Engineering ground motion selection based on displacement-spectrum compatibility

C. Smerzini & R. Paolucci
Dipartimento di Ingegneria Strutturale, Politecnico di Milano, Italy

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

SUMMARY:
In this paper we address the selection of displacement-spectrum compatible natural accelerograms for displacement-based seismic design and assessment by nonlinear dynamic analysis. This involved: i) the definition of a target displacement spectrum for Italian sites, that fits the results of probabilistic seismic hazard analyses both at short and at long periods, ii) the construction of an *ad hoc* high quality strong ground motion database, namely SIMBAD, and iii) the development of the software REXEL-DISP to select suites of real accelerograms compatible with target displacement spectra. Illustrative applications of REXEL-DISP are presented to underline some interesting features of displacement-based ground motion selection, namely the good performance of unscaled records and the possibility to achieve broadband spectral compatibility, given the availability of tools for computer aided record selection.

Keywords: Displacement-Based Design, earthquake strong motion database, ground motion selection

1. INTRODUCTION

Recent performance-based approaches to seismic design have given an increasing emphasis on the proper definition of the seismic demand at long periods. This is even more important when one refers to the definition of seismic demand in terms of displacement response spectra, such as in the capacity-spectrum (FEMA, 2005) and the direct displacement-based design approaches (Priestley et al., 2007), where the availability of reliable earthquake ground motions up to long periods is required.

This has stimulated several research works concerning, on one side, the development of improved displacement design spectra based on independent evaluations of long period spectral ordinates rather than on the use of the standard pseudo-spectral rule (Faccioli et al., 2004) and, on the other side, the definition of simple criteria to assess the reliability of digital strong motion data (Paolucci et al., 2008). Such advances have supported the calibration of up-to-date empirical ground motion prediction tools extending to long periods (Cauzzi and Faccioli, 2008), the improved quantification of site effects at long periods (Manou et al., 2007; Figini and Paolucci, 2009), the formulation of new seismic hazard maps at long periods in Italy (Faccioli and Villani, 2009).

In the framework of performance-based seismic design and assessment, a relevant issue is the selection of a *suitable* set of ground motion records to represent the design seismic excitation for nonlinear dynamic analysis (NLDA). According to the vast majority of international codes, such as the Eurocode 8, or EC8 (CEN, 2004), the current Italian seismic code, or NTC08 (CS.LL.PP., 2008), and US ASCE 7-10 provisions (ASCE, 2010), the selected suite of records needs to match, within prescribed tolerance limits, the target design spectrum. Moreover, appropriate acceleration histories shall be obtained from records having magnitudes, distances and source mechanisms consistent with those controlling the target spectrum in the range of periods of interest for a given application. While tools designed for the selection of earthquake ground motions compatible with design acceleration response spectra for earthquake engineering purposes are progressively becoming available, e.g., REXEL (Iervolino et al., 2010) and REXELite (Iervolino et al., 2011), the instruments apt for the selection of displacement-spectrum compatible accelerograms are still very limited and at research stage (e.g., Corigliano et al., 2012).

In this work we aim at introducing a user-friendly software, namely REXEL-DISP, as a by-product of the REXEL series, which allows to automatically select suites of real ground motion records compatible with a target displacement spectrum. Records may also reflect the seismogenic features of the sources, ground motion intensity measures, and soil conditions appropriate to the site. The need to provide reliable displacement spectral ordinates over a broad range of vibration periods, e.g., up to about 10 s, led us to embed in REXEL-DISP an *ad hoc* strong motion database, SIMBAD (Selected Input Motions for displacement-Based Assessment and Design), consisting of high quality three-component acceleration recordings from shallow crustal earthquakes worldwide in near field conditions.

An innovative feature of REXEL-DISP is the definition of the target displacement spectra: besides the design spectra from the NTC08 and EC8 norms, an alternative target displacement spectrum for Italian sites is introduced. The latter combines the norm prescriptions at short periods and the main results of the Probabilistic Seismic Hazard Assessment (PSHA) study for Italy of Faccioli and Villani (2009) at long periods. Illustrative applications at selected Italian sites will be illustrated to test the feasibility of REXEL-DISP and also to shed some light on relevant features of ground motion selection, if compared to conventional approaches based on spectral acceleration matching.

2. DATABASE FOR BROADBAND ENGINEERING ANALYSES

One of the key issues related to the definition of the seismic demand in terms of displacement spectra is the availability of reliable response spectral ordinates up to long vibration periods of potential interest for earthquake engineering applications. The need to provide reliable displacement spectral ordinates over a broad range of periods, say up to about 10 s, led us to construct an *ad hoc* strong ground motion database mainly consisting of digital recordings.

