REXELweb: A tool for selection of ground-motion records from the Engineering Strong Motion database (ESM)

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ABSTRACT: This paper illustrates REXELweb, an updated online version of REXEL, which is a tool for the automatic selection and scaling of spectrum-compatible ground-motions for dynamic analysis of structures. REXELweb allows to define target spectra according to user-definition or design provisions (Eurocode 8 and Italian building code), as well as to uniform hazard spectra (UHS) based on a European hazard model. REXELweb implements all functionalities and options of REXEL through web-services that are accessible either via a MATHWORKS-MATLAB® script or a user-friendly web-interface. The program selects records from the Engineering Strong Motion database (ESM), which is a daily-updated Pan-European repository of high-quality ground-motion records. These features make REXELweb a potentially useful tool for researchers and practitioners.

1 INTRODUCTION

Seismic input selection is a key issue in non-linear dynamic analysis of structures. Design building codes may require the use of acceleration time-histories such as: (i) natural accelerograms (earthquake records); (ii) artificial time-histories; (iii) simulated time-histories. In recent years, the increasing availability of online repositories of strong-motion records has shifted the focus mainly towards the use of natural accelerograms. Several studies deal with the selection and scaling of suites of real ground-motions (e.g., Bommer & Acevedo, 2004; Iervolino & Cornell, 2005). However, the implementation of code provisions for record selection can be cumbersome for practitioners. To address this issue, the software REXEL (Iervolino et al., 2010) was developed to provide computer-aided ground-motion selection, consistent with the design spectrum and seismic hazard at the site of interest. REXEL is available at the website of the *Rete dei Laboratori Universitari di Ingegneria Sismica* (ReLUIS – www.reluis.it). A first attempt of integrating REXEL with a dynamic database of accelerograms is REXELite (Iervolino et al., 2011), which implements some basic functions of REXEL. The main advantage of REXELite is the full integration with the *Italian Accelerometric Archive* (ITACA, http://itaca.mi.ingv.it) and the *Engineering Strong Motion datatabase* (ESM, http://esm.mi.ingv.it), that ensure a continuous waveform availability.

The present article describes REXELweb, a web platform that integrates REXEL's functionalities with a link to a dynamic database. The user can access REXELweb either through a MATHWORKS-MATLAB® script, downloadable at http:\\esm.mi.ingv.it\REXELweb.html, or a user-friendly web-interface, currently under development. The main characteristics of REXELweb are: (i) a direct link to an open and constantly-updated repository such as the Engineering Strong Motion (ESM) database; (ii) the capability to search for record sets matching either user-defined target spectra or design spectra according to Eurocode 8 (CEN 2003) and the Italian Building code NTC (NTC08 and NTC18), or even uniform hazard

spectra (UHS) based on the EFEHR (European Facilities for Earthquake Hazard and Risk; http://www.efehr.org/en/home/) European hazard model; (iii) the possibility to retrieve the peak ground acceleration (PGA) used to anchor the design spectra, directly from the hazard maps provided for both Italy (esse1.mi.ingv.it) and Europe (within the framework of SHARE, i.e. the EU-FP7 project named *Seismic Hazard Harmonization in Europe*; http://www.efehr.org/en/home/). This article describes the main structure and the workflow of REXELweb and some application examples.

2 REXELWEB

2.1 *The Engineering Strong-Motion (ESM) database*

REXELweb operates on ESM, a daily updated Pan-European database. ESM collects three-component strong-motion records from Europe and the Middle East in quasi-real time and is specifically designed to provide high quality and uniformly processed waveforms. It also contains the event and station metadata that are periodically revised. An overview of the ESM database can be found in Luzi et al. (2016). The magnitude, M (either moment M_w or local M_L), versus epicentral distance, R, distribution of ESM is shown in Figure 1.

The ESM database collects more than 33000 manually processed three-component waveforms generated by roughly 6000 seismic events (of M larger than 4.0) recorded in the period 1973-2018 by 2883 recording stations (updated to November 2018).

2.2 *Web-services workflow*

REXELweb performs spectrum-compatible records selection through a set of three Web-Services (WSs), designed to support the following user requests: (i) definition of a target spectrum (WS1), (ii) preliminary selection of records, whose metadata satisfy the criteria defined by the user (WS2); (iii) selection of a combination of accelerograms that matches, on average, the target spectrum with given tolerances (WS3). The core engine underneath the WSs is composed by three Python scripts and the original FORTRAN routine for seeking out spectral combinations embedded in REXEL. An illustrative schematic view of REXELweb workflow and related tools is given in Figure 2.

