REXEL 3.3: Closing the Loop of Computer Aided Record Selection

I. Iervolino, C. Galasso & E. Chioccarelli
Universitá degli Studi di Napoli Federico II, Italy.

SUMMARY:
REXEL is a software, developed since 2005, for computer aided selection of spectrum matching real records sets to be used as an input for dynamic structural analysis. The tool, initially developed aiming at matching European standards, has been significantly enhanced recently, and now it is possible to define target spectra according to several international codes, and to select worldwide records from three different databases. Moreover, it is now possible to pre-select records based on ground motion intensity measures, alternatively to magnitude, distance, and *epsilons*. For Italian sites, REXEL now also allows to link the selected record set to the hazard at the site through the design earthquakes from disaggregation. Finally, implemented conditional hazard allows to account in selection for the cyclic content of ground motion in a probabilistically consistent manner with respect to the design acceleration. Major improvements implemented in REXEL 3.3 beta are shown in the paper.

Keywords: seismic input, design, performance-based earthquake engineering.

1. INTRODUCTION

Determination of design seismic actions mostly relies on a target spectrum, which is also the basis of record selection in seismic input definition for nonlinear structural analysis. Because a rational performance target should account for the seismic hazard at the site of interest, the uniform hazard spectrum (UHS), or an approximation of it, is often used as the design spectrum. The UHS is built entering the elastic spectral acceleration, Sa(T), hazard curves for several T values at a specified probability of exceedance (e.g., 10% in 50 years or, equivalently, 475 yr return period, Tr), and plotting the corresponding ordinates versus T.

Given the UHS for the structural limit-state of interest (i.e., the UHS corresponding to the specified Tr), current or advanced (depending on the context where it is applied) practice today, which may require aid by a seismologist, would select a set of records reflecting the likely magnitudes (M), source-to-site distances (R), and other earthquake parameters thought to drive the probabilistic seismic hazard analysis (PSHA) for the site (McGuire, 2004), and which are believed to matter with respect to structural response. Finally, the records are usually manipulated to match the UHS, individually or in average sense, at the period of the first mode of the structure (T*), Figure 1.1, or in an interval around it (e.g., Iervolino and Cornell, 2005).

It has been discussed (e.g., Iervolino et al., 2008, 2009; Iervolino, 2010) that international codes, at least in principle, may be seen as not very far from that. In fact, once the target spectrum has been defined, the main criterion is that the records have to match, or exceed it, in a range of periods. Codes often also require the selected records to reflect some characteristic of the relevant seismic sources (e.g., magnitude and distance) jointly with the design spectrum, this for example applies to ASCE Standard ASCE/SEI 7-10 (ASCE, 2010) and Eurocode 8 or EC8 (CEN, 2003). However, in applying code provisions, some issues may impair the job of the practitioner in defining the seismic input for structural analysis. For example, it may be hard to select sets of real records matching on average the design spectrum in a broad range of periods. Moreover, it is unlikely that the engineer is able to qualify the input ground motions with respect to the seismological features of the sources driving the hazard. Finally, when it is believed that other ground motion features, other than the acceleration elastic response spectrum, may be relevant for the structural assessment (i.e., those related to duration of ground motion), in the most of cases, procedures are not readily available, at a professional or code level, to account for them in an hazard-consistent manner.

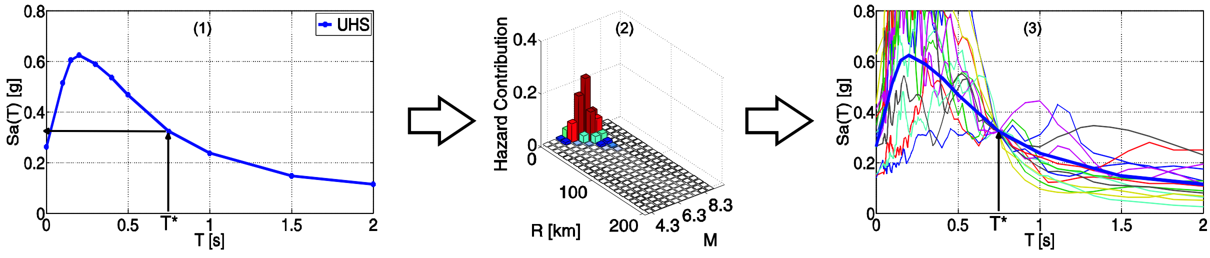

Figure 1.1 Steps to define seismic action according to the hazard at the site, from left to right: (1) UHS for the site and limit-state of interest; (2) hazard disaggregation for the spectral ordinate of interest (T*); (3) selection of a set of records compatible to disaggregation and matching the target spectrum at T*