The SIMBAD database (Selected Input Motions for displacement-Based Assessment and Design) was obtained by assembling records from different worldwide ground motion databases according to the following criteria:

i) near field strong motion records from shallow crustal earthquakes worldwide with moment magnitude (M_W) ranging from 5 to 7.3 and at epicentral distances (R_{epi}) less than 30 km. This ensures to provide near field strong ground motion records of engineering relevance for most of the design conditions of interest in Italy (but not limited to it), that can be used without introducing large scaling factors.

ii) High quality accelerograms in terms of signal-to-noise ratio especially at long periods, so that we considered only processed records for which the high-pass cut-off frequency used by the data provider is below 0.15 Hz. Therefore, most records (about 80%) included in the database are from digital instruments, while only those records with a good signal to noise ratios at long periods (typically from large magnitude earthquakes) were retained from analog instruments.

iii) Availability of V_{S30} (shear wave velocity averaged over the top 30 meters) measurement or, alternatively in a few cases, the definition of the ground categories according to the EC8, or equivalently, the NTC08, based on quantitative estimates.

Table 2.1 reports a list of the strong motion databases used for assembling the SIMBAD database. It is worth underlining that data from the Japanese strong motion networks K-Net (http://www.k-net.bosai.go.jp/) and KiK-net (http://www.kik.bosai.go.jp/) of the National Research Institute for Earth Science and Disaster Prevention (NIED) were predominantly used to compile the SIMBAD database (60% of total records).

As mentioned above, we introduced in the database only records corrected by the data provider, presenting a high-pass cut-off frequency not larger than 0.15 Hz. Only for the Japanese records, that are available in the uncorrected format in the database, we first applied a baseline correction (constant de-trending) on the pre-event, and, subsequently, a 4th order acasual Butterworth high pass filter with cut-off frequency f_c = 0.05 Hz. After these preliminary steps, we took out records the spectral ordinates of which fell outside the standard dispersion band of the Cauzzi and Faccioli (2008) relationship, to reduce the number of outliers and speed up the spectrum-compatible record search procedures.

The resulting SIMBAD database consists at present of 384 three-component acceleration time histories, from 122 earthquakes worldwide. Most records come from Japan (57%), Italy (17%) and USA (14%), with minor contributions from other countries such as Greece, Turkey, Iran and New Zealand (12%), as shown in Figure 2.1. Special care has been devoted to assemble records to provide a distribution as uniform as possible in terms of magnitude and distance.

Based on the European and Italian seismic norms, we adopted the site classification into 5 ground categories: A (rock, $V_{S30} \geq 800$ m/s), B ($360 \leq V_{S30} < 800$ m/s), C ($180 \leq V_{S30} < 360$ m/s), D ($V_{S30} < 180$ m/s) and E (site C or D with thickness smaller than 20 m over rigid rock). Most records are representative of soil B (51%) and C (37%), while a few of them were registered on rock (7%), soil D (4%) and E (1%).

Table 2.1. Source of strong ground motion records included in the SIMBAD database.

Country	No. of records	Data owner
Japan	220	K-NET[a]
		KiK-net[b]
Italy	66	ITalian ACcelerometric Archive ITACA[c]
USA	53	Center for Engineering Strong Ground Motion Data: CESMD[d]
		PEER Strong Motion Database[e]
		U.S.Geological Survey National Strong Motion Project: NSMP[f]
Europe	17	European Strong-Motion Data Base: ESMD[g]
New Zealand	15	Institute of Geological and Nuclear Sciences: GNS[h]
Turkey	10	Turkish National Strong Motion Project: T-NSMP[i]
Iran	3	Iran Strong Motion Network ISMN[l]

[a]http://www.k-net.bosai.go.jp/ - [b]http://www.kik.bosai.go.jp/ - [c]http://itaca.mi.ingv.it/ - [d]http://strongmotioncenter.org/ - [e]http://peer.berkeley.edu/peer_ground_motion_database - [f]http://nsmp.wr.usgs.gov/ - [g]http://www.isesd.hi.is/ - [h]http://www.geonet.org.nz - [i]http://daphne.deprem.gov.tr - [l]http://www.bhrc.ac.ir/

