting

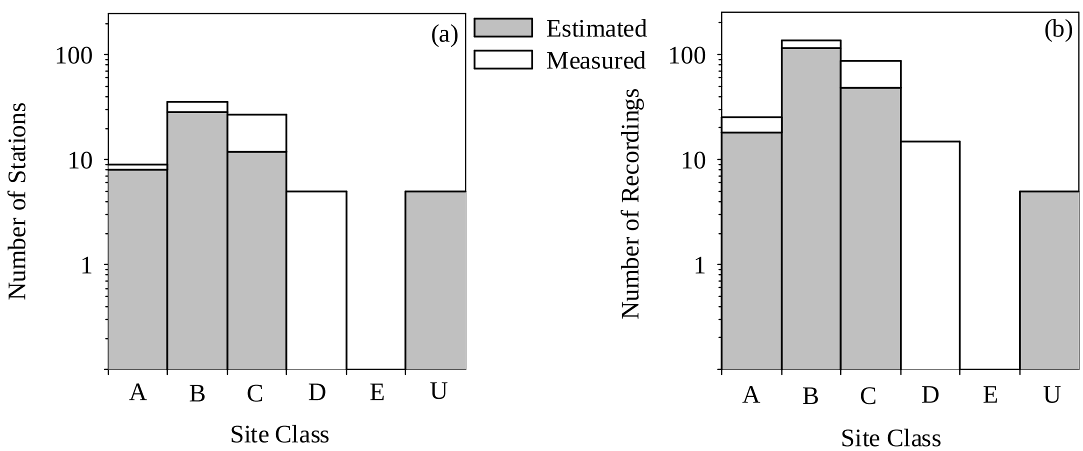


Figure 4. Greek (a) station and (b) recording distribution as a function of site class. The nomenclature used for site classes is adopted from Eurocode 8 (CEN, 2004). A site class is VS30 ≥800 m/s, B site class is 800 m/s

< VS30 ≤ 360 m/s, C and D site classes are 360 m/s < VS30 ≤ 180 m/s and VS30 < 180 m/s, respectively. The F site class requires site-specific geological and geophysical exploration. The letter "U" designates strong-motion stations and accelerograms with unknown site classification.

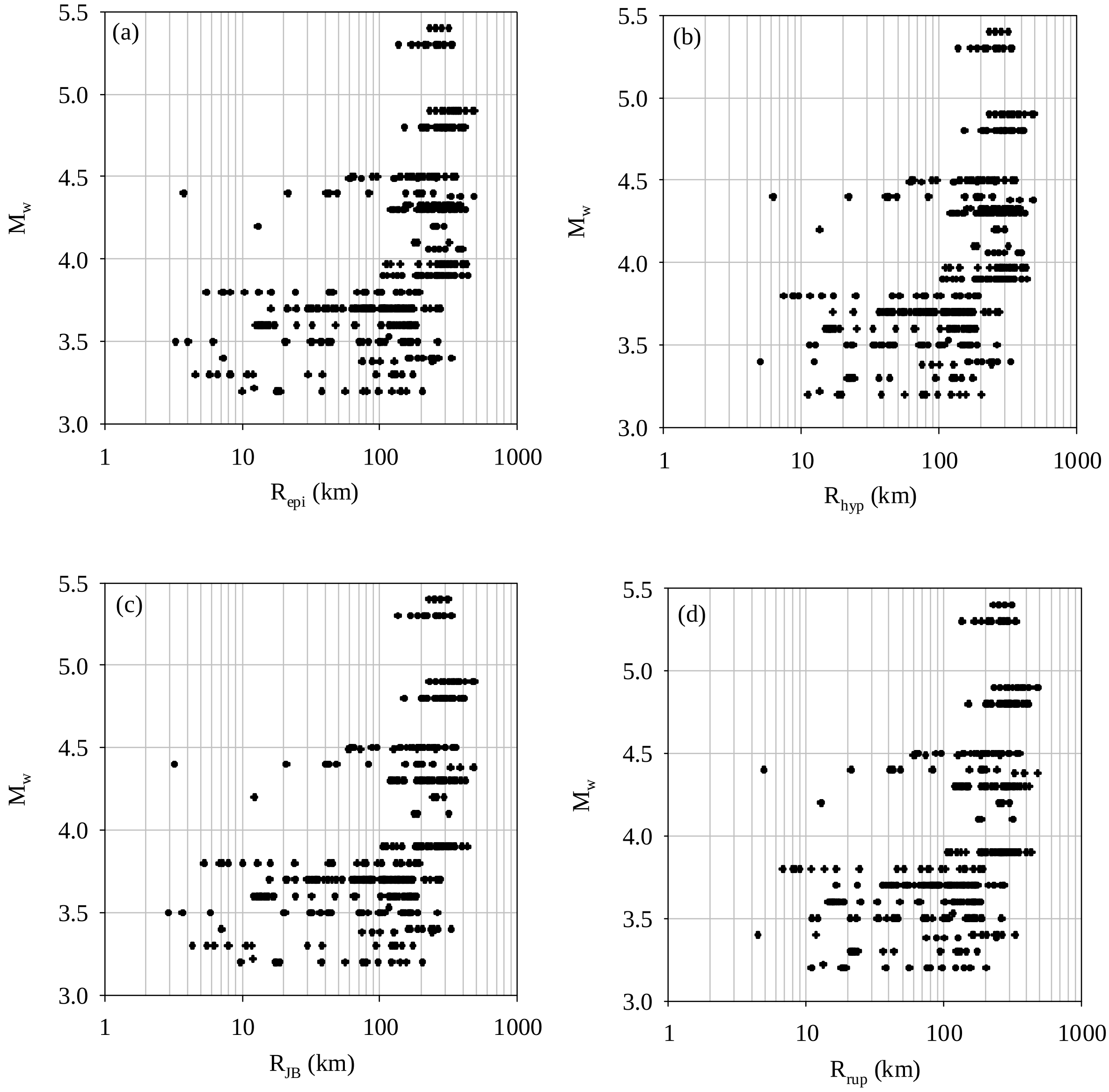


Figure 5. Same as Figure 1 but for Swiss accelerometric data compiled for RESORCE.

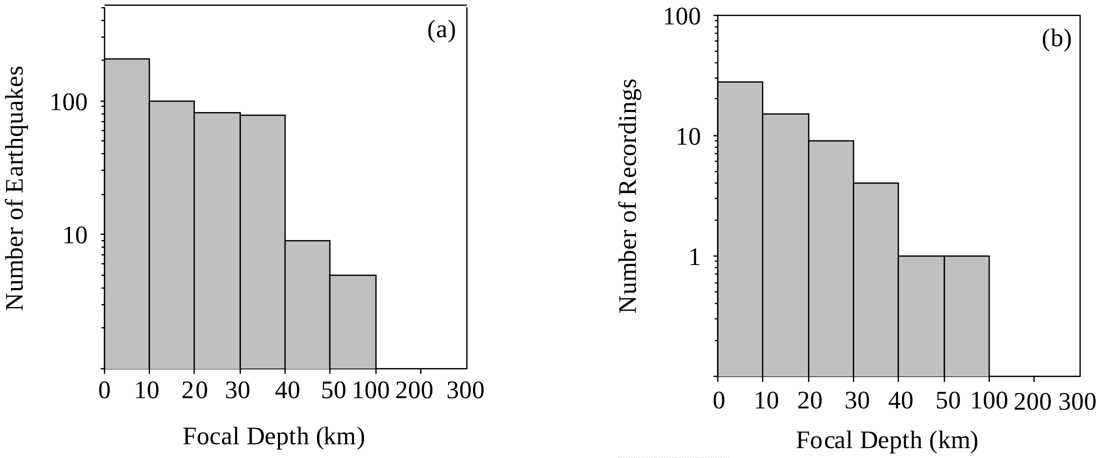


Figure 6. Same as Figure 2 but for Swiss accelerometric data compiled for RESORCE. a) Number of recordings, b) Number of earthquakes.

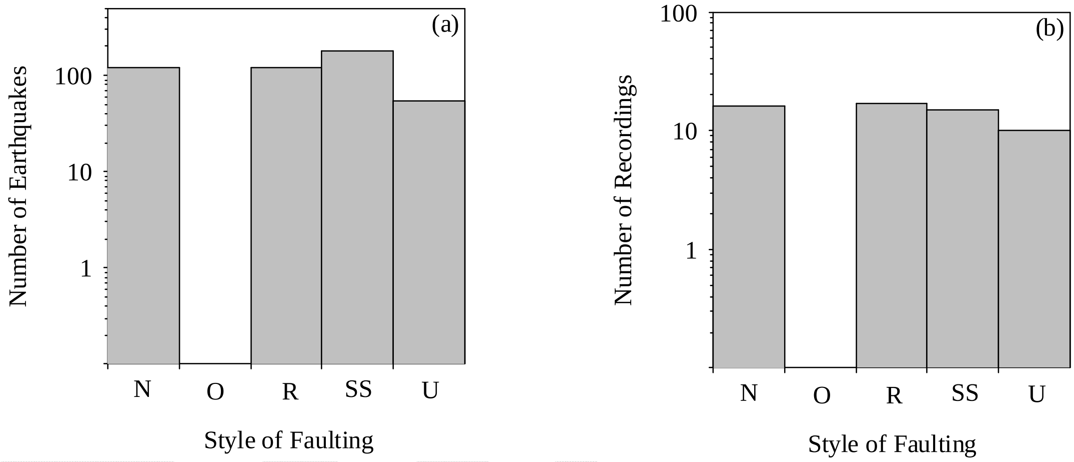


Figure 7. Same as Figure 3 but for Swiss accelerometric data compiled for RESORCE. a) Number of recordings, b) Number of earthquakes.

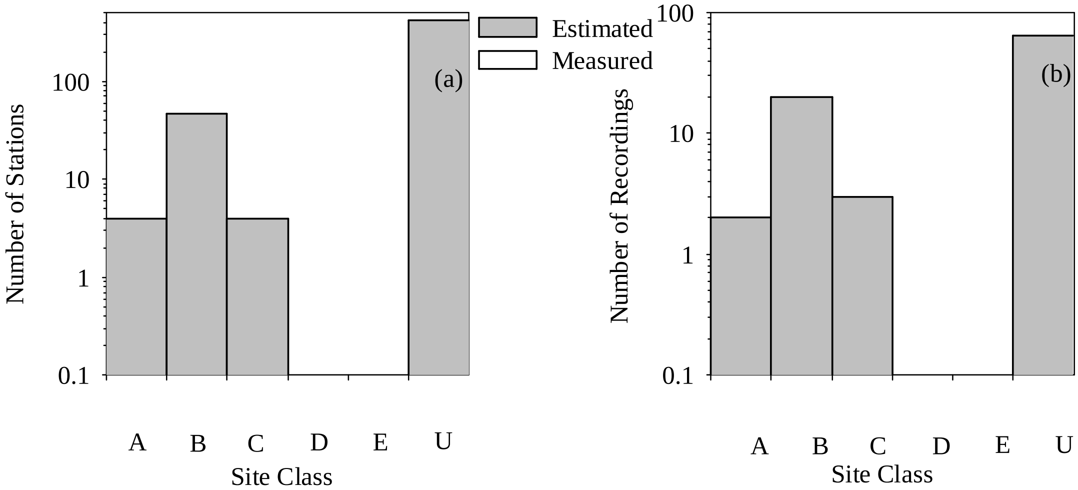


Figure 8. Same as Figure 4 but for Swiss accelerometric data compiled for RESORCE. a) Number of recordings, b) Number of earthquakes.

French Accelerometric Archive

We considered the French accelerometric data (RAP; http://www-rap.obs.ujf-grenoble.fr) recorded between 1995 and 2007 that is examined by Péquegnat et al. (2008), Péquegnat et al. (2011), and Roca et al. (2011). A total of 1751 digital recordings from 90 stations and 389 earthquakes were compiled in the framework of this study. The French accelerometric database includes information on earthquake coordinates, depth and magnitudes in local magnitude scale. The station coordinates and local network names are also given in the French accelerometric inventory. There are very few strong-motion stations with measured VS30 values. However, Régnier et al. (2010) provide site classes for the French accelerometric stations that do not have VS30 values from in-situ measurements. This report provides estimated VS30 values for the French accelerometric stations with inferred site classification by using the study of Régnier et al. (2010).

Most of the earthquakes recorded at French strong-motion stations occurred in Italy and Switzerland. Thus, similar to the approach followed for the Swiss data the event information for such cases was primarily obtained from the Italian and Swiss local agencies. For events having no earthquake metadata information from local agencies, we used the ISC bulletin (http://www.isc.ac.uk/iscbulletin/search/bulletin/) as the primary international seismological reference. Needless to say, the peer-reviewed papers studying specific French earthquakes have the highest priority in the metadata compilation for the French accelerometric database. These steps are consistent with the metadata compilation of RESORCE – version 1 as described in our previous reports as well as Akkar et al. (2013). Table 4 shows the list of sources (in order of preference) that are used to compile earthquake metadata information for the French data.

Table 4. Preferred sources for the compilation of French events

References	Event
Bajc et al. (2001)*	1998 Bovec Earthquake (Slovenia)
ISESD§ ESMD§ Bommer et al. (2007) ITACA§ ISC§ RAP§ GCMT§ RCMT§ SED1§ SED2§ SED3§ IAG§	Rest of events

* Literature survey from ISESD (Ambraseys et al., 2004a).
§ See Appendix A for abbreviations

The distributions of M_w versus different source-to-site distance measures for French data are shown in Figure 9. Figure 10 and 11 give histograms of event and recording distributions for depth and style-of-faulting, respectively. Figure 12 presents the site class distribution of French strong-motion stations and recordings. The formats of these plots are similar to those given for the Greek and Swiss accelerometric databases.

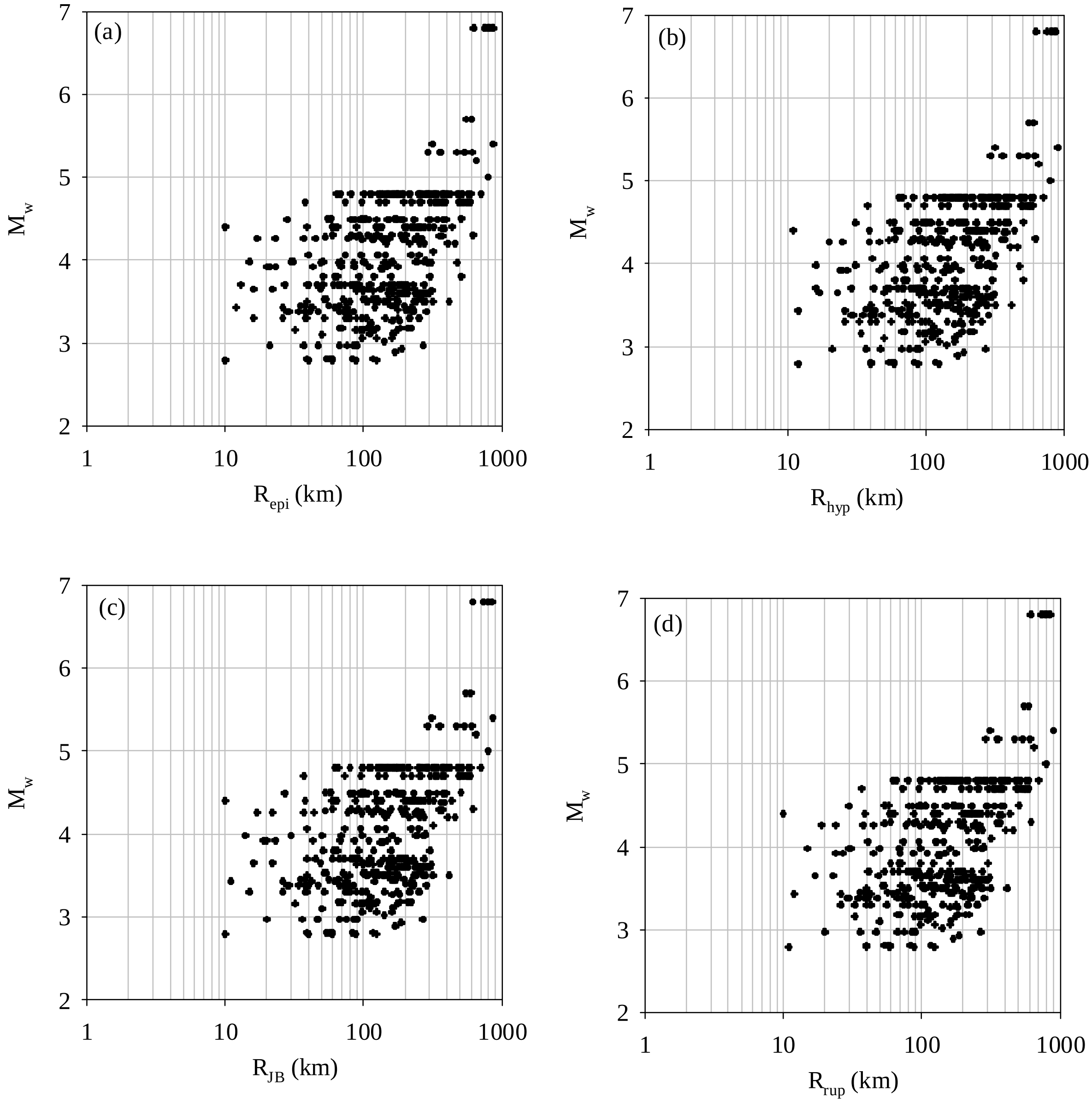


Figure 9. Same as Figures 1 and 5 but for French accelerometric data compiled for RESORCE.

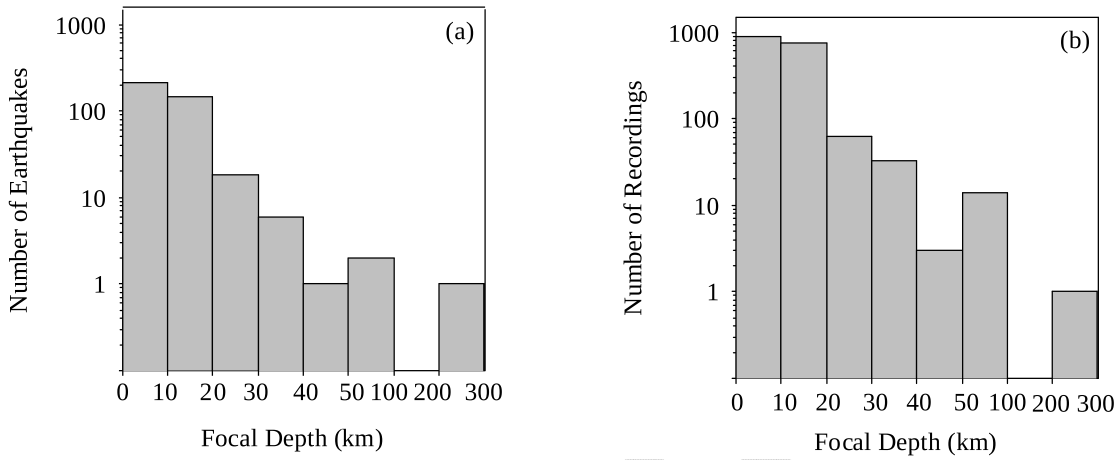


Figure 10. Same as Figures 2 and 6 but for French accelerometric data compiled for RESORCE.

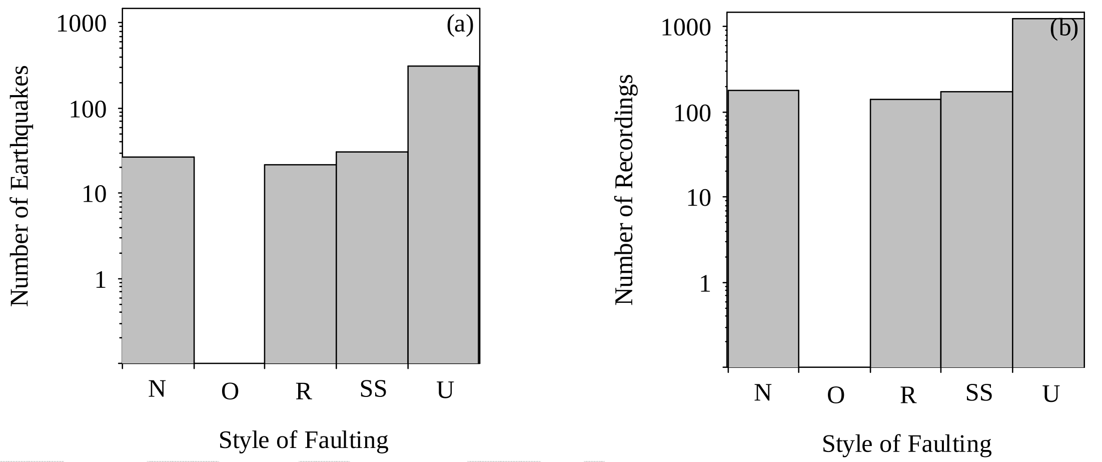


Figure 11. Same as Figures 3 and 7 but for French accelerometric data compiled for RESORCE.

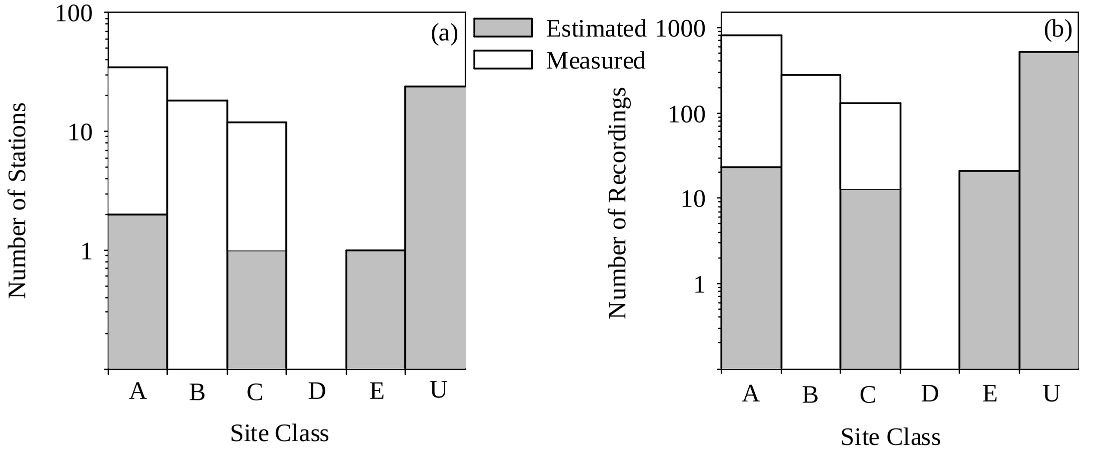


Figure 12. Same as Figures 4 and 8 but for French accelerometric data compiled for RESORCE.

Overall effects of integrated Greek, French and Swiss data on RESORCE

Figure 13 shows the Mw vs Repi scatter for Greek, Swiss and French data to describe the contributions of these databases to RESORCE. The French events with missing Mw information are designated by a different color code in these plots. These events are reported with local magnitude in the French accelerometric database. The information given in Figure 13 indicates that the contribution of French and Swiss data is mainly moderate-to-low magnitude events. The Swiss data contain recordings of distant events whereas the French accelerograms are concentrated around short-to-intermediate epicentral distances (20 km < Repi < 50 km). The magnitude range of Greek data is higher than those of French and Swiss events. The Greek recordings are mostly from moderate size events and there are 2 particular events (the 2003 Lefkada and 2006 Kythera earthquakes) with Mw > 6.

The SoF information of these recently considered databases is given in Table 5. All three databases contain normal, reverse and strike-slip events but there are still a significant number of events (mainly from very low magnitudes) that do not have any information about their faulting mechanism. Table 6 lists the site class breakdown of the French, Greek and Swiss strong-motion databases. Strong-motion stations with no site class attributes are not included in Table 6. This table indicates that the site class information of French strong-motion stations is almost complete, whether from measured VS profiles or inferred from local geology and estimations that rely on other methods (e.g., geotechnical borehole logs). The Greek strong-motion sites follow the French data but the site characterization of roughly 40% of Greek sites was made from on-site geological observations without having actual geophysical measurements. Currently none of the Swiss strong-motion sites in RESORCE have site classifications from geophysical or geological measurements. The site characterization of Swiss strong-motion stations based on measured VS profiles will be made public in 2014 (per. comm., Dr. Donat Faeh, 2012).

The above observations suggest that the inclusion of Greek, French and Swiss strong-motion databases has increased the magnitude and distance coverage of RESORCE towards lower magnitudes and longer distances. These data should still be elaborated in terms of station and earthquake metadata information. Most of these events are small and more detailed studies are required to determine their source parameters. It is recommended that the strong-motion sites without measured shear-wave velocity profiles should be studied by grants provided from different project sources, including SIGMA.

Table 5. SoF distributions of French (FR), Greek (GR) and Swiss (CH) databases

SoF	FR	GR	CH
Normal	27	22	16
Reverse	22	7	17
Strike-Slip	31	14	15
Unknown	309	99	10

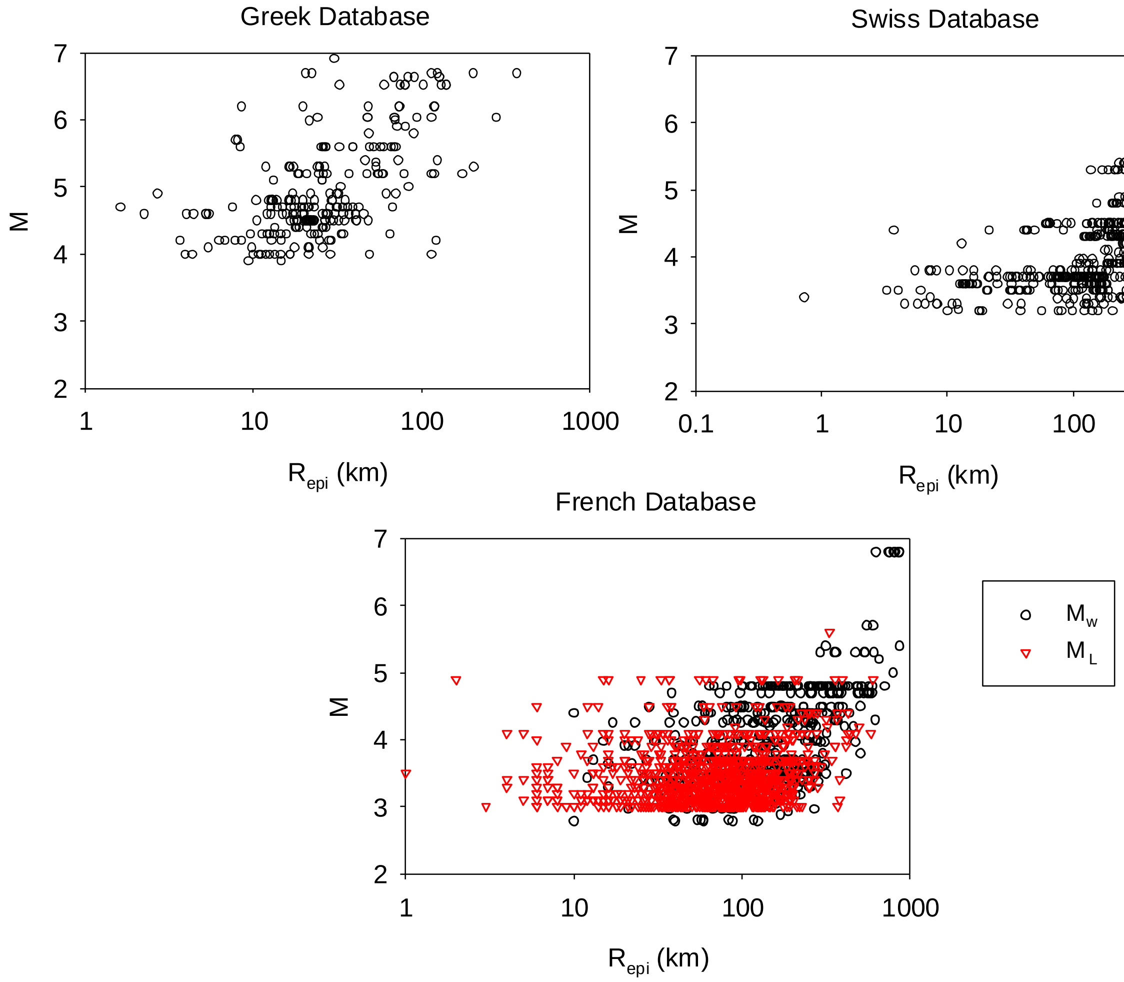


Figure 13. Magnitude vs. R_{epi} distributions of (a) Greek, (b) Swiss and (c) French databases that are recently included in RESORCE

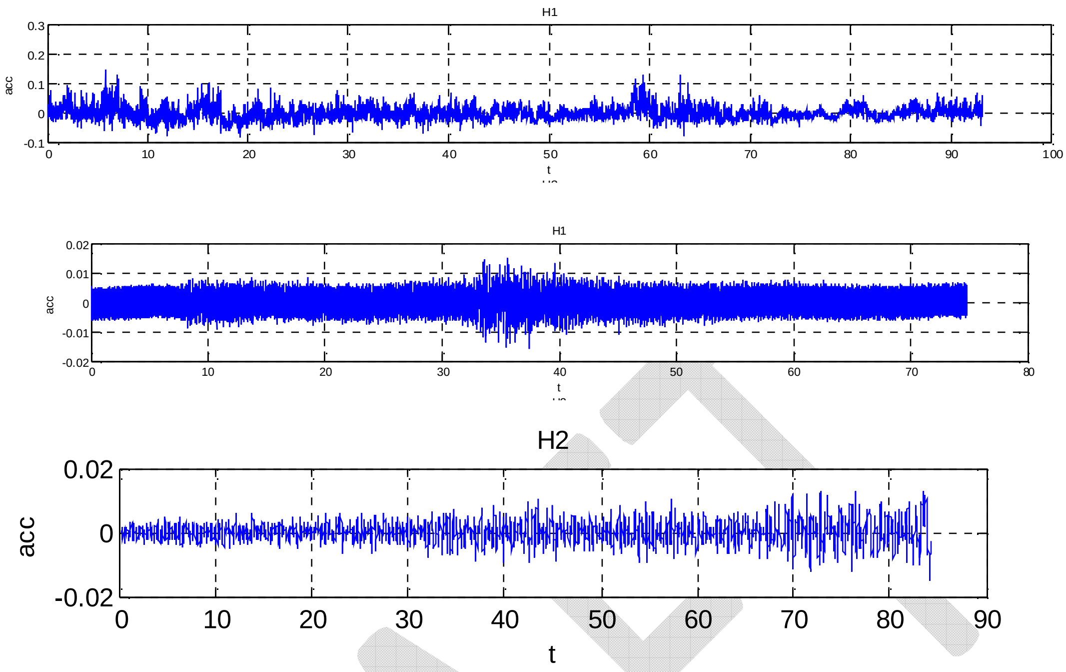
Table 6. Site class information based on measured or estimated V_{S30}. The site classes given in Eurocode 8 (CEN, 2004) is used to group the strong-motion stations of French (FR), Greek (GR) and Swiss (CH) accelerometric databases. (Strong-motion stations that are not classified in any one of these site classes due to missing site information are not included in the list).