Based on that, record selection for nonlinear seismic analysis of structures has been one of the hot topics of earthquake engineering research of almost the last two decades. The first part of this effort has been devoted to the determination of key factors affecting record selection procedures, but recently as these have reached consensus and are becoming established, a second phase initiated and is currently in progress. It is devoted to the development of software tools implementing such research results in an attempt to aid practice, exactly as structural simulation software did in the past.
The presented paper is intended to discuss how seismic input selection is at a stage which may factually address current seismic codes requests. This goal is pursued by means of discussing a computer software continuously developed since 2005 to incorporate progressively, in a practitioner-friendly format, as much as possible of research results on this topic. In fact, the search engine was initially developed to simply address the step (3) above, that is, to select sets of seven (the size of samples required by the most of international codes) real records. Now, the software allows to carry out the complete procedure, also extending it in some respect, having the following main features:

- To define code-based (European- or US-related) or arbitrary target elastic acceleration response spectra;
- To search within three international records database for spectrum matching sets reflecting ground motion features; e.g., magnitude, distance, soil conditions, peak and duration-related parameters, etc.;
- To selects sets of size from one two thirty recordings, which may comprise one, two, or three ground motion components;
- To minimize the variability of the records with the set with respect to the target spectrum;
- To reflect in the selection, disaggregation of probabilistic seismic hazard and resulting design scenarios;
- To account for secondary intensity measures in a conditional hazard approach, that is, keeping consistency with the hazard to which the target spectrum and therefore the code it is based on, yet reflecting hazard for vector-valued intensity measures.

Previous articles (e.g., Iervolino et al., 2010a) have reported the evolution of this approach. However, only these very recent updates allow to factually show how a software of this kind contributes to close the record selection loop.

2. REXEL SEARCH ENGINE FROM 2005 TO 2011

In a series of investigations, developed between 2005 and 2006, to assess the practicability of code provisions (with particular focus on EC8), an algorithm was developed to analyze all possible combination of seven elastic spectra within a list, to find those having the average compatible with a target spectrum in a range of periods and with some upper- and lower-bound tolerance. That algorithm was employed to find sets compatible to EC8 spectral shapes, and to draw the conclusions depicted in the papers by Iervolino et al. (2008) and (2009). Subsequently, with the introduction in Italy of a new Building Code or NTC08 (CS.LL.PP., 2008), the algorithm at its second generation of development was given of a graphic user interface (GUI), named REXEL 2.0 (beta), and released publicly at the website of the Italian consortium of earthquake engineering laboratories (*Rete dei Laboratori Universitari di Ingegneria Sismica – ReLUIS*; http://www.reluis.it/index_eng.html).

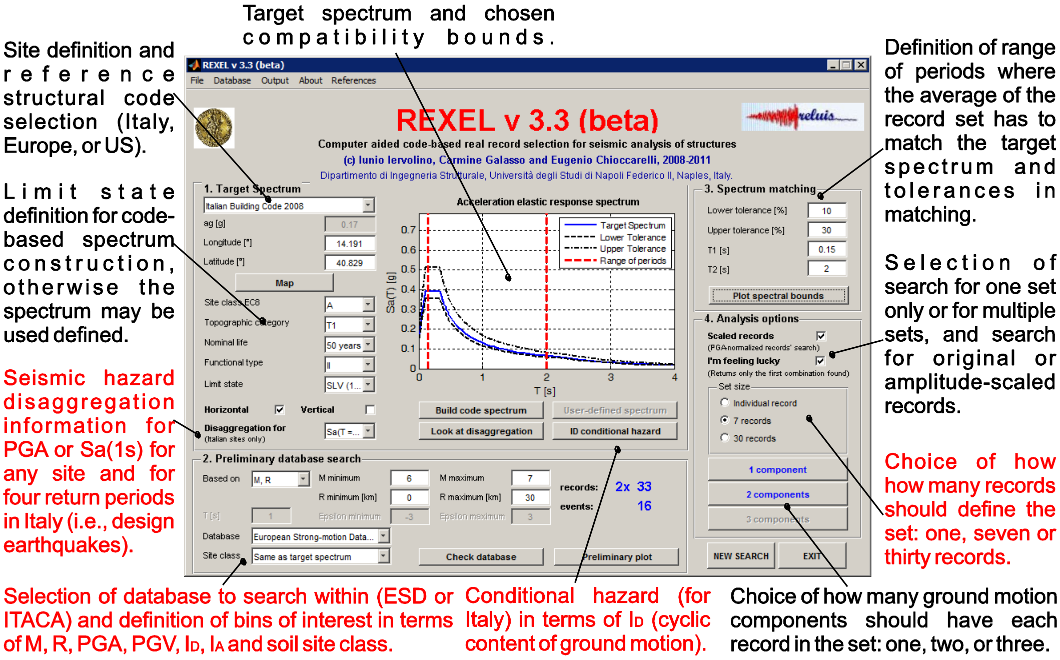

Figure 2.1 REXEL 3.3 beta user interface and main functions, in red the major new features described herein. (See the following for acronyms' definition.)

