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ORIGINAL RESEARCH PAPER

Engineering ground motion record selection in the ITalian ACcelerometric Archive

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Abstract This paper introduces REXELite, an internet version of REXEL, a software for automatic selection of ground motion suites for nonlinear dynamic analysis of structures. REXELite was developed with the aim of integrating an advanced earthquake records' repository, such as the ITalian ACcelerometric Archive (ITACA), with a tool to define seismic input for engineering seismic analysis according to international standards (with priority to Europe). In fact, REXELite allows to define target design spectra according either to Eurocode 8 or to the Italian building code, and to search ITACA for suitable sets of seven records (comprised of one or two horizontal ground motion components) matching such target spectra: on average, in a user-specified period range, and with the desired tolerance. The records in the set also have, individually and according to some criteria, the most similar spectral shape with respect to that of the code. Selection options include magnitude, source-to-site distance, soil conditions and, if desired, linear scaling of records to reduce further record-to-record variability of the selected suite.

Keywords Response spectrum matching · Dynamic analysis · REXEL · Performance-based earthquake engineering · ITACA

1 Introduction

The new ITalian ACcelerometric Archive ITACA (http://itaca.mi.ingv.it) was developed within the S4 research Program (http://esse4.mi.ingv.it), in the framework of the 2007–2009

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research agreement between the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV – Italian institute of geophysics and volcanology) and the *Dipartimento della Protezione Civile* (DPC – Italian department of civil protection). This program continued the activity originally developed by S6 research program (http://esse6.mi.ingv.it), within the previous 2004–2006 DPC-INGV agreement, in which the *alpha* version of ITACA was originally released (Luzi et al. 2008).

The main goal of both S6 and S4 programs was to organize into a comprehensive, informative, and reliable database (and related web tools) the wealth of strong-motion waveforms, recorded in Italy during the seismic events occurred in a period starting from the Ancona earthquake in 1972, up to the L'Aquila 2009 sequence.

The availability of internet strong-motion databases as ITACA is of certain interest also to earthquake engineering community, as it facilitates seismic input definition for dynamic structural analysis by means of real records. However, seismic structural codes, regarding the ground motion selection issue, often require that the suite of records has to "match" the elastic design spectrum for the site and for the limit state of interest. This, along with other provisions, makes selection of real records hardly feasible for the practitioner if not adequately aided, as demonstrated in Iervolino et al. (2008, 2009), at least in the case of Eurocode 8, or EC8 (CEN 2003), and the new Italian building code, or NIBC (CS.LL.PP 2008).

To address this issue, also with the aim of translating into practice of code-based seismic analysis recent research achievements about real strong-motion record selection (e.g., Bommer and Acevedo 2004; Beyer and Bommer 2007), a software tool, REXEL, was developed (Iervolino et al. 2010a). REXEL, freely available at the website of the Italian *Rete dei Laboratori Universitari di Ingegneria Sismica* (ReLUIS), also funded by DPC, allows to search for suites of waveforms, compatible to target acceleration response spectra either user-defined or automatically generated according to EC8 and NIBC.

While REXEL is a standalone software, this paper presents a web-based version, REXELite, with the same record selection algorithms (yet optimized for its inclusion in a web portal) operating online on ITACA since January 2010. REXELite intends to standardize and aid seismic input definition for practice purposes, allowing to search for combinations of seven 1- or 2-horizontal components strong motion records, compatible on average with a specified target (code) spectrum, in a range of periods of interest and with arbitrary tolerances.

Because when selecting a set of accelerograms for structural analysis the main objective is to reflect the relevant hazard scenarios at the site, for example from *disaggregation* (e.g., Iervolino et al. 2011), REXELite allows to select suites which also belong to user-defined magnitude (M) and source-to-site distance (R) bins, and to the same site class of the location of the structure, or to any site class. ITACA may be searched for spectrum-matching sets of records which are original (unscaled) or ground motions linearly scaled in amplitude. Finally, REXElite not only ensures the set resulting from the search has its average matching the target spectrum, but also that it is the one with the smallest individual record-to-record variability (see Sect. 3).

While the interested reader is referred to Pacor et al. (2011a) for a comprehensive presentation of the strong motion records in ITACA, the distribution of the records that are actually used by REXElite, as a function of magnitude (moment or local), epicentral distance and site conditions, is summarized in Fig. 1.

In the following provisions regarding record selection for dynamic structural analysis are briefly reviewed, laying emphasis on NIBC and EC8 procedures. Then, how REXELite addresses these tasks and interacts with the various search options available in ITACA (Pacor et al. 2011b) is discussed and examples of online code-based record selection are shown.

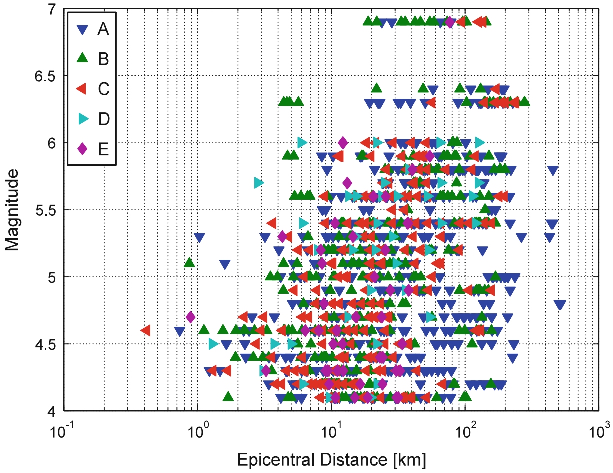


Fig. 1 Moment magnitude (or local magnitude in the case moment magnitude was not available) and epicentral distance distribution for the ITACA dataset on which REXELite operates. The records are grouped by site class according to EC8 classification

2 European and Italian standards about record selection for dynamic structural analysis

Nonlinear dynamic analysis (NLDA) of structures implies that, given that a model for the structure is available, the seismic performance is determined by time-history response analysis to a suite of earthquake ground motions. The apparently simple procedures for selecting and scaling (or more generally manipulating) ground motion records for an engineering project, and their implementation in state-of-the-art or next generation of seismic codes, have been the subject of much research in recent years; see Iervolino and Manfredi (2008) for a review.

Once a target spectrum (i.e., a *design* spectrum) is defined, for example in terms of an *uniform hazard spectrum* (UHS) from probabilistic seismic hazard analysis (PSHA), a relatively rational approach, in real record selection, is to choose ground motions associated with the *design earthquakes* (i.e., one or more event scenarios in terms of magnitude, distance, and possibly other characteristics). This choice, consistently with derivation of the spectrum from PSHA, should be driven by disaggregation of seismic hazard (e.g., Convertito et al. 2009; Iervolino et al. 2011) in order to identify the scenario giving the largest contribution to the hazard of the spectral ordinates more relevant for the behaviour of the structure (e.g., close to the fundamental period, T_1). Then, a repository of waveforms may be accessed and a suite of records selected compatibly with the values of source parameters defining the design earthquakes.[1] Finally, records are rendered somehow compatible to the target spectrum, for example by scaling each waveform to the design spectrum ordinate at the fundamental vibration period of the structure, $Sa(T_1)$, or in a range around it, Fig. 2.