	Site Class	FR	GR	CH
Measured	A	6	8	0
	B	2	28	0
	C	0	12	0
	D	0	0	0
Estimated		80	30	25

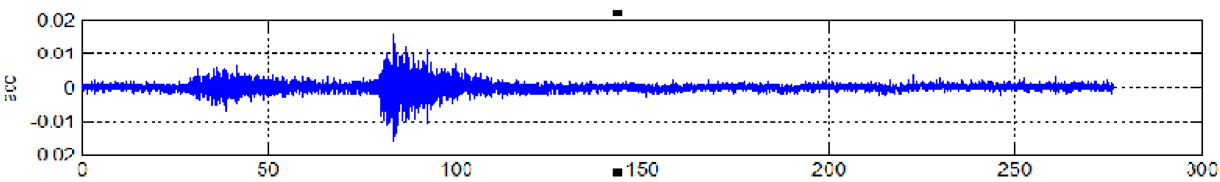
2.3. Processing of the accelerograms

The strong-motion data processing is based on visual screening and band-pass filtering of raw accelerograms. The visual screening of waveforms is used to detect and remove non-standard errors (Douglas, 2003; Bommer and Douglas, 2004). Band-pass filtering is implemented right after visual inspection if the records are free of non-standard errors. Otherwise, band-pass filtering constitutes the second stage of the data processing scheme after removing the non-standard errors. Figure 14 presents a set of sample recordings that show different cases of non-standard errors. Extremely low-quality accelerograms (Figure 14.a) are not band-pass filtered. A total of 85 (42 H1, 43 H2) horizontal and 41 vertical acceleration components are classified as very low quality recordings. Here unclear cases (first two figures) and not-complete cases are considered as low-quality recordings. The acceleration trace of the major event is considered for accelerograms with multiple-shock recordings (Figure 14.b). The time interval of the major event is roughly determined by identifying the starting and ending times of the smaller amplitude recordings on the entire accelerogram. The very high-frequency spikes having abnormally high amplitudes with respect to the overall data trend in accelerograms (Figure 14.c) are removed.

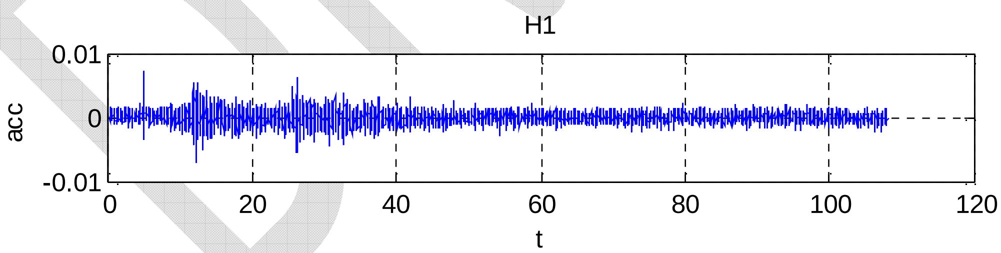
The band-pass filter cut-off frequencies are selected by studying the Fourier acceleration spectrum (FAS) of each raw accelerogram to detect the physically unjustifiable frequency content at high- and low-frequency components of the ground motion. 4-pole Butterworth acausal filtering is applied in the frequency domain and the post processing procedure described in Boore et al. (2012) is used to remove the additionally introduced zero pads during band-pass filtering. The entire Band-pass filtering and post-processing scheme is described thoroughly in Akkar et al. (2013) (modified from Boore et al., 2012). The original version of the implemented procedure is given in Chiou et al. (2008).



(a)



(b)



(c)

Figure 14. Non-standard errors, (a) low quality, (b) multiple-shock, (c) spike

2.4. Removal of low quality data from RESORCE

The total number of multi-component accelerograms in RESORCE is 7622. The quality of some of these accelerograms is low due to sensor limitations or large source-to-site distances. Their use for engineering and seismological studies is, hence, limited. These waveforms are removed from RESORCE by applying two criteria:

1. Remove unprocessed strong-motion recordings due to their low quality (see Figure 14c for a typical example); and
2. Remove distant (very small amplitude) recordings based on a set of magnitude-dependent filtering rules that are given below:
    a. Exclude records with Mw ≤ 4 and Repi > 100 km;
    b. Exclude records with Mw ≤ 5 and Repi > 200 km;
    c. Exclude records with Mw ≤ 6 and Repi > 300 km;
    d. Exclude records with Mw ≤ 7 and Repi > 400 km; and
    e. Exclude records with Mw ≤ 8 and Repi > 500 km.

Use linear interpolation for magnitudes and distance that fall between these intervals.

Implementation of these criteria resulted in filtering out 1985 multi-component accelerograms. The Mw vs. Repi scatter of the removed data is shown in Figure 15. The solid line represents the distance limits applied. Records that are on the right side of the solid line are removed as they do not conform to the distance limits given above. In other words, neither their amplitudes nor their quality are sufficient for research or professional use.

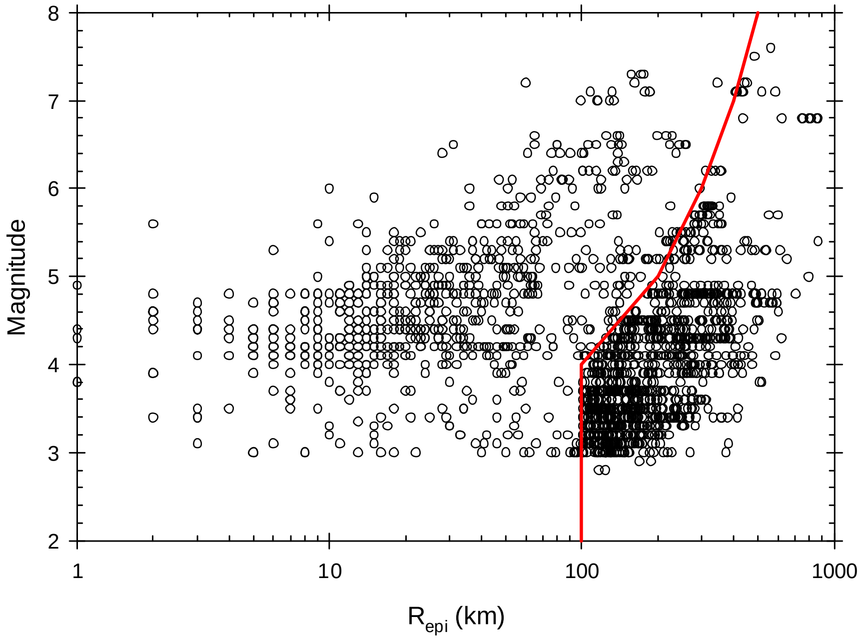


Figure 15. Distribution of magnitude vs. distance of excluded recordings in RESORCE

2.5. Overall features of RESORCE – 2013 version

The additional accelerometric data from Greece, France and Switzerland enlarges the content of the RESORCE. This section presents a general picture of the characteristics of RESORCE in order to understand the extent as well as the limitations of the most recent pan-European strong-motion databank.

The databank consists of 5637 accelerograms from 1481 strong-motion stations and 1713 earthquakes, after removing the low-quality data as discussed in the previous section. A total of 5571 accelerograms are tri-axial recordings whereas the rest are missing either one of the horizontal components or the vertical component. Figure 16 shows the number of recordings per event in RESORCE. The total number of singly-recorded events is 906. Events with 2 to 5 recordings constitute 32% of RESORCE. There are only 100 events in RESORCE that have 10 or more strong-motion accelerograms.

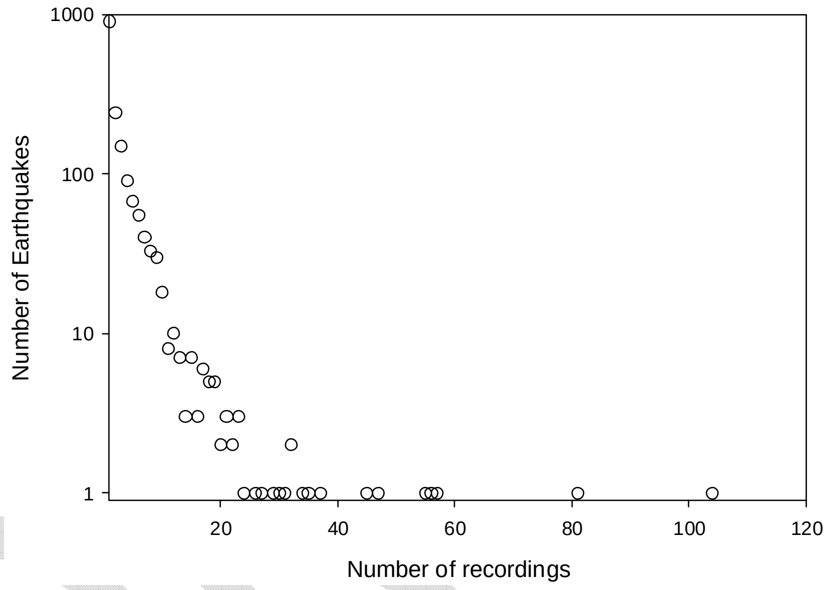


Figure 16. Number of recordings per event in the RESORCE inventory

Figure 17 demonstrates the yearly distribution of the earthquakes and accelerograms in the databank. The strong motions archived in the databank date back to early 1970s. 60% of the earthquakes and approximately 70% of accelerograms in the databank are from earthquakes that occurred in the last 15 years (1998-2012). The higher concentration of events and records within the last 15-year time span can be attributed to the increased number of strong-motion stations all around the pan-European region. Most of the accelerograms collected in the last 15 years are recordings from digital sensors. As a matter of fact the analog and digital waveform percentages in RESORCE are 22% and 74%, respectively and almost all digital data were collected in the last decade. The remaining accelerograms do not have any sensor information.

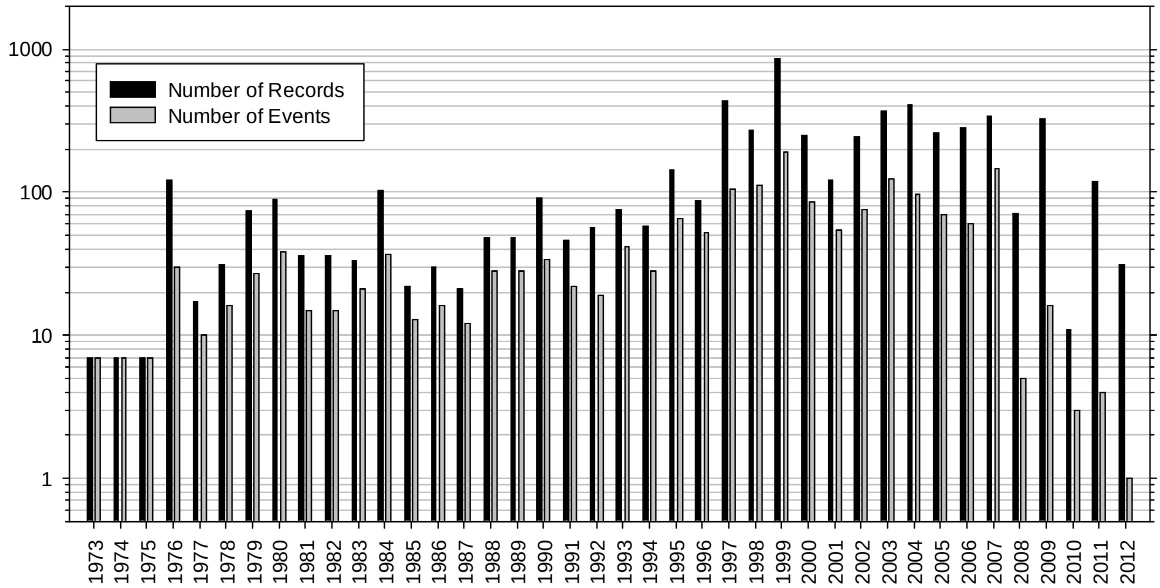
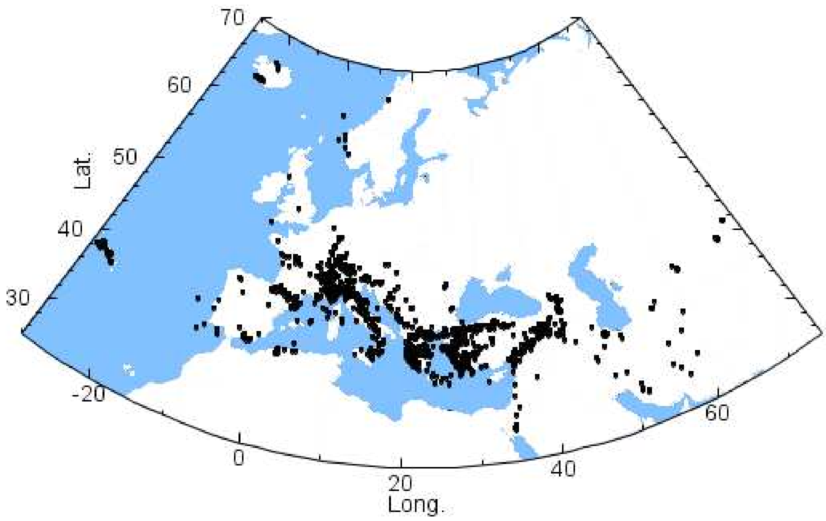


Figure 17. Annual distribution of accelerograms and earthquakes in RESORCE

The geographical distribution and the country-based breakdown of earthquakes and stations in RESORCE are displayed in Figure 18 and Table 7, respectively. Table 7 also shows the limitations of RESORCE in terms of Mw, distance and depth ranges. These two separate sources of information, when interpreted together, indicate that almost all recorded events are shallow active crustal earthquakes and most of the accelerograms are from Turkey, Italy and Greece on the Mediterranean coast as well as from France and Switzerland in central Europe. This information emphasizes the importance of updates and expansion of metadata as well as accelerometric waveform content from these countries.



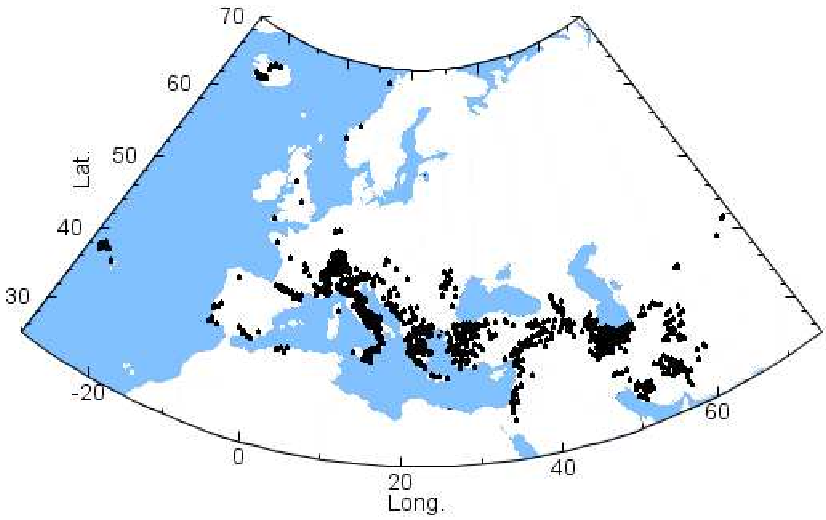


Figure 18. Geographical distributions of (a) earthquakes and (b) strong-motion stations in RESORCE

Table 7. Country based contributions to RESORCE

Country Name	Number of Events	Number of Records	Number of Stations	R_{epi} Range (km)	Focal Depth Range (km)	M_w Range
Albania	3	4	2	7-35	12-25	5.9
Algeria	1	3	3	29-59	10	5.9
Armenia	11	34	10	3-78	3-28	5.5-6.8
Austria	3	7	7	12-33	7-8	3.3
Bosnia and Herzegovina	5	11	9	7-19	10-15	5.7
Bulgaria	3	3	2	6-12	3-10	5.7
Croatia	5	10	7	4-168	0-39	5.5
Egypt	3	6		35-412	12-18	4.5-7.2
France	151	674	86	1-160	0-18	2.8-4.8
Georgia	11	30	9	4-181	6-19.7	4.8-7
Germany	12	65	18	4-142	4-22	3.1-5.2
Greece	297	576	123	1-370	0-127	3.1-6.9
Hungary			1	0	0	
Iceland	44	177	31	3-154	1.4-17	4.3-6.5
Iran	40	356	294	1-362	0-33	4.6-7.3
Israel	3	6	11	18-81	9-18	5.1-5.3
Italy	299	1403	350	1-279	0-255.3	3.2-6.9
Lebanon	1	1	0	75	5	5.1
Liechtenstein	1	3	1	2-5	11	3.7
Macedonia	3	9	12	12-80	15-20	5.9
Montenegro	21	58	13	1-342	5-40	5.4-6.9
Netherlands	1	3	0	58-103	14.6	5.3
Norway	2	2	1	26-78	15	5.3
Portugal	45	78	23	5-332	0-77	4.7-7.8
Romania	4	31	14	6-208	86-135.9	6.3-7.5
Serbia	7	7	1	8-21	3-10	6.3-7.5
Serbia	1	1	2	237	10	5.5
Slovenia	14	30	14	1-152	4-16	4.3-5.7
Spain	38	127	12	1-145	1.6-28	3.9-5.3
Switzerland	40	184	95	1-100	1-30	3-3.9
Syria	1	1	1	55	29	5.5
Turkey	628	1705	315	2-404	0.2-95	2.8-7.6
United Kingdom	2	2	2	35-76	8-13	2.8-7.6
Uzbekistan	13	30	12	1-53	0-45	6.8

Figure 19 shows the earthquake (left column) and accelerometric (right column) data distributions in RESORCE for moment magnitude, depth and SoF. A total of 725 events have reported moment magnitudes from international and local seismological agencies as well as earthquake-specific literature studies (first row plots). When moment magnitudes that are estimated from empirical magnitude conversion relations are included, the number of events with Mw information increases to 1234. The moment magnitudes are concentrated between 3.5 and 5.5. These relatively small events come from HEAD, T-NSMP and ITACA. They often correspond to convert local magnitudes (ML) for Greek and Italian events. The total number of accelerograms having Mw information is 4430 (3486 measured and 944 converted) out of 5637.

The event and record based distributions of moment magnitude suggest the dominancy of moderate-size events (4 ≤ Mw ≤ 6) in RESORCE (61% of earthquakes and 58% of accelerograms). The fraction of events that can be considered as large earthquakes (i.e., Mw ≥ 6.5) is only 2% of the entire population. The corresponding number of accelerograms constitutes 7% of the accelerometric data in RESORCE. The total number of events without moment magnitude information is 479 (28% of RESORCE) and 21% in terms of recordings. These events (labeled as "Unknown" on the histograms) are reported in different magnitude scales but their corresponding Mw values cannot be estimated due to the lack of appropriate magnitude conversion relationships. The second row histograms display the depth distribution of RESORCE. Focal depths are less than 30km for about 92% of the events. The corresponding percentage in terms of strong-motion recordings is 98%, indicating that RESORCE is dominated by shallow crustal events. The events of depths ranging between 50 km and 140 km are mainly from the Hellenic and Cyprus Arc subduction zones, the Vrancea region, Portugal and southern Turkey.

The distribution of event and accelerometric data in terms of SoF is given in the last column of Figure 19. The majority of events and accelerograms are from strike-slip, SS, (29% of events and 30% of records) and normal, N, (22% of events and 28% of records) faults. The number of reverse, R, events and accelerograms are small when compared to the other SoF classes but they still constitute 9% of the events and 14% of the strong-motion records. The depth and SoF distributions also indicate that information is still missing (designated as "Unknown" on each histogram) for a significant portion of earthquakes in RESORCE. This lack mainly concerns the small magnitude range (Mw ≤ 5). Earthquakes and accelerograms falling into this category are more prominent in the SoF statistics. The major reason behind this deficiency is the lack of double-couple fault-plane solutions for small magnitude earthquakes that provide direct information for the identification of SoF and depths. Inherently, the literature (i.e., earthquake-specific publications) rarely focuses on the solutions of such small events unless they are associated with a destructive earthquake. There are pragmatic solutions to estimate the style-of-faulting of such small events. One procedure is to overlay them on seismotectonic maps to judge their SoFs from their proximity to different fault zones. The complexity of source kinematics as well as insufficient resolution of seismotectonic maps in Europe and surrounding countries would increase the associated uncertainty in such classifications (e.g. Bommer et al., 2003). Thus, such an approach is discouraged for SoF classification and it is not implemented in the current version of RESORCE.

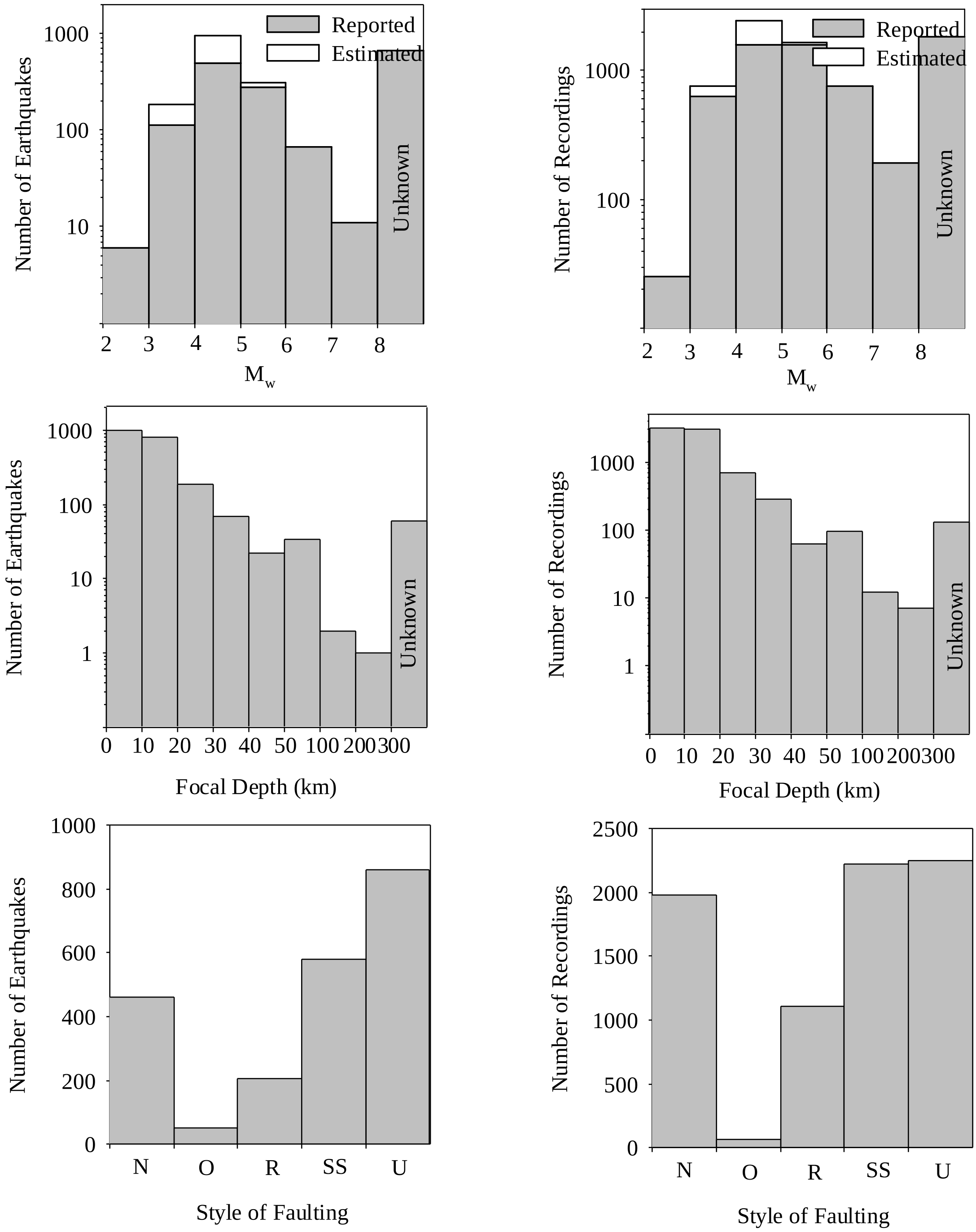


Figure 19. Distributions of events (first column) and accelerograms (second column) in RESORCE in terms of moment magnitude (first row), depth (second row) and SoF (third row). The vertical bars labeled as "Unknown" refer to the events or accelerograms that cannot be classified within any one of these classes due to missing event information.

Figure 20 presents similar histograms as in Figure 19 to describe the distributions of strong-motion stations (left panel) and accelerograms (right panel) in terms of Eurocode 8 (CEN, 2004) site classification. The statistics are based on measured V_{S30} values and inferred site classes from local site geology. The site information of RESORCE contains a total of 419 strong-motion stations with known V_{S30} values thanks to site characterization studies in Greece, France, Italy and Turkey. The corresponding number of accelerograms recorded at these stations is 2618. The number of strong-motion sites and accelerograms with site classes inferred from the local geological conditions is 632 and 2321, respectively. Of the entire accelerometric data 698 records (12% of strong-motion records in RESORCE) do not have any site characterization. The majority of accelerometric data (35%) is recorded at site class B (stiff soil) strong-motion stations. Only 2% of the accelerograms in RESORCE fall into site class D (very soft soil). The accelerograms in site class A (rock) and C (soft soil) constitute 26% and 23% of the databank, respectively.