The procedure implemented for record selection deploys in four basic steps:

a) definition of the target horizontal and/or vertical spectra the set of records has to match on average; the spectra can be built based on some code provisions or may be arbitrary;
b) list and plot of the records contained in the database and embedded in REXEL which fall into the magnitude and distance bins specified by the user for a specific site class;
c) assigning the period range where the average spectrum of the set has to be compatible with the reference spectrum, and specification of tolerances in compatibility;
d) running the search for combinations of seven records which include one, two of all three components of motion and that, on average, match the design spectrum with parameters specified in step c; the records may be original (unscaled) or linearly scaled in amplitude.

One of the most advanced improvement of REXEL v 2+, with respect to the first generation, was that the search algorithm was optimized to return, as fast as possible (i.e., within seconds), the combination with the smallest record-to-record variability with respect to the target spectrum. As it is well known, that large variability, which may result from such kind of search (e.g., Iervolino et al., 2008 and 2009) may affect significantly the confidence in the estimation of structural response if only seven records are used as an input for structural analysis.
REXEL 2.31 (beta) was described in Iervolino et al. (2010) the reader is referred to for further details regarding the basics of the approach. At that stage, the software enabled basically step 1 and 3 depicted in Figure 1.1, missing the link with the scenario earthquakes from disaggregation of hazard the design spectrum derives from. This has been possible in the third generation of the software. In fact, a comprehensive disaggregation study (for Italy so far; Iervolino et al., 2011a), now suggests M and R ranges consistent with the hazard for the design spectral ordinates of interest (i.e., step 2 of Figure 1.1).

The same design earthquakes embedded may also be used, via the conditional hazard approach (Iervolino et al., 2010b) also implemented, to select records matching the design spectrum and at the same time reflecting likely (in a probabilistic sense) other ground motions intensity measures; e.g., cyclic content of ground motion for duration sensitive structures.
REXEL v 3+ defines target spectra according to several international codes and the sets may be searched among three records databases embedded. The spectrum matching waveforms may be preliminarily selected, alternatively to M, R and *epsilon*, by bins of peak and integral ground motion intensity measures (IMs); i.e., step (c) above may be now also according to ground motion IMs and not only magnitude and distance. Finally, other options as displacement spectrum compatibility check and repeating record sets' search excluding undesired records, further improve the selection.
In this section, a brief report of how the new features and enhancements of REXEL 3.3 beta (Figure 2.1) allows for a comprehensive and practice-ready record selection, is presented. The next section illustrate some examples of applications.

2.1 ASCE/SEI 7-10 target spectrum

To build the elastic acceleration response spectrum for a site of interest, four options are available in REXEL 3.3: (1) NTC08; (2) EC8 (Type 1 and Type 2 spectra); (3) ASCE/SEI 7-10 and (4) user-defined spectral shape. Options (1), (2) and the corresponding code spectral shapes, and option (4) are described in detail in Iervolino et al. (2010a). In the United States, ASCE/SEI 7-10 "Minimum Loads for Buildings and Other Structures" is currently the primary document that is referenced by building codes for determining seismic action for structures. Seismic maps developed by United States Geological Survey (USGS) are used to construct deign spectra corresponding to the MCE (Maximum Considered Earthquake) and DBE (Design Basis Earthquake). The MCE earthquake is intended to have a 2475 yr return period (i.e., probability of exceedance of 2% in 50 yr) while DBE earthquake has a 475 yr return period (i.e., probability of exceedance of 10% in 50 yr). The USGS maps are developed by computing the seismic hazard at a large number of grid points covering the entire United States and they give spectral acceleration ordinates at 0.2s (Ss) and 1s (S1) respectively. Once these spectral values are obtained from the seismic maps, for example using tools available online at http://earthquake.usgs.gov/hazards/, they have to be entered in REXEL, together with the transition period (TL) between constant spectral velocity and constant spectral displacement regions of the spectrum, to define the MCE target response spectrum on firm soil (site class B). It is necessary to specify also the site class in order to automatically compute the soil modification factors, i.e., site coefficients Fa and Fv (as a function of site class, Ss and S1). The detailed rules to build the target spectrum are defined in Chapter 11 of ASCE 7-10. Based on MCE spectrum, the DBE spectral ordinates, which are the basis for record selection, are automatically computed and plotted by REXEL as 2/3 of the corresponding MCE spectral ordinates.

2.2 Embedded databases

REXEL had built in the records belonging to the European Strong Motion Database or ESD (last accessed July 2007 at http://www.isesd.hi.is/). Recently, Italian free-field records of earthquakes with M larger than 4 from the ITalian ACcelormetric Archive, or ITACA (http://itaca.mi.ingv.it, updated to April 2011) and worldwide free-field records of earthquakes with M larger than 5 from the Selected Input Motions for displacement-Based Assessment and Design database, or SIMBAD (updated to July 2011), were also embedded[1].
ESD, ITACA and SIMBAD have some records in common although with different seismological processing. There was no attempt by the authors to homogenize/combine the three databases, which are separated in the software. In particular, the number of records from the ESD and ITACA database is comparable although ESD is characterized by generally larger magnitude and distances. ITACA, which contains records from Italy only, is more dense in its magnitude and distance ranges, and covers slightly better some soft site conditions. Moreover, it takes advantage of state-of-the art record

[1] A simplified web-based version of REXEL, namely REXELite was also developed and it operates online on ITACA since January 2010 (Iervolino et al., 2011b).

processing and constant updating. SIMBAD was developed in the framework of ReLUIS 2010-2013 Project, task *Displacement Based Approaches for Seismic Assessment of Structures*, as a strong ground motion database suitable for displacement-based design and assessment (Smerzini et al., 2012). It contains at present 384 three-component accelerograms from 122 earthquakes worldwide.