The WSs can be executed via a MATHWORKS-MATLAB® script, which provides a flexible tool for user to access the results, and via a guided web-interface, currently under development. Advanced users can also invoke the WSs directly through command-line instructions or scripts by using any software that supports data transfer with URLs (e.g., CURL; https://curl.haxx.se/).

The three WSs are described by three web-pages, each one contains all of the information required for running the WS and a link to the query options and samples queries. It is
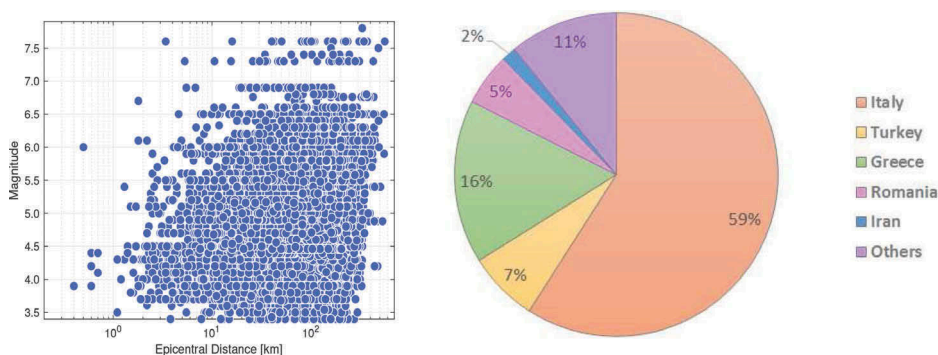

Figure 1. Magnitude – epicentral distance distribution (on the left) and geographical distribution (on the right) of records in ESM (updated to November 2018).
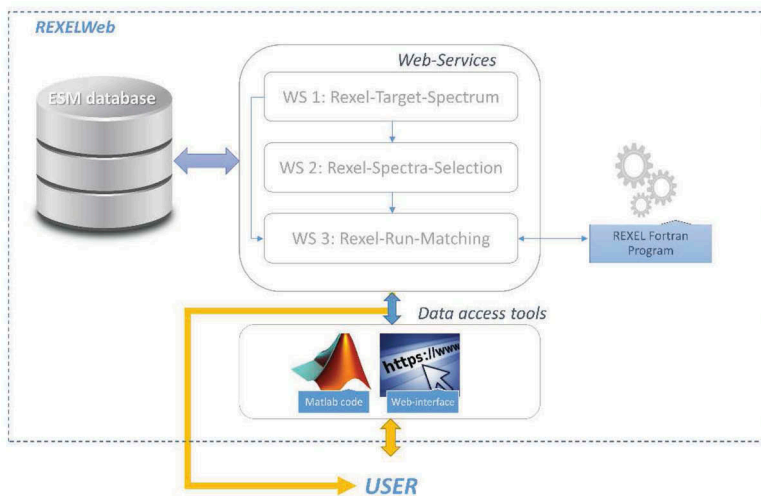
Figure 2. REXELweb workflow.

mandatory for users to register at the ESM web page, that even supports google or ORCID (https://orcid.org) credentials. The URLs to access to the WSs are:

– WS1: http://esm.mi.ingv.it/esmws/rexel-target-spectrum/1/
– WS2: http://esm.mi.ingv.it/esmws/rexel-spectra-selection/1/
– WS3: http://esm.mi.ingv.it/esmws/rexel-run-matching/1/

2.2.1 *Step 1: Definition of the target spectrum (WS1)*

The first WS allows the computation of 5%-damped pseudo-acceleration elastic response spectra (for both horizontal and vertical components of ground-motion), that represent the target to match. The target spectrum can be built according to the following options: (i) user-defined spectra; (ii) Eurocode 8 (EC8); (iii) Italian building code NTC (NTC08 and NTC18); (iv) the EFEHR-based UHS. In case (i), the input spectrum is defined through a query asking for the user periods and the spectral ordinates. In cases (ii) and (iii), the peak ground acceleration (PGA) values necessary to build the design spectra are automatically retrieved by REXELweb as a function of the geographical coordinates of the site (latitude and longitude). Alternatively, in case of European sites, the reference PGA can be manually entered by the user to build the EC8 design spectra. In case (iv), EFEHR uniform hazard spectra are provided for 10% of probability of exceedance in 50 years on rock sites. Once all the input options have been specified, the target spectra are generated and plotted for thirty periods ranging from 0.01s to 4.00s. The output is represented by two-column text files (horizontal and vertical component) containing periods and target spectral ordinates together with a summary text file that saves the input options.