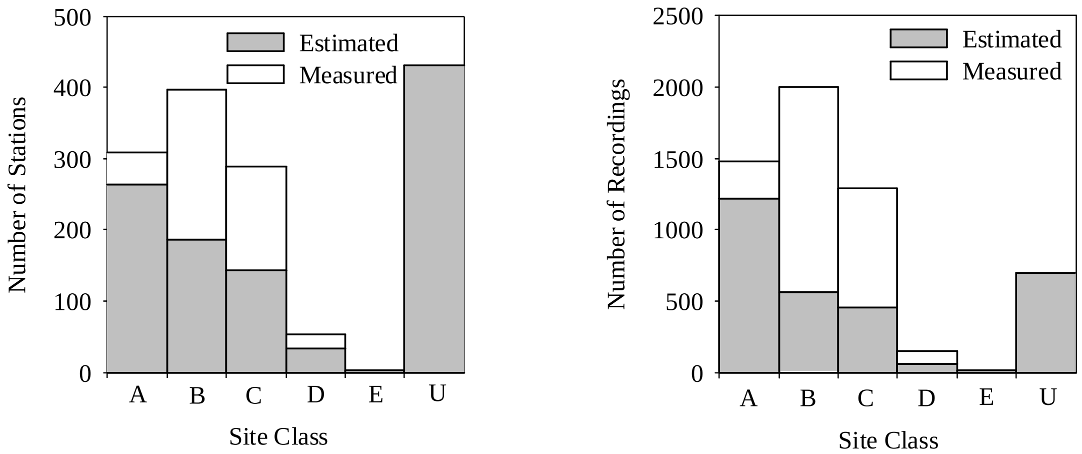


Figure 20. Distributions of strong-motion stations (left panel) and accelerograms (right panel) in RESORCE in terms of Eurocode 8 (CEN, 2004) site classes. The explanation about the labels designated as "Unknown" is similar to the one given in the caption of Figure 19.

Figure 21 shows a general picture for M_w vs. distance distributions in RESORCE. The distance metrics (R_{epi}, R_{hyp}, R_{JB} and R_{rup}) are plotted up to 200 km to have a better perception of the M_w vs. distance distributions. The calculations of R_{epi} and R_{hyp} distance metrics are easier than R_{JB} and R_{rup} as the latter two distance measures require additional information about the ruptured fault geometry. All the accelerometric data in RESORCE (5637 records) are associated with R_{epi} estimates. The number of accelerograms having R_{hyp} information is 5529 as 108 recordings lack depth information. A total of 3396 records in RESORCE have R_{JB} values. This number reduces to 2188 recordings for R_{rup} as the calculation of this distance measure involves the largest number of earthquake parameters, which are difficult to acquire with the current content of the reference sources used during the compilation process. The information on ruptured fault geometry as well as double-couple fault-plane solutions becomes poor for small events (see discussions in the previous paragraphs) and these adverse features primarily affect the R_{rup} computations in the low magnitude range. The scatters in Figure 21 show that the M_w vs. distance distribution is fairly uniform for distances greater than 10 km and moment magnitudes greater than 4. For shorter distances and smaller magnitudes, the homogeneity in M_w vs. distance distributions diminishes. This is more visible in R_{hyp} and R_{rup}.

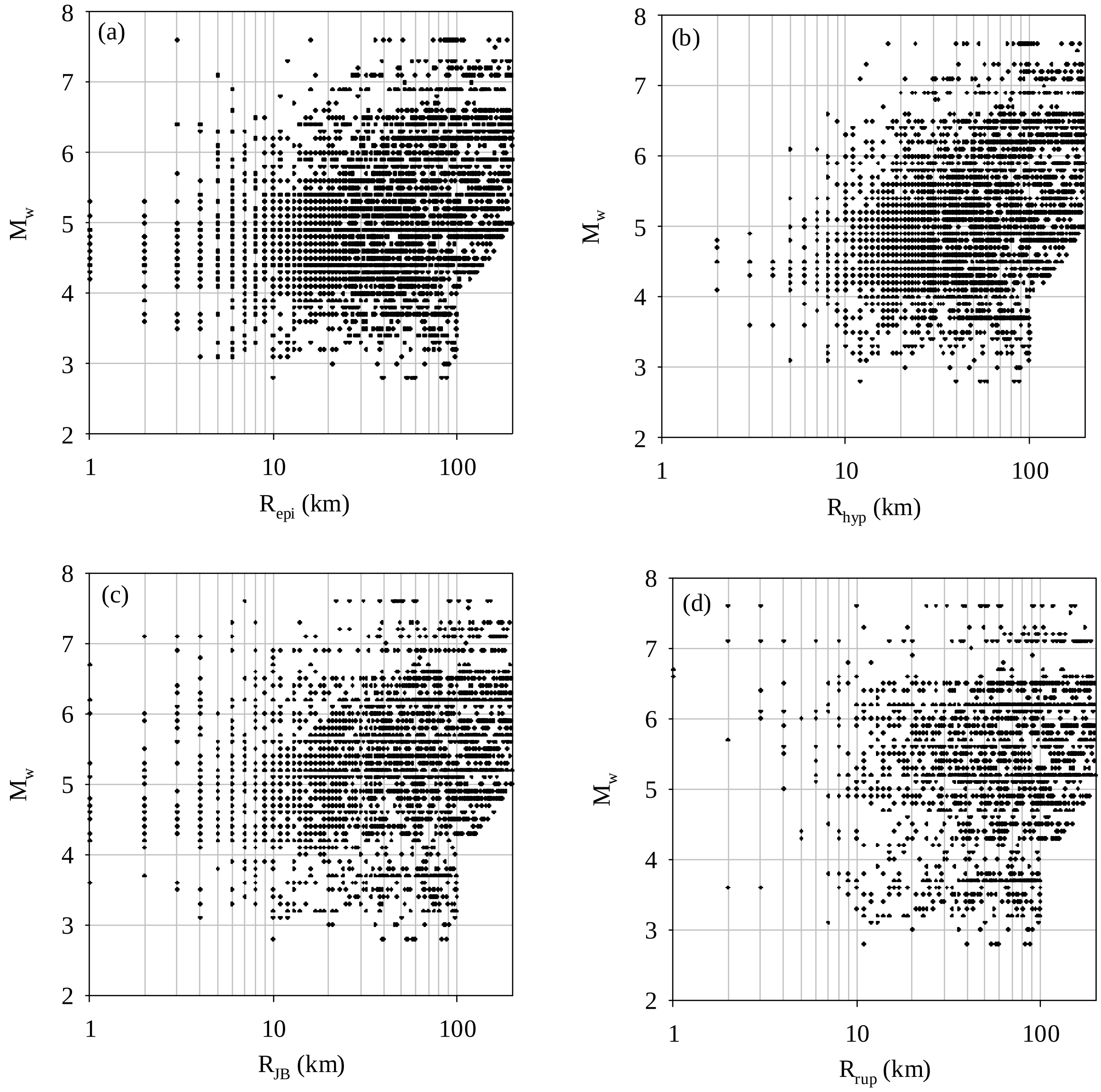


Figure 21. Distribution of M_w vs. (a) R_{epi}, (b) R_{hyp}, (c) R_{JB} and (d) R_{rup}.

Figures 22 and 23 show the magnitude-dependent variation of low-cut ($f_{low\text{-}cut}$) and high-cut ($f_{high\text{-}cut}$) filter cut-off frequencies used in the RESORCE data processing, respectively. Each row shows the chosen filter cut-off frequencies for a different Eurocode 8 (CEN, 2004) site class. The panels on the left show the filter cut-offs of the horizontal components. The right-hand-side panels describe the same information for the vertical components. The straight lines on Figure 22 also show the magnitude-dependent variation of theoretical corner frequencies, f_a and f_b, that are used for guidance while deciding on the individual low-cut frequencies of accelerograms. The scatter diagrams in Figure 22 indicate that only few selected low-cut frequencies are above the corresponding f_b values suggesting that the actual low-frequency content of the processed accelerograms is preserved fairly well. The low-cut filter values tend to decrease with increasing magnitude except for site class A (VS30 ≥ 800 m/s) ground motions. The described trend in $f_{low\text{-}cut}$ vs. Mw is not very clear with respect to similar comparisons made by previous studies (e.g., Akkar et al., 2010). The major reason behind this observation might be the large percentage of analog accelerograms (22%) among the processed data whose resolution in time- and frequency-domain does not permit the selection of very low flow-cut values with increasing magnitude. The marginal drop in $f_{low\text{-}cut}$ with increasing Mw for site class A recordings justifies the above assertion as 63% of ground motions in this site class are analog recordings. The scatters given in Figure 23 indicate that, except for a few cases, the chosen high-cut filter frequencies are almost exclusively above the 10 Hz limit. The records subjected to severe high-cut filtering are from low-quality analog and digital waveforms. These accelerograms constitute approximately 23% of the entire RESORCE archive. This demonstrates once again the importance of waveform quality in order to extract the maximum information from the processed recordings.

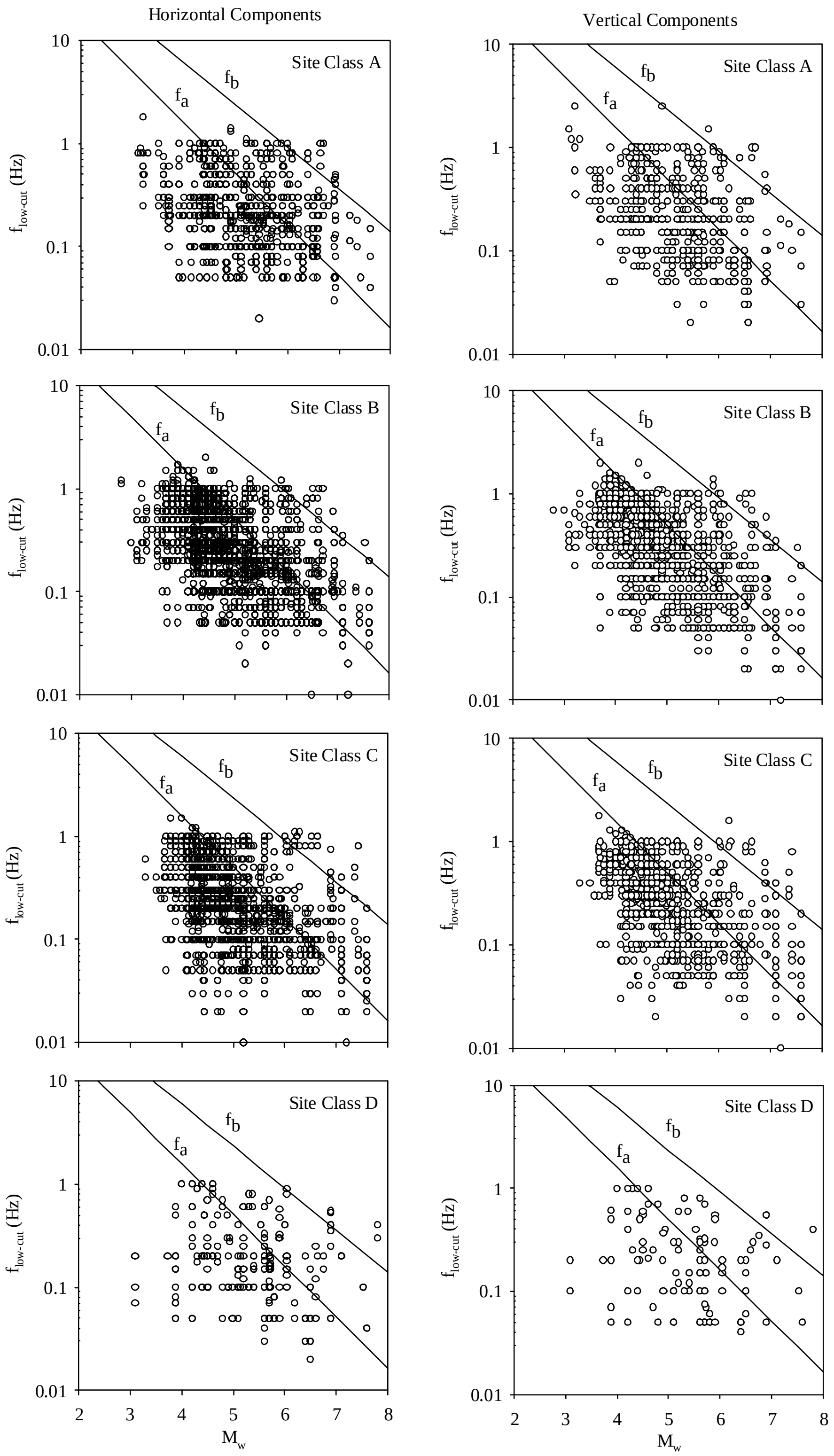


Figure 22. Variation of low-cut filter frequencies as a function of Mw for different site classes in RESORCE.

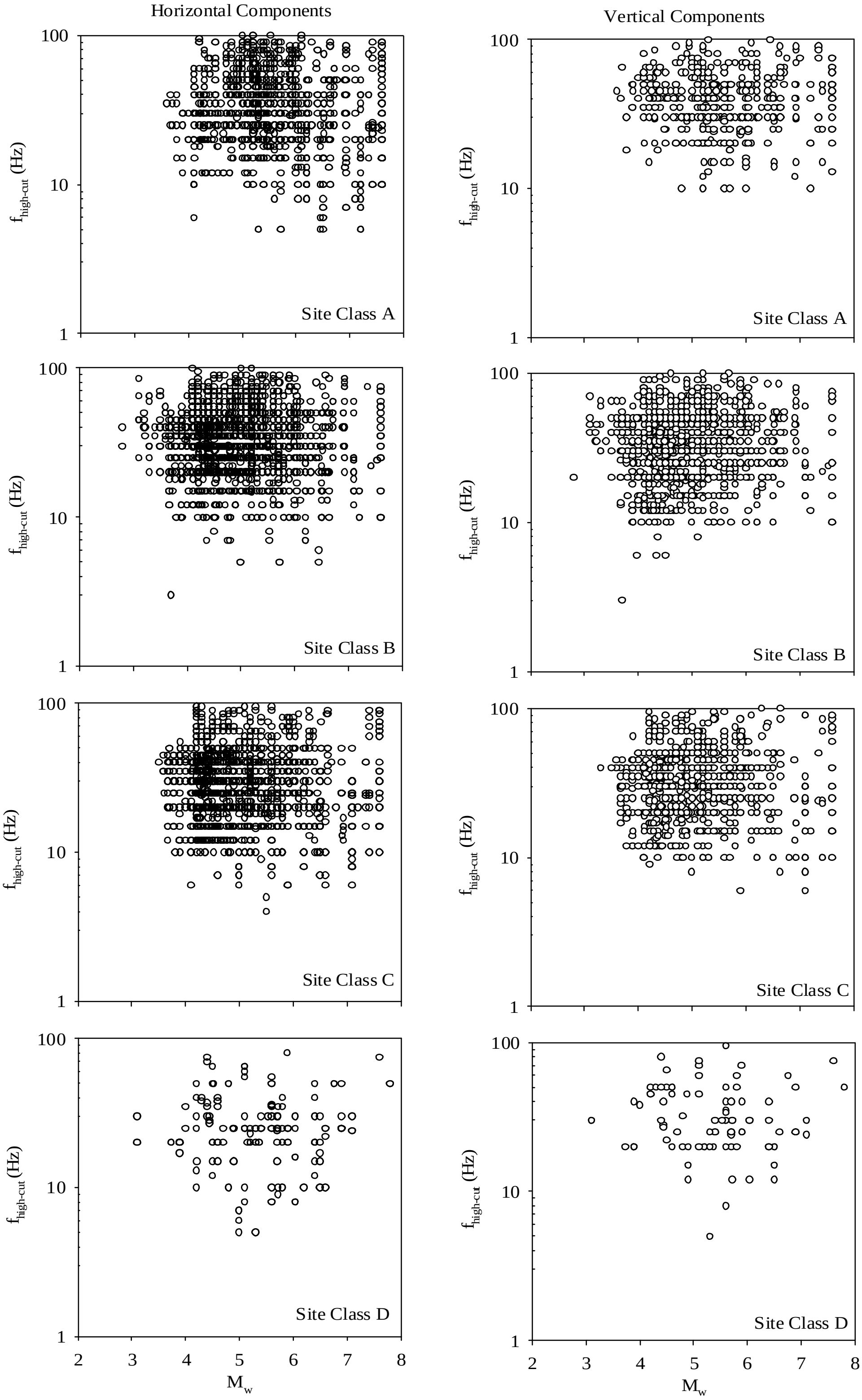


Figure 23. Same as Figure 22 but for high-cut filter frequencies.

3. RESORCE: database and portal

This chapter presents the RESORCE portal developed by the EMSC to provide access to the metadata and waveforms that comprise the RESORCE database. Using this portal, end users have access to strong-motion data related to earthquakes allowing them to, for example, analysis existing ground-motion models and create new ones.

In 2012, the first edition of RESORCE was released. This version is now frozen, although it is still available online. A new and extended version was released in 2013 (RESORCE-2013), which includes additional events along with its associated metadata. A versioning system has been set up to enable the user to access the database of interest.

The following sections discuss the additional metadata available in the RESORCE-2013 database.

3.1. Metadata

3.1.1. Input information

The metadata available to describe each accelerogram has been extended since the first edition, following the recommendations of the scientific committee.

In comparison with the first version of RESORCE, five additional parameters are now available:

- Mw Flag: information on the Mw source (computed, reported or converted);
- RJB_plane1 (km) and RJB_plane2 (km): distance to the 2 fault planes; and
- Rrup_plane1 (km) and Rrup_plane2(km): distance to the 2 fault planes.

In 2012, the first edition of RESORCE was released including 1664 events recorded by 1449 stations in Europe. This version can no longer be modified while it is still available online to allow access to the data used to create the ground-motion models that will be published in the up-coming special issue of Bulletin of Earthquake Engineering. The new version is now ready as RESORCE-2013, including 150 additional events.

In Resorce-2013, the database is populated with:

- 1713 events (49 additional events);
- 1481 stations;
- 5640 records corresponding to;
- 16911 components (1449 additional components)

After review of the metadata and records by the scientific committee, the information is passed to the EMSC to populate the database. Its content reflects the outcome of the EC-funded FP7 SHARE project, extended by additional data and parameters. The reference documentation of the metadata is provided by Sinan Akkar (METU).

All the information described in the metadata, the definitions, the format and the characteristics were reviewed. This includes the value range, the type, the uniqueness and its optional characteristics (optional or mandatory).

The meta-parameters available are organised in four main tables:

- Earthquake : source and fault information;
- Station : location, instrument and site information;
- Record : processing and parameters information; and
- Component : processing and parameters information

For each recording, the only unique field is waveform ID. It is the core of the database and of the metadata.

3.1.2. Enhanced information

Each seismological organisation defines its own earthquake parameters (location, origin time, magnitude, etc) following various procedures. A unique catalogue was set up by the EMSC within the NERIES project to allow linking of numerous seismological products using a single event identifier (UNID). Through the European Seismic Portal (www.seismicportal.eu/), users can access broad-band waveforms, accelerometric data, and in the near future shake maps and the EMMA Focal Mechanism Database. This portal is build upon the unique catalogue. Therefore, events available within RESORCE were linked to this catalogue, allowing further comparison between locations, magnitudes and depths, which is useful for the assessment of uncertainties in accelerometric parameters. For example:

RESORCE information:

Date	Time	Lat.	Long.	Depth	Mag.
2006-10-24	17:31:48.78	43.9273	7.5875	14.4	4

Unique catalogue information:

2006-10-24	17:31:48.7	43.87	7.62	5	3.7

Currently the unique catalogue contains the following information:

- since 1972 based on ISC information for events larger than magnitude 5 worldwide;
- since 1998 based on the Euro-Med bulletin; and
- since 2006 based on the EMSC real time information worldwide.

Out of the 1713 events available within RESORCE, 1135 are available in the unique catalogue. Events for which no UNID is available are mostly before 1998 and/or with a low magnitude. When the unique catalogue is enriched, the mapping with RESORCE will be updated.

3.2. Accelerograms and spectral responses

For all the available records, a single page gathering the waveforms and the spectral responses for the different damping levels were generated. It provides a preliminary glimpse of the data for RESORCE end users.

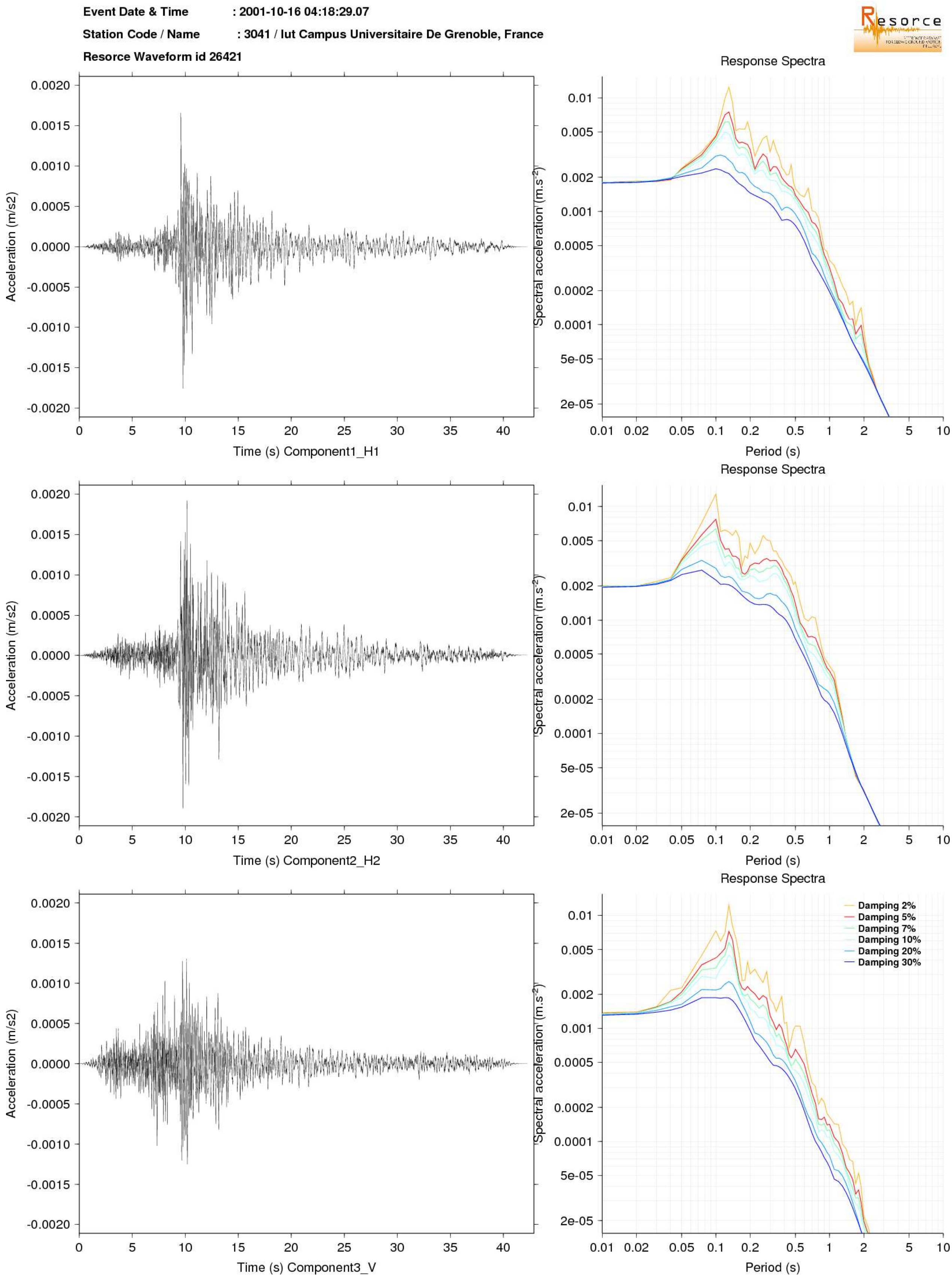


Figure 24: Example of waveforms and response spectra graph available on the RESORCE portal

3.3. Database and portal

Within the Sigma project an Internet Portal is developed to show, query and deliver Strong Motion Waveform from the database. This portal can be reached at http://www.resorce-portal.eu.

Figure 25: Summary of RESORCE deployment.

RESORCE back end uses the PostgreSQL[1] open source Database to be accessible through a Web User Interface.

3.3.1. Editions

RESORCE information is frozen for each version in order to let the user retrieve the same information than selected in its previous analysis. Therefore, the different versions of RESORCE are and will remain available online. Download of the full database in .csv format is also provided for each version.

Currently the data are not public and access should be granted by the RESORCE advisory panel. At this time, 42 different users are registered.

[1] http://www.postgresql.org/

Figure 26 : The New home page of the RESORCE portal

3.3.2. Query page

The portal allows users to query the database applying filters through the “query tab”. The user interface is based on the JQuery Mobile[2] javascript library. Filters can be set upon 21 parameters:

- Event : datetime, depth, geolocalisation, magnitude, magnitude type, name, country and Fault mechanism
- Station : name, country, geolocalisation, VS30, EC8,Network and Site type
- Record : PGA,PGV, Distance Epi, Hyp, Jb and Rup

2 http://jquerymobile.com/

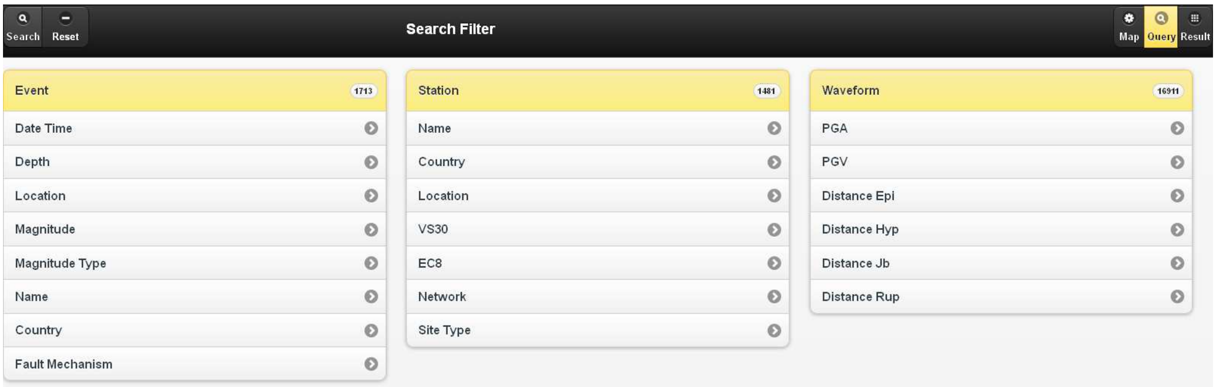


Figure 27: Zoom on the RESORCE query page with 21 parameters filter

3.3.3. Map page

The result of the request is displayed on a map. The map displayed uses the Tile Map Service Specification defined by the OsGeo[3] using the Leaflet[4] javascript library. The use of a standard like OGC is useful for the integration of the events database into standard tools like GIS and also to have a well defined XML definition of web services.

When a user applies a filter to his selection, a new call is made to regenerate tiles to show the new result on the map. The tile server[5] queries the database and plot small area of the map returning the result to the Web Browser.

3 http://wiki.osgeo.org/wiki/Tile_Map_Service_Specification
4 http://leafletjs.com/
5 http://tilestache.org/

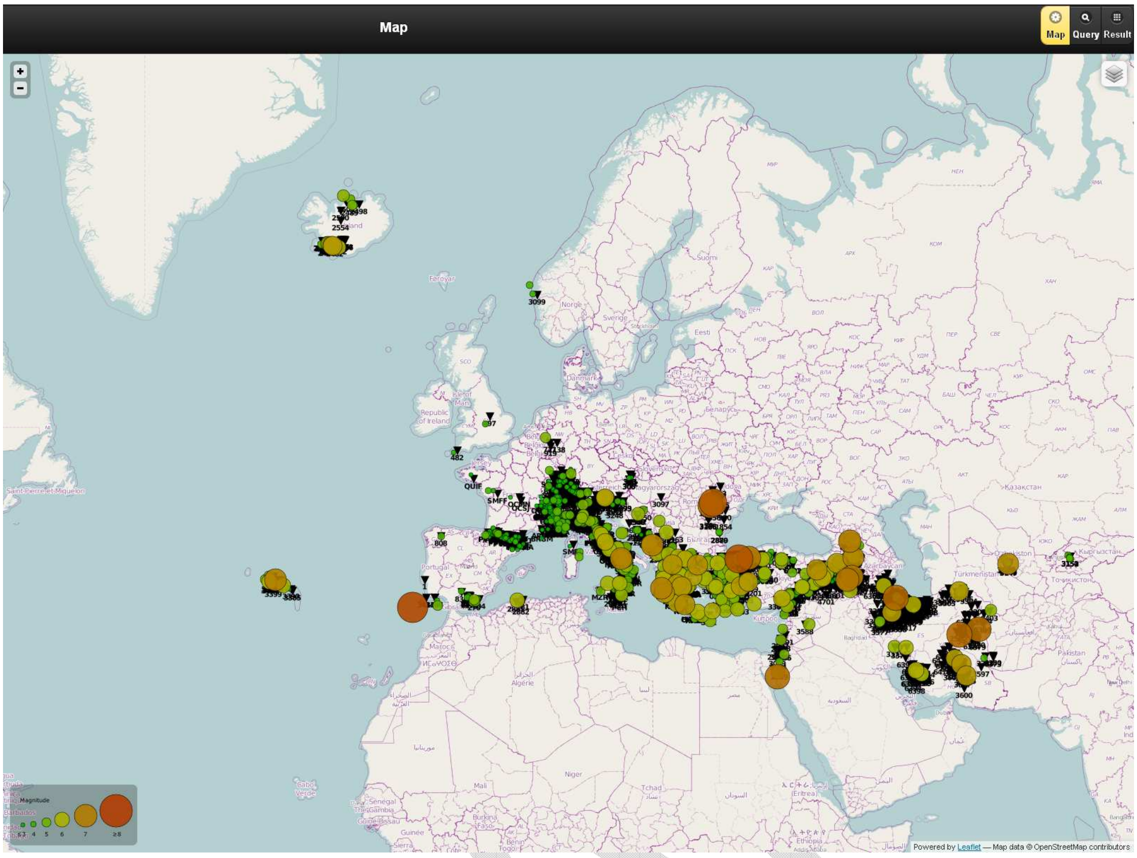


Figure 28 : Map view of the RESORCE events and stations distribution

The user can zoom and click on visual element (event/station) to have more detail information like event latitude/longitude, datetime, magnitude, name of the event and the country location. A direct access to the available recorded waveform is presented (cf : fig2)

Figure 29 : View of the associated records for a given event

3.3.4. Results page

The user can then view in the “result tab” details on the metadata along with waveforms and response spectra. This dynamic pages showing the results pages are generated server side by the Django[6] Python Web Framework. He can select which records should be added to a downloadable compressed file including metadata, corrected and raw data.

