# New features of REXEL 2.61 beta, a tool for automated record selection.

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**ABSTRACT**
In code-based seismic structural design and assessment it is often allowed the use of real records as an input for nonlinear dynamic analysis. On the other hand, international seismic guidelines, concerning this issue, have been found generally poor and hardly applicable by practitioners. This is related to both the difficulty in rationally relating the ground motions to the hazard at the site, and the required selection criteria, which do not favour the use of real records, but rather various types of spectral matching signals. To overcome some of these obstacles a software tool for code-based real records selection was developed. REXEL, freely available at the website of the Italian network of earthquake engineering university labs, allows to search for suites of waveforms compatible to target spectra user defined or automatically generated according to Eurocode 8 and the recently released Italian seismic code. The selection reflects the prescriptions of the considered codes and others considered important by recent research on the topic.
In this paper, a descriptions of the new features implemented in REXEL 2.61 beta with respect to the previous versions are given.

*Keywords: Eurocode 8 · Hazard · Seismic design · Response spectrum*

## 1. INTRODUCTION

One of the key issues in non-linear dynamic analysis of structures is the selection of appropriate seismic input, which should allow for an accurate estimation of the seismic performance on the basis of the seismic hazard at the site where the structures is located.
In the case of nonlinear dynamic analysis, codes basically require a certain number of records to be chosen consistently with the seismogenetic features of the source (e.g., the design earthquake) and the code spectrum in a broad range of periods. Then, the performance of the structure is assessed verifying whether the maximum or average response of the structures to the record exceeds the seismic capacity. Studies show how the most of practitioners may experience difficulties in handling code-based record selection, first of all because determining the design earthquakes may require hazard data often not readily available to engineers, or, when these are provided by authorities (e.g., in Italy), it may still require seismological skills beyond their education. Furthermore, if real records are concerned, to find a suite matching a design spectrum in broad range of periods, may be hard or practically unfeasible if appropriate tools are not available (e.g., Iervolino et al., 2008, 2009). These issues traditionally favoured the use of spectrum matching accelerograms, either artificial or obtained through manipulation of real records. On the other hand, real records are recognized by many as the best representation of seismic loading for structural assessment and design, motivating attempts to develop tools for computer aided code-based record selection, one of which being that of Naeim et al. (2004).
The recent years' work of the authors in this direction resulted in REXEL (Figure 1), a computer software freely distributed over the internet on the website of the *Rete dei Laboratori Universitari di Ingegneria Sismica* (ReLUIS, http://www.reluis.it/), which allows to build design spectra (according to Eurocode 8 (EC8) (CEN, 2003), the new Italian seismic code (NIBC) (CS.LL.PP., 2008), or completely user-defined) and to search for sets of 7, 14 or 21 groups (each group may be made of 1, 2 or 3 component of motion) of records, from the European Strong Motion (ESD) database or from the ITalian

ACcelerometric Archive (ITACA). These sets found are compatible to the target spectra with respect to codes' prescriptions, but also reflect some research-based criteria considered relevant for seismic structural assessment. REXEL searches for sets of records for a various range of structural applications and seems to actually make the selection quick and effective in most of cases.
In Iervolino et al. (2010a), the procedures concerning determination of seismic action and record selection, according to EC8 and the NIBC, are reviewed along with finding of other studies on the topic. Then, the algorithms implemented in REXEL 2.31 are described; the use of the software is illustrated via some examples which show how it can effectively aid code-based record selection for seismic structural analysis.
In this paper, a description of the new features implemented in REXEL 2.61 beta with respect to REXEL 2.31 is given. Some illustrative examples show how these new options further help for a rational record selection for code-based earthquake engineering applications.