[1] It is to note that some studies (e.g., Iervolino and Cornell 2005) have shown that, to some extent, if the target spectrum is matched, it may not be strictly necessary to also select records reflecting specific magnitude and distance values. In other words, if records are selected to match the spectrum, to also consider disaggregation of seismic hazard does not add much information with respect to structural response. However, it is always prudent to include magnitude and distance as selection constraints and often required by codes.

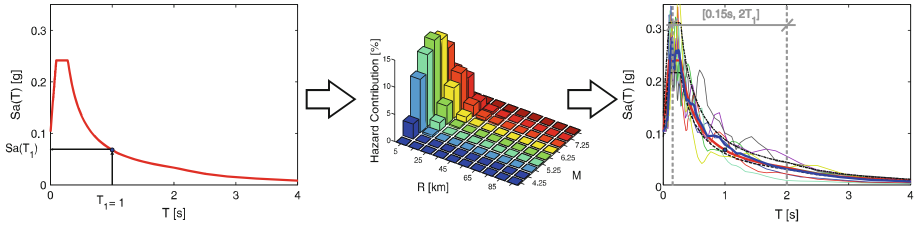


Fig. 2 Steps to define seismic action according to the hazard at the site; from *left* to *right*: target spectrum for the limit-state of interest; disaggregation of seismic hazard for Sa(T_1); selection of a set of records compatible to disaggregation and matching the target spectrum in a range of periods

Modern codes allow such a procedure although not requiring it explicitly (e.g., Iervolino et al. 2010a,b). In fact, the recently released Italian building code takes advantage of the work by the INGV concerning the seismic hazard analysis of the whole Italian territory in the framework of a specific research program, namely S1 program (http://esse1.mi.ingv.it); Montaldo et al. (2007). This is reflected in the definition of seismic action on structures based on location-dependent elastic acceleration spectra closely approximating UHS (for several return periods) at each site.

Regarding seismic input for NLDA, there are a number of allowed options to obtain suites of acceleration time-histories, including the generation of spectrum-compatible accelerograms (i.e., artificial records), or the simulation of records (through a physical simulation of earthquake process). Concerning real accelerograms, according to NIBC and EC8, selection should match *the seismogenetic features of the source and the soil conditions appropriate to the site*. NIBC, then, requires to render the spectra of the records *similar* to that of the elastic design spectrum.[2] Alternatively, if information about the *seismogenetic features of the source* is not available, it is possible to only match the elastic design spectrum. More specifically, if the latter approach is chosen, the main condition to be satisfied is that the average elastic spectrum (of the chosen set) does not underestimate the 5% damping elastic code spectrum, with a 10% lower bound tolerance (see next section), in the larger range of periods between [0.15s,2s] and [0.15s,2T_1] for safety verifications at *ultimate limit state* (T_1 is the fundamental period of the structure in the direction where the accelerograms will be applied) or in the larger period ranges between [0.15s,2s] and [0.15s,1.5T_1], for structural safety verifications at *serviceability limit state*.[3] For seismically isolated structures, the code provides a narrower range of spectrum matching around the fundamental period, [0.15s,1.2T_{is}], where T_{is} is the equivalent period of the isolated structure.

EC8 has very similar provisions, but, for each site class, gives two spectral shapes to be selected depending on the surface wave magnitude of the *earthquakes contributing most to the seismic hazard* being above or below 5.5. The elastic design spectrum depends on hazard only by its anchoring value (i.e., a_g or peak ground acceleration, PGA, on stiff soil) and

[2] Concerning real records, nowadays techniques also exist to modify the frequency/time domain to obtain spectral compatibility in a range of periods, for example via *wavelets*; see Iervolino et al. (2008) for a discussion.

[3] In NIBC, these conditions are explicitly provided for artificial records only, while in EC8, they apply to any form of accelerograms, i.e., real, artificial or simulated. The guidelines for the implementation of the NIBC (CS.LL.PP 2009) allow to use the conditions of average spectral compatibility defined for artificial signals also for the suites of real records, respecting the geological conditions of the site and choosing accelerograms whose spectrum is, if possible, generally similar to that of the target design spectrum.

matching in the [0.2T$_1$, 2T$_1$] range[4] is always mandatory. Moreover, *the mean of the zero period spectral response acceleration values (calculated from the individual time histories) should not be smaller than the value of a_g S for the site in question*, where *S* is the soil amplification factor with respect to the design spectrum for reference rock sites. Both NIBC and EC8 specify that a minimum of 3 records should be selected and that, if less than 7 records are used, the maximum structural response (in absolute terms) must be used as the basis for design and assessment. Alternatively, if 7 or more time-histories are employed, then the average structural response can be considered.

3 REXELite

In attempting to apply the provisions described in the previous section into practice, it is easy to recognize the benefit from suitable tools to aid record selection for code-based applications. In fact, to reconcile seismic code provisions with results of the last 10 years research about record selection, specific algorithms were developed since 2006 and finally embedded into the software REXEL (Iervolino et al. 2008, 2009, 2010a,b). REXEL, available at http://www.reluis.it/index.php?lang=en from which it may be downloaded, contains[5] the accelerograms of the *European Strong-motion Database* or ESD (http://www.isesd.hi.is/, last accessed July 2007 at former URL http://www.isesd.cv.ic.ac.uk/), and of ITACA, satisfying the free-field conditions and produced by earthquakes of magnitude larger than 4.

REXEL allows one to search for combinations of accelerograms whose average is compatible with the target spectrum, and in which individual records have the shape as similar as possible with respect to that of the target and in an arbitrary periods' range. Records may also be selected reflecting disaggregation of seismic hazard in terms of magnitude and source-to-site distance and specific ranges of ground motion intensity measures. Several options related to management of REXEL's output, and advanced research-based tools for improving and rendering record selection hazard-consistent (e.g., *conditional hazard*; Iervolino et al. 2010c), are also included.

In the framework of the mentioned S4 research program, an internet version of the standalone software REXEL was developed and named REXELite (Fig. 3). While REXEL has more advanced features and more than one waveform database embedded, REXELite is a simplified version (although based on the same search engine and algorithms the details of which may be found in Iervolino et al. 2010a,b) easily accessible over the web, with the significant advantage to be constantly synchronized with the continuing evolution of ITACA, including new records, updated site classifications and new or revised information on existing waveforms. It represents an interesting prototype for future similar tools interfacing seismology and earthquake engineering at the level of seismic input definition for structural analysis.