The user can click on the direct link and see the corresponding waveforms for this event on the result page. The user can also go to the results page to see all the records available for his query and select which records should be included in his selection to download.

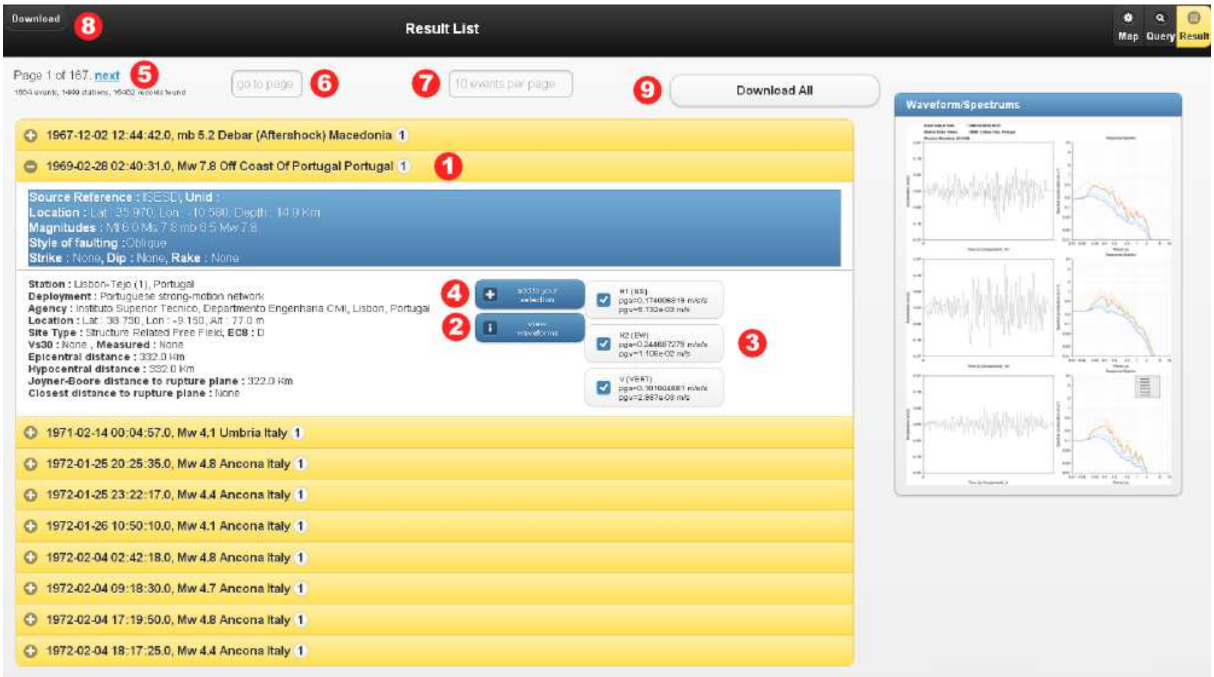


Figure 30 : Zoom on the RESORCE results page

1 – The user can view all record from a specific event clicking on the event tab

2 – To view the corresponding waveforms and spectra the user can click on the « view waveform » button

3 – The user selects the component he wants to add to the selection

4 – The user adds the components to the selection clicking on « add to the selection » button

5 – The user can navigate the result page by page to add more record to his selection

6 – The user can navigate directly to a page

7 – The user can choose to display more events on a page

8 – After selecting his waveform, the user click on the download button

9 – The « download all » button selects automatically all waveforms from all records

[6] https://www.djangoproject.com/

3.3.5. Download page

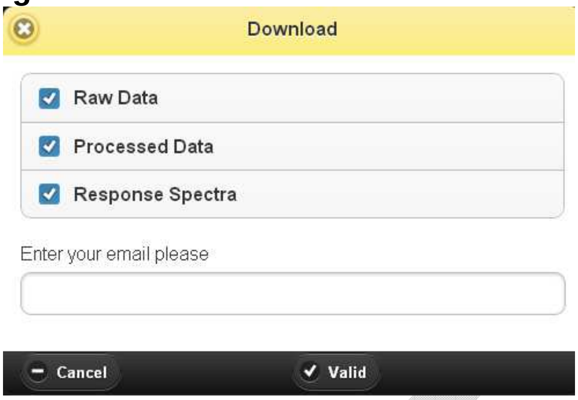


Figure 31 : Download dialog window

The user can specify which information he wants to download: raw data, processed data and or response spectra. The user email is mandatory as the construction of the downloadable archive can take some times so a message queue system[7] is used to queue all user request and process them one at a time, generate the archive and send a notification email to the user informing him of the availability of the downloadable archive. The user can then download his result.

3.3.6. Link to other seismological information

Through the RESORCE portal, external earthquake information is available on the result page by using the unid (see paragraph 3.1.2). It includes ISC and EMSC location information for the events available in RESORCE.

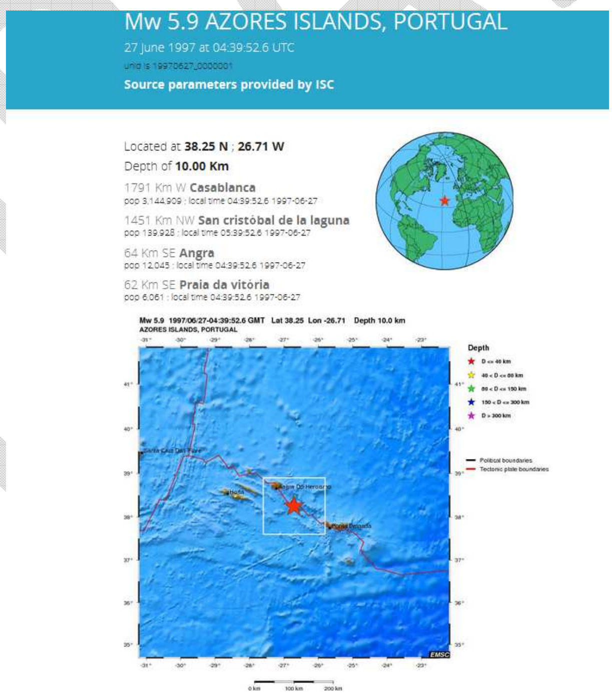
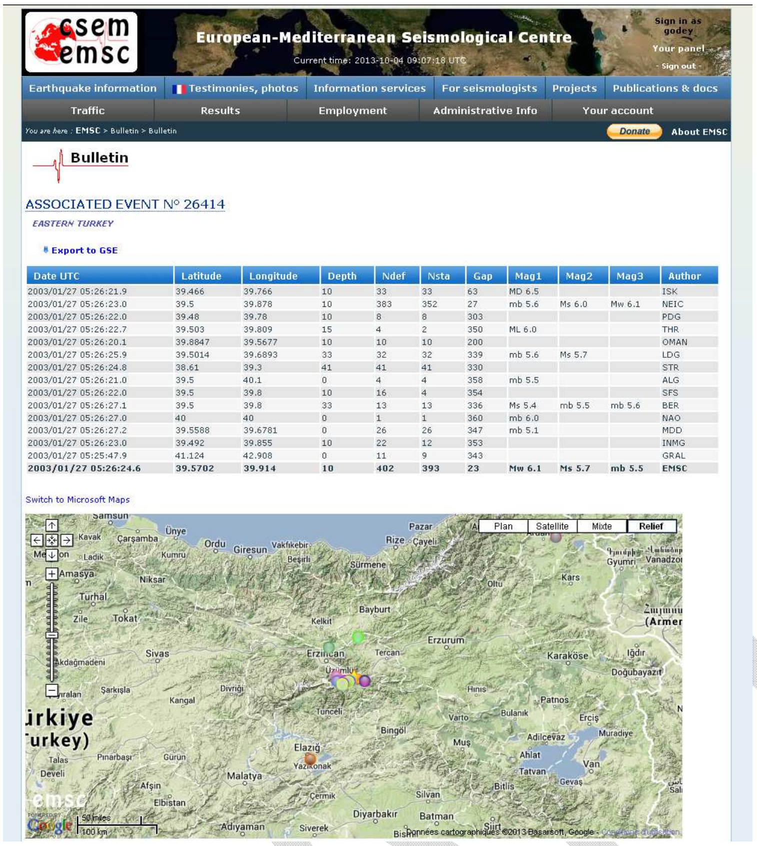


Figure 32 : Example of ISC location page for a RESORCE event based on the unid www.resorce-portal.eu/events/19970627_0000001.html

[7] http://www.rabbitmq.com/



Date UTC	Latitude	Longitude	Depth	Ndef	Nsta	Gap	Mag1	Mag2	Mag3	Author
2003/01/27 05:26:21.9	39.466	39.766	10	33	33	63	MD 6.5			ISK
2003/01/27 05:26:23.0	39.5	39.878	10	383	352	27	mb 5.6	Ms 6.0	Mw 6.1	NEIC
2003/01/27 05:26:22.0	39.48	39.78	10	8	8	303				PDG
2003/01/27 05:26:22.7	39.503	39.809	15	4	2	350	ML 6.0			THR
2003/01/27 05:26:20.1	39.8847	39.5677	10	10	10	200				OMAN
2003/01/27 05:26:25.9	39.5014	39.6893	33	32	32	339	mb 5.6	Ms 5.7		LDG
2003/01/27 05:26:24.8	38.61	39.3	41	41	41	330				STR
2003/01/27 05:26:21.0	39.5	40.1	0	4	4	358	mb 5.5			ALG
2003/01/27 05:26:22.0	39.5	39.8	10	16	4	354				SFS
2003/01/27 05:26:27.1	39.5	39.8	33	13	13	336	Ms 5.4	mb 5.5	mb 5.6	BER
2003/01/27 05:26:27.0	40	40	0	1	1	360	mb 6.0			NAO
2003/01/27 05:26:27.2	39.5588	39.6781	0	26	26	347	mb 5.1			MDD
2003/01/27 05:26:23.0	39.492	39.855	10	22	12	353				INMG
2003/01/27 05:25:47.9	41.124	42.908	0	11	9	343				GRAL
2003/01/27 05:26:24.6	**39.5702**	**39.914**	**10**	**402**	**393**	**23**	**Mw 6.1**	**Ms 5.7**	**mb 5.5**	**EMSC**

Figure 33 : Example of EMSC location page for a RESORCE event based on the unid http://www.emsc-csem.org/Bulletin/earthquake.php?id=26414

For automatic processing, the associated data from ISC or EMSC are available in QuakeML format.


```
- <quakeml>
  - <eventParameters publicID="smi://eu.emsc/unid">
    - <event publicID="quakeml:eu.emsc/event/20030127_0000007">
        <preferredOriginID>quakeml:eu.emsc/origin/emb/26414/1377967</preferredOriginID>
      - <preferredMagnitudeID>
          quakeml:eu.emsc/NetworkMagnitude/emb/26414/1377967/1460081
        </preferredMagnitudeID>
        <type>earthquake</type>
      - <creationInfo>
          <agencyURI>smi:smi-registry/organization/EMSC</agencyURI>
          <authorURI>smi:smi-registry/organization/EMSC</authorURI>
          <creationTime>2013-10-04T09:08:09+00:00</creationTime>
          <version>1.0.1</version>
        </creationInfo>
      - <origin publicID="quakeml:eu.emsc/origin/emb/26414/1377953">
        - <time>
            <value>2003-01-27T05:26:21.9+00:00</value>
          </time>
        - <latitude>
            <value>39.466</value>
          </latitude>
        - <longitude>
            <value>39.766</value>
          </longitude>
        - <depth>
            <value>10</value>
          </depth>
          <depthType>from location</depthType>
          <methodID>smi:eu.emsc-csem/origin_method/NA</methodID>
        - <quality>
```


Figure 34 : Example of QuakeML event information for a RESORCE event based on the unid RESORCE review process

4. RESORCE review process

This chapter concerns the reviews of RESORCE that have been conducted. The reviewers of RESORCE consist of members of the scientific advisory board for this task (John Douglas, Bruno Hernandez, Lucia Luzi and Gabriele Ameri) as well as the two task leaders (Paola Traversa and Fabrice Cotton). In addition, an internal check of the data format and consistency between events, stations and records was conducted by EMSC (Stéphanie Godey and Laurent Frobert) when they received the data from METU (lead: Sinan Akkar) and before they published the data online.

The following section presents the review procedure that was followed. The subsequent section discusses the subjects that were covered by the review. The special issue of the international journal Bulletin of Earthquake Engineering concerning new ground-motion models for Europe, which includes an article on RESORCE and five models based on this database, is then briefly introduced.

4.1. Review procedure

The reviews of each version of RESORCE were principally conducted in the period running up to face-to-face day-long meetings that were held roughly annually in Paris between the parties listed above. These meetings took place on 9th June 2011, 9th May 2012, 6th July 2012 and 5th July 2013. In addition, there were some telephone conferences to discuss specific points, particularly early on in the project.

Some weeks before these meetings an Excel spreadsheet containing the metadata, the peak ground acceleration (PGA) and other ground-motion measures was circulated within the group. In addition, the database could be accessed through the portal developed by EMSC but the Excel spreadsheet made analyses of the complete database easier. At the same time METU generally circulated a draft of their report detailing the modifications made to RESORCE since the previous version and a summary of the current data available.

Three complementary methods were followed to discover potential problems with the data and metadata of RESORCE. The first of these consisted of reviewing the report of METU and highlighting potential problems with the approach followed or the choices made. Secondly, various large-scale comparisons between the data and metadata of RESORCE to other databases or expectations based on seismological experience were conducted. Although such procedures will catch most gross errors, it is useful to conduct a 'random walk' through the database to highlight other potential problems. In this approach the reviewer 'follows his nose' and, by visually examining time-histories and their metadata, the reviewer can find potential errors based on his experience and knowledge of strong-motion data. This type of approach cannot be made automatic since it relies on human ability to detect unusual data. The results of these complementary approaches were generally circulated before the meeting to enable METU to respond during the meeting.

In the first part of the review meetings METU showed the progress that had been made since the previous meeting. The other group members commented and made suggestions during the presentation when specific points of interest were raised. Following the formal presentation more detailed comments and suggestions were made by the participants based on the analyses previously conducted. These often include brief presentations by members of the advisory board to illustrate their findings. These comments were discussed within the group and decisions sought. In the days following the meeting, these comments and the decisions made were formalised in the minutes drafted by Paola Traversa and circulated in the group for potential modifications and final agreement.

Some errors or inconsistencies were also discovered between meetings by advisory board members accessing the database. For example, the incorrect scaling of 13 records was highlighted in April 2013 in this manner.

4.2. Subjects covered by the review

Strong ground motions show considerable variability for the same magnitude and source-to-site distance. It has been shown many times (e.g. Strasser et al., 2009) that this variability is well characterised by a lognormal distribution, at least up to three standard deviations. This means that derivations of more than three standard deviations from the median expected ground motion (e.g. PGA) predicted using an appropriate ground motion prediction equation (GMPE) for a given scenario should only be seen about once or twice in every thousand records. This provides a way of quickly checking for large errors in the metadata (e.g. grossly incorrect magnitude), data (e.g. incorrect scale conversion factor) or in assignments of a record to a certain earthquake or station.

This technique was followed by John Douglas using the GMPE of Bommer et al. (2007) to predict the median PGA and the expected ground-motion variability (standard deviation). This GMPE was selected as it was derived using data from Europe and the Middle East (the geographical region covered by RESORCE) from a wide magnitude range (Mw 3 to 7.6) and it did not use independent variables (e.g. depth to top of rupture) that are not listed by RESORCE. The normalized residuals with respect to this GMPE were computed for all records in RESORCE and those with an absolute normalized residual greater than three were highlighted. About one hundred records were highlighted by this technique. The metadata and PGAs of these records were examined at the advisory board meetings and it was often possible to suggest a possible reason for the large derivations. However, many large deviations could not be attributed to an error but were thought to be due to natural variability in the motions or the use of a GMPE that was not applicable for the magnitude or distance of the record. A similar approach was used by Bruno Hernandez using the GMPE of Berge-Thierry et al. (2003) and considering the complete spectrum and not just PGA.

Such an approach is able to detect large errors in the data or metadata. However, it cannot find errors that do not lead to large residuals. The detection of this type of error requires non-automatic procedures, such as listed below.

Lucia Luzi made comparisons between the Italian records and their metadata listed in RESORCE with those contain in ITACA (the official strong-motion database of Italy). This comparison led to the modification of some filter cut-offs for the processing of Italian records and the discovery of some errors in the metadata reported in RESORCE for Italian records.

Gabriele Ameri undertook a comparison between the magnitudes and locations reported in RESORCE and those given in the GEM-ISC catalogue and also the moment magnitudes reported by the Regional Centroid Moment Tensor catalogue. This brought to light a few earthquakes for which the magnitudes given by RESORCE appeared suspect and a number of earthquakes where the earthquake locations were likely incorrect. These errors were corrected.

The advisory board also indicated to METU various scientific articles concerning some earthquakes (generally the larger events) that could contain better locations (or other source information) than currently given in RESORCE. METU will analyse these articles before the next version of RESORCE is published and extract the relevant information.

4.3. Special issue

Towards the end of the project Seismic Hazard Harmonization in Europe (SHARE) funded by the European Commission's Seventh Framework Programme it was decided to make use of the strong-motion database compiled by METU during SHARE (the forerunner of RESORCE) to develop a new set of ground-motion prediction equations using various techniques. Five sets of developers produced ground-motion models using RESORCE (version 2012), which was kindly released by EDF to researchers outside SIGMA solely for this purpose. The results of this exercise will be published in a special issue of Bulletin of Earthquake Engineering in early 2014 (these articles are already available online), which is being guest edited by John Douglas. One of the eight articles in this special issue is a presentation of RESORCE by Akkar et al. (2014). This article went through two rounds of peer-review by two international anonymous reviewers. This review helped highlight some points where RESORCE can be improved.

Analysis of the residuals for their ground-motion model, led Bindi et al. (2014) to highlight possible problems with the metadata (specifically magnitudes) of some earthquakes. These problems were reported at the RESORCE meeting of 5th July 2013 and were corrected by METU. Bindi et al. (2014) suggest that the local to moment magnitude conversions used should be revisited because they may be contributing to the high between-event variability for small earthquakes. They suggest that it may be better to derive ground-motion models for small earthquakes in terms of local magnitude rather than use these magnitudes converted to moment magnitudes. They also suggest that the high-pass corner frequencies of the records from small earthquakes should also be checked. The authors of all five ground-motion models were invited to comment on RESORCE but only Bindi et al. (2014) did so, which is an indication of the high quality of the database.

In conclusion, the various peer reviews of RESORCE undertaken over the past three years have led to a high-quality strong-motion database that will be invaluable for the assessment of seismic hazard in Europe and elsewhere.

5. Exchanges & collaborations with related EC projects

This chapter illustrates the complementarity between RESORCE and other EC projects and initiatives in the field of accelerometric data, as well as the importance of coordination. The following sections summarize the ongoing EC initiatives to build and maintain an infrastructure for accelerometric data exchange, storage and dissemination at the pan-European level. Exchanges between RESORCE and the management of various EC projects are focused on assuring the transparency, complementarity and coordination of respective actions, avoiding duplication of efforts, as well as assuring the long-term sustainability of RESORCE after the end of the SIGMA project.

5.1. Ongoing efforts to build a European infrastructure for accelerometric data

The NERA project (www.nera-eu.org), through its activity NA3, promotes strong-motion databases and the networking of strong-motion data providers in Europe to assure data exchange, storage and dissemination in the long term. This objective will be achieved by performing the activities described in the following paragraphs.

Improving the waveform parameterization procedures for near-real time accelerometric data using the European Integrated Data Archive (EIDA, www.orfeus-eu.org/eida/eida.html) as the major infrastructural utility. The near-real time accelerometric data is designated as the Rapid-Raw Strong Motion (RRSM) database as it is the collection of accelerometric data obtained immediately after an earthquake of any size.

Assembling a prototype strong-motion database (defined as Engineering Strong Motion, ESM, database) with an initial core formed by the accelerograms recorded by the major Italian and Turkish strong-motion data providers. ESM is structured to contain not only the data available in EIDA but also off-line data; earthquake and strong-motion metadata providing more detailed information than the corresponding metadata in RRSM as almost all of the accelerograms in ESM are archived collections of relatively large magnitude events that are of engineering significance. The waveform parameterization and metadata information of such accelerometric data are processed in a different way for their use in engineering applications.

Improving the broadband station inventory in the broader Europe region and extending it by including strong-motion stations across Europe and in the surrounding regions.

5.2. The role and position of RESORCE with respect to RRSM and ESM

In the framework described above, the infrastructure for sharing, exchanging and disseminating seismic motion data will be organized at different levels.

At a first level, the RRSM database will be nourished in real-time after the occurrence of an earthquake of any size with the collection of accelerometric data and metadata. This procedure will be fully automatic, so no quality check on data or metadata is expected at this level. Also, only data coming from seismic agencies having real-time data exchange tools will be included in this database.

At a second level, and a short time after the occurrence of an earthquake, the ESM database will be supplemented, including RRSM data as well as off-line data. ESM is meant to provide more detailed information about earthquakes and strong-motion metadata than the corresponding metadata in RRSM. In particular, for large magnitude events that are of engineering significance, the waveform parameterization and metadata information of such accelerometric data are processed for their use in engineering applications.

Both databases at the first and second levels are meant to be dynamic databases, i.e. updated in a nearly continuous way after the occurrence of an earthquake.

The third level is represented by RESORCE, which is meant to be a static high-quality database of seismic motion, only containing validated data to be used to, for example, derive and test ground-motion models and for earthquake engineering applications. As described in the previous sections, RESORCE is a “frozen” database evolving through successive versions. Therefore, one will be able to go back to the data used to derive a given model at any time. Figure 5.1 illustrates the evolution modes of these two types of database.

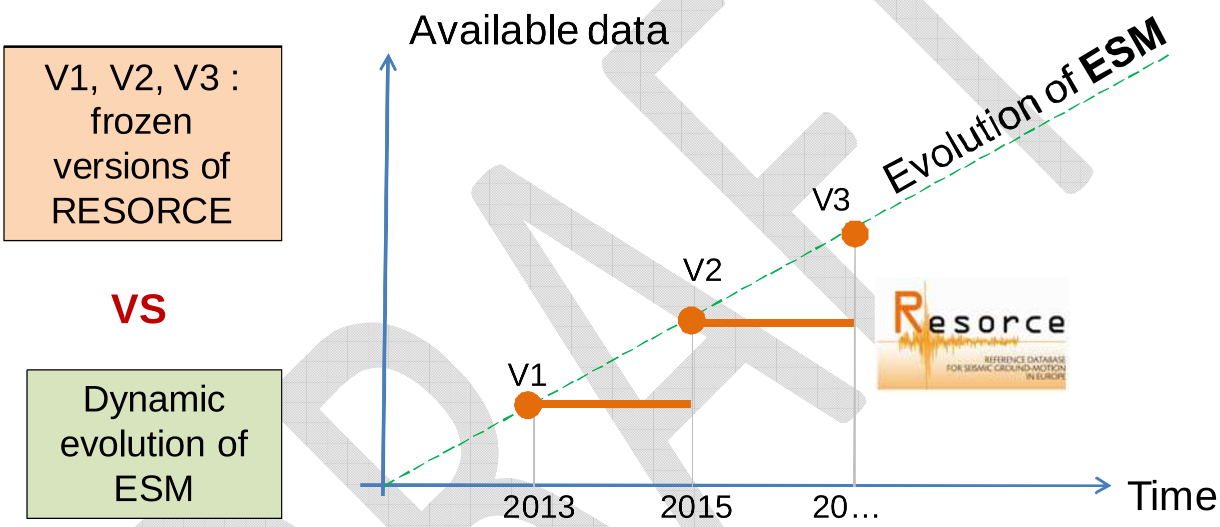


Figure 35 : Schematic representation of the evolution of ESM (Engineering Strong-Motion) database and of RESORCE as function of time and available data.

5.3. ORFEUS Working Group 5 – acceleration and strong motion data

The first two-year activities of the NERA-NA3 work package were shared with the strong-motion community of Europe and surrounding countries during the 2012 Observatory Coordination Workshop that was held in Istanbul, Turkey (www.koeri.boun.edu.tr/orfeus2012/) and organized by ORFEUS (www.orfeus-eu.org). The major theme of this Workshop was to bring forward the NERA-NA3 activities to develop policies for the integrated pan-European accelerometric databank.

The major outcome of the Workshop was the common agreement to continue with the efforts of NERA-NA3 by the constitution of a Working Group (WG5 – acceleration and strong motion data, www.orfeus-eu.org/workinggroups/wg5.html) that operates under the umbrella of ORFEUS. WG5 will build the basis for the sustainable integrated pan-European accelerometric data distribution. Structuring the working group under ORFEUS can also benefit the future project opportunities that will be supported by EPOS (www.epos-eu.org/), as ORFEUS is the EPOS seismological thematic service.

The responsibilities and duties of the WG5 are envisaged as follows:

- Setting rules for data dissemination
- Establishing Memoranda of Understanding with data providers
- Collaborating with EPOS for the preparation of projects
- Contacting similar establishments in other parts of the world
- Ensuring the quality of metadata and waveforms:
- Checking the quality of processed data from the partner institutions
- Suggesting/developing state-of-the-art techniques for metadata compilation and data processing
- Ensuring IT development improvements:
- Optimizing data transfer, archiving and dissemination techniques etc
- Coordinating with related activities of ORFEUS/EPOS

WG5 will be formed by representatives of the strong-motion data providers willing to join the initiative. A preliminary board has been created with representatives of Greece, Turkey, Italy, France, Switzerland and Iceland and the Governance of the group is defined.

Data distribution policy will be extensively discussed at the workshop on strong-motion data that will be held in Ankara in spring 2014. The outcome of the workshop should be a common policy for strong-motion data distribution, in order to have a general consensus on the Memoranda of Understanding that will be signed between data providers and ORFEUS.

5.4. Future

ORFEUS is going to be one of the EPOS thematic services and, in the framework of WG5, it will compile a continuously updating ESM (Engineering Strong-Motion) database containing all data from the major data providers in Europe and it will perform preliminary quality checks, semi-automatic processing and metadata revision. ORFEUS will maintain and distribute the ESM (Engineering Strong-Motion) database and it will sign agreements with data providers for strong-motion data sharing and distribution.

As a proposal, ORFEUS could include RESORCE in the agreements signed with data providers as a by-product of the European strong-motion database.

In this framework, RESORCE could be updated and improved in time exploiting the availability of data in the Engineering Strong-Motion database. Figure 5.2 summarizes the plan of the functioning and exchange systems between ESM database and RESORCE in the future.