2.3 Preliminary search parameters

To make sure the selected set of spectrum matching records has the desirable characteristic the user can limit the search to waveforms falling in specific M and R bins[2] or M, R and *epsilon* bins. If the spectrum is hazard-based, as it happens in Italy where the code assigns design spectra which are basically UHS, the selection of such bins can follow disaggregation of seismic hazard for the region of the target spectrum of interest (to follow). Alternatively, REXEL 3.3 introduces pre-selection in bins from a specific range of a selected IM. More specifically, the user may select the records in the databases corresponding to a given range horizontal peak ground acceleration (PGA), peak ground velocity (PGV), the *Cosenza and Manfredi index* (I_D) (selection according to this parameter may be guided by conditional hazard, see section 2.5) and, finally, *Arias Intensity* (I_A).
A parameter that is desirable to include in record selection is the site classification. However, specifying a close match for this parameter in record selection may not always be feasible, because for some soft soils only a few records may be available. Moreover, if the spectral shape is assigned by the code, the site class of real records may be of secondary importance. In light of these considerations, there may be cases in which it may be useful to relax the matching criteria for site classification. Therefore, in REXEL 3.3 beta it is now possible to select records from *same as target spectrum* soil or from *any site class*. The latter option, as shown in the following, could help to find spectrum matching sets when insufficient records are available for a specific site condition.
After M-R (or IM) bins and site classification are defined, the software returns the number of records, and the corresponding number of originating earthquake events, available in the intervals. This list constitutes the inventory of records in which to search for sets compatible, via their average, with the target spectrum. Spectra of records from preliminary database search may also be plotted along with the target spectrum (i.e., the *preliminary plot* option) to have a picture of the spectra REXEL will search among. This, in most of the cases, enable to immediately understand if the search for spectrum matching sets will be successful.

2.4 Design earthquakes from disaggregation

When the design spectrum is derived from PSHA (e.g., a UHS as it happens in the Italian code), the *disaggregation* procedure allows to identify, from a probabilistic point of view, the contribution to the hazard of each source (in terms, for example, of M, R and *epsilon*). In particular, *epsilon* (ε) is defined as the number of standard deviation by which the logarithmic ground motion (in terms of spectral ordinates) departs from the median predicted by the chosen attenuation relationship; Ambraseys et al. (1996) for this specific study. Such an information can address the identification of scenarios relevant for design; i.e., the *design earthquakes* which are dependent on the spectral ordinate of interest and on return period the spectrum refers to. In fact, as briefly reviewed in the introduction, most of the codes requires to account in record selection for the features of the seismic sources of interest for hazard at the site, and this may be rationally referred to disaggregation.
To address this issue, a comprehensive disaggregation analysis for the pseudo-accelerations hazard (in terms of four return periods (Tr): 50, 475, 975, and 2475 yr) has been carried out for more than 10000 Italian sites considering and two spectral periods: PGA and Sa(1s). The former IM is considered representative for the short period portion of the response spectrum, while the latter has been found adequate for moderate-to-long period structures; details may be found in Chioccarelli (2010) and Iervolino et al. (2011a). Results of the analyses are implemented in REXEL which now provides, for

[2] It is always moment magnitude (M_W) for ESD, except for site E where M is expressed in terms of local magnitude (M_L), as M_W was not available in ESD. For ITACA, it is M_w or M_L, based on availability in the database. R is always the distance from the epicenter of the event because fault distance was available for part of the records only. However, in those cases where the latter is also available it is provided by REXEL.

each site, together with the design spectrum, a plot of disaggregation distribution[3] in terms of magnitude and source-to-site distance corresponding to the closer return period and structural period with respect to those of interest. This is to guide the definition of M and R bins in which to find spectrum matching sets; i.e., linking all steps of Figure 1.1.