REXELite allows one to automatically define the target spectra according to NIBC or to EC8. For this purpose, it is necessary to enter the geographical coordinates of the site, *latitude* and *longitude* in decimal degrees, and to specify the *Site Class* (according to EC8 classification), the *Topographic Category* (as in EC8), the *Nominal Life*, the *Functional Type*, and the *Limit State* of interest.[6]

[4] This range applies for building, whereas for bridges the [0.2T$_1$,1.5T$_1$] interval should be considered (see Iervolino et al. 2009).

[5] It is currently undergoing the inclusion of non-European databases in REXEL.

[6] The NIBC states the principle that seismic actions on buildings are defined on the basis of the seismic hazard at the site in terms of *maximum expected* horizontal acceleration on rock and the corresponding elastic

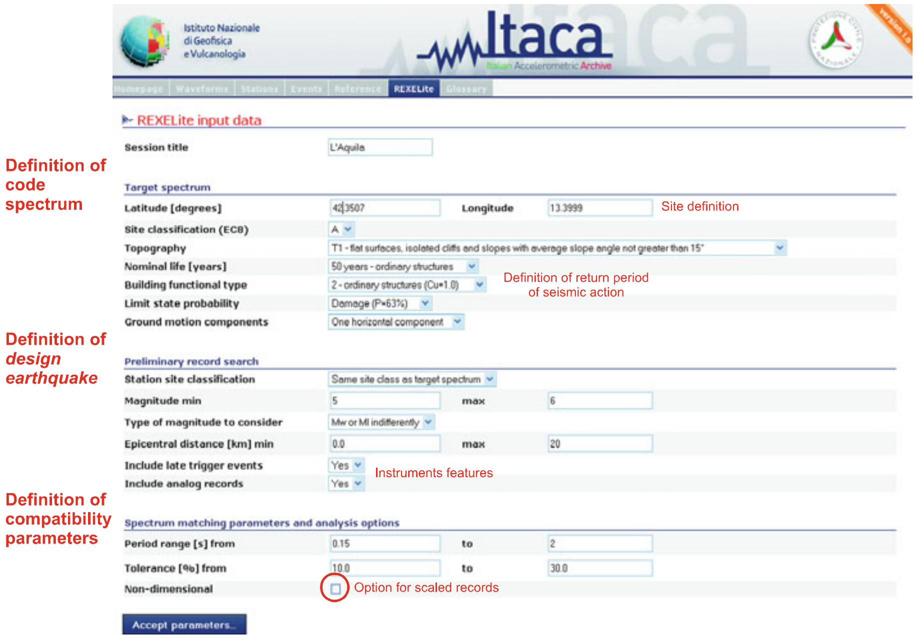


Fig. 3 REXELite user interface

For EC8 spectra, it is necessary to specify only the anchoring value of the spectrum (and therefore may be used for engineering projects outside Italy) and the site class because, as mentioned, the design spectrum is only function of a_g and S.

REXELite allows one to search for records within ITACA belonging to the same site class of the defined spectrum or to *any site class* (i.e., records referring to different site conditions may show up in the same set matching the target spectrum; see next section) and corresponding to magnitudes and epicentral distances of interest. In fact, the intervals [$\mathrm{M_{min}}$, $\mathrm{M_{max}}$] (moment and/or local magnitude) and [$\mathrm{R_{min}}$, $\mathrm{R_{max}}$] (epicentral distance, in km), in which to search for sets of accelerograms, have to be defined.

Also the recording instrument features may be specified, e.g., whether *late-triggered* and/or analogue recordings should be included or not in the search. For an introduction and discussion on the quality of ITACA records, and specifically of the late-triggered records, see Paolucci et al. (2011) and Pacor et al. (2011b).

Once these options have been defined, REXELite returns the number of records (and the corresponding number of events and recording stations) available in ITACA. The spectra of the records returned by this preliminary search are used by REXELite to find a combination of seven accelerograms, whose average is compatible with the defined target spectrum and some tolerance in an arbitrary interval of periods [$\mathrm{T_1}$, $\mathrm{T_2}$] between 0s and 4s (Fig. 4).

Footnote 6 continued
response spectrum. The maximum acceleration is defined as the peak of the acceleration which has a certain probability of being exceeded – depending on the *limit state* of interest – in a reference period V_R. V_R is equal to the *Nominal Life* of the structure (V_N, in years), times the *Importance Coefficient* for the construction (C_U). The nominal life is the number of years in which the structure, subjected to scheduled maintenance, may be used for the purpose it was designed for. The value of the importance coefficient depends on the severity of losses consequent to the achievement of a defined limited state and then on the "importance" of the structure (i.e., the *Functional Type*).

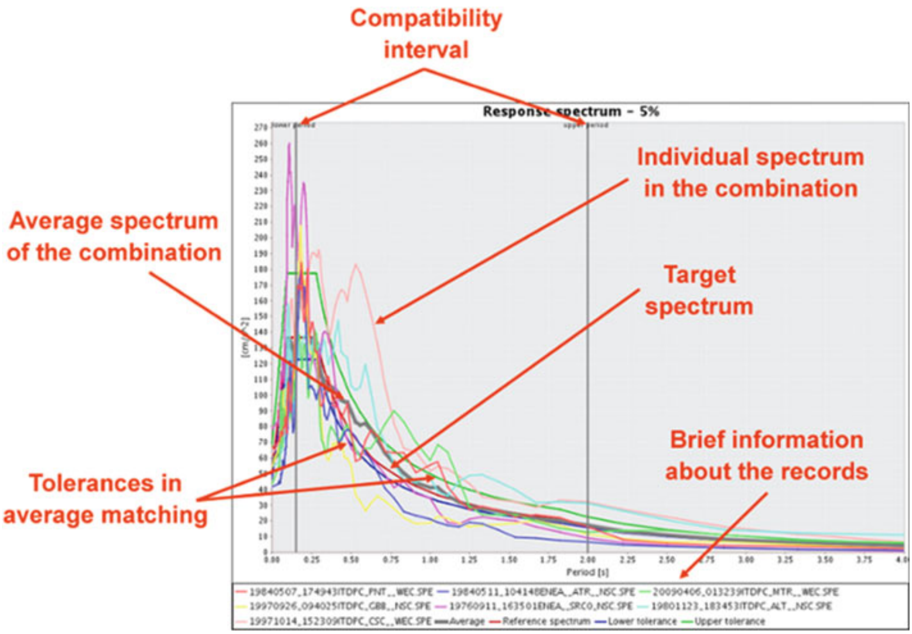


Fig. 4 Definition of spectral matching parameters and illustration of REXElite output as it appears to the user

As shown in Fig. 4, the user has to specify the tolerated deviations, *lower* and *upper* in percentage terms, which the average spectrum of the combination can have with respect to the target in the chosen range of periods. NIBC and EC8 provide constraint about the maximum tolerance according to which the average of the record set may underestimate the target spectrum (i.e., 10%), but do not supply any instruction about the upper limit. It is obvious that reducing as much as possible the overestimation of the average spectrum is a rational choice.