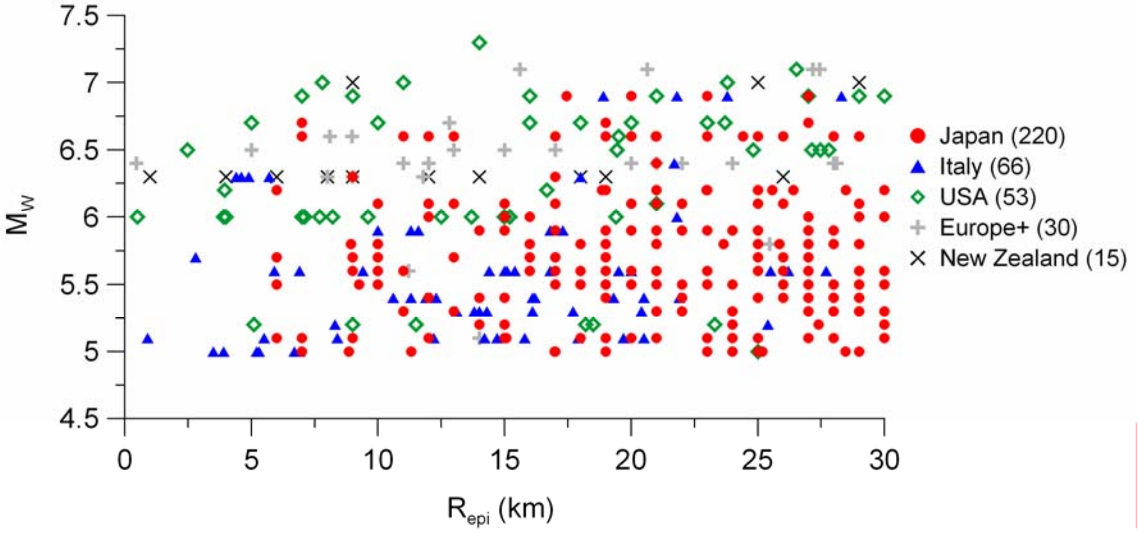


Figure 2.1. Distribution of magnitude (M_W), epicentral distance (R_{epi}) and geographical origin of the records included in the SIMBAD database.

3. TARGET DISPLACEMENT SPECTRA

The feasibility of ground motions selection based on displacement-spectrum compatibility is analyzed with respect to different target spectra:

i) design displacement spectrum from EC8;
ii) design displacement spectrum from NTC08;
iii) a target displacement spectra for Italian sites, that fits the NTC08 requirements at short periods and the result of the PSHA study at long periods for Italy of Faccioli and Villani (2009).

3.1. Displacement design spectrum according to EC8 and NTC08

As illustrated in Figure 3.1, the most relevant features of the displacement design spectrum according to EC8 and NTC08 are the following:

i) the key parameter that controls the shape of the spectrum is the corner period T_D marking the beginning of the Maximum Spectral Displacement plateau (*MSD* in Figure 3.1). The EC8 defines a constant value of T_D, but an indirect dependence on magnitude is introduced by assigning T_D = 2.0 s for the Type 1 spectrum (i.e., seismic hazard associated to earthquakes of surface-wave magnitude $M_S \geq 5.5$) and T_D = 1.2 s for Type 2 ($M_S < 5.5$). On the other hand, in the NTC08, the corner period T_D is made dependent on the peak ground acceleration (*PGA*) on exposed rock (class A), a_g, the latter being related to the return period under consideration through the results of a specific PSHA for Italy (Stucchi et al., 2011). A common feature of these norms is that T_D does not depend on the site class.

ii) the application of the pseudo-acceleration rule is limited up to a corner period, T_E, ranging between 4.5 and 6.0 s, as a function of the ground category. Beyond T_E, a linear decreasing branch of the spectrum is defined, up to the control period T_F =10 s, beyond which the spectral displacement remains equal to the peak ground displacement $d_{max} = 0.025 \cdot a_g \cdot S \cdot T_C \cdot T_D$, where S is the soil amplification factor and T_C is the control period that marks the start of the constant velocity branch of the design spectrum.

iii) the ratio MSD/d_{max} is equal to the ratio MSA/a_{max} of the maximum response spectral acceleration (*MSA*) with respect to the design peak ground acceleration $a_{max} = a_g \cdot S$. This ratio is 2.5 according to EC8, while the NTC08 denote such ratio as F_o and provide a map of values, based on the results of PSHA at a national scale.

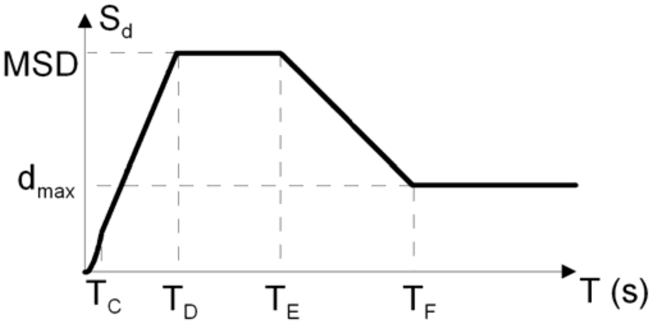


Figure 3.1. Elastic displacement design spectrum according to the NTC08 and EC8 seismic norms.