2.5 I_D conditional hazard

When seismic analysis of structures sensitive to cyclic content of ground motion is concerned, to match the design spectrum may be insufficient to properly characterize the set of records used as an input. In other words, two sets similar in matching the same spectrum may induce very different response in the structure if this is somehow sensible to integral parameters of ground motion (e.g., Iervolino et al., 2006).
A way to account for multiple IMs (acceleration and one related to duration in this case) at the same time, is to compute the so-called vector-valued hazard analysis for the site (e.g., Bazzurro and Cornell, 2002). Although computationally demanding, this analysis allows to compute the joint hazard for more than one IM. However, if in a vector of two, one IM is seen most important with respect to another, an alternative, easy yet hazard-consistent way of including secondary intensity measures in record selection is represented by the *conditional hazard* (Iervolino et al., 2010b and Chioccarelli et al., 2012). This consists of computing hazard curves of the secondary IM conditional to a specific value of the primary IM.
Conditional hazard is especially appropriate if the primary IM is the design acceleration value (for example PGA) provided by the code, and one wants to include in selection the likely value of the secondary IM conditional to it.In fact, an application of conditional hazard is implemented in REXEL where PGA is assumed as the primary IM and the *Cosenza and Manfredi index* (I_D), which is considered a proxy for the cyclic content of ground motion, Eqn. (1.1), is the secondary IM. In Eqn. 1.1, a(t) is the acceleration time-history, t_E is the total duration of the ground motion recording.

$$I_D = \frac{1}{PGA \cdot PGV} \int_0^{t_E} a^2(t)\,dt \tag{1.1}$$

Having conditional hazard implemented for Italian sites, REXEL suggests to the user the distribution (in terms of complementary cumulative density functions) of I_D given the design PGA. This allows improving seismic input selection including, in a probabilistically consistent manner, care for cyclic content without having to change the code design hazard.

2.6 One, seven, or thirty records' set

In the previous releases of REXEL, it was possible a selection of seven records each of those featuring one, two or three components of motion. This was because seven is a reference set size in many codes. Now REXEL allows the search for sets comprised of one, seven, or thirty records. The new option has been included as one may be interested in one record individually matching a spectrum, as well as large group of records (i.e., thirty) for an analysis in which structural response is assessed with more confidence with respect to use seven records only.

2.7 Repeat search excluding a station

After a spectrum matching set is found, the analyst may want to exclude a particular record. In fact, REXEL finds sets matching the target spectrum via their average, thus a particular record may have a spectral shape the user wants to disregard for some reason. To address this issue, REXEL now

[3] It is to note that official Italian hazard data, on the basis of which code spectra are built, include disaggregation although for PGA only (data available at http://esse1-gis.mi.ingv.it); thus, results included in REXEL, referring to a specific independent and although generally consistent study, should be used with some consciousness (Iervolino et al., 2011a).

includes the option *Repeat search excluding a station*, which allows to repeat the performed analysis by excluding any record from an already found solution. This allows to refine the selection in an iterative yet very fast way as it is guided by visual inspection of individual spectra in a found set.

2.8 Displacement spectra compatibility

REXEL 3.3 beta allows to check the displacement spectra compatibility for a found set. In fact, pseudo-acceleration spectra in a set resulting from a search are transformed into displacement spectra together with the target spectrum[4]. This is a minor improvement allowing to see goodness of matching in the 5% damped spectral displacement space.

3. APPLICATION EXAMPLES

In this section only some of the described features (for the sake of brevity) are shown via record selection examples. Sections 3.1 to 3.3 refer to the same site located in Viterbo (longitude: 12,1095°, latitude: 42,4188°), central Italy (Figure 3.1a). The considered code for defining design spectra is the Italian one[5]. In Section 3.4, an example referring to the ASCE/SEI 7-10 Standard provisions is presented.

3.1 Accounting for design earthquakes

Consider first the selection of seven scaled accelerograms for the damage state limit of an ordinary structure (*Functional Class II*) on soil type A with a nominal life of 50 years, which corresponds to the design for a 50 yr return period according to the chosen code. Setting the coordinates of the site and the other parameters to define the seismic action in the Italian code, the software automatically builds the elastic design spectrum. It is assumed that the first mode of the structure correspond to a period somehow close to 1s, therefore disaggregation of Sa(1s) hazard with 50 yr return period at the site is considered to pre-select records.

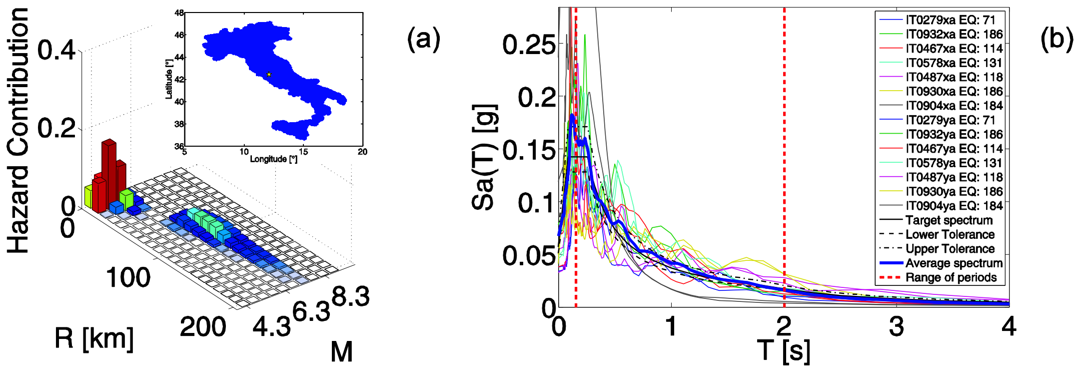

Figure 3.1 Disaggregation of Sa(1s) with 50 years return period on rock for Viterbo (a); set of seven unscaled records (two horizontal components) found for the considered example (b).