The compatible combination can include 7 accelerograms to be applied in one horizontal direction for analysis of bi-dimensional (plan) structures or 7 pairs of accelerograms (i.e., two horizontal recordings of a single station) to be applied in both horizontal directions for the analysis of three-dimensional structures, as actually required by NIBC and EC8.

The software, in principle, takes into account all the possible combinations of seven spectra that can be built from records found in the database for the ranges of magnitude and distance chosen, and which satisfy the soil and instrument options specified by the user, checking whether each combination is compatible, in an average sense and within the assigned tolerances, to the code spectrum.[7]

The analysis stops as soon as the first compatible combination is found. Because of a specific feature of the search algorithm, the record combination returned by REXELite is likely the one better approximating the target spectrum among those that may be obtained by the preliminary search in the database (see Iervolino et al. 2010a).

[7] In the case when the suites should include seven records featuring both horizontal components of ground motion, the software takes the average of all 14 waveforms and compares it with the target spectrum. This was found appropriate in previous studies; i.e., Iervolino et al. (2008, 2009).

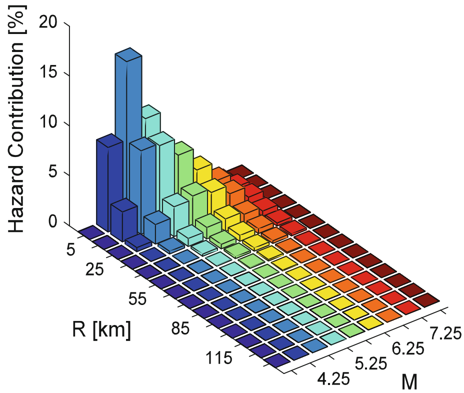


Fig. 5 Disaggregation of PGA with 50 years return period on rock for L'Aquila (http://esse1.mi.ingv.it)

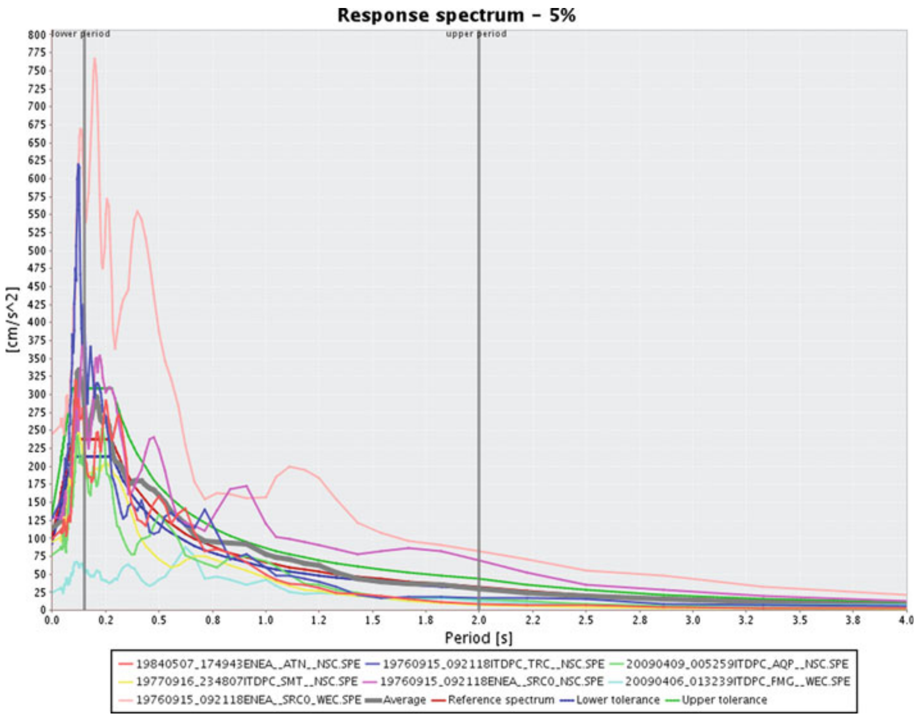
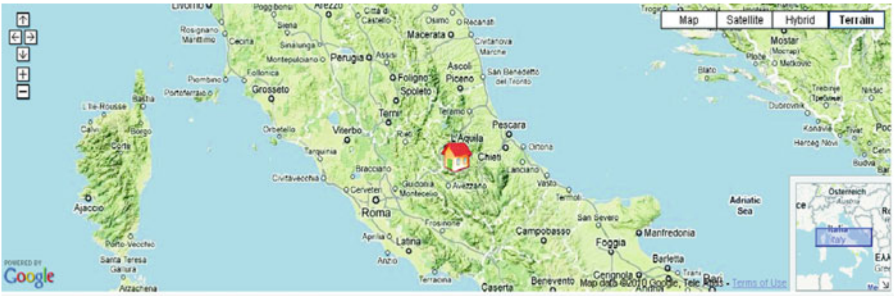


Fig. 6 Unscaled 1-component combination found for the assigned example in L'Aquila in the case of *damage limit state*

REXELite allows one to obtain combinations of accelerograms compatible with the code spectrum that do not need to be scaled, but it also allows one to choose sets of accelerograms compatible with the reference spectrum, if scaled linearly. In fact, given a target spectrum, allowing the records to be scaled increases the probability of finding a matching combination. Moreover, amplitude linear-scaling of records gives combinations whose spectra are generally more similar to the target spectrum. This has the advantage to reduce the record-to-record spectral variability within a set and may increase the statistical confidence in the estimation of structural response assessed using the found set of records. The maximum mean



Network	Station code	Type	Event time	Scale factor	Usable Bandwidth	Orientation	Waveform	Sparkline
ITDPC	TRC	Analog	1976-09-15 09:21:18	1.0	14.85	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	1.0	28.9	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	1.0	28.9	WE		
ITDPC	SMT	Analog	1977-09-16 23:48:07	1.0	14.7	NS		
ENEA	ATN	Analog	1984-05-07 17:49:43	1.0	26.75	NS		
ITDPC	FMG	Digital	2009-04-06 01:32:39	1.0	39.9	WE		
ITDPC	AQP	Digital	2009-04-09 00:52:59	1.0	39.93	NS		

Fig. 7 Metadata returned by REXELite for the combination of Fig. 6

scale factor (SF) allowed is 5, i.e., REXELite discards combinations with a mean SF (i.e., averaged scaling factors among the records in the combination) larger than 5.

When the desired combination is found, several interactive options allow users to explore selected waveforms in both time and frequency domains, to download records and/or response spectra, and to retrieve detailed information on the corresponding recording station and on the corresponding earthquakes of origin.