2.2.2 *Step 2: Preliminary record selection (WS2)*

This step provides the pre-selection pseudo-acceleration (5%-damped) response spectra included in ESM. The program preliminarily selects from ESM the spectra that satisfy the selection criteria entered by the user, such as ranges of magnitude (M), distance (R), EC8 soil category, peak ground acceleration (PGA), peak ground velocity (PGV), Cosenza-Manfredi index (Cosenza & Manfredi, 2000), spectral shape factor I_{Np} (Bojòrquez & Iervolino, 2011) and Arias Intensity (Arias, 1970). The number and type of ground-motion components can be selected among three options: (i) one horizontal component, (ii) two horizontal components and (iii) vertical component. The three options can be selected simultaneously for three-dimensional applications to structural analysis.

As in REXEL, the response spectra that satisfy the selected (preliminary) search options are ordered on the basis of a *score* (Iervolino et al., 2010), which is a variable in the range [0-1], indicating the distance between the target and the spectrum of an individual record (i.e., a lower score indicates a spectral shape relatively close to the target). The ordered list of spectra allows to speed up the matching procedure (see step 3 described in the next section), and includes up to one-thousand records to avoid long execution time. The outputs of WS2 are ASCII files containing: (i) the list of the selected records ordered by the *score* (results are sorted so that the records with the smallest deviation from the target spectrum are placed at the beginning of the list); (ii) the spectral ordinates of the selected records; (iii) the periods of the spectral ordinates of selected records; (iv) the summary file with the query options.

2.2.3 *Step 3: Selection of the accelerogram combination matching the target spectrum (WS3)*

This step allows searching for a suite of waveforms, whose spectra, on average, match the target spectrum. Additional options are required, such as user-specified period and tolerance ranges. The tolerance range represents the acceptable positive and negative deviation of the average spectrum from the target, within the prescribed range of periods. The match is performed by the original FORTRAN routine implemented in REXEL. Tolerance and period ranges for the vertical spectral matching may be different from those regarding the horizontal components.

As in REXEL, REXELweb contains an option to search for *scaled* spectra (i.e., spectra computed from records linearly scaled in PGA). If this option is selected, it is also possible to specify the maximum allowed value of the mean scale factor (SF_{mean}) for the combination, SF being the ratio between the PGA of the target spectrum and the PGA of the single record. When searching for *unscaled* (as-originally-recorded) spectra, the *pga-flag* option checks the goodness-of-match according to the EC8 requirement (i.e., the average PGA of the selected records should not be smaller than the design value). REXELweb also allows choosing the size of the record suite: one, seven or thirty (the search for two-horizontal-components is only allowed in case of seven records, that returns fourteen accelerograms). If more than one suite is available, the user can opt to retrieve the first compatible set only (this option corresponds to *I'm feeling lucky* in REXEL). This option is used to minimize execution time, by providing the combination formed by the spectra with the smallest individual scatter with respect to the target spectrum (Iervolino et al., 2010).

The program returns a list of combinations compatible with the target, in the range of periods of interest and within the assigned tolerances. In order to limit the execution time per single request, the program stops after few minutes if no spectral matching is found and returns a run-time error to the user.

The result of the analysis is a compressed file containing: (i) a list of the spectrum-compatible accelerograms for horizontal/vertical components; (ii) the corresponding acceleration time-series in ASCII format; (iii) a summary file with the query options from the three steps.

3   APPLICATIONS

The first application illustrates the selection of a set of seven unscaled one-component accelerograms for Milan, Italy (lat. 45.4628, lon. 9.0376) according to EC8 criteria (option *EC8_it*). The target spectrum is defined for soil class EC8-B. For records selection, the following options have been set: (i) EC8 soil categories B and C; (ii) spectrum *type 1*; (iii) M in the range [4.5 - 5.5] and R in the range [0 - 100 km]; (iv) lower and upper tolerance 10% and 30%, respectively; (v) period range [0.15 – 1.8] s; (vi) accelerograms from digital instruments. REXELweb performs a preliminary search of 1000 records (step 2). Finally, the code finds the combination of records with the smallest deviation and produces the plot of the seven spectra (Figure 3). The record names (including networking code, station code, sensor code, component, event id) and related metadata, as retrieved from the ESM are listed in Table 1.

