REXELite, online record selection for the ITalian ACcelerometric Archive

I. Iervolino & C. Galasso
Dipartimento di Ingegneria Strutturale, Università degli Studi di Napoli Federico II, Naples, Italy.

R. Paolucci
Dipartimento di Ingegneria Strutturale, Politecnico di Milano, Milan, Italy.

F. Pacor
Istituto Nazionale di Geofisica e Vulcanologia, sezione di Milano, Milan, Italy.

Ohrid
30.08-03.09
14 ECEE 2010

ABSTRACT:
This paper presents REXELite, an internet version, operating on the ITalian ACcelerometric Archive (ITACA), of REXEL, a software developed for automatic selection of ground motion suites for nonlinear dynamic analysis of structures. REXELite allows to search for horizontal combinations of seven 1- or 2-components strong motion records, compatible on average with a specified target spectrum. More specifically, REXELite: (1) automatically builds code spectra for any *limit-state* according to Eurocode 8 and the new Italian building code; (2) searches, in ITACA, the set of seven records having the most similar spectral shape with respect to that of the code, and whose average also matches the target spectrum in a user-specified period range and with the desired tolerance. The records are selected according to specific features, in terms of magnitude, distance and soil conditions, selected by the user. The set of accelerograms of the combination may include unscaled (original) or amplitude-scaled records. REXELite was developed, by the authors, as a partnership of ReLUIS (*Rete dei Laboratori Universitari di Ingegneria Sismica*) and the INGV (*Istituto Nazionale di Geofisica e Vulcanologia*) within the S4 Project funded by the Italian DPC (*Dipartimento della Protezione Civile*).

Keywords: Record Selection · Dynamic Analysis · ITACA · REXEL.

1. INTRODUCTION

The development of the new Italian strong-motion database ITACA (ITalian Accelerometric Archive, http://itaca.mi.ingv.it) is in progress under the sponsorship of the Italian *Dipartimento della Protezione Civile* (DPC) within the S4 Project (http://esse4.mi.ingv.it), in the framework of the 2007-09 research agreement between the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) and DPC. This project has continued the activity originally developed by S6 Project (http://esse6.mi.ingv.it), within the previous 2004-2006 DPC-INGV agreement, in which the alpha version of ITACA was originally developed (Luzi et al., 2008).

The main goal of the S6 and S4 Projects is to organize into a comprehensive, informative and reliable database (and related webtools) the wealth of strong-motion records, obtained in Italy during the seismic events occurred starting from the Ancona earthquake in 1972, up to the L'Aquila 2009 sequence.

The beta version of ITACA includes several improvements and additional innovative features making it a dynamic and user-friendly tool for engineers and seismologists (both professionals and researchers).

The availability of an internet strong-motion databases as ITACA, which allows to obtain records easily, makes the use of real records an attractive option for defining the input to dynamic analyses in earthquake engineering. However, because structural seismic codes, regarding record selection, often require to use sets of records matching a design spectrum, additional tools may be required.

To this aim, to further facilitate the use of real strong-motion record in structural analysis, a software for code-based real records selection was recently developed. REXEL (Iervolino et al., 2010a), freely available at the website of the Italian *Rete dei Laboratori Universitari di Ingegneria Sismica* (ReLUIS, (http://www.reluis.it/index_eng.html), also funded by DPC, allows to search for suites of waveforms, compatible to target spectra user-defined or automatically generated according to Eurocode 8, EC8 in the following, (CEN, 2003) and the new Italian building code, or NIBC (CS.LL.PP., 2008).

This paper presents a simplified version of REXEL, named REXELite, operating online on ITACA since January 2010. REXELite allows to search for horizontal combinations of seven 1- or

2-components strong motion records, compatible on average with a specified target spectrum. More specifically, REXELite: (1) automatically builds code spectra for any limit state according to Eurocode 8 and the new Italian building code; (2) searches, in ITACA, the set of seven records having the most similar spectral shape with respect to that of the code, and whose average also matches the target spectrum in a user-specified period range and with the desired tolerance. The records are selected according to specific features, in terms of magnitude, distance and soil conditions, selected by the user. The set of accelerograms may include unscaled (original) or amplitude-scaled records and may be used for code-compliant nonlinear time history analyses of structures.

In the following, after an introduction to ITACA, the procedures concerning record selection according to the NIBC are briefly reviewed. Then, REXELite is described and examples of record selection in ITACA are shown.

2. The ITalian ACcelrometric Archive (ITACA)

The beta version of ITACA, that will be soon updated at the end of S4 Project, contains contains 2550 three-component waveforms: 2293 of them were recorded during 1002 earthquakes with a maximum moment magnitude of 6.9 (the 1980 Irpinia earthquake) between 1972 and 2004, while the rest comes from the M_w 5.4 2008 Parma (Northern Italy) and from the M_w 6.3 2009 L'Aquila (Central Italy) earthquakes and related M_w > 4 aftershocks. The recordings mainly come from the National Accelerometric Network (RAN, *Rete Accelerometrica Nazionale*), operated by DPC. RAN presently consists of 334 free-field digital stations and 84 analogue stations, the replacement of which with digital instruments is currently in progress. The goal is to achieve a final configuration of more than 500 digital stations installed throughout the Italian territory, with an average inter-station distance of about 20-30 km in the most seismically active regions of Italy. Further records are provided by the Strong Motion Network of Northern Italy (*Rete Accelerometrica dell'Italia Settentrionale*, RAIS, http://rais.mi.ingv.it/), consisting of digital instruments, installed around the Garda lake area, and by sparse stations (analogue and digital) operated by ENEA (*Ente per le Nuove tecnologie, l'Energia e l'Ambiente*), between 1972 and 2004. In addition to these, waveforms recorded during the L'Aquila seismic sequence by the accelerometer installed in the AQU station (http://mednet.rm.ingv.it) are also included.

All ITACA records have been re-processed with respect to the alpha version (Massa et al., 2009), with a special care to preserve information about late-triggered events and to ensure compatibility of corrected records; i.e., velocity and displacement traces obtained by the first and second integration of the corrected acceleration should not be affected by unrealistic trends. The newly adopted processing scheme is described in Paolucci et. al (2010).

Figure 1 summarizes the main characteristics of the ITACA dataset. Magnitude (either M_w or M_l) ranges from 2 to 6.9. The epicentral distance (R_{epi}), for M < 5.5 events, and the Joyner-Boore distance (R_{jb}), for stronger earthquakes, are considered.

All ITACA stations are classified according to the EC8 classification; i.e., on the basis of the V_{s30} (average shear wave velocity in the upper 30 meters) either determined by direct measurement or on geological maps.

The waveforms collected in ITACA were recorded by 665 strong-motion stations. Among these stations, 287 are presently not in operation, since they were either part of temporary networks or equipped with old analogue instruments, which were removed. Station metadata were included in ITACA after collection of pre-existing data and field investigations performed during the S6 Project and the ongoing S4 Project.

ITACA, also includes a wide range of search tools enabling the user to interactively retrieve events, recording stations and waveforms with particular features.

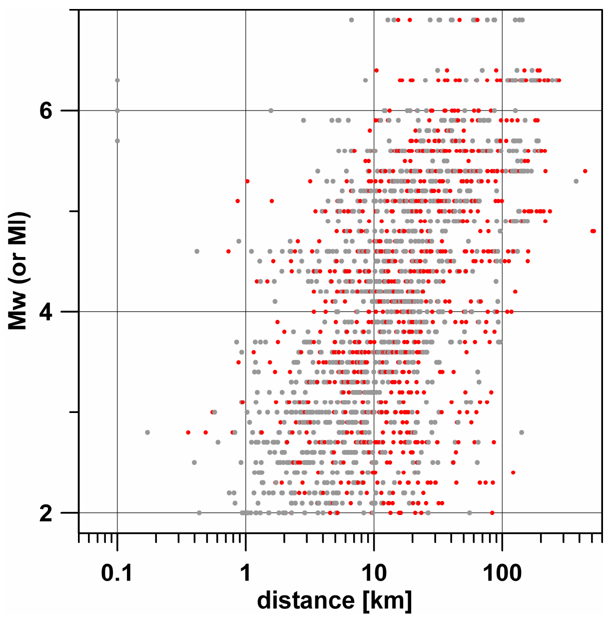

Figure 1. Magnitude (M_w or M_l) vs distance (either Joyner-Boore for M > 5.5 or epicentral distance otherwise) distribution for the ITACA dataset. The records are grouped by site class: grey for soft soil (B-E classes according to EC8 classification), red for stiff soil (A-class according to EC8 classification).

3. RECORD SELECTION ACCORDING TO THE NEW ITALIAN SEISMIC CODE

The recently released NIBC avails of the work of the INGV concerning the seismic hazard analysis of the Italian territory in the framework of a specific project (http://esse1.mi.ingv.it) (Montaldo et al., 2007). This is reflected in the definition of seismic action on structures based on site-dependent elastic acceleration spectra closely approximating the uniform hazard spectra (UHSs) for each site, making the Italian seismic code one of the most advanced with respect to this issue, at least in Europe. This also affects the seismic input selection for nonlinear structural analysis if appropriate tools are available to practitioners, as discussed in the following.
The NIBC outlines the requirements for the seismic input for dynamic analysis in section 3.2.3.6, after specifying the elastic response spectrum. The signals that can be used for the seismic structural analysis can belong to the following three categories: artificial waveforms, simulated accelerograms and natural records from real events. The main condition to be satisfied by artificial records is that the average elastic spectrum (of the chosen set) does not underestimate the 5% damping elastic code spectrum, with a 10% tolerance, in the larger range of periods between [0.15s, 2s] and [0.15s, $2T_1$] for safety checks 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 checks at serviceability limit states. For seismically isolated structures, the code provides a narrower range of matching around the fundamental period, [0.15s, $1.2T_{is}$], where T_{is} is the equivalent period of the isolated structure.
Natural accelerograms or accelerograms generated through a physical simulation of source mechanism, travel, and path, may be used, provided that the samples used *are adequately qualified with regard to the seismogenetic features of the source and the soil conditions appropriate to the site*. Selected real records have to be scaled to match the elastic response spectrum in a range of periods of interest for the shaking of the structure. These prescriptions may approximate the current best practice in record selection and manipulation, that is, the accelerograms have to be selected to reflect the likely magnitudes, distances and other earthquake parameters believed to dominate the hazard at the site (this choice may be driven by disaggregation of seismic hazard; see Bazzurro and Cornell, 1999); then, the records are scaled to match the target spectrum at the period corresponding to the first mode of the structure. However, even in the fortunate Italian case, where hazard data are available for any given site, the seismogenetic features of the source of engineering interest are not always available (see, Convertito et al. 2009 for a

discussion). Furthermore, some studies have shown that in some cases, to consider magnitude and distance deriving from disaggregation can be not strictly necessary for a correct estimate of the structural response (Iervolino and Cornell, 2005). Therefore, the instructions for the implementation of the NIBC (CS.LL.PP., 2009) allows us to use, as an alternative, 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. It is also specified that, if the accelerograms are to be scaled linearly in size, the scale factor is to be limited in the case of signals from events of small magnitude; see Iervolino et al. (2010b) for details.

4. REXELite

To enable the selection of records according to NIBC specifications, a specific software tool was developed. REXEL 2.61 beta, available on the ReLUIS website, contains the accelerograms from the European Strong-motion Database or ESD (http://www.isesd.cv.ic.ac.uk/) and from 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 reference spectrum, and that may possibly reflect the characteristics of the source of interest (in terms of magnitude and epicentral distance). In the framework of the ongoing S4 Project, an internet simplified version of the stand-alone software REXEL was developed and named REXELite (Figure 2).

First of all, the software allows to automatically define the target spectra according to the NIBC (or to the EC8). To do this, 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[1] (for the Eurocode 8 spectra, it is necessary to specify only the anchoring value of the spectrum, a_g, and the soil class). In addition, it is necessary to specify the number of horizontal components of ground motion (1 or 2) desired to be included in the set.

REXELite allows to search for records within ITACA belonging to the same site class of the defined spectrum or to *any site class* and corresponding to magnitudes and epicentral distances of interest. In fact, the intervals [M_{min}, M_{max}] (moment magnitude) and [R_{min}, R_{max}] (epicentral distance, in kilometers) in which the accelerograms have to fall have to be defined; also the recording instrument features may be specified (e.g., if also analogue stations have to be included in the search). When these options have been defined, REXELite returns the number of records (and the corresponding number of events and recording stations) available in ITACA.

The main feature of the developed software is that the spectra of the records returned by the M and R search may be used to find a combination of seven, whose average is compatible with the defined reference spectrum and with some tolerance (also defined by the user) in an arbitrary interval of periods [T1, T2] between 0s and 4s. The compatible combination can comprise 7 accelerograms to be applied in one horizontal direction for analysis of bi-dimensional structures; 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[2].

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. This, as already demonstrated in Iervolino et al. (2008), gives

---

[1] 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 response spectrum. The maximum acceleration is defined as the peak of the acceleration which has a certain probability to be 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. *Functional Type*).

[2] The stand-alone version of REXEL, allows to search also for 7 groups of accelerograms which include the two horizontal plus the vertical recordings of 7 recording stations.

combinations whose spectra are generally more similar to the target spectrum, so reducing the record-to-record spectral variability within a set. The maximum mean scale factor allowed is 5.
The software analyzes 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 checks whether each combination is compatible, in an average sense and with the assigned tolerances, with the code spectrum. 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 that better approximating the target spectrum among those that may be obtained by the preliminary search in the database (see Iervolino et al., 2010b)
When the desired combination is found, several display options allow users to view data in different formats and to download time series and/or response spectra.
The examples below show how REXELite works and how it may facilitates the selection of accelerograms for code-based nonlinear dynamic analysis of structures.

Figure 2. REXELite user interface

4.1 Application

As an example, consider the selection of horizontal accelerograms according to the NIBC for the damage state limit 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-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 equal to [5, 6] and [0km, 20km] respectively, including also late trigger 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 142 waveforms (71 x 2 components

of motion) from 30 different earthquakes on 33 different recording stations.
When assigning, as tolerance for the average spectral matching, 10% lower and 30% upper in the period range 0.15s ÷ 2s, REXELite immediately[3] returns the combinations of accelerograms in Figure 3 if the 1-component search is performed. 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 waveforms and component codes are also given.

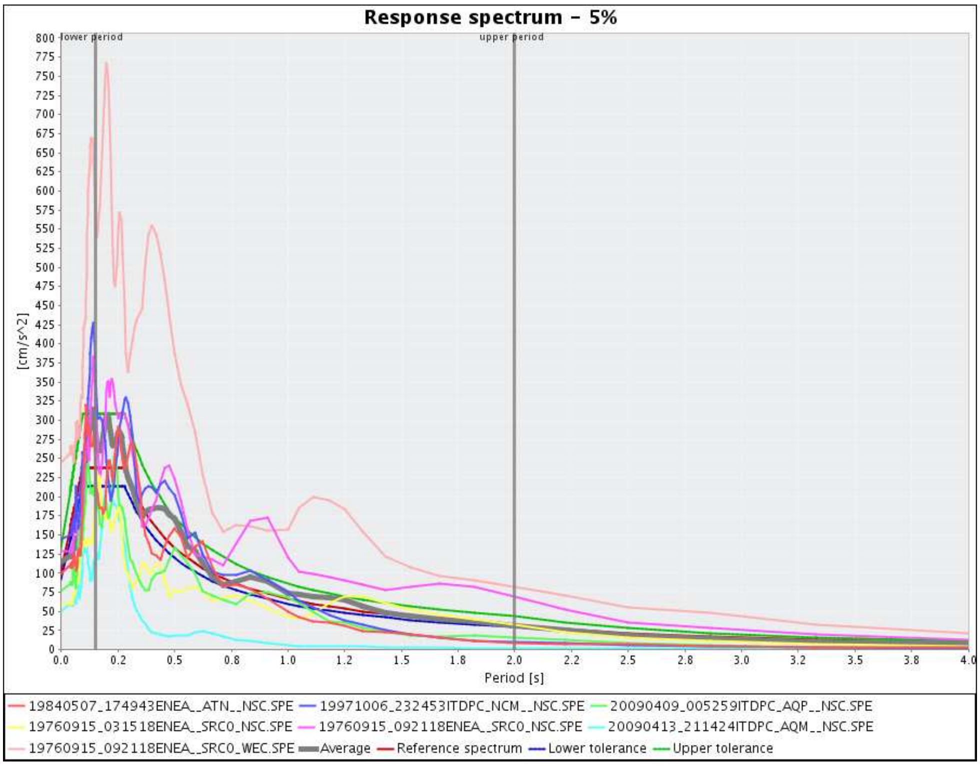

Figure 3. Combinations found for the assigned example in L'Aquila in the case of damage limit state.

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[4] can be used, 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 ranges, with the same compatibility criteria as the previous case, the software immediately returns the combination shown in Figure 4, which features records with less scattering with respect to the un-scaled ones of Figure 3. The records in Figure 4, are multiplied by the scaling factors (SFs, automatically computed and provided by the software (Figure 5), which are required to render the set compatible with the code spectrum in the case of a non-dimensional search.
REXELite also returns the detailed information about the individual records as retrieved by ITACA (Figure 5), e.g. recording station code and station type (analog or digital), event (date and time), ecc. Other functions are related to return of selected waveforms to the user[5] (grouped in a compressed file by REXELite) and to visualization of waveforms using ITACA tools (Luzi et al., 2008).

---

[3] The software returns an error message if processing time is longer than 180 seconds.
[4] The *Non-dimensional* option means choosing whether to search *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. Combinations found in this way have to be scaled to be compatible in an average sense with the reference spectrum.
[5] The strong-motion data are provided in the unprocessed and processed version together with acceleration response spectra.

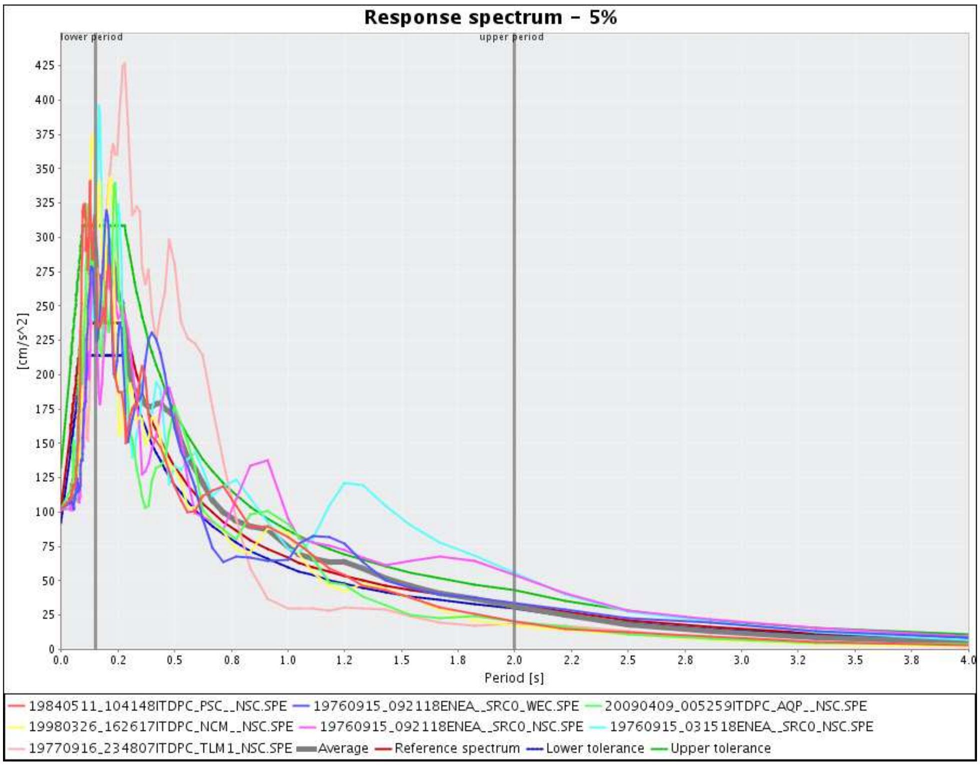

Figure 4. Scaled combinations found for the assigned example in L'Aquila in the case of damage limit state.

Network	Station code	Type	Event time	Scale factor	Usable Bandwidth	Orientation	Waveform	Sparkline
ENEA	SRC0	Analog	1976-09-15 03:15:18	1.7363597	28.85	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	0.7934115	28.9	NS		
ENEA	SRC0	Analog	1976-09-15 09:21:18	0.41635963	28.9	WE		
ITDPC	TLM1	Analog	1977-09-16 23:48:07	1.5893693	14.8	NS		
ITDPC	PSC	Digital	1984-05-11 10:41:48	5.5840697	12.8	NS		
ITDPC	NCM	Analog	1998-03-26 16:26:17	10.693141	14.5	NS		
ITDPC	AQP	Digital	2009-04-09 00:52:59	1.3381444	39.93	NS		

Figure 5. Essential record data returned by REXELite for the combination of Figure 4.

5. CONCLUSIONS

Real earthquake accelerograms are a desirable option for providing input to dynamic analysis of structures, being more realistic than spectrum-compatible artificial records and easier to obtain than synthetic records generated from simulation of seismological source models. To facilitate the use of strong-motion record in engineering analysis and design, tools for the automatic selection of combinations of real (recorded) accelerograms compatible, in an average sense, with a target (i.e., a code-based) spectrum, may be required.

REXELite is an internet version, operating on the ITalian ACcelerometric Archive, of REXEL, a software developed for automatic selection of ground motion suites for code-based structural analysis, and freely available at the website of Rete dei Laboratori Universitari di Ingegneria Sismica (ReLUIS) research programs.

REXELite allows multiple selection options, that reflect not only the criterion of compatibility with the target spectrum, but also seismological parameters (e.g., magnitude, source-to-site distance).

The program analyzes all combinations of seven groups of spectra (according to code's requirements) defined by the input parameters and returns the set whose average spectrum is compatible with the target within the chosen period range and with the tolerances accepted. The combination found by REXELite is likely that better approximating the target spectrum and may be used for code-compliant engineering puroposes.

ACKNOWLEDGEMENTS

The study presented in this paper was developed within the activities of the ReLUIS and INGV within the ReLUIS-DPC (2005-2008) and the S4 DPC-INGV (2007-2009) research programs.

REFERENCES

Bazzurro, P., Cornell, C.A. (1999). Disaggregation of seismic hazard. *Bulletin of the Seismological Society of America*. **89:2**, 501–520.

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.

Convertito, V., Iervolino, I., Herrero, A. (2010). The importance of mapping the design earthquake: insights for southern Italy. *Bulletin of the Seismological Society of America*. **99:5**, 2979–2991.

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

CS.LL.PP. (2009). Istruzioni per l'applicazione delle norme tecniche delle costruzioni. *Gazzetta Ufficiale della Repubblica Italiana*, 47. (in Italian)

Iervolino, I., Cornell, C.A. (2005). Record selection for nonlinear seismic analysis of structures. *Earthquake Spectra*. **21:3**, 685-713.

Iervolino, I., Galasso, C., Cosenza, E. (2010a). New features of REXEL 2.61 beta, a tool for automated record selection. *Proc. of 14th European Conference on Earthquake Engineering*, Ohrid, Republic of Macedonia.

Iervolino, I., Galasso, C., Cosenza, E. (2010b). REXEL: computer aided record selection for code-based seismic structural analysis. *Bulletin of Earthquake Engineering*. **8:2**, 339-362.

Iervolino, I., Maddaloni, G., Cosenza, E. (2008). Eurocode 8 Compliant Real Record Sets For Seismic Analysis of Structures. *Journal of Earthquake Engineering*. **12:1**, 54–90.

Luzi, L., Hailemikael, S., Bindi, D., Pacor, F., Mele, F. (2008). ITACA (ITalian ACcelerometric Archive): a web portal for the dissemination of Italian strong motion data. *Seismological Research Letters*. **79:5**, 716-722.

Massa, M., Pacor, F., Luzi, L., Bindi, D., Milana, G., Sabetta, F., Gorini, Marcocci, A. (2010). The Italian Accelerometric Archive (ITACA): processing of strong motion data. *Bulletin of Earthquake Engineering*. DOI 10.1007/s10518-009-9152-3. (in press)

Montaldo, V., Meletti, C., Martinelli, F., Stucchi, M., Locati, M. (2007). On-Line seismic hazard data for the new Italian building code. *Journal of Earthquake Engineering*. **11:S1**, 119–132.

Paolucci, R., Pacor, F., Puglia, R., Ameri, G., Cauzzi, C., Massa, M. (2010). Record processing in ITACA, the new Italian strong-motion database. *Proc. of 2nd Euro-Mediterranean meeting on Accelerometric Data Exchange and Archiving*. Editor: S. Akkar andd P. Gulkan, Springer (in press).