4 Applications

As an example, consider the selection of 1-component horizontal accelerograms according to NIBC for the *damage limit state* of an ordinary structure (*Functional Class II*) located in L'Aquila (Italy) (longitude: 13.3999°, latitude: 42.3507°) on soil type A with a nominal life of 50 years, which corresponds to the design for a 50-years return period according to the code. When setting the geographical coordinates of the site and the other parameters to define the seismic action according to the NIBC, the software automatically builds the elastic design spectrum. Assume also that selection should reflect disaggregation of PGA hazard[8] on rock with a 50-years return period (Fig. 5) at the site, which may be easily obtained by the S1 program website given above.

[8] Note that it is often recommended to consider as design earthquakes the results of hazard disaggregation for the spectral ordinates in the range of interest for the nonlinear structural behavior. This may significantly differ from disaggregation of PGA hazard (e.g., Convertito et al. 2009; Iervolino et al. 2011).

Table 1 Sample from the *data.txt* file for the combination of Fig. 6

Position (line) in data.txt file	Waveform code	δ
1	19840507_174943ENEA__ATN__NSC.SPE	0.259194157
2	19760915_092118ITDPC_TRC__NSC.SPE	0.321637501
4	20090409_005259ITDPC_AQP__NSC.SPE	0.322704447
5	19770916_234807ITDPC_SMT__NSC.SPE	0.334124185
35	19760915_092118ENEA__SRC0_NSC.SPE	0.530274041
62	20090406_013239ITDPC_FMG__WEC.SPE	0.697072126
126	19760915_092118ENEA__SRC0_WEC.SPE	1.615000801

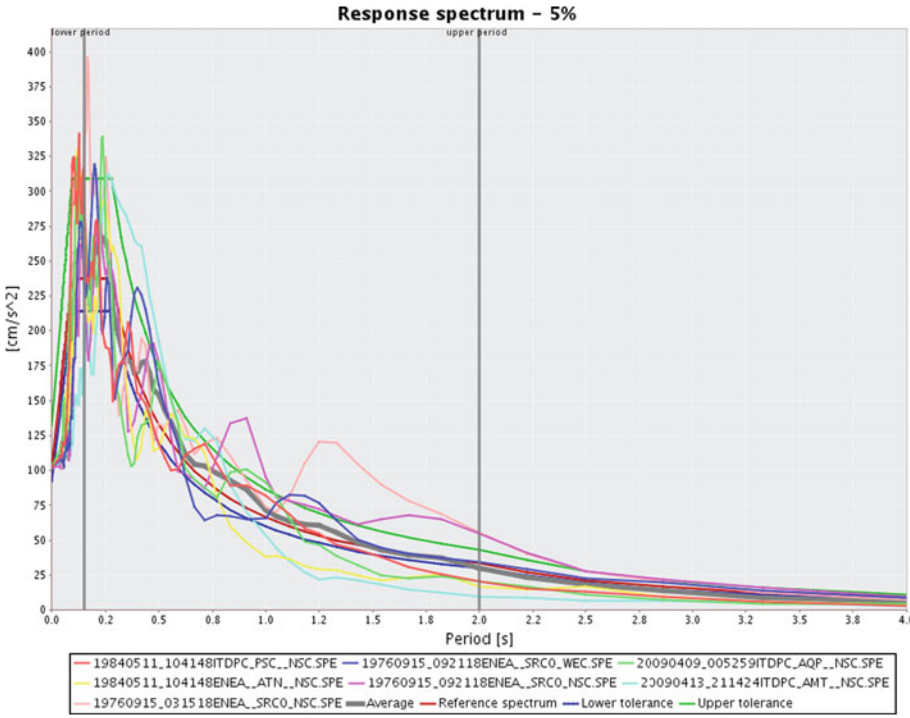


Fig. 8 Scaled 1-component combination found for the assigned example in L'Aquila in the case of *damage limit state*

Specifying the M (moment and local magnitude indifferently[9]) and R intervals equal to [5, 6] and [0 km, 20km] respectively, including also late-triggered events and analogue stations, and choosing to select records belonging to the same local geology category of the site in question (i.e., A site class), REXELite found[10] 130 waveforms (65 $\times$ 2 components of motion) from 31 different earthquakes at 32 different recording stations.

[9] It has was mentioned that for some records only local magnitude is available in ITACA. The local and moment magnitude scales are not coincident; however, this is practically irrelevant with respect to the selection of ground motion suites.

[10] All examples in this section refer to REXELite accessed in June 2011 on the ITACA website.

Table 2 Sample of *data.txt* file for the combination of Fig. 8

Position (line) in data.txt file	Waveform code	δ
1	19840511_104148ITDPC_PSC__NSC.SPE	0.169868902
2	19760915_092118ENEA__SRC0_WEC.SPE	0.219179379
3	20090409_005259ITDPC_AQP__NSC.SPE	0.239597264
6	19840511_104148ENEA__ATN__NSC.SPE	0.244673986
9	19760915_092118ENEA__SRC0_NSC.SPE	0.288677309
33	20090413_211424ITDPC_AMT__NSC.SPE	0.379114194
61	19760915_031518ENEA__SRC0_NSC.SPE	0.470464817

Network	Station code	Type	Event time	Scale factor	Usable Bandwidth	Orientation	Waveform	Sparkline
ENEA	SRC0	Analog	1976-09-15 03:15:18	1.73636	28.85	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	0.793411	28.9	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	0.41636	28.9	WE		
ITDPC	PSC	Digital	1984-05-11 10:41:48	5.58407	12.8	NS		
ENEA	ATN	Analog	1984-05-11 10:41:48	4.09246	28.7	NS		
ITDPC	AQP	Digital	2009-04-09 00:52:59	1.33814	39.93	NS		
ITDPC	AMT	Digital	2009-04-13 21:14:24	4.832	39.9	NS		

Fig. 9 Metadata returned by REXELite for the combination of Fig. 8

Once the sub-set of records that satisfied the selection criteria is identified, assigning as tolerance for the average spectral matching 10% lower and 30% upper in the period range 0.15s÷2s, REXELite immediately[11] returns the combination of accelerograms shown in Fig. 6. The figure automatically plotted by the software, gives the average of the set and the code spectrum along with the seven individual spectra of the combination, the tolerances in matching and the period range bounds where compatibility is ensured. In the legend, the ITACA waveforms codes are also given.[12]

REXELite also returns the detailed information about the individual records as retrieved by ITACA (Fig. 7), e.g. recording station code and station type (analog or digital), event (date and time), etc. The selected site (and possibly also recording stations and event) is plotted using Google Maps© interface.

The strong-motion data, in terms of acceleration time history, are provided in a compressed file containing the 7-corrected waveforms along with the corresponding acceleration response

[11] The software stops and returns a message if processing time is longer than 180 seconds.