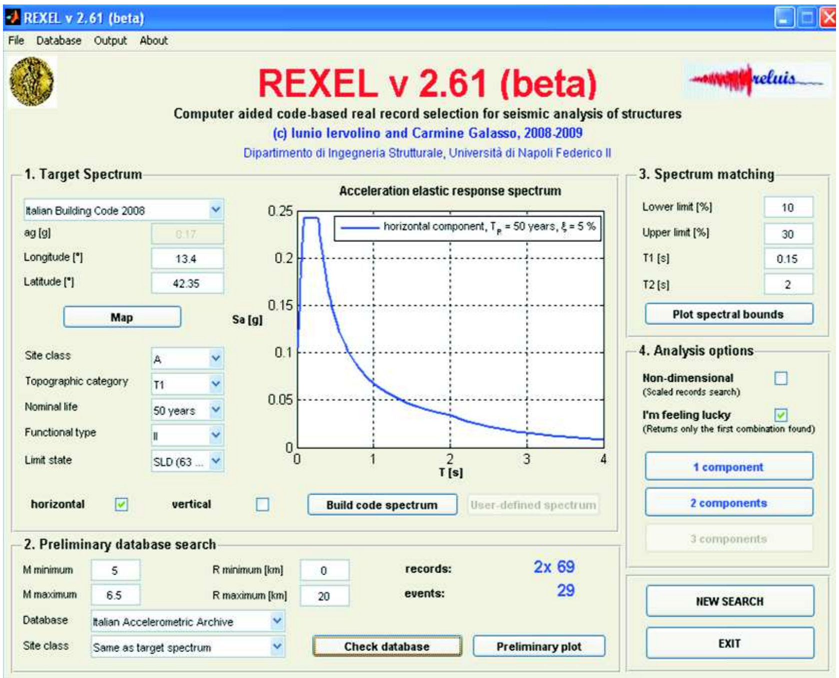


**Figure 1.** Image of the software GUI

## 2. REXEL 2.61 beta

The procedure implemented in REXEL for record selection deploys in 4 basic steps:

1. definition of the design (target) horizontal and/or vertical spectra the set of records has to match on average; the spectra can be built according to EC8, NIBC, or user-defined;

2. listing of the records contained into the two databases and embedded in REXEL which fall into moment magnitude (M) and epicentral distance (R) bins specified by the user for a specific site class or for any site class;

3. assigning the period range where the average spectrum of the set has to be compatible with the target spectrum; specification of tolerances in compatibility;

4. running the search for combination of seven records which include one, two of all three components of motions and that, on average, match the design spectrum with parameters of step 3.

Other functions are related to visualization of results, return of selected waveforms to the user, and secondary options as search for combinations of size larger than 7; see also the REXEL tutorial (Iervolino and Galasso, 2010) for further details.

### 2.1 New features in REXEL 2.61 beta

***Databases.*** REXEL, has built in the records belonging to 1) the European Strong-motion Database, or ESD, (http://www.isesd.cv.ic.ac.uk/; last accessed July 2007) and 2) the ITalian ACcelormetric Archive, or ITACA[1] (http://itaca.mi.ingv.it; updated to March 2010). All the records contained in REXEL satisfies the free-field conditions and were produced by earthquakes of moment magnitude larger than 4. Figure 2 shows distributions regarding ESD and ITACA in REXEL.
ESD and ITACA have records in common although with different seismological processing. There was no attempt by the authors to homogenize/combine the two databases, which are separated in the software. Moreover, the two databases cover different magnitude and distance ranges, therefore the appropriate database to use in searches may also depend on which range of magnitude and distance one is interested in.