Although not shown here for brevity, it is worth remarking that significant discrepancies exist among different seismic norms worldwide in the criteria to define the corner period T_D and its dependence on magnitude.

Table 3.1 synthesizes the range of variability of T_D according to the EC8, NTC08, ASCE 7-10 and the New Zealand seismic standards NZS 1170.5 (NZS, 2004). Note that in the NZS 1170.5 a constant value T_D = 3.0 s is defined, regardless the seismic hazard associated to the selected site.

Table 3.1. Range of variability of the corner period T_D according to the seismic norms worldwide.

Displacement spectrum	Range of variability of T_D	
EC8	1.2 s for $M < 5.5$	2.0 s for $M > 5.5$
NTC08	Ranging from about 1.8 s (for $a_g/g = 0.05$) to 2.8 s (for $a_g/g = 0.30$)	
NZS 1170.5	3.0 s	
ASCE 7-05	Ranging from about 4 s (for M = 6.0-6.5) to 16 s (for M = 8.0-8.5)	

The ASCE 7-10 guidelines define the long period branch of the response spectra by providing maps of the long period transition period T_L (equivalent to T_D) as a function of the modal magnitude (M_d) of each region, determined by disaggregation of PSHA (Bazzurro and Cornell, 1999) for probability of exceedence of 2% in 50 years. As illustrated by Crouse et al. (2006), referring to the old version of US guidelines ASCE 7-05 (ASCE, 2006), mapped values of T_L for the conterminous United States show a large variability, ranging from 4 (for M_d in the 6.0-6.5 range) up to 16 s (M_d in the 8.0-8.5 range), and were computed based on the combined consideration of seismic source scaling relationships, of the analysis of strong motion recordings with reliable long period content, and of results of ground motion simulations.

3.2. A Target Displacement Spectrum for Italian sites (TDSI)

In this section we present the major results regarding the recent long period PSHA studies for Italy, that led us to define an alternative target displacement spectrum. The reference work is that of Faccioli and Villani (2009), who proposed a novel representation of long period seismic hazard for Italy in the framework of Project S5 "*Seismic input in terms of expected spectral displacements*" funded by the Department of Civil Protection from 2005 to 2007 (http://progettos5.stru.polimi.it/). This study produced new hazard maps for Italy in terms of horizontal displacement response spectral ordinates in a wide range of vibration periods, from 0.05 s up to 20 s, using the broadband ground motion attenuation relationship developed by Cauzzi and Faccioli (2008). Specifically, the main results of the PSHA study consist of hazard maps of D_{10}, i.e., 5%-damped displacement response spectral ordinate at $T = 10$ s, and T_D, i.e., the corner period defining the beginning of the constant displacement branch of the spectrum, for three return periods (T_R), i.e., 72 yr, 475 yr and 975 yr, and for three different percentile levels, i.e., 16th, 50th and 84th.

To satisfy the short period prescriptions of the NTC08, on one side, and, on the other side, the results of PSHA at long periods from Project S5, we introduce the following Target Displacement Spectrum for Italy, valid for 5% damping, referred to as TDSI hereafter (see Figure 3.2):

$$S_d(T) = \begin{cases} T \le T_C & \textit{see NTC08} \\ T_C < T \le T_D & a_g\, S\, F_0 \left(\dfrac{T_C}{T}\right)^{\alpha} \dfrac{T^2}{4\pi^2} \\ T_D < T \le T_E & D_{10}\ S\, C_c \\ T_E < T \le T_F & D_{10}\ F + D_{10}\ \left(S\, C_c - F\right) \dfrac{T_F - T}{T_F - T_E} \\ T > T_F & D_{10}\ F \end{cases} \tag{3.1}$$

where:

- D_{10} and T_D are defined based on the mapped values of long period PSHA, i.e., Faccioli and Villani (2009);
- a_g and F_o have been introduced in the previous section, S and C_C are the soil factors as a function of ground type, T_C, T_E, T_F are corner periods. All the previous parameters are provided according to the NTC08 norms.
- $\alpha = \log\left(\dfrac{4\pi^2 D_{10}\, C_c}{a_g F_0 T_D^2}\right) / \log\left(\dfrac{T_C}{T_D}\right)$ is the factor introduced to ensure matching between short and long period branches of the proposed spectral shape (see dotted line in Figure 3.2a). Values of α for Italy range approximately between 0.85 and 1.4, the largest values being typically found in low seismicity regions, such as Piemonte, Lombardia and Trentino, while regions of high seismicity are characterized by values close or slightly less than unity, as along the Calabria arch and the Central-Southern Appenines chain.
- $F = \left(800 / V_{S30}\right)^{0.375}$ is the site factor for long periods, as obtained in the framework of Project S5 (Cauzzi et al., 2007). To compute the long period site factor F, average values of V_{S30} within the variability range of each site class have been considered, namely: V_{S30} = 800 m/s for site class A (F=1.0), V_{S30} = 580 m/s for class B (F=1.13), V_{S30} = 270 m/s for classes C and E (F=1.5), V_{S30} = 140 m/s for class D (F=1.9).

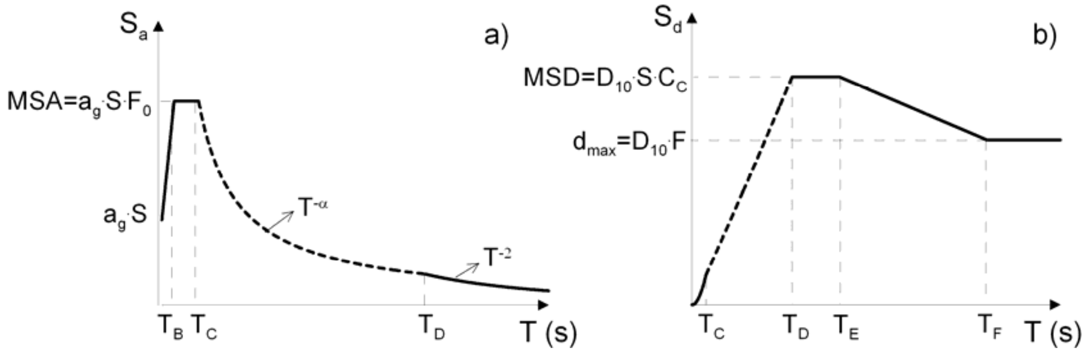


Figure 3.2. Target Displacement Spectrum for Italy (TDSI), see Eq. (3.1), in the short (a) and long (b) period range, based on the results of the PSHA at long periods developed by Faccioli and Villani (2009).

To match the NTC08 spectra when site factors are accounted for, we have considered the same site factor $S \cdot C_C$ as in the NTC08 between T_C and T_E, while the long period site factor F from Project S5 was adopted for periods $T \geq T_F$; for intermediate periods a linear variation of the site factor was adopted.

4. REXEL-DISP: COMPUTER AIDED DISPLACEMENT-BASED RECORD SELECTION

The availability of both a high quality digital strong motions database as SIMBAD, and a new Target Displacement Spectrum for Italian sites, may allow a rational record selection for displacement-based seismic design and assessment. To this aim, a user-friendly software for computer-aided real record selection, namely REXEL-DISP (Figure 4.1), has been developed based on the same algorithms (yet optimized for the acceleration-based approach) of REXEL (Iervolino et al., 2010, Iervolino et al. 2012) and REXELite (Iervolino et al., 2011).

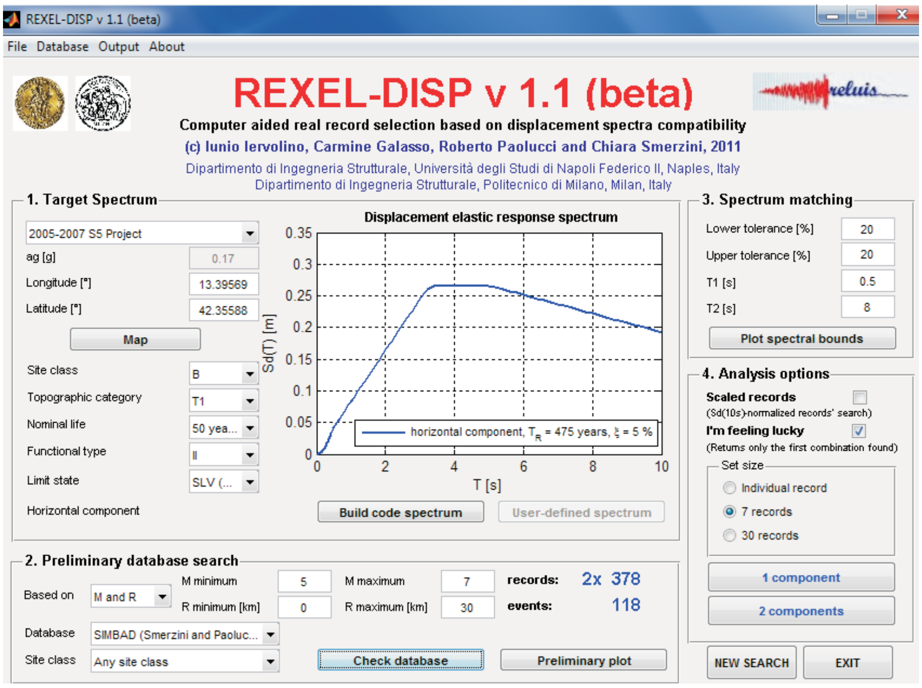
REXEL-DISP, available at http://www.reluis.it/index_eng.html, allows one to search for combinations of horizontal accelerograms whose average is compatible with a target displacement spectrum, and in which individual records have the shape as similar as possible with that of the target in a prescribed period range. Records may also reflect desired magnitude and source-to-site distance bins or specific ranges of some peak and integral ground motion intensity measures.