[12] These codes include several information, i.e., origin date and time, network code, station code and component of the motion and a flag specifying whether or not the record has been processed (*C* means *corrected*), for a total length of 33 characters (if network and/or station codes have less than 5 characters, the rest is replaced by one or more underscores).

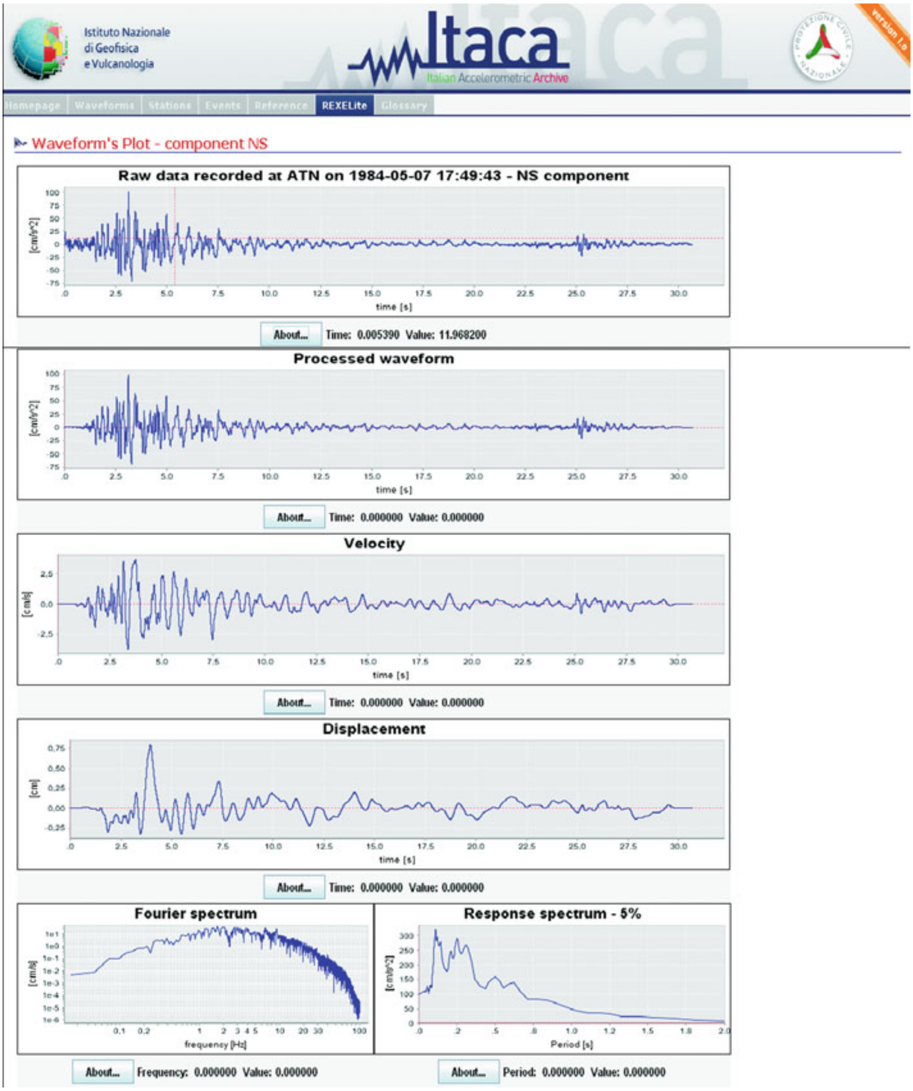


Fig. 10 Screenshot of web-based waveform visualization

spectra (in ASCII format[13]). A file containing a summary of the performed elaboration (in terms of selected parameters and options) is also provided to the user (*readme.txt*).

The output file includes also the target spectrum and a file, namely *data.txt*, containing the list of records obtained by the preliminary search in ITACA (i.e., those in which REXELite has searched for spectrum-matching suites). The records in the list in the *data.txt* file are reported in ascending order of the parameter (also given) defined in Eq. (1), which

[13] The ASCII-format records are characterized by a header of 43 rows, containing several information in order to make the record self-consistent; see ITACA User Manual (http://itaca.mi.ingv.it/ItacaStage/doc/Manual_ITACA_beta_version.pdf) for details.

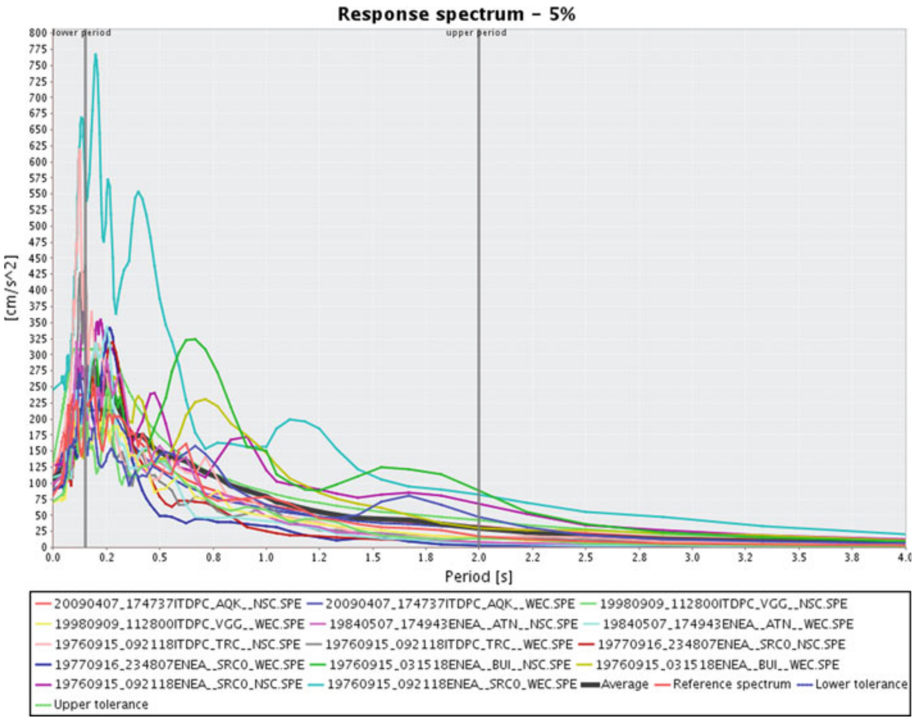


Fig. 11 Unscaled 2-component combination found for the assigned example in L'Aquila in the case of *damage limit state*

gives a measure of how much the spectrum of an individual record deviates from the target spectrum. The records with the lower valued of δ are analyzed first by the search algorithm.

$$\delta = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Sa_j(T_i) - Sa_{target}(T_i)}{Sa_{target}(T_i)}\right)^2} \tag{1}$$

In Eq. 1, $Sa_j(T_i)$ is the pseudo-acceleration ordinate of the real spectrum j corresponding to the period T_i, while $Sa_{\text{target}}(T_i)$ is the value of the spectral ordinate of the target spectrum at the same period, and N is the number of points sampling the spectra within the considered range of periods. As an example, in Table 1, an excerpt from the *data.txt* file for the combination of Fig. 6 is shown. Four of the seven records in the combination of Fig. 6 are in the first ten positions in the preliminary search output sort; i.e., in the ordering of individual spectra based on the similitude with the code spectrum.