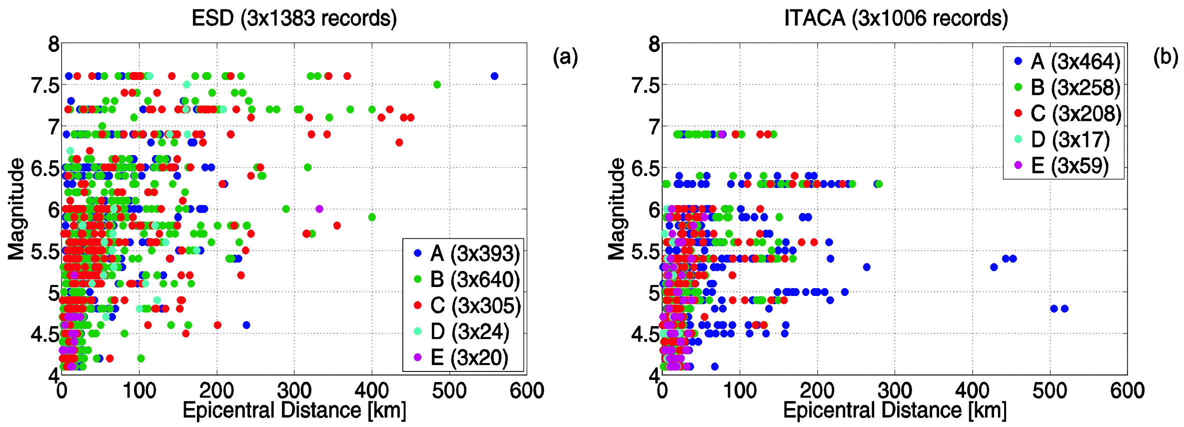


**Figure 2.** Magnitude and distance distribution of ESD and ITACA records featured in REXEL 2.61 beta. The records are grouped by EC8 site classes.

***Any site class***. A parameter that is desirable to include in record selection is the site classification, affecting both the amplitude and shape of response spectra. 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 are usually 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 it is now possible to select records from *same as target spectrum* soil or from *any site class*. This, as shown in the following, should help to overcome some of the problems when for specific site conditions it is hard to find spectrum matching sets.

***Repeat search excluding a station.*** In some cases, the analyst may want to exclude a particular record appearing in a found combination. To this aim, REXEL now includes the option *Repeat search excluding a station*, which allows to repeat the performed analysis by excluding from the list of records created in the *Preliminary database search* (i.e. from the list of accelerograms that fall in the ranges of M and R specified, and belonging to a certain local geology) one or more waveforms, in an iterative way.

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

***Displacement spectra compatibility.*** REXEL 2.61 beta allows to check the displacement spectra compatibility for a combination selected to match a pseudo-acceleration spectrum. For each period T, the elastic spectral displacement is computed as inverse transformation of elastic pseudo-spectral acceleration.

## 3. EXAMPLES

As an example of selection in the ITACA database, consider the selection of horizontal accelerograms according to the NIBC for the damage state limit of an ordinary structure 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-year return period according to the code. When setting the 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.
Specifying the M and R intervals[2] at [5, 6.5] and [0km, 20km] respectively and choosing to consider only records on A site class (that is, selecting the *Same as target spectrum* option), REXEL 2.61 beta found 138 records (69 x 2 components of motion) from 29 different earthquakes.
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 combination is found (i.e., *I'm feeling lucky*), REXEL immediately returns the combinations of accelerograms in Figure 3a if the 1-component search is performed.