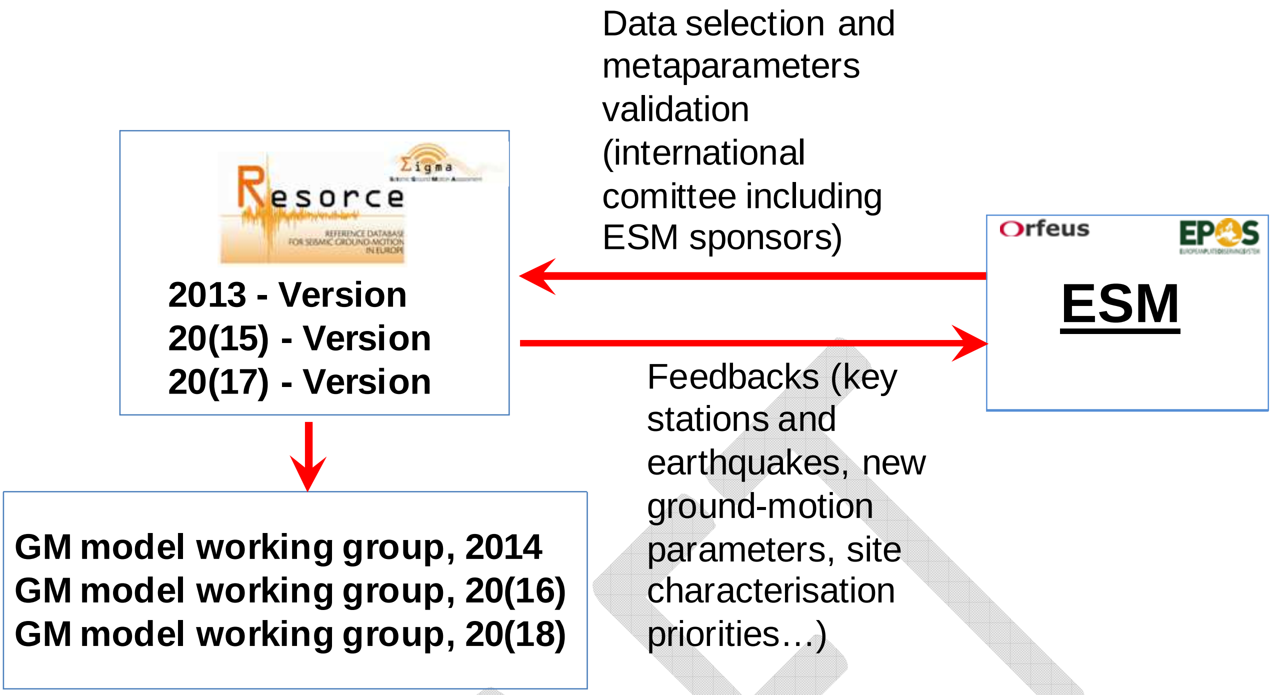


Figure 36 : Schematic view of the future functioning and exchange system of the ESM database and RESORCE.

6. Conclusion

This report summarizes the general features of the most recent pan-European strong-motion databank that updates and expands previous version of RESORCE. The current version of RESORCE increases the record and event size of its predecessor by approximately 1.5 times with improvements in magnitude and distance distributions through additional data from recent Swiss, Greek and French events. The size of RESORCE reaches 7622 multi-component accelerograms. However, the recordings with little engineering and seismological use are removed from RESORCE and the above number has decreased to 5637 in the final version of RESORCE. These recording are from 1713 events. The total number of strong-motion stations in the inventory is 1481 out of which one-third of stations have direct shear-wave velocity profiles. Almost 70% of the events have moment magnitude information. The earthquake magnitudes range between 2.8 and 7.8 in RESORCE. Almost entire population of the databank has point-source distance metrics (i.e., Repi and Rhyp). Some Rhyp information is missing in RESORCE as few events lack the focal depth information. The accelerograms with extended-fault distance metrics (R_{JB} and R_{rup}) constitute 58% of the databank.

The improvements on the data access portal, as well as the setting up of the versioning system are described in section 3.

The content of RESORCE – 2013 version has been reviewed and validated, following the procedure described in section 4.

The complementarity and the transparency between RESORCE project and ongoing EC initiative in the field of accelerometric data is assured by the frequent exchanges and the collaboration among the management of the different projects.

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Appendix A

References	Event
ESMD	European strong-motion database (ESMD, Ambraseys et al. 2004b)
GCMT	Global Centroid Moment Tensor Catalog Search (GCMT, www.globalcmt.org)
HEAD	Hellenic Accelerogram Database (HEAD, http://www.itsak.gr/en/db/data)
IAG	Instituto Andaluz de Geofisica (http://www.ugr.es/~iag/)
ISC	International Seismological Centre (ISC; http://www.isc.ac.uk/)
ISESD	Internet site for European strong-motion data (ISESD; Ambraseys et al., 2004a)
ITACA	Italian accelerometric archive (ITACA, Luzi et al., 2008)
RAP	French Acceleremoteric Network; http://www-rap.obs.ujf-grenoble.fr
RCMT	European-Mediterranean Regional Centroid Moment Tensor catalog (RCMT; http://www.bo.ingv.it/RCMT/)
SED	The Swiss Seismological Service (arclink.sed.ethz.ch)
SED1	SED/ETH RealTime Regional Moment Tensors Catalog (http://www.seismo.ethz.ch/prod/tensors/mt_list/index)
SED2	The Swiss Seismological Service Discontinued Moment Tensor Catalogs (http://www.seismo.ethz.ch/prod/tensors/mt_disc/index)

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ORIGINAL RESEARCH PAPER

Reference database for seismic ground-motion in Europe (RESORCE)

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Abstract This paper presents the overall procedure followed in order to assemble the most recent pan-European strong-motion databank: Reference Database for Seismic Ground-Motion in Europe (RESORCE). RESORCE is one of the products of the SeIsmic Ground Motion Assessment (SIGMA; projet-sigma.com) project. RESORCE is intended to be a single integrated accelerometric databank for Europe and surrounding areas for use in the development and testing of ground-motion models and for other engineering seismology and earthquake engineering applications. RESORCE aims to contribute to the improvement of earthquake risk studies in Europe and surrounding areas. RESORCE principally updates and

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extends the previous pan-European strong-motion databank (Ambraseys et al. in Bollettino di Geofisica Teorica ed Applicata 45:113–129, 2004a) with recently compiled Greek, Italian, Swiss and Turkish accelerometric archives. The updates also include earthquake-specific studies published in recent years. The current content of RESORCE includes 5,882 multi-component and uniformly processed accelerograms from 1,814 events and 1,540 strong-motion stations. The moment magnitude range covered by RESORCE is $2.8 \leq M_w \leq 7.8$. The source-to-site distance interval extends to 587 km and distance information is given by the common point- and extended-source distance measures. The paper presents the current features of RESORCE through simple statistics that also quantify the differences in metadata and strong-motion processing with respect to the previous version of the pan-European strong-motion databank.

Keywords Pan-European strong-motion databank · Strong-motion data processing · Earthquake and strong-motion station metadata compilation

1 Evolution of strong-motion data collection in Europe

The attempts to collect and compile strong-motion data from Europe and the Middle East started in the first half of 1970s at Imperial College, London after the 1967 Debar and 1969 Portugal earthquakes (Ambraseys 1978). The volunteer work undertaken at Imperial College was later funded through various grants provided by the governmental agencies of the UK and the European Commission (Bommer and Douglas 2004); the latter being collaborative projects with different European research centers (Ambraseys 1990; Ambraseys and Bommer 1990, 1991; Bommer and Ambraseys 1992). The major focus point in these projects was the consistent evaluation of earthquake and strong-motion station metadata information as well as uniform processing of strong-motion records, leading to a reliable strong-motion databank for earthquake-induced hazard and risk studies in Europe.

The efforts that grew out from these studies resulted in a CD-ROM of 1068 tri-axial accelerograph data (Ambraseys et al. 2000) that was expanded later by additional recordings from the broader Europe (pan-European) region. The expanded strong-motion databank (2213 accelerograms from 856 earthquakes recorded at 691 strong-motion stations) is disseminated through the Internet Site for European Strong-Motion Data web page (ISESD; http://www.isesd.hi.is; Ambraseys et al. 2004a). The ISESD strong-motion databank considers special studies on earthquakes (released as either institutional reports or articles published in peer-reviewed journals) as the primary sources for the earthquake and strong-motion station metadata. In the absence of such earthquake-specific studies, the earthquake metadata (e.g., epicentral location, focal depth as well as magnitude estimations other than local magnitude, M_L) were mostly taken from the Bulletin of the International Seismological Center (www.isc.ac.uk). The local magnitude information was gathered from local and national networks. The preferred source of information for earthquake location is the local or national networks whenever they were assessed as more reliable with respect to the international seismic agencies. The network owners are rated as the most reliable information source for strong-motion station metadata information (e.g., site conditions, station coordinates, shelter type) when strong-motion sites lack specific monograms. The soil conditions of strong-motion stations are classified using the Boore et al. (1993) scheme that is based on V_{S30} intervals ($V_{S30} <$ 180 m/s; 180 m/s $\leq V_{S30} <$ 360 m/s; 360 m/s $\leq V_{S30} <$ 750 m/s; $V_{S30} \geq$ 750 m/s) where V_{S30} is the average shear-wave velocity in the top 30 m soil profile. However, the unavailable shear-wave velocity profiles at almost all strong-motion stations constituted the major difficulty in the soil classification of strong-motion sites. Almost all the processed strong-motion records in ISESD were band-pass filtered using an elliptical filter with constant high-pass and low-pass cut-off frequencies (0.25 and 25 Hz, respectively). A subset of ISESD was re-processed using the bi-directional (acausal) Butterworth filter with cut-off frequencies adjusted individually for each accelerogram. The individual filter cut-off frequencies were determined from the signal-to-noise ratio of each accelerogram. This subset, later, was released as another CD-ROM (ESMD; European Strong-Motion Data; Ambraseys et al. 2004b) after the inauguration of the ISESD web site.

The efforts for the compilation of ISESD strong-motion databank were followed by important national and international strong-motion and seismic hazard projects in Europe and the surrounding regions. Of these projects the ITalian ACcelerometric Archive Project (ITACA; http://itaca.mi.ingv.it; Luzi et al. 2008) and the Turkish National Strong-Motion Project (T-NSMP; http://kyh.deprem.gov.tr/; Akkar et al. 2010) are national initiatives to compile, process and archive local (national) accelerometric data using state-of-art techniques. The ITACA project compiled a total of 2,182 accelerograms from 1,004 events (Luzi et al. 2008) whereas T-NSMP studied 4,607 strong-motion records from 2,996 earthquakes recorded at 209 stations (Akkar et al. 2010). Both ITACA and T-NSMP also improved the site characterization of strong-motion stations either by reassessing the existing shear-wave velocity profiles and soil column lithology information or by utilizing invasive or noninvasive site exploration techniques to compute the unknown V_{S30} and other relevant site parameters (e.g., Sandıkkaya et al. 2010). A similar effort has also been started in Greece after 2000 to archive the uniformly processed Greek records of strong-motion stations operated by ITSAK (http://www.itsak.gr/; Theodulidis et al. 2004) under the HEAD (HEllenic Accelerogram Database) databank. The Seismic Hazard HARmonization in Europe project (SHARE; www.share.eu.org), a grant provided by the European Commission, compiled a strong-motion databank (Yenier et al. 2010) by collecting shallow crustal accelerometric data from the worldwide strong-motion databanks (ISESD, ESMD, ITACA and T-NSMP are among these databanks) to test the performance of candidate ground-motion prediction equations (GMPEs) for hazard calculations in Europe. This databank (13,500 records from 2,268 events recorded at 3,708 stations) neither updates the metadata information nor develops a uniformly processed accelerometric data archive from the existing events of the selected strong-motion databanks. However, the developers of the SHARE strong-motion databank gave careful consideration to the removal of duplicated entries in the event, station and waveform information through a hierarchical approach.

2 Motivation behind the development of RESORCE

Despite the significant efforts put forward in the development of ISESD, it suffers from poor strong-motion site characterization and the use of constant filter cut-offs in data processing. This latter feature has been proven to be inappropriate as it may result in misrepresentation of actual ground-motion frequency content of the recorded events (e.g., Akkar and Bommer 2006). Recent national strong-motion projects (major ones have already been discussed in the previous section) tried to prevent these drawbacks but they evolved as individual attempts. These projects implemented their own procedures while assembling the databases that may result in lack of uniformity in metadata compilation and record processing during their integration under a single strong-motion databank. The SHARE project gathered strong-motion data from recent strong-motion databanks but no attempt was made to homogenize the data processing of accelerograms. Improvements of earthquake and station metadata from recent studies in the literature were also out of the scope of the SHARE strong-motion databank. The recordings from recent earthquakes of engineering significance in the broader European region (e.g., 2009 L'Aquila Earthquake M_w6.3; 2011 Van Earthquake M_w7.1; 2011 Van-Edremit Earthquake M_w5.6; 2011 Kütahya-Simav Earthquake M_w5.9; 2010 Elazığ-Kovancılar Earthquake M_w6.1) are either entirely or mostly disregarded in the SHARE strong-motion databank.

The primary motivation behind RESORCE is to be a single integrated accelerometric databank for the broader European area. The basic ingredient of RESORCE is the pan-European subset of the SHARE strong-motion databank (Yenier et al. 2010). It updates and expands the ISESD accelerometric archive using information gathered from recently carried out strong-motion database projects as well as from other relevant earthquake-specific studies in the literature. The uniform data processing of accelerograms as well as improved magnitude and source-to-site distance distributions constitute other important steps in RESORCE. RESORCE is one of the products of the SIGMA (**S**e**I**smic **G**round **M**otion **A**ssessment) project whose main goal is to improve seismic hazard assessment methods in France and neighboring regions, with realistic characterization of aleatory and epistemic uncertainties. RESORCE, which is built using a consistent approach, is one of the building blocks for achieving these objectives. The development of RESORCE is realized as a collaborative work under SIGMA-Work Package 2 that consists of researchers from Électricité de France (EDF), Institut des Sciences de la Terre (ISTerre), Bureau de Recherches Géologiques et Minères (BRGM), Euro-Mediterranean Seismological Centre (EMSC), Istituto Nazionale di Geofisica e Vulcanologia (INGV), Laboratoire de detection et de Géophysique (LDG) and Middle East Technical University (METU). The last institute is responsible for the compilation and processing of RESORCE whereas the first five institutions are heavily involved in its scientific revision, coordination and dissemination. RESORCE went through a peer review process during its evolution to provide verified accelerometric data together with reliable metadata that can be used in engineering seismology and earthquake engineering studies. The steps followed in assembling RESORCE are described in the following sections with emphasis on the differences between ISESD and RESORCE so as to display the level of improvements in the current pan-European accelerometric data archive.

3 Strategy followed in the compilation and strong-motion data processing

The accelerometric data and corresponding metadata information gathered in RESORCE are a collection of recordings from local accelerometric data providers, previously established regional and global databanks, seismological agencies and recent studies in the literature. Table 5 lists the 6 major sources (designated under the "Accelerogram" column) used for collecting the raw accelerograms in RESORCE. These reference sources also contain earthquake and strong-motion station metadata information as presented in Table 5. The existing earthquake and strong-motion station metadata from these sources as well as other reliable references were studied individually while assembling RESORCE. The waveforms of raw accelerometric data were visually inspected one by one in terms of waveform quality and frequency content to implement a well-established data processing technique into the entire strong-motion databank. The steps followed in this entire process are summarized below.

3.1 Compilation of earthquake and strong-motion station metadata

The major structure of RESORCE consists of two principal blocks: (1) earthquake and station metadata information, and (2) accelerometric data. Inherently, these two blocks are related to each other and are assembled from almost the same reference sources (see Table 5). Figure 1 summarizes the overall structure of RESORCE in this perspective. ISESD and its subset ESMD are considered as the primary sources of earthquake (M_w, epicentral coordinate, depth, style-of-faulting, fault geometry etc.) and strong-motion station (soil conditions, station coordinate, different source-to-site distance measures, recoding type—analog vs. digital—etc.) metadata for pre-2004 events. This preference is waived for the earthquakes that occurred in Italy as well as the Italian strong-motion stations as ITACA contains the most up-to-date station and event information for Italy. Notwithstanding, for Italian events that lack of M_w, the Castello et al. (2007) $M_L - M_w$ empirical magnitude conversion relationship was used. This is the only modification made to ITACA within the context of these studies.[1] The preeminence of ISESD and ESMD for pre-2004 earthquake metadata of Turkish events is not overruled because T-NSMP provides earthquake information from a set of seismological references for each entry in its archive and both ISESD and ESMD are among these seismological sources. Thus, the decision on preferring ISESD and ESMD for pre-2004 Turkish earthquake metadata is in line with the database compilation policy of T-NSMP. The earthquake and station information of additional references, other than ISESD and ESMD, (see Fig. 1 as well as Tables 5 and 6) is primarily taken into account for post-2004 earthquake and station metadata in RESORCE. These references are also used for the pre-2004 RESORCE inventory to complete some of the missing earthquake metadata components of individual events or for including additional earthquakes that are not covered by the ISESD or ESMD archives. The event- and station-based information collected from earthquake-specific literature studies are always ranked as the primary reference for earthquake and station metadata in RESORCE regardless of the corresponding information in the other studied sources. Table 6 presents the peer-reviewed literature studies used from this standpoint. This table also lists the earthquake-specific literature survey compiled and used by ISESD that is inherently considered during the compilation of RESORCE. The reported M_w values of seismic agencies are based on global or regional moment tensor solutions. These M_w values are accepted as they are and no quality assurance is made by tracing back the number of stations used in their computation. In a similar fashion while converting the body-wave magnitude (m_b) scale into M_w, the possibility of positive biases in m_b for small-to-moderate size events was not considered. Such additional quality assurance checks should be made in the upcoming versions of RESORCE to improve the reliability of information released by this strong-motion databank.

An important detail about the RESORCE station metadata is the site characterization of the Turkish and Greek strong-motion stations. The T-NSMP strong-motion inventory is preferred for the site information of the national-network stations of Turkey because it contains the most updated site characterization of these stations. Similarly, the recent site information of 19 Greek stations from the HEAD archive is used to update the site classification of corresponding Greek recordings in RESORCE. The site information of 7 Turkish strong-motion stations other than those pertaining to the national-network is compiled from the literature survey (Rosenblad et al. 2002; see Table 6). Site information of 3 Greek strong-motion stations not covered by HEAD is obtained via personal communication with Prof. Kyriazis Pitilakis and Ms. Evi Riga (AUTH, Greece). The primary parameter used for strong-motion site characterization in RESORCE is V_{S30} as ITACA, T-NSMP, HEAD as well as recent

[1] A similar magnitude conversion process was also implemented in HEAD and T-NSMP during their compilation (Theodulidis et al. 2004; Akkar et al. 2010). For Greek events, Papazachos et al. (2002) was used for $M_L - M_w$ conversion. The empirical relationships of Akkar et al. (2010) were used for M_w conversion of Turkish earthquakes if they are reported in other magnitudes. The resulting moment magnitude estimations are taken into account in RESORCE for Greek events, post-2004 Turkish earthquakes as well as for those that occurred before 2004 whenever they are not included in ISESD or ESMD.

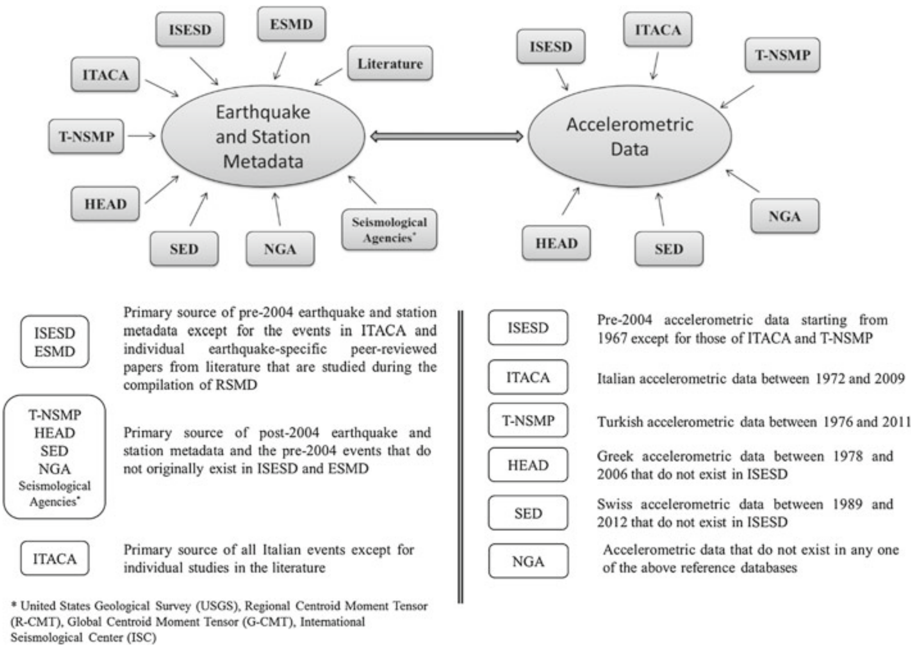

Fig. 1 Basic structure of RESORCE and reference sources that build the metadata information as well as the accelerometric data in RESORCE

Table 1 In-situ site measurements of the RESORCE strong-motion recording stations

Measurement description	Reference source
Seismic cross-hole	HEAD and ITACA
Seismic down-hole	HEAD and ITACA
Extended spatial autocorrelation method from microtremor array measurements (ESAC)	ITACA
Frequency wavenumber spectrum method from microtremor array measurements (ESAC-FK)	ITACA
Multi-channel analysis of the surface waves (MASW)	ITACA and T-NSMP
Spectral analysis of surface waves (SASW)	Rosenblad et al. (2002)

literature studies that are accounted for while compiling the RESORCE station metadata use in-situ shear-wave velocity profiles measured by invasive and noninvasive site exploration techniques. Table 1 presents the geophysical site exploration techniques whose shear-wave velocity measurements are evaluated by the above reference sources for site characterization of strong-motion stations in their archive.

The unification of earthquake and station metadata for RESORCE as described in the previous paragraphs is finalized by homogenizing the classification of style-of-faulting (SoF). The homogenization of the SoF classification was a necessary step as the existing double-couple fault-plane solutions are evaluated differently by each reference source to identify the SoF of each event in their inventory. The procedure proposed in Boore and Atkinson (2007) is used to remove the differences in SoF classification of the considered reference sources.

Table 2 Criteria of style-of-faulting classification using plunge angles

Style of faulting	P-axis plunge angle	T-axis plunge angle
Normal	P-pl>40	T-pl<40
Reverse	P-pl<40	T-pl>40
Strike-slip	P-pl<40	T-pl<40

This procedure, which is modified from Frohlich and Apperson (1992) and Zoback (1992), uses the plunge angles of the T- and P-axes of the double-couple fault-plane solutions. The procedure does not require the actual fault plane solution, which makes it appealing in the determination of SoF for earthquakes that occur on faults without a rupture trace on the surface. It determines a unique SoF, which is not the case for SoF classifications based on the rake angle. The rake angles of actual and auxiliary planes from double-couple fault-plane solutions can sometimes result in two different SoF classifications for the same earthquake. The missing plunges of the T- and P-axes for certain events in RESORCE does not constitute a drawback in the implementation of the Boore and Atkinson (2007) procedure as they can be computed from the strike, dip and rake angles of the fault-plane solutions (Snoke 2003). Table 2 lists the intervals of the plunges of the T- and P-axis for SoF classification in RESORCE.

The completed earthquake and station metadata of RESORCE enabled the computation of missing source-to-site distance measures (R_{epi}, R_{hyp}, R_{JB} and R_{rup})[2] as well as the evaluation (and, if necessary, re-calculation) of existing ones that are collected from the considered reference sources. The strategy outlined in gathering the RESORCE earthquake and station metadata guided this phase of the work: the existing source-to-site distance information in ISESD and ESMD for the pre-2004 accelerograms is kept as it is except for (a) the source-to-site distances originated from ITACA, (b) the distance modifications based on the revised earthquake metadata resulting from literature survey, and (c) the new distance calculations upon the completion of missing parameters from other reference sources. The distance measures of the post-2004 accelerograms as well as the additional pre-2004 recordings that are not considered by ISESD are also obtained from the other reference sources. In the absence of extended-source distance measures (R_{JB} and R_{rup}) by the reference source databases their computation is based on the double-couple fault-plane solutions extracted from international or local seismic agencies. For such cases, upon the existence of double-couple fault-plane solutions, the nucleation point is assumed to be at the center of the fault surface and the rupture dimensions of the fault (length and width) are estimated from Wells and Coppersmith (1994).[3] The extended source metrics are calculated as pairs (i.e., $R_{JB_1} - R_{JB_2}$ and $R_{rup_1} - \mathrm{R}_{rup_2}$) for each plane using the procedure described in Kaklamanos et al. (2011). RESORCE source-to-site distance inventory contains these distance pairs as well as their arithmetic averages ($\overline{\mathrm{R}_{JB}}$ and $\overline{\mathrm{R}_{rup}}$) as alternatives for the end user. The averaging approach that is mostly implemented for events falling into $3.0 \leq M_w \leq 6.8$ certainly involves

[2] R_{epi}: epicentral distance; R_{hyp}: hypocentral distance; R_{JB}: closest distance to the surface projection of ruptured fault; R_{rup}: closest distance to ruptured fault.

[3] Leonard (2010) recently proposed a set of scaling relationships that relate M_w with rupture length, rupture width and rupture area. These relationships are self-consistent as they enable to estimate any one of these parameters from the others. Thus, the empirical relationships proposed by Leonard (2010) supersede Wells and Coppersmith (1994). The impact of these alternative approaches on the estimated extended-source distance measures is examined by running a set of analyses that consists of 1,582 strong-motion records. The computed R_{JB} values from Leonard (2010) and Wells and Coppersmith (1994) did not show significant deviations from each other. Thus, the extended-source distance computations are completed by using the rupture length and width formulations provided by Wells and Coppersmith (1994).

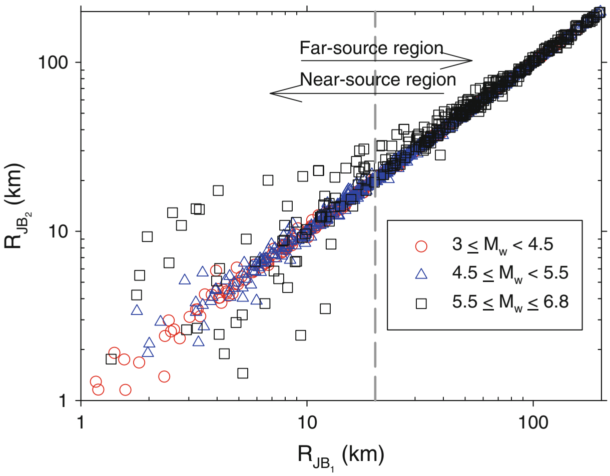

Fig. 2 Differences between $R_{JB_1} - R_{JB_2}$ pairs computed from the two planes given by the double-couple fault-plane solutions in the absence of extended-source distance measures (R_{JB} and R_{rup}) in the reference source databases. *Different color codes* and *symbols* indicate different magnitude intervals

uncertainties in the computed extended-source distances. The observations on the computed $R_{JB_1} - R_{JB_2}$ and $R_{rup_1} - R_{rup_2}$ pairs indicate that the differences between the components of each pair are small for far-source accelerograms and small-to-moderate size earthquakes (i.e., $3.0 \le M_w \le 5.5$). The difference between the components of extended-source distance pairs becomes significant for some large-magnitude ($5.5 < M_w \le 6.8$) recordings that are close to the source. Figure 2 documents these cases for $R_{JB_1} - R_{JB_2}$ pairs. The far-source recording trends in Fig. 2 indicate that unless there is a compelling reason for preferring one of the components of extended-source distance pairs, the choice of their average for distant accelerograms would not result in significant errors. The near-source scatters on this figure suggest that the averaging approach, rather than the random choice of one of the distance components, is a rational compromise for extended-source distance metrics that show significant component-wise differences within this distance range. If a double-couple fault-plane solution does not exist for a given event, no attempt is made to calculate the extended-source distance metrics by using one of the suggested methods in the literature (e.g., Scherbaum et al. 2004; EPRI 2004).

3.2 Strong-motion data processing

As in the case of metadata compilation, the ISESD strong-motion databank is taken as the primary source of raw pre-2004 accelerograms except for those that are archived by ITACA and T-NSMP. The raw accelerometric data compiled by these projects constitute the first-hand information as they are directly obtained from the national strong-motion networks of Italy (ITACA) and Turkey (T-NSMP), respectively. The HEAD and SED accelerograms are used either for completing the non-existing pre-2004 raw Greek and Swiss data in ISESD or expanding RESORCE for Greek and Swiss accelerograms for the post-2004 period. Some additional pan-European accelerometric data (16 multi-component accelerograms) from the NGA-West1[4] strong-motion databank are also integrated into RESORCE. These accelero-

[4] Next Generation Attenuation Project (Power et al. 2008).

grams were retrieved from the NGA database as processed and are accepted in this format as their band-pass filtering and post-processing scheme is almost identical to the one implemented in RESORCE. A total of 89 already-processed multi-component accelerograms from ISESD are directly incorporated into RESORCE because of their missing raw waveforms. Although the data processing schemes of ISESD and RESORCE are different, these data are not disregarded in order not to overlook the good-quality recordings of the pan-European events while establishing RESORCE.