As a first step of record selection, REXEL-DISP allows to automatically define the TDSI or target spectra according to the NTC08, EC8 or arbitrary (user-defined). In case of the TDSI and the NTC08, it is necessary to input 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 (see Iervolino et al., 2010). For EC8 spectra, it is necessary to specify only the anchoring value of the spectrum and the local geological condition. In addition, it is necessary to specify the number of horizontal components of ground motion (1 or 2) to be included in the set.

In the definition of the analysis constraints, REXEL-DISP allows to search for records within SIMBAD belonging to the same site class of the defined spectrum, or to *any site class* (i.e., recording referring to different site conditions may show up in the same set matching the target spectrum). As mentioned, the records may correspond to magnitudes and epicentral distances from pre-defined bins or to selected ranges of: i) *PGA*; ii) peak ground velocity or *PGV*; iii) Cosenza and Manfredi (2000) index (I_D); iv) Arias Intensity (I_A).

Once the selection options are defined, REXEL-DISP returns the number of records (and the corresponding number of events) available in SIMBAD, which match these. The spectra of the records returned by this preliminary search are used by REXEL-DISP to find sets of record (one, seven, or thirty), whose average is compatible with the defined target spectrum in an arbitrary interval of periods [T_1, T_2] between 0 s and 10 s. Spectrum matching is ensured with some tolerance also defined by the user as an analysis' option.

The compatible record set found can be either comprised of single-component accelerograms, hence to be applied in one horizontal direction for analysis of bi-dimensional (plan) structures, or of pairs of horizontal components (therefore, for example, if one searches for a set, of seven ground motions, the software actually returns fourteen records) for the analysis of three-dimensional structures.



REXEL-DISP v 1.1 (beta)

Computer aided real record selection based on displacement spectra compatibility

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Dipartimento di Ingegneria Strutturale, Università degli Studi di Napoli Federico II, Naples, Italy
Dipartimento di Ingegneria Strutturale, Politecnico di Milano, Milan, Italy

1. Target Spectrum
2005-2007 S5 Project
ag [g]: 0.17
Longitude [°]: 13.39569
Latitude [°]: 42.35588
Site class: B
Topographic category: T1
Nominal life: 50 yea...
Functional type: II
Limit state: SLV (...
Horizontal component

2. Preliminary database search
Based on: M and R
M minimum: 5
M maximum: 7
R minimum [km]: 0
R maximum [km]: 30
records: 2x 378
events: 118
Database: SIMBAD (Smerzini and Paoluc...
Site class: Any site class

3. Spectrum matching
Lower tolerance [%]: 20
Upper tolerance [%]: 20
T1 [s]: 0.5
T2 [s]: 8

4. Analysis options
Scaled records ☐
(Sd(10s)-normalized records' search)
I'm feeling lucky ☑
(Returns only the first combination found)
Set size
○ Individual record
● 7 records
○ 30 records

Figure 4.1. Image of the graphic user interface of REXEL-DISP.

It is important to underline that, for the purpose of the selection of a set of records, the software analyzes all the possible combinations of spectra that can be built from the waveforms found in the database after the preliminary search, and checks whether each combination is compatible, in an average sense and with the assigned tolerances, with the target spectrum. The *I'm feeling lucky* option allows to stop the analysis as soon as the first compatible combination is found. In this case, thanks to a specific feature of the search algorithm, the record combination returned by REXEL-DISP is likely to be the one that approximates best the target spectrum among those that may be obtained by the preliminary search in the database according to the parameter defined in Eq. (4.1). The latter gives a measure of how much the spectrum of an individual record deviates from the target spectrum. In Eq. (4.1), $Sd_j(T_i)$ is the displacement ordinate of the real spectrum j corresponding to the period T_i, while $Sd_{target}(T_i)$ is the value of the displacement spectrum of the target spectrum at the same period, and N is the number of values within the considered range of periods.