Another example concerns the selection of a set of seven unscaled one-component accelerograms for Messina, Italy (lat 38.178, lon 15.410) fixing the target spectrum to the UHS
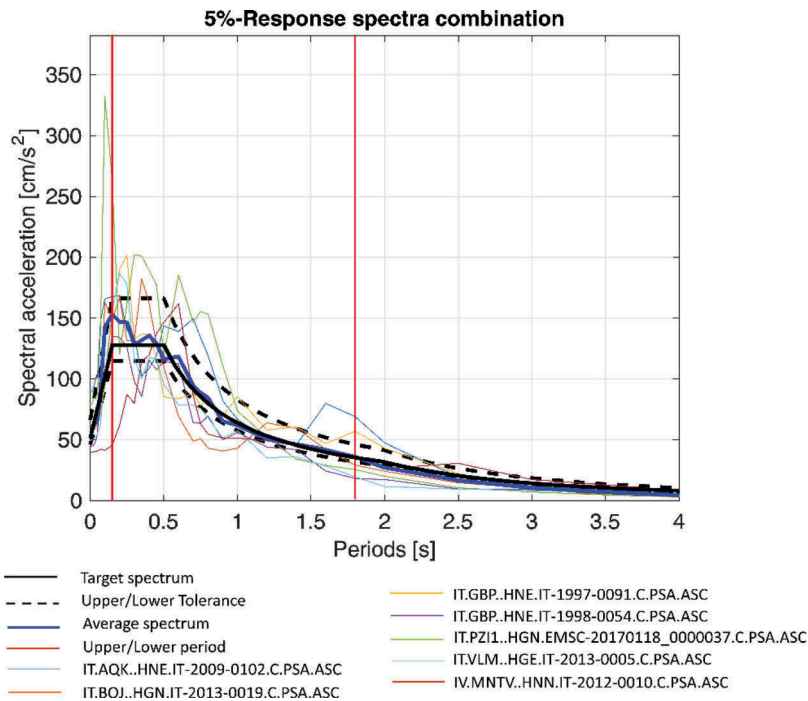
Figure 3. Unscaled suite of spectra for Milan (the target spectrum is defined according to EC8).

Table 1. Waveforms obtained for the combination of Figure 3 (last REXELweb run on November 2018).

Record name	Event name (Municipality)	Event Date	M	R [km]	Score
IT.AQK..HNE.IT-2009-0102	CENTRAL_ITALY (Fossa, Italy)	2009.04.07 17:47:37	5.5	8.4	0.443
IT.BOJ..HGN.IT-2013-0019	Caserta (Castello del Matese, Italy)	2013.12.29 17:08:43	5.0	10.4	0.312
IT.GBP..HNE.IT-1997-0091	CENTRAL_ITALY (Foligno, Italy)	1997.10.06 23:24:51	5.4	38.6	0.277
IT.GBP..HNE.IT-1998-0054	CENTRAL_ITALY (Gualdo Tadino, Italy)	1998.04.03 07:26:36	5.1	22.0	0.272
IT.PZI1..HGN.EMSC-20170118_0000037	CENTRAL_ITALY (Montereale, Italy)	2017.01.18 10:25:26	5.4	8.5	0.647
IT.VLM..HGE.IT-2013-0005	NORTHERN_ITALY (Fivizzano, Italy)	2013.06.21 10:33:56	5.1	37.1	0.302
IV.MNTV..HNN.IT-2012-0010	NORTHERN_ITALY (Cavezzo, Italy)	2012.05.29 10:55:56	5.5	35.0	0.322

provided by EFEHR (option *EFEHR_UHS*). For this record selection, the following options have been set: (i) EC8 soil category B; (ii) M in the range [4.0 - 6.0] and R in the range [0 - 50 km]; (iii) lower and upper tolerance 10% and 30%, respectively; (iv) period range [0.15 – 2] s; (v) accelerograms from digital instruments. The final set is shown in Figure 4 and corresponding records are given in Table 2.

Despite the fact that the combinations of both examples were obtained using *unscaled* records, the deviation of the average spectrum from the target is relatively small.

5%-Response spectra combination

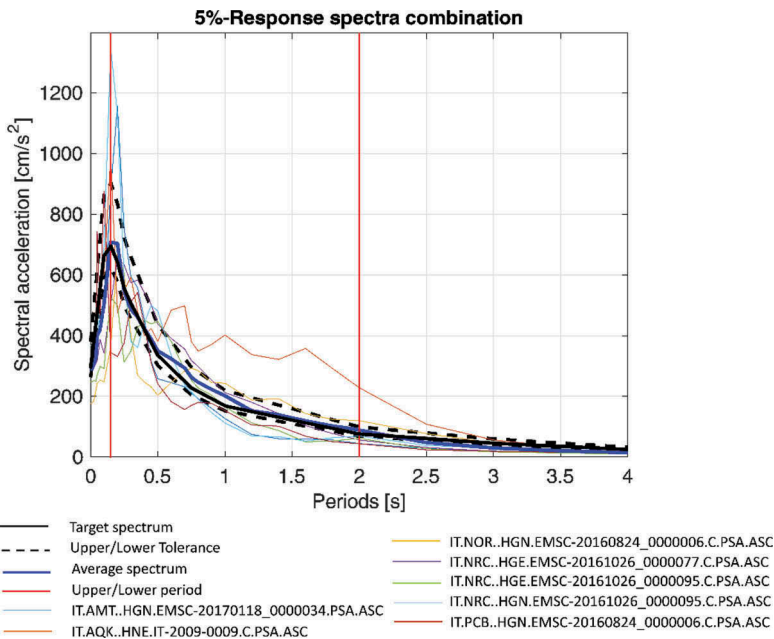|	
— Target spectrum	— IT.NOR..HGN.EMSC-20160824_0000006.C.PSA.ASC
--- Upper/Lower Tolerance	— IT.NRC..HGE.EMSC-20161026_0000077.C.PSA.ASC
— Average spectrum	— IT.NRC..HGE.EMSC-20161026_0000095.C.PSA.ASC
— Upper/Lower period	— IT.NRC..HGN.EMSC-20161026_0000095.C.PSA.ASC
— IT.AMT..HGN.EMSC-20170118_0000034.PSA.ASC	— IT.PCB..HGN.EMSC-20160824_0000006.C.PSA.ASC
— IT.AQK..HNE.IT-2009-0009.C.PSA.ASC	

Figure 4.   Unscaled suite of spectra for Messina (EFEHR-UHS target spectrum).

Table 2.   Waveforms obtained for the combination of Figure 4 (last REXELweb run on November 2018).

Record name	Event name (Municipality)	Event Date	M	R [km]	Score
IT.AMT..HGN.EMSC-20170118_0000034	CENTRAL_ITALY (Capitignano, Italy)	2017.01.18 10:14:12	5.5	11.3	0.355
IT.AQK..HNE.IT-2009-0009	CENTRAL_ITALY (L'Aquila, Italy)	2009.04.06 01:32:40	5.9	1.8	0.869
IT.NOR..HGN.EMSC-20160824_0000006	CENTRAL_ITALY (Accumoli, Italy)	2016.08.24 01:36:32	6.0	15.6	0.368
IT.NRC..HGE.EMSC-20161026_0000077	CENTRAL_ITALY (Castel Sant'Angelo sul Nera, Italy)	2016.10.26 17:10:36	5.4	9.4	0.331
IT.NRC..HGE.EMSC-20161026_0000095	CENTRAL_ITALY (Visso, Italy)	2016.10.26 19:18:06	5.9	13.2	0.362
IT.NRC..HGN.EMSC-20161026_0000095	CENTRAL_ITALY (Visso, Italy)	2016.10.26 19:18:06	5.9	13.2	0.363
IT.PCB..HGN.EMSC-20160824_0000006	CENTRAL_ITALY (Accumoli, Italy)	2016.08.24 01:36:32	6.0	17.8	0.345

4   CONCLUSIONS

REXELweb, an updated version of the seismic design-support tool REXELite has been presented. The most innovative feature of REXELweb is the capacity to combine all the functionalities of REXEL with the link to ESM, a continuously updated and manually checked repository of strong-motion waveforms and metadata. The implemented architecture based on a set of web-services provides many advantages:

- direct access to the three WSs through the web-interface under development in the framework of the ESM and ITACA web-portals, without the need to download and install any software package;
- capability to implement different user-interfaces directly invoking the three WSs, such as the provided MATHWORKS-MATLAB® code;
- availability of the web-services for use as independent modules, particularly for advanced users interested in applying the record selections retrieved by the WS2, as input into custom spectrum-compatibility algorithms;
- more flexibility towards potential future extensions and new features.

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