The strong-motion data processing of RESORCE is based on visual screening and band-pass filtering of raw accelerograms. The visual screening of waveforms is used to detect and remove non-standard errors[5] (Douglas 2003; Bommer and Douglas 2004). Band-pass filtering is implemented right after visual inspection if the records are free of non-standard errors. Otherwise, band-pass filtering constitutes the second stage of the data processing scheme after removing the non-standard errors. Figure 3 presents a set of sample recordings that show different cases of non-standard errors. Extremely low-quality accelerograms (Fig. 3a) are not band-pass filtered as such records would not reveal reliable information in time- and frequency-domain for engineering seismology and earthquake engineering studies. A total of 1,658 horizontal and 1,083 vertical acceleration components are classified as very low quality recordings in RESORCE. The acceleration trace of the major event is considered for accelerograms with multiple-shock recordings (Fig. 3b). The time interval of the major event is approximately determined by identifying the starting and ending times of the smaller amplitude recordings on the entire accelerogram. Although this procedure may impose some uncertainty on the actual length of the major event, the introduced errors are assumed to be negligible and they do not critically distort the particular features of the major event in the time- and frequency-domain. The very high-frequency spikes having abnormally high amplitudes with respect to the overall data trend in accelerograms (Fig. 3c) are removed by replacing the acceleration ordinate of the spike with the average of the data on either side. No spikey noise that repeats itself due to instrument imperfection (or any other source triggering this kind of high frequency noise) is detected in the visually inspected accelerograms that may require more complicated de-spiking algorithms (e.g., Evans 1982). The S-wave triggered records (Fig. 3d) are not subjected to time-domain manipulation as in the case of other non-standard errors. They are band-pass filtered without tapering to prevent the clipping of original peak acceleration. The details of band-pass filtering are described in the following paragraph.

The band-pass filter cut-off frequencies are selected by studying the Fourier acceleration spectrum (FAS) of each raw accelerogram to detect the physically unjustifiable frequency content at high- and low-frequency components of the ground motion. The accelerograms are assumed to be contaminated by low- and high-frequency noises beyond the chosen filter cut-off frequencies whose identification is described in the relevant literature (e.g., Boore and Bommer 2005; Akkar and Bommer 2006; Douglas and Boore 2011). The theoretical corner frequencies of Atkinson and Silva (2000) double-corner source spectrum are used as guidance to the selection of low-cut filter frequencies. These magnitude-dependent corner frequencies are designated as f_a and f_b that are related to the major and sub-fault fault sizes, respectively. Although the use of Atkinson and Silva (2000) double-corner source spectrum is still not verified for Europe, the low-cut filter frequencies that are greater than f_b can be interpreted as the removal of an integral part the signal while filtering the low-frequency noise. The selection of high-cut filter values is based on the high-frequency noise behavior discussed in

[5] Non-standard errors refer to types of problems in strong-motion records that cannot be dealt by standard filtering or baseline adjustment techniques. Some of the frequently observed non-standard errors are high-frequency spikes, S-wave trigger, insufficient digitizer resolution, insufficient sampling rate, multiple shocks, early termination of coda and clipping of accelerograms (Douglas 2003).

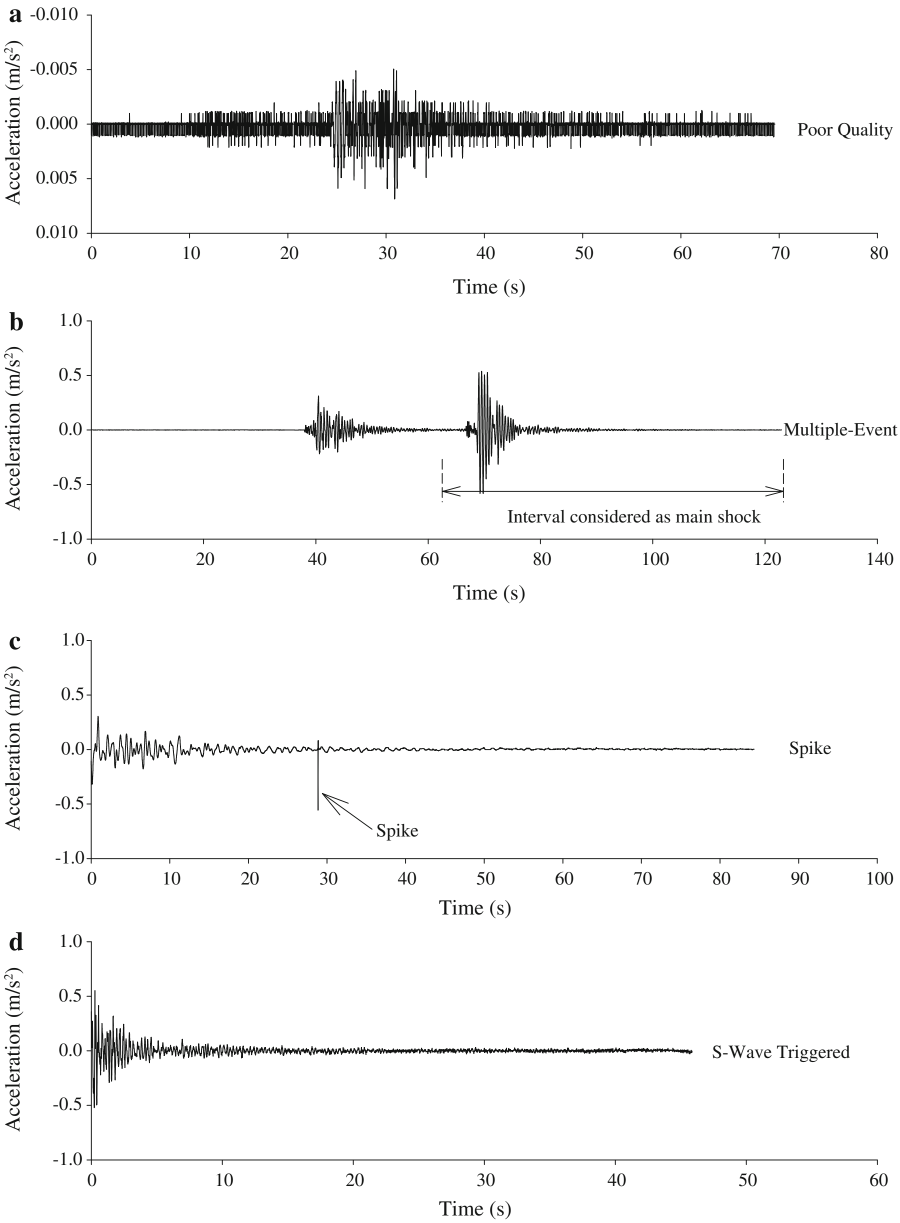

Fig. 3 Example waveforms featuring different types of non-standard errors in time domain

Douglas and Boore (2011). The flat portion at the high-frequency end of FAS that is contrary to the expected high-frequency attenuation of ground acceleration is removed by choosing an appropriate high-cut filter frequency. If such an unexpected behavior is not observed at the high-frequency end of FAS, the record is not high-cut filtered and the Nyquist frequency of the accelerogram is considered to represent its high-cut filter frequency value. The selected high- and low-cut filter frequencies are documented in RESORCE. The Butterworth acausal filter is

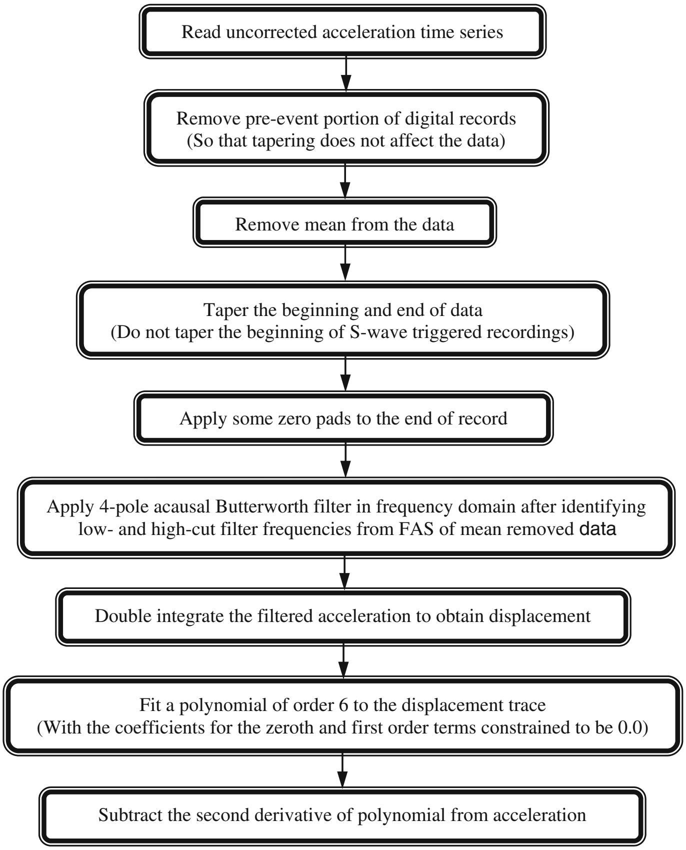

Fig. 4 Band-pass filtering and post-processing scheme (after the removal of existing non-standard errors) used in RESORCE (modified from Boore et al. 2012). The original version of the implemented procedure is given in Chiou et al. (2008)

preferred as acausal filters do not distort the phase content of processed records that results in lesser sensitivity of response spectrum ordinates as well as peak ground motions to the chosen filter cut-off frequencies. 4-pole Butterworth acausal filtering is applied in the frequency domain and the post processing procedure described in Boore et al. (2012) is used to remove the additionally introduced zero pads during band-pass filtering. The entire RESORCE data processing scheme is given in Fig. 4 for completeness. The RESORCE provides the raw accelerometric data as well as those processed by the procedure outlined in Fig. 4.

4 Modifications made to ISESD during the compilation of RESORCE

The major emphasis of the previous section is the use of ISESD as the primary reference source while structuring RESORCE. The content of ISESD is either updated (if necessary) or expanded from the other reference sources by following a hierarchical approach. The first part of this section describes the modifications to ISESD in metadata information. This subsection is followed by summarizing the improvements brought over ISESD in terms of data processing.

4.1 Metadata modifications to ISESD

Figure 5 presents the magnitude, depth and source-to-site distance differences between the original ISESD strong-motion databank and the version integrated in RESORCE. The upper left panel of Fig. 5 indicates that the modifications in moment magnitude are noticeable in the small magnitude range ($M_w < 5$). Almost all events that show a difference of 0.1 magnitude units come from the updates using the recent ITACA information. The upper right panel of the same figure shows the changes in the ISESD depth information after the modifications. The differences are noticeable as depth computation involves significant uncertainties. The modifications in depth stem from the information retrieved from the literature survey and the ITACA project. The lower panel of Fig. 5 addresses the source-to-site distance differences. The discrepancies in distance are emphasized by using the R_{JB} distance measure as its computation would also reflect the overall modifications made in ISESD in terms of depth, epicentral location as well as the geometry of ruptured fault plane. The major differences in R_{JB} between the original and modified versions of ISESD appear at short distances because extended-source metrics are sensitive to the above source parameters within this distance range. As in the case of changes in magnitude and depth, the major sources of distance modifications are recent literature studies and updated Italian event and station information by ITACA.

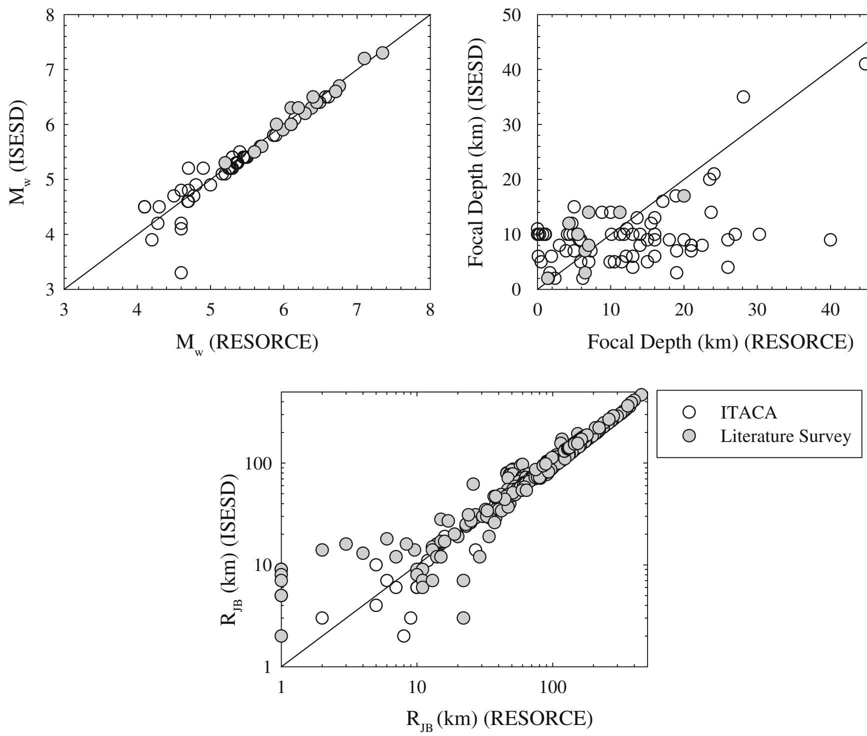

Fig. 5 Differences in moment magnitude (M_W), focal depth and source-to-site distance (R_{JB}) information before and after updating the ISESD strong-motion databank by following the strategy outlined in the previous section (*Grey circles* show the modifications based on recent literature survey. *White circles* denote the modifications due to ITACA)

Table 3 Changes in site classes between RESORCE and ISESD

	RESORCE			
	A	B	C	D
ISESD				
A		36	2	–
B	1		58	1
C	–	3		19
D	–	–	–	

Table 3 shows the changes in strong-motion station site classification of ISESD after evaluating the updates made by the HEAD, ITACA, T-NSMP as well as other sources from the literature. The modifications are listed as Eurocode 8 (Comité Européen de Normalisation (CEN) 2004) site classes (site class A: $V_{S30} \geq 800\,\text{m/s}$; site class B: $360\,\text{m/s} \leq V_{S30} < 800\,\text{m/s}$; site class C: $180\,\text{m/s} \leq V_{S30} < 360\,\text{m/s}$ and site class D : $V_{S30} < 180\,\text{m/s}$). The information given in Table 3 indicates that the strong-motion site class updates are significant. A considerable amount of strong-motion sites that are previously categorized as site class B is identified as site class C in RESORCE. Similarly, strong-motion stations falling under rock sites are modified as site class B in RESORCE after the recent information released by the above reference sources. Although not listed in Table 3, a total of 362 strong-motion stations that lack site information in ISESD are classified into one of the site categories of Eurocode 8 (via measured V_{S30} values) after the compilation of RESORCE. Of these strong-motion stations 195 sites are identified as site class C whereas 148 stations are defined as site class B. The rest of the strong-motion stations are site class A (7) and D (12). The reliability of new site classification in RESORCE is high with respect to the previous information given by ISESD as it is mainly based on measured V_{S30} values that are determined from the geophysical site exploration techniques (Table 1).

4.2 Comparisons between ISESD and RESORCE data processing

Figure 6 summarizes the modifications in ISESD due to the adopted data processing scheme in RESORCE. The histograms describe the processed PGA (left panel) and spectral acceleration [PSA (T = 4.0 s); right panel] ratio statistics of ISESD versus RESORCE data processing. The differences in spectral acceleration ratios are quite noticeable with respect to those of PGA statistics. This observation indicates the importance of low-cut filter frequency choice in strong-motion data processing that is emphasized in various articles (e.g., Boore and Bommer 2005; Akkar and Bommer 2006; Douglas and Boore 2011; Akkar et al. 2011) by studying the influence of high- and low-cut filter values on short- and long-period spectral ordinates, respectively. The common finding of these papers is the lesser influence of the selected high-cut filter frequency on short-period spectral values, which is exactly the opposite trend in terms of the low-cut filter effect on the long-period spectral band. The PSA (T = 4.0 s) statistics suggest that the spectral ordinates at long periods after RESORCE data processing are significantly larger than those originally reported by ISESD. This observation points out that the RESORCE processing scheme that tailors the decision on filter cut-offs from the frequency content of each ground motion results in smaller low-cut filter frequencies than the constant filter cut-off (0.25 Hz) used by ISESD for most of the accelerometric data. The insignificant differences in the PGA ratio statistics certify the lesser influence of high-cut filter frequencies on the short and very short spectral periods. However, the consideration of ground-motion frequency content by the RESORCE processing is believed to result in

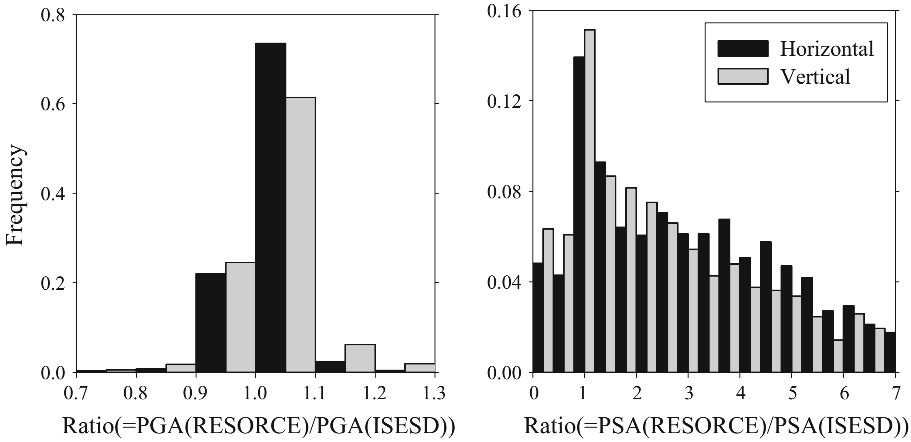

Fig. 6 PGA (*left panel*) and PSA (T = 4 s) (*right panel*) ratio statistics of ISESD versus RESORCE data processing schemes

minimum interference to the high-frequency content of the processed accelerometric data rather than the use of a constant high-cut filter frequency of 25 Hz, which is the case in ISESD.

5 Overall seismological features

The compilation strategy of RESORCE and the summary of updates with respect to ISESD are given in the previous sections. This section presents a general picture about the major characteristics of RESORCE in order to understand the extent as well as the limitations of the most recent pan-European strong-motion databank.

The databank consists of 5,882 accelerograms from 1,540 strong-motion stations and 1,814 earthquakes. A total of 5,810 accelerograms are tri-axial recordings whereas the rest misses either one of the horizontal components or the vertical component. The total number of singly-recorded events is 1,021 in RESORCE. Events with two and three recordings constitute 14 and 9 % of RESORCE, respectively. This percentage decreases to 3.3 % for earthquakes having five recordings. There are only 245 events in the RESORCE inventory that have six or above strong-motion accelerograms. Figure 7 demonstrates the yearly distribution of the earthquakes and accelerograms in the databank. The strong motions archived by the databank date back to the 1970s; the 1967 Debar Earthquake record occurred in Debar, Macedonia. More than half of the events and approximately 65 % of accelerograms in the databank are compiled from the earthquakes that occurred in the last 15 years (1998–2012). Consequently, the current compilation efforts summarized in this paper resulted in an increase of ∼30 % in data size over ISESD. The higher concentration of events and records within the last 15-year time span can be attributed to the increased number of strong-motion stations all around the pan-European region. Most of the accelerograms collected in the last 15 years are recordings of digital sensors. As a matter of fact the analog and digital waveform percentages in RESORCE are 27 and 68 %, respectively and almost the entire digital data (98 % of the digital accelerograms) are recordings from the last two decades.

The geographical distribution and the country-based breakdown of earthquakes and strong-motion stations in RESORCE are displayed in Fig. 8 and Table 4, respectively.

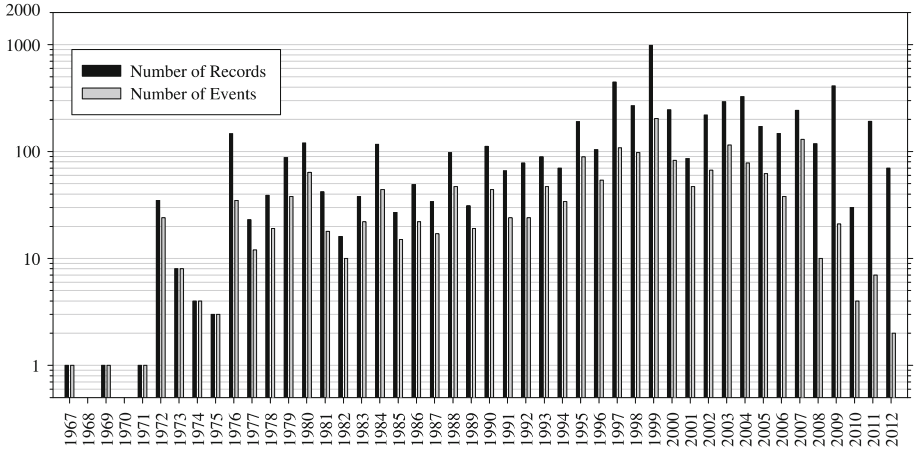

Fig. 7 Annual distribution of accelerograms and earthquakes in RESORCE

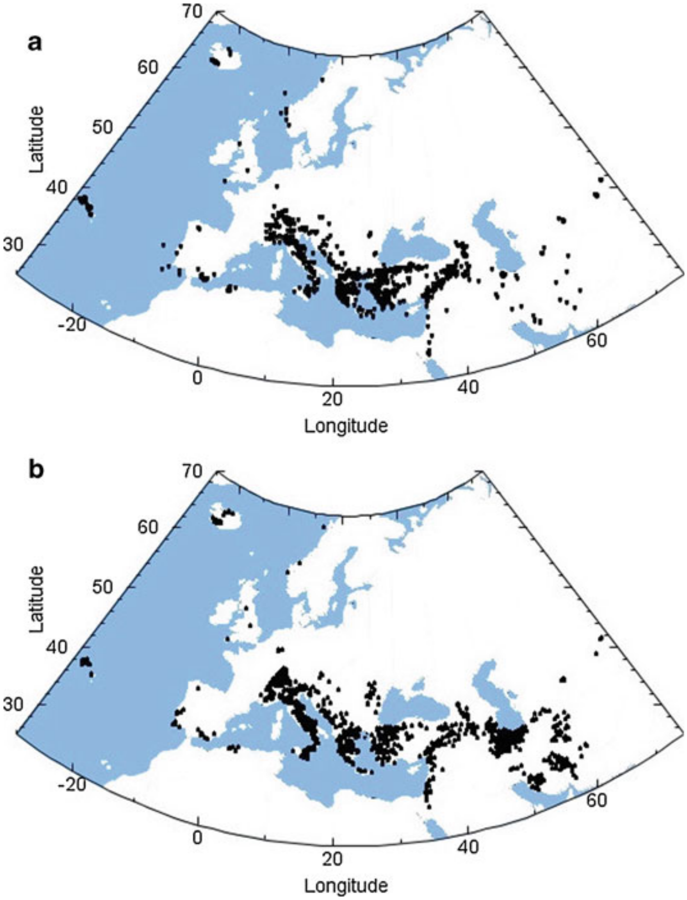

Fig. 8 Geographical distributions of **a** earthquakes and **b** strong-motion stations in RESORCE

Table 4 Country-based contributions to the RESORCE

Country Name	Number of events	Number of records	Number of stations	Focal depth range (km)	M_w Range	R_{epi} Range (km)
Albania	4	5	3	5–25	5.4–5.9	7–35
Algeria	22	28	5	2–12	5.2–5.9	3–50
Armenia	13	38	12	3–28	5.5–6.7	3–77
Austria	5	20	7	7–8	3.3–3.6	12–247
Bosnia and Herzegovina	7	13	11	10–33	5.7	7–44
Bulgaria	3	3	2	3–10	–	6–12
Croatia	10	15	9	0–39	5.5	4–132
Cyprus	1	1	–	19	6.8	435
Egypt	3	9	–	12–24	4.5–7.1	32–93
France	19	84	20	0–18	3.4-4.9	5–302
Georgia	13	46	10	4–19.7	4.8–6.8	9–115
Germany	12	74	19	4–22	3.1–5.2	4–260
Greece	386	772	130	0–127	3–6.9	1–238
Hungary	1	1	2	6	–	17
Iceland	47	205	31	1.4–17	4.3–6.6	4–64
Iran	44	396	325	0–44	4.6–7.4	1–375
Israel	3	6	15	9–18	5.1–5.3	22–46
Italy	315	1577	361	0–255.3	3.3–6.9	1–427
Kyrgyzstan	2	5	3	0–18	–	28–29
Lebanon	1	1	–	5	5.1	75
Liechtenstein	1	4	1	11	3.7	4
Macedonia	3	9	12	12–20	6.1	21–80
Montenegro	22	59	13	4–40	5.4–6.9	3–91
Netherlands	1	3	–	14.6	5.3	83
Norway	7	10	3	0–21	3.6–5.5	26–309
Portugal	60	125	32	0–77	4.7–7.8	5–332
Romania	4	32	14	86–137	6.3–7.5	7–484
Serbia	8	8	3	3–10	5.5	8–237
Slovenia	14	32	16	4–16	4.3–5.7	1–88
Spain	12	23	16	5–28	3.9–5.3	1–486
Switzerland	30	208	110	1–31	3–3.9	2–119
Syria	1	10	10	29	5.5	303
Turkey	724	2027	330	0–98	2.8–7.6	2–399
United Kingdom	3	3	3	8–19	–	35–135
Uzbekistan	13	30	12	0–45	6.8	1–53

Table 4 also shows the limitations of RESORCE in terms of M_w, source-to-site distance and depth ranges. These two separate sources of information, when interpreted together, indicate that almost all recorded events are shallow active crustal earthquakes and most of the accelerograms are from Turkey, Italy and Greece on the Mediterranean coast as well as from Switzerland in central Europe. This information emphasizes the importance of updates and expansion of metadata as well as accelerometric waveform content from above stated countries in RESORCE. The upcoming versions of RESORCE will include French accelerometric data for a wider coverage of low-to-moderate size events in Europe.

Figure 9 shows the earthquake (left column) and accelerometric (right column) data distributions in RESORCE for moment magnitude, depth and SoF. A total of 838 events have the reported moment magnitude information from international and local seismological agencies as well as earthquake-specific literature studies (first row plots). When moment magnitudes that are estimated from empirical magnitude conversion relations are included, the number of events with M_w information raises to 1,460. The moment magnitude estimations are concentrated between $3.5 \leq M_w \leq 5.5$. These relatively small events come from T-NSMP, HEAD and ITACA. They are originally reported as duration magnitude (M_d), local magnitude (M_L) and body-wave magnitude (m_b) for Turkish events; whereas M_L is the original magnitude scale in Italian and Greek earthquakes. The total number of accelerograms having M_w information is 5,285 (4,269 reported and 1,016 estimated) out of 5,882. The event and record based distributions of moment magnitude suggest the dominancy of moderate-size events ($4 \leq M_w \leq 6$) in RESORCE (41 % of earthquakes and 50 % of accelerograms). The fraction of events that can be considered as large earthquakes (i.e., $M_w \geq 6.5$) is only 2 % in the entire population. The corresponding number of accelerograms constitutes 8 % of the accelerometric data in RESORCE. The total number of events without moment magnitude information is 354 (20 % of RESORCE). These events (labeled as "Unknown" on the histograms) are reported in different magnitude scales but their corresponding M_w values cannot be estimated due to the lack of proper empirical magnitude conversion relationships. The second row histograms display depth distribution in RESORCE. The depth range is less than 30 km for about 94 % of the events in RESORCE. The corresponding percentage in terms of strong-motion recordings is also 94 % indicating that RESORCE is dominated by shallow crustal events. The events of depths ranging between 50 and 140 km are mainly from the Hellenic and Cyprus Arc subduction zone, Vrancea region, Portugal and southern Turkey. The distribution of event and accelerometric data in terms of SoF is given in the last row of Fig. 9. The majority of events and accelerograms are from the strike-slip, SS, (31 % of events and 35 % of records) and normal, N, (25 % of events and 31 % of records) faults. The data size of reverse, R, events and accelerograms are small when compared to the other SoF classes but they still constitute 11 % of the events and 16 % of the strong-motion records. The depth and SoF distributions also indicate that the corresponding information is still missing (designated as "Unknown" on each histogram) for some earthquakes in RESORCE that mainly fall into the small magnitude range ($M_w \leq 5$). Earthquakes and accelerograms falling into this category are more prominent in the SoF statistics. The major reason behind this deficiency is the lack of double-couple fault-plane solutions for small magnitude earthquakes that provide direct information for the identification of SoF and depth parameters. Inherently, the literature survey (i.e., earthquake-specific publications) rarely focuses on the solutions of such small events unless they are associated with a major destructive earthquake. There are pragmatic solutions grossly determining the style-of-faulting of such small-size events. One alternative methodology is to overlay them on the seismotectonic maps to judge their SoF from their proximity to the fault zones. The complexity of source kinematics as well as insufficient resolution of seismotectonic maps in Europe and surrounding countries would increase the associated uncertainty in such classification. Thus, such an approach should be discouraged in SoF classification and is not implemented in the current version of RESORCE.