Disaggregation distribution in terms of M and R for the site, spectral ordinate, and return period of interest is easily obtained with REXEL via the *look at disaggregation* button, and is reported for this case in Figure 3.1a. If one wants to reflect in selection the first of the two modes which disaggregation shows, it is possible to specify the M and R bins as [4.3, 5.8] and [0km, 30km] in the *preliminary database search*. Choosing to select records belonging to any local site classification (that is, selecting

[4] See Smerzini et al. (2012) for a version of REXEL (i.e., REXEL-DISP) entirely devoted at record sets matching displacement response spectra.
[5] A detailed review of Italian Building Code and Eurocode 8 provisions on record selection is given in Iervolino et al., 2010a.

the *Any site class* option), REXEL found 1030 waveforms (515 x 2 components of motion) from 141 different earthquakes in ITACA. 10% lower and 20% upper tolerance in the period range 0.15s ÷ 2s for the average spectral matching are assigned and selecting the option to stop the search after the first found set (i.e., *I'm feeling lucky*) is selected. Searching for a set of seven un-scaled records, REXEL immediately returns the set of accelerograms in Figure 3.1b if the 2-component search is performed.

3.2 Accounting for both spectrum matching and hazard-consistent cyclic content

Suppose one needs to select seven horizontal scaled accelerograms with reference to the same target spectrum of the previous examples. Moreover, consider, for example, the structure may be especially sensitive to cyclic content of ground motion so that selection should reflect the conditional hazard, provided by REXEL (Figure 3.2a), in terms of I_D given the PGA with the return period the target spectrum refers to. Specifying I_D intervals equal to [10,15] (conditional probability of exceedance of I_D larger than 10%) and choosing records from *Any site class* option, REXEL found 408 waveforms (204 x 2 components of motion) from 118 different earthquakes in the ESD.
Once the sub-set of records that satisfies the selection criteria was identified, assigning as tolerance for the average spectral matching, 10% lower and 30% upper in the period range 0.15s ÷ 2s and selecting the option to stop the search after the first set is found (i.e., *I'm feeling lucky*), REXEL immediately returns the set of scaled accelerograms in Figure 3.2b if one horizontal component search is performed. The average scale factor, which the user may limit, was set to 3.

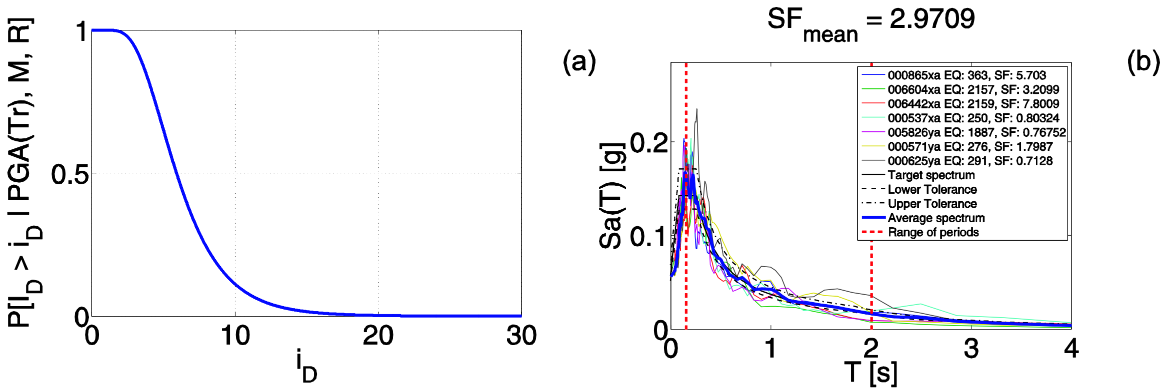

Figure 3.2 Probability of exceedance of I_D given PGA of the target spectrum (a); scaled set of seven records (one horizontal component) found compatible with the target spectrum and featuring I_D within the range derived from conditional hazard (b).

3.3 Binning by ground motion IM and search for large spectrum matching sets

Consider now the selection of thirty scaled accelerograms for the life safety limit state of an ordinary structure (*Functional Class II*) a nominal life of 50 years, which corresponds to the design for a 475 yr return period according to the Italian code. Moreover, suppose one is interested only in ESD records characterized by PGV values between 0.02 m/s and 0.5 m/s, disregarding again the constraint on site classification (*Any site class* option selected). Assigning a compatibility tolerance with respect to the average spectrum of 10% lower and 30% upper in the period range 0.15s ÷ 2s, the software immediately returns the set shown in Figure 3.3a (1-component search).
When selecting the option to search for a set of thirty pairs of horizontal components (e.g., 2-component search), instead, the software returns the set shown in Figure 3.3b. The average scale factor, which the user may limit, was set to 5 in both cases.