What also emerges from Fig. 6 is that, to have the best average spectral compatibility, it is hard to reduce the variability of individual spectra records keeping them unscaled. Therefore, it is also possible to search for combination of records which require to be linearly scaled to match the target spectrum. To this aim, REXElite has the *non-dimensional* option.[14]

[14] The *Non-dimensional* option means choosing whether to search for *scaled* record sets or not. In fact, if this option is chosen the spectra to be analyzed to search for compatible combinations, are preliminarily normalized dividing the spectral ordinates by their PGA. Combinations of these spectra are compared to the non-dimensional code spectrum. Suites found in this way have to be scaled to be compatible in an average sense with the reference spectrum.

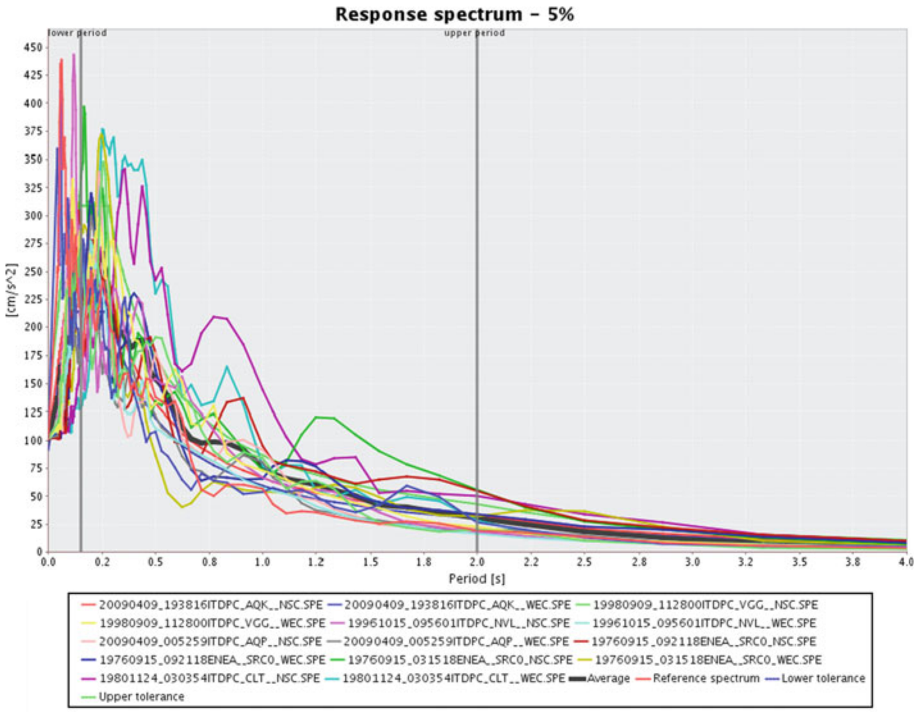


Fig. 12 Scaled 2-component combination found for the assigned example in L'Aquila in the case of *damage limit state*

In this case, repeating the search for L'Aquila considering the same magnitude and distance ranges, with the same compatibility criteria as the previous case, the software returns the combination shown in Fig. 8, which features records with less scattering (maximum δ-value equal to 0.47) with respect to those un-scaled of Fig. 6, see Tables 1 and 2. The records in Fig. 8, are multiplied by the scaling factors, SFs, automatically computed and provided by the software (Fig. 9).

Other functions are concerned with the visualization of waveforms using ITACA tools (Luzi et al. 2008) allowing users to view data in different ways and to extract ground motion data of interest. For example, each individual record of the combination can be displayed (in terms of uncorrected and corrected acceleration, velocity and displacement time-histories, Fourier spectrum, and acceleration response spectrum), see Fig. 10.

When selecting the option to search for a set of seven pairs of horizontal components, with all other conditions being equal (i.e., magnitude and distance range, site class, instrument features, tolerances and periods range), the software doesn't find a compatible set of records for the given target spectrum within 180 s. Therefore, choosing to select the *any site class* option, thus enlarging the number of records among which to search for compatible sets (161 pairs of waveforms from 42 events on 76 stations), REXELite returns, in a few seconds, the combination of Fig. 11. If the *non-dimensional* option is chosen, the software returns the combinations of Fig. 12.

Both combination of Figs. 11 and 12 may feature records belonging to different local site conditions. In fact, one may argue that one is often interested in searching for combinations matching a specific site class; i.e., the one of the construction site (codes often

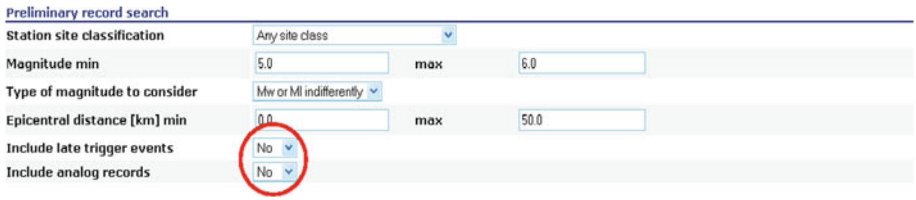


Fig. 13 Preliminary record search criteria

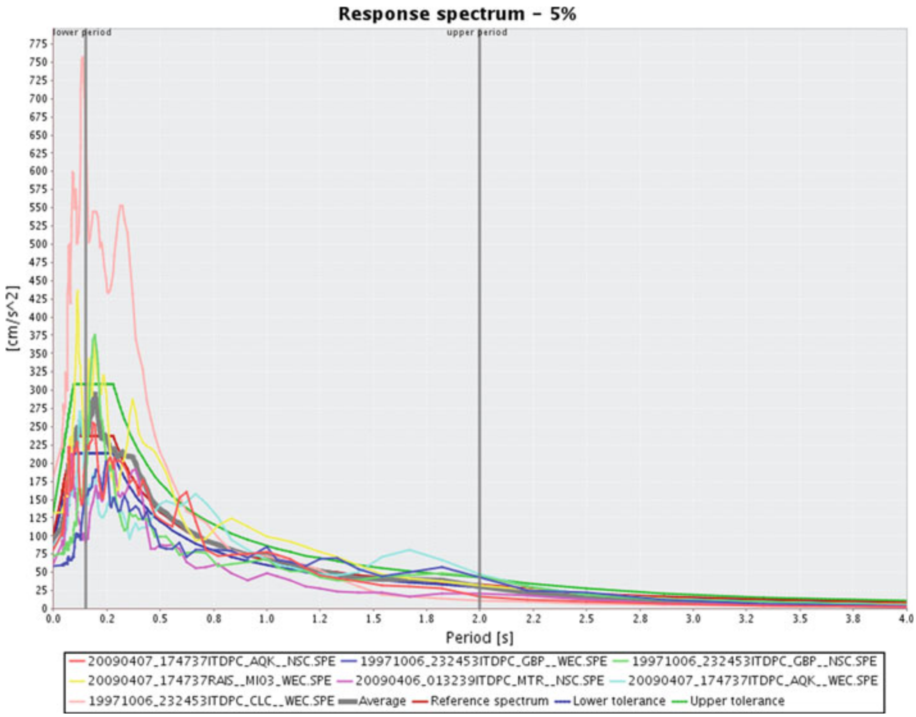


Fig. 14 Unscaled 1-component combination (only digital, normally triggered records) found for the assigned example in L'Aquila in the case of *damage limit state*