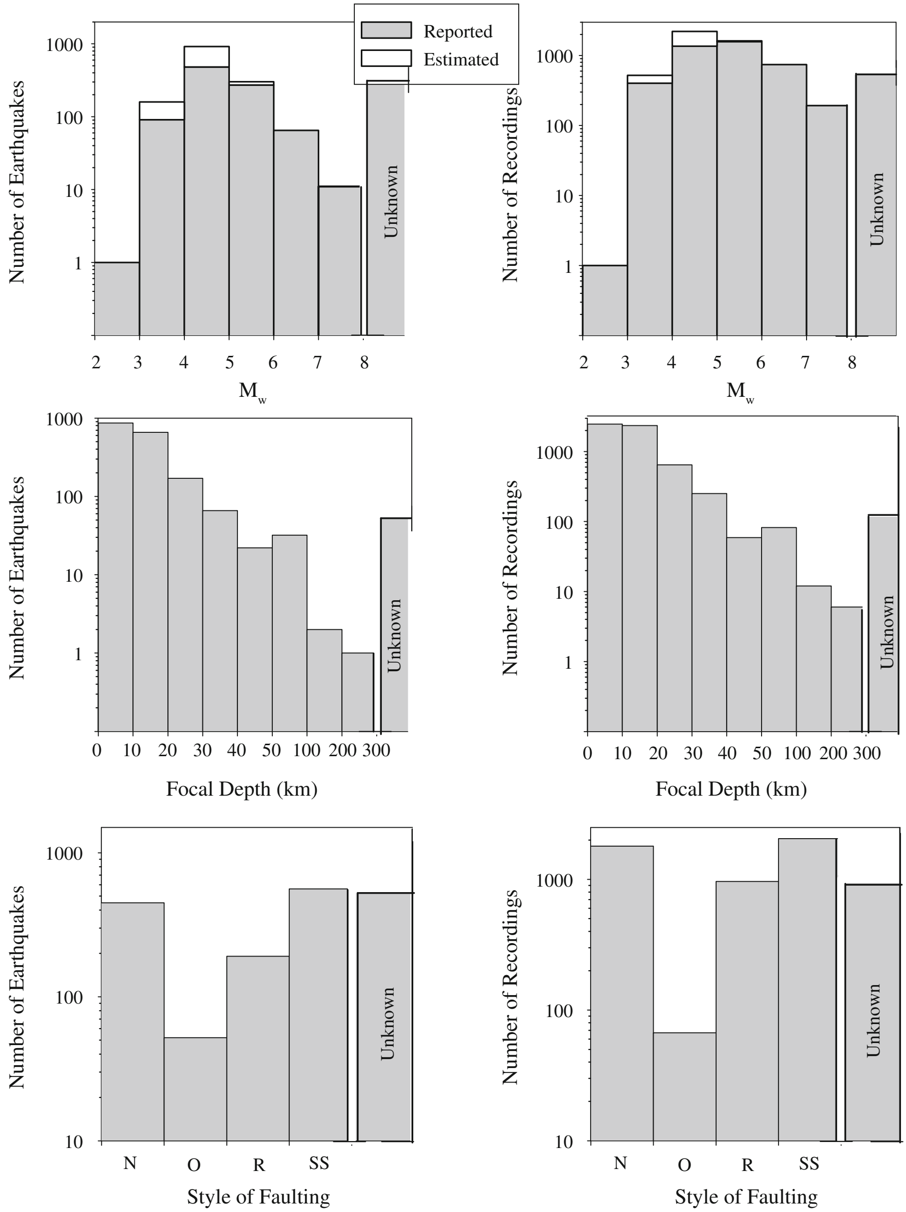

Fig. 9 Distributions of events (*first column*) and accelerograms (*second column*) in RESORCE in terms of moment magnitude (*first row*), depth (*second row*) and SoF (*third row*). The *vertical bars* labeled as "Unknown" refer to the events or accelerograms that cannot be classified within any one of these parameters due to missing event or strong-motion station metadata information

Figure 10 presents similar histograms as of Fig. 9 to describe the distributions of strong-motion stations (left panel) and accelerograms (right panel) in terms of Eurocode 8 (Comité Européen de Normalisation (CEN) 2004) site classification. The statistics are based on measured V_{S30} values and inferred site classes from local site geology. The site informa-

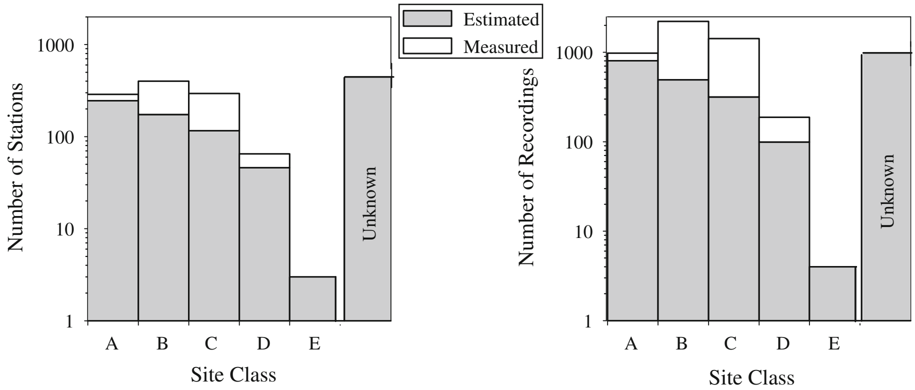

Fig. 10 Distributions of strong-motion stations (*left panel*) and accelerograms (*right panel*) in RESORCE in terms of Eurocode 8 (Comité Européen de Normalisation (CEN) 2004) site classes. The explanation about the labels designated as "Unknown" is similar to the one given in the caption of Fig. 9

tion of RESORCE contains a total of 423 strong-motion stations with known V_{S30} values due to the site characterization studies in Greece, Italy and Turkey (details are given in Table 1). The corresponding number of accelerograms recorded at these stations is 2,936. The number of strong-motion sites and accelerograms with site classes inferred from the local geological conditions is 627 and 1,876, respectively. Of the entire accelerometric data 1,070 records (18 % of strong-motion records in RESORCE) do not have any site characterization. The majority of accelerometric data (38 %) is recorded at site class B strong-motion stations. Only 3 % of the accelerograms in RESORCE fall into site class D. The accelerograms in site class A and C constitute 17 and 24 % of the databank, respectively.

Figure 11 shows a general picture for M_w versus distance distributions in RESORCE. The red and black circles refer to analog and digital recordings, respectively. Figure 11 depicts relatively large volumes of analog recordings in RESORCE. Inherently, the recording quality of digital accelerograms is better than those of analog recordings except for the first-generation digital recorders having 12 bit resolution. In most cases the dynamic range of analog accelerographs varies between 45 and 55 dB (Trifunac and Todorovska 2001) indicating high noise contamination that particularly dominates the recording quality of small-amplitude and distant events. The sampling intervals of accelerograms is RESORCE are mostly 0.01 and 0.005 s regardless of the recorder type. The record quality of accelerograms in RESORCE is further emphasized while discussing the filter cut-off frequencies in the subsequent paragraphs.

The distance metrics (R_{epi}, R_{hyp}, R_{JB} and R_{rup}) are plotted up to 200 km to have a better perception in the M_w versus distance distributions. The calculations of R_{epi} and R_{hyp} distance metrics are easier than R_{JB} and R_{rup} as the latter two distance measures require additional information about the ruptured fault geometry. The entire accelerometric data in RESORCE (5,882 records) contain the R_{epi} information. The number of accelerograms having R_{hyp} information is 5,751 as 131 recordings lack depth information. A total of 3,906 records in RESORCE have R_{JB} values. This number reduces to 2,490 recordings for R_{rup} as the calculation of this distance measure involves the largest number of seismic parameters, which is difficult to acquire with the current content of the reference sources used during the compilation process. The information on ruptured fault geometry as well as double-couple fault-plane solutions becomes poor towards smaller magnitude events in RESORCE (see

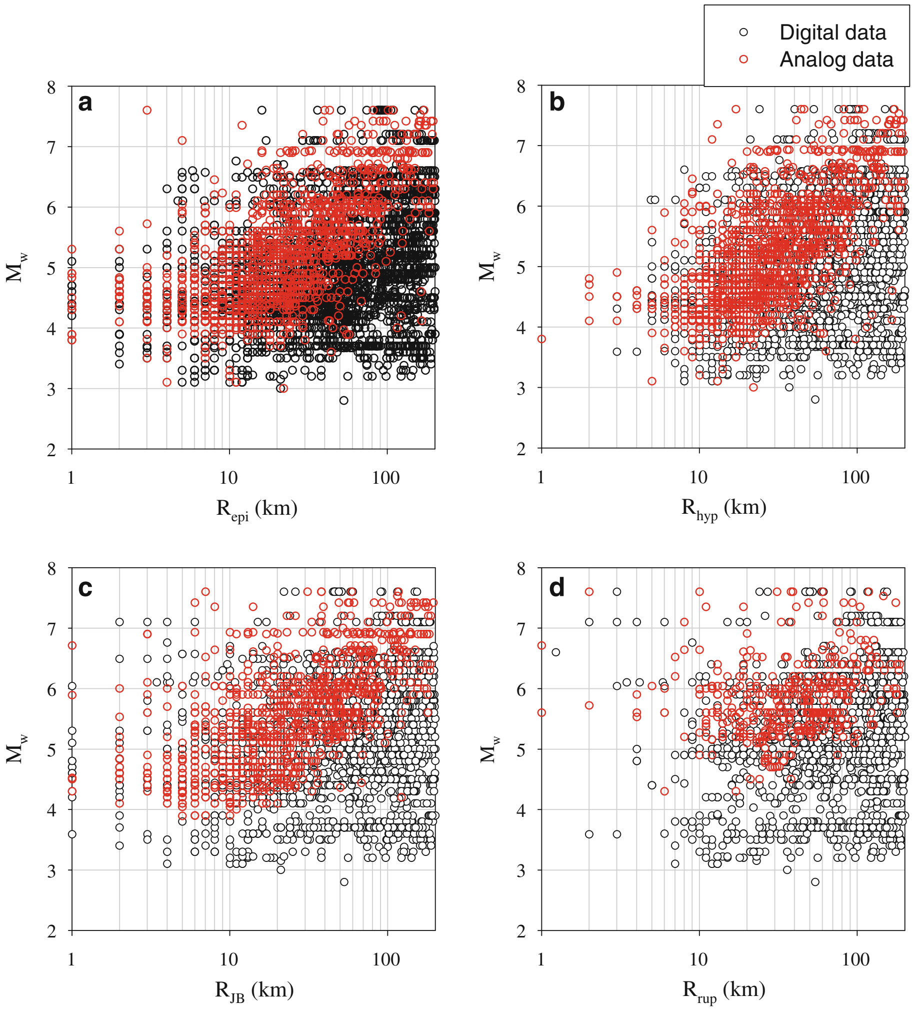

Fig. 11 Distribution of M_w versus **a** R_{epi}, **b** R_{hyp}, **c** R_{JB} and **d** R_{rup}. Circles in *red color* indicate analog records whereas black circles designate digital records. Moment magnitude information given on each plot is either directly extracted from the original reference source (see Tables 5, 6) or estimated from an empirical relationship as explained under the "Compilation of Earthquake and Strong-Motion Station Metadata" subsection

discussions in the previous paragraphs) and these adverse features primarily affect the R_{rup} computations in the small magnitude range. The scatters in Fig. 11 depict that the M_w vs. distance distribution is fairly uniform for distances greater than 10 km and moment magnitudes approximately greater than 4. For shorter distances and smaller magnitudes, the homogeneity in M_w versus distance distributions diminishes and this is more visible in R_{hyp} and R_{rup}.

Figures 12 and 13 show the magnitude-dependent variation of low-cut ($f_{low\text{-}cut}$) and high-cut ($f_{high\text{-}cut}$) filter cut-off frequencies used in the RESORCE data processing, respectively. Each row shows the chosen filter cut-off frequencies for a different site class in Eurocode 8 (Comité Européen de Normalisation (CEN) 2004). The panels on the left show the filter cut-

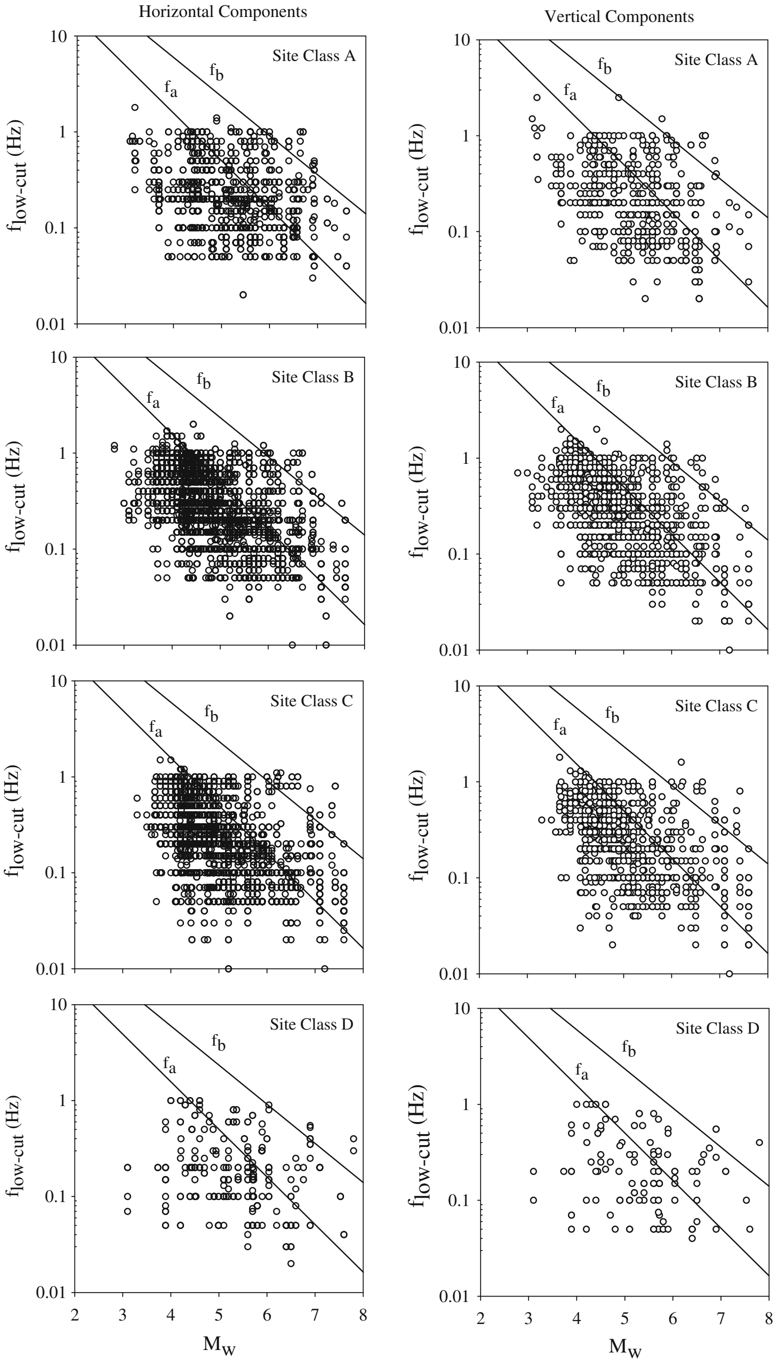

Fig. 12 Variation of low-cut filter frequencies as a function of M_w for different site classes in RESORCE. Moment magnitude information given on each plot is either directly extracted from the original reference source (see Tables 5, 6) or estimated from an empirical relationship as explained under the "Compilation of Earthquake and Strong-Motion Station Metadata" subsection

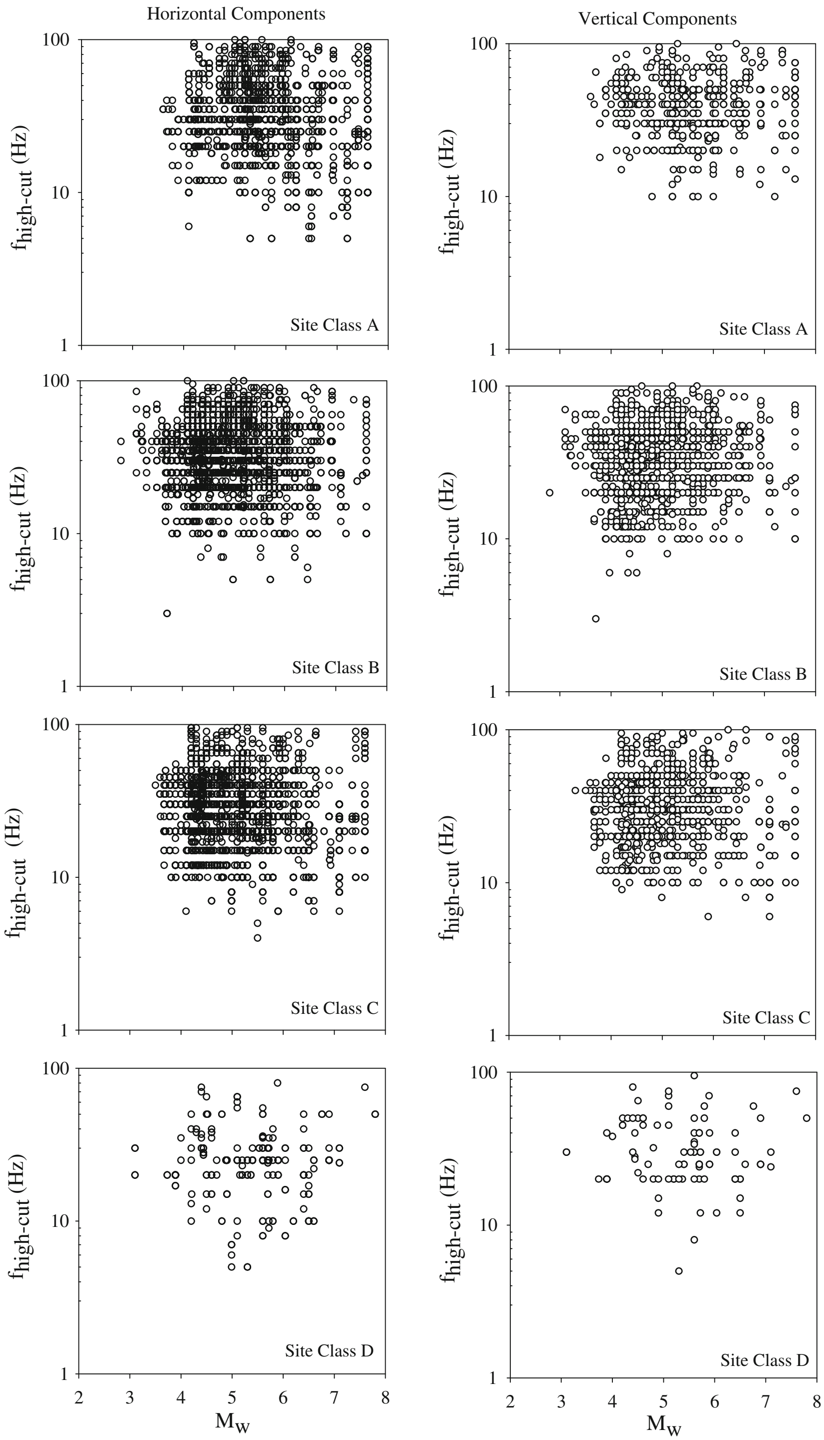

Fig. 13 Same as Fig. 12 but for high-cut filter frequencies

off values of the horizontal acceleration components. The right-hand-side panels describe the same information for vertical acceleration components. The straight lines on Fig. 12 also show the magnitude-dependent variation of theoretical corner frequencies, f_a and f_b, that are used for guidance while deciding on the individual low-cut frequencies of accelerograms. The scatter diagrams in Fig. 12 indicate that only few selected low-cut frequencies are above the corresponding f_b values suggesting that the actual low-frequency content of the processed accelerograms is preserved fairly well. The low-cut filter values tend to decrease with increasing magnitude except for site class A ($V_{S30} \geq 800\,m/s$) ground motions. The $f_{low\text{-}cut}$ trend is not very clear with respect to similar type of comparisons made by previous studies (e.g., Akkar et al. 2010). The major reason behind this observation might be the large percentage of analog accelerograms (30 %) among the processed data whose resolution in time- and frequency-domain does not permit the selection of very low $f_{low\text{-}cut}$ values with increasing magnitude. The marginal drop in $f_{low\text{-}cut}$ with increasing M_w for site class A recordings justifies the above assertion as 73 % of ground motions in this site class are analog recordings. The scatters given in Fig. 13 indicate that, except for a few cases, the chosen high-cut filter frequencies are almost exclusively above the 10 Hz limit. The records subjected to severe high-cut filtering are mainly from low-quality analog and digital waveforms. These accelerograms constitute approximately 23 % of the entire RESORCE archive. This discussion once again advocates the importance of waveform quality in order to extract the utmost information from the processed recordings.

6 Summary and conclusions

This paper summarizes the general features of the most recent pan-European strong-motion databank that updates and expands its predecessor developed by Ambraseys et al. (2004a). The details of the topics discussed in this paper will be posted as a separate document on the official web site of RESORCE when the databank is made available for public use. The online documentation will use flags to describe the specific features of each entry (e.g., reference source of magnitude and V_{S30} information, specific literature on fault rupture information or data processing parameters etc.) in the metadata. The dissemination of RESORCE will be realized in the near future under the collaboration of multi-national European projects SIGMA, Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (NERA) and European Plate Observing System (EPOS) together with non-profit European data centers (EMSC and ORFEUS—Observatories and Research Facilities for European Seismology—). As a matter of fact, a working group has already been established under ORFEUS and EPOS to coordinate these efforts for long-term sustainability of RESORCE. This new structure aims to shape the future policies among accelerometric networks in the broader European region to enhance integral approaches for the efficient use of strong-motion data in engineering seismology and earthquake engineering studies.

The current version of RESORCE increases the record and event size of its predecessor by approximately 2.5 times with improvements in magnitude and distance distributions through additional data from recent Turkish, Italian, Swiss and Greek events. The data size will be increased further in the upcoming versions of RESORCE by including recordings of the French Accelerometric Network (RAP, http://www-rap.obs.ujf-grenoble.fr). The inclusion of French accelerograms in RESORCE will result in a larger coverage of moderate-to-low seismic events in Europe. The procedure followed in the compilation of RESORCE results in more reliable earthquake and station metadata. The strong-motion site characterization is primarily calibrated by measured V_{S30}. The extended- and point-source distance measures are computed from reliable literature studies or by following a systematic approach. The uniform strong-motion data processing, as part of these efforts, has increased the usable period range of the accelerograms in the inventory as the choice of filter cut-offs is guided by the frequency content of the accelerograms. This step, implemented efficiently in the evolution of RESORCE, supersedes the use of the constant filter cut-off approach in ISESD.

The current size of RESORCE consists of 5,882 multi-component accelerograms from 1,814 events recorded between 1967 and 2012. The number of strong-motion stations in the inventory is 1,540 out of which one-third of stations have direct shear-wave velocity profiles. Almost 80 % of the events have moment magnitude information. The earthquake magnitudes range between 2.8 and 7.8 in RESORCE. The entire databank has the R_{epi} source-to-site distance information. The corresponding numbers for R_{hyp}, R_{JB} and R_{rup} source-to-site distance metrics are 5,751, 3,906 and 2,490, respectively. The total number of uniformly processed accelerograms is approximately 86 % of the entire RESORCE population.

The information summarized in this paper comprises the entire accelerometric recordings that are evaluated in RESORCE. The public open version will not include the accelerograms suffering from extremely low quality waveforms in all three components. A set of source-to-site distance versus event size criteria will also be established to remove small-amplitude and far distance accelerograms from the final version of RESORCE that are limited in use for engineering seismology and earthquake engineering.

The overall picture given in the above paragraphs makes RESORCE an important source of information for hazard and risk studies in and around Europe. The quality and content of RESORCE is comparable with similar databanks such as those from the NGA-West1 (Power et al. 2008) and NGA-West2 (Bozorgnia et al. 2012) projects. As summarized in the first paragraph the efforts put forward in the compilation of RESORCE should be supplemented by long-term research projects within the European context to complete the missing or (partially) unreliable metadata information. In particular, efficiently oriented financial funds for site characterization of strong-motion stations in terms of measured shear-wave velocity profiles or well-defined source characterization projects that seek double-couple solutions of small-to-moderate size events from regional seismotectonic and stress field studies as well as relocation of earthquakes for improvements in the spatial distribution of events will certainly minimize the metadata related uncertainties in RESORCE. Projects encouraging the inclusion of recordings from pan-European countries other than those contributing significantly to the accelerometric archive of RESORCE will also lead to a better reflection of seismic activity in the region covered by this strong-motion databank. Such grants will also create numerous research opportunities in the fields of earthquake engineering and engineering seismology in Europe. As a matter of fact the growth rate of accelerometric data in the broader Europe in the last two decades makes such Europe-wide projects indispensable.

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7 Appendix

See Table 5 and 6.

Table 5 Major reference sources used in the compilation of RESORCE strong-motion databank

Source	Accelerogram	Station metadata	Earthquake metadata
Internet site for European strong-motion data (ISESD; Ambraseys et al. 2004a)	√	√	√
Italian accelerometric archive (ITACA, Luzi et al. 2008)	√	√	√
The Next Generation Attenuation Models Project (NGA, Power et al. 2008)	√	√	√
Turkish national strong-motion project (T-NSMP, Akkar et al. 2010 and Sandıkkaya et al. 2010)	√	√	√
The Swiss Seismological Service (SED, www.seismo.ethz.ch)	√	√	√
Hellenic Accelerogram Database (HEAD, http://www.itsak.gr/en/db/data; Theodulidis et al. 2004)	√	√	√
European strong-motion database (ESMD, Ambraseys et al. 2004b)		√	√
European-Mediterranean Regional Centroid Moment Tensor catalog (RCMT; http://www.bo.ingv.it/RCMT/)			√
Global Centroid Moment Tensor Catalog Search (GCMT, www.globalcmt.org)			√
International Seismological Centre (ISC; http://www.isc.ac.uk/)			√
U.S. Geological Survey (USGS; http://earthquake.usgs.gov/)			√
Cauzzi and Facciolli (2008)		√	

Table 6 Earthquake-specific literature used in earthquake and strong-motion station metadata in RESORCE

References	Main focus
Abercrombie et al. (1995)[b]	Source information on the 1981 Alkion earthquakes (Greece)
Amorese et al. (1995)[b]	Source information on the 1976 Gazli earthquake (Uzbekistan)
Arvidsson and Ekström (1998) and Chouliaras and Stavrakakis (1997)[c]	Magnitude information on three earthquakes occurred in 1995 (Greece)
Anderson et al. (2001)[b]	Source information on the 1995 Dinar earthquake (Turkey)
Anderson and Jackson (1987)[b]	Source information on the 1978 Basso Tirreno earhquake
Bajc et al. (2001)[b]	Source information on the 1998 Bovec earthquake (Slovenia)
Benetatos and Kiratzi (2006)[c]	Source information on the 1979 Montenegro earthquake (the M_W 6.2 aftershock)
Benetatos et al. (2007)[c]	Source information on the 2003 Lefkada earthquake (Greece)
Berberian et al. (1992)[b]	Source information on the 1990 Manjil earthquake (Iran)
Bernard et al. (1997)[b]	Source information on the 1992 Erzincan earthquake (Turkey)
Boore et al. (2009)[c]	Source information on the 2003 Kythira earthquake (Greece)

Table 6 continued

References	Main focus
Decriem et al. (2010)[c]	Source information on the 2008 Olfus earthquake (Iceland)
Delouis et al. (2002)[c]	Source information on the 1999 Kocaeli earthquake (Turkey)
Erdik (1984)[b]	Source information on the 1983 Pasinler earthquake (Turkey)
Haessler et al. (1988)[b]	Source information on the 1984 Umbria earthquake (Italy)
Hatzfeld et al. (1997)[b]	Source information on the 1995 Kozani earthquake (Greece)
Jackson et al. (2006)[c]	Source information on the 2003 Bam earthquake (Iran)
Louvari et al. (2004)[b]	Source information on the 1983 Kefallinia Island earthquake (Greece)
Lyon-Caen et al. (1988)[b]	Source information on the 1986 Kalamata earthquake (Greece)
Makaris et al. (2000)[b]	Source information on the 1997 Strofades earthquake (Greece)
Oncescu and Bonjer (1997)[b]	Source information on the 1977 Bucharest earthquake (Romania)
Pace et al. (2002)[b]	Source information on the 1984 Lazio Abruzzo earthquakes (Italy)
Pedersen et al. (2003)[c]	Source information on the two June 2000 Iceland earthquakes
Perniola et al. (2004)[c]	Source information on the 1976 Friuli earthquake and its major aftershocks (Italy)
Roumelioti and Kiratzi (2002)[b]	Source information on the 1979 Montenegro earthquake (Montenegro)
Salvi et al. (2000)[b]	Source information on the 1997 Umbria-Marche earthquake (Italy)
Soufleris et al. (1982)[b]	Source information on the 1978 Volvi earthquake (Greece)
Talebian et al. (2006)[c]	Source information on the 2005 Dahooeiyeh-Zarand (Kerman) earthquake (Iran)
Tan et al. (2011)[c]	Source information on the 2008 Kovancılar earthquake (Turkey)
Tatar et al. (2007)[c]	Source information on the 2004 Kojur-Firoozabad earthquake (Iran)
Triep et al. (1995)[b]	Source information on the 1991 Racha earthquake (Georgia)
Tselentis and Zahradnik (2000)[b]	Source information on the 1999 Ano Liosia (Athens) earthquake (Greece)
Tselentis et al. (1996)[b]	Source information on the 1995 Aigion earthquake (Greece)
Umutlu et al. (2004)[c]	Source information on the 1999 Düzce earthquake (Turkey)
Walker et al. (2003)[b]	Source information on the 1978 Tabas earthquake (Iran)
Walker et al. (2005)[b]	Source information of the 2002 Avaj earthquake (Iran)
Kyriazis Pitilakis and Evi Riga (AUTH)[d]	Updated V_{S30} information of some of the Greek sites that are not considered in HEAD
Rosenblad et al. (2002)[c]	Updated V_{S30} information of some of the Turkish sites operated by KOERI[a]

[a] KOERI: Kandilli Observatory and Earthquake Research Institute
[b] Literature survey from ISESD (Ambraseys et al. 2004a)
[c] Additional literature survey
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Review on the deliverable SIGMA-2013-D2-91 - D. Baumont on November 8th, 2013.