3.4 ASCE Standard-based selection of a large spectrum matching sets from SIMBAD database

As an example of selection in the SIMBAD database, consider the selection of scaled horizontal accelerograms according to the ASCE/SEI 7-10 for a site characterized by Ss = 1g, S1 = 0.4g and TL = 2s on soil type B.

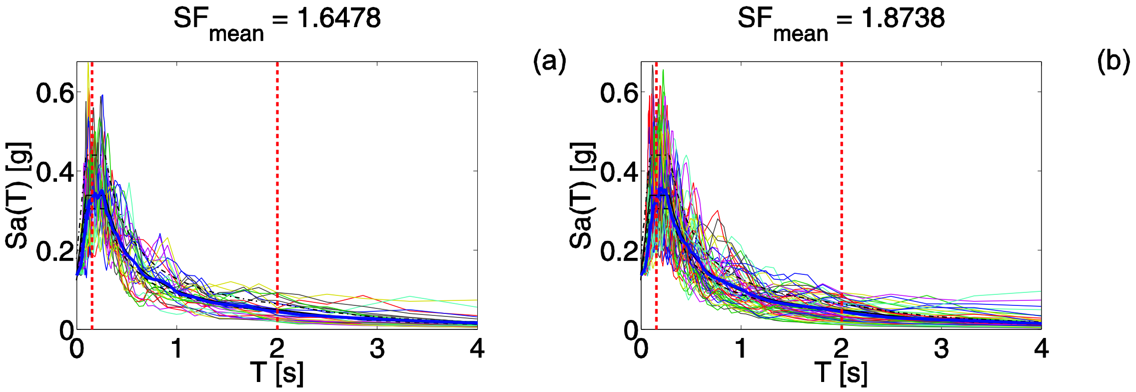

Figure 3.3 Thirty records scaled sets found for the assigned example in Viterbo: (a) one horizontal component set; (b) two horizontal components set.

When setting the parameters for the site and soil class is specified, the software automatically builds the DBE spectrum. Specifying the M and R intervals at [6.5, 7.5] and [10km, 40km] respectively, REXEL found 124 records (62 x 2 components of motion) from 22 different earthquakes[6].
Assigning as tolerances for the average spectral matching, 10% lower and 20% upper in the period range 0.15s ÷ 2s and selecting the option to stop the search after the first combination is found (i.e., *I'm feeling lucky*), REXEL immediately returns the combinations of unscaled accelerograms in Figure 3.4a if the 1-component search is performed. In Figure 3.4b, the displacement spectra compatibility for the selected combination of Figure 3.4a is shown.

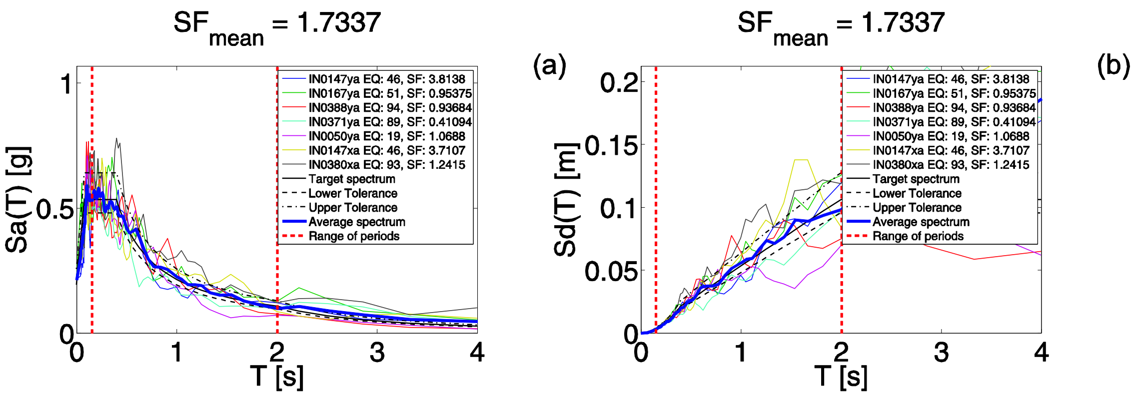

Figure 3.4 Unscaled sets found in the SIMBAD database for the assigned example according to ASCE/SEI 7-10: (a) and displacement spectra compatibility for the same combination (b) .