explicitly require it). However, as mentioned, several studies claim that, given the spectral, shape all other ground motion parameters are of secondary importance with respect to structural response. This may be extended, in principle, to soil site classification, and therefore, *any site class* is an option when a soil-constrained search do not returns solutions.

Finally, suppose one needs to select 1-component horizontal accelerograms according to NIBC prescriptions with reference to the same target spectrum as in the previous examples. Moreover, suppose one is interested in only digital, normally triggered records (Fig. 13).

Specifying that the magnitude and distance intervals are equal to [5, 6] and [0, 50km] respectively (the distance range was enlarged to balance the new constraint on data type), REXELite finds in the database 162 pairs of accelerograms (horizontal components) from 24 different earthquakes (recorded at 55 stations on all the possible site class). Assigning a compatibility tolerance with respect to the average spectrum of 10% lower and 30% upper

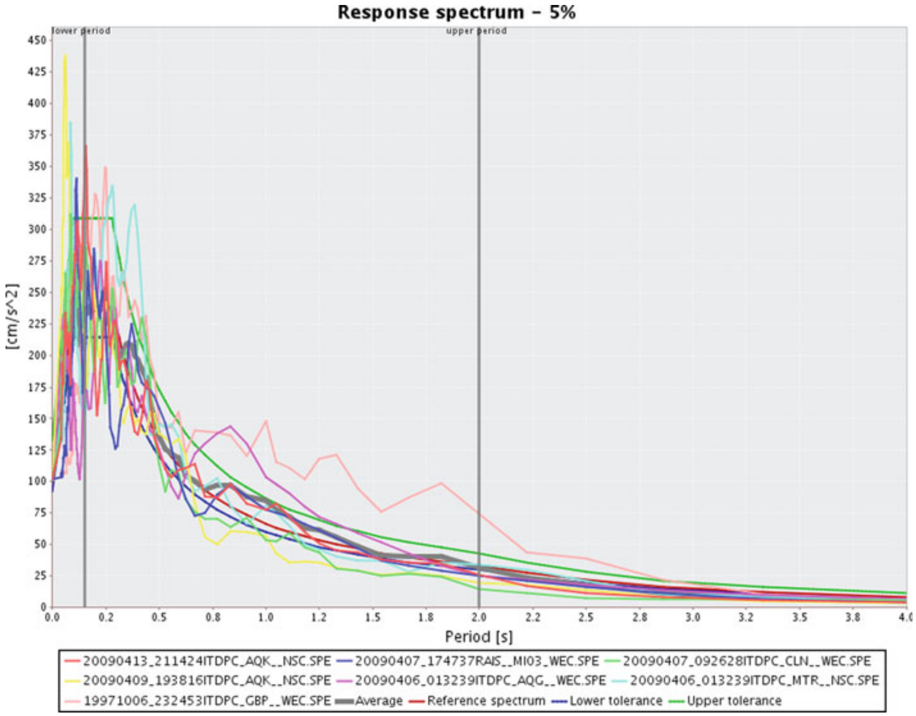


Fig. 15 Scaled 1-component combination (only digital, normally triggered records) found for the assigned example in L'Aquila in the case of *damage limit state*

Network	Station code	Type	Event time	Scale factor	Usable Bandwidth	Orientation	Waveform	Sparkline
ITDPC	GBP	Digital	1997-10-06 23:24:53	1.72015	29.85	WE		
ITDPC	AQG	Digital	2009-04-06 01:32:39	0.233102	39.9	WE		
ITDPC	MTR	Digital	2009-04-06 01:32:39	1.66145	39.92	NS		
ITDPC	CLN	Digital	2009-04-07 09:26:28	19.6819	39.9	WE		
RAIS	MI03	Digital	2009-04-07 17:47:37	0.780069	39.9	WE		
ITDPC	AQK	Digital	2009-04-09 19:38:16	4.28971	39.9	NS		
ITDPC	AQK	Digital	2009-04-13 21:14:24	5.11851	39.93	NS		

Fig. 16 Metadata returned by REXELite for the combination of Fig. 15

in the period range 0.15s÷2s, the software returns the combinations shown in Figs. 14 and 15, in the case of unscaled and scaled records respectively.

REXELite returns again the detailed information about the individual records as retrieved by ITACA (Fig. 16); note that actually only accelerograms recorded by digital stations show up in the output combination.

5 Conclusions

It is widely recognized that a proper input record selection is a key issue in nonlinear dynamic structural analysis for seismic applications. On the other hand, applying such record selection in practice may be difficult, especially with respect to code provisions and if one is looking for a suite of ground motions recorded during real earthquakes. To improve the practical applicability of strong-motion records in engineering analysis, tools implementing research-derived search algorithms may be useful. To this aim, REXELite was developed as internet software operating on the ITalian ACcelerometric Archive, for automatic selection of ground motion suites for code-based structural analysis if Eurocode 8 or the Italian seismic building codes are concerned.

Being based on the same algorithms embedded in REXEL, the originality of REXELite is its web implementation within a *living* database such as ITACA, so that the user can benefit of all features of a constantly updated repository, including the easy access to the records and to the extended information about the earthquakes and/or about the recording stations.

REXELite allows one to build design spectra, according to EC8 and NIBC, based on geographical coordinates in Italy or on the anchoring value of the spectrum, and then to preliminarily select a list of records within arbitrary bins of seismological parameters (i.e., magnitude, source-to-site distance) and recording instrument features. Then, the program analyzes the spectra of the combinations of seven groups (1- or 2-components of ground motion) of these records, and returns the best set whose average spectrum is compatible with the target in the chosen period range and with the desired tolerances; this set may be used for engineering proposes. The combination found by REXELite is not only compatible on average with the design spectrum, but also it ensures that the individual records have the spectral shape as similar as possible, among those preliminarily selected, to the target spectrum.

REXELite may be a successful example on how the integration of seismological and earthquake engineering research may effectively support and improve seismic design and assessment practices.

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