$$\delta_j = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\frac{Sd_j(T_i) - Sd_{target}(T_i)}{Sd_{target}(T_i)}} \tag{4.1}$$

REXEL-DISP 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 target spectrum, if scaled linearly (in this case, the individual records scale factors are also provided). If this second option is chosen, the user has to check the *Scaled records* box, and the spectra of the preliminary search are normalized dividing the spectral ordinates to the value at 10 s. Combinations of these spectra are compared to the non-dimensional target spectrum. If this option is selected, it is also possible to specify the maximum mean scale factor (SF) allowed, and REXEL-DISP will discard combinations with an average SF larger than that assigned.

As for other REXEL tools, complementing functions of REXEL-DISP are related to: visualization of results, return of selected waveforms and spectra to the user, repeating the search excluding an undesired waveform from a found combination, or visualization of acceleration spectra compatibility for the selected set (see Iervolino et al., 2012).

5. APPLICATIONS AT SELECTED SITES

In this Section some representative applications for selected Italian sites are presented to clarify some of the relevant issues related to displacement-based ground motion selection.

As a first application, we perform the selection of a set of 7 horizontal ground motions compatible with both the NTC08 design spectrum and the TDSI of Eq. (3.1) for the life safety limit state of an ordinary structure (functional class II) with a nominal life of 50 years, i.e., $T_R = 475$ yr, located on soil type B, in absence of topographic irregularities (topographic class T1), within the town of L'Aquila (13.39569°E; 42.35588°N). As criteria for spectral compatibility, we assume a broadband matching in the period range between $T_1 = 0.5$ s and $T_2 = 8$ s with 20% lower and upper tolerance, with no introduction of scaling factors. It is worth underlining that the selection has been carried out using wide magnitude and distance intervals (5-7 and 0-30 km) and *Any site class* as preliminary selection options, i.e., 2 x 378 records from 118 events.

With the above parameters REXEL-DISP returns the suites of 7 unscaled accelerograms according to the NTC08 spectrum and to the TDSI shown in Figure 5.1a and Figure 5.1b, respectively (*I'm feeling lucky* option). On both plots, the thin solid lines represent the displacement response spectra of the selected accelerograms, the thick blue line denotes the average spectrum of the output combination, while the thick black line indicates the target displacement spectrum along with the corresponding lower and upper tolerances (dashed black lines). The vertical red lines indicate the range of periods where spectral compatibility is ensured.

A good agreement is found between the average displacement spectrum and the target spectrum, resulting in an average spectral deviation δ_{avg} (computed by the software as in Eq. 4.1 replacing $Sd_j(T_i)$ with the average spectral acceleration of the combination) of around 10% and 6% for the NTC08 and TDSI, respectively. In both cases, the maximum spectral deviation of individual records is limited to about 30% (the deviation of each spectrum is also provided by the software). However, when searching for records compatible with the NTC08 prescriptions, it is noted that the response spectral ordinates of selected records divert significantly from the decreasing branch of the design spectrum, starting from 5 s.

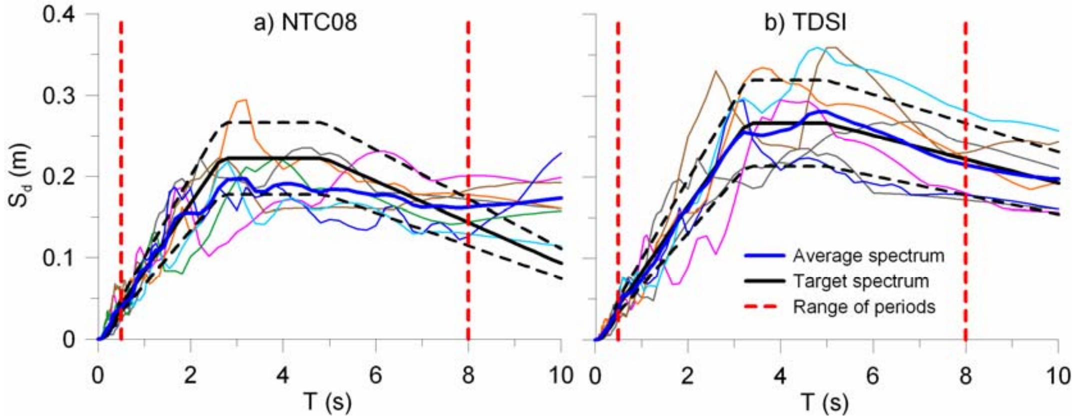

Figure 5.1. Displacement response spectra, at 5% damping, of the set of 7 unscaled horizontal ground motions compatible with the NTC08 design spectrum (a) and the TDSI of Eq. (3.1) (b) for the reference site of L'Aquila (class B) and for $T_R = 475$ years.