"Database of earthquake ground motion data for Europe - Resorce, 2013 version" by S. Akkar et al. and the related publication Akkar et al. (2013)

The document SIGMA-2013-D2-91 has been sent for review before the scientific committee of the SIGMA program research which will be held on November 13-15th 2013. It has been sent with a related paper published recently in Bulletin of Earthquake Engineering as well as an acess to the Resorce Web portal. This study presents the overall procedure followed in order to assemble the most recent pan-European strong-motion databank. This work is of great interest as it aims at producing a reference strong ground motion database with reliable metadata information. The collect of the data, the uniform reprocessing, the internal reviews, the development of the portal interface represent a tremendous work.

General comments

- Reading through the documentation sent for the SC of SIGMA cannot represent a good way to perform an in-depth review of the RESORCE database. Several massive comparisons and tests were already performed by the internal reviewers during the construction of the database itself. These tests/comparisons should be documented and presented in great details. What are the main issues raised through the internal review process? How were these issues solved? Did you keep the records or erase them? Did you tag the records for which specific actions were required?

- The uncertainties on the source parameters are not provided (Mw, depth, location) in the RESORCE database whereas it is needed to account for uncertainty in the metadata in the ground motion studies. If the idea of improving the metadata is to identify how much the uncertainty on the source parameters may contribute to the aleatory variability, it is crucial to quantify this uncertainty. It should also be important to account for such uncertainties when developing the GMPEs (e.g. relative weighting schemes).

- Did the authors tag (flag) in the RESORCE database the Mw estimates that were obtained by applying a magnitude conversion? Do the authors account for the several magnitude conversions proposed in the literature?

- The calculations of the extended-source distance metrics rely on several assumptions. However, the uncertainties on the distances are not provided in the RESORCE database (only 1 alternative plane geometry tested). For instance, does the choice of Wells and Coppersmith (1994) rather than Leonard (2010) may affect significantly the estimates? How the uncertainty on the depth affect the distance to the rupture ?

- Did the authors envisage including Rx distance measure which is needed for incorporating hanging wall term for instance (see Kaklamanos et al., 2011)?

- Did the authors define different filters to be applied on the horizontal components of a given record, or a single filter? If the filtering is different, how different and how this can affect the future analysis?

- The choice of the cut-off frequencies should be discussed and illustrated in greater details as it may strongly influence the results. End-member cases should be provided and discussed, showing specifically what spectral characteristics of the signal do not satisfy the pre-conceived model. In figure 12, it can be noticed that many low cut-off frequencies are greater than f_a and for a few records even greater than f_b. It seems also that many high cut-off frequencies are lower than f_b (the authors should also report f_a and f_b on the graphs for the high cut-off frequencies). Does the filtering applied on these cases affect strongly the response spectra? Should these records be tagged (flagged) in the Resorce database to let the analyst choose to keep them or not in their study?

- The authors themselves identified needs for improvement of the RESORCE database that should be detailed or illustrated on some cases.

- Problems encountered when navigating through the portal with internet explorer - Functionality "download' not operable? (Exchange with S. Godey)

Specific comments

- Figure 1 - Are there any records for R_{jb} equal to 0?

- Figure 3 - How is defined the style of faulting "O" (oblique)?

- Figure 4 - Information reported as measured in this figure means that "Measured/Inferred VS30" = 0. The log scale does not seem appropriate to represent the repartition between estimated and measured.

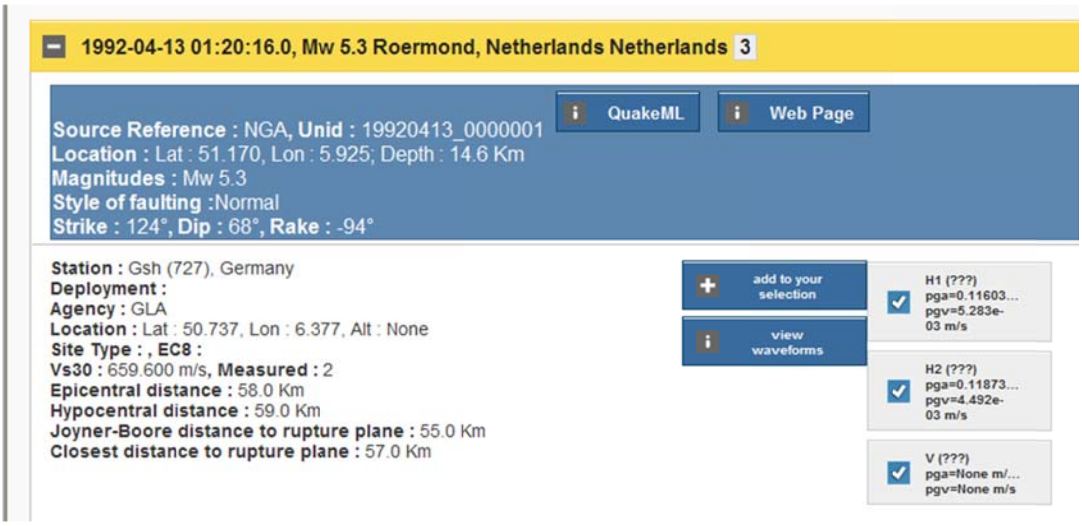
- Figure 12 (Idem Fig 4) – According to table 6, for only 8 out of 88 stations, the site class was defined based on measured Vs30. Figure 12 does not provide such statistics.

- Figure 17 - Why do we observe a reduction of the number of events in the RESORCE database since 2008?

- Page 46 - "The authors of all five ground-motion models were invited to comment on RESORCE but only Bindi et al. (2014) did so, which is an indication of the high quality of the database". This is only an interpretation of the authors.

<u>Extract of WEBPAGE for 1992, Roermond EQ</u>

http://www.resorce-portal.eu/edition2013/ui/index.html#/edition2013/ws/resorce_geteventlist?page=1&ev_id__in=3695&



- Why EC8 information is not provided whereas Vs30 is provided? Only provided for some Vs measured-type?

- It would be better to provide the “Vs30 Measured” field in a more understandable way.

- NGA is the defined as the source reference. Does it apply to location/magnitude/FM/etc. How is dealt this field in case where several sources are used for the various field? Are there any specific studies for this event?

Extract of WEBPAGE for 1995, Aigion EQ

http://www.resorce-portal.eu/edition2013/ui/index.html#/edition2013/ws/resorce_geteventlist?page=1&ev_datetime__range=[15-6-1995,16-6-1995]&

- What does the source reference refer to? In their paper, Tselentis et al. (1996) reported different location, depth, magnitude (see below 38.309N/22.141E/depth 12.78, Ml 6.2).

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Table 2

List of the 293 well-located events

Date	Origin	Lat.°N	Long.°E	Depth	Mag.
950615	015 50.90	38–18.54	22– 8.46	12.78	6.21

From Tselentis et al. (1996)

Report on the deliverable D2-91: « **Database of earthquake ground motion data for Europe** » by P. Traversa and co-workers. [M. Granet, EOST].

General comment: this review is mainly a short résumé of the report (it is an excellent report) which contains interrogations or comments or suggestions.

The manuscript presents the current state of the RESORCE (Reference database for seismic ground motion in Europe) database. This new version (called RESORCE-2013) includes in addition to the former frozen version recently compiled Greek, Italian, French, Swiss and Turkish accelerometric archives. An important effort was done to improve the content and quality of the metadata. The document is organized in four main sections (in addition to an abstract, an executive summary, an introduction (which presents in particular historical strong-motion data bases in Europe, insisting on the remarkable pioneering work by Ambraseys and the role of various projects supported within FP6 and FP7 European programs), a conclusion and references):

- Section 1 - RESORCE-2013 content and improvements;
- Section 2 - RESORCE: database and portal;
- Section 3 - RESORCE review process;
- Section 4 - Exchanges and collaborations with related EC projects.

As a main effort to develop a reference, integrated, with validaded data, strong-motion database at the Pan-European level, one of the scientific objectives of RESORCE is to develop/improve/test seismic ground motion models to be used for engineering seismology, seismic hazard studies and for earthquake engineering purposes. This includes the reduction of associated uncertainties. For that, RESORCE will be an up-to-date, homogeneous, integrated European seismic motion database containing only validated data. The RESORCE project can be seen as the continuation of the ISESD (Internet Site for European Strong-motion Data) data bank developed by Ambraseys (2004) and his group, which was obliged to stop the work due to a lack of financial support, an inadequate manpower and a limited involvement of seismic European agencies.

The former version of RESORCE (the philosophy is to keep and make accessible in a long term time the different successive versions of the database), reviewed in November 2011, consisted mainly of Italian and Turkish data (ITACA - Italian Accelerometric Archive, T-NSMP - Turkish national strong-motion database, ISESD, …, data banks). The current version (RESORCE-2013) includes accelerograms compiled from Greece (HEAD – Hellenic Accelerometric Data), Switzerland (SED – Schweizerische Erdbebendienst *[Service sismologique Suisse]* and France (RAP – Réseau Accélérométrique Permanent) seismic agencies. It is made of 5 460 multicomponent and uniformly-processed accelerograms from 1 713 earthquakes (within the magnitude range 2.8 < Mw < 7.8) recorded at 1 481 strong-motion stations. Not only has the number of records increased since the last version but improvements (see after) in data processing have been made (the processing was made by METU – Middle East Technical University, Ankara): the uniform data processing of accelerograms as well as a improved magnitude and source-to-site distance distribution constitutes important steps in the RESORCE project. The data access web portal (metadata-driven data searches) has also been improved (www.resorce-portal.eu / see after). The portal is developed and maintained by EMSC (Euro-Mediterranean Seismological Centre). One also should note that the future of the database is related to EC-funded projects (NERIES[1], EPOS, NERA – Network of European Research

[1] NERIES is an Integrated Infrastructure Initiative project in the FP6 Program of the EC, aiming at networking the European seismic networks, improving access to data (including the implementation of a real time database of accelerometric records - shake maps), allowing access to specific seismic infrastructures and pursuing targeted research developing the next generation of tools for improved service and data analysis.

Infrastructures for Earthquake Risk Assessment and Mitigation, SHARE[2]) and the ORFEUS[3] data center.

I- RESORCE-2013 content and improvements

This part – the most important – consisted of 26,5 pages, 23 figures and 7 tables. As the main document, it is well written, easy to read and understand. The reader appreciates.

- Overall procedure for the integration of Greek, Swiss and French data.
  The RESORCE version 2013 includes additional Greek, Swiss and French accelerometric data with a procedure similar to the one used when building version 1 of RESORCE.
  It consists of 5 steps:
  - ✓ Determination of duplicated recordings stations and events; a lot of attention has been paid to this point as the largest earthquakes were recorded by different European seismic agencies;
  - ✓ Event metadata compilation of non-duplicate earthquakes (the new ones): in addition to peer-reviewed literature, a main contribution comes from local seismological agencies due to the small-to-moderate magnitude of the integrated earthquakes (26 % of the new data contains double-couple fault-plane solutions, the style of faulting is from Boore & Atkinson (2007);
  - ✓ Compilation of station and site information: they mainly come from the Greek, Swiss and French databases (there is a need to complete the missing station metadata);
  - ✓ Calculation of source-to-site distance metrics (R_{epi}, R_{hyp}, R_{JB}, R_{rup}) for the recently added data;
  - ✓ Ground motion data processing is identical to RESORCE-2011 (see Akkar et al., 2013).
- Overall features of new databases added to RESORCE-2013.
  This section gives a detailed description of the content of each integrated database. A new strategy has been applied for the duplicated data.
  - ✓ Greek data come from the HEAD (Hellenic Accelerometric Data) database; it spans from 1973 to 1999 and also includes 2 recent Greek earthquakes (Lefkada, Mw 6.2, 2003; Kythera, Mw 6.7, 2006). It consisted of 263 accelerograms from 142 events recorded at 83 stations, of which 48 having site class information. A “view” of these new data is provided by 4 figures (Figures 1 to 4) and 1 table (table 2).
  - ✓ Swiss data come from the SED database; it includes the main metadata. As 50 % of events are located on the Italian territory, earthquake information is taken from ITACA or RCMT Italian databases. Four figures (figures 5 to 8) and one table (table 3) provide a visual inspection of the data characteristics.
  - ✓ French data are from the RAP database; it spans from 1995 to 2007 and consisted of 1751 recordings from 389 events and 90 stations. One should note that the RAP database provided few measured V_{S30} values but it is possible to infer these V_{S30} profiles from site classes (Régnier et al., 2010). As a lot of earthquakes occurred in Italy or Swiss, event information was primarily obtained for those events from the Italian and Swiss agencies. Four figures (figures 9 to 12) and one table (table 4) provide a visual inspection of the data.

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[2] SHARE is a Collaborative Project in the Cooperation program of the Seventh Framework Program of the European Commission. SHARE's main objective is to provide a community-based seismic hazard model for the Euro-Mediterranean region with update focal mechanisms.
[3] ORFEUS (Observatories and Research Facilities for European Seismology), is the non-profit foundation that aims at coordinating and promoting digital, broadband (BB) seismology in the European-Mediterranean area.

- Overall effects of integrated Greek, French and Swiss data on RESORCE-2013

  The contribution of the French and Swiss databases consists mainly in providing low-to-moderate magnitude events. Globally, it increases the magnitude and distance coverage towards smaller magnitude (France and Swiss are countries characterized by a moderate seismicity) and larger distances (illustrated on figure 13 and table 6). However, more detailed studies are required to determine source parameters.

- Processing of accelerograms

  It is based on a visual screening of accelerograms (to remove extremely low quality accelerograms) and a band-pass filtering of raw accelerograms; a Fourier acceleration spectrum of each raw accelerogram is studied in order to determine the band-pass filter cut-off frequencies (this is described in the paper by Akkar et al. (2013).

- Removal of low quality data from RESORCE

  All records whose interest for engineering and/or seismological studies is limited are removed. This led to filter out 1 985 records from the initial number of multi-components records; not only are accelerograms removed of poor quality, but also those having small amplitudes.

- Overall features of RESORCE-2013

  The RESORCE-2013 databank consists of 1 713 events (5 637 accelerograms) recorded from 1 481 strong-motion seismic stations (note the large number of single station recordings (called singly-recorded events by the authors?): 906; only ~100 events have more than 10 accelerograms).

  A series of figures/histograms (from figure 16 to figure 19) allows a visual and statistical inspection of the database. The main features are:

  - ✓ About 60 % of the events and ~70 % of the accelerograms are from the time period 1998-2012);
  - ✓ There are 22 % analog waveforms and 74 % digital ones;
  - ✓ A not surprising correlation between the geographical distribution of events and stations is observed; table 7 provides the country based contribution to RESORCE-2013 (they are mainly from: Turkey with 628 events and1 705 records; Italy: 299/1 403; Greece: 297/576; France: 151/674).
  - ✓ Almost all records are from shallow active faults (my interpretation of “shallow active crustal earthquakes”, p.24).
  - ✓ Figure 19 shows statistics for moment magnitude, depth and style of faulting:
    - ▪ The moment magnitudes (either converted from M_L or measured: see later) are concentrated between 3.5 and 5, while the event and record based distributions of Mw suggest the dominancy of moderate-size earthquakes in RESORCE-2013: 4 < Mw < 6 characterizes 61 % of the events; 21 % of records are without Mw.
    - ▪ Focal depths are less than 30 km for 92 % of the events.
    - ▪ Concerning the SoF, about half of events are from strike-slip (29 %) and normal (22 %); reverse constitutes 9 % of the events.
  - ✓ In terms of Eurocode 8 site classes, the majority of accelerometric data are recorded on stations classified as B (stiff soil, 35 %) as deduced from known V_{S30} values and site classes inferred from the geological conditions (A – rock – 26 %; C – soft soil – 23 %).
  - ✓ No major features are deduced from the distribution of Mw versus R_{epi}, R_{hyp}, R_{JB}, R_{rup}. The R_{rup} computations are affected by a lack of information on ruptured faults and double-couple fault-plane solution in the low magnitude range.
  - ✓ Finally, figure 22 (resp. 23) shows the variation of low-cut (resp. high-cut) filter frequencies as a function of Mw for different site classes: the low frequency content of the accelerograms appears to be well preserved (except for class A, the low-cut filter values tend to decrease with increasing magnitude); the chosen high-cut filter frequencies are almost exclusively above the 10 Hz limit.

II- RESORCE: database and portal

This part is made of 10 pages and 10 figures.

It presents the RESORCE portal developed by the EMSC to provide access to the metadata and waveforms that comprise the database. The portal gives also access to the RESORCE-2011 frozen database. Its content reflects the outcome of the FP7 SHARE project, extended by additional data and parameters.

- Metadata

  All the information described in the metadata, the definitions, the format and the characteristics were reviewed by the scientific committee (see below). In comparison with the first version of RESORCE, five additional parameters are available: Mw flag (Mw computed, reported or converted), R_{JB} planes 1 and 2 (km), R_{rup} planes 1 and 2 (distances to the 2 fault-planes).

  Events available within RESORCE were linked to a unique European catalogue (which allows to link numerous seismological products using a single event identifier: UNID) set up by the EMSC within the NERIES project (see foot note, page 1). Out of the 1 713 events available within RESORCE, 1 135 are available in this unique catalogue. The non-UNID events are mostly before the year 1998 and/or with a low magnitude.

- Accelerograms and spectral responses

  For all available records within RESORCE-2013, a single page gathering the waveforms and the spectral responses for different damping levels allows to have a first look at the data for end-users.

- Database and portal (http://www.resorce-portal.eu)

  Different versions of RESORCE will remain available on line, hence allowing to retrieve the same information than those selected in a previous analysis. This is a very good thing. One question concerns an open access to the database: **will the database stay open for every user in the future?**

  A series of figures shows the new *homepage* (figure 26), a zoom on the RESORCE *query page* (figure 27) – the portal allows users to query the database applying filters through the "query tab" with a set of 21 parameters filter -, an example of a *map page* (figures 28 and 29) which allows to see the result of the request, a zoom on the RESORCE *results page* (figure 30) – the user can view in the result tab details on the metadata along with waveforms and response spectra -, and the *download page* (figure 31).

  In order to have a more direct "physical contact" with the database, I used the connection parameters provided by Stéphanie Godey (CSEM).

  It is easy to "walk" inside the base, to have a global view of its contents via the *map page*, to see and to select either one or several events from this map page, and to find out which stations have recorded a given event or which events that have been registered by one or several stations.

  In fact, one can either select directly the data from the *map page* or from the *query page* (easy also to use). Few minutes after validating my request, I got a mail saying that my request is under process (subject: Resorce DB Information), then a second mail (subject: ResorceDB Request Processed) providing the ftp address in order to download the data. This works well.

  The last step is to be able to process the data (and to read them) on my own computer. This is still in process at the date and time where I write these lines!

- Link to other seismological information

  Access to external earthquake information is available on the *result page* by using the UNID. It includes ISC and EMSC location information.

III- RESORCE review process

This part is made of 3 pages.

Methodology and content of RESORCE are reviewed by the members of the scientific advisory board (plus the contributions of METU - in charge of preparing the data - and EMSC, especially for conducting an internal check of the data format and consistency between events, stations and records).

- Review procedure

  The backbone of the review process consists of one day meetings (4 up to now) by all parties (scientific advisory board, METU, EMSC) and some additional telephone conferences. Two associated documents accessible before the meeting are an Excel spreadsheet and a draft of the report by METU. The process is based on 3 methods:

  - ✓ Reviewing of the report by METU;
  - ✓ Various large-scale comparisons with other databases;
  - ✓ A "random walk" through the database.

  The results of these three approaches are circulated before the meeting to enable METU to respond. The meeting itself allows to discuss and to express comments and suggestions after a presentation by METU (in order to show the progress since the previous meeting), and also on the results of the review achieved before the meeting. The report of the meeting formalizes comments and decisions.

  The review process involving all parties (METU, scientific advisory board, EMSC) appears well thought by combining different actions before, during and after a one day meeting. However, the document says nothing on the number of errors (or inconsistencies) which were detected (and hence corrected) by following the procedure described above.

- Subjects covered by the review

  The variability of the ground motion for same magnitude and source-to-site distance is well characterized by a lognormal distribution up to 3 standard deviations. Concerning RESORCE, this variability is checked by measuring the derivations of more than 3 σ - indication of large errors - from a comparison between the data (including the metadata) and a median expected ground motion predicted using an appropriate ground motion prediction equation (GMPE). This is done by using the GMPE by Brommer et al. (2007) to predict the median PGA and the expected ground motion variability. About one hundred records were highlighted and metadata and PGAs of these records were analyzed. A similar approach was taken by considering the GMPE of Berge-Thierry et al. (2003) and the complete spectrum. Other comparisons of metadata and data between RESORCE and other databases (RESORCE vs ITACA for Italian records; RESORCE vs GEM-ISC catalogues for the magnitude and location data; RESORCE vs Regional Centroid Moment catalogue) were made. Finally, the advisory board indicates to METU various scientific papers that may contain better locations.

- Special issue

  Ground motion models using RESORCE (the former version) were computed. The results will be published in a special issue of Bulletin of Earthquake Engineering in early 2014. Article by Bindi et al. (2014) reports problems with the local to moment magnitude conversions and the authors suggest using M_L rather than a converted Mw to derive ground motion models for small earthquakes. **However, one should note, that it is now possible to determine properly Mw for small earthquakes (see conclusions).**

  One more remark: the absence of comments by the other authors using RESORCE is not an indication of the high quality of the database. This may just reflect the fact that no errors were discovered when computing new GMPEs.

However, I fully agree with the conclusion by Traversa and colleagues that these peer reviews as well as the methodology used and the data processing carried out in the past three years have led to a database of very high quality for the assessment of seismic hazard in Europe.

IV- Exchanges and collaborations with related EC projects (4 pages, 2 figures)

This last part is made of 4 pages, including 2 figures.

The document describes positive exchanges between RESORCE and others EC projects (e.g. NERA, SHARE). These exchanges focused on assuring the transparency, complementary and coordination of respective actions, hence avoiding duplication of efforts and guarantying the sustainability of RESORCE after the end of SIGMA.

Within these EC projects - which aim at promoting strong-motion databases and the networking of strong-motion data – ongoing efforts consist of:

- Improving the waveform parameterization procedures for near real-time accelerometric data using EIDA[4] as the major infrastructure utility (designed as RRSM - Rapid Raw Strong Motion - data base for shake map purposes, for example);
- Assembling a prototype strong-motion data base (ESM - Engineering Strong Motion database) with an initial core formed by the major Italian and Turkish accelerograms providers;
- Improving the broadband station inventory in Europe and extending it by including strong-motions stations across Europe.

The role and position of RESORCE is well defined with respects to RRSM and ESM. In fact, sharing, exchanging and disseminating strong-motion data appears to be well organized in Europe at different levels:

- First level: Rapid raw strong-motion - RRSM - database consisting of strong records obtained immediately after an earthquake (fully automatic procedure, no quality check, only records from agencies having real-time data exchange tools;
- Second level: Engineering strong motion – ESM – which will supplement RRSM after a short time after an event; it includes RRSM and off-line data, waveforms parameterization and metadata information of large magnitude accelerometric data are processed; RRSM and ESM are closely connected within the FP7 NERA project;

  First and second levels are updated in an almost continuous way, leading to a "dynamic" database.
- Third level: RESORCE database, which is characterized by high quality validated data for driving and testing ground motion models.

As a main outcome of an Observatory coordination workshop held in Istanbul in 2012 and organized by ORFEUS, it has been decided to continue the efforts of NERA by the creation of a working group whose objective is to build the basis for the sustainable integrated Pan-European accelerometric data distribution. The GT will operate under the umbrella of ORFEUS.

As ORFEUS will (continue to) play a main role in Europe - as it goes to be one of the EPOS thematic services - for maintaining and distributing seismological waveforms, it will take charge of the "ESM" database, and the "RESORCE static" database will be included in the agreements signed between ORFEUS and strong-motion data providers in Europe. This is illustrated in a schematic view (figure 36) of the future functioning and exchange system for the ESM and RESORCE databases.

[4] EIDA: European Integrated Data Archive (www.orfeus-eu.org/eida/eida.html).

Conclusion

- The report summarizes the general features and the current status of RESORCE. This 2013 version increases the number of events and accelerograms by including Greek, Swiss and French accelerometric validated data. This lead to significant improvements in M and distance distribution by ~1.5 times. The database contains 5 637 accelerograms from 1 713 events recorded at 1 481 strong-motion stations, out of which 1/3 have direct VS30 profiles.
- 70 % of the events have magnitude information with a magnitude range between 2.8 and 7.8. The choice was made to use magnitude conversion equations for Greek (Papazachos et al., 2002) and Italian (Castello et al., 2007) “small” earthquakes without Mw. For French events, the retained magnitude is ML (from LDG or from other regional or national agencies?).

  This is an important point especially when considering one of the main objectives of the RESORCE database, which is to compute new strong motion models. The document indicates that Bindi et al. (2014) using the RESORCE database to determine GMPE have analyzed the residuals of their ground motion model. Doing so, they highlight possible problems with the metadata, especially the magnitudes. As they observed high between-event variability for small earthquakes (which range of magnitude?), they suggest either to revisit the Mw conversions or to use only ML to derive ground-motion models from small earthquakes.
- However, the moment magnitude Mw could be estimated for small earthquakes (for example, see publications by EHTZ concerning earthquakes which occured at the Basel geothermal field). This is done from the low frequencies spectrum and simultaneously by determining the focal mechanism. In addition, it looks possible to compute Mw for small earthquakes (M > 3) (a method by B. Delouis: Delouis et al., BSSA, 2009) or routinely (ETHZ for earthquakes with a magnitude as small as 3.5). Globally, the document shows impressive results and RESORCE appears to be already a performing tool at the pan European level for engineering studies and others.
- Cooperation at the European level is going on, the role of ORFEUS will be reinforced, which is probably the best way to insure the sustainability of the database.
- Improvements of RESORCE are still needed as said by the co-authors. This includes the increase in the quality of the metadata which nowadays mainly come from the original databases (for example by including more parameters estimated in specific studies) and to progress in the data processing (filtering, magnitude conversion …). As RESORCE is/will be the basic ingredient for the ground-motion model developments and ground-motion studies in Europe (examples: Ground-motion predictive equations, seismic hazard studies), another aspect is obviously to insure the completeness of the database by integrating recent earthquakes for which the importance for such studies and engineering purposes is demonstrated.