4. CONCLUSIONS

A software tool developed for automatic selection of a set of seven recordings including 1, 2 or 3 components of ground motion was developed by the authors and introduced in previous papers. REXEL selects set of un-scaled or scaled records whose average spectrum is compatible, in an arbitrary period range and with desired tolerance, with a target spectrum built either from the current Italian building Code, Eurocode 8 or ASCE/SEI 7-10 Standard, as well as with user defined spectra. REXEL was developed to aid some fundamental step in real record selection in engineering practice both code- or research-based. Now, thanks to some improvements, the major of which include:

(i) automatic definition of design earthquakes from disaggregation of seismic hazard,
(ii) conditional hazard to account for cyclic content of ground motion together with spectrum

[6] In the case of ASCE spectra, *Any site class* is the only available option. This is to avoid inconsistencies due to soil site classification in the databases which is according to EC8.

matching,

(iii) two extended records' databases in which is possible to pre-select records, beside magnitude, distance and site classification, also by peak and integral ground motion intensity measures,

(iv) set size which may consist of one, seven, or thirty multi-component records,

(v) other search options such has excluding a record from a set found and the displacement spectra compatibility check,

it may represent an example of how to consistently close the loop of record selection for earthquake engineering practice.

ACKNOWLEDGMENTS

The study presented in this paper was developed within the activities of *Rete dei Laboratori Universitari di Ingegneria Sismica—ReLUIS* for the research program funded by the *Dipartimento della Protezione Civile* (2010-2013).

REFERENCES

Ambraseys, N.N., Simpson, K.A. and Bommer, J.J. (1996). Prediction of Horizontal Response Spectra in Europe. *Earthquake Engineering and Structural Dynamics* **25**, 371-400.

ASCE, American Society of Civil Engineering (2010). Minimum Design Loads for Buildings and Other Structures (7-10), Standards ASCE/SEI 7-10.

Bazzurro, P. and Cornell, C.A. (2002). Vector-valued Probabilistic Seismic Hazard Analysis (VPSHA). *Proceedings of 7th U.S. National Conference on Earthquake Engineering*, Boston, MA, USA.

CEN, European Committee for Standardization. (2003). Eurocode 8: Design provisions for earthquake resistance of structures, Part 1.1: general rules, seismic actions and rules for buildings, Pren1998-1.

Chioccarelli, E. (2010). Design Earthquakes for PBEE in Far-Field and Near-Source Conditions. PhD Thesis, Dipartimento di ingegneria Strutturale, Università degli Studi di Napoli Federico II, Italy. Available at: http://www.dist.unina.it/doc/tesidott/PhD2010.Chioccarelli.pdf.

Chioccarelli, E., Esposito, S. and Iervolino, I. (2012). Implementing Conditional Hazard for Earthquake Engineering Practice: the Italian Example. *Proceedings of the 15th World Conference on Earthquake Engineering,* Lisbon, Portugal.

CS.LL.PP. (2008). DM 14 Gennaio 2008. Norme tecniche per le costruzioni. *Gazzetta Ufficiale della Repubblica Italiana*, 29. (in Italian)

Iervolino, I., Manfredi, G. and Cosenza E. (2006). Ground motion duration effects on nonlinear seismic response. *Earthquake Engineering and Structural Dynamics* **35**, 21–38.

Iervolino, I. (2010). Hazard, ground motions, and code-based structural assessment: a few proposals and yet unfulfilled needs. *Proceedings of 14th European Conference on Earthquake Engineering*, Ohrid, Republic of Macedonia.

Iervolino, I., Chioccarelli, E. and Convertito, V. (2011a). Engineering design earthquakes from multimodal hazard disaggregation. *Soil Dynamics and Earthquake Engineering* **31**, 1212–1231.

Iervolino, I., and Cornell, C.A. (2005). Record selection for nonlinear seismic analysis of structures. *Earthquake Spectra*, **21**, 685-713.

Iervolino, I., Galasso, C. and Cosenza, E. (2010a). REXEL: computer aided record selection for code-based seismic structural analysis. *Bulletin of Earthquake Engineering* **8**, 339-362.

Iervolino, I., Galasso, C., Paolucci, R. and Pacor F. (2011b). Engineering ground motion record selection in the ITalian ACcelerometric Archive. *Bulletin of Earthquake Engineering* **9**, 1761-1778.

Iervolino, I., Giorgio, M., Galasso, C. and Manfredi, G. (2010b). Conditional hazard maps for secondary intensity measures. *Bulletin of the Seismological Society of America* **100**, 3312–3319.

Iervolino, I., Maddaloni G. and Cosenza, E. (2008). Eurocode 8 compliant real record sets for seismic analysis of structures. *Journal of Earthquake Engineering* **12**, 54-60.

Iervolino, I., Maddaloni G. and Cosenza, E. (2009). A note on selection of time-histories for seismic analysis of bridges in Eurocode 8. *Journal of Earthquake Engineering* **13**, 1125–1152.

McGuire, R.K. (2004). Seismic Hazard and Risk Analysis. Earthquake Engineering Research Institute Publication, Report MNO-10, Oakland, CA, USA.

Smerizini, C., Galasso, C., Iervolino, I. and Paolucci, R. (2012). Engineering ground motion selection based on displacement-spectrum compatibility. *Proceedings of the 15th World Conference on Earthquake Engineering,* Lisbon, Portugal.