As a further application, we evaluate the performance of REXEL-DISP for various period ranges where spectral compatibility is enforced. For this purpose, we consider the same example at L'Aquila (class B) for the TDSI ($T_R = 475$ yr) and compare the results using two different period ranges, namely, a) $T = [0.5,3]$ s, and b) $T = [0.15,10]$ s, with a upper and lower tolerance of 20%. The results are illustrated in Figure 5.2, not only in terms of displacement response spectra (left-hand side), but of acceleration spectra as well (right-hand side). This example clearly points out that a very broadband spectrum compatibility can be achieved, as shown in application b), with satisfactory matching parameters (δ_{avg} = 8% and δ_{max} = 40%) and without scaling the ground motion records. Restricting the period range of spectrum compatibility improves the search performance in the selected range, but returns a set of accelerograms with large variability at longer periods, thus involving a reduced homogeneity of the suite in terms of magnitude;

Therefore, the proposed REXEL-DISP software, coupled with a high-quality strong motion database such as SIMBAD, is able to provide suites of natural unscaled spectrum compatible accelerograms within a wide range of periods, apt for use within both short period and long period earthquake engineering analyses.

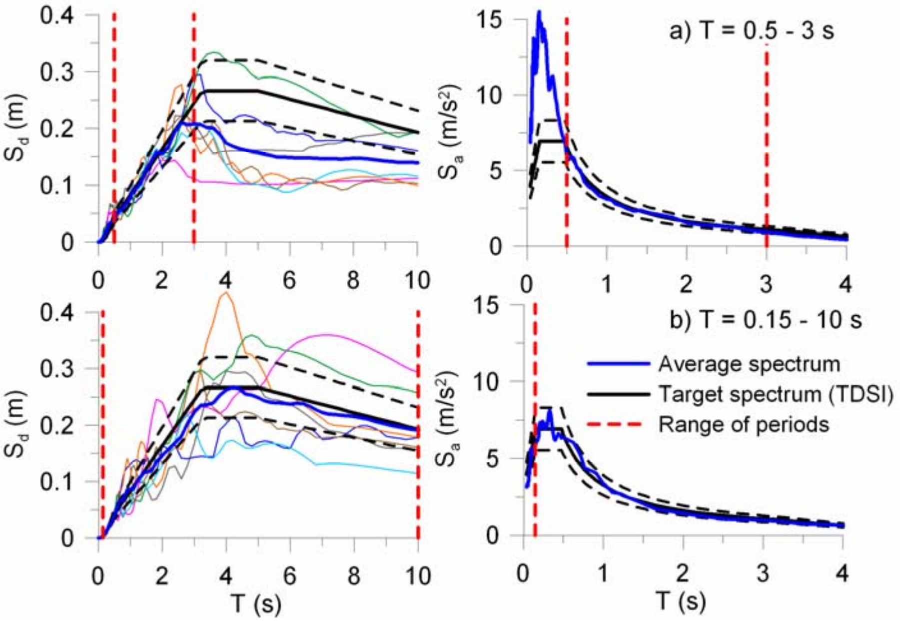

Figure 5.2. Displacement (right-hand side) and acceleration response spectra of the suites of records compatible with the TDSI (T_R = 475 yr) selected by REXEL-DISP for an ideal site in the city of L'Aquila considering two different ranges of vibration periods: a) T = 0.5-3 s, and b) T = 0.15 – 10 s.

6. CONCLUSIONS

Given the ongoing research interest in performance-based approaches to seismic design and assessment, in this note we have addressed the selection of displacement-spectrum compatible real accelerograms. To this end, a strong ground motion database, namely SIMBAD, consisting of records usable over a wide range of vibration periods, has been constructed and embedded in a new software REXEL-DISP, which allows to search for suites of real records compatible with displacement target spectra. A Target Displacement Spectrum for Italian sites, specifically tailored to fit the norm prescriptions at short periods and the results of an *ad hoc* long period PSHA study for Italy, has also been developed and introduced in REXEL-DISP.

Illustrative applications of the software have been illustrated, pointing out that selection of displacement-spectrum compatible ground motion records yields generally good results without using any scaling factors and also in the case that spectral compatibility is enforced over a very broad range of vibration periods, e.g., between 0.15 and 10 s. This is particularly attractive because it allows one to select suites of natural unscaled ground motion accelerograms apt for use within a wide range of dynamic engineering analyses.

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