SelEQ: a web-based application for the selection of earthquake ground motions for structural analysis

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ABSTRACT:
Given the continuous development and availability of strong-motion databases containing real accelerograms, the consideration of such information in nonlinear structural analysis becomes increasingly attractive. However, the selection of records to adopt in structural analysis requires not only the consideration of consistent selection criteria but also the availability of computational tools that allow for fast and efficient searches of earthquake records within such databases. In this context, and following the recent advances in internet-based technologies, the present paper introduces SelEQ, a web-based application for the search and selection of earthquake records. This tool incorporates a number of filtering procedures allowing for the search of seismic records based on geophysical data but also on more advanced criteria such as spectral shape matching. Furthermore, SelEQ allows also the selection of earthquake records according to current seismic design code requirements, such as those of Eurocode 8, which demand for record suites compatible with a given response spectrum.

Keywords: Record selection, Strong-motion databases, nonlinear dynamic analysis

1. INTRODUCTION

The application of performance-based earthquake engineering principles in both structural assessment and design requires better predictions of structural demands. This is achieved through the use of more advanced analysis methods such as nonlinear static and time-history analyses. A reliable application of the latter requires the consistent definition of the seismic input in the form of earthquake records.

In general, two different criteria for record selection can be employed. One consists of choosing the records according to strong-motion parameters, and the other is based on geophysical criteria (Bommer and Acevedo, 2004). The decision between the two criteria is based on the amount of information available to the engineer at the analysis stage. In reality, for structures of low to medium complexity, detailed site-specific seismological studies are not normally available and the designer is therefore bounded by limited code guidance. In this case, record selection is fundamentally based on strong-motion parameters. In other words, the search consists of finding records that have similar shape to the design spectrum provided by the code and that were obtained for a site with similar characteristics. Although, the two criteria for record selection have limitations, it seems more rational to combine both. On the one hand, a selection mainly based on strong-motion parameters is unrealistic because it does not consider any earthquake scenarios (magnitudes, fault distances, durations). On the other hand, a selection primarily based on geophysical parameters may result in records that do not have reasonable correspondence with the design spectrum proposed by the seismic hazard assessment. It seems therefore sensible to base the record selection on geophysical and strong-motion parameters, but to also couple this with spectral mismatching checks to ensure suitability for the analysis.

Currently, there are several available online strong-motion databases such as the PEER NGA (PEER, 2010), the COSMOS Virtual Data Center (COSMOS, 2010), the NERIES Seismic Data Portal (NERIES, 2010) and the Italian Accelerometric Archive (ITACA, 2009). However, these databases were developed for searches mainly based on geophysical criteria. Recently, a new selection software, REXEL (Iervolino et al., 2010), was developed for code-based real record selection. This tool allows the search of sets of 7, 14 or 21 records compatible with the response spectra prescribed in Eurocode 8 (CEN, 2004), in the Italian seismic code (CS.LL.PP., 2008) or with a user-defined spectrum. In spite of the clear advantages of REXEL, this tool can only be run on MS Windows® based systems and requires the installation of the MATLAB Component Runtime. Moreover, the update of the strong-motion database requires the installation of new versions of the application. These limitations were recently overcome with the release of REXELite (ITACA, 2009), which runs in the web platform of the ITACA strong-motion database. Still, REXEL does not allow searches solely based on geophysical criteria nor the search of individual records or sets of records with sizes other than the previously referred.

This paper introduces SelEQ (http://seleq.fe.up.pt), a web-based application for the search and selection of earthquake records developed at the Faculty of Engineering of the University of Porto, Portugal. This tool incorporates a number of filtering procedures allowing for the search of seismic records based on geophysical data but also on more advanced criteria such as spectral shape matching. Furthermore, SelEQ allows also the selection of earthquake records according to current seismic design code requirements, such as those of Eurocode 8, which demand for record suites compatible with a given response spectrum.