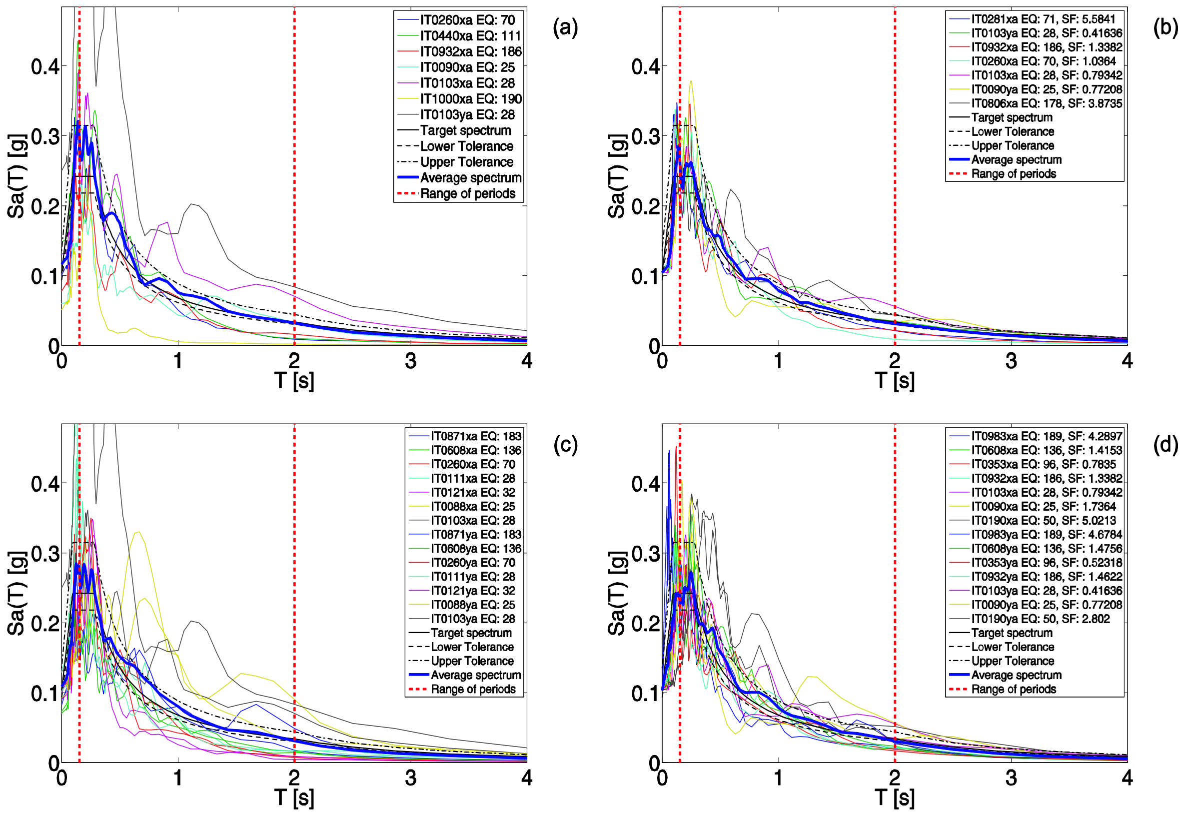


**Figure 3.** Combinations found for the assigned example in L'Aquila using the *I'm feeling lucky* option: (a) horizontal 1-component combination; (b) horizontal 1-component scaled combination; (c) horizontal 2-component combination using *Any site class* option; (d) horizontal 2-component scaled combination using *Any site class* option.

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[2] This choice may be supported by the availability of information about the design earthquake or events of interest for the design, for example from disaggregation of seismic hazard (e.g. Convertito et al., 2009).

The figure automatically plotted by the software, gives the average of the set and the code spectra, 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 station and component codes, along with the earthquake code, are also given. Detailed information on the spectra of the sets, which are automatically provided by the software, can be also derived from the ITACA website.

The results presented show that the deviation of the individual spectra compared with the target can be large. To reduce the scatter of individual records further, the *non-dimensional* option can be used (see Iervolino et al., 2010a, for details), which means that records found have to be linearly scaled when used in a structural analysis for spectral matching on average. In this case, repeating the search for L'Aquila considering the same magnitude and distance bins and with the same compatibility criteria as the previous case (using the *I'm feeling lucky* option), the software immediately returns the combination shown in Figure 3b, which features records with less scattering with respect to the un-scaled ones of Figure 3a. The records in Figure 3b, are multiplied by the scaling factors (SFs, automatically computed and shown in the legend) required to render the set compatible with the code spectrum (this only has to be done in the case of a non-dimensional search). The average scale factor was limited to 2.

When selecting the option to search for a set of seven pairs of horizontal components (e.g., for the analysis of 3D structures), instead, the software doesn't find a compatible set of records for the given target spectrum. This result was expected; in fact, by *Preliminary plot* function, it is clear that the search likely would not have given back a positive response because the average spectrum of the records from the *Preliminary database search* is lower than the target spectrum (Figure 4a).

To find a 2-components compatible combination, it was chosen to select the *Any site class* option, thus enlarging the number of records for the search for compatible sets (from 69 pairs corresponding to 29 events to 164 pairs from 38 different events). As Figure 4b shows, selecting the *Any site class* option, there is a good chance to get some results from the subsequent search.

Thanks to the *I'm feeling lucky* option, the program returns the combination of Figure 3d in seconds. Selecting the *non-dimensional* option, the software immediately returns the combinations of Figure 3d. The mean scale factor was limited to 2 also in this case.

In Figure 5, the displacement spectra compatibility for the combinations selected in the previous examples is shown.

Finally, suppose that the IT0103 recording has to be excluded from the last set of accelerograms selected (Figure 3d) because it has a particularly high energetic content at low frequencies. Selecting the *Repeat search excluding a station* option, the software repeats the performed analysis excluding the above station, finding immediately the combination of Figure 6.

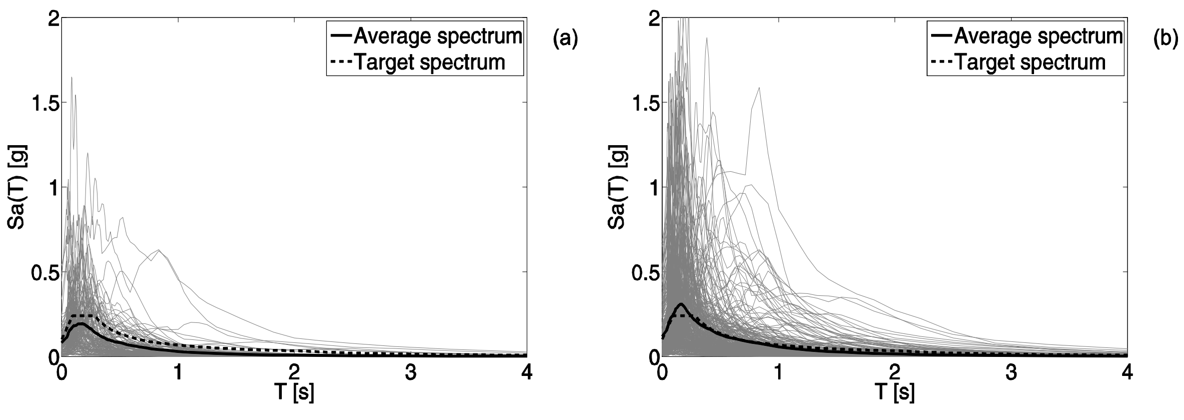


**Figure 4.** Plot of the spectra found in ITACA for the selected M and R bins in the case of (a) A site class (*same as target spectrum*) and (b) *any site class*

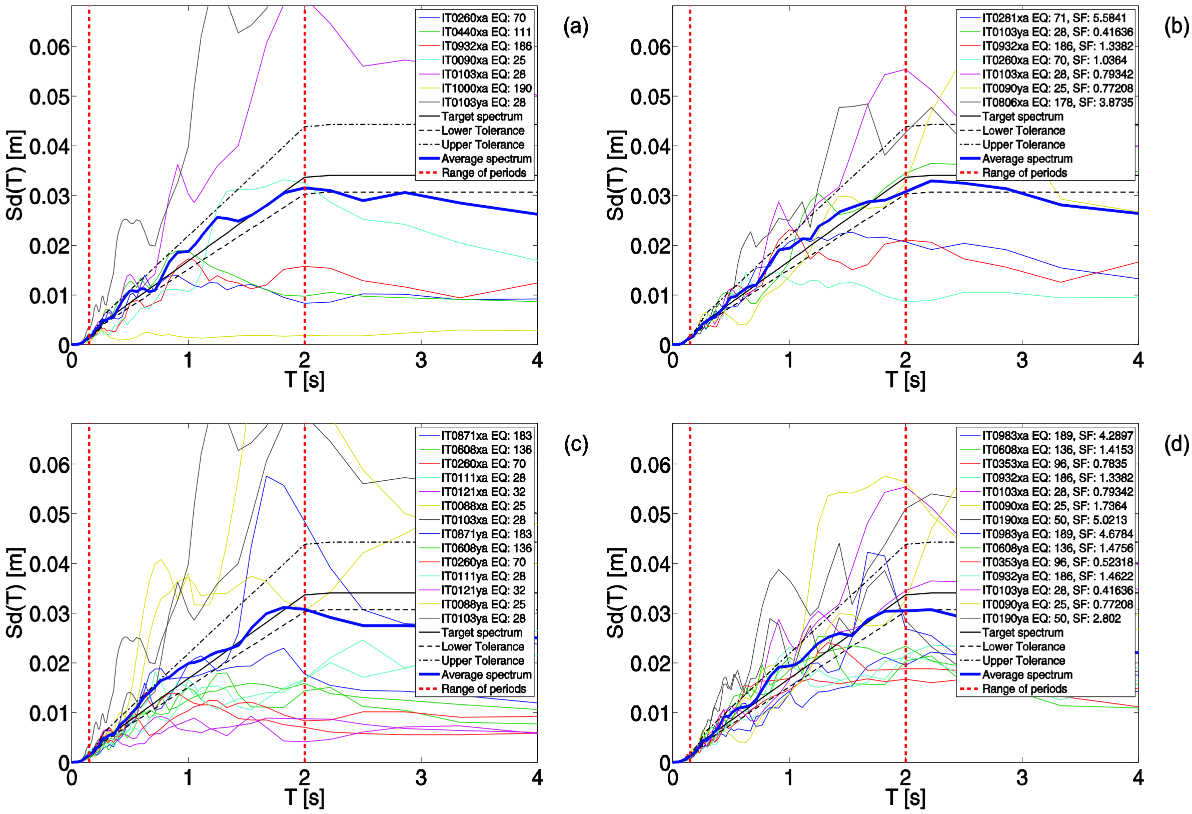


**Figure 5.** Displacement spectra compatibility for the sets of Figure 4.

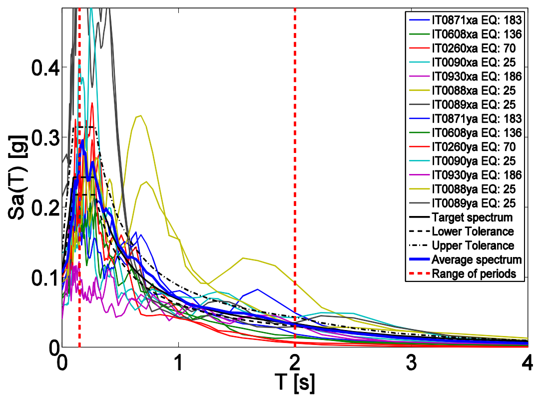


**Figure 6.** Combination found excluding the IT0103 record.

## 4. CONCLUSIONS

A software tool developed for automatic selection of seven recordings including 1, 2 or 3 components of ground motion was developed and presented in previous studies by the authors. The main selection criterion, for unscaled or scaled sets, is the compatibility, in broad period ranges, of the average spectrum with the design spectra (which the program automatically builds) of the new Italian building code, the Eurocode 8, or user defined. REXEL 2.61 beta, freely available on the internet on the RELUIS website, allows multiple selection options that also may account for design earthquakes (in terms of magnitude and distance) for any of the three components of ground motion. Moreover, it ensures that individual records in the combination have a spectral shape like that of the code as much as possible, which is important as spectral shape is currently seen as the best proxy for earthquake damage potential

on structures.
In this paper, a descriptions of the new features implemented in REXEL 2.61 beta with respect to the previous versions are given. Some illustrative examples show how these new options easily permit a rational record selection for code-based earthquake engineering applications.

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