2. DESCRIPTION OF THE WEB-BASED APPLICATION SelEQ

2.1. Main Features

SelEQ has been developed with the objective of allowing for a wide range of search options as well as to facilitate its scalability in the future. Currently, the application enables the search of earthquake accelerograms as well as for single records (Figure 1) available in the NGA database. An additional option, which is under development, is the search of record sets according to several selection criteria. An accelerogram is herein considered to be a group of records of an earthquake recorded by a given station in two or three orthogonal directions. While in the search for accelerograms only filters based on general (earthquake name, recording station name, etc) and geophysical parameters (magnitude, epicentral distance, soil type, etc) are available (Figure 2), the search for records comprises filters based on general, geophysical and strong-motion parameters (peak ground acceleration, duration according to different definitions, etc) (Figure 3). Additionally, the record search options of SelEQ include advanced filtering criteria based on spectral compatibility checks. The user can define upper and lower limits for the acceptable mismatches between the record and the reference spectra. This reference spectrum can be user-defined or set according to the expressions given in Eurocode 8.

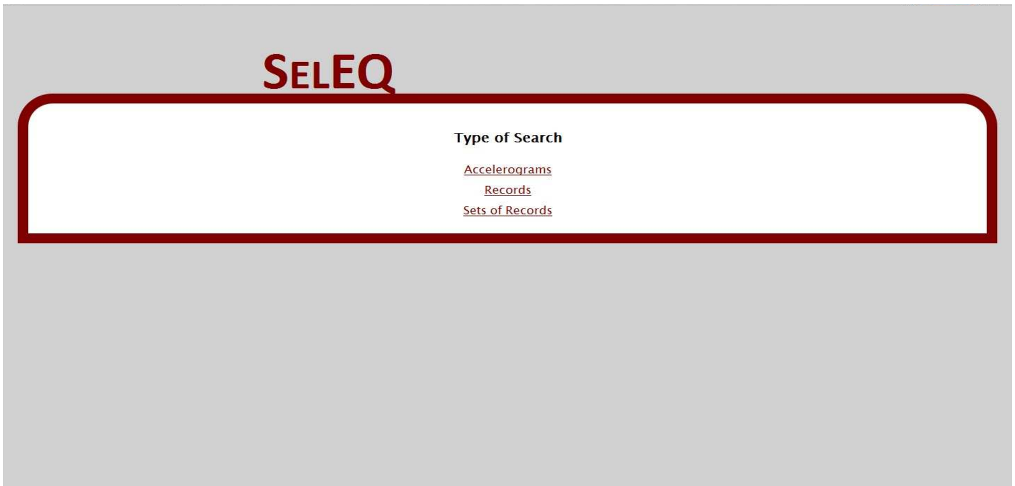


Figure 1. Main menu of SelEQ

A useful feature of SelEQ is the possibility of the user to customize the output parameters of the search independently of the parameters selected for the filtering criteria. Moreover, the search results can be sorted according to any of the output parameters. When spectral compatibility checks are considered in the search for records, additional output parameters become available such as the maximum and minimum mismatches between spectra, the scaling factor that minimizes the differences between spectra, among other parameters.

In addition to the above features, the application allows the user to browse the search results and to visualize plots of the acceleration, velocity and displacement time series. The response spectra for various damping levels are also available for visualization. This data is available to the user through several downloading options.

Figure 2. Menu for the search for accelerograms

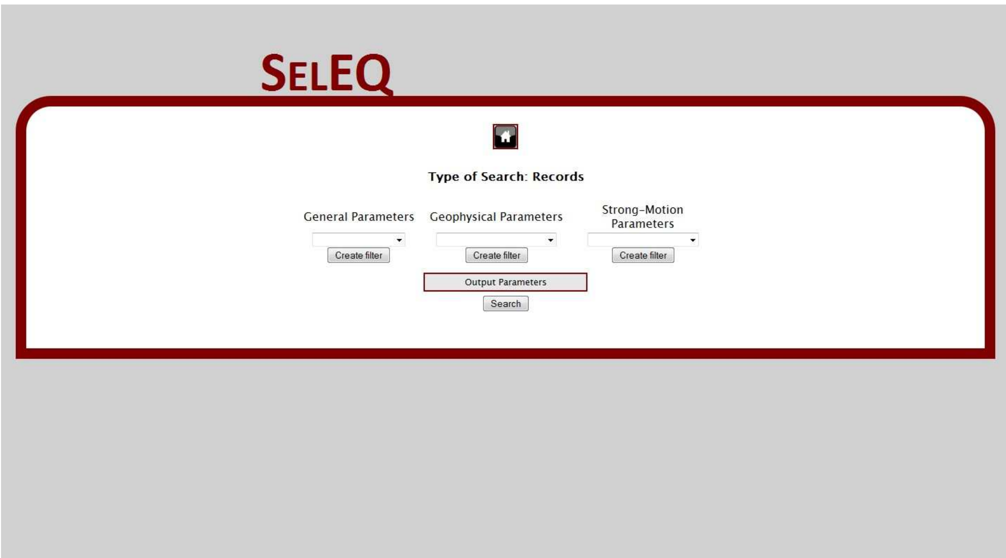


Figure 3. Menu for the search for records

2.2. Implementation Details

SelEQ is a web-based querying application built with free and accessible technology. SelEQ was developed in a way that allows for its improvement and evolution, given the modular structure that was implemented. The back-end of the application was created in PHP 5.3, which is a reliable and well established scripting language, and JavaScript. The MVC architecture pattern was followed, to isolate the business rules from the application interface, allowing for more maintainability by modularity. The most CPU demanding calculations are carried out with a specially developed executable file, coded in C language, contributing to a considerable increase in the application's performance. The front-end of the application was built with XHTML and CSS. Given this fact, a PHP server, version compliant, is necessary to run the application on the server side. This specificity is transparent to the end-user whose only requirements are an Internet connection and a generic browser to access the application. Because SelEQ was implemented in a client-server, three-tier architecture, the application is located in only one place, as opposed to desktop applications, which need to be installed on the users' computer. This means that SelEQ is easily extensible and that the business rules can be changed with no effort from the users to update to a newer version, thus promoting the application's transparent scalability.

The entire system runs over a database which is the main core of the application. This database was designed in MySQL, which is free and fast, thus meeting two of the base requirements. The database's data model and the interaction with the database were designed to enable the possibility, in the future, to add different databases to the system. The modular design of the application and the capacity to add new filtering criteria and databases considerably increases the application's scalability.

3. APPLICATION EXAMPLE

Two examples will be presented in the following sections with the aim of illustrating the potential of SelEQ. The first example consists of a search for accelerograms while the second example focuses the search for records and incorporates spectral compatibility checks.

3.1. Accelerograms Search Example

Two filters based on geophysical parameters are considered in this example, namely magnitude range and epicentral distance. As shown in Figure 4, the search is conducted for accelerograms recorded from earthquakes with a magnitude ranging between 6.0 and 6.1, and with an epicentral distance ranging between 20km and 25km.

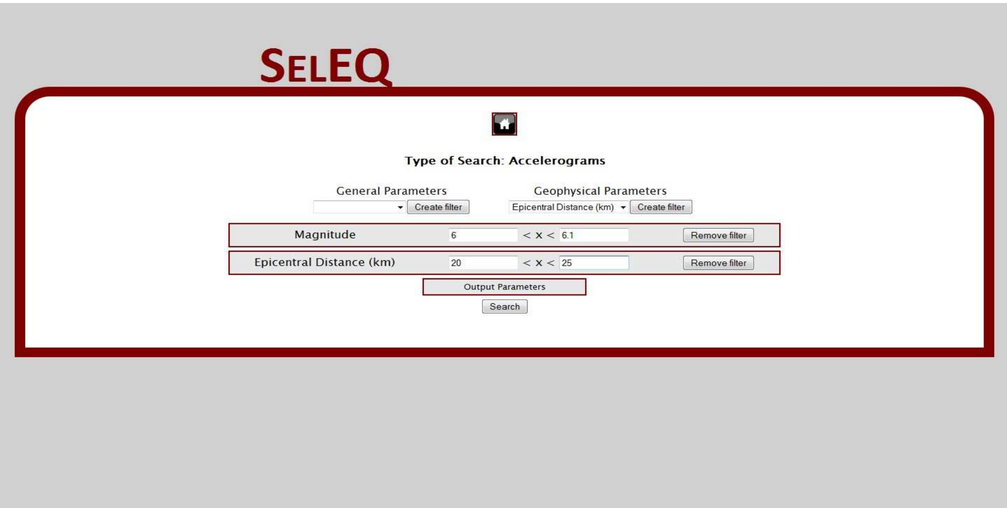


Figure 4. Filters considered in the search for accelerograms

The results of the search are shown in Figure 5. As illustrated in the figure, the application found 4 accelerograms complying with the searching criteria. As can be seen from the table of results, the customised output parameters include the ID of the accelerogram in addition to the earthquake and recording station names, the date of the earthquake as well as the magnitude. The results can be easily sorted according to different criteria by clicking in the table headers. If needed, the user is able to re-organize the columns sequence by clicking and dragging them with the mouse. Additional information concerning the accelerogram, earthquake and recording station can be obtained by clicking on the relevant table outputs. For example, by clicking on a given earthquake name, a new pop-up window is launched where the available geophysical information is presented along with a representation of the epicentre in Google Maps (Figure 6). Furthermore, a list of the stations that recorded that earthquake is also provided. If the user clicks the name of one of these stations, another pop-up window is launched with relevant information about the station which includes a list of the earthquakes recorded by that station (Figure 7). Therefore, all the data available in the database is linked and hence easily accessed. Additionally, by clicking the ID number of one the accelerograms, a new pop-up window is launched with a menu where the user can view plots of the accelerogram components and of the response spectrum for different damping values. To illustrate this feature, Figure 8 presents examples of these plots for one of the accelerograms in Figure 5.

Figure 5. Results of the search for accelerograms

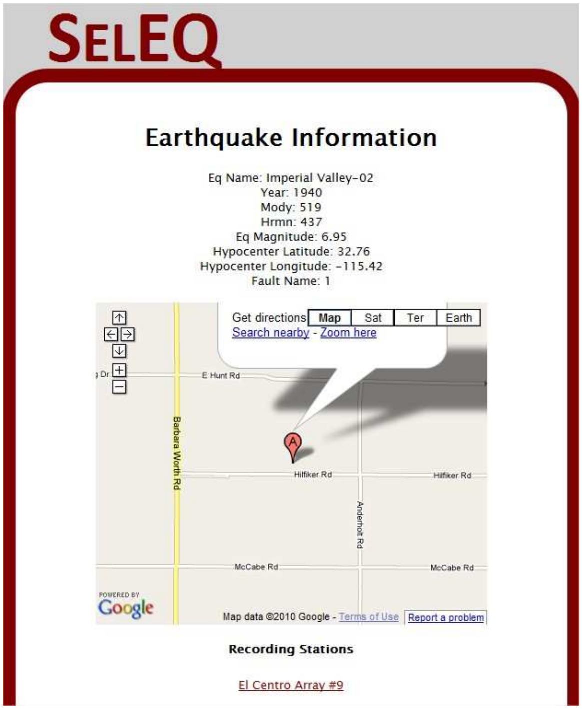


Figure 6. Pop-up window showing the epicentre location in Google Maps

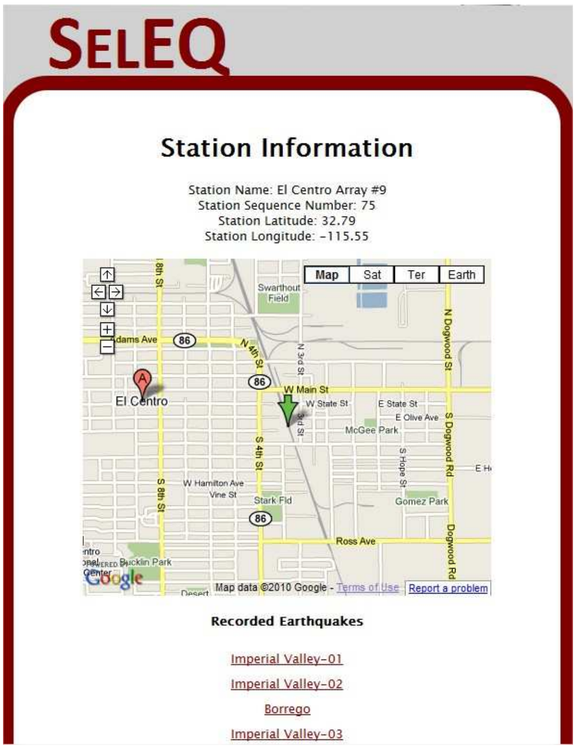


Figure 7. Pop-up window showing information relative to the earthquake recording station

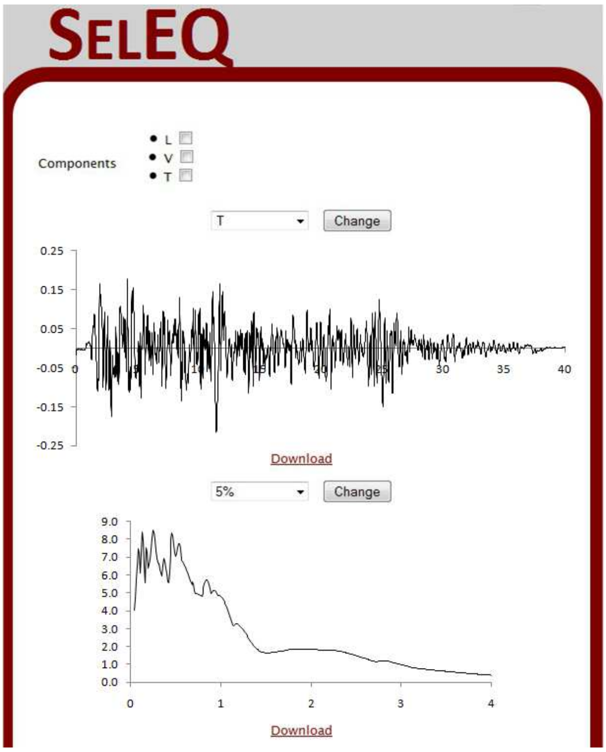


Figure 8. Pop-up window showing information relative to one the accelerogram components

3.2. Records Search Example

In this example, the search comprises filters based on both geophysical and strong-motion parameters (Figure 9). Two filters based on geophysical parameters are considered: an earthquake magnitude ranging between 5.5 and 6.0 and an epicentral distance ranging between 20km and 25km. In relation to the strong-motion filters, only spectral compatibility criteria are defined. As shown in Figure 9, a target acceleration response spectrum is defined according to Eurocode 8. The parameters defining the response spectrum assume a seismic action of Type 1, a soil of type B and a damping value of 5%. For the compatibility check between the target spectrum and the record spectra, maximum and minimum values of 15% are defined for the acceptable spectral mismatches over a period range specified between 1.5 and 2.0 secs. The selected output parameters for this search are the earthquake name, the recording station the year of the earthquake, the earthquake magnitude, the peak ground acceleration, the maximum and minimum spectral mismatches and the scaling factor that minimizes the differences between the spectra.

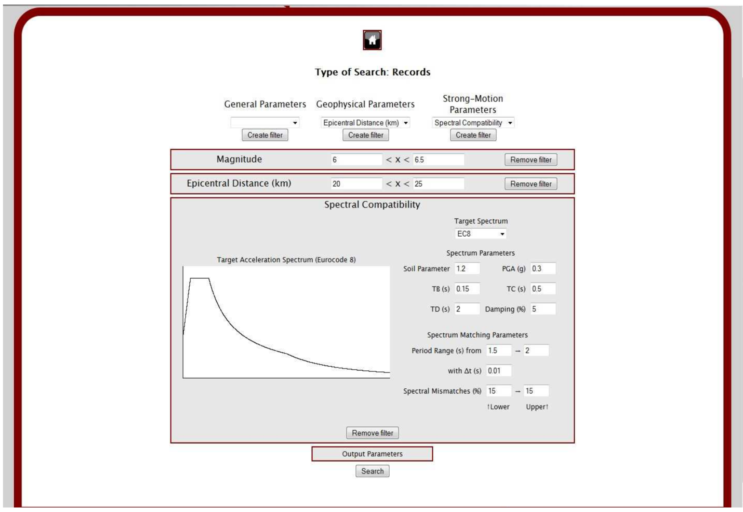
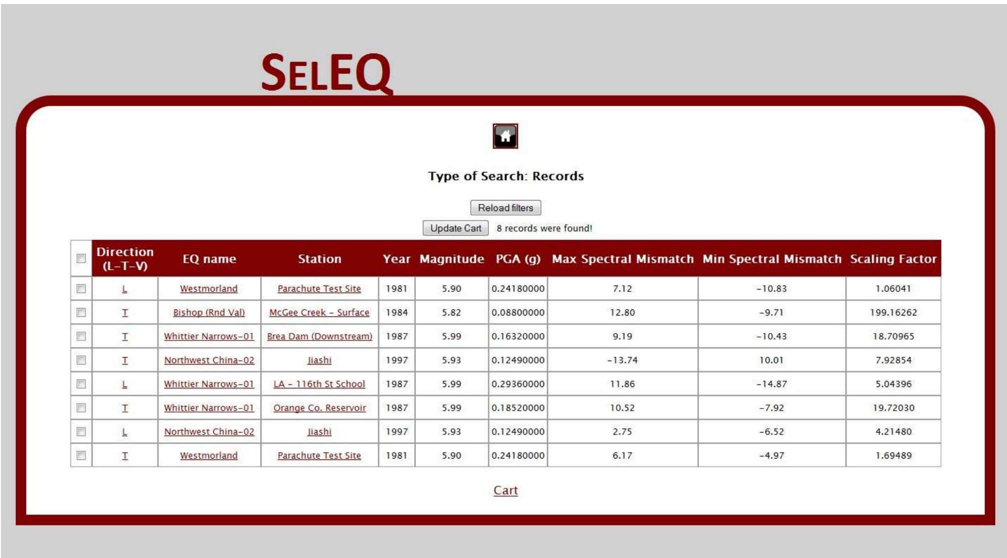


Figure 9. Results of the search for accelerograms

The results of the search are shown in Figure 10. As for the results of the search for accelerograms, additional information and result arrangement options can be accessed by clicking on the table header and on some of the results of the table. Namely, the output results can be sorted by ascending values of the scaling factor in order to choose the records leading acceptable values of this parameter while complying with the selected mismatch limits.



	Direction (L-T-V)	EQ name	Station	Year	Magnitude	PGA (g)	Max Spectral Mismatch	Min Spectral Mismatch	Scaling Factor
	L	Westmorland	Parachute Test Site	1981	5.90	0.24180000	7.12	-10.83	1.06041
	T	Bishop (Rnd Val)	McGee Creek - Surface	1984	5.82	0.08800000	12.80	-9.71	199.16262
	T	Whittier Narrows-01	Brea Dam (Downstream)	1987	5.99	0.16320000	9.19	-10.43	18.70965
	T	Northwest China-02	Jiashi	1997	5.93	0.12490000	-13.74	10.01	7.92854
	L	Whittier Narrows-01	LA - 116th St School	1987	5.99	0.29360000	11.86	-14.87	5.04396
	T	Whittier Narrows-01	Orange Co. Reservoir	1987	5.99	0.18520000	10.52	-7.92	19.72030
	L	Northwest China-02	Jiashi	1997	5.93	0.12490000	2.75	-6.52	4.21480
	T	Westmorland	Parachute Test Site	1981	5.90	0.24180000	6.17	-4.97	1.69489

Figure 10. Results of the search for accelerograms

4. FINAL REMARKS

The performance-based philosophy that is inherent to current seismic assessment provisions and design codes, increasingly relies on the use of nonlinear dynamic analysis. Simultaneously, the increasing availability of strong-motion databases containing real accelerograms also enables the development of such trend. However, the selection of records to adopt in structural analysis is still a difficult task in most cases. The available code guidelines for this purpose are clearly scarce and must be complemented by adequate selection criteria. Still, the selection of adequate ground motion records for structural analysis requires not only the consideration of consistent selection criteria but also the availability of computational tools that allow for fast and efficient searches of earthquake records within the existing databases. Therefore, the development of applications such as SelEQ represents a step forward in the development of adequate performance-based earthquake engineering methods.

In this paper, SelEQ, an application for the search of earthquake accelerograms and records, was described. SelEQ is a web-based application and features simple and more advanced searching capabilities. Both geophysical and strong-motion related parameters can be defined as filtering criteria. Moreover, spectral compatibility checks can be defined so that searching based on code criteria can be easily performed. The modular design of SelEQ increases the application's scalability, namely by permitting to easily include new filtering criteria

The current version of SelEQ relies on records from the NGA database. However, the inclusion of other strong-motion databases can be readily implemented. The potential of the application was illustrated with two application examples. Ongoing work is being carried out with the aim of implementing the search for record sets according to several selection